JTG

Industry Standards of
the People's Republic of China
中华人民共和国行业标准

JTG 3450—2019(EN)

Field Test Methods of Highway Subgrade and Pavement

公路路基路面现场测试规程

(英文版)

Issue date: December 10, 2019 Effective date: April 1, 2020

Issued by Ministry of Transport of the People's Republic of China

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Editing organization for English version: China Road and Bridge Corporation

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中华人民共和国交通运输部

公　　告

第 10 号

交通运输部关于发布《公路工程质量检验评定标准 第一册　土建工程》英、法文版等 4 项公路工程行业标准外文版的公告

为促进公路工程行业标准的对外交流，现发布《公路工程质量检验评定标准 第一册 土建工程》英文版［JTG F80/1—2017（EN）］［代替标准号 JTG F80/1—2004（E）］及其法文版［JTG F80/1—2017（FR）］、《公路路基路面现场测试规程》英文版［JTG 3450—2019（EN）］［代替标准号 JTG E60—2008（E）］、《公路技术状况评定标准》［JTG 5210—2018（EN）］。

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特此公告。

中华人民共和国交通运输部

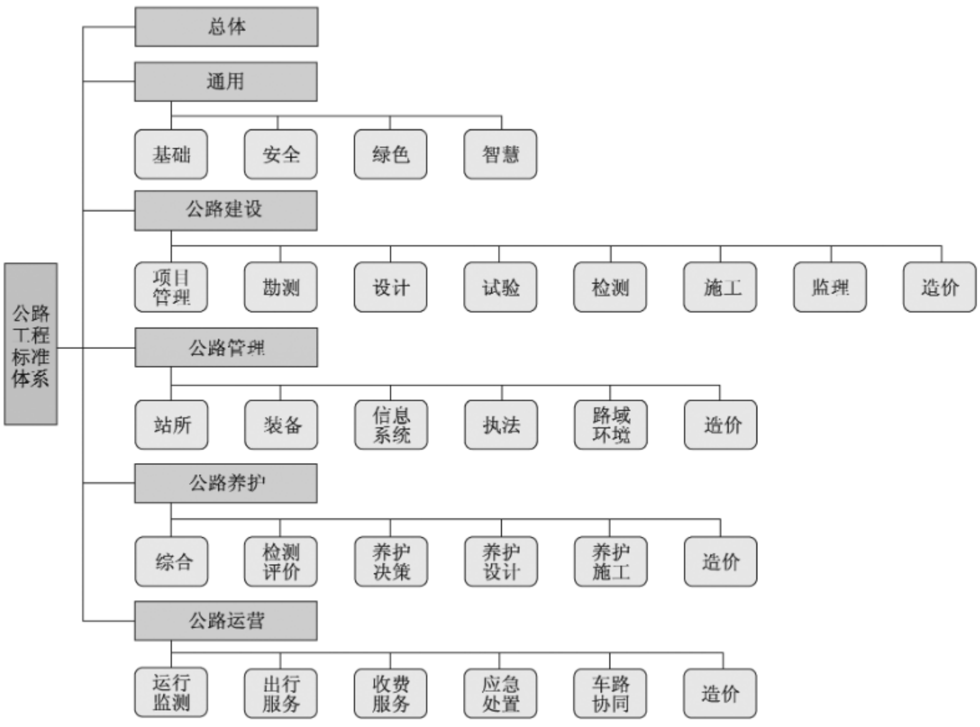
2022 年 1 月 18 日

交通运输部办公厅　　2022 年 1 月 19 日印发

英文版编译出版说明

标准是人类文明进步的成果，是世界通用的技术语言，促进世界的互联互通。近年来，中国政府大力开展标准化工作，通过标准驱动创新、合作、绿色、开放的共同发展。在“丝绸之路经济带”与“21 世纪海上丝绸之路”，即“一带一路”倡议的指引下，为适应日益增长的全球交通运输发展的需求，增进世界连接，促进知识传播与经验分享，中华人民共和国交通运输部组织编译并发布了一系列中国公路行业标准外文版。

中华人民共和国交通运输部发布的公路工程行业标准代号为 JTG，体系范围包括公路工程从规划建设到养护管理全过程所需要制定的技术、管理与服务标准，也包括相关的安全、环保和经济方面的评价等标准。



《公路路基路面现场测试规程》(简称《规程》)是公路路基路面工程实体质量与性能试验检测工作的重要技术标准，主要用于公路工程路基路面的现场测试、施工过程中的质量管理与检查、施工结束后的竣（交）工验收，以及道路使用期的路况评定，可供质量监督部门、检测机构、工程监理及施工企业等使用。1995 年由交通部首次发布实施，其前瞻性引入了当时具有世界先进水平的试验检测设备与方法，为中国此后大规模公路网尤其是高速公路建设提供了基础性保证，在工程设计、施工及养护阶段的质量控制、检验和评价中发挥了重要作用。《规程》在充分总结中国相关科研成果和大量工程经验的基础上，吸收借鉴国际先进的工程测试技术，不断进行改进与修订，2008 年曾发布修订版，2019 年再次发布新版《规程》，重点对公路路基路面现场测试方法的技术要求进行统一和规范，主要内容包括试验方法的适用范围、所用仪器材料技术要求、测试步骤及数据处理方法等。《规程》以成熟性、先进性和可操作性为基本制订原则，并关注测试方法在工程现场的适应性和经济性，针对各类质量评价指标，提出适用于不同成本投入、应用场景、准确度需求的多种测试方法，可适用于不同经济发展阶段的公路工程质量控制要求。本英文版的编译发布便是希望将中国的工程经验和技术成果与各国同行进行交流分享，为其他国家公路路基路面工程的质量控制与评价工作提供参考借鉴。

本英文版的编译工作由中华人民共和国交通运输部委托中国路桥工程有限责任公司主持完成，并由中华人民共和国交通运输部公路局组织审定。

本英文版标准的内容与现行中文版一致，如出现异议时，以中文版为准。

感谢中文版主要编写者和松、窦光武先生在本英文版编译与审定期间给予的指导与支持。

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The People's Republic of China
Ministry of Transport
Public Notice

No. 10

Public Notice for Issuing the English version of the *Standards for Quality Inspection and Verification of Highways, Part 1: Civil Engineering Works*, and three other international versions of the Highway Transportation Industry Standards

For international cooperation and standardization of the highway transportation industry, four international versions of the Highway Transportation Industry Standards (JTG) are issued hereby:

(1) the English version of the *Standards for Quality Inspection and Verification of Highways, Part 1: Civil Engineering Works* [JTG F80/1—2017(EN)], to replace its former edition [JTG F80/1—2004(E)];

(2) the French version of *Standards for Quality Inspection and Verification of Highways, Part 1: Civil Engineering Works* [JTG F80/1—2017(FR)];

(3) the English version of *Field Test Methods of Highway Subgrade and Pavement* [JTG 3450—2019(EN)], to replace its former edition JTG E60—2008(E); and

(4) the English version of *Highway Performance Assessment Standards* [JTG 5210—2018 (EN)].

The general administration and final interpretation of the Highway Performance Assessment Standards belong to Ministry of Transport of the People's Republic of China, while particular interpretation for application and routine administration of the international version of these Standards shall be provided by the China Road and Bridge Corporation.

Comments, suggestions and inquiries are welcome and should be addressed to the China Road and Bridge Corporation (Address: C88, Andingmenwai Dajie, Beijing, Postal Code: 100011, email: kjb@crbc.com). The feedback will be considered for future revisions.

It is hereby announced.

Ministry of Transport of the People's Republic of China

January 18, 2022

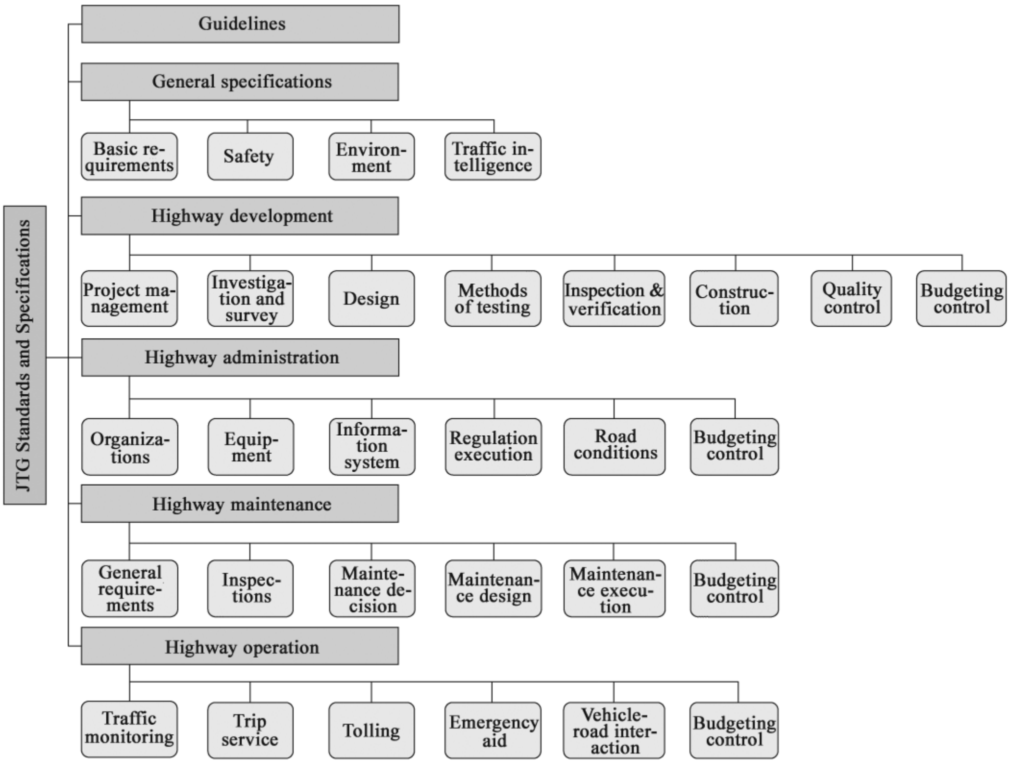
General Office of Ministry of Transport Printed on January 19, 2022

Introduction to English Version

Standards reflect the achievement of civilization, provide common language for technical communication, and improve global connectivity. In recent years, the Chinese government has been proactively implementing a strategy for standardization to stimulate innovation, coordination, greening, and opening up for shared development in China and worldwide. In the light of mutual development along the Silk Road Economic Belt and the 21st-Century Maritime Silk Road (so called 'the Belt and Road Initiative'), the Ministry of Transport of the People's Republic of China organized translation and published an international version of the Chinese transportation industry standards and specifications to cater for the increasing demands for international cooperation in world transportation, achieve interconnected development and promote knowledge dispersion and sharing experience.

JTG is the designation referring to the standards and specifications of the highway transportation industry, issued by the Ministry of Transport of the People's Republic of China. It covers the standards and specification in terms of technology, administration and service for process from highway planning though to highway maintenance. The criteria for safety, environment and economic assessment are also included.

"Field Test Methods for Subgrade and Pavement Layers in Highway Engineering" (shortened as "Methods") is a collection of important technical standards for examining or testing the constructed highway subgrade and pavement layers and their performance. It is mainly used for testing the subgrade and pavement layers of a highway in the field, for quality control during the process of construction, for acceptance checking at the end of construction, or for road condition assessments during their service life. It may be used by quality monitoring departments, testing organizations, project supervisors or contractors. It was first issued and implemented by the Ministry of Transport (MOT) in 1995.



The MOT had the foresight to incorporate the internationally advanced testing and evaluation equipment and methods at the time. This provided a basis for the development of an extensive highway network in China of especially the motorways. Furthermore, the Methods played an important role in formalizing quality control, examination or assessment of project design, construction and maintenance. The Methods incorporated relevant Chinese scientific research results and extensive practical experience besides also incorporating international advanced testing technologies. The Methods were improved and revised, and published in 2008. In 2019, the Methods were again revised and reissued. In this version the focus was mainly to maintain consistency and standardizing the technical requirements for field test methods on the subgrade and pavement layers of a highway. The revision included the applicable scope of a test method, technical requirements for test equipment and materials, test procedures and data processing methods. The basic principle for revising the Methods was that the method should be mature, advanced and practical. Its adaptability and economic efficiency when applied in the field were also considered. Depending on the assessment indexes, various test methods were provided to suit different costs, application scenarios and accuracy demands which could be used for highway quality control purposes demanded by different economic development stages. The purpose of publishing this English version of the Methods is to exchange and share Chinese experience and technical achievements with counterparts in other countries, and to provide a reference for quality control and assessment for highway subgrade and pavement layers.

The translation and updating of the English version was conducted by China Road and Bridge Corporation under the authorization of the Ministry of Transport （MOT）, China and approved by the Highway Administration of MOT China.

The content and numbering of the chapters, sections, clauses and sub-clauses in the English version are exactly the same as those in the Chinese version. In case of any ambiguity or discrepancies, the Chinese version should be used and accepted.

Acknowledgement is given to Mr. He Song and Mr. Dou Guangwu, the Editors in charge of the Chinese version, for the valuable assistance and suggestions during editing and reviewing of the English version.

Comments , suggestions and inquiries are welcome and should be addressed to the organization responsible for the English version: China Road & Bridge Corporation (Address: 88C Andingmenwai Dajie, Postal Code: 100011, E-mail: kjb@crbc.com). The feedback shall be taken into account in future editions.

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Foreword to Chinese Version

The Ministry of Transportation through its General Office requested in its ‘notice of the year 2014’s schedule of highway industry standards to be revised’ that the ‘Research Institute of Highways, China Ministry of Transportation’ revise ‘Field Test Methods for Subgrade and Pavement Layers in Highway Engineering’ (JTG E60—2008) (hereinafter called the former edition).

Based on many years’ practices and new technological developments, as well as referring to the large number of standards and technical information both from China and abroad, the Standard is revised based on the principle of ‘meeting the practical needs first.’ The primary contents being revised are:

1. Refined some methods by their title names, ranges of application, requirements on equipment and materials and methods or procedures

2. In Chapter 3 the ‘Sampling method’ in the former edition, is now titled ‘Field sampling’; it is further divided into ‘Approach in selecting sampling or measuring positions’ and ‘Sampling by coring or by cutting’.

3. In this document ‘strength and modulus (Chapter 7 of the former edition)’ and ‘bearing capacity (Chapter 8 of the former edition)’ are combined into Chapter 7.

4. Chapter 12 ‘faults’ and Chapter 13 ‘ruts’ in the former edition are combined into Chapter 11 ‘subgrade and pavement distresses’ in this edition.

5. Chapter 14 ‘construction control’ in the former edition is re-written as ‘Supplements’ and become Chapter 12 in this edition.

6. In this edition new methods are included: ‘T 0926, Method for determining settlement difference of soil and rock fill embankment’, ‘T 0935, Measuring roughness with profilograph’, ‘T 0946 – 2019 Method for testing soil subgrade

modulus with falling ball instrument', 'T 0957 – 2019 High speed laser – based deflectograph for measuring pavement deflection', 'T 0958, Strength of cement concrete pavement by testing sampled cores'. 'T 0969, Friction coefficient of a pavement by digital pendulum tester', 'T 0974, Test method for determining apparent pavement surface distress', 'T 0975, Checking Portland cement concrete pavement slabs for lack of support (curling, blow-up, or pumping) by deflection measurement', 'T 0976 Test pit for investigating pavement structure distress', 'T 0985 Method for checking inter-layer bond strength', 'T 0986 Measuring traffic noise impact of a pavement by means of a statistical pass-by method', 'T 0987 Road and tire noise emission assessment by CPX (with trailer). In addition Appendix C contains: 'Correlation test method'.

7. Two methods in the former edition were removed, namely: 'T 0956 – 1995 Test method to quickly determine cement concrete strength by pin-shooting', and 'T 0983—2008 Check method for total mass of bitumen mixture'.

This document consists of twelve chapters and three appendixes. Chapters 1,2,3,6 and Appendix A, B, C were drafted by Hesong and Douguangwu. Chapter 4 was drafted by Limeng. Chapter 5 was drafted by Zhouxuli and Zhangbo. Chapter 7 was drafted by Shenxiaojun and Hejing. Chapter 8 was drafted by Sujing and Zhaoxiangmin. Chapter 9 was drafted by Hesong. Chapters 10 and 12 were drafted by Yanerhu. Chapter 11 was drafted by Liu Yangshao and Wangzhibin.

'The Research Institute for Highways, China Ministry of Transport' holds the authority and responsibility to interpret These Field Methods'. Suggestions and comments are welcome and shall be sent to 'The Research Institute for Highways, China Ministry of Transport'. Address: 8#, West Tuchen Road, Haidian district, Beijing. Post code: 100088, E-mail: s. he @ rioh. cn. The feedback will be considered in a future revision and update.

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Contents

1 General provisions

1.0.1 To meet the requirements for highway development and management, it is essential that the quality of design, construction and maintenance relating to the subgrade and pavement is specified in terms of a set of uniform technical requirements for site test methods. This document, 'Field Test Methods of Highway Subgrade and Pavement' (hereinafter referred as the Standard) was established to fulfill this need.

1.0.2 The Standard is applicable for site investigation, quality of work inspection and inspection of technical condition of highway subgrade and pavement layers.

1.0.3 Whenperforming field tests on highway subgrade or pavement layers, test methods specified in the Standard shall be used according to the requirements in terms of their practical use and required standards.

1.0.4 The instruments and equipment used in tests specified by the Standard shall be calibrated and validated before use by a certified technical institution of metrology. Their application shall also follow the operating instructions of the manufacturer.

1.0.5 the Standard complies with international legal measurement system of units.

1.0.6 In conducting field tests, not only the requirements inthe Standard shall be followed, but other related national or industry standards shall also be followed.

***Background*:**

The Standard applies to field tests for highway subgrade and pavement layers, quality control and inspection during the construction period, acceptance inspection after completion and assessing road condition during the service period. It could be used by quality monitoring departments, test or inspection institutes, work supervisors and contractors. Aimed at ensuring precise, reliable and *accurate data from field tests, the purpose of the Standard is to specify every field test and to ensure scientifically reliable methods for all application situations. Quality evaluation standards are not included.. Thus, when testing a technical indicator for highway subgrade or pavement layers, suitable technical methods shall be chosen based on their practical usage and scope of application.*

The appropriate technical method shall be selected according to the actual use and scope of application, and shall follow the requirements inthe Standard. In addition to the data processing and report content requirements for testing, it shall also comply with the corresponding provisions of technical specifications such as construction, maintenance, and acceptance especially in terms of road section selection, sampling methods, data statistics and eligibility criteria, etc.

The prerequisite for obtaining reliable test results is to use qualified instruments and equipment. A large number of instruments or equipment is used in the highway industry. Although equipment of the same type may appear to measure the same properties, different producers use different operating theory or test method or precision control standard. Consequently the test results may be different without a technical standard which shall be followed universally to guarantee the reliability of the test quality. Recently automatic or smart testing equipment have been introduced and it was found that 'black box' effects are emerging. Questions such as whether the instruments or equipment are correctly calibrated, whether their technical stability is constant over time, cannot be answered by eye but they shall be checked by some special technical procedures. Thus, before field testing the work depending on which technical indicators are to be checked, the correct instruments or equipment shall be chosen. This means they shall have the required precision and accuracy and in good condition. If feasible and necessary the instruments or equipment shall be sent to those special institutions on metrological technology for calibration before being applied. For those automatic and vehicular instruments & equipments which are intensely used in These Methods, their operation requirements, operation instructions shall be carefully read. Their required surrounding environment, notice for operations and others shall be kept in mind. This will ensure that the instruments or equipment is correctly operated in a scientific and standard manner so that accurate and reliable test results could be achieved.

2 Terms and symbols

2.1 Terms

2.1.1 Subgrade width

The width of traffic lanes plus shoulders, measured in meters. If there is a median, speed changing lane, climbing lane or emergency parking strip, their widths shall be included.

2.1.2 Pavement width

The sum of widths of traffic lanes, curbs, speed changing lane, climbing lane, hard shoulders or emergency parking strip, measured in meters.

2.1.3 Subgrade cross slope

Onthe upper subgrade surface, the ratio of the elevation difference between the center line and the inner edge of the shoulder to their horizontal distance, expressed as a percentage.

2.1.4 Pavement cross slope

The slope ofthe straight part of a pavement cross – section on both sides of the road crown or median, expressed as a percentage

2.1.5 Deviation of pavement center-line

The distance between the real center line of the pavement and pavement design center line, measured in mm.

2.1.6 Degree of compaction

The ratio of road materialdry density after compaction to its standard or laboratory dry density, expressed as a percentage.

2.1.7 Roughness

The deviation of road surface from its ideal plane, normally expressed asa maximum gap, accumulated road bump value or IRI, measured in mm/m or m/km.

2.1.8 Deflection

Under the specified load, the total verticalmovement (total deflection) or vertical rebound movement (rebound deflection) of the surface of subgrade or pavement layer, measured in 0.01mm.

2.1.9 Texture depth

The depth of texture or irregularities of road surface in a specified area is also termed macrotexture. Based on different inspection areas, or different computational models, it is abbreviated as TD、SMTD、MPD, measured in mm.

2.1.10 British pendulum number

The value representsthe coefficient of friction measured by pendulum skid tester under wet road surface condition, which is 100 times of coefficient of friction, termed BPN and is dimensionless. Note that the BPN relates to low speed (50 km/h) skidding resistance of a passenger vehicle.

2.1.11 Sideway force coefficient

Atest wheel is positioned at an angle of 20°to the direction of travel, and travels at a defined travel speed. The value of the sideway force coefficient is its axial resistance from the special tire rubbing against the wet road surface divided by its vertical load, termed SFC and is dimensionless.

2.1.12 Water permeability coefficient

Undera specified initial water head, the volume of water which permeates from a confined area into the pavement within a unit time, measured in mL/min.

2.1.13 Faulting at joints in slabs

The abrupt elevation difference at the joints of different structures or concrete slabs, measured in mm.

2.1.14 Rutting

The permanent deformation by flow, wear or depression of a pavement under repeated traffic loads, which results in strip depressions in the wheelpaths of vehicles. Normally the depth of the deepest rut in a cross – section of a pavement is taken as the rut indicator, measured in mm.

2.1.15 Field CBR of the soil subgrade

2.1.15 An indicator to represent the bearing capacity of soil subgrade, that is, at the field condition, the pressure of the test load applied on a standard piston to the specified penetration divided by standard load pressure, expressed as a percentage.

2.1.16 Resilient modulus

The stress ofa subgrade, pavement layer or road material under repeated loading actions divided by the corresponding resilient strain, measured in MPa.

2.1.17 Distress ratio

The sum of all the areasof pavement distress divided by the area checked, expressed as a percentage.

2.1.18 Broken slab ratio

The number of concrete pavement slabs which are broken into two or more pieces divided by the total number of slabs in theroad section investigated, expressed as a percentage.

2.1.19 Pavement cracking ratio

Thesum of the area cracked in the pavement divided by the total area of pavement investigated, expressed as percentage.

2.1.20 Voids

Separation of layers or voids that occur between pavement layers, are represented by their sizes, measured in mm.

2.2 Symbols

BPN——British pendulum number

CBR——California bearing ratio

CW——Coefficient of Water

D——Pavement slab faulting

E_0——resilient modulus of soil subgrade

E_1——resilient modulus of pavement layer

IRI——International roughness index

K——Compaction degree

RU——Rut depth

SFC——Sideway force coefficient

TD（SMTD、MTD、MPD）——Texture depth

VBI——Bump Integrator value

Δ_{CL}——deviation of pavement center line

δ_{m}——roughness（the greatest gap）

μ——Poisson′s ratio of pavement layer material

3 Field sampling

T 0902—2019 Approach in selecting sampling or measuring positions

1 Scope of application

This method is applicablefor selecting individual sampling positions for field tests on the subgrade or pavement layer to evaluate various technical indicators of the works.

2 Methods and procedures

2.1 Evenlydistributing method

Divide the roadinto an equal spacing in the longitudinal and transverse directions. Make marks in each cross points. Decide on the sampling positions based on these marks.

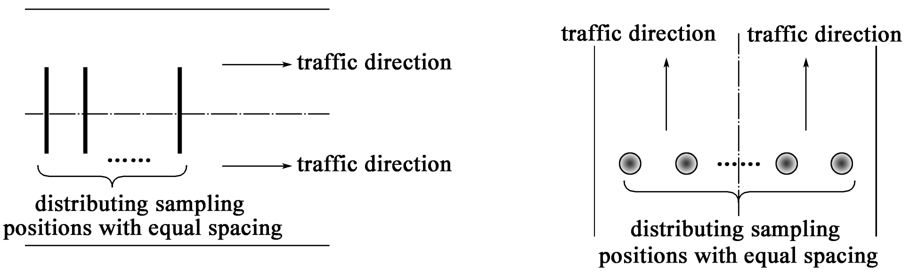


Illustration T 0901-1 Evenly distributing method

2.2　Randomlyselected positions

Select areas or cross – sections or points for sampling as indicated in Appendix A

2.3　Directed sampling method

Select sampling positions in wheel paths, or from positions having other characteristics or from specified positions like cracks, faults, or broken corners.

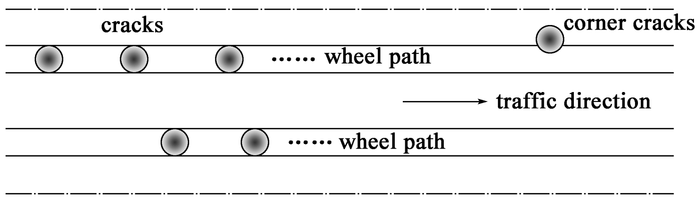


Illustration T 0902-2　Directed sampling approach

2.4　Continuous method

Followingthe specified standard, evenly and continuously distribute sampling positions along the road direction.

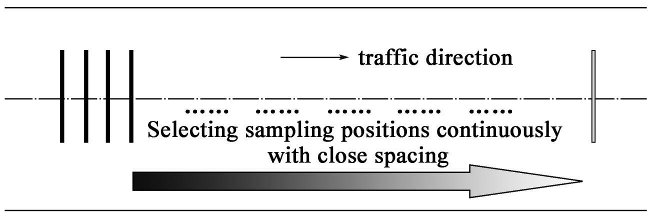


Illustration T 0902-3　Continuous method

2.5　Comprehensive method

Use two or moreof the above methods together to select the sampling positions. Generally select sampling areas continuously along the length of the road. Randomly select sampling positions inside such areas. Alternatively, use evenly distributed sampling areas along the road direction, and select sampling positions in the direction of the measurement area.

***Background*:**

The correct and standardized selection of sampling points is a prerequisite to ensure reliability and representativeness of test results of subgrade and pavement layers with reliability and representativeness. Different methods in selecting sampling positions may result in contradictory test conclusions Therefore the Standard gives typical methods for selecting sampling positions for subgrade and pavement layer field tests. If the representativeness of sampling is insured, coring of a newly built road may be based on the road marking lines to reduce unnecessary damage to the road structure.

T 0903—2019 Sampling by coring or by test hole

1 Scope of application

1.1 This method is applicable for acquiring representative samples from a pavement layer by coring or by cutting with a core drill or powered pavement cutter.

1.2
This method is used to take samples from a cement concrete pavement, an asphalt pavement or inorganic binder (such as cement) stabilized base course to test their density and other physical – mechanical properties.

2 Technical requirements of equipment and materials

(1) Core drill for pavement use: hand propelled or mounted on a vehicle, equipped with a water cooling system. Diameter of the bit is ϕ100mm or ϕ150mm.

(2) Powered saw cutter: hand propelled or self-propelled, electrically powered, or driven by external power through a hydraulic pump. Accessories are diamond saw blades and water cooling system.

(3) Platform scale

(4) Sample holders (bags) or metal or other trays.

(5) Dry ice (solid CO_2)

(6) Sample tags

(7) Other tools: picks, shovels, tape measure or ruler (ropes), brushes, hard paper, cotton rags.

3 Method and procedures

3.1 Preparation

(1) Select a bit with a diameter 3 times greater than that of the maximum aggregate particle size.

(2) Determine road section for testing. It may be a section of road from the contractor's breakdown of tasks, or a road section being a job completed in one day, or a length of road section as required by the relevant specifications.

(3) Determine sampling or testing positions as required in T 0902 of the Standard.

(4) Clean the sampling positions.

3.2 Sampling procedures

(1) Determine the areas to be cut based on the purpose and requirements ofthe test. Mark the positions to be cored or roughly mark the areas to be cut.

(2) Align the core drill vertically with the sampling position, start rotation of the bit and lower the bit onto the pavement layer, keep uniform pressure on the bit. Ensure that the core drill is stable and will not move during the coring process.

(3) Turn on the cooling water, start the motor, slowly press down the drill but the pressure shall not be too high. When the coring depth is reached at the total thickness of the samples, lift the stem and bit, stop the motor and prevent damage to the sample. Carefully remove the sample from the bit. Samples of asphalt concrete or cement concrete may be cleaned with clean water for later testing. If tests prescribe that no cooling water shall be used, dry coring shall be applied. To prevent damage to the bit, 3kg dry ice could be placed over the coring position to cool down the pavement layer for about 1 hour. During the coring process, cooling gas such as cold CO_2 could be used instead of cooling water.

(4) When using a powered cutter, the cutting blade shall be aligned with the cutting position. Switch on the cooling water and start the motor. Lower the blade slowly until the required depth is reached. Move the cutter forward carefully to the required length. After four sides have been cut, use picks or shovels to recover the sample slab. Samples shall have four complete corners, and particles shall not be lost.

(5) The sample ofan asphalt layer shall be cored in a complete layer and shall not be broken. Cored or cut samples shall be kept in sample holders. If necessary, use plastic bags to envelop them.

(6) Write down the sample particulars on tags and make two copies. One copy is attached to the sample and the other is kept on file for checking.

(7) Use a cotton rag or similar material to dry the remaining water, and use the same road material to fill the hole that was cored or cut, after the road has dried.

No. of sample
No. of road or project name______________________
Type of material
Construction date:
Sampling date: ·····································
Sampling position: stake,
center line left m right m
Name ofperson sampling :
Sample keeper:
Note:
(purpose of sampling and test result)

Illustration T 0903 Sample bag tag

Background:
Taking samples in a consistent manner will ensure that test results are not affected. For field testing of subgrade and pavement layers, taking samples from the pavement by coring is an important way in taking samples. From the cored samples, the results such as layer thickness, density, strength and others properties may be obtained.

There are two types of bit for coring. One is for cement concrete and inorganic binder stabilized base course. The other is for asphalt layers or for general purpose use, equipped with a cooling water system. The diameters of cored samples depend on the coring bits. Normally they are φ50mm、φ100mm、φ150mm. The diameter of a sample shall be at least 3 times of maximum aggregate particle size. Normally, for asphalt layers or for a cement concrete pavement, a φ100mm bit is used. For an inorganic binder (lime or cement) stabilized base a φ100mm is used for fine grained soil whereas φ150mm is for coarse grained material.

4 Geometric control

T 0911—2019 Measurement of the dimensions of subgrade and pavement layers

1 Scope of application

The method isused to measure the widths of subgrade and pavement layers, elevations of longitudinal profile, cross slope, deviation of center line, side slope, elevation difference between two connected cement concrete slabs and the evenness of transverse or longitudinal joints in order to evaluate road alignment and its geometric features.

2 Technical requirements for equipment and materials

(1) Steel tape and steel ruler with graduations of 1mm.

(2) Feeler gauge with graduations no more than 0.5mm.

(3) Theodolite, level; total station
Theodolite, precision DJ2
Level, precision DS3
Total station: angular accuracy 2″, ranging accuracy [2mm + 2 × 10-6s(s as measured range)]

(4) Spirit level: made of metal. Its base plane shall be level, with a length not less than 600mm or not more than 2000mm.

(5) Slope gauge: scale 1°

(6) Nylon cord: diameter not more than 0.5mm

3 Method and procedure

3.1 Preparation

(1) Confirm the stake values on subgrade or pavement layer.

(2) Follow method T 0902 in the Standard, select a cross section from the road section under consideration and mark its position. A single cross-section shall be selected to check the width, cross slope, elevation and center line deviation of subgrade or pavement layer. It is recommended to select the cross section at the stake with an integer value (of meters).

(3) Based on the road design, determine the edge line of the subgrade or pavement layer and mark it.

(4) Based on the road design, determine the position of design profile elevation and mark it.

(5) Based on the road design, determine the position of the actual center line of the cross section (which is perpendicular to center line) of the finished pavement layer, and mark it.

(6) In the case where the side slope is checked with a total station, determine the positions of top of slope and foot of slope, from the road design and mark them.

3.2 The procedure for checking the width of each part ofthe subgrade or pavement layers and their total width.

Usea steel tape to measure the width B1 of each part of the subgrade or pavement layer in the direction perpendicular to the center line, measured in meters, with the precision of 0.001m. The steel tape shall be kept level, and shall not follow the road surface. A leather tape shall not be used.

3.3 Longitudinal profile elevation measuring procedure

(1) Set the level at a position on the road where the surface is even. Adjust it to level. Place the leveling staff on the points of the longitudinal profile which represent the design elevation.

Elevation is referenced to a nearby benchmark. Check (read and record) the elevation H1 (in meters) with the precision of 0.001m.

(2) Check all the control points and ensure that the benchmarks can be closed with a closure error meeting the leveling requirement of Class-III.

3.4 Measuring the cross slopes of subgrade and pavement layers

(1) For a pavement divided by a median: set the level or the total station at an even part of the road, and set up the instrument. Place the leveling staff at the edge (d1) of the marginal strip which is the delineation of pavement and center median (or its corresponding point at the top of the subgrade), and the delineation (d2) of pavement to shoulder or edge of outer curb (or its corresponding point at the top of the subgrade. Note that d1 and d2 shall be on the same cross section. Read and record the elevation of d1 and d2 in meter with a precision of 0.001m.

(2) For a pavement without a center median, set up the level or total station on an even place on the road. Place the leveling rod at the road center (d1) (or its corresponding point at the top of subgrade), and the delineation (d2) of pavement to shoulder or edge of outer curb (or its corresponding point at the top of subgrade). Note that d1 and d2 shall be on the same cross section. Read and record the elevation of d1 and d2 in meter to a precision of 0.001m.

(3) Measure the horizontal distance between two measuring points with a steel tape, in meters, to a precision of 0.005m.

3.5 The procedurefor checking the deviation of the center line

(1) For a road with its center line having known coordinates, based on the chainage (stakes) of point P which is to be checked, mark such a point P over the road. For this point P obtain the design coordinates which may be found from the design documents, set out and mark such a point P' with a theodolite or total station. Measure the distance of PP' in mm with a precision of 1mm. This value is the deviation of the center line ΔC.

(2) For a road with its center line having no known coordinates, based on the chainage (stakes) of point P which is to be checked, mark such a point P on the road. Next calculate its coordinate according to the design information, and set out and mark such a point P', measure the length of PP' in mm with a precision of 1mm. This value is the deviation of the center line ΔC.

3.6 The procedurefor checking the side slope of the subgrade

(1) By total station

Setup the total station in a flat place on the road, select two points on the same cross section as ‘a’ (at the top of slope) and ‘b’ (at the foot of slope). Check the relative elevations of these points as Ha and Hb respectively, measure the horizontal distance between the points in meter with a precision of 0.001m and record.

(2) By slope measuring instrument

Set themeasuring surface of slope measuring instrument perpendicular to the road center line and on the side slope to be checked. Turn its dial to set the bubble to the level position. Read and record the indicated value from the dial to a precision of 0.01. This is the side slope of the subgrade.

3.7 The procedurefor measuring elevation difference between two adjacent concrete slabs

Set the level ruler across the joint on the higher slab, level it and insert the feeler gauge under the ruler on the lower slab and read the elevation difference. The maximum difference H in mm represents the elevation difference between two adjacent slabs, with a precision to 0.5mm.

3.8 The procedurefor checking the alignment of longitudinal and transverse joints on concrete pavements

(1) On a straight length of a road to be checked, set a nylon cord aligned with both ends of a 20m long segment of longitudinal joint, pull the nylon cord tight and straight, then measure the maximum distance in mm between the nylon cord and the longitudinal joint with a steel ruler, to the precision of 1mm. This is the alignment of the longitudinal joint.

(2) Set a nyloncord aligned with both ends of a transverse joint, pull the nylon cord tight, then measure the maximum distance in mm between the nylon cord and the transverse joint with a steel ruler, to the precision of 1mm. This is the alignment of the transverse joint.

4 Data processing

4.1 According to the formula(T0911-1), calculate the difference in the measured width Bli to the design width B0i at each cross section. The total deviation width is the sum of the width of each part of subgrade or pavement layer.

$$\Delta B_{\mathrm{i}} = B_{1\mathrm{i}} - B_{0\mathrm{i}} \qquad (\mathrm{T0911\text{-}1})$$

Where: $B_{1\mathrm{i}}$——the measured width at cross section i (m)

$B_{0\mathrm{i}}$——the design width at cross section i (m)

ΔB_i——the width deviation at cross section i (m)

4.2 According to the formula(T0911-2), calculate the difference of the measured elevation H1i to the design elevation H0i at each cross section.

$$\Delta H_i = H_{1i} - H_{0i} \tag{T0911-2}$$

Where: H_{1i}——the measured longitudinal profile elevation at cross section i

H_{0i}——the design longitudinal profile elevation at cross section i

ΔH_i——the deviation of longitudinal profile elevation at cross section i

4.3 Calculate the difference between measured cross slope i1i and design cross slope i0i by means of the following formulas (T0911-3、T0911-4), with a precision of 0.01%.

$$i_{1i} = \frac{d_{1i} - d_{2i}}{B_{1i}} \times 100 \tag{T0911-3}$$

$$\Delta i_i = i_{1i} - i_{0i} \tag{T0911-4}$$

Where: i_{1i}——the cross slope at the cross section i(%),

d_{1i} and d_{2i}——readings of elevation at the positions d_{1i}, d_{2i} of cross section i (m),

B_{1i}——the horizontal distance between points d_{1i} and d_{2i}(m)

Δi_i——the deviation of cross slope at the cross section i (%)

i_{0i}——the design cross slope at the cross section i

4.4 Side slope is normally expressed as 1:m. Whenusing a total station to calculate cross slope, the formulas(T 0911-5、T 0911-6) shall be used. Side slope with its elements is illustrated in Figure T0911.

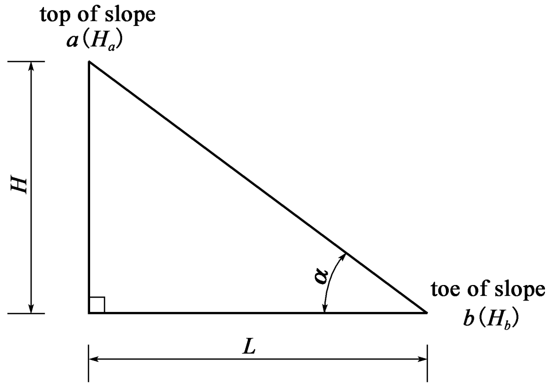


Figure T0911-1 Side slope and itselements

$$H_i = H_{ai} - H_{bi} \tag{T0911-5}$$

$$m = L_i / H_i \tag{T0911-6}$$

Where: H_i——the elevation difference or vertical distance between top of slope and foot of slopeat cross section i(m)

H_{ai}, H_{bi}——the readings of relative elevation of top of slope and foot of slope at cross section i (m)

m_i——the value of slope at the cross section i, expressed as $1:m_i$

L_i——the horizontal distance between top of slope and foot of slope at cross section *i*.

5 Report

This methoddescribes the technical content that must be reported:

(1) Information related to the positionsthat were measured (stakes, coordinates).

(2) Measured width, design width and the deviation of width.

(3) Measured longitudinal profile elevation, the design elevation, and the deviation of elevation.

(4) Measured cross slope, design cross slope, and the deviation.

(5) Measured side slope.

(6) Deviation of center line, elevation difference ofadjacent concrete slabs and alignment of longitudinal or transverse joints.

Background:
The 'Quality Inspection and Evaluation standards for Highway Engineering' (Volume I, civil works) (JTG F80/1—2017) requires that the quality control process of subgrade construction and at the time of acceptance inspection, to check side slope and for cement concrete pavement to check the elevation difference of two adjacent slabs and alignment of longitudinal or transverse joints. This newly revised method incorporate methods for measuring elevation difference of two adjacent slabs and alignment of longitudinal or transverse joints, and side slope.

Gradiometer, or slope measuring instrument, is a device developed recently following the need to measure side slopes. It is simple and convenient to use. However, its effective length is short and the results are affected by the construction quality. Consequently proper positions have to be selected when measuring slopes.

T 0912—2019 Measuring the pavement layer thickness by cutting or coring methods

1 Scope of application

This method is applicable to check pavementlayer thickness. Cutting is used to check the base layer or granular layers. Coring is used to check an asphalt surface layer, cement concrete slab or a type of base layer from which a complete core removed.

2 Technical requirements for equipment and materials

(1) Pick, shovel, chisel, hammer, scoop, brush

(2) Coring machine, hand-propelled or mounted on a vehicle, equipped with cooling water. The diameter of a standard bit is φ100mm. If the core is only for checking thickness, without the need for further testing, a bit of φ50mm is also acceptable to check the thickness of an asphalt surface layer or cement concrete slab. If the core of a base layer tends to disintegrate, a φ150mm bit may also be used, but the depth of coring shall reach to the bottom of the layer. .

(3) Ruler: steel ruler, Vernier caliper, with a scale not more than 1 mm.

(4) Others: straight edge, enameled plate and cotton cloth.

3 Method and procedure

3.1 Preparation

(1) Following the method specified by T 0902 of the Standard to determine the positions to be cut or cored. On an old road those positions with obvious defects such as potholes or joints shall be avoided.

(2) At the determined sampling position, select a uniform surface with an area of about 400mm × 400mm and sweep it clean.

3.2 The procedure for digging a hole to check thickness

(1) Based on the hardness of material to be removed, choose a suitable tool like pick, shovel, chisel or others. Remove the layer to the bottom. The digging area shall be small to reduce the amount of work. The hole shall be roughly in a round shape. Remove the material that was loosened by digging and place in an enameled plate.

(2) Clear the bottom of the hole with a brush, and ensure the top of the lower layer was reached.

(3) Place the straight edge across the hole, set the steel ruler upright positioned in the center of hole to measure the distance between the bottom of the hole and the underside of the straight edge. This is the thickness T1 of the layer being checked, measured in mm, with the precision to 1mm.

3.3 The procedure for the coring method to check thickness

(1) To take a core sample with a coring machine following T 0903 of the Standard, ensure that the cored depth shall be greater than the layer to be checked.

(2) Take out a complete core sample and locate the interface with the lower layer.

(3) Use a steel ruler or Vernier caliper to measure the thickness of the core (distance from the top of the core to the interface) by checking at 4 positions which form two perpendicularly crossed diameters. As there are 4 measured values, their average value in mm shall be calculated to give a layer thickness T1, with the precision of 1 mm.

3.4 Clearn the remaining material in the hole, dry up the water induced from coring with a cotton rag. After the hole has dried, fill and compact the pit with similar material.

4 Data processing

4.1 Calculate the difference between the measured thickness T1i and the designed thickness T0i according to equation T0912-1

$$\Delta T_i = T_{1i} - T_{0i} \qquad \text{(T0912-1)}$$

Where: T_{1i}——the measured thickness of ith layer of pavement

T_{0i}——the design thickness of ith layer of pavement

ΔT_i—— the thickness difference of ith layer of pavement

4.2 Calculate the average thickness, the standard deviation of a road test section, and the representative value of the thickness.

5 Report

This methoddescribes the technical content that must be reported:

(1) Data related to the position being measured (stake, pavement structure and others).

(2) The measured thickness, the design thickness and deviation of thickness at each measured position.

(3) The average thickness, standard deviation and the representative value ofthe thickness of a road section.

Background:
Themethod to back fill a test pit or coring hole in the former edition is not included in the Standard as they are not test methods. Principles are given in this edition for back filling without detailing the procedure.

T 0913—2019 Measuring pavementlayer thickness with ground penetrating radar

1 Scope of application

1.1 This method isused for measuring pavement layer thickness by ground penetrating radar.

1.2 This method is not applicable towet pavements, or being made with road materials rich in ferrous slag with a high dielectric constant.

2 Technical requirements for instruments and materials

A hood-antenna ground penetrating radar testing system consists of a vehicle to carry the system, transmitting antenna, receiving antenna and control unit. The basic technical requirements are as follows:

(1) Distance calibrated error is no more than 0.01%

(2) Minimum resolution of thickness not more than 40mm

(3) The required measuring precision as shown in the table T 0913-1

Table T 0913-1 The required measuring precision of the system

Tested depth	Allowable measuring error
$H < 100$mm	±3mm
$H \geqslant 100$mm	±(3% H)mm

(4) Antennas: air coupling mode, their band width shall be appropriate for the selected frequencies of the transmitted pulse.

3 Method and procedure

3.1 Preparation

(1) Before testing, design drawings, construction material data and other information shall be collected to decide on a road section to be verified.

(2) Distance shall be calibrated as required.

(3) Antennas shall be fixed firmly, and connected to a computer by means of cables. The system shall be warmed-up before testing.

(4) Place a metal plate exactly under the antenna and start the controlling program to calibrate the system.

(5) Based on the testing purpose, set the parameters such as the sampling interval, time window and gain for the controlling program.

3.2 Testing procedure

(1) Turn on warning light on the vehicle, place the antenna directly over the starting point, start the controlling software for testing, slowly accelerate the vehicle to its normal testing speed.

(2) During testing the operator shall mark the start and end points of structures like bridges or tunnels within the road section being tested.

(3) During testing the vehicle shall stop at each defined distance interval for recording them into the program. Ensure the radar image is clear, recognizable, with no abrupt changes, and mark out the corresponding point in relate to antenna's center point on the ground. At this point a core sample shall be taken by following T 0912 of this edition radar testing program, the wave velocity is calibated. The average wave velocity of the cored samples along the road section is entered into the testing software. Ensure that sample positions over the road section are evenly distributed. Sampling intervals shall not be greater than 5km and the number of samples shall ensure that the results are representative and accurate.

(4) When the vehicle reaches the end point of the road section, the program is stopped.

(5) Operating personnel shall examine the data files to be sure that files are complete withappropriate content.

(6) Switch off the power to the test system to end this test.

4 Data processing

4.1 The radar wave recognition program will automatically identify the interfaces of each pavement layer, and calculate the two way wave travel time Δt in each layer. Based on Δt and the transmitting speed of the radar wave in the road material, the thickness of the surface layer can be obtained from the following formula (T 0913-1).

$$T = v \times \frac{\Delta t}{2} \quad \text{(T 0913-1)}$$

Where: T——thickness of surface layer, mm;

v——transmitting velocity of the radar wave in the road material (mm/ns);

Δt——two way travel time by radar wave (ns)

4.2 Follow the requirements by Appendix B of JTG3450-2019 to calculate the values of average thickness, standard deviation and the representative thickness.

5 Report

The report shall includethe following technical content:

(1) Data related to the road section being tested (stakes of start point and end point, type of material in the pavement layers).

(2) Transmitting speed in road material by radar wave and surface layer thickness.

(3) The averagelayer thickness of tested road section, its standard deviation and representative value.

Background:
In measuring pavement layer thickness by this method, the frequency of the radar antenna is an important factor which affects the results. It is recommended to select an antenna with a frequency based on the nominal thickness of the pavement layers to be tested. Normally, an antenna with a frequency not less than 2GHz shall be selected if the nominal pavement layer thickness is less than 10cm. An antenna with a frequency not less than 1.5GHz shall be selected if the nominal pavement layer thickness is between 10 and 25cm, and frequency not less than 1GHz, if the nominal thickness is greater than 25cm.

In this edition, the technical requirements and precision of measurement error for the ground penetrating testing system are readjusted to coincide with the regulation for metrological verification for such equipment, entitled "Ground penetration radar for highway cross section void detection and structural layer thickness checking' (JG124 - 2015).

Theoperating temperature requirements for the testing system are deleted in this edition. The main reason for this is because the temperature difference is great between South and North China. Such requirements do not only impede the general use of the equipment, but also impede fulfilling the testing demands in the South and North. From experience in using the systems, it was found that all systems are temperature sensitive to a certain extent. However, testing requirements and precision are all being satisfied. Thus the temperature requirements have no practical implications.

To calculate pavementlayer thickness accurately, the dielectric constant of the road materials or the transmission speed of the radar wave is required. When the dielectric constant of material to be tested is available, transmission speed of the radar wave is calculated according to equation (T 0913-2)

$$v = \frac{c}{\sqrt{\varepsilon_r}} \quad \text{(T 0913-2)}$$

Where: v——' s transmission speed of the radar wave in the road material(mm/ns);

c——transmission speed of radar wave in air, taken as 300mm/ns;

ε_r—— the relativedielectric constant of the road material.

Asthe dielectric constant (wave speed) varies with pavement design layer thickness, aggregate type, origin of bitumen, material type, construction quality, density, moisture content, normally the wave speed shall be calibrated by taking cores out of the pavement. Based on the uniformity of the above factors, determine a reasonable length of road section for calibration and taking an adequate number of core samples, to ensure that the wave speed being calibrated is representative and accurate. Normally a calibration length shall not be more than 20km. Within the calibration length, if the number of core samples is more than 3, it was found from experience that the calibrated wave speed is representative and accurate. The ranges of relative dielectric constants of some common materials are listed in Table T 913-2 for reference in calibrating wave speed.

Table T 0913-2 Ranges of relative dielectric constants of some common materials for reference

Media type	Range of relativedielectric constant
air	1
water	81
Ordinary cement concrete	4-15
Asphalt concrete	3-10
Dry sand	3-6
limestone	7-9

T 0914—2019 Measuring road alignment with Road Geometry Data Acquisition System (RGDAS)

1 Scope of application

1.1 This method may be used to collect pavement cross slope or camber, longitudinal slope and vertical and horizontal curvature through a Road Geometry Data Acquisition System (RGDAS), to evaluate the road alignment.

1.2 This method is unsuitablefor measuring pavements with distress, such as severe potholes, rutting, etc.

2 Technical requirements for instruments and materials

The Road Geometry Data Acquisition System (RGDAS) consists of a vehicle which contains the system, alaser distance meter, triaxial accelerometer, gyroscope, distance measurement instrument (DMI) and computer system.

2.1 Basic technical requirements for the vehicle carrying the system

The body of thevehicle that contains the Road Geometry Data Acquisition System shall not be more than 1.7m in height.

2.2 Technical requirements and parameters for RGDAS

(1) Distance calibration error shall not be more than 0.1%

(2) The measured cross slope has to be within a deviation ±0.1°.

(3) The measured longitudinal slope has to be within a a deviation of ±0.1°.

(4) The resolution of the radius of a curve (angle measurement error after a 360°turn in the horizontal plane or vertical plane) shall not be more than 1°.

3 Methods and procedures

3.1 Preparation

(1) Check on the weather forecast to be sure that the wind speed on the day of measurement are to be taken do not exceed 7.9m/s.

(2) After the vehicle has traveled 5000km or after its tires were replaced or repaired, the distance calibration shall be made on a calibration section of 1000m, and the error shall not be more than 0.1%.

(3) Turn on the power from the console, check all the functional buttons and indicator lights, and select the technical parameter modes.

3.2 Measuring procedures

(1) After switching on the system, the warm up time shall be as specified.

(2) Before performing any measurements or every 100 km distance the system shall be reset to delete accumulated errors.

(3) The measuring mode shall be set based on the technical requirements of the road section to be tested.

(4) Gently accelerate the vehicle to its measuring speed, which normally is 30 to 80 km/h, before the start of the section. The vehicle shall be positioned along a normal wheel path, moving at a constant speed. Ensure that other vehicles are not overtaken (unless unavoidable) and the RGDAS keeps to its travelling lane and lateral position.

(5) In the process of testing, record the data of positions such as start point, end point and any other specifically fixed points.

(6) When the vehiclereaches the end of the test section, stop the vehicle and stop data recording and switch all the instruments to their initial state.

(7) Check tested data and ensure the results are normal. Otherwise the section shall be re-tested.

(8) Turn off the power for the system which means the test is complete.

4 Data processing

4.1 Calculation of cross slope

The principle to calculate the measured cross slope is as shown in Figure T 0914-1.

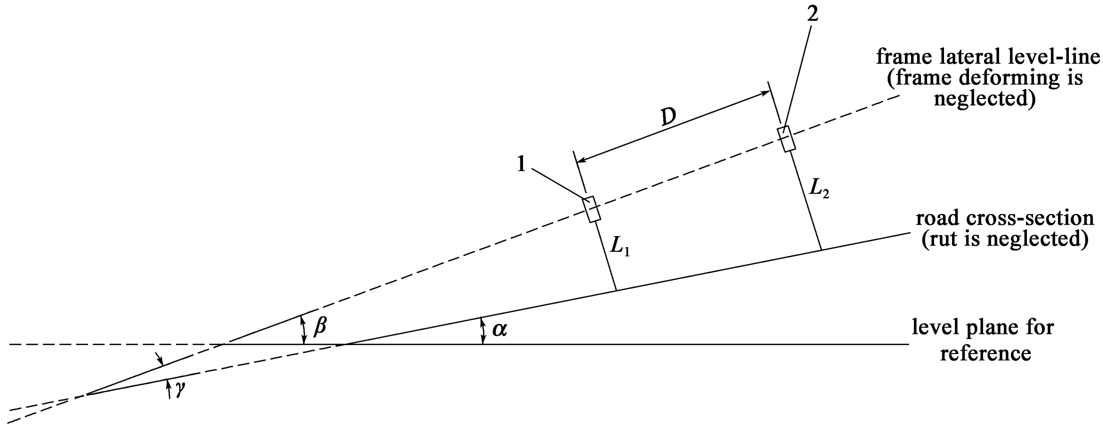


Figure T 0914-1 The principle to calculate the measured cross slope

1—distance measuring equipment; α—the horizontal angle of road cross section, or cross slope; β—angle of vehicle transverse axis relative to the level plane; γ—the angle between vehicle transverse axis andthe road pavement; L_1、L_2—the distance between the distance meters and the road surface; D—the distance between two distance meters.

Cross slope or longitudinal slope is calculated from equations (T 0914-1)、(T 0914-2).

$$i = \tan(\alpha) \quad \text{(T 0914-1)}$$

$$\alpha = \beta - \gamma \quad \text{(T 0914-2)}$$

where: i——Cross slope or longitudinal slope, with a precision to 0.01%;

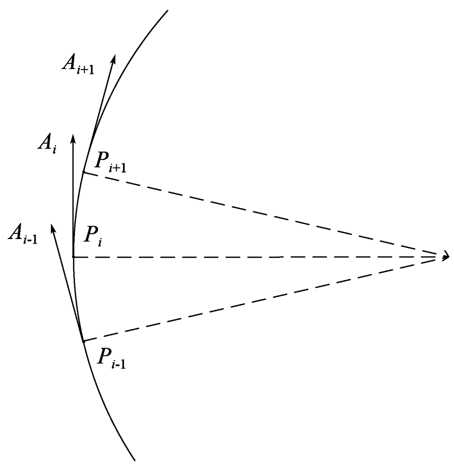
α——the horizontal angle of road cross section(°);

β——vehicle transverse axis angle, measured by RGDAS(°);

γ——the angle between vehicle transverse axis and road pavement, measured by RGDAS(°)。

4.2 Calculation of radius of curvature

The principle of measuring and calculation of the radius of curvature is shown in Figure T 0914-2



The radius of curvature is calculated from equations (T 0914-3)、(T 0914-4)

FigureT 0914-2. The principle of measurement and calculation of radius of curvature

$$R_i = 1/C_i \qquad (T\ 0914\text{-}3)$$

$$C_i = \pi \times (A_i - A_i - 1)\ /(180 \times d) \qquad (T\ 0914\text{-}4)$$

where: R_i——radius of curvature at measurement point i(m), with the precision to 1m;

C_i——curvature at measurement point i;

π——$P_i = 3.14$;

A_i、A_i-1——offset angles corresponding to measurement points P_i、P_i-1, measured by RGDAS (°);

d——distance between samples(m)。

5 Report

The report of this method shall include the following technical content:

(1) The information about the test road section (stakes of start and end points, road name or number)

(2) Cross slope, longitudinal slope, radius of curvature

Background:

As the longitudinal slope and radius of curvature (radius of horizontal curve or radius of vertical curve) as indicators are becoming more important in the acceptance inspection and in evaluating the operational conditions of the highway works during service. Consequently measuring methods are included in this edition and the method is renamed as 'Measuring the road alignment'. If the results are questioned, they shall be re-checked by the conventional leveling measurement method.

The technical requirements for the RGDAS testing system are consistent with the method of metrological verification (JJG 110-2012) 'Collection of road geometry data by vehicle'. At the time of monitoring road situations, a GPS positioning system is typically used to collect the measured positions.

As the test results are easily affected by pavement conditions and the prevailing wind speeds or other factors when carrying out vehicle surveys, the height of the vehicle and the wind speed are being restricted.

5 Field density

T 0921—2019 Testing field density with sand cone method

1 Application range

1.1 This method is applicable for testing the in-situ density of a base layer, subbase layer, gravel pavement layers or subgrade to evaluate the compaction quality of structural layers.

1.2 This method cannot be used for testing the density of those layers with large voids such as rock fill embankments.

2 Technical requirements of instruments and materials.

(1) Testing apparatus: the testing apparatus shall include a sand container, a calibrating container and a density plate.

① Sand container: made of metal, its shape and dimensions are shown in figure T 0921, and meet the requirements specified in Table T 0921-1. The upper part of the sand container is a cylinder, whereas the lower part is a cone funnel. There is a shutter between the bottom of the cylinder and the top of the cone funnel.

② Calibrating container: made of metal, its top-end has a flange, and its shape and dimensions are shown in Figure T 0921 as well as being specified in Table T 0921-1.

③ Density plate: a square plate of metal, with a circular hole in the center, with dimensions meeting the requirements in Table T0921-1.

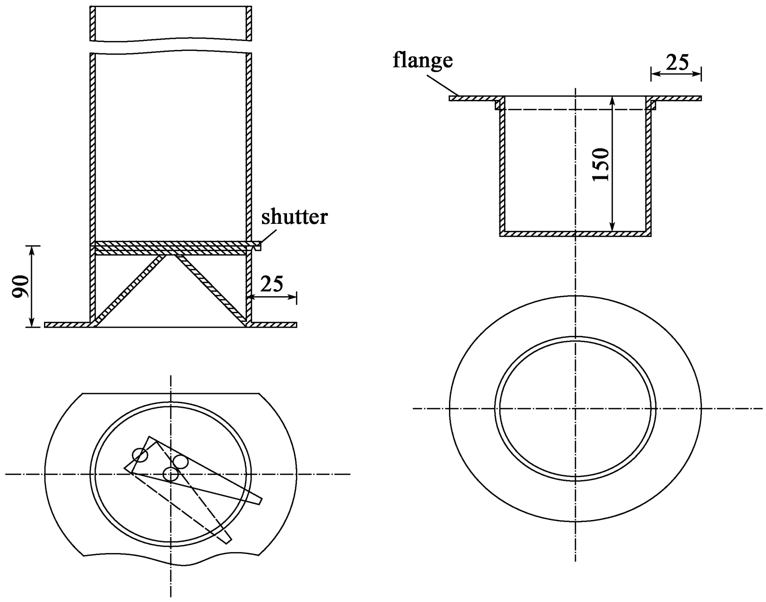


Figure T0921 Sand container and calibrating container (in mm)

Table T0921-1 Dimensional requirements of the apparatus

Type of apparatus			Small apparatus	Medium apparatus	Large apparatus
Sand container	Sand cylinder	Diameter(mm)	100	150	200
		Volume(cm^3)	2121	4771	8482
	Shutter	Diameter(mm)	10	15	20
Calibrating container	Calibrating container meter	Inner diameter(mm)	100	150	200
		Outer diameter(mm)	150	200	250
Density plate	Metal square plate	Side length(mm)	350	400	450
		Depth(mm)	40	50	60
	Circular hole	Diameter(mm)	100	150	200
	Plate thickness	Thickness(mm)	≥1.0(steel)	≥1.0(steel)	≥1.0(steel)
			≥1.2 (aluminum alloy)	≥1.2 (aluminum alloy)	≥1.2 (aluminum alloy)

Note: the volume of the sand container is selected based on thickness of the layer to be checked. Other parameters shall be kept the same to ensure that the sand filling process is consistent.

Select a sand container: based on the maximum particle size in the layer to be tested and thickness of the test layer, that meet the requirements specified in Table T 0921-2

Table T 0921-2 Sand container type(mm)

Sand container type	Maximum particle size in layer to be tested	Total thickness of layer to be tested
Φ100	<13.2	≤150
Φ150	<31.5	≤200
Φ200	<63	≤300
Φ250and over	≤100	≤400

Note: in the case that the particle size of the subgrade is greater than 100mm, other density testing methods shall be used. If in the process of digging, more than 10% of particles have a size greater than the specified size, the test shall be re-made in another position close by. If during the test the sand inside the sand container is insufficient to fill the test hole, it means that the size of the sand container is too small, and a larger one shall be selected to re- do the test. It is not permitted to add sand from another container during the test.

(2) Glass plate: rectangular plate with side lengths of 500mm to 600mm

(3) Sample tray and aluminum container: samples dug out from a small hole in the density plate would be kept in aluminum containers. Samples dug out from large holes in the density plate would be kept in enamel sample trays with dimensions of 300mm × 500mm × 40mm

(4) Electronic scale: graduations shall not be more than 1g.

(5) Electronic balance to measure moisture content:. Sample sizes will depend on fine grained soil, medium grained soil or coarse grained soil, and the balance scales shall have a resolution of 0.01g, 0.1g and 1.0g respectively.

(6) Equipment for testing moisture content: aluminum container, oven or microwave oven.

(7) Measuring sand: Must be clean and dry, with of 0.3mm to 0.6mm sieve size. About 20kg to 40kg is required per test. Before use, the sand shall be washed and dried and then sieved to meet all the requirements. The prepared sand must be spread open for about 24 hours to allow the sand to stabilize at the same humidity as the atmosphere.

(8) Containers for holding sand: plastic buckets or similar.

(9) Thermometer; scale graduations no more than 1℃.

(10) Other tools: chisel, screwdriver, hammer, scoop with long handle, dust pan with long handle, brush etc.

3 Method and procedure

3.1 Preparation

(1) Based on related standards and methods to test the maximum dry density (ρ_c) of a pavement layer material by the compaction test (Proctor or Modified proctor test).

(2) Select test apparatus as specified in Clause 2 of this method.

(3) Calibrating the sand mass inside the cone, namely the lower part of the sand container.

① Fill the sand cylinder a height of 15mm ± 5mm beneath its top. Weigh the mass m_1 of sand inside the cylinder, with a precision of 1g. For each further calibration or test, be sure to keep the sand fill height or mass the same.

② Open the shutter and let the sand flow out freely. Ensure that the sand volume flow is consistent with the volume of calibrating container (or equal to the volume of the hole to be dug at the site). Once the flow has stopped, close the shutter.

③ Without tilting the sand cylinder, move the sand container gently onto the glass plate, and open the shutter to let sand flow out until no more sand flows out. Close the shutter and remove the sand container.

④ Weigh the sand mass left on the glass plate or the sand mass remaining inside the sand cylinder, with a precision to 1g. The sand mass left on the glass plate is also the sand mass (m_2) inside the cone.

⑤ Repeat the test three times, and calculate the average value.

(4) Calibrating the loose density ρ_s (g/cm^3) of the measuring sand:

① Use water at a temperature of 15℃ ~ 25℃ to measure the volume of the calibrating container, with a precision to 1mL.

② Fill the sand cylinder with the sand which has a mass m_1. Place the sand container over the calibrating container. Open the shutter to let sand flow out until it flows no more. Be careful not to bump the sand container in the process . Close the shutter. Remove the sand container and weigh the mass (m_3) of the sand remaining in the sand container, with a precision of 1g.

③ Calculate the mass of sand which filled fully the calibrating container from equation T 0921-1

$$m_a = m_1 - m_2 - m_3 \quad (T\ 0921\text{-}2)$$

Where: m_a——mass of sand inside calibrating container(g);

m_1——mass of sand filled into sand cylinder(g);

m_2——mass of sand inside the cone(g);

m_3——mass of sand remaining in the sand container after calibrating container being filled (g)

④ Repeat the test three times to calculate the average value.

⑤ Calculate sand loose density from equation(T0921-2).

$$\rho_s = \frac{m_a}{V} \quad (T\ 0921\text{-}2)$$

Where: ρ_s——sand loose density(g/cm^3).

V——volume of calibrating container(cm^3).

3.2 Test procedure

(1) At the test location, select an even area larger than the density plate and clean it thoroughly.

(2) Place the density plate on the cleaned area. Place the sand container which holds sand with a mass (m_1) over the circular hole in the density plate and mark the position of the density plate. Open the shutter to let sand flow into the hole of density plate until the sand stops flowing. Close the shutter. Remove the sand container. Weigh the mass(m_5) of sand remaining in the sand cylinder, with a precision of 1g.

(3) Remove the density plate. Collect the measuring sand remaining in the test location and ensure that it has no foreign matter. Clean the surface again.

(4) Place the density plate in its original position. Dig a hole through the central hole in density plate, to a diameter the same as that of the sand container. In the digging process, do not lose the material being dug out, but place it into a plastic bag or a large aluminum container to prevent the moisture from evaporating. The depth of the test hole shall be equal to the thickness of the layer being tested. However, ensure that material from the under-layer is not removed. Weigh the mass m_w of the material that was dug out, with a precision to 1g. If the thickness is to be measured, measure the thickness first, then weigh the mass. This is to ensure that any material dislodged is included into the mass of material removed.

(5) From all the materialremoved from the layer, select a representative sample, place it into an aluminum container or enamel plate. Test its moisture content(ω) according to 'Highway soil test method' (JTG E40-2007). A moisture sample shall have the following mass: for a test with a small sand container, or fine grained soil, not less than 100g. For medium grained soils, not less than 500g. However, for the medium sand container and a fine grained soil, the sample is not less than 200g. For all other types of medium grained soil, not less than 1000g. For coarse grained soil, or material stabilized with inorganic binders such as cement, lime, fly-ash, all the material taken out from the hole shall be oven-dried and has a mass more than 2000g; this weight is the mass(m_d). When the large sand container is used, all the material taken from the hole shall be oven-dried to weigh its mass(m_d).

(6) Fill the sand container with a mass of m_1. Place the density plate over the position of the test hole. Place the sand container at the center of the density plate, with the test hole matching the hole of the density plate. Open the shutter to let sand flow into test hole. Do not bump the sand container during the process, until the sand stops flowing. Close the shutter. Remove the sand container. Weigh the mass (m_4) of sand remaining in the container, with a precision to 1g.

(7) If the cleaned even area is not coarse, steps(2) and(3) need not be performed. After test hole is completed, position the sand container directly over the test hole. The density plate is not required. Open the shutter. Let the sand flow into the hole. Do not bump the container in the process, until the sand stops flowing. Close the shutter. Remove the sand container. Weigh the mass(m_4') of sand remaining, with a precision of 1g.

(8) Remove the sand from the sand cylinder for future use.

(9) Remove the density plate. The sand remaining in the test hole can be retrieved if no foreign matter is included. Clean the remaining sand in the hole. Fill the hole with the same material as was used in pavement layer that was tested, and compact the back-fill in 3 to 4 layers.

(10) The recycled sand can be re-used if it is dried and re-sieved, and then kept for over 24h until a balance is achieved with the humidity of the atmosphere.

4 Data processing

4.1 Calculate the mass of sand which completely filled the test hole from equation (T 0921-3) or (T 0921-4)

For the case that a density plate was used:

$$m_b = m_1 - m_4 - (m_1 - m_5) \qquad (T\ 0921\text{-}3)$$

For the case that a density plate was not used:

$$m_b = m_1 - m'_4 - m_2 \qquad (T\ 0921\text{-}4)$$

Where: m_b——the mass of sand which completely filled the test hole(g);

m_1——the mass of sand in the sand container before sand is used to fill the hole(g);

m_2——the mass of sand in the cone(g);

m_4、m_4'——the mass of sand remaining in the sand cylinder after sand filling(g);

$(m_1 - m_5)$——the mass of sand in the cone plus sand from between the density plate and the coarse surface(g).

4.2 Calculate the wet density of material from the test hole by using equation T 0921-5

$$\rho_w = \frac{m_w}{m_b} \times \rho_s \qquad (T\ 0921\text{-}5)$$

Where: ρ_w——wet density of material from the test hole(g/cm^3);

m_w——the mass of all the material dug out from the test hole(g);

ρ_s——loose density of measuring sand(g/cm^3)。

4.3 Calculate the dry density of material from test hole by using equation(T 0921-6)

$$\rho_d = \frac{\rho_w}{1 + 0.01\omega} \qquad (T\ 0921\text{-}6)$$

where: ρ_d——dry density of material from test hole(g/cm^3);

w——moisture content of material from test hole(%)

4.4 For the case the layer material is stabilized by cement, lime, fly-ash etc, the density will be calculated from equation(T 0921-7)。

$$\rho_d = \frac{m_d}{m_b} \times \rho_s \qquad (T\ 0921\text{-}7)$$

Where: ρ_d——density of stabilized material(g/cm^3)

m_d——mass of dried stabilized material removed from test hole(g)。

4.5 Field density can be calculated from equation T 0921-8

$$K = \frac{\rho_d}{\rho_c} \times 100 \qquad (T\ 0921\text{-}8)$$

Where: ρ_d——dry density of sample(g/cm^3);

ρ_c——maximum dry density from Proctor compaction test(g/cm^3) 。

5 Report

The report of this test shall include the following technical information：

(1) The information about test positions (stake, layer)

(2) Dry density, maximum dry density

(3) Field density

***Background*：**
This method referredto a number of other specifications, such as 'Standard for soil test method' (GB/T 50123-1999), 'Test methods for materials stabilized with inorganic binders in Highway Engineering' (JTG E51-2009), 'Test Methods for Soils in Highway Engineering' (JTG E40-2007), 'Code for soil tests in railway engineering' (TB 10102-2010) and AASHTO standard. It also included recent research results obtained in China. The requirements that were revised are selecting the type of sand container, thickness of density plate, testing sand having to be uniform. Requirements that were added are the height of sand in the container and the temperature at the time of calibration.

The sand cone or sand replacement method is a standard test used on most construction sites. It appears to be elementary but in practice many errors are incurred by personnel not following specified operations. As field compacted density depends on the test results, there are many confrontations between quality inspection departments and contractors. For this reason the method shall be followed exactly. To improve the confidence in the test results, the following details shall be noted:

(1) The measuring sand is carefully specified. Before each batch of fresh sand is used, the mass of sand in the cone and its loose density shall be re-measured. Recycled sand from a test hole shall not be re-used before it has been re-processed. Careful preparatory work shall be done on the measuring sand before use. Never use sand from another source before confirming compliance, as the test cannot be performed in haste.

(2) The principle in selecting a sand container is first to consider the particle size of the layer material to be tested, and then to consider the thickness of the layer. As stated in 'Highway subgrade construction specifications' (JTG F10-2006), 'normally, the maximum particle size of a subgrade material is 100mm (for road bed, or subgrade in a cut section), or 150mm for an

embankment'. In this method, the sizes of sand container are listed only for maximum particle size smaller than 100*mm. For the case the maximum particle size is between* 100*mm to* 150*mm, normally, the sand container with a diameter more than* 250*mm, or by water balloon measuring method would be applied based on practical considerations. If during the process of digging the hole, more than* 10% *of particles have sizes greater than the specified size, the test shall be re-made in an adjacent position. For rock-gravel or rock fill subgrade with particle sizes even greater, compaction quality is normally controlled by the settlement difference method,*

*In practice, particle sizes larger than the specified size are not uncommon. Shall this occur, testing personnel shall determine the reason for the over-size material. Is it from segregation, or an exception, or does it occur consistently? If it is from segregation, construction personnel shall be informed and they shall deal with it. If it is an exception, the test could be re-made in an adjacent position based on the percentage of oversized particles. It is not recommended to adjust the over-sized grains as specified in 'Highway soil test method' (JTG E*40-2007*). The reason for this is that the method is too complicated, not representative or lack of support from test data.. If it occurs consistently, other methods could be applied to test the compaction quality. Alternatively, the Proctor laboratory test could be re-done. Shall the particle sizes of the layer material occur regularly, additional groups of Proctor tests could be made, to identify a relationship between density and gradations, and calculate a correction factor to adjust the density results. However, be careful, as such adjusted results are only meaningful within same section of the construction site; they are not universally applicable to other places.*

(3) *The calibrated loose density of the measuring sand directly affects the compaction quality test results. For this reason the depth of sand in the calibrating container shall be kept similar to the depth of the test hole. From site test data, if the depth of sand in the calibration container increases by* 5 *cm, then the loose density of the measuring sand will increase by* 0.15%, *without substantial effect on site test results. Thus the depth of sand of* 15*cm in the calibrating container could be used in for a compacted layer with various thicknesses on large scale construction, but the thickness of any layer shall not be more than* 30*cm.*

(4) *The moisture content could be tested in alternative quicker ways. Based on research results, the moisture content tested by microwave-oven has a correlation of* 99% *compared with the oven drying test. Therefore the moisture content could be tested by microwave-oven.*

(5) *The surface of a layer to be tested shall be smooth. A rough surface with only* 1*mm protrusions will result in the calculated volume of the test hole being increased as the height of a thin layer is added. By not considering the thickness of the density plate, test results will be seriously affected. So, normally as a first step, the density plate is placed over a coarse surface to obtain the additional sand. Only in the case of a smooth surface can this step be skipped.*

T 0922—2008 Testing field density with a nuclear density gauge

1 Scope of application

1.1 This method is used to test the density or moisture content of subgrade and pavement layer material with a nuclear density gauge, and calculate the field degree of compaction to evaluate the compaction quality of the pavement layers.

1.2 This method has two test procedures, namely backscatter and direct transmission. The backscatter procedure is used to test the density of asphalt concrete or cement concrete as it is difficult to drill holes. Direct transmission is used to test density and moisture content of the subgrade, granular base layer or cement concrete before it has hardened, for it is easy to drill a hole in these materials. The thickness of the layers shall not be more than 30cm.

2 Technical requirements for instruments and materials

(1) The nuclear density gauge (nuclear gauge) shall satisfy the requirements of industrial standard of JT/T 658, 'Nuclear density/moisture content gauge', and satisfy the requirements for health protection and safety according to national regulations. A nuclear gauge shall be calibrated every 12 months. The range of density that can be tested is 1.12 ~ 2.73 g/cm^3. The allowable test error shall not be more than ±0.03g/cm^3. The range of moisture content is 0 ~ 0.64 g/cm^3, and the allowable test error shall not be more than ±0.015g/cm^3. A nuclear gauge consists of:

① Radioactive source: γ ray source (double sealed isotope source, such as Cesium 137, Cobalt 60, or Radium 226) or neutron source (such as Americium 241 or beryllium).

② Detector: γ ray detector (such as G-M counter tube) or thermal neutron detector (like Helium 3 tubes)

③ Reading display equipment: like liquid-crystal display, pulse counter, counting rate meter, direct reading meter etc.

④Standard block: a block whose density and hydrogen content are fixed, used for measuring the number of counts from the block for the purpose of checking the nuclear gauge condition and to set a standard of ray counting.

⑤Punching rod: for punching a hole to receive the gauge rod

⑥ Safety and protection equipment that must meet all the requirements from national health regulations.

⑦ Scraper, drill pipe, wire etc

(2) Fine sand:0.15 mm ~ 0.3mm。

(3) Others: brush, etc

3 Method and procedure

3.1 Preparation

(1) Shall a nuclear gauge not fulfill the specified counting limit after maintenance, or during working operations, it shall be recalibrated before further use. After calibration, the nuclear gauge shall have a calibration response of ±16 kg/m^3 at each test depth on all the reference blocks.

(2) Every day, before use, or when the test results are questionable, the standard value shall be checked by performing the following steps:

① Place the nuclear gauge where it is even and compacted, with no other source of rays within a distance of 8 m.

②Switch the power on and allow the gauge to warm up as specified.

③ Place the gauge on the reference block and evaluate the standard count as required. If the standard count is outside the specified limit, repeat the standard count again. Shall the result be outside the limit, the nuclear gauge shall be considered as malfunctioning and needs to be repaired.

3.2 Test procedure.

(1) Use method T0902 of the Standard to determine the test positions, ensuring that there is a distance of 30cm or more away from pavement edges or other objects.

(2) Check the area surrounding the nuclear gauge and if there is another source of rays

(including another other nuclear gauge) within a distance of 8m then move the other source away or select another position.

(3) To check the density of asphalt pavement layer by the backscatter method, asphalt surface texture shall be filled with fine density sand over its surface to fill all the surface voids (as shown in figure T0922-1). Then place the gauge on the test position as shown in figure T0922-3.

(4) When the direct transmission method is used, drill a hole at the test position by means of the guide plate and drill. The depth of the hole shall be greater than the test depth. Gauge shall be kept vertical after the gauge rod is inserted into the hole (as shown in figure T0922-2). Following the method shown in figure T0922-4, insert the gauge rod into the test hole, move the gauge left and right, backward and forward, to ensure the gauge is stable.

(5) Switch on the gauge, select the testing time and ensure that personnel are more than 2m from the gauge for safety reasons. After the testing time, read the recorded value, switch off the gauge and keep the handle in the safety position. This is the end of the test.

Note: the nuclear gauges from different manufacturers may have small variations in the test procedure. These requirements shall be followed.

(6) After the test is completed, the nuclear gauge shall be placed inside its special carry case. The case shall be placed such that safety requirements for nuclear radiation are fulfilled.

(7) Based on the measured test results the wet density and moisture content is calculated. Next the dry density and degree of compaction is calculated. For an asphalt concrete surface layer, calculate the degree of compaction directly from determined wet density of the layer.

For the backscatter method, a set of tested values shall have at least 13 test points. The average value of the compaction results applies to the road section.

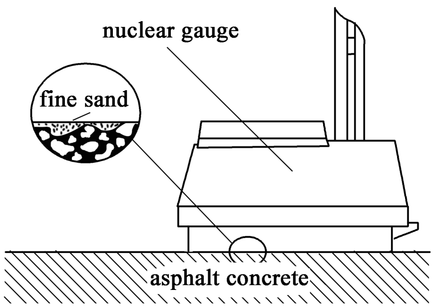


Figure T 0922-1 Fine filling sand placed into surface voids to provide a smooth surface

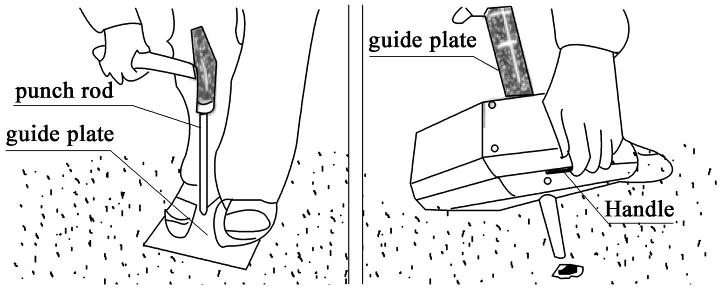


Figure T 0922-2 punching a hole in road

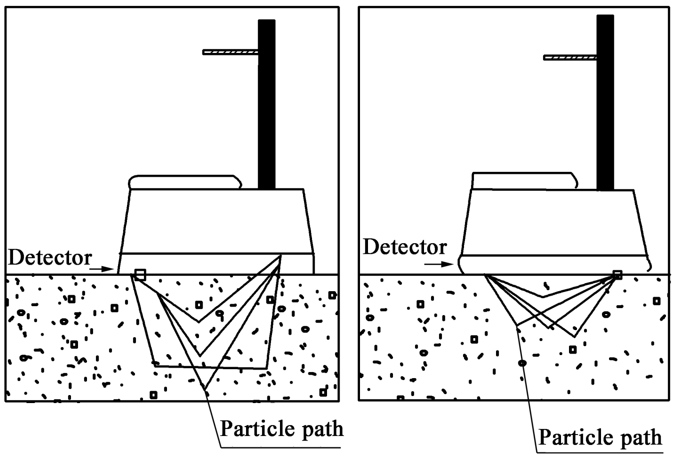


Figure T 0922-3 Backscatter method

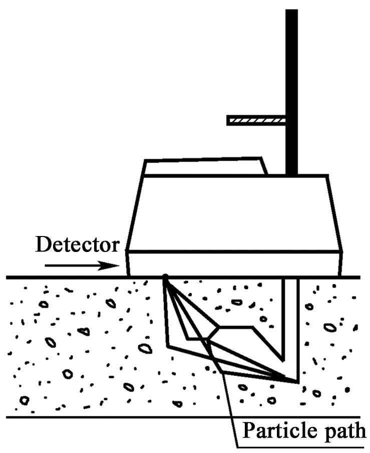


Figure T 0922-4 Direct transmission method

4 Data processing

4.1 Calculate field dry density and degree of compaction from equations T 0922-1 and T 0922-2

$$\rho_d = \frac{\rho_w}{1 + \omega} \quad \text{(T 0922-1)}$$

$$K = \frac{\rho_d}{\rho_c} \times 100 \quad \text{(T 0922-2)}$$

where: ρ_d——measured asphalt concrete density (or the dry density of subgrade or base material) (g/cm^3);

ρ_w——wet density of subgrade or base material (g/cm^3);

w——moisture content, expressed in decimals;

ρ_c——standard density of asphalt concrete (or maximum dry density of subgrade, base material)

4.2 Based on the method stated in Appendix B of the Standard, calculate the average value, standard deviation, coefficient of variation and the representative value of density of the tested road section.

5 Correlation test

Before using nuclear gauge, the correlation between the nuclear gauge method and standard method for measuring degree of compaction shall be determined on a trial road section. For asphalt concrete construction, the correlation between the nuclear gauge method and coring method shall be determined, and for subgrade or base layer application the correlation between the nuclear gauge method and sand cone method shall be determined. The procedures are as follows:

(1) Select a 200m road section as a trial section.

(2) Perform steps (2) to (5) of Clause 3.2. (the procedure) of this method.

(3) For an asphalt concrete pavement, perform the density test according to method T 0924 at the specified test points. For base or subgrade, perform the density test according to method T 0921, but the position of the dug hole shall be avoided.

(4) For a pavement layer with the same thickness, material composition, number of roller passes, loose laid thickness, combination of equipment and required degree of compaction, before

using nuclear gauge during production control take comparisons on at least 15 tests at points within a trial section to calculate the deviation value $\Delta_{\rho i}$ between the two test methods. The average value Δ is calculated and is used as input Δ for the correction factor in the nuclear gauge.

(5) For a pavement layer with the same thickness, material composition, number of roller passes, loose laid thickness, combination of equipment, but with different required degree of compaction, before using the nuclear gauge during production control, several trial sections may be selected to determine the correlation. Each trial section shall have more than 10 test points. Following Appendix C of the Standard, calculate the correlation equation between the two test methods. It could be used to correct test results, provided the correlation coefficient is not less than 0.95.

6 Report

The report of this method shall include following technical content:

(1) Information of road test section (stake, type of pavement layer and thickness)

(2) Measured density, standard laboratory density, degree of compaction

(3) Average value, standard deviation, coefficient of variation and representative value of density of tested road section

(4) If correlation was tested, the correction factor or correlation equation and correlation coefficient shall also be reported.

***Background*:**
The nuclear gauge method is a popular method abroad. From the 1990*s it was introduced to China and applied to some extent for testing density and moisture content of subgrade and pavement layer materials. Since there are strict requirements for its use and storage, many users stopped using it in the recent past. It is an accurate test method for density and is kept in this edition as another purpose is for this method to be compatible with technical documents of other countries.*

*Revision of this edition mainly focuses on the calibration of the nuclear gauge in use and application conditions. It shall be noted that the standard density for testing the density of an asphalt concrete layer shall conform to the current 'Quality inspection and evaluation standards for highway engineering' (JTG F*80/1-2004*) and 'Technical Specification for Highway Asphalt Pavement Construction' (JTG F*40-2004*). For other materials the standard density shall be from* *the laboratory Proctor test.*

The nuclear gauge is convenient and rapid, but it is sensitive to the temperature of the layer and other environment factors and thus test values from it are unstable. It shall be regularly calibrated during use and ensure that the temperature during testing is consistent with the temperature at the time the trial section was tested. For a layer with a coarse texture, fine sand shall be used to achieve intimate contact and ensure the test accuracy.

The nuclear gauge is most sensitive to the material near the surface. If the surface of the layer being tested material has voids beneath the bottom of gauge, the results will be inaccurate in the backscatter method). In the direct transmission method there is no obvious discrepancy. The particle size, gradation, uniformity and composition of the layer material hardly affect the test results. Some materials containing bound water in the crystal structure will affect the moisture content test results. These are kaolin and other type of clay, mica, gypsum and lime. In such cases the test results shall be corrected by comparing them with reliable test results obtained by oven drying. Normally, the nuclear gauge method is inappropriate for testing the moisture content at a test site having crystal water or organic matter.

The nuclear gauge method is also used to monitor the density change in the pavement layer or for determining the required the number of roller passes for the equipment combinations or other construction parameters before determining the achieved density on the trial section.

In testing a newly paved layer of hot mix asphalt, instruments shall not be placed on the hot pavement layer to avoid test results being affected. After the test is completed, the nuclear gauge shall be moved away from the pavement to allow them to cool.

Personnel who handle and use nuclear gauges must comply with the relevant regulations about radiation testing.

T 0923—2019 Testing density with core cutter

1 Scope of application

This method is suitable to test the in-situ density of fine-grained soil or to test fine-grained soil stabilized with inorganic stabilizer within 2 days of construction. Then the field degree of compaction can be calculated to evaluate the degree of compaction of the pavement layers.

2 Requirements for instrument and materials

(1) The manual sampler, shown in figure T 0923-1, includes: a steel ring cutter, collar, guide cylinder and rammer system (rammer staff, rammer, handle). The inner diameter of the cutter is 6cm ~ 8cm, height 2cm ~ 5.4cm and wall thickness 1.5mm ~ 2mm.

(2) Electric extractor, shown in figure T 0923-2, includes the base, column, lifting mechanism, coring mechanism, power and transmission mechanism.

①The base, consists of a base plate, positioning pins and travelling wheels. The base plate is for supporting the whole instrument. Positioning pins are for holding the instrument during the sampling process. Travelling wheels are for moving the instrument over a short distance to sample at another point.

②The column, consists of a column and a sleeve. It is fixed on the base plate, and serves as a frame for the lifting mechanism, cutting mechanism, power and transmission mechanism.

③The lifting mechanism consists of a lifting hand wheel and locking handle. It is for adjusting the height of cutting mechanism. By loosening the locking handle, turning the lifting hand wheel, the cutting mechanism can be placed on the required position. By tightening the handle, the cutting mechanism will be in the correct position.

④The cutting mechanism consists of a cutting head, lifting shaft. The cutting head is a metal cylinder. Two alloy steel cutting bits are welded onto the bottom and a cover is welded onto the top. A nut is welded onto the cover for fixing the cutting head to the lifting shaft by a bolt. There are three sizes of cutting head, namely 50mm × 50mm、70mm × 70mm and 100mm × 100mm, which are replaceable. Accessories are a sampling core sleeve, spanners and aluminum container.

⑤The power and transmission mechanism consists of a DC motor, speed controller and gear box. Accessories are a battery and charger.

(3) Balance: its scale graduations shall not be more than 0.01g.

(4) Others: pickaxe, small spade, knife or soil cutter, brush, ruler, wire saw, petroleum jelly, wood board and equipment for testing the moisture content.

3 Method and procedures

3.1 Perform a Proctor test on the layer material to determine the maximum dry density and optimum moisture content.

3.2 Select two positions close to each other to serve as parallel test points.

3.3 The procedure for using the manual sampler to test the density of cohesive soil or inorganic binder stabilized fine grained soil.

(1) Clean the steel ring cutter and weigh its mass M_2 with a precision of 0.1g.

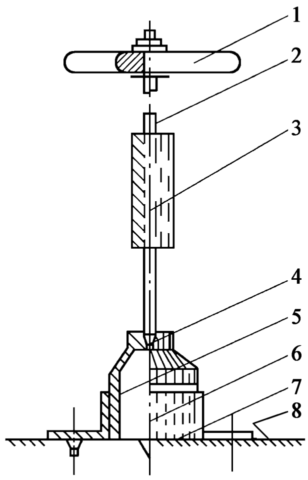


Figure T 0923-1 Sampler

1-handle;2-rammer staff;3-rammer;4-collar;5-ring cutter;6-guide cylinder;7-positioning pin;8-surface of layer

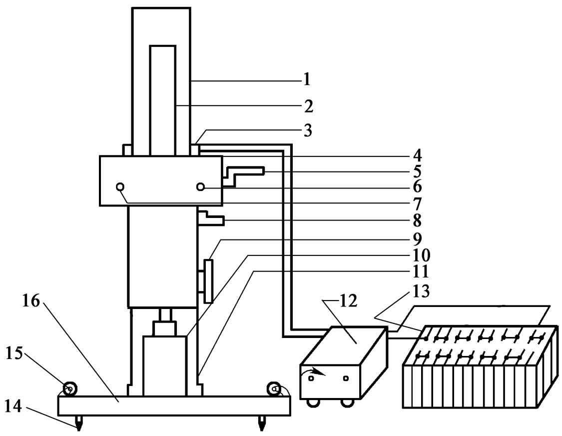


Figure T 0923-2 Electric extractor

1-column;2-lifting shaft;3-power input;4-DC motor;5-lifting mechanism handle;6-power indicator;7-power indicator;8-locking handle;9-lifting mechanism;10-coring head;11-column sleeve;12-speed controller;13-battery;14-travelling wheel 15-positioning pin;16-base plate

(2) Clean the layer surface over an area of about 30cm × 30cm in the test area and remove the loose or uneven material on the surface.

(3) Fix the positioning pins of the guide cylinder in the smooth surface. Place cutter and collar in sequence into the guide cylinder and keep them perpendicular to the surface.

(4) Keeping the rammer vertical, ram the cutter into the compacted pavement layer. The central height of the cutter shall be at mid- depth of the layer to be tested for the purpose of construction control and quality evaluation. For other purposes, other depths may be chosen as required.

(5) Remove rammer and guide cylinder and then take out the cutter and sample by pickaxe.

(6) Gently remove the collar, and then remove the extra soil at both ends of the cutter with a knife from the outside to the center, and check both ends with a ruler until they are even.

(7) Clean the outer wall of cutter, weigh the mass M_1 of cutter and sample with the precision of 0.01g.

(8) Remove the sample from the cutter, select a representative sample of soil (not less than 100g) to test the moisture content (ω). The moisture content shall be tested by referring to 'Highway soil test method' (JTG E40-2007).

3.4 The procedure for testing the density of sandy soil or sandy layer by manual sampler

(1) If a sandy soil is wet, the rammer and guide cylinder shall not be used for testing. At a leveled ground surface, dig downward in a circle to form a sandy soil column with a diameter a little bit larger than the outer diameter of a ring cutter. Place the cutter rightly over the column with its cutting edge downward. Press the cutter down steadily with both hands, till the half-height of the cutter reaches mid-depth of the compacted layer.

(2) Cut off the extra sandy soil on the cutting edge of the ring, and use a ruler to smooth the ends.

(3) Cover the upper end of the cutter with a flat wooden board, press it with one hand, and use a small spade with the other hand to cut the sample from the bottom of the ring. Then turn the cutter the sample inside upside down. Remove extra sandy soil from cutting edge and level it with a ruler.

(4) Clean the outer wall of the cutter, weigh the mass (M_1) of cutter and sample with a precision of 0.01g

(5) Select a representative sample of soil from the cutter (not less than 100g) to test the moisture content. Moisture content shall be tested by referring to 'Highway soil test method' (JTG E40-2007).

(6) For dry sandy soil which will not become a column by digging, the cutter may be pressed or rammed directly into the soil until the depth as required in Clause 3.3(4) is reached.

3.5 The procedure for testing density of inorganic stabilized fine grained soil or dry plastic soil by electric extractor.

(1) Mount a cutting head with the required size. Before taking samples, select an even road section, raise the four travelling wheels and press down the four positioning pins into soil. Unlock the locking handle, turn the lifting wheel until the coring head makes contact with the soil. Lock the locking handle.

(2) Connect the battery to the speed controller. Insert the output plug from the speed controller into the core extractor power socket. Ensure that the indicator light is on, which means that the electric circuit is ready. Turn on the switch and the coring mechanism rotates with the power supplied from motor. The rotating speed shall be regulated based on the moisture content. By operating the lifting handle until it reaches the depth specified in Clause 3.3, then lift the coring mechanism and stop the motor. Remove the electric extractor. Place the core sleeve over the soil sample, shake the sleeve and remove the soil sample.

(3) Remove the sample, smooth both ends of the sample immediately to length of core sleeve with a knife or wire saw. A soil core is to the required size. For other test purposes samples shall be placed in a sealed container to be sent to the laboratory.

(4) Weigh the mass M_1 of soil sample plus core sleeve. Select a small sample of soil to test the moisture content.

4 Data processing

4.1 Calculate the wet density and dry density of the sample from equation T 0923-1 and T 0923-2.

$$\rho = \frac{4 \times (M_1 - M_2)}{\pi \cdot d^2 \cdot h} \quad (T\ 0923\text{-}1)$$

$$\rho_d = \frac{\rho}{1 + 0.01\omega} \quad (T\ 0923\text{-}2)$$

where: ρ——wet density of core(g/cm^3);

M_1——mass of cutter or core sleeve and sample(g);

M_2——mass of cutter or core sleeve(g);

d——diameter of cutter or core sleeve (cm);

h——height of cutter or core sleeve(cm);

ρ_d—— dry density of core(g/cm^3);

ω——moisture content(%)。

4.2 Calculate the field degree of compaction by using equation T 0923-3.

$$K = \frac{\rho_d}{\rho_c} \times 100 \quad (T0923\text{-}3)$$

Where: ρ_c——maximum dry density from Proctor test(g/cm^3)。

4.3 Calculate the difference between the two parallel test results. If difference is not more than 0.03 g/cm^3, use the average value as the test result. Otherwise, the test shall be repeated.

5 Report

The report of this method shall include following technical content:

(1) The position of the test point (stake, layer)

(2) Field dry density, maximum dry density, degree of compaction.

Background:

Research has shown that field dry density from a core cutter test may not be correct as fine grained material inside the core cutter may be disturbed. It is recommended that further research be carried out when possible to develop a correction factor to allow for this disturbance. That may be done when performing the Proctor test in the laboratory, by pressing a core cutter into soil in the Proctor mold to find the ratio between the density of the disturbed soil and the density of the Proctor test soil.

T 0924—2008 Testing field density of an asphalt layer by core drilling

1 Scope of application

This method specifies how a core is drilled from a compacted asphalt layer to test its density and calculate the field degree of compaction to evaluate the compaction quality of the layer.

2 Technical requirements for instrument and materials

(1) Pavement core drill

(2) Balance: scale is not more than 0.1g

(3) Water tank which is temperature controlled within the range of ±0.5℃.

(4) Basket

(5) Paraffin wax

(6) Others: caliper, brush, sample holder (bag), electric fan

3 Method and procedures

3.1 Sampling the core

(1) Drill a core from an asphalt layer in accordance with method T 903, with a diameter not less than 100mm. For a case where the core consists of several asphalt layers the different layers shall be separated along the interfaces between each layer.

(2) Drilling a core sample shall only occur after the pavement has cooled. For an asphalt concrete layer it shall be done on the following day after paving. For modified asphalt or SMA layer the drilling shall take place after the third day of laying.

3.3 Density of test core

(1) Place the core into water and clean it with a soft brush to clean any dust or dirt.

(2) Dry the core naturally or blow with an electric fan for over 24h until its weight is stable.

(3) According to the method for testing the density of an asphalt mix 'Test method for asphalt and asphalt mixes for Highway Engineering' (JTG E20-2011), test the density ρs, of the core. Normally, the bulk relative density of the sample is performed by the surface dry method. For samples with water absorption more than 2%, bulk relative density shall be tested by the wax seal method. For a dense asphalt mix with water absorption less than 0.5%, the apparent relative density is measured by the method of weighing the sample immersed in water for the purpose of construction quality inspection.

3.3 Determine het standard density based on 'Technical specification for highway asphalt pavement construction' (JTG F40-2004).

4 Data processing

4.1 When calculating the standard density based on the density from laboratory Marshall test or from the density of a core drilled from the trial section, the degree of compaction of the asphalt surface layer shall be calculated from equation T 0924-1:

$$K = \frac{\rho_s}{\rho_0} \times 100 \qquad (T\ 0924\text{-}1)$$

where: ρ_s——tested density of asphalt core sample (g/cm^3);

ρ_o——standard density of asphalt mix (g/cm^3).

4.2 When calculating the standard density based on the maximum theoretical density, the degree of compaction of an asphalt surface layer shall be calculated from equation T 0924-2.

$$K = \frac{\rho_s}{\rho_t} \times 100 \qquad (T\ 0924\text{-}2)$$

Where: ρ_t——maximum theoretical density of asphalt mix (g/cm^3).

4.3 According to the method in Appendix B of the Standard, calculate the average value, standard deviation, coefficient of variation of the degree of compaction of a road section being tested, and calculate the representative value of the degree of compaction.

5 Report

The report of this method shall include the following technical content:

(1) Test positions (stake, layer and others).

(2) Measured density、standard density (or maximum theoretical density)、degree of compaction.

(3) The average value, standard deviation, coefficient of variation and representative value of degree of compaction in a road section that was tested.

Background:
*The test for determining the degree of compaction by the drilled core method is revised in this edition based on practices at home as well as abroad and by referring to 'Technical Specification for Highway Asphalt Pavement Construction' (JTG F*40-2004).

T 0925—2008 Testing asphalt density with non-nuclear density gauge

1 Scope of application

This method is suitable to perform a quick test of asphalt mix density for any asphalt layer on the day when it is paved before opening to traffic. The degree of compaction is then calculated. These approximate results cannot be used for acceptance inspection.

2 Technical requirements for instruments and material

The non-nuclear density gauge consists of an electronic module and rechargeable battery. The probe shall be non-nuclear and without capacitance. The technical requirements for a non-nuclear density gauge are as follows:

(1) Maximum detection depth of equipment : ≥10cm

(2) Minimum detection depth of equipment: ≤2.5cm

(3) Single measurement time: not more than 5s.

(4) Precision: 0.003g/cm^3

(5) A standard density block for calibration.

3 Method and procedures

3.1 Preparation

(1) Before the non-nuclear gauge is used for the first time, its software shall be set up and all the settings shall be stored. This means that operating personnel are not required to set it up every time after booting.

(2) Before the non-nuclear gauge is used, it shall be carefully calibrated on the standard density block. Through the correlation test its reliability is confirmed.

3.2 Test procedure

(1) Select the test positions according to method T 0902. The test points shall be at least 30 cm away from the pavement edge and the surface shall be dry.

(2) Placethe non-nuclear gauge on a position so that it is stable. Ensure that it will not move. If the road surface texture is coarse then even it out with fine sand to fill the surface voids and ensure that the instrument is in close contact with the pavement layer

(3) After switching on the non-nuclear gauge, check its operating condition, such as battery voltage and internal temperature. Enter the test date, time, measurement point number and any other location values.

(4) For each test point enter setup parameters such as the thickness of the asphalt layer, units of measurement, maximum nominal particle size and others. Select the test mode as 'single point'. The equipment is now ready for testing.

(5) Press the test button for 3 seconds and then read and record the data. At this time, the

moisture content of the surface of the measured material as displayed on the non-nuclear gauge shall be between 0 and 10. If over 10, the data must be discarded and tests performed at other selected positions.

(6) If the correction value method is used the raw data ρd is displayed. If the correlation equation is used the measured density ρd shall be calculated by entering raw data into the equation, with a precision of 0.01g/cm3.

4 Data processing

4.1 Calculate the degree of compaction (K) using equation T 0925.

$$K = \frac{\rho_d}{\rho_0} \times 100 \qquad \text{(T 0925)}$$

Where: ρ_d——measured density of asphalt mix (g/cm^3);

ρ_o——standard density of asphalt mix (g/cm3), which shall be chosen from 'Technical specification for highway asphalt pavement construction' (JTG F40-2004).

4.2 By using the method given in Appendix B of the Standard, calculate the average value, standard deviation and coefficient of variation of degree of compaction for the road section tested, and then calculate the representative value of the degree of compaction.

5 Test the correlation of the degree of compaction between the non-nuclear gauge method and the core drill method

5.1 Choose a road section for the correlation calculation.

(1) Choose a road section to be tested with a length not less than 200m

(2) Decide on the test positions as specified in Clause 3.2(1) of this method.

(3) There shall be more than 15 test positions for pavement structures with same asphalt layer thickness, mix design, roller passes, uncompacted paved thickness, equipment composition and standard degree of compaction. More than 10 test positions for pavement structure with same asphalt layer thickness, mix design, uncompacted paved thickness, equipment composition but different required degree of compaction.

5.2 Test procedure

(1) Select 5 points at each test position as shown in Figure T 0925-1. Use the non-nuclear gauge to test each point according to steps (2) to (5) as stated in Clause 3.2 of this method. Select the average output mode. Test in sequence and record the displayed value of density, moisture content, temperature and others. Take the average value of density as the measured density at this position.

(2) Drill a core sample from each position to test its degree of compaction according to method T 0924 'Testing field density of an asphalt layer by core drilling'.

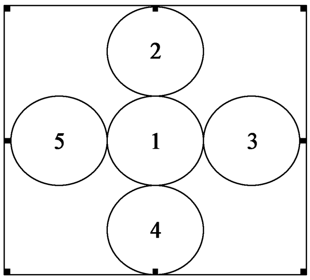


Figure T 0925-1 Sketch of 5 point method

5.3 Data processing

(1) For pavement structures with the same pavement thickness, mix design, roller passes, uncompacted paved thickness, equipment composition and required degree of compaction, calculate the density deviation value of $\Delta\rho i$ at each test point. This is the difference between the measured values from the non-nuclear gauge and from core drilling. The average deviation value is taken as the correction factor Δ.

(2) For pavement structures with same pavement thickness, mix design, uncompacted paved thickness, equipment composition but different required degree of compaction, data shall be processed as specified in Appendix C to calculate a correlation equation. The correlation coefficient R shall not be less than 0.9.

(3) When the correction value is used, it could be input into the non-nuclear gauge, and the displayed value is then the corrected value. When the correlation equation is used it is necessary to calculate the value of the non-nuclear gauge.

6 Report

The report of this method shall include following technical content:

(1) Test position (stake, layer).

(2) Measured density, standard density, degree of compaction.

(3) Average value, standard deviation, coefficient of variation and representative value of the degree of compaction of the road section tested.

(4) When the correlation test is used, the correction value or correlation equation and its correlation coefficient shall also be reported.

***Background*:**

The principles of operation of Chinese-made non-nuclear gauge are typically the electromagnetic method and the time-domain reflectometry method. Currently it is mainly used for the construction control process. It is not suitable for acceptance inspection or quality determination. For newly paved asphalt pavement layers it allows for test results to be obtained quickly and reliably. The benefit is that contractors can control compaction quality immediately.

Recently, several soil non-nuclear density gauges have appeared. From investigation and research, all of these gauges require that the layer material shall have an exactly constant gradation. However, in practice, the layer material is not constant, which affects the accuracy of results. Consequently these gauges shall not be promoted at present and for this reason, the soil non-nuclear density gauge is not included in this edition. Furthermore an industry standard for monitoring compaction by intelligent technology is being prepared. By combining with digitalized construction processes control together with traditional control by testing, it will be possible to monitor the degree of compaction degree in real time for all activities and construction items. This is a new concept to improve testing efficiency and evaluate compaction objectively.

For ensuring accuracy, attention shall be paid to the following items when using a non-nuclear density gauge:

(1) *Temperature does not affect the results from a non-nuclear gauge. However, to prevent damage to the instrument, the temperature shall be controlled to be less than* 170 °*C.*

(2) *The moisture content of the surface of material tested has a significant influence on the test results. During testing, test results are reliable when moisture content is in the range of* 0 *to* 10. *During compaction with a steel roller water is sprinkled over the roller drum. To control the influence of the water on the test results, normally, a dry pavement area is to be selected to perform a test.*

T 0926—2019 Method for determining settlement difference of soil and rock fill embankment

1 Scope of application

This method is used to measure the degree of compaction of soil or rock fill embankments by measuring changes in settlement during the process of compaction of soil or rock-fill embankments, and combining with parameters of the construction technique.

2 Technical requirements for instruments and materials

(1) Vibratory roller, dead load more than 20 tonne.

(2) Level: DS3

(3) Steel tape, measuring range 50m, scale no more than 1mm.

(4) Others: hammer, shovel and others

3 Method and procedure

3.1 Preparation

(1) Before compacting the subgrade select a trial road section.

(2) Along the road length select a measurement cross section every 20m. Evenly distribute measurement points along the cross section to every 5m to 10m. At each observation point a fixed object (normally a steel ball) is placed. During compaction its position in the horizontal plane shall not change and the measuring point will be fixed.

(3) The compaction of the trial section is carried out according to the defined roller combination and process parameters of for construction. Each round trip of a roller is considered as a pass and compaction continues until there is no obvious roller mark.

3.2 Test procedure

(1) After the initial compaction of the subgrade has been completed, move the vibrating roller 20m ahead of the road test section and start the vibratory roller, adopting required frequency

(2) Compact the test section at a speed not more than 4km/h, and a round trip is considered as a pass.

(3) After each pass, use a level to measure the elevation of each fixed object, which is hi1、hi2…hij, with a precision to 0.1mm.

(4) Repeat steps (2) and (3) to measure the elevation of each fixed object h(i+1)1、h(i+1)2…h(i+1)j,…,h(i+n)1、h(i+n)2…h(i+n)j, with a precision to 0.1mm.

(5) Randomly select the representative areas to test the field dry density of the material by the water replacement method in accordance with 'Highway soil test method' (JTG E40-2007), and determine the apparent density in accordance with 'Highway aggregate test methods' (JTG E42-2005). Reclaim the fixed objects and record new parameters for the construction technique. Use the same material as was used in the trial section to complete the fill embankment.

4 Data processing

4.1 Calculate the settlement difference Δhi(i+1)-j between pass i and pass i+1 using equation T 0926-1

$$\Delta h_{i(i+1)-j} = h_{(i+1)-j} - h_{i-j} \qquad \text{(T 0926-1)}$$

Where: $\Delta h_{i(i+1)-j}$——the settlement difference of fixed object j between pass i and pass i+1 (0.1mm);

$h_{(i+1)-j}$—— elevation of fixed object j after pass i+1 was rolled (0.1mm);

h_{i-j}——elevation of fixed object j after pass i was rolled (0.1mm);

i——pass rolled;

j——number of fixed objects, 1, 2…n。

4.2 Calculate the average value of settlement difference $\Delta \bar{h}_{i(i+1)}$ -j between pass i and pass i+1 using equation T 0926-2

$$\Delta \overline{h}_{i(i+1)} = \frac{\sum_{j=1}^{n} \Delta h_{i(i+1)-j}}{n} \quad (T\ 0926\text{-}2)$$

where: $\Delta \overline{h}_{i(i+1)}$—— average value of settlement difference $\Delta \overline{h}_{i(i+1)} - j$ between pass i and pass i + 1(0.1mm)。

4.3 Calculate the standard deviation of settlement difference $S_{i(i+1)}$ between pass i and pass i + 1 using equation T 0926-3

$$S_{i(i+1)} = \sqrt{\frac{\sum_{j=1}^{n} (\Delta h_{i(i+1)-j} - \Delta \overline{h}_{i(i+1)})^2}{n-1}} \quad (T\ 0926\text{-}3)$$

where: $S_{i(i+1)}$——standard deviation of settlement difference $S_{i(i+1)}$ between pass i and pass i + 1(0.1mm)。

4.4 Calculate the porosity according to 'Specification for highway subgrade design' (JTG D30-2004)

4.5 According to the method given in Appendix B, calculate the average value, standard deviation and representative value of settlement difference of a road test section.

5 Report

The report of this method shall include the following technical content:

(1) Location of road test section (stakes and layers)

(2) Aggregate grade and type of fill material

(3) Roller type and combination and roller passes

(4) Settlement difference and porosity

(5) Average value, standard deviation and representative value of road test section

Background:

For a long time the compaction quality of rock fill or soil and rock mixed subgrade has been a challenge. The main reason is that measuring the field density is difficult. To evaluate it by the degree of compaction is more difficult and it takes time to perform this test. In practice, there are *methods for controlling compaction quality such as by settlement difference or by the number of roller passes applied. Although the results of these methods are reliable, these evaluation methods are poorly defined and lack unified quantitative indicators. They depend on personal construction experience. With the development of our society and transportation, heavy machinery and equipment are being used for construction. Projects are inclined to adopt the compaction control method of settlement difference for rock fill or soil and rock mixed subgrade. Unfortunately the test method, controlling criteria and evaluation standard of this method are not unified. This impedes the progress in improving the subgrade compaction quality.*

To improve the standardization, accuracy, and relevance of the controlling method for compaction quality of rock fill or soil and rock mixed subgrade, and to reduce construction disturbance and increase work efficiency, several documents are used. These are 'Specifications for Design of Highway Subgrades' (JTG D30)、'Technical specifications for Construction of Highway Subgrades' (JTG F10)、'Quality inspection and evaluation standards for highway engineering' (JTG F80/1), combined with practical experience and research performed in Guangdong and Fujian as well as other provinces, the method for determining settlement difference of soil and rock fill embankment is established. As this method is a double control method, which combines process parameters, degree of compaction is represented by stability of the settlement. So in its application, it is not only the process parameters that shall be compatible and consistent, but the subgrade overall deformation shall also be considered to keep the construction stable during operations.

If construction is on a large scale, and fill material does not obviously changed, the porosity test may be omitted. The requirements for settlement are given in the design documents or relevant standards. Requirements for porosity arte given in 'Specification for design of highway subgrade' (JTG D30-2015).

For a subgrade of mixed soil and rock, methods in 'Test Methods for Soils for Highway Engineering' (JTG E40-2007) like a vibrating compaction tester or vibrating table tester are often used in practice to measure the maximum density. The water replacement method may be used to evaluate subgrade degree of compaction in the field.

6 Roughness

T 0931—2008 Roughness tested with a 3m straight edge

1 Scope of application

1.1 This method is applicable to measuring the maximum gap (δm) between road surface and a 3m straight edge to characterize the roughness of a road surface.

1.2 This method is suitable to test each pavement layer from the subgrade to the surfacing after compaction.

2 Technical requirements for instruments and materials

(1) A 3m straight edge: measurement reference edge is 3m long. The reference edge shall be flat and straight, made from hard wood or aluminum alloy or similar materials.

(2) Instruments to measure the maximum gap

①Wedge gauge: wedge gauge with a handle, made from hard wood or metal. The ratio of depth to length shall not be less than 1/10, width not more than 15mm with marks on the sloping side, and the scale shall be in depth increments of 0.5mm

②Depth gauge: made from metal, with a handle. The end of the measuring bar shall have a diameter more than 10 mm and the depth scale shall have graduations of 0.5mm.

(3) Others: measuring tape or steel ruler, etc.

3 Method and procedures

3.1 Preparation

(1) Define the test method. When testing the construction quality of an asphalt layer during the paving process, each measurement could be made individually by straight edge. The test position shall be close to joints. For other cases, ten (10) consecutive straight edge measurements are normally accepted.

(2) Select test positions. Except for special situations, select one of the wheel paths in a traffic lane (0.8m to 1.0m away from the lane edge) as the position for consecutive testing. For an existing road which has rutting, select the centerline of the rut as the test position.

(3) Clean away dirt at the test positions.

3.2 Test procedures

(1) Place the straight edge lengthwise over the test position.

(2) By visual inspection of the gaps between the bottom of the straight edge and the road surface, determine the position of the maximum gap.

(3) Insert the wedge gauge with height marks into the gap to measure the maximum gap. Alternatively use the depth gauge to measure the depth at the test position to the top of straight edge. By subtracting the height of straight edge, the maximum gap is obtained. It is measured in mm, with a precision of 0.5mm.

4 Data processing

The roughness of a single measurement by straight edge is calculated by taking the maximum gap (δm) between the straight edge and the road surface as the result. For 10 consecutive measurements, the maximum gap (δm) at each measurement shall be judged to determine whether it meets the requirements, termed qualified. The percentage of qualified readings and the average value of the ten maximum gaps shall be calculated.

5 Report

The report of this method shall include the following technical content:

(1) The information of test positions (stake and test methods)

(2) Maximum gap (δm)。

(3) For 10 consecutive measurements, the average value, unqualified measurements and qualification rate.

Background:
Based on the current standards for evaluating the quality of highway projects, the technical indicators for roughness are usually indicated as maximum gap (δm), standard deviation (σ), or international roughness index (IRI). The method of maximum gap is specified here. It is widely used to measure each compacted layer from subgrade to the asphalt pavement layer during construction. This is a convenient method of construction control.

Based on current instruments used for measuring roughness (maximum gap) and the precision required, the requirements for the scale of a wedge gauge and depth gauge are adjusted in this edition.

T 0932—2008 Measuring roughness with a rolling straight edge roughness

1 Application range

1.1 This method is suitable for measuring the standard deviation (σ) of longitudinal relative elevation by a rolling straight edge roughness tester to indicate road surface roughness.

1.2 This method is unsuitable for testing a road with many potholes or which is severely damaged.

2 Technical requirements for instruments and materials

(1) Rolling straight edge roughness tester

①Structural framework: the structural design of a rolling straight edge roughness tester is shown in Figure T 0932-1. Except for special situations, the standard length of the tester is 3 m. Its frame is 3m long and retractable or foldable. There are four wheels at the front and rear of the frame. The distance between the centers of the two groups of wheels is 3m.

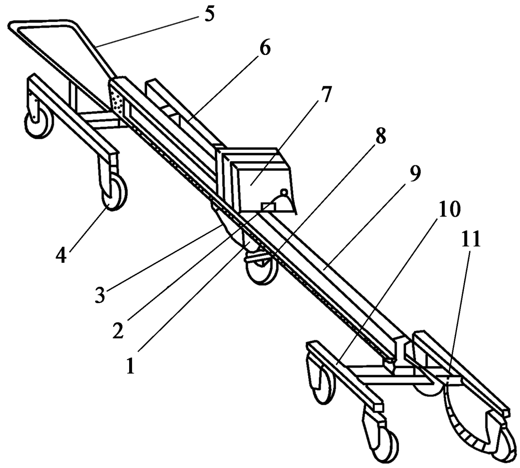


Figure T 0932-1 Illustration of rolling straight edge roughness tester

1-frame 2-clutch 3-return spring 4-wheel, 5-towing handle, 6-front of frame, 7-recorder, 8-measuring wheel, 9-main frame, 10-rear of frame, 11-flexible cable

②The sensor for measuring surface elevation is installed in the middle of frame. It may be a measuring wheel that moves up and down or a laser distance meter.

③Ancillary units: battery power source, distance sensors, control box for collecting, processing, storing and outputting data, a computer and a printer.

④Measurement interval is 100mm, and for each 100m of road the test results shall be output.

⑤Calculations and output: record the test length (m), the number of times the curve amplitude is greater than a certain value (such as 3mm, 5mm, 8mm, 10mm), the cumulative value of a uni-directional deviation (hump or depression) and the curve of surface deviation referring to the center point of the frame.

⑥Frame has a towing hook or a handle to be drawn by manpower or car.

(2) Towing vehicle: car or other small size towing vehicle

(3) Tape or measuring cord

3 Method and procedure

3.1 Preparation

(1) For quality control during the construction process, determine the test points as needed. For acceptance inspection of quality of pavement layers or for evaluating road condition, normally select one of the wheel paths in a traffic lane as standard position for continuous tests. For an existing road surface with rutting, select one of the ruts and test along its center.

(2) Clean off the dirt from test positions on the road surface

(3) Inspect each part of the test equipment to ensure that it is functional and sensitive. Be sure the tire pressure is correct. Connect all connecting wires. Install recorder.

3.2 Test procedure

(1) Set the rolling straight edge roughness tester on the starting point of the road section to be tested. Ensure that the measuring wheel is always within the wheel path.

(2) Hitch the back of towing car to the rolling straight edge roughness tester, and complete all the necessary preparations.

(3) Start the towing car and drive along the road, ensuring that the lateral position remains constant.

(4) Keep the rolling straight edge roughness tester working normally at a constant speed along the traffic lane. The preferred speed is 5km/h, but may not exceed 12km/h at any time. If the test section is short, the tester can be towed by manpower, and kept at a constant speed.

4 Data processing

4.1 Take a 100m road length as a calculation section, calculate the standard deviation σi of the collected value of the deviation distance(di) as the roughness, indicated in mm, with a precision of 0. 1mm.

$$\sigma_i = \sqrt{\frac{\sum di^2 - (\sum di)^2/N}{N-1}} \qquad (T\ 0932)$$

Where:

σ_i—the calculated value of roughness in each calculated road section(mm) ;

d_i—take 100m road length as a calculation section, collect road surface deviated value(up or down) (mm) at certain intervals (10cm for auto-collecting, 1. 5m for manual collecting) ;

(Note from translator: there could be some differences in test results between two selected intervals, which shall be kept in mind.)

N—number of data points collected for calculating the deviation value at a calculation section

4.2 Following the method stated in Appendix B, calculate the average value, standard deviation and coefficient of variation of roughness over a test section.

5 Report

The report of this method shall include the following technical content:

(1) Location information of tested road section (stake, length)

(2) The length of the test section, interval for collecting data and calculating roughness

(3) Average value of roughness, standard deviation and coefficient of variation of a test section

Background:

There are different types of rolling straight edge roughness testers used internationally with different length and design. They may have 4 wheels, 8 wheels or 16 wheels even if they are 3m long. However, typically equipment with 8 wheels and a length of 3m is used. In China currently only one design of 3m long with 8 wheels is used. It is also the only tester specified in this method.

The calculation value of roughness is indicated as the standard deviation. It is related to the length of the calculation section (see T 0932-2). The longer the section, the smaller the standard deviation. Based on Chinese practice and experience abroad (or example, in 'Japanese pavement *test method 7-2' , it is specified as 100m ~ 300m) , 100m is specified as the calculation length of this method.*

The principle of the 3m long roughness tester is the same as using a 3m straight edge to measure continuously. The calculation method is the same. These two methods have a good correlation.

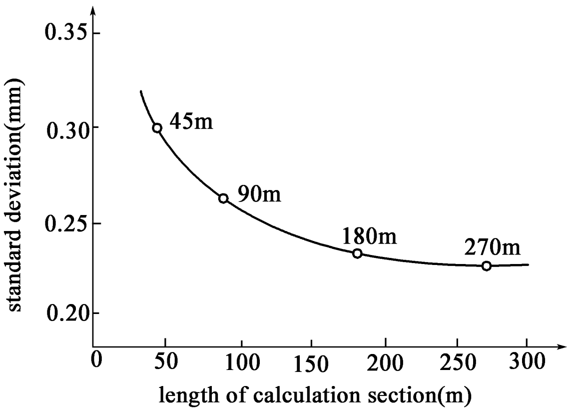


Figure T 0932-2 The relation between calculated value of standard deviation and length of calculation section

Most roughness testerscurrently used in China have an automatic calculation function. They may output and print the standard deviation of a section tested, together with the number of occurrences of deviation greater than a fixed value (such as 3mm, 5mm, 8mm, 10mm). However, imported testers may not have this function. This is because foreign countries may require certain abnormal data in the test method such as when testers run over potholes, joints, end of layer, catch basins or other artificial works. These data shall not be included in calculation. However auto-testers do not have the ability to identify abnormal data. For this reason, two kinds of calculation, auto calculation and manual calculation, are specified in this method.

T 0933—2008 Measuring roughness by vehicle mounted bump-integrator

1 Application range

1.1 This method is suitable for measuring roughness by vehicle mounted bump-integrator which continuously collects cumulative surface response displacements to indicate road roughness.

1.2 This method is not suitable for measuring a road surface with severe distresses such as potholes or rutting.

2 Technical requirements for instruments and materials

This test system consists of a vehicle, distance measuring equipment, a bump integrator tester and a main control system. The required basic technical parameters are as follows:

(1) Test speed: 30 to 80km/h

(2) Range of test amplitude: −0.2 to 0.2 m

(3) Resolution of vertical displacement, 1mm

(4) Distance calibration error, <0.5%

3 Method and procedures

3.1 Preparation

(1) If any of following situations occurred to the vehicle, a correlation test shall be carried out between this test system and road sections with known International Roughness Index (IRI): having travelled more than 2000km or one year since the previous calibration, or when shock absorbers, or tires or other components were replaced or repaired.

(2) Check the tire pressure (cold) of the test vehicle before use to ensure that it is at the required standard pressure. Tires shall be clean without mud attachment. The load of the test vehicle (including passengers) and load distribution shall be the same as when the correlation test was performed. Note that the test vehicle shall not be used for general transport.

(3) When installing the distance measuring system at the construction site, ensure that the fixing device is firm and all bolts are tight.

(4) Check each part of the test system for compliance with requirements and that there is no visible.

(5) Switch on the power, start controlling program, and check the working conditions of each part of the system.

3.2 Test procedure

(1) Before testing, let the test vehicle run a distance of 5 to 10km at the test speed to warm up the test vehicle.

(2) The test vehicle shall be stopped about 300 to 500m ahead of the starting point of the test section. Start the roughness test program of the system. Set the test mode as required by site conditions.

(3) The driver shall accelerate to the testing speed before entering into test section, and enter into the test section along the normal wheel paths.

(4) At the start of the test section, the operator shall start the data collection and recording program of the system. During the test process, the positions of starting point, end point, and any other special fixed points shall be input into recording.

(5) At the end of the test section, the operator shall stop data collection and recording, and reset the test equipment to the initial conditions.

(6) The operator shall check that the data is complete and normal, else the test shall be repeated before leaving the site.

(7) Switch off the power to the test system as the test has ended.

4 Data processing

Convert the bump-integrator values (VBI) using a correlation equation as described in Clause 5 of this method for each 100m section to IRI, indicated as m/km, with a precision of 0.01 m/km.

5 Correlation tests between measured bump-integrator value and IRI

5.1 Basic requirements

The measured values from a bump-integrator are affected by factors such as test speed. Consequently each test speed used shall have an independent correlation equation. The test process and analyzed results shall be recorded and saved.

5.2 Test conditions

(1) Based on the IRI value, select at least 4 sections that have an increment more than 1.0m/km and have different roughness to cover the full range anticipated during testing, and also have adequate length for acceleration or deceleration. More calibration sections may be added based on the actual distribution of IRI on the road to be tested.

(2) Each calibration road section shall not be less than 300m.

(3) Each selected section shall have a uniform roughness, including on the 50m approach length.

(4) Only straight sections with minimal gradient changes shall be used. Furthermore traffic over the section shall be light and easy to control.

(5) The calibration shall be carried out along the normal wheel paths. The start and end points of a calibration road section shall be clearly marked.

5.3 Test procedure

(1) Distance calibration

① Select a level and straight road section with minimum gradient changes, with a length of at least 500m. Mark out the start and end points and the wheel paths.

②Before calibration, let the test vehicle run 5 to 10km at the testing speed, and warm up the testing system for a required warm up time.

③Align the front wheels of the test vehicle with the starting point and start the program for distance calibration. Run the test vehicle along the wheel paths, go straight and do not deviate from the wheel paths. Abrupt acceleration or deceleration shall be avoided. Decelerate the test vehicle to stop it with its front wheels in line with section end point. This completes the distance calibration. This process may be repeated until the distance pulse equivalent of the distance sensor is within the accuracy limits.

(2) According to Clause 3.2 of this method, measure the response value of each calibration section by bump-integrator at a selected uniform speed. Repeat the test 5 times or more and calculate the average value as the response value of thee calibration section.

(3) Determine the IRI of the calibration section

①Use a precise level as a standard instrument. Measure the longitudinal elevation of both wheel paths every 250mm. Measure the precision of elevation to 0. 5mm. Then use the IRI standard computing program to calculate the IRI using the longitudinal elevation of each wheel path. Confirm that the elevations are correct and that there are no outliers by using the plotting routine of the program. Calculate the IRI value per 100m in each wheel path, and calculate the average IRI value of both wheel paths as IRI value of this calibration section.

②Other instruments acknowledged by the World Bank as Class 1 testing instruments (such as laser profilometers) can also be used to determine standard IRI value of a calibration section.

5.4 Data processing

Follow the method specified in Appendix C of the Standard to calculate a regression equation between the standard IRI value and bump-integrator value on all the calibration sections. The regression equation shall have a correlation coefficient of at least 0.99.

6 Report

The report of this method shall include the following technical content:

(1) Information of road test section (stakes, lengths).

(2) Test speed, bump-integrator value (VBI), IRI.

(3) If a calibration test is conducted, the correlation equation and correlation coefficient shall also be reported.

***Background*:**
Vehicle mounted response roughness testers (such as the bump-integrator) are still widely used in China as they are easy to use and are inexpensive. However, their results are related to the dynamic properties of the vehicle, the test speed and characteristics of the road surface. If the vehicle has been parked for a long time, or run over a long distance, or their tires or shock absorbers are replaced or repaired, their dynamic properties could be affected. For these reasons vehicle independent test methods shall be used to ensure the accuracy of the test results.

This method is applicable to the vehicle mounted bump-integrator, but other response type instruments may use this method as a reference.

T 0934—2008 Measuring roughness by vehicle mounted laser roughness meter

1 Scope of application

1.1 This method is suitable for measuring IRI with a vehicle mounted laser roughness meter.

1.2 This method is suitable to measure roughness of a pavement under normal traffic conditions, without serious potholes or rutting, and without water, ice, snow, or mud.

2 Technical requirements for instruments or materials

Avehicle mounted laser roughness meter consists of a vehicle, distance sensors, longitudinal profile elevation sensors and a main control system. The basic technical parameters are as follows:

(1) Test speed: 30 to100 km/h

(2) Sampling interval: ≤500mm。

(3) Precision of laser sensor: 1.0mm。

(4) Distance calibration error: ≤0.05%。

3 Method and procedure

3.1 Preparation

(1) Check that each of the laser sensors of the meter is measuring correctly by using a spacer block.

(2) Check that the tire pressure of the vehicle is at the standard pressure. Tires shall be clean and without any mud or dirt.

(3) When installing the distance sensors on site ensure that the fasteners are fixed firmly and there are no loose bolts.

(4) Check each part of the meter to ensure that it meets the test requirements and that there is no damage.

(5) Switch on the power for the system, start the control program and check the working status of every part.

3.2 Test procedures

(1) Before starting to test, let the vehicle run 5 to 10km at the test speed and allow the system to warm up for the required warm up period.

(2) Stop the vehicle about 50 to 100m ahead of the starting point of the test section. Start the program for the roughness system. Enter the test conditions for all the technical requirements for the test.

(3) The driver shall keep the vehicle speed within the required test speed range, normally between 50 and 80 km/h. Avoid sudden acceleration or deceleration. The vehicle speed shall be reduced at sharp curves. Drive into test section along the normal wheel paths.

(4) On entering test road section, the operator shall start system program for data collection and recording. Accurately enter into the test data records the positions of start and end points, and other fixed points along the test section.

(5) At the end of the test section the operator shall stop data collection and recording. Reset each element of the test equipment to their initial conditions.

(6) The operator shall check that the data is complete with normal results, else the test shall be repeated.

(7) Switch off the power and end the test.

4 Data processing

Alaser roughness meter collects data of the relative elevation of the pavement. Use a 100m length as a calculation section. Use the standard program to calculate the IRI value, as m/km, with a precision of two decimals.

5 Correlation test between measured IRI of a laser roughness meter and standard IRI

5.1 Test conditions

(1) Select at least 4 sections which have different roughness levels and their IRI value intervals shall be more than 1.0. They shall also have sufficient length for acceleration or deceleration. More calibration sections may be added based on the actual IRI distribution on the test road.

(2) Each section shall be longer than 300m.

(3) The roughness in each section shall be uniform, including the 50m approach length.

(4) Only straight sections of road with minimal gradient changes shall be selected. The traffic over the sections shall not be heavy and easy to control.

(5) If there are multiple sets of roughness equipment in a vehicle, each set of equipment shall be tested separately.

(6) Calibrating shall be performed along the normal wheel paths. Start and end points of the calibration section shall be clearly marked.

5.2 Test procedure

(1) Distance calibration

①Select a level and straight road section with minimum gradient changes, with a length of at least 500m. Mark out the start and end points and the wheel paths.

②Before starting calibration, let the vehicle run 5 to 10km at the testing speed, and warm up the test system for a required warm up time.

③Align the front wheels of the vehicle with the starting point and start the test system. Drive the vehicle in a straight line in the wheel paths. Travel at a constant speed and void abrupt acceleration or deceleration. Towards the end of the calibration section decelerate the vehicle to stop it with the front wheels in line with end point. Record the value of the measured distance. This process may be repeated until the distance sensor error is within limits.

(2) According to Clause 3.2 of this method, perform 5 repeated roughness tests on the test road section. Take the average value of the calculated IRI values as the tested value of this section.

(3) Determine IRI

①Take the precise level as the standard instrument. Measure the longitudinal elevation of the test road section at an interval of 250mm in both wheel paths. Read the precision of elevation to 0.5mm. Then use the standard IRI computing program to calculate the IRI on the measured values of longitudinal elevation values. In this way, the IRI value of the calibration road section is obtained.

②Other instruments acknowledged by the World Bank as Class 1 testing instruments (such as laser profilometers) can also be used to determine the standard IRI value of a calibration section.

5.3 Data processing

Use the method in Appendix C of *the Standard* to calculate the regression equation between IRI value and the roughness meter values of each test section. The correlation equation shall have a correlation coefficient of at least 0.99.

6 Report

The report of this method shall include the following technical content:

(1) Information on the test road section (stakes, length).

(2) The value of IRI and its conversion value.

(3) The results of the correlation test, such as correlation equation and correlation coefficient shall be reported

***Background*:**
There are many automatic test systems for measuring roughness. However, their design, operation principles, and output indicators vary greatly. Referring to the research results of the World Bank Report No. 46 which studied roughness test methods, two groups of systems were identified based on how the longitudinal profile is measured and their precision. These are response type roughness meters and longitudinal profile roughness meters.

Response type systems (RTS) measure the vehicle response as its vertical displacement between the *axle and the body or the vertical acceleration of the body when the test vehicle runs over a pavement. The results are related to the dynamic properties of the vehicle. Such systems have inherent disadvantages, such as instability over time, difficult to convert, difficult to compare. The measurements must be converted to the IRI value by means of a correlation equation. This group of RTS includes the bump-integrator, BPR roughometer and NAASRA roughness meter. Longitudinal profile roughness meters output IRI directly to indicate roughness. This group includes laser roughness meter, ultrasonic roughness meter, APL analysis meter, multi-wheel rolling straight edge roughness meter and so on. These systems take elevation measurements at an interval not more than 250mm. The elevation sensor error of these systems is 1mm. If such requirements cannot be met, such systems shall be considered as response type systems.*

IRI is recommended bythe World Bank as a standard roughness indicator. In the World Bank Report No. 46, a standard calculation program for IRI based on a quarter car model was provided. IRI is a mathematical statistical indicator of the longitudinal road profile. It is stable over time, and can be re-checked easily anywhere in the world. It has a good frequency response characteristic for the wave lengths in the range of 1. 2m to 30. 5m. IRI results correlate well with most roughness measures, including the standard deviation σ currently used in specifications in China. By using IRI as a standard roughness measure, the results from various other roughness test systems can be compared to each other.

According to the classification standard of the World Bank, if a longitudinal profile test system has a sampling interval less than or equal to 250mm, and its profile elevation measurement precision 0. 5mm, it is classified as a Class 1 roughness test system. Examples are precise level, profilographs or laser roughness testers. For calibration and control purposes select 5 road sections with IRI values in the range of 0 to 5m/km and each section having a different roughness within the range. Determine their longitudinal profile by precise level, profilographs, and laser testers respectively. The results of IRI from the three methods shall very close. So any test system classified as Class 1 by the World Bank, after being calibrated, may be used as a calibration instrument to develop a correlation between a response type system and IRI.

An ultrasonic roughness tester may be used as a reference instrument in this method.

T 0935—2019 Measuring roughness by profilograph

1 Application range

1. 1 This method is suitable for measuring IRI of a pavement to indicate its roughness by

profilograph.

1.2 This method is suitable for measuring roughness of a pavement under normal traffic, but without standing water, snow, or mud.

2 Technical requirements for instruments and materials

(1) A profilograph consists of height sensors, a data collection and processing system, a measurement beam, a distance measuring wheel, test feet and a main frame. It is illustrated in figure T 0935. Its technical requirements are as follows:

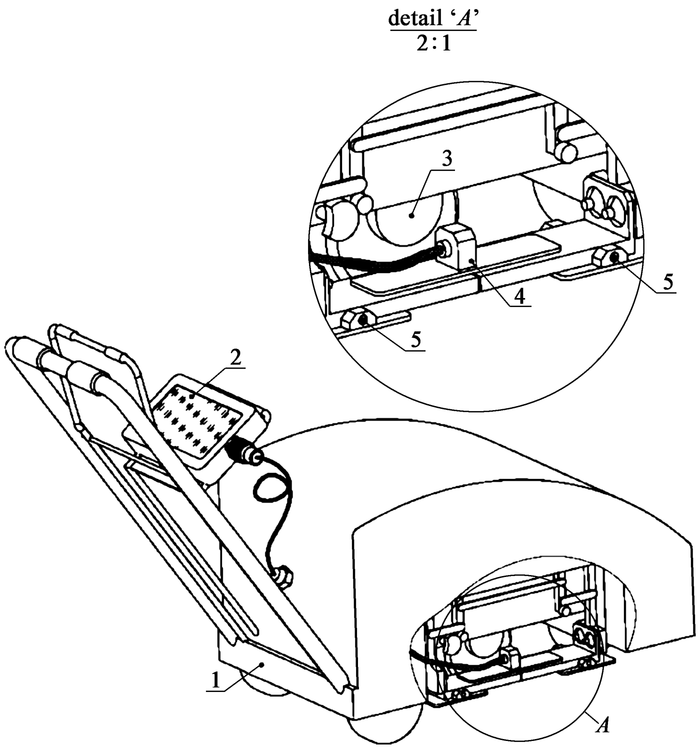


Figure T 0935 Illustration of a profilograph

1-main frame, 2-data collection and processing system, 3-distance measuring wheel, 4-sensors , 5-test feetA-details of measurement beam

①Maximum test speed: 0.80km/h

②Sampling interval: ≤25.4mm。

③Distance calibration error: ≤0.1% 。

④Elevation measurement precision: ±0.1mm。

⑤Horizontal precision: ±0.381mm。

⑥Maximum longitudinal slope of test section: 9.5°

(2) Other: measuring tape or steel tape, chalk, broom, etc.

3 Method and procedure

3.1 Preparation

(1) Clean the pavement surface to be tested. Check each part of the instrument to ensure there are no loose or damaged parts. Check test feet to be sure they are not damaged or have attached debris.

(2) Connect all the data wires. Switch on power. Warm up the system as required.

(3) Check the battery to be sure it is charged for the duration of the test.

(4) Before testing, the test system shall be calibrated. Selected a time when there is a minimal change in which the ambient temperature does not change much.

3.2 Test procedure

(1) Mark the position ofthe start point near a wheel path of the pavement to be tested.

(2) Place the instrument over the start point of the test road section. Start the program and enter the required test conditions.

(3) The profilograph shall be pushed by the test personnel to move steadily at the specified speed and in a straight line. Both test feet shall be positioned over the test line. Do not push the handle vertically. During the test process, if a temporary stop is necessary, the measurement beam shall be raised as high as possible and the measuring wheel shall be locked. On reaching the end of the section the measurement beam shall be raised and the measuring wheel locked in position.

(4) Save the data and switch off the power.

4 Data processing

Using the data of road profile relative elevations, taking 100m as a calculation length, calculate the value of IRI through the IRI Standard program in m/km to two decimals.

5 Report

The report of this method shall include the following technical contents:

(1) The information of tested road section (stakes, length)

(2) The value of IRI

Background:
A profilograph collects and measures pavement information continuously (including distance, profile slope and IRI). It is a precise instrument, meeting the Class 1 requirements of ASTM E950, and considered as Class 1 equipment for measuring the profile by the World Bank. It can be used for quality evaluation of roads or airport runways, and can also be used as a calibration reference for response type instruments or other roughness measuring instruments.

The profilograph is compact and easy to transport or operate. It is used for performing technical research or in practical applications. Consequently it is included in this edition. During testing, time on standby, distance travelled and temperature or humidity affect the test results. Therefore, the instrument needs to be calibrated before using it. During testing the factors that affect the results shall be considered.

7 Bearing capacity

T 0941—2008 Test method for determining in situ soil foundation CBR

1 Scope of application

1.1 This method is suitable for the in situ testing of the CBR of various soil foundation materials. It is also suitable for testing the field CBR value of a base, sandy soil subbase, natural granular material, graded crushed stone or others.

1.2 This method is not suitable for testing the field CBR for fill with a particle size more than 31.5mm.

2 Technical requirements for instruments or materials

(1) Counter weight system: use the rear axle of a heavy duty truck with an axle load not less than 60kN. Fix a stiffening beam behind the rear axle as a loading frame.

(2) Loading system: consists of a jack, a load indicator (load ring indicator or pressure gauge) and a ball seat. It is shown in Figure T 0941-1. The jack must have the capability to penetrate the piston at a penetration speed of 1 mm/min. The range of the load indicator shall not be less than the strength of the layer to be tested, with a precision not less than 1% of the capacity of the load indicator.

(3) Penetrating piston: a metal rod with a diameter of Φ50mm, and about 200mm long.

(4) Surcharge weights: two annular bearing plates with an outer diameter of Φ150mm and an inner diameter of Φ52mm, which is split in the middle, so there are 4 half-annular pieces, each one weighing 1.25kg.

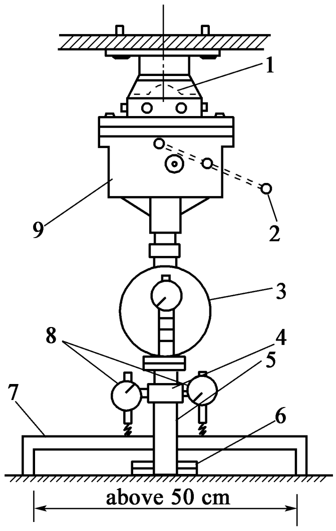


Figure T 0941-1　Schematic of field CBR test apparatus

1-jack, 2-handle, 3-load indicator, 4-displacement dialgauge 5-holder for dial gauges, 6-penetrating piston, 7-rigid platform, 8-surcharge weights, 9-ball seat

(5) The displacement measuring system, shown in Figure T 0941-1, is made of a rigid platform, and two dial gauges which have a measuring range of 20mm, with a precision to 0.01mm, which are fixed symmetrically to the penetrating piston. The dial gauges just touch the rigid platform which has a span greater than 50mm. The dial gauge system may also be replaced by two Benkelman beam deflectometers.

(6) Fine sand: clean and dry, size 0.3 to 0.6mm

(7) Others: shovel, tray, straight ruler, brush, balance, etc.

3　Method and procedure

3.1　Preparation

(1) Level the test point over a diameter of about 300mm. Brush off all the surface dust. When the surface texture is coarse soil, spread a thin layer of fine sand to fill the voids and to make it smooth. The fine sand may not cover the complete area to avoid forming a foreign layer.

(2) Place the penetrating piston and jack as shown in Figure T 0941-1. Set the jack propping up the stiffening beam. The penetrating piston shall be in close contact with ground surface

(3) Position the rigid frame and dial indicators (or two Benkelman beam deflectometers) as shown in Figure T 0941-1.

3.2 Test procedure

(1) Place the 4 pieces of 1.25kg half-annular surcharge weights, with the total weight of 5kg, around the penetrating piston.

(2) Before starting penetration, apply a load of 45N on the penetrating piston, then zero the load indicator and dial gauges and write down the initial readings.

(3) Increase the jack pressure continuously to force the penetrating piston into the soil at a rate of 1 mm/min. Write down the load indicator readings at dial gauge penetrations of 0.5mm、1.0mm、1.5mm、2.0mm、2.5mm、3.0mm、4.0mm、5.0mm、7.5mm、10.0mm and 12.5mm. The penetration value shall be the average of the two dial gauges. If the difference between the two dial gauges is more than 30% of their averaged reading, stop testing. Identify the reason for the discrepancy. In some cases the test may be ended when the penetration reaches 7.5mm.

(4) Unload the jack and remove the test apparatus.

(5) Take a sample from the layer at the test position to calculate the moisture content. The sample sizes of the soil are as follows:

①For maximum particle size not more than 4.75mm, take a sample of about 120g.

②For maximum particle size not more than 19.0mm, take a sample of about 250g.

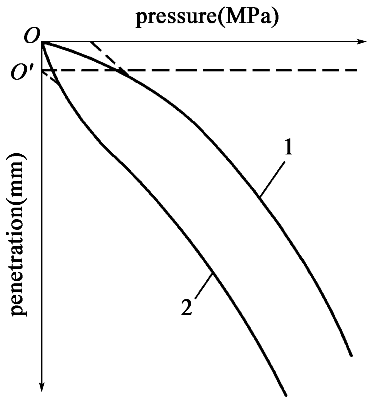
③For maximum particle size not more than 31.5mm, take a sample of about 500g.

(6) At a position near the CBR test point perform a soil density test by the sand cone method or core cutter method.

4 Data processing

4.1 Dividing the load for each penetration value by the sectional area of the penetrating piston

(1963.5mm^2), the pressure in MPa is calculated. Draw the load-penetration curve as shown in Figure T 0941-2. Curve 1 in the Figure does not require correction. Curve 2 needs to be corrected as there is an obvious concave upwards curve at the beginning. By drawing a tangent from the inflection point to intersect with Y-axis at point O′, O′ will be the corrected zero point.



FigureT 0941-2 The CBR penetration curve

4.2 From the load-penetration curve, read P1 (load pressure) at the penetration values of 2.5mm and 5mm. Calculate the CBR (site) value by using equation T 0941-1. Normally the value of CBR at 2.5mm penetration is the test value. If the CBR value at the penetration of 5mm is greater than the CBR value at the penetration of 2.5mm, the test shall be repeated. If the result of repeated test remains the same, take the CBR value at the penetration of 5mm as the test result.

$$CBR_{site} = \frac{p_1}{p_0} \times 100 \qquad (T\ 0941)$$

Where:

CBR_{site}—California bearing ratio (%), keep its precision to 0.1%;

P_1—load pressure (MPa);

P_0—standard pressure, for penetration of 2.5mm it is 7MPa, for penetration of 5mm it is 10.5MPa.

5 Report

The report of this method shall include the following technical content:

(1) Information of test position (stakes, type of site, material particle sizes)

(2) Moisture content, dry density

(3) Load pressure, standard pressure and CBR at each corresponding penetration.

Background:

The method in the former edition did not elaborate Curve 1 and Curve 2 for the load-penetration relation. This edition reproduces the two curves and illustrates the corrections to be made. The test results of this method are sensitive to the particle size of fill material. This method is normally used for soil with a particle size less than 19.0mm, in which case, a better result will be produced.

T 0943—2008 Plate bearing test method for determining in situ soil resilient modulus

1 Scope of application

This method is suitable for testing a soil foundation on site by loading and then unloading a plate in stages over its surface, measuring the rebound deflections of the soil at each loading stage and to calculate the resilient modulus of the soil foundation.

2 Technical requirements for instruments and materials

(1) Counter weight: use the rear axle of a heavy duty truck with an axle load not less than 60kN. Fix a stiffening beam behind the rear axle as a loading frame.

(2) Loading system: as shown in Figure T 0943-1 it consists of a jack, a load indicator (load ring or pressure gauge) and a ball seat.

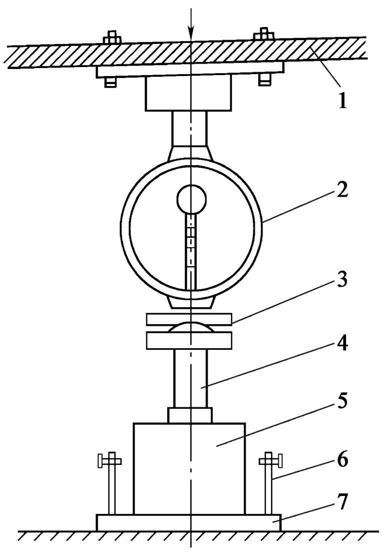


Figure T0943-1 Illustration of a site plate bearing test apparatus

1-jack, 2-steel cylinder, 3-steel plates and a ball seat, 4-load indicator, 5-stiffening beam, 6-bearing plate, 7-column and support

(3) A rigid bearing plate, 20mm thick and Φ300mm in diameter. On both plate edges across a diameter, there are two upright bars with seats whose heights are adjustable. The Benkelman beam tips are placed on the seats to measure deflection. The bearing plate is placed directly on the ground.

(4) Two sets of Benkelman beams, dial gauges and their supports.

(5) A hydraulic jack of 80 to 100kN capacity, with a pressure gauge or force measuring ring, whose capacity shall not be less than the strength of soil foundation, and the test accuracy not less than 1% of the measurement range.

(6) A stopwatch.

(7) Spirit level.

(8) Others: fine sand, brush, plumb bob, pick, shovel, etc.

3 Method and procedure

3.1 Preparation

(1) Select a representative test position at the site. It shall be on a level soil surface, where the soil is uniform and the site is clean.

(2) Level the soil surface, spread a thin layer of fine sand over small depressions, but ensure that the sand does not form a foreign layer. (Note from translator: the plaster of Paris is also practicable.)

(3) Seat the plate horizontally by adjusting it with the spirit level.

(4) Move the counterweight vehicle to a position over the test point. Hang a plumb bob from the middle of the stiffening beam, and orient the plumb bob over the center of the bearing plate. Then remove the plumb bob.

(5) Place the jack on the bearing plate. On top of the jack, place the steel cylinder, steel plate and ball seat, with the ball seat in contact with the stiffening beam. If a load ring is used the ring shall be placed between the jack and the stiffening beam. The jack and steel cylinder shall be kept vertical to avoid an accident during the loading process, or getting inaccurate test data.

(6) Place the measuring tips of two Benkelman beams respectively on the seats of the upright columns of bearing plate.

3.2 Test procedure

(1) Start loading with the jack, watch the ring gauge or pressure gauge until a pre-load of 0.05 MPa is reached. Keep this pressure for 1 min to seat the bearing plate on the soil surface and to check that the dial gauges are normal. Unload the jack and after 1 min. zero in the dial gauge or zero it to another suitable reading. Record the initial readings.

(2) Record the pressure-deflection curve of the soil. Use step-by-step load and unload with the jacking increments. Loading is controlled by pressure gauge or ring gauge. Each increment is0.02MPa more than the previous increment up to a load of 0.1 MPa, and thereafter in increments of 0.04 MPa. For convenience in loading and computing, the load may be adjusted to be an integer. When loading reaches the pre-set value in maintain the load for 1 min. Read the two deflection gauges. Then unload, by lightly loosening the valve on the jack to let the load return to zero. Maintain this situation for 1 min and read the deflection gauge again. Do not zero the deflection gauge after each unloading. Take the average value of the two dial gauges when their difference is less than 30% of the average value. Otherwise, repeat the test at another position. When the rebound deflection is greater than 1mm, loading may be stopped.

(3) The rebound deflection at each stage and at the end of the test shall be calculated as follows:

Rebound deformation at any increment = (Average reading after loading − average reading after unloading) x leverage ratio of Benkelman beam

Total rebound deflection at end of test = (Average loaded reading at end of test − initial average reading before loading) x leverage ratio of Benkelman beam

(4) After the last cycle of loading-unloading, remove the jack, read the gauges as the initial reading. Then move the vehicle 10m away from the test point to take the final readings. The total influence quantity 'a' is calculated as follows:

Total influence quantity 'a' = (Average of initial readings -average of final readings) x leverage ratio of Benkelman beam

(5) Take a soil sample from the test position to determine the moisture content. The sample sizes are as follows:

①For maximum particle size not more than 4.75mm, take a sample of about 120g.

②For maximum particle size not more than 19.0mm, take a sample of about 250g.

③For maximum particle size not more than 31.5mm, take a sample of about 500g.

(6) At a position near the plate bearing test point, perform a soil density test by sand cone method or core cutter method.

4 Data processing

4.1 influence quantity of each loading increment a_i is calculated from equation T 0943-1

$$a_i = \frac{(T_1 + T_2)\pi D^2 p_i}{4T_1 Q} \cdot a \qquad (T\ 0943\text{-}1)$$

Where:

a_i—influence quantity of load increment i (in 0.01mm)

T_1—the axle distance between vehicle front axle and rear axle (m);

T_2—distance between stiffening beam and vehicle rear axle. (m);

D—diameter of bearing plate, (m), take it as 0.3m;

p_i—the pressure on bearing plate under load increment i (Pa);

Q—vehicle rear axle load (N);

a—total influence quantity (0.01mm)。

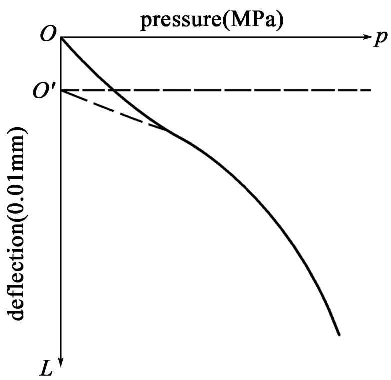


Figure T0943-2 Illustration of modified zero point

4.2 The calculation value of rebound deflection (L_i) is the rebound deflection plus the influence quantity at this increment. Eliminate the obvious incorrect points. Draw a smooth curve pressure-deflection curve. If there is a concave curve at the beginning, origin O shall be modified to move to O' by referring to Figure T 0943-2. The point O' is the modified origin.

4.3 Calculate the value of soil rebound modulus Ei at the load stage i from equation T 0943-2:

$$E_i = \frac{\pi D}{4} \cdot \frac{p_i}{L_i}(1 - \mu_0^2) \qquad \text{(T 0943-2)}$$

Where:

E_i—soil rebound modulus E_i (MPa) at the load increment i;

μ_0—Poisson's ratio of soil, take its value as indicated in the design specifications. If not specified, take 0.30 for non-cohesive soil, 0.50 for highly plastic soil, normally take the value as 0.35 or 0.40.

L_i—calculated value of rebound deflection under the load increment pi (cm)。

4.4 Calculate the soil rebound modulus E0 by the linear regression method from equation T 0943-3 and calculated values of rebound deflection at each test increment.

$$E_0 = \frac{\pi D}{4} \cdot \frac{\sum p_i}{\sum L_i}(1 - \mu_0^2) \qquad \text{(T 0943-3)}$$

5 Report

The report of this method shall include the following technical content:

(1) Information of test position (stake)

(2) Moisture content and soil density at the test location.

(3) Rebound deflection, influence quantity and soil rebound modulus

Background:

This method belongs to the group of static rebound modulus test methods.

As types and dimensions of normal heavy duty vehicles are not legally specified, there are no fixed values for the distance between the front and rear axles, or for the distance between stiffening beams and rear axles. The influence quantity at each load increment (with the load of the rear axle being 60 KN) as given in Table T 0943-1 in the former edition is not applicable. Hence it is removed from this edition. The influence quantity at each load increment shall be calculated by equation T 0943-1. In addition, the equation for the total influence quantity is added in this edition.

T 0944—1995 Benkelman beam test method for determining the resilient modulus of subgrade and pavement layers

1 Scope of application

This method is suitable todetermine the resilient modulus on the surface of soil or combined layers of granular material with a thickness more than 1m. By checking the value of rebound deflection at each test point with the Benkelman beam, the resilient modulus of the tested material can be calculated. This method is also suitable to determine the combined resilient modulus of subgrade plus pavement on an existing road.

2 Technical requirements for instruments and materials

(1) Load vehicle, Benkelman beam, dial gauge and its holder, road surface thermometer shall be selected according to T 0951 of the Standard.

(2) Others: tape measure, etc.

3 Method and procedure

3.1 Preparation

Select test points on the cleaned surface of the subgrade or pavement layer, and mark the test points with their numbers.

3.2 Test procedure

Measure the surface rebound deflection (Li) at each test point following T 0951 of *the Standard*.

4 Data processing

4.1 In accordance with Appendix B of *the Standard*, calculate the arithmetic mean value ($\bar{L}$) and standard deviation(S) of all the test points. Thereafter calculate the natural error (r_0) using equation T 0944-1

$$r_0 = 0.675 \times S \qquad (\text{T 0944-1})$$

Where:

r_0—the natural error of themeasured value of the rebound deflection in 0.01mm

S—standard deviation of the measured value of the rebound deflection in 0.01mm

4.2 Calculate the deviation ($d_i = L_i - \bar{L}$) between the measured value of each point and the arithmetic mean value . Then calculate the ratio of the largest deviation to the natural error d_i/r_0. If such ratio d_i/r_0 from certain test points are larger than the maximum value of d/r in Table T 0944-1, they shall be discarded. Recalculate the arithmetic mean value ($\bar{L}$) and standard deviation(S) of the remaining test points as given in Appendix B of *the Standard*.

Table T0944-1 Maximum value of d/r corresponding to the total number N of test points

N	5	10	15	20	50
d/r	2.5	2.9	3.2	3.3	3.8

4.3 Calculate the representative value of deflection with equation T 0944-2

$$L_1 = \bar{L} + S \qquad (\text{T 0944-2})$$

Where:

L_1—calculated representative deflection(in 0.01mm);

L—arithmetic mean value from the remaining test points after discarding outlier test points (in 0.01mm);

S—standard deviation from the remaining test points after discarding outlier test points (in 0.01mm)。

4.4 Based on equation T 0944-3, calculate the rebound modulus of the foundation soil or pavement structure consisting of subgrade plus pavement layers or existing roads.

$$E_1 = \frac{200p\delta}{L_1}(1 - \mu^2)a \qquad (\text{T 0944-3})$$

Where:

E_1—the rebound modulus of subgrade or pavement structure consisting of subgrade plus pavement layers or existing roads. (MPa);

p—average vertical pressure of the wheels of the load vehicle(MPa);

δ—radius of a tire equivalent contact circle based on the assumption of dual tire contact circles from the test load vehicle(mm);

μ—Poisson's ratio of the material of the layer tested. Its value shall be taken from relevant design specifications.

a—deflection coefficient, taken as 0.712.

5 Report

The report of this method shall include the following technical content:

(1) Test positions (stakes, etc)

(2) Rebound deflection and representative deflection

(3) Poisson's ratio, rebound modulus

Background:
This edition no longer has requirements for an integral trial section (or trial trench) when testing the rebound deflection modulus of an unbound granular material.

T 0945—2008 Dynamic Cone Penetrometer test for checking in situ CBR of subgrade and pavement layers

1 Scope of application

1. This method is suitable for quickly testing the value of the in situ CBR of an unbound subgrade or pavement layer material with a Dynamic Cone Penetrometer (DCP) to evaluate the bearing capacity.

2 Technical requirements for instruments and materials

(1) DCP: itsdesign is illustrated as Figure T 0945-1. It consists of a handle, hammer, hammer shaft, anvil/coupling, clamp ring, drive rod, 1m scale and cone.

Standard hammer weigh 10kg, made from No. 45 carbon steel or other steel which is of a higher quality. Surface hardness HRC = 45 to 50 after hardening. The drive rod and coupling shall be made from fatigue resistant steel.

(Note from translator: if a hammer with other weights or taper angles is adopted, anothercorresponding correlation shall be build by referring the procedures of this method.)

The tip of the cone has a taper angle of 60°. The cone has a maximum diameter of 20mm. If the tip diameter is worn and is less than 18 mm in diameter, or tip height is reduced by 4 mm in height, then the cone must be replaced by a new one.

(2) others: spanner, spade and others

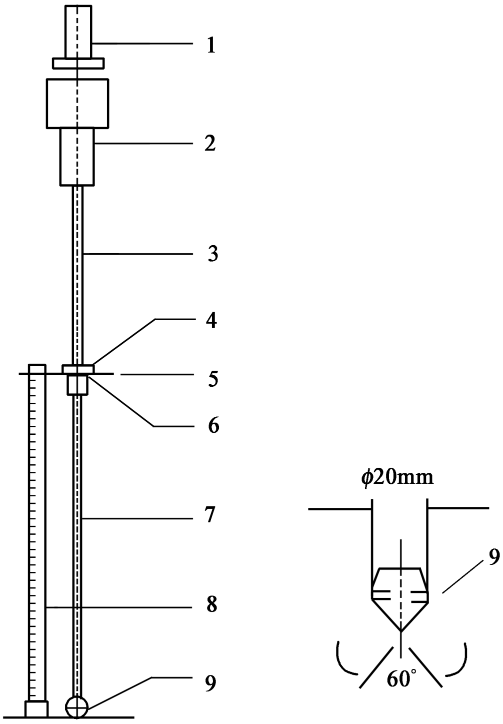


Figure T 0945-1 Illustration of the design of the DCP

1-handle; 2-hammer; 3-hammer shaft; 4-anvil/coupling; 5-handguard; 6-clamp ring; 7-drive rod; 8-1m scale; 9-cone

3 Method and procedure

3.1 Preparation

(1) Place the hammer on the anvil, and tightly fix hammer shaft, taking care of finger safety, and check the tightness of the drive rod.

(2) Hold the DCP vertical on hard ground (like concrete), and record the initial zero reading. (Notefrom translator: the penetration shall substract the height of tip of the cone)

(3) Select test points which are representative. Test points shall be on an even surface of

subgrade, base layer or surface layer. If at the test point there is a hard impenetrable layer, such a hard layer shall be removed by digging or boring. Do not use the DCP to break hard material.

3.2 Test procedures

(1) Position the DCP on the test point. One person holds the handle to keep the DCP upright and another person lifts the hammer to the handle at the top of the upper rod, then releases it to let it free fall over a distance of 575 mm. If the DCP is slightly out of the vertical do not try to correct it as it will bend. If the tilt becomes more severe and the hammer does not fall freely, then this point shall be discarded.

(2) Read the penetrated depth in mm about every 10mm more of penetration, record the number of hammer blows and the corresponding penetration. For a granular base, read the penetration about every 5 to 10 hammer blows. For a soft pavement layer (high penetration rate), read the penetration every 1 or 2 hammer blows.

(3) Continue the penetration to a depth of about 800 mm recording the penetration as given in previous paragraph. If a pavement layer is very hard and no difference in the penetration value is seen after 10 blows, the test may be stopped or the hard layer is removed by drilling through the hard layer to continue with the DCP test.

(4) Remove the DCP by knocking the hammer against the upper handle

4 Data processing

4.1 The test results of the DCP can be expressed by a penetration curve with the number of blows as x-coordinate and penetration depth as y-coordinate.

4.2 Calculate the average penetration per blow from equation T 0945-1. From Clause 5 of this method, a correlation equation T 0945-2 can be used to calculate the CBR.

$$D_d = \frac{D}{n} \qquad \text{(T 0945-1)}$$

Where:

D_d—penetration per blow (mm);

D—penetration (mm);

n—number of blows

$$\lg(\mathrm{CBR}) = a + b \cdot \lg(D_d) \qquad (\mathrm{T}\ 0945\text{-}2)$$

Where:

CBR—field value of CBR of pavement material

a、b—correlation coefficients

4.3 Another method for processing the penetration data is to calculate the dynamic penetration resistance Q_d from equation T 0945-3, then developing a correlation equation by following Clause 5 of this method. The CBR value can then be calculated from equation T 0945-4.

$$Q_d = \frac{M}{M+m} \cdot \frac{MgH}{AD_d} \qquad (\mathrm{T}\ 0945\text{-}3)$$

Where:

Q_d—dynamic penetration resistance, kPa ;

M—mass of hammer, kg;

m—mass of penetrating materials (including mass of cone, drive rod, anvil and upper rod), kg;

g—acceleration of gravity, $g = 9.8\,\mathrm{m/s^2}$;

H—drop height, m;

A—area of cone, cm^2。

$$\lg(\mathrm{CBR}) = a + b \cdot \lg(Q_d) \qquad (\mathrm{T0945\text{-}4})$$

5 Correlation between penetration per blow Dd and CBR

Correlation test shall be made on local field material. Referring to the requirements of Appendix C, build a correlation equation (T 0945-2 or T0945-4 between the value of the field CBR and penetration degree Dd or dynamic penetration resistance Qd. There shall be more than 15 points. The correlation coefficient shall be at least 0.95.

6 Report

The report of this method shall include the following content:

(1) Information of test positions (stake)

(2) Number of hammer blows and the corresponding penetrations

(3) The depth of penetration when the test was stopped.

(4) CBR value, correlation equation and correlation coefficient.

***Background*:**

The material to be used for the manufacture of the DCP is specified in this edition, which refers to 'In situ test methods on for railway engineering geology' (TB 10018—2003). As the taper angle of the cone has little influence on the test results (see Figure T 0945-2), in this edition, the hammer is specified having a mass of 10kg and a taper angle of the cone is specified as 60°.

$$\mathrm{CBR} = \frac{405.3}{D_d^{1.259}} \quad (D_d \text{ penetration value})$$

There are many relations in China and other countries for the correlation between CBR and penetration value or dynamic penetration resistance. However, the correlation shall apply to local conditions. From the AASHTO specifications, there is a relationship between DCP penetration value and CBR as follows:

$$\mathrm{CBR} = \frac{405.3}{D_d^{1.259}} \quad (D_d \text{ penetration value})$$

The British TRL in its 'Design Guide for Asphalt Pavement Pavements' (Road Note 31) gives a relationship between CBR and DCR (Penetration Value), see Figure T 0945-2.

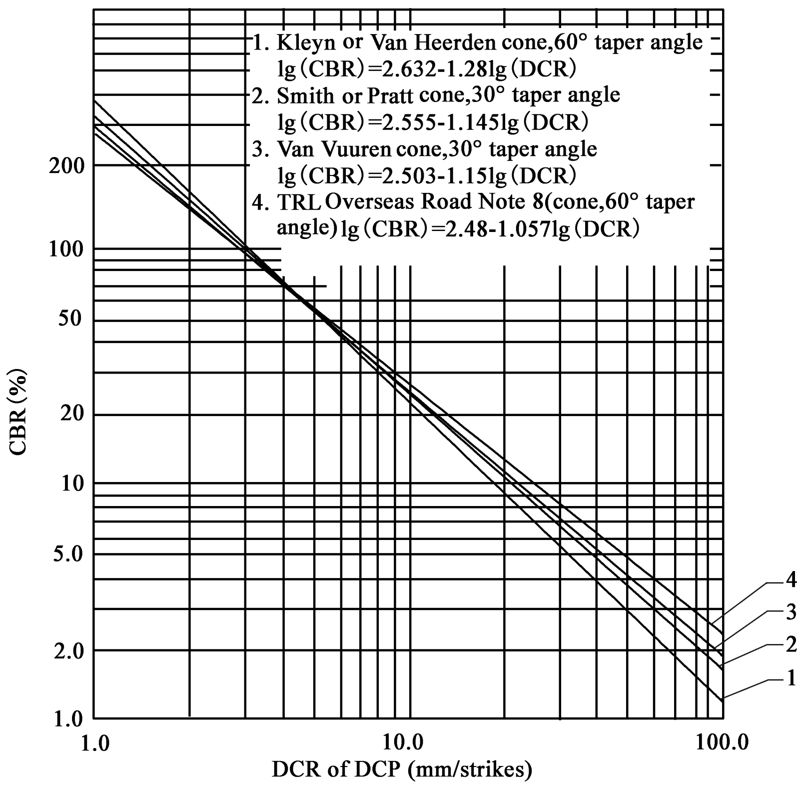


Figure T 0945-2 Relationship of DCR and CBR

T0946—2019 Method for testing soil subgrade modulus with falling ball instrument

1 Scope of application

1.1 This method is suitable to quickly test the modulus of compression and resilient modulus of subgrade soil consisting of from clay, silt, granular soil, gravel soil.

1.2 This method is unsuitable for testing a subgrade with a maximum particle size greater than 100mm.

2 Technical requirements for instruments and materials

(1) The falling ball tester consists of an impact unit, a signal pickup assembly, measurement and analysis software etc. The maximum impact influence is 250mm. The design of the instrument is shown in Figure T 0946-1. The main components are as follows:

①Impact unit: a ball head with a handle, made of stainless steel, with an annealing hardness not more than 235HB, and quenching and softening hardness not less than 192HB. The ball head has a radius of 120 ±5 mm. If the ball surface becomes damaged and uneven, replace it. The ball head mass shall be 19.1 ±0.2 kg. The mass of the handle shall be less than 1.3kg.

②Signal acquisition system: an accelerometer is mounted in the ball head. On impact the acceleration change over time is recorded. Ensure that the system has the following:

——a pre-trigger function.

——an adjustable signal gain to suit different soils.

——sampling interval of A/D card shall be less than 2μs and its resolution ratio shall not be less than 16 Bit.

③Measurement and analysis system: software can record, save measured data, has filter functions, and can automatically analyze all testing parameters.

(2) Others: tape measure, position limiter, installation tools.

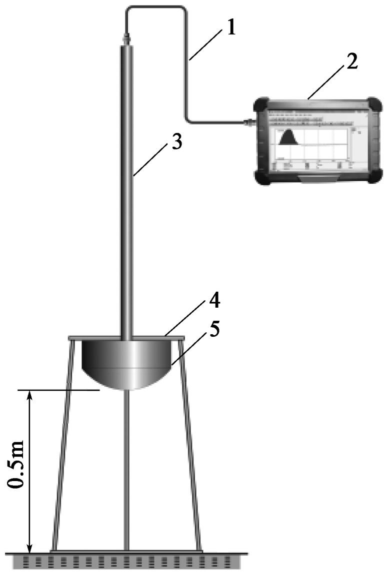


Figure T 0946-1　Illustration of falling ball instrument

1-computer;2-cable;3-handle;4-position limiter; 5-ball head

3　Method and procedure

3.1　Preparation

(1) Select the areas to be tested. The selected areas shall be marked and numbered. Every 10-20m in each traffic lane can serve as a test area. A test area shall meet the following conditions:

①No ponding of water or evidence of moisture on its surface, no visible debris such as gravel. The fill material in such an area is normally relatively uniform.

②The slope at the area is less than 10°.

③No construction activities, magnetic fields or static electricity nearby which may affect the test results.

(2) Each test area shall have at least 7 test points which shall be more than 500mm apart from each other. An area with fill material having obvious large particles shall not be used. For the arrangement of test points refer to Figure T 0946-2.

(3) Connect and commission the tester.

(4) Enter the mass of falling ball, radius of curvature, Poisson's ratio and drop height. Based

on the material type in the road section to be tested, select a Poisson's ratio(κ) and correction factor (κ) from Table T 0946-1.

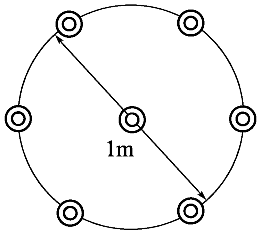


Figure T 0946-2 Test point arrangement(◎ : test points)

Table T 0946-1 Poisson's ratio(μ_s) and correction factor (κ)

Material	Gravel soil	Sandy soil	Silty soil	clay
Poisson's ratio μ_s	0.20	0.30	0.35	0.40
correction factor κ	0.66	0.85	0.90	1.00

3.2 Test procedure

(1) Place the instrument over the test point. Adjust the position limiter to ensure that the distance from the bottom of the ball head to the ground is 0.5m. If there is no position limiter, use a ruler to measure the drop height and be sure it is 0.5m.

(2) By means of the handle lift the ball to the pre-determined position and allow the ball head to fall freely and impact with the test surface. The instrument will automatically collect and then output the modulus of compression or modulus of resilience E_i of this point.

(3) The expected wave form of a suitable test point is approximately a half sine wave. If the wave has a lot of noise (such as too many peaks), a newspaper or plastic film may be placed over the test point to reduce the frictional static of the fill material against the ball head.

(4) After confirming that the test data is valid, save the collected date. Each test point may only be tested once. No repeat test on the same point is allowed.

4 Data processing

4.1 Calculate the modulus $\widetilde{E}$ of each tested area by equation T 0946-1,

$$\widetilde{E} = \frac{N}{\sum_{i=1}^{N}(1/E_i)} \tag{T 0946-1}$$

Where:

$\widetilde{E}$—modulus of the tested area(MPa);

N— number of test points

E_i—modulus at each test point(MPa)。

5 Report

The report of this method shall include the following technical content:

(1) The information of the tested area (stakes, type of material)

(2) Modulus

Background:

Elastic modulus may be calculated by the Hertz Impact Theory based on the process of acceleration-duration of an impact between an impactor and the subgrade. The process may be divided into a compression phase and a rebound phase. Hence the elastic modulus in the phase of compression and in the phase of rebound can be calculated respectively. For a compacted subgrade material, the difference between the duration of compression and rebound is very small. In this method the whole duration of impact is considered to calculate the resilient modulus. The resilient modulus and modulus of compression of each test point is calculated by equations T 0946-2 *and T* 0946-3:

$$E_{li} = \frac{\kappa \cdot (1-\mu_s^2) \cdot m_f E_f}{0.0719 E_f \cdot \sqrt{R_f v_0} \cdot T_c^{2.5} - m_f(1-\mu_f^2)} \tag{T 0946-2}$$

$$E_{si} = \frac{\kappa \cdot (1-\mu_s^2) \cdot m_f E_f}{0.0719 E_f \cdot \sqrt{R_f v_0} \cdot (2T_{cc})^{2.5} - m_f(1-\mu_f^2)} \tag{T 0946-3}$$

Where:

E_{li}— resilient modulus (MPa)

E_{si}—modulus of compression (MPa)

κ—material correction factor, see Table T 0946-1;

μ_s—Poisson's ratio of subgrade material, see Table T 0946-1;

μ_f—stainless steel Poisson's ratio, accept as 0.3;

m_f—the mass of ball head(kg), take as 19.1kg;

E_f—the deformation modulus of ball head material (stainless steel)(MPa), accept as

200 × 10^3MPa;

T_c—impact duration(s);

T_{cc}—compression duration during impact (s);

R_f—radius of falling ball(m), being 0.12m;

ν_0—the velocity of the free falling ball at the moment of impact with the subgrade (m/s):

$\nu_0 = \sqrt{2gH}$, where: $g = 9.80\text{m/s}2$;

H—drop height (m). If drop height is 0.5m, $\nu_0 = 3.10\text{m/s}$

Since subgrade materials are made from rock and soil, which lack of linearity and homogeneity, different test methods will give different results. Based on a large number of test data, the main factors which affect the falling ball test results are found to be the particle size and the gradation. Compared with the plate bearing test, the results of the falling ball test are normally larger. The larger the particle size, the greater the difference. By considered the test data from more than 50 construction projects in China or abroad, this method gives representative values for Poisson's ratio and correction factor in Table T 0946-1.

Figure T 0946-3 shows the comparative results between falling ball test and plate bearing test, which demonstrate:

(1) The results of the falling ball test are about 8% lower, which is conservative.

(2) The correlation coefficient is 0.957, which suggests a good correlation.

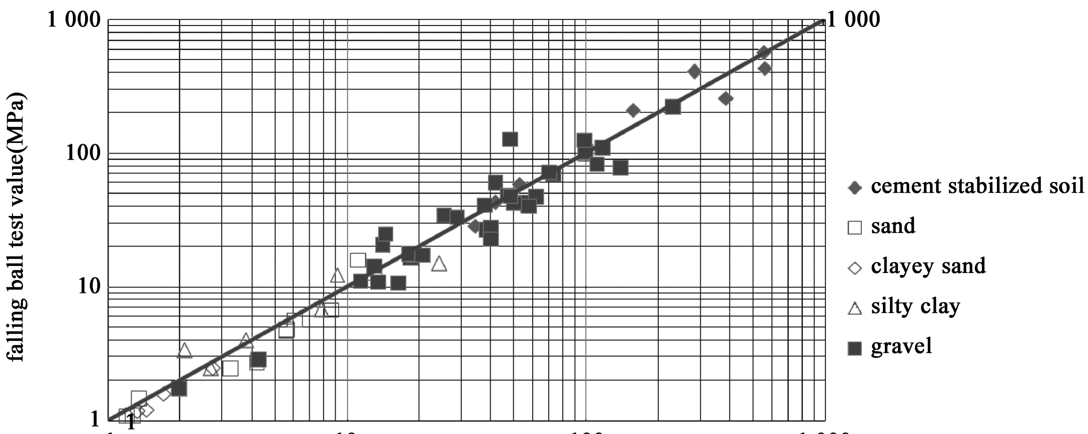


Figure T 0946-3 Comparison of falling ball modulus (y-axis) and plate bearing modulus(x-coordinate) on subgrade materials

Duringthe same period, a comparison was made between the falling ball test and the Benkelman beam test in more than 10 highway projects across China, namely Xinzhou and Jinzhone in Shanxi, Hangzhou in Zhejiang, Luoyang in Henan, Xiangyang in Hubei, and Chongqing municipality. The *results demonstrate*:

(1) In most cases, the resilient moduli obtained from the falling ball tests and from Benkelman beam tests are basically consistent in their average values and trend.

(2) As the effective depth of the falling ball test is less than that of the Benkelman beam test, it is largely affected by the surface material. If the test surface is moist, the resilient modulus from the falling ball test tends to be smaller as would be expected. On road sections which have a large number of heavy truck traffic, the results of falling ball test tend to be larger because of the compaction of the upper layer.

The measured value of the falling ball test also correlates well with the dynamic modulus of geomaterials. From a practical need, and by referring to the specifications in Appendix C of this edition, a correlation could be developed to obtain a conversion relation between the modulus of the falling ball test and dynamic modulus.

T 0951—2008 Benkelman beam test method for rebound deflection of subgrade and pavement layers

1 Scope of application

1.1 This method is suitable to test the rebound deflection of subgrade and the asphalt pavement to evaluate the bearing capacity.

1.2 This method is not suitable for testing the rebound deflection of a frozen subgrade.

2 Technical requirements for instruments and materials

(1) Benkelman beam: it is made of aluminum alloy with a level bubble. The length ratio between the front arm and rear arm is 2:1. There are two types of Benkelman beam. Their respective lengths are 5.4m (3.6m + 1.8m) and 3.6m (2.4m + 1.2m). It is shown in Figure T 0951-1. The 5.4m long beam is suitable for testing rebound deflection on all types of pavement structure. The 3.6m long beam is suitable for asphalt pavements with a flexible base.

(2) Load vehicle: heavy truck with a single rear axle with dual-wheels on each side. The gap between the dual wheels shall allow the free entry of the beam tip. The axle load and tire pressure and other parameters shall conform to the requirements given in Table T 0951

(3) Dial gauge and its holder.

(4) Road surface thermometer: resolution not more than 1℃.

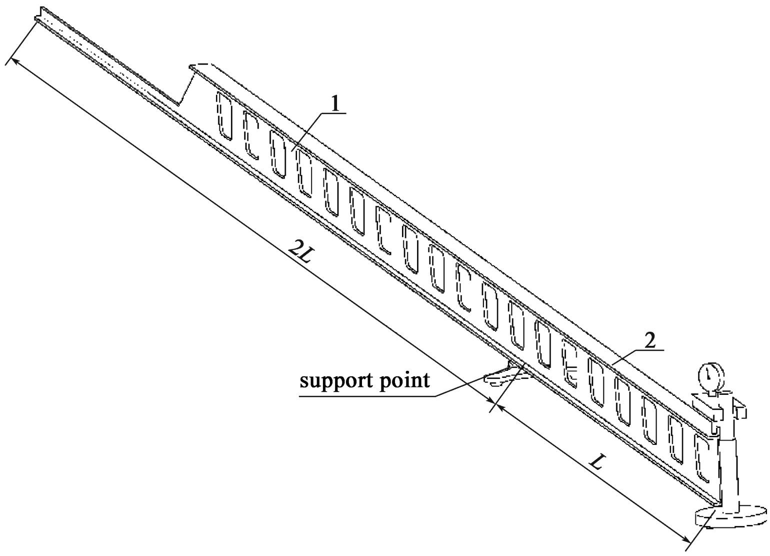


Figure T 0951-1 Benkelman beam design

1-front arm, 2-rear arm

(5) Others: steel ruler, etc.

Table T 0951 Parameters required for load vehicle

Normal rear axle load P (kN)	100 ± 1
Dual wheel load each side (kN)	50 ± 0.5
Tire pressure (MPa)	0.7 ± 0.05
Circular area equivalent to tire contact area of a single wheel (mm^2)	$(3.56 \pm 0.20) \times 10^4$

3 Method and procedure

3.1 Preparation

(1) Check and keep the load vehicle used in this test in good condition with sound braking performance. Its tire pressure shall meet the requirements listed in Table T 0951.

(2) Counter weight on the vehicle. Weigh it by platform scale to be sure its rear axle load and dual-wheel load on each side meet the requirements listed in Table 0951. Such an axle load shall be kept constant during the test process, even when the vehicle moves.

(3) For a new vehicle or when the tire becomes worn, the tire contact area shall be checked. The checking method is: ensure that the load and tire pressure meet the requirements in Table 0951. Jack up the rear axle on a hard and flat road surface. Spread a sheet of graph paper and a sheet of carbon paper below the tire. Lower the rear axle to mark the graph paper. Measure the marked area by planimeter or by counting the number of grids. Be sure that such an area meets the requirements for an equivalent circle area for tire contact area of a single wheel.

(4) When testing an asphalt pavement, the mean temperature over 5 days before testing shall be obtained from a weather station (average value of highest temperature and lowest temperature).

(5) Record the material type and design thickness of the pavement structural layers.

3.2 Test procedure

(1) Stop the load vehicle over the test position, with its rear wheels normally in the traffic wheel paths. Position the beam tip of the Benkelman beam in-between two wheels of the dual-wheel from behind the load vehicle. The Benkelman beam shall not touch the tires. Its tip shall be over the test point which is 30-50mm ahead of center of the gap of the wheels. Measure and record the surface temperature of road near the test point. Two Benkelman beams may be used simultaneously to test the dual-wheels on both sides of load vehicle.

(2) Position the dial gauge with its holder, on the top of Benkelman beam in contact with the beam. Tap the beam slightly to ensure that the dial gauge returns properly.

(3) Direct the load vehicle to move forward gently, normally at a speed of about 5km/h. The reading on the dial gauge increases continuously as the pavement deflects. Take the initial reading L1 when the gauge shows a maximum value. The vehicle continues without stopping. The reading on the dial gauge starts to go in the opposite direction. When the vehicle is beyond the deflection bowl (further than 3m from the test point), and the reading on the dial gauge remains steady, take the final reading L2.

(4) Direct the load vehicle to go forward along the wheel path to reach the next test position. Repeat the procedure (1) to (3) to complete the rebound deflection test on the road section to be tested.

3.3 When a 5.4m long Benkelman beam is employed, normally no correction is required for the deflection at the beam supporting point. Should the supporting point deflect, such deflection shall be measured by testing. By placing another Benkelman beam behind the test Benkelman beam with its beam tip at the side of the supporting point of the test Benkelman beam. When the load vehicle moves forward, record readings of deflection of both Benkelman beams. If the readings show that there is a deflection at the supporting point of the test Benkelman beam, then the deflection at the supporting point shall be recorded to be used for correcting the test value. When measuring on the same structural layer, the deflection of the supporting point may be repeated 5 times at different positions to obtain their average value to be used for correction of subsequent tests on a road section with the same structural layer. The principle for fulcrum correction is shown in Figure T 0951-2.

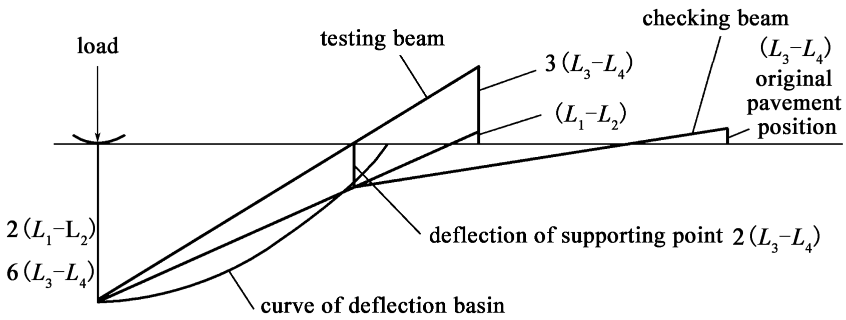


Figure T 0951-2 Correction for deflection of supporting point during Benkelman beam test

4 Data processing

4.1 The deflection value of a test point shall be calculated by using equation T 0951-1

$$l_t = 2(L_1 - L_2) \quad \text{(T 0951-1)}$$

Where:

l_t—rebound deflection at the average temperature t of the asphalt surface layer (0.01mm)

L_1—maximum reading of dial gauge when vehicle rear wheel is centered near the beam tip of Benkelman beam (0.01mm).

L_2—final reading of dial gauge when it remains constant after vehicle is out of range of influence (0.01mm).

4.2 When correction is required because the supporting point is deflecting, the rebound deflection value shall be calculated using equation T 0951-2

$$l_t = 2(L_1 - L_2) + 6(L_3 - L_4) \quad \text{(T 0951-2)}$$

Where:

L_3—maximum reading of check beam dial gauge when the load vehicle is centered near the beam tip of the test beam (0.01mm).

L_4—final reading in check beam dial gauge when vehicle is out of range of influence (0.01mm).

Note: This equation is applicable when the test beam supporting point is being deflected, but the holder of the dial gauge does not deflect.

4.3 When the thickness of the asphalt surface layer is more than 50mm, the rebound deflection value shall be corrected for temperature, by the following procedure:

(1) Calculate the average temperature of the asphalt surface layer at the time of testing with equation T 0951-3

$$t = \frac{t_{25} + t_m + t_e}{3} \quad \text{(T 0951-3)}$$

Where:

t—average temperature of asphalt surface layer at the time of testing

t_{25}—the temperature at the depth of 25mm underthe surface, determined from t0 and Figure T 0951-3

t_e—the temperature at the bottom ofthe asphalt surface layer determined from t0 and Figure T 0951-3

t_m—the temperature at the mid-depth ofthe surface layer, determined from t0 and Figure T 0951-3

t_e—the temperature at the bottom ofthe surface layer, determined from t0 and Figure T 0951-3

t_0—the sum of road surface temperatures at the time of testing and average mean temperature of 5 days before of testing. Mean daily temperature is the mean temperature of daily highest temperature and lowest temperature.

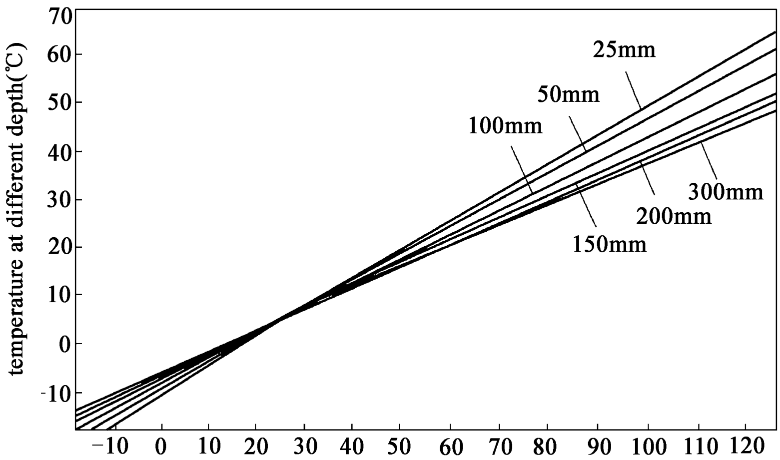


Figure T 0951-3 Determining the average temperature of asphalt surface layer

Note: the numbers shown with the lines indicate various depths from the road surface(mm)

(2) When the average temperature of the asphalt surface layer is at 20 ± 2℃, the correction factor for temperature K = 1.0therwise, the correction factor for temperature K shall be determined for asphalt surface layers with different base layers, based on the thickness of the asphalt layers, and by applying Figure T 0951-4 and Figure T 0951-5.

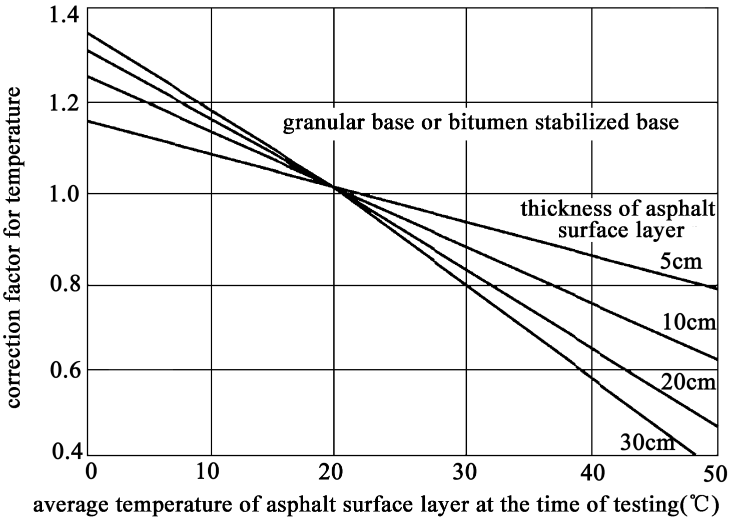


Figure T 0951-4 Correction factor K for temperature for road deflection (suitable for granular base or bitumen stabilized base)

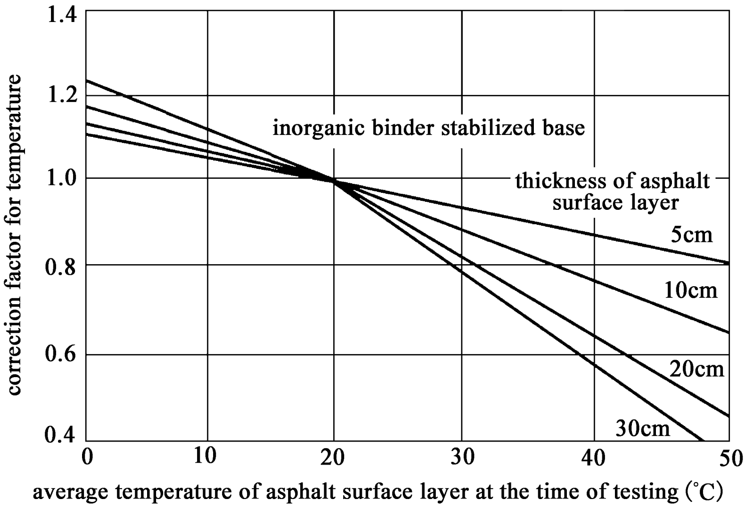


Figure T 0951-5 Correction factor K for temperature for road deflection (suitable for inorganic binder stabilized semi-rigid base)

(3) Calculate the corrected rebound deflection l_{20} by equation T 0951-4

$$l_{20} = l_t \cdot K \quad \text{(T 0951-4)}$$

Where:

K—correction factor for temperature

4.4 Calculate the average value, standard deviation of rebound deviation for a road section tested as described in Appendix B of this method. And representative value of rebound deviation shall be calculated based on test purposes and relative specifications.

5 Report

The report of this method shall include the following technical content:

(1) The information of road section tested (stakes, material type of pavement structural layers and the design thickness).

(2) Average temperature, correction factor for temperature, rebound deflection of asphalt surface layer.

(3) Average value of rebound deflection, the standard deviation and the representative value.

Background

The load vehicleplays an important role for measuring the rebound deflection of the subgrade or of pavement layers with the Benkelman beam. China used to specify the JieFang CA-10B and Huanghe JN-150 as two standard vehicles representing two load levels. These vehicles are no longer manufactured and are now seldom used. Thus they cannot be specified as standard vehicles any longer. In this revision, no specific model of vehicle is specified as load vehicle. However, from Table T 0951-1, the main parameters such as rear axle load, dual-wheel load on each side, tire pressure, and the area of an equivalent circle of a single wheel are specified. Every vehicle meeting these requirements may be used for testing. In Table T 0951 of the former edition, the radius of the equivalent circle of the contact area of a single tire is specified. However, in practice, the area of the equivalent circle is used. For that reason, in this edition, the area of the equivalent circle representing a single tire is specified. The conditions under which the tire shall be checked, is specified. The checking procedures are specified in detail.

The rebound deflection of an asphalt pavement is greatly affected by temperature. To allow comparison of the rebound deflections tested at different temperatures, the standard test temperature is set at 20℃. If the thickness of the asphalt layers is over 50mm, correction for temperature is required. The procedures are described in Clause 4.3 of this method. In the practice, a correction is usually obtained from the table given in the former edition. Unfortunately serious human errors occur by such a correction method. Because of limited amount of information and lack of original data it is impossible to verify now. Based on the graphs for temperature correction in the former edition (1995), by repeated checking and verification, engineers at the

'*Research Institute of Highways*, *China Ministry of Transportation*' *produced equations shown in Tables T* 0951-2、*T* 0951-3、*T* 0951-4.

Table T 0951-2 Determination of the average temperature of an asphalt layer

The depth from the surface25mm	The temperature at different depths
25mm	$T_{25} = 0.5943T_0 - 12.3120$
50mm	$T_{50} = 0.5483T_0 - 11.0248$
100mm	$T_{100} = 0.5034T_0 - 9.8736$
150mm	$T_{150} = 0.4667T_0 - 8.6477$
200mm	$T_{200} = 0.4464T_0 - 7.8857$
300mm	$T_{300} = 0.4227T_0 - 7.0723$

Table T 0951-3 Correction factor for temperature for pavement rebound deflection

(suitable for granular base and bitumen stabilized base)

Asphalt layer thickness	Correction factor for temperature	
	0 to 20℃	20 to 50℃
50mm	$\kappa_{50,1} = -0.0077T + 1.1544$	$\kappa_{50,2} = -0.0068T + 1.1328$
100mm	$\kappa_{100,1} = -0.0136T + 1.2688$	$\kappa_{100,2} = -0.0118T + 1.2340$
200mm	$\kappa_{200,1} = -0.0159T + 1.3153$	$\kappa_{200,2} = -0.0169T + 1.3321$
300mm	$\kappa_{300,1} = -0.0172T + 1.3425$	$\kappa_{300,2} = -0.0208T + 1.4124$

Table T 0951-4 Correction factor for temperature for pavement rebound deflection

(suitable for inorganic binder stabilized semi-rigid base)

Asphalt layer thickness	Correction factor for temperature	
	0 to 20℃	20 to50℃
50mm	$\kappa_{50,1} = -0.0045T + 1.0916$	$\kappa_{50,2} = -0.0065T + 1.1319$
100mm	$\kappa_{100,1} = -0.0061T + 1.1220$	$\kappa_{100,2} = -0.0117T + 1.2365$
200mm	$\kappa_{200,1} = -0.0084T + 1.1690$	$\kappa_{200,2} = -0.0179T + 1.3599$
300mm	$\kappa_{300,1} = -0.0112T + 1.2251$	$\kappa_{300,2} = -0.0208T + 1.4173$

If the tested values of rebound deflections are generally small or deflection basins for pavements with semi-rigid base are large, *correction for the deflection of the supporting points shall be considered. The procedure is given in Clause 3.3 of this method.*

T 0952—2008 Automatic Lacroix deflectograph for measuring pavement deflection

1 Scope of application

1.1 This method is suitable for measuring the total deflection of an asphalt pavement by means of the automatic Lacroix deflectograph, and then evaluating its bearing capacity.

1.2 This method is not suitable to measure the deflection of a pavement with serious potholes or rutting, or for roads that do not have normal traffic conditions.

2 Technical requirements for instruments and materials

Theautomatic Lacroix deflectograph: consists of a load vehicle, measuring frame, control system, sensors for displacement and temperatures, data collection and processing system. It is illustrated in Figure T 0952.

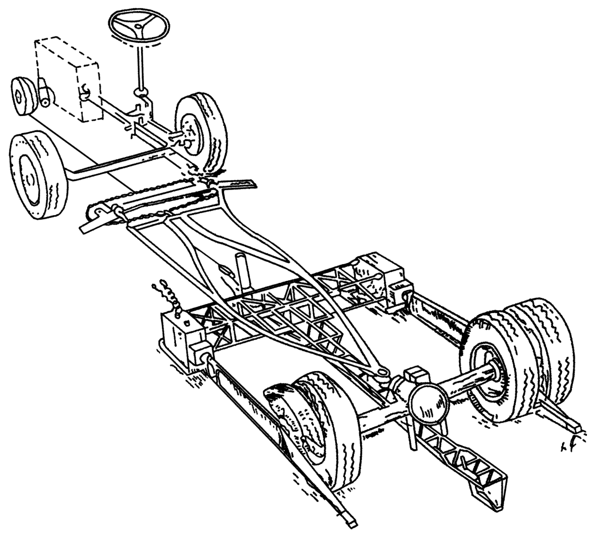


Figure T 0952 Illustration of measuring system of the automatic Lacroix deflectograph

(1) Load vehicle: truck with single rear axle and dual wheels on either side. The axle load and tire pressure shall meet the requirements in Table T 0951.

(2) Sensors for displacement and temperature.

①Resolution of displacement sensor：≤0.01mm。

②Displacement sensor range：≥3mm。

③Indication error of distance sensor：≤1%。

3 Method and procedure

3.1 Preparation

(1) Check that the condition of the load vehicle and brake performance is good. Tire pressure shall meet the requirements in Table T 0951.

(2) If the rear axle load of loading vehicle is changed due to maintenance, follow T 0951 of the Standard to be sure the requirements in Table T 0951 are fulfilled.

(3) Check that there is no damage to the measuring frame, and replace damaged parts.

(4) Switch on the power to check that the functional buttons, indicator lights and monitors are normal.

(5) Before testing, the displacement sensors shall be calibrated. The calibration data shall be recorded and stored.

(6) Start the load vehicle and move 2-3 test intervals to test a trial distance, so as to be sure the testing system works normally.

(7) When testing an asphalt pavement, the mean temperature over 5 days before testing shall be obtained from a weather station (mean value of highest temperature and lowest temperature).

(8) Record the material type of the asphalt structural layers, the design thickness and cross slope.

3.2 Test procedure

(1) Switch on power to warm up the testing system.

(2) Switch on the warning signs like construction warning lights and guide signs. Place the measuring frame 20m ahead of the road section to be tested.

(3) Enter the required test parameters according to the on-site technical conditions of road section to be tested.

(4) Slowly accelerate the load vehicle to the test speed, normally below 3.5km/h. If the actual test speed on site is over the limit, a correlation test shall be made to correct the test results. The load vehicle is now driven into the test section along the normal wheel paths to start testing. During this process, the start point, end point, stakes of specific positions like bridges or culverts shall be input into the data recording as the loading vehicle passes them. At the same time the road surface temperature shall also be recorded.

(5) At the end of test road section, stop data collection and recording, let the vehicle slow to a stop, and lift the measuring frame.

(6) Check the data file to see if it is complete and its contents are normal. If not, the test shall be repeated.

(7) Switch off the power of the test system and end the test.

4 Data processing

4.1 The peak value of the pavement deflection basin collected by automatic deflectometer is the total deflection of the pavement. The measured value by the left arm or right arm shall be treated as an independent deflection.

4.2 The value of deflection shall be corrected for the temperature following T 0951 of the Standard.

4.3 Road cross slope correction of deflection

If the cross slope is less than 4%, no correction is needed, if greater than 4%, correct the deflection as given in Table T 0952.

Table T 0952 Road cross slope correction of deflection

Cross slope range	Correcting factor for higher position	Correcting factor for lower position
>4%	$\frac{1}{1-i}$	$\frac{1}{1+i}$

Note: i is the cross slope (%).

4.4 If the test speed is greater than 3.5km/h, a correlation test shall be performed as given in

Clause 5 of this method. The deflection value shall be corrected.

4.5 According to the method in Appendix B of the Standard, calculate the average deflection of a road section tested and its standard deviation. The representative value of rebound deviation shall be calculated based on test purposes and relative specifications.

5 A correlation test between automatic deflectometer and Benkelman beam deflection results.

5.1 Test conditions

(1) Select 4 or more test sections of road with similar pavement structure but with different deflection values, each section normally has a length of 300 to 500m. Mark out their start and end points.

(2) The test sections shall be clean and dry without nearby heavy traffic or vibrations.

(3) A clear day without wind shall be selected for the tests. The temperature during testing shall be between 10 and 35℃, without sudden temperature changes.

5.2 Test procedure

(1) Test a section with the automatic deflectometer at the normal speed in accordance with Clause 3.2 of this method. At every third test point, or about 20m, mark out the positions of those test points.

(2) After the automatic deflectometer has completed testing, wait for 30min., then measure the rebound deflection at the marked points with the Benkelman Beam according to method T 0951.

5.3 Data processing

For each marked point extract the Benkelmanbeam and the automatic deflectometer deflections. Compare the individual values in the two groups one by one. The correlation equation between Benkelman beam and automatic deflectometer deflections can be calculated according to Appendix C of the Standard. Ensure that the correlation coefficient shall not be less than 0.95.

6 Report

The report of this method shall include the following technical content:

(1) Information of road section tested (stakes, material type of structural layers of pavement, design thickness, cross slope)

(2) Average temperature, correction factors for temperature, correction factors for cross slope, deflection.

(3) If a correlation test is performed, then present the correlation equation and the correlation coefficient.

***Background*:**
Test results in both Britain and China have shown that the automatic deflectometer deflections are affected by test speeds. If the deflection is less than 40(0.01mm), the effect is small and need not be considered. If the deflection is greater than 40(0.01mm), test results are affected and must be adjusted.

Normally the automatic deflectometer can measure and record the temperature of the road surface. When this function is not available, the road surface temperature shall be measured and recorded at appropriate time intervals according to the temperature change.

A difference in pavement structure and the subgrade will affect the correlation relationship. Therefore, in selecting the road test sections for comparison, the conditions of the pavement and subgrade shall be similar. For a region several road sections with different pavement and subgrade conditions can be selected to develop several correlation relationships for the conversion calculations. To make the equation more robust, the deflections of the road sections shall have a wide range. At the time of testing there shall be no heavy traffic or other vibration nearby, or the test results will be affected.

In the Benkelman beam test, the load vehicle shall not stand still on the pavement around the test points for a long time. Thus, for every three test intervals, select a comparison test point. To give pavement a sufficient recovery time, after the automatic deflectometer test ends, wait for 30min before performing the Benkelman beam test.

T 0953—2008 Falling weight deflectometer for measuring pavement deflection

1 Scope of application

This method defines the use of the falling weight deflectometer (FWD) to measure the deflection of the road surface under the action of an impact load. This is a dynamic deflection which can be used to evaluate the bearing capacity of pavement and subgrade.

2 Technical requirements for instruments and materials

The falling weight deflectometer (FWD) consists of drop mass mechanism, a deflection measurement device, control system and a trailer. Detailed requirements are as follows:

(1) Drop mass mechanism: select a weight whose mass and drop height are defined by its purpose and highway Class. The impact load is measured by sensors. Normally, the weight has a mass of (200 ± 10) kg which can generate an impact load of 50 ± 2.5 kN. The load plate is divided into four segments in a cruciform symmetry, with rubber base. The diameter is normally 300mm, or 450mm in some cases.

(2) Deflection measuring device: consists of a sensor or several sensors with displacement resolutions not greater than 0.001mm (see Figure T 0953. There is a displacement sensor in the center of the load plate. Other displacement sensors are all placed in a line towards the center, normally within the range up to 2500mm from the center. When used to calculate the modulus of the pavement structural layers, there shall be at least seven displacement sensors. Positions of 0mm, 300mm, 600mm and 900mm shall be included.

(3) The control system: for the duration of the waves generated by the impact load, measure and record the impact load and dynamic deflection at each sensor.

(4) Towing vehicle, for pulling the FWD and housing the control system.

3 Method and procedure

3.1 Preparation

(1) Adjust the mass and drop height of the mass to provide an impact which meets the requirements of Clause 2 of this method.

(2) Check the condition and performance of the FWD to ensure that it will function normally.

(3) Tow the FWD to the test position at a speed of less than 50km/h.

(4) Switch FWD on to calibrate the sensors.

3.2 Test procedure

(1) Tow the FWD to the start point of test section. Input the test position information as well as the test parameters.

(2) Position the center of the load plate exactly over the test point which is normally in the wheel path. Lower the load plate and position the displacement sensors.

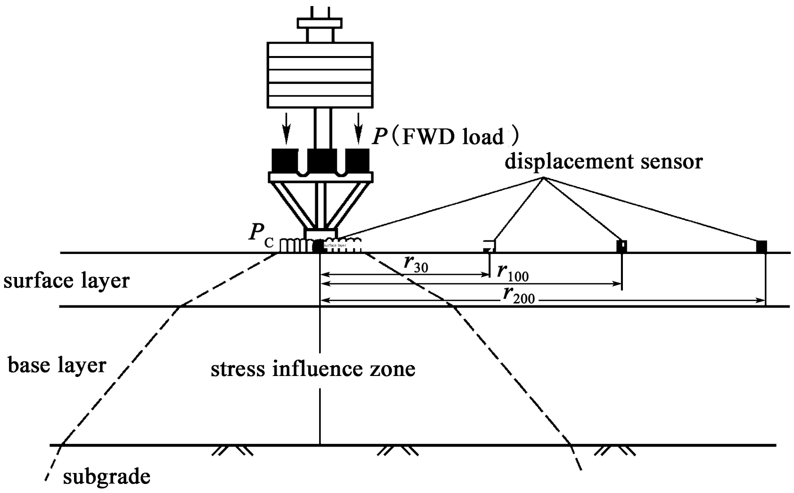


Figure T 0953 Schematic diagram of sensor layout and stress distribution of FWD

(3) When the loading device is activated the weight falls freely with an impact on the load plate. Then the weight is automatically lifted to its original position and fixed. During this process the load data is recorded automatically as well as all the displacement sensor measurements. The peak value of the displacement is considered as the deflection value. The measurement cycle shall

be repeated at least three times on a test point.

(Note from translator: The first drop is a seating drop and shall be discarded. Only from the second drop is valid data collected.)

(4) Lift the sensors and the load plate. The vehicle moves forward to the next test point. Repeat the procedure given in (2) and (3) to complete all the tests on a road section.

4 Data processing

(1) Discard the first deflection value at a point. All other deflection values shall be used to calculate the average value, which is the deflection value of the test point.

(2) Correct the deflection value for temperature as described in the 'Specifications for the Design of a Highway Asphalt Pavement' (JTG D50—2017).

(3) Calculate the average deflection of a road section, the standard deviation according to Appendix B of the Standard. And representative value of rebound deviation shall be calculated based on test purposes and relative specifications.

5 Report

The report of this method shall include the following technical content:

(1) The information of the road section tested (stakes, material type of pavement structure layer and design thickness).

(2) Temperature influence coefficient of surface deflection, deflection readings.

(3) Average deflection of road section tested, its standard deviation and representative value.

(4) The data of the deflection basin can be reported, if required.

***Background*:**
According to the design code for asphalt pavements, the deflection shall no longer be considered as a design indicator, but it may still be considered as an indicator for acceptance inspection for pavement layers or subgrade. In this revision, there are no mandatory requirements for a

correlation test between FWD and Benkelman beam test results. If a correlation relationship is needed, the following procedure may be executed.

(1) Select road sections

Select road sections with the same type of structure which is typical in a region. Then perform comparison tests between two test methods, so that the results from FWD may be converted into the values of Benkelman beam test. The length of the selected road section shall be 300 to 500m. The deflection in such a section shall have a range of values.

(2) The procedure for the correlation test

①*Use a FWD and Benkelman beam which are used on the project. The impact load of the FWD shall be the same as the dual-wheel load of rear axle of Benkelman beam vehicle.*

②*Mark out the starting point of the road section.*

③*Arrange the test points as given in Clause 3. 1 of this method. Measure the rebound deflection of a test point by Benkelman beam as described in method T 0951 of edition. After the load vehicle moves away, draw a circle with a radius of 150mm to mark the test point.*

④*Position the load plate of the FWD over the circle with a deviation not more than 30mm. Follow the Clause 3 of this method to perform the test. The time interval between the two types of deflection test shall not exceed 10min.*

⑤*Calculate the correlation of both instruments point by point. From the comparison, a regression equation can be calculated with the form*

$$LB = a + bLFWD,$$

where LFWD、LB represent respectively deflection values of FWD and Benkelman beam. The correlation coefficient of this regression equation shall not be less than 0. 95.

Correlation relationship will be different if pavement structures, fill materials, subgrade conditions, temperature, hydrological conditions and pavement service conditions are different. For a more reliable correlation, normally correlation tests shall be conducted for different situations.

T 0957—2019 High speed laser-based deflectograph for measuring pavement deflection

1 Scope of application

This method is suitable to test pavement deflection by laser-based deflectograph which applies the Doppler theory of speed detection.

2 Technical requirements for instruments and materials

The laser-based deflectograph consists of a load vehicle, detection control system, Doppler laser sensors, distance measuring system and a temperature control system. It is illustrated in Figure T 0957-1. The basic technical parameters are as follows:

(1) The range of testing speed: 30 to 90km/h。

(2) The resolution of the laser sensor: 0.01mm/s

(3) The number of test lasers: not less than 4

(4) Distance calibration error: ≤0.1%

(5) The load vehicle shall have two or more axles, with its middle axle and rear axle fitted with dual-wheels on each side. The rear axle load, dual-wheel load on each side and tire pressure shall meet the requirements of Table T 0951.

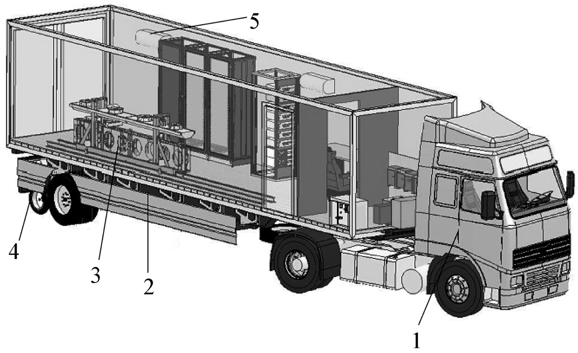


Figure T0957-1 Schematic of laser-based deflectograph

1-load vehicle, 2-detection control system, 3-Doppler laser sensor, 4-distance measuring system, 5-temperature control system

3 Method and procedure

3.1 Preparation

(1) Check the standard rear axle load of the load vehicle, the dual-wheel load on both sides, tire pressure and other parameters. They shall fulfill the requirements of Clause 2 of this method.

(2) Check the performance of the load vehicle and all sensors.

(3) Switch on and check all the parts of the equipment namely the computer, data collecting and computing software and warning lights.

(4) Start the laser-based deflectograph, and ensure the entire system is working correctly.

(5) When testing an asphalt pavement, obtain the data of the mean temperature (mean value of the hottest temperature and lowest temperature) over 5 days before testing from observatory weather station.

(6) Record the type of asphalt pavement, structural layers and design thickness.

3.2 Test procedure

(1) Switch on the power to warm up the system and to ensure that the temperature inside equipment compartment meets the test requirements. Turn on the warning lights, guide lights and other warning signals.

(2) Lower the distance measuring wheel, set the test mode meeting the technical requirements of the test section.

(3) Accelerate the load vehicle to the test speed and drive it into the test section along the wheel paths. Maintain the proper position and speed.

(4) Start measuring before the load vehicle enters the test section, ensure that there is an effective length of at least 200m before the starting point. With an event marker, mark out the start point when the load vehicle reaches it. If there are bridges, pavements in poor conditions or other unexpected conditions, these special positions shall be marked to record their information including their stakes.

(5) When the load vehicle reaches the end point, mark it. Stop data collection after the vehicle has travelled past the end point for at least 200m. Return the entire system to the ready state.

(6) Check the test data for completeness. Unless the test results are complete and normal repeat the test.

(7) Switch off the power of test system and end the test.

4 Data processing

4.1 Data shall be processed by special data processing software and calculation models.

4.2 Correct the results for temperature and cross-slope by following the methods stated in T 0951 and T 0952 of the Standard. Data outside the section will be discarded. Based on the requirements, the pavement deflection values for the road section with the required length will be saved.

4.3 Calculate the average deflection value of the road section, the standard deviation in accordance with the method stated in Appendix B. And representative value of rebound deviation shall be calculated based on test purposes and relative specifications.

5 Correlation test between Laser-based deflectograph and FWD deflections

5.1 Test conditions

(1) Select 4 or more road sections with similar pavement structures but with a range of deflection values.

(2) Test road sections shall be even and straight, without damage, no ponding water, no debris and no intersections.

(3) Test road sections shall be clean and dry, without heavy traffic or vibrations close by.

(4) Testing shall be performed on a clear day without wind. The temperature during testing shall be between 10 and 35℃, and the temperature shall not change rapidly.

5.2 Test procedure

(1) The FWD testing shall follow T 0953 of the Standard and move at a normal speed to test

the deflection of a road section. Mark out the test points at an interval of about 10m.

(2) After the FWD completed the measurements, wait for 10min before testing by laser-based deflectograph.

5.3 Data processing

According to the position of the FWD testing points select the corresponding deflection values measured by the laser-based deflectograph from its recorded data. Match the two groups of deflection values with the value. Develop a correlation equation between measurements of the FWD and laser-based deflectograph by following the method given in Appendix C. The correlation coefficient shall be greater than 0.90.

6 Report

The report of this method shall include the following technical content:

(1) The information of the road section tested (stakes, material type of pavement structural layers and design thickness).

(2) Average temperature of asphalt surface layer, correction factor for temperature, correction factor for cross-slope, deflection.

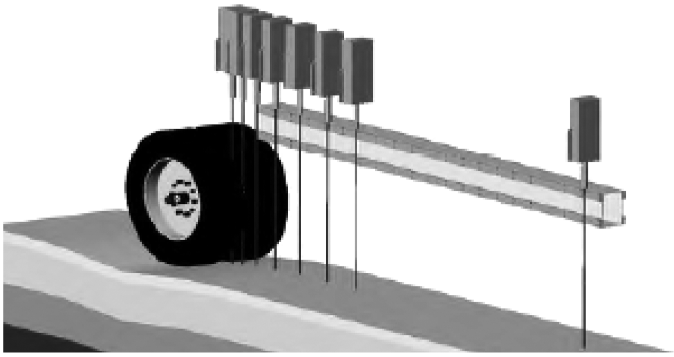
(3) If a correlation test is performed, the correlation equation and correlation coefficient shall be reported.

***Background*:**

The laser-based deflectograph is currently the most advanced deflection measuring equipment in the world. By applying laser-Doppler technology, it measures the vertical deflection rate of the road surface under a load from a fast moving vehicle. With appropriate analysis software the maximum deflection and deflection basin is calculated. This type of equipment was first developed by Greenwood Co., Denmark, but China has also developed its own laser-based deflectograph with independent intellectual property rights.

The test principle of laser-based deflectograph is based on the Laser-Doppler effect to measure the depression rate of the road surface under a load applied by a fast moving vehicle. An inertial system is used to record the real-time vibration of the Doppler laser sensors for calculating and correcting the actual rate of change of pavement deflection. The test principle is illustrated in the

Figure T 0957-2.



FigureT 0957-2　Schematic of the working principle of the laser-based deflectograph

The principle of Laser Doppler effect is that when a light ray with a frequency f_{d1} *reaches test surface, is moving vertically under the load. The light ray reflected by the moving test surface will have a frequency of* f_{d2}, *the Laser-Doppler sensors will measure the frequency variation and calculate the vertical rate of movement of the test surface. The principle is illustrated in Figure 0957-3.*

$$v_D = \frac{(f_{d1} - f_{d2}) \cdot \lambda}{2} \qquad (T\ 0957)$$

Where:

v_D——speed of vertical movement of the test surface

f_{d1}—frequency of emitted light ray

f_{d2}— frequency of reflected light ray

λ—wave length of emitted light ray

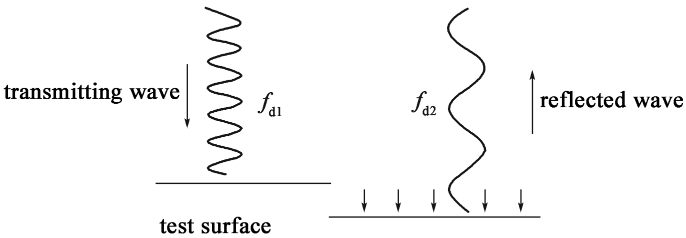


Figure T 0957-3　Illustration of Laser-Doppler effect

When the tested surface reaches its maximum deflection, its moving speed is zero then. By analyzing and calculating the moving speed variations to each point spread over deflection basin, the maximum deflection can be obtained. As Laser-based deflectograph works with a non-contact way, it can measure surface deflection accurately at a high speed which even reaches 120km/h.

Currently China mainly uses two types of automatic deflection measuring equipment, namely the *automatic deflectometer and falling weight deflectometer. Although their test principles are different, the test speeds are normally under 3. 5km/h. Test efficiency is low. As they work at a slow moving speed, there are dangers if working on the motorway under traffic. The Laser-based deflectograph, however, can test on the motorway under traffic at a test speed in the range of 30 to 90 km/h. Consequently test efficiency and productivity is greatly improved. Furthermore, it also has advantages such as not disturbing traffic and being safe.*

8 Strength of cement concrete

T 0954—1995 Method for testing the strength of cement concrete with the rebound tester

1 Scope of application

1.1 This method is suitable to quickly check the compressive strength of a cement concrete pavement, but shall not be used as evidence for verifying its strength, or for arbitration or as criteria for acceptance control.

1.2 This method is not suitable for determining the strength of cement concrete if there are obvious differences in surface and internal parts, or internal defects.

1.3 This method is not suitable for testing the strength of cement concrete with a thickness less than 100mm.

2 Technical requirements for instruments and materials

(1) Rebound tester for cement concrete: Direct reading concrete rebound tester with a pointer scale. A schematic and the main parts are given in Figure T 0954. A rebound tester with a digital display or one that can record results automatically may also be used. The specific technical requirements are as follows:

①If a horizontal test is performed, the nominal energy of the rebound tester is 2.207J at the moment the rebound hammer is released from its hook.

②At the moment the rebound hammer strikes the rebound rod, the impact tension spring is in a free state. At this moment, the head of rebound hammer shall be at the zero point of the scale.

③On the steel anvil with Rockwell hardness 60 ± 2 HRC, the calibration value of the rebound tester shall be 80 ± 2.

④The rebound tester shall be equipped with a digital display. It shall also have a pointer scale. The difference between the rebound value of the digital display and the direct reading indicated value of the pointer shall not exceed 1.

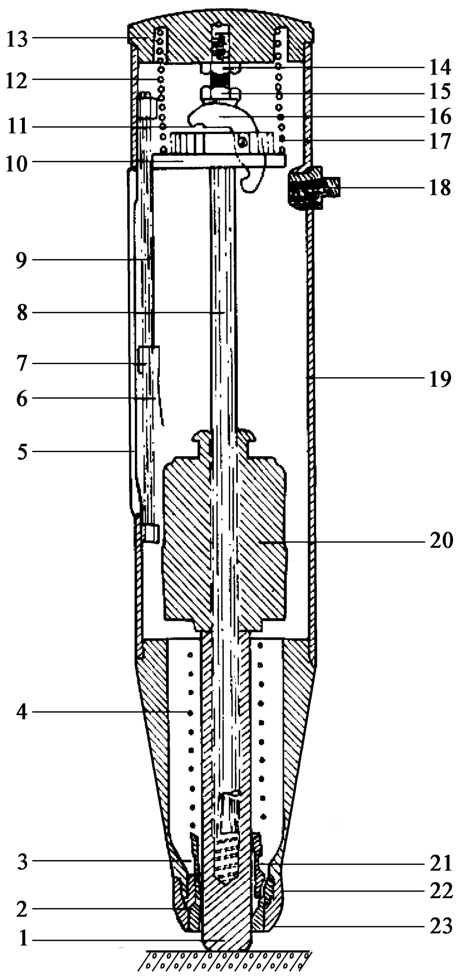


Figure T 0954 Schematic of a rebound tester for concrete strength

1-rebound rod; 2-bounce tension spring; 3-spring seat; 4-rebound hammer; 5-pointer block; 6-pointer piece; 7-pointer axis; 8-pointer scale; 9-guiding flange; 10-center guiding rod; 11-buffer spring; 12-hook; 13-compression spring for hook; 14-hook pin; 15-compressed spring; 16-zero adjustment screw; 17-tightening nut; 18-end cover; 19-cap; 20-clamp ring; 21-felt seal ring; 22-button; 23-shell

(2) Phenolphthale in alcohol solution: concentration 1% to 2%.

(3) Vernier caliper: graduation scale 0.02mm

(4) Carbonation depth gauge: graduation scale 0.25mm

(5) Steel anvil: Rockwell hardness 60 ± 2 HRC

(6) Others: portable grinding wheel, chisel, hammer, rubber pipette bulb

3 Method and procedure

3.1 Preparation

(1) Ensure that the ambient temperature is between −4 and 40℃ at the time of testing.

(2) Calibration of rebound tester

①Before using the rebound tester, it shall be calibrated against the steel anvil. At the end of each working day, or if it gives dubious results during testing, it shall also be calibrated.

② The calibration of the rebound tester shall be made at a temperature of between 5 and 35℃. The steel anvil for calibration shall have a dry and clean surface. It shall be placed on a hard surface. When the rebound hammer bounces downwards, the rebound rod shall be turned 4 times with each turn being about 90°. Bounce 3 − 5 times, and use the last 3 stable results to calculate the average value as the calibration value.

(3) Layout of measuring areas and measuring points

①Determine the concrete slabs that shall be tested according to the method stated in T 0902. Each concrete slab shall have 10 or more test areas. The distance between two adjacent test areas shall not be more than 2 m. Measurement areas should be spread evenly over a slab, avoiding joints and corners.

②The surface of test areas shall be clean, dry and even. There shall be no loose skin, no painted layers, no laitance or grease stains, no honeycombing or pitted surface. If necessary, clean away unwanted surface or unevenness with a grinding wheel. The repaired or polished surface shall have no residues or remaining debris.

③A measurement area shall be no more than 200mm × 200mm. There shall be 16 test points on each measurement area. The distance between two adjacent test points shall not be less than 30mm. The distance of a test point to an edge or joint shall not be less than 200mm.

3.2 Test procedure

(1) Rebound value test

During the testing process, the axis of the rebound tester shall be kept perpendicular to the concrete surface. The operation shall meet the following requirements:

①Press the rebound-hammer of the rebound tester against the concrete surface, press it lightly to release the button, extend the rebound rod slowly and hang the hammer on the hook.

② Hold the rebound tester and press it slowly and evenly against the concrete until the rebound hammer is released from the hook and strikes the rebound rod. The rebound hammer moves the pointer to a position. The value indicated on the scale by the pointer is the rebound value of this point. The measuring point shall not be located over pores or exposed stones. Each test point will only be impacted once.

③ Use the method above, read and record in sequence the value of every impact. If it is difficult to obtain a value at a certain point, press the button and lock the core mechanism, move the rebound tester to another position to be able to read easily, with an accuracy of 1 unit.

④After the end of the tests, push the rebound rod into the instrument, tension it and then press down the button to lock the core mechanism for next time.

(2) Carbonation depth test

① After the rebound tests are completed, the carbonation depth shall be tested over representative test areas. The number of points to be tested for the carbonation depth shall be more than 30% of the number of test areas used for the rebound tests. Their average value is deemed as the carbonation depth of each test area. If the deterioration is severe and the value of the carbonation depth is over 2.0mm, every test area shall be tested separately for carbonation depth.

②For testing the carbonation depth, use appropriate tools to make a hole with a diameter about 15mm in the concrete surface (the depth shall be a little more than the carbonation depth). Use the rubber pipette bulb to blow away powder and debris (do not flush it with liquid). Then spray Phenolphthalein alcohol solution with a concentration of 1% to 2% over the wall of the hole. When the separation line between the carbonated and uncarbonated is clear (uncarbonated material turns purple), measure the vertical distance between the separation line to the concrete surface 3 times with a carbonation depth gauge or a Vernier caliper. Their average value is the carbonation depth, accurate to 0.5mm.

4 Data processing

4.1 From the 16 rebound tester values in a test area, remove the 3 maximum values and 3 minimum values. Evaluate the average rebound value of the remaining 10 points by equation T 0954-1.

$$\overline{N}_s = \frac{\Sigma N_i}{10} \qquad (T\ 0954\text{-}1)$$

Where:

N_s—average value of a test area, accurate to 0.1, dimensionless ;

N_i—the rebound value at the point i.

4.2 In case the axis of rebound tester during testing is not in horizontal, the rebound value shall be corrected based on the measured rebound value and the angle between its test axis and the horizontal. When testing a cement concrete pavement where the test axis is vertically downward, the test angle shall be taken as −90°. The correction value ΔN is shown in Table T 0954-1.

$$\overline{N} = N_s + \Delta N \qquad (T\ 0954\text{-}2)$$

where:

N_s—tested average value of a test area before being corrected

ΔN—correction to a tested average value for a non-horizontal test. It can be read from Table T 0954-1 or it can be obtained by linear interpolation from the values in Table T 0954-1, accurate to 0.1.

Table T 0954-1 Rebound correction value for non-horizontal test

$\overline{N}_s$	The angle between test axis and horizontal							
	+90°	+60°	+45°	+30°	−30°	−45°	−60°	−90°
20	−6.0	−5.0	−4.0	−3.0	+2.5	+3.0	+3.5	+4.0
30	−5.0	−4.0	−3.5	−2.5	+2.0	+2.5	+3.0	+3.5
40	−4.0	−3.5	−3.0	−2.0	+1.5	+2.0	+2.5	+3.0
50	−3.5	−3.0	−2.5	−1.5	+1.0	+1.5	+2.0	+2.5

Note: α-the angle between test axis and the horizontal. Ns combinations not listed in the table, may be determined by linear interpolation.

4.3 Calculate the average carbonation depth from equation T 0954-3

$$L = \frac{1}{n}\sum_{i=1}^{n} L_i \qquad (T\ 0954\text{-}3)$$

where:

L—(average) carbonation depth (mm)

L_i—carbonation depth at point i (mm);

n—number of test points

If the average carbonation depth is 6.0mm or more, take the depth value as 6.0mm.

4.4 Concrete strength calculation

Use the following method to convert the rebound value into concrete strength:

(1) If conditions permit, a strength measurement curve can be established by testing. A strength measurement curve is only applicable to concretes with the same material quality, molding, curing and age. The standard test cube of 150mm × 150mm × 150mm, with 5 cement/water ratios being 1.5, 、1.75, 、2.0, 、2.25、, 2.50 respectively is used to obtain at least 30 pairs of data. Test specimens shall have similar curing conditions as the concrete being evaluated. When the test age is reached, the test block shall be pressed with a pressure of 30 to 50 kN and kept steady. Use rebound tester to test 8 points on each of two side faces. Calculate the average rebound value from equation T 0954-1. After that, perform the cube crushing test. A correlation equation can be developed by the least squares method. The correlation equation may be linear or curved, but the correlation coefficient must be at least 0.95. This will allow the concrete strength to be calculated from the strength measurement curve based on the rebound value of a test area.

(2) When it is not possible to build a strength measurement curve, the compressive strength of a test area can be read from Table T 0954-2 based on its average rebound value and average carbonation depth.

Table T 0954-2 Conversion table of concrete compressive strength of a test area

Average rebound value	R_i (MPa) Concrete compressive strength of a test area (MPa)												
	$\bar{L}$ (mm) Average carbonation depth (mm)												
	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	≥6
20	10.3	10.1											
21	11.4	11.2	10.8	10.5	10.0								
22	12.5	12.2	11.9	11.5	11.0	10.6	10.2						
23	13.7	13.4	13.0	12.6	12.1	11.6	11.2	10.8	10.5	10.1			
24	14.9	14.6	14.2	13.7	13.1	12.7	12.2	11.8	11.5	11.0	10.7	10.4	10.1
25	16.2	15.9	15.4	14.9	14.3	13.8	13.3	12.8	12.5	12.0	11.7	11.3	10.9
26	17.5	17.2	16.6	16.1	15.4	14.9	14.4	13.8	13.5	13.0	12.6	12.2	11.6
27	18.9	18.5	18.0	17.4	16.6	16.1	15.5	14.8	14.6	14.0	13.6	13.1	12.4

continue

Average rebound value	R_i (MPa) Concrete compressive strength of a test area (MPa)												
	$\overline{L}$ (mm) Average carbonation depth (mm)												
	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	≥6
28	20.3	19.7	19.2	18.4	17.6	17.0	16.5	15.8	15.4	14.8	14.4	13.9	13.2
29	21.8	21.1	20.5	19.6	18.7	18.1	17.5	16.8	16.4	15.8	15.4	14.6	13.9
30	23.3	22.6	21.9	21.0	20.0	19.3	18.6	17.9	17.4	16.8	16.4	15.4	14.7
31	24.9	24.2	23.4	22.4	21.4	20.7	19.9	19.2	18.4	17.9	17.4	16.4	15.5
32	26.5	25.7	24.9	23.9	22.8	22.0	21.2	20.4	19.6	19.1	18.4	17.5	16.4
33	28.2	27.4	26.5	25.4	24.3	23.4	22.6	21.7	20.9	20.3	19.4	18.5	17.4
34	30.0	29.1	28.0	26.8	25.6	24.6	23.7	23.0	22.1	21.3	20.4	19.5	18.3
35	31.8	30.8	29.6	28.0	26.7	25.8	24.8	24.0	23.2	22.3	21.4	20.4	19.2
36	33.6	32.6	31.2	29.6	28.2	27.2	26.2	25.2	24.5	23.5	22.4	21.4	20.2
37	35.5	34.4	33.0	31.2	29.8	28.8	27.7	26.6	25.9	24.8	23.4	22.4	21.3
38	37.5	36.4	34.9	33.0	31.5	30.3	29.2	28.1	27.4	26.2	24.8	23.6	22.5
39	39.5	38.2	36.7	34.7	33.0	31.8	30.6	29.6	28.8	27.4	26.0	24.8	23.7
40	41.6	39.9	38.3	36.2	34.5	33.3	31.7	30.8	30.0	28.4	27.0	25.8	25.0
41	43.7	42.0	40.2	38.0	36.0	34.8	33.2	32.3	31.5	29.7	28.4	27.1	26.2
42	45.9	44.1	42.2	39.9	37.6	36.3	34.9	34.0	33.0	31.2	29.8	28.5	27.5
43	48.1	46.2	44.2	41.8	39.4	38.0	36.6	35.6	34.6	32.7	31.3	29.8	28.9
44	50.4	48.4	46.4	43.8	41.3	39.8	38.3	37.3	36.3	34.3	32.8	31.2	30.2
45	52.7	50.6	48.5	45.8	43.2	41.6	40.1	39.0	37.9	35.8	34.3	32.7	31.6
46	55.0	52.8	50.6	47.9	45.2	43.5	41.9	40.8	39.7	37.5	35.8	34.2	33.1
47	57.5	55.2	52.9	50.0	47.2	45.2	43.7	42.6	41.4	39.1	37.4	35.6	34.5
48	60.0	57.6	55.2	52.2	49.2	47.4	45.6	44.4	43.2	40.8	39.0	37.2	36.0
49		60.0	57.5	54.4	51.3	49.4	47.5	46.2	45.0	42.5	40.6	38.8	37.5
50			59.9	56.7	53.4	51.4	49.5	48.2	46.9	44.3	42.3	40.4	39.1
51				59.0	55.6	53.5	51.5	50.1	48.8	46.1	44.1	42.0	40.7
52					57.8	55.7	53.6	52.1	50.7	47.9	45.8	43.7	42.3
53					60.0	57.8	55.6	54.2	52.7	49.8	47.6	45.4	43.9
54						60.0	57.8	56.3	54.7	51.7	49.4	47.1	45.6
55							59.9	58.4	56.8	53.6	51.3	48.9	47.3
60												58.3	56.4

Note: This conversion table is applicable to concrete with an age greater than 14 days. The range of compressive strength is between 10 and 60 MPa. Intermediate values can be determined by linear interpolation.

(3) According to the method stated in Appendix B, calculate the average compressive strength of concrete for all the test areas, the standard deviation and coefficient of variation.

5) Report

The test report of this method shall include the following technical content:

(1) Information of the test positions (test points, the number of test areas)

(2) Strength measurement curve, the correlation equation between rebound value and compressive strength, coefficient of correlation.

(3) Rebound value, and calculated compressive strength.

(4) Average value of concrete compressive strength, the standard deviation and coefficient of variation.

Background:

By referring to 'Technical Specification for Testing Concrete Compressive Strength by Rebound Method' (JGJ/T 23—2011) of the Ministry of Housing and Urban-Rural Development, and conforming to the principle of uniformity in revising JTG standards, parts of the former versions of this method were revised. In this revision, the requirement that concrete strength shall be calculated with equation T 0954-4 is cancelled. This means that if there is insufficient test data or the correlation equation is not satisfactory, then the concrete (non-pumped) strength can be read from Table T 0954-2. For pumped concrete, the strength can be calculated as given in the method in Appendix B of 'Technical Specification for Testing Concrete Compressive Strength by Rebound Method' (JGJ/T 23—2011).

$$R = 0.025\overline{N}^2 \tag{T 0954-4}$$

where:

R—compressive strength of cement concrete (MPa);

$\overline{N}$—rebound value of test areas

For the rebound tester method, the rebound tester and the steel anvil for calibration shall be well maintained and regularly checked.

(1) Generally, when one of the following situations exist, the rebound tester shall be calibrated by a legal verification institute which will be valid for six months

①*A new rebound tester which is being used for the first time.*

②*One of the main parts is replaced. The main parts include spring seat, rebound rod, buffer spring, center guiding rod, guiding flange, rebound hammer, pointer axis, pointer hand, pointer block, hook and zero adjustment screw.*

③ The head of the bounce tension spring is not at the initial position of its seat or zero adjustment screw is loose.

④For a rebound tester with a digital display, if the difference between rebound values read from the digital display and from the pointer indication is more than 1.

⑤The calibration value against the steel anvil after being maintained is not correct.

⑥Suffered severe impact or other damage.

(2) When the rebound tester has one of following conditions, maintenance is required.

①The rebound tester has bounced more than 2000 times.

②The rating on the steel anvil is not correct.

③The test values are in doubt.

(3) The maintenance of the rebound tester can be carried out as follows:

①Firstly, unhook the rebound hammer from the hook, take out the core mechanism, then remove the rebound rod and take out the buffer spring inside it, then take out the rebound hammer, bounce tension spring and spring seat.

②Clean each part of the core mechanism, especially the center guiding rod, rebound hammer and the inner holes and impacting surface of the rebound rod. After this, apply a thin layer of watch oil over the center guiding rod; other parts shall not be oiled.

③Clean the inner wall of the shell of the rebound tester, remove the scale, and check the pointer. The friction force shall be 0.5 to 0.8N.

④For a digital rebound tester, maintenance shall be according to the product manual.

⑤During maintenance, do not rotate the tightened zero adjustment screw. Do not use self-made parts or non-original parts from other sources to replace original parts.

⑥The rebound tester shall be calibrated after maintenance.

After using the rebound tester extend the rebound rod out of the casing and remove dirt and dust from the *rod and the spherical surface, the surface of the scale and the outer shell. When the rebound tester is not in use, press the rebound rod into the casing, press the button on the hook to lock the movement. Then load it into the equipment case. The equipment case shall be placed in a dry and cool place. If an rebound tester has a digital display, remove the battery if it will not be used soon.*

T 0955—2019 Flexural strength of cement concrete tested by ultrasonic-rebound method

1 Scope of application

1.1 This method is suitable for the rapid testing of a cement concrete pavement in the field by means of an rebound tester and ultrasonic tester by using a strength measurement curve to evaluate the flexural strength of cement concrete. It shall not be used as evidence for arbitration, or as criteria for acceptance inspection.

1.2 This method is not suitable for cement concrete in the following situations:

(1) Concealed or exposed local defective areas.

(2) Area with cracks or micro-cracks (including concrete near expansion joints or construction joints)

(3) Part of a pavement with steel corner bars or edge bars, especially in an area where the direction of the ultrasonic wave is in line with the steel bars.

(4) An area within 100mm from an edge.

2 Technical requirements for instruments and materials

(1) Ultrasonic tester: It has good stability, with a display screen and a manual cursor reading function. The display shall be clear and stable, with the range of acoustic time between 0.5 and 9999μs and the test accuracy of 0.1μs. When the display of acoustic time is modulated in the range of 20 to 30μs, its drift within 2h shall not be more than ±0.2μs. Comparing the error between the calculated sound velocity in air and measured sound velocity shall be within ±0.5%.

(2) Transducer: It consists of a piezoelectric material with a thickness vibration mode. The frequency range is within 50 and 100 kHz. The difference between the measured frequency and nominal frequency shall not be more than ±10%.

(3) Coupling agent: a material which can be easily deformed, has a large acoustic resistance and good viscosity but does not flow. Generally, yellow wax oil or Vaseline petroleum jelly can be used.

(4) Rebound tester: shall conform to the requirements in T 0954 of this method.

(5) Handheld grinder

(6) Others: grease cleaning agent, brush, cleaning cloths.

3 Method and procedures

3.1 Preparation

(1) Ensure that the density of the cement concrete is in the range of 1.9 to 2.5g/cm^3. The thickness of the pavement slab shall be greater than 100mm. The age of the concrete shall be more than 14 days. The strength shall be greater than 80% of the design strength. The ambient temperature shall be between −4 and 40℃.

(2) Calibrate the rebound tester in accordance with T 0954 of this method.

(3) Layout of measuring areas and measuring points

①Determine the concrete slab to be tested according to the method stated in T 0902 of this Standard. Ten test areas shall be arranged evenly over a slab with each test area having a size greater than 150mm × 550mm. The test surface shall be clean, dry and even, without defects such as honeycombing or pitting. Laitance and grease stains and rough areas shall be cleaned away or polished by a grinder. Then wipe off residual dust.

②The test points shall be evenly arranged in a test area, but not located on pores or exposed stones, as shown in Figure T 0955-1. The distance between two adjacent test points shall not be less than 30mm.

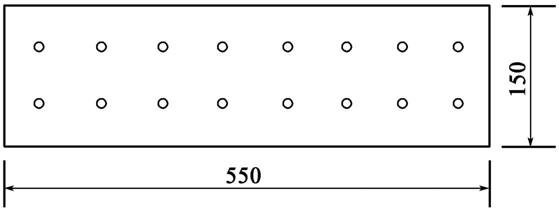


Figure T 0955-1　The test point arrangement for rebound measurements(units mm)

3.2　Test procedure

(1) As described in T 0954 of this method, use the rebound tester to test 16 test points in each test area to measure the rebound values.

(2) Ultrasonic wave time measurement

①Arrange 3 measuring axis lines (as shown in Fig. T 0955-2) in each test area where the rebound test was performed in order to arrange the transducers.

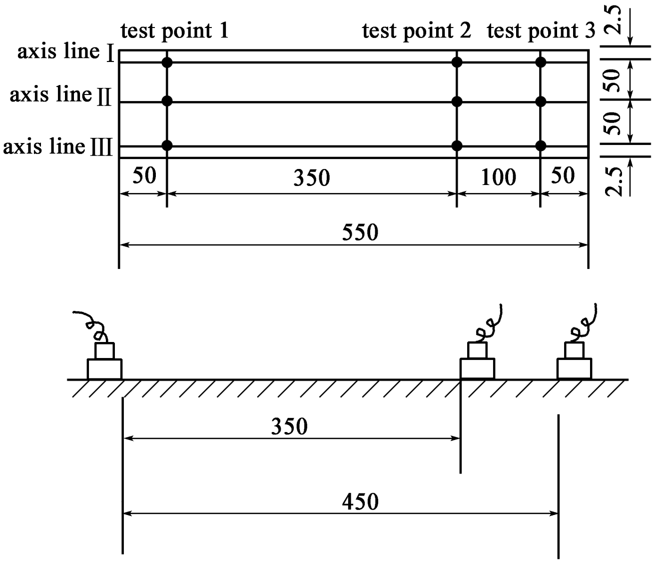


Figure T 0955-2　The arrangement of transducers (unit: mm)

②Spread the coupling agent over the points where the transducers are to be seated. The coupling agent for testing ultrasonic wave time shall be same as was used for building the strength measurement curve.

③Seat the transducers at Point1 and Point2 on the axis line I, in intimate contact with the concrete and has a good connection. These transducers are for emitting and for receiving. The centerline of the diameter shall be in line with the test axis line and their edges shall be in tangential contact with the distance measuring lines. Adjust the ultrasonic tester amplitude to the specified 25 to 30mm. The ultrasonic time measured is t11, with a precision of 0.1μs.

④The transducer at Point1 remains in position, but the transducer at Point2 moves to Point3. The ultrasonic time measured then becomes t12, with a precision of 0.1μs.

⑤Continue with the measuring axis line II and III with the above method and the ultrasonic time measured is t21, t22, t31, t32.

4 Data processing

4.1 By using equations T 0955-1、T 0955-2、T 0955-3 and T 0955-4 calculate the velocity of the ultrasonic waves, accurate to 0.01km/s:

$$v_{i1} = \frac{350}{t_{i1}} \quad \text{(T 0955-1)}$$

$$v_{i2} = \frac{450}{t_{i2}} \quad \text{(T 0955-2)}$$

$$v_i = \frac{1}{2}(v_{i1} + v_{i2}) \quad \text{(T 0955-3)}$$

$$v = \frac{v_1 + v_2 + v_3}{3} \quad \text{(T 0955-4)}$$

Where:

v_{i1}—the velocity at axis line i, between Point1 and Point2 with a distance of 350mm apart (km/s), i = 1 to 3;

v_{i2}—the velocity at axis line i, between Point1 and Point3 with a distance of 450mm apart (km/s), i = 1 to 3;

v_i—the average velocity at axis line i (km/s), i = 1 ~ 3;

V—the average velocity of the test area (km/s);

t_{i1}—ultrasonic time at axis line i with a distance of 350mm (μs);

t_{i2}—ultrasonic time at axis line i with a distance of 450mm (μs);

Should the average velocities of two out of three axis lines differ by 15% or more from the average velocity of their test area, the results of this test area are invalid. Select a new test area to repeat the test.

4.2 Calculation of the flexural strength of concrete

(1) Determine special strength measurement curve

Use the same raw materials as used in the concrete pavement to design several concrete mixes with different cement/water ratios (normally 4 mixes, including one which is the same as the mix of the concrete pavement). Prepare at least 6 beam specimens with a size of 150mm × 150mm × 550mm from each mix. Cure them for 28 days under standard conditions. Then perform ultrasonic and rebound tests as already described. Thereafter, perform the flexural strength test according to the 'Highway Engineering Cement and Cement Concrete Test Methods (JTG E30—2005). Then use the nonlinear equation to do the regression from equation T 0955-5 to determine regression coefficients and obtain a strength measurement curve. Its relative standard error 'e_r' shall not be more than 12%

$$R_f = av^b e^{cN} \qquad (T\ 0955\text{-}5)$$

where:

R_f—concrete flexural strength (MPa);

V—velocity of ultrasonic wave (km/s);

N—rebound value;

e—natural logarithm;

a、b、c—regression coefficients;

The relative standard error is calculated from equation T 0955-6:

$$e_r = \sqrt{\frac{\sum_{i=1}^{n}(R'_{fi}/R_{fi} - 1)^2}{n-1}} \times 100 \qquad (T\ 0955\text{-}6)$$

where:

e_r—relative standard error (%);

R'_{fi}—measured flexural strength of specimen i (MPa);

R_{fi}—calculated flexural strength of specimen I by ultrasonic and rebound test (MPa);

n—the number of specimens (counting each specimen as a block)。

(2) Calculate the flexural strength of the concrete pavement

①Each strip of pavement from each road section (or sub-section) is a unit for flexural strength evaluation.

②The first and second requirements for evaluating flexural strength is calculated by equations T 0955-7and T 0955-8

$$R_{n1} = 1.18(\overline{R}_n - m \cdot S_n) \qquad (T\ 0955\text{-}7)$$

$$R_{n2} = 1.18(R_{fi})_{\min} \qquad (T\ 0955\text{-}8)$$

where:

R_{n1}—first requirement for flexural strength (MPa), accurate to 0.1MPa;

R_{n2}—second requirement for flexural strength (MPa), accurate to 0.1MPa;

S_n—standard deviation of flexure strength (MPa), calculated from equation T 0955-9, accurate to 0.1MPa;

$$S_n = \sqrt{\frac{\sum (R_{fi})^2 - n(\overline{R_n})^2}{n-1}} \quad (T\ 0955\text{-}9)$$

where:

$\overline{R_n}$—average flexural strength (MPa), calculated from equation T 0955-10, accurate to 0.1MPa;

$$\overline{R_n} = \frac{1}{n}\sum R_{fi} \quad (T\ 0955\text{-}10)$$

n—number of test points;

m—coefficient for qualification determination, when $n = 10$ to 14, $m = 1.70$; when $n = 15$ to 24, $m = 1.65$; when $n \geqslant 25$, $m = 1.60$。

$$R_N = \min\{R_{n1}, R_{n2}\} \quad (T\ 0955\text{-}11)$$

Where:

R_N—rated value for concrete flexural strength (MPa), accurate to 0.1 MPa.

(3) Using equation T 0955-11, take the smaller value from the first requirement and the second requirement to be taken as the value for the concrete flexural strength.

5 Report

The report of this method shall include the following technical content:

(1) Information about the test positions (test location, number of test areas)

(2) Strength measurement curve, average flexural strength, standard deviation, the first and second requirements for flexural strength, evaluated flexure strength

***Background*:**

For measuring the flexural strength of a cement concrete pavement by ultrasonic method, the strength measurement curve shall be developed from equation T 0955-5. If it is difficult to build such a curve by this method, the strength can be calculated from equations T 0955-12 or T 0955-13, but it shall be verified. The number of specimen for verification shall not be less than 10 groups (each group has 3 specimens). Allow the specimens to cure for 28 days under standard conditions, then perform ultrasonic and rebound tests on them. The flexural strength R_f *can be calculated from equation T 0955-12 or T 0955-13. Then perform the flexural strength test to obtain the actual flexure strength* R'_f *by following 'Highway Engineering Cement and Cement Concrete Test Methods' (JTG E30—2005). Input the value of* R'_f *into equation T 0955-6 to calculate the relative error 'er'. If 'er' ≤14%, these two* *equations can be used.*

(*1*) *when cement isslag cement*

$$R_{\mathrm{f}} = kv^{0.2348} e^{0.02646N} \qquad (\mathrm{T}\ 0955\text{-}12)$$

(*2*) *when cement is Portland cement*:

$$R_{\mathrm{f}} = kv^{0.3541} e^{0.02334N} \qquad (\mathrm{T}\ 0955\text{-}13)$$

when cement isslag cement:

$$k = \frac{\sum R'_{\mathrm{fi}} v_i^{0.4048} e^{0.02646N_i}}{\sum v_i^{0.4096} e^{0.05292N_i}} \qquad (T\ 0955\text{-}14)$$

when cement is Portland cement:

$$k = \frac{\sum R'_{\mathrm{fi}} v_i^{0.3541} e^{0.02334N_i}}{\sum v_i^{0.7082} e^{0.04668N_i}} \qquad (\mathrm{T}\ 0955\text{-}15)$$

where:

N_i—corrected rebound value of specimen i

After verification (*specimens for verification shall not be less than 10 groups with each group having 3 specimens*) ,*if* ‘*er*’ ≤*14%* ,*equations T 0955-16 or T 0955-17 can be used directly for calculation.*

(*1*) *when cement is slag cement*:

$$R_{\mathrm{f}} = 1.39v^{0.2348} e^{0.02646N} \qquad (\mathrm{T}\ 0955\text{-}16)$$

(*2*) *when cement is Portland cement*:

$$R_{\mathrm{f}} = 1.22v^{0.3541} e^{0.02334N} \qquad (\mathrm{T}\ 0955\text{-}17)$$

T 0958—2019 Strength of cement concrete pavement by testing sampled cores

1 Scope of application

This method is suitable to evaluate the strength of a cement concrete pavement by taking cores from the pavement to check the splitting tensile strength and compressive strength.

2 Technical requirements for instruments and materials

(1) Pavement core drill: manual type or vehicle mounted type, ϕ150mm core bit with water

cooling facilities.

(2) Vernier caliper : measuring range not less than 200mm with its graduations being 0.02mm

(3) Steel tape: measuring range not less than 5m with its graduations being 1mm

(4) Universal angle ruler: division value being 2′.

(5) Feeler gauge: minimum graduation value 0.02mm

(6) Steel ruler: length not less than 300mm

(7) Concrete crushing machine: conform to specifications given in T 0551 of ' Highway Engineering Cement and Cement Concrete Test Methods' (JTG E30—2005)

(8) Sample holder: conform to specifications given in T 0561 of ' Highway Engineering Cement and Cement Concrete Test Methods' (JTG E30—2005)

(9) Others: diamond saw, manual grinder, shovel and brush.

3 Testing procedures

3.1 Preparation

(1) Determine test locations by following the method stated in T 0902 of the Standard.

(2) Clean the test locations by removing dust.

3.2 Testing procedure

(1) Take core samples by following method T 0903 of the Standard.

(2) Process core samples as described below:

①For the splitting tensile test, core samples shall have a diameter of 150mm. For the crushing test, core samples shall also have a diameter of 150mm, and the ratio of height to diameter is 1:1.

② The core may not contain steel bars or steel fibers.

③After the core samples have been cut, their ends shall be polished with a grinder.

④ Measure the size of the prepared core samples as follows:

a. Use a Vernier caliper to measure the diameters of the core in two perpendicular directions at both ends and in the middle of the core. The average is the diameter of core, accurate to 0.5mm.

b. Use a Vernier caliper to measure the distance between two ends of the core from four positions which form two perpendicular diameters. The average is the height of the core, accurate to 0.5mm.

c. Use a universal angle ruler to check the angles between the two end faces, with precision to 0.1°.

d. Place a steel ruler against the pressure bearing surface of the core sample, and use a feeler gauge to check the gap between the steel ruler and the pressure bearing surface of the core. The maximum gap is considered as the evenness of the core sample.

⑤ When the core sample dimensions exceed the value listed below, the corresponding test data is invalid:

a. The actual ratio of height/diameter is less than 0.95 or more than 1.05,

b. The difference between any diameter along the range of the core height and the average is greater than 2mm,

c. One or both faces of the core has a misalignment with the axis greater than 1°,

d. The unevenness is greater than 0.1mm over a length of 100mm.

(3) Perform the splitting tensile test on the prepared core sample by following the requirements stated in 'Highway Engineering Cement and Cement Concrete Test Methods' (JTG E30—2005)

(4) Perform the crushing test on the prepared core sample by following the requirements stated in 'Highway Engineering Cement and Cement Concrete Test Methods' (JTG E30—2005)

4 Data processing

4.1 Splitting tensile strength of core sample f_{ct} is to be calculated using equation T 0958-1

$$f_{ct} = \frac{2F}{\pi d_m \times l_m} \qquad (T\ 0958\text{-}1)$$

Where:

f_{ct}—splitting tensile strength of core sample(MPa)

F—failure load (N)

d_m—average diameter of core sample(mm);

l_m—average length of core sample(mm)。

4.2 Compressive strength of core sample f_{cu} is to be calculated by using equation T 0958-2

$$f_{cu} = \frac{F}{A} \qquad (T\ 0958\text{-}2)$$

Where

f_{cu}—compressive strength of core sample (MPa)

F—failure load(N)

A—cross-sectional area of core sample(mm^2)

4.3 The test values for strength and the rejection principle for abnormal data are as follows: take the average of the measured value of 3 samples is considered as the test value accurate to 0.01 MPa. If the difference between the maximum or minimum value and the middle value has a deviation of more than 15%, the middle value is taken as the test value. In case both samples have deviations over 15% to the middle value, the data of this test group is invalid.

The results of splitting tensile strength shall be accurate to 0.01MPa. The results of compressive strength shall be accurate to 0.1MPa

5 Report

The report of this method shall include the following technical content:

(1) The information of the test locations (test positions and number of test areas).

(2) Information of core samples and their curing conditions.

(3) The values of splitting tensile strength and compressive strength.

Background:

This method is compiled by referring to 'Technical specification for testing concrete strength with drilled core method' (CECS 03:2007)、'Highway Engineering Cement and Cement Concrete Test Methods'

(JTG E30—2005)、'Specifications for design of highway cement concrete pavement' (JTG D40—2011) and 'Technical guidelines for construction of highway cement concrete pavement' (JTG/T F30—2014). There are some differences in these specifications regarding coring method for testing splitting strength.

Two problems were encountered during theinvestigation and revision stage for compiling this method.

(1) One is the ratio of height/diameter. In CECS 03:2007, it specifies a minimum diameter of core sample is 100mm, with a ratio of height/diameter being 1:1. In JTG E30—2005, it specifies minimum diameter is 100mm, with a ratio of height/diameter being 2:1. In JTG/T F30, it specifies that a minimum diameter is 150mm, with a ratio of height/diameter being 1:1. Theoretically, the splitting tensile strength of a material shall be independent of sample size or ratio of height/diameter. But the results of test samples are affected by the boundary conditions, the compositional uniformity and loading speed. There are thus likely discrepancies. Just like a standard concrete cube testing block has a size of 150mm, the diameter of a core is specified as 150mm in this method. The ratio of height/ diameter is specified as 1:1 by considering that the ratio of 2:1 is sometimes unrealistic as it is restricted by the pavement thickness or steel reinforcing.

(2) The other problem is how to unify the conversion equation between splitting tensile strength and compressive strength. As they are clearly specified in Clause 13.2.7 of 'Technical guidelines for construction of highway cement concrete pavement' (JTG/T F30—2014), no explanation is given here as JTG/T F30 can be used as reference.

From the specifications of Clause 13.2.7 of 'Technical guidelines for construction of highway cement concrete pavement' (JTG/T F30—2014), splitting tensile strength of a core sample taken from pavement, a splitting tensile strength of a cylinder sample and flexural strength of a standard beam sample, and the conversion equation between them are specified here as: (1) for motorway or the Class 1 highway, a regression equation for each project shall be developed by doing independent tests. The number of test groups to determine the regression equation shall not be less than 15. The cement content shall be varied in a range of ±50kg/m^3. If the concrete strengths satisfy the requirements for statistical analysis, the splitting strength of the core sample of φ150mm × 150mm taken from pavement, the cast cylinder sample of ϕ150mm × 150mm and cast cube sample of 150mm × 150mm × 150mm shall be considered the same if they have a same age. For a Class 2 highway and lower, the splitting strength of a core sample taken from the pavement can be converted to flexural strength of a standard beam by using the following equations, based on the aggregate rock type:

Concrete made with limestone or granite aggregate

$$f_c = 1.868 f_{sp}^{0.871} \quad \text{(T 0958-3)}$$

Concrete made with basalt aggregate

$$f_c = 3.035 f_{sp}^{0.423} \qquad (\text{T } 0958\text{-}4)$$

Gravel concrete

$$f_c = 1.607 + 1.035 f_{sp} \qquad (\text{T } 0958\text{-}5)$$

where:

f_c—concrete flexural strength of standard beam (MPa);

f_{sp}—the splitting tensile strength of concrete core sample from pavement (MPa).

9 Skid Resistance Performance

T 0961—1995 Surface texture depth of a pavement tested by the sand patch method

1 Applicable scope

This method is suitable for testing the surface texture depth of an asphalt pavement and cement concrete pavement without grooves which is used to evaluate the skid resistance performance of the pavement surface.

2 Technical requirements for instruments and materials

(1) Manual sand patch instrument: It is composed of a sand measuring cylinder and a spreader disc. The detailed technical requirements are as follows:

①Sand measuring cylinder: The shape and size is shown in Figure T 0961-1. The one end is closed, and the volume is 25 ± 0.15 mL. The volume (V) can be determined by weighing the water in the cylinder, and its height can be adjusted in order to meet the specified volume requirements. A special scraper is used for scraping the sand which must be leveled and smooth at the cylinder mouth.

②Spreader disc: The shape and size are shown in Figure T 0961-2. The spreader disc shall be made of wood or aluminum, with a diameter of 50mm. A 1.5mm thick rubber pad is glued to the bottom. A cylindrical handle is fixed to the upper part of the disc.

(2) Measuring sand: sufficient quantity of dry and clean uniform sand with a particle size of 0.15 to 0.30 mm shall be used.

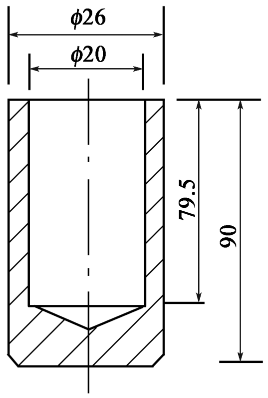


Figure T 0961-1 Sand measuring cylinder (unit: mm)

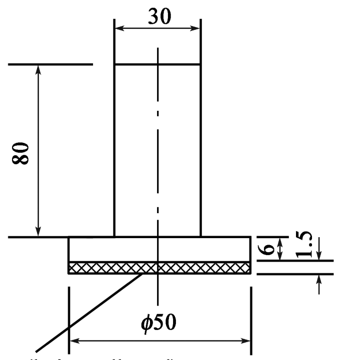


Figure T 0961-2 Spreader disc (unit: mm)

(3) Measuring ruler: steel ruler or special texture depth ruler.

(4) Others: spatula to fill the cylinder, broom or brush, a shield to control the wind.

3 Method and procedures

3.1 Preparation

(1) Preparation of measuring sand: Sieve clean fine sand after air drying. The sand must pass the 0.30 mm sieve and be retained on the 0.15 mm sieve. After sieving, place it in a proper container for later use. During the test, the measuring sand can only be used once and shall not be reused unless the material has been sieved again.

(2) Select the test positions (cross sections) at which test points shall be selected as described in T 0902 of JTG 3450—2019. The test points shall be selected in the wheel paths and more than 1m away from the pavement edge.

3.2 Test procedure

(1) Clean an area of not less than 30cm × 30cm on the pavement around the test point with a broom or brush.

(2) Place the prepared measuring sand into the cylinder with a small spatula until it is heaped up over the cylinder in a cone shape. Lift the cylinder by hand holding its upper part. Tap the cylinder 3 times with a steel ruler in the middle, and use a scraper to scrape and level the cylinder mouth in one operation.

Note: Do not use the sand cylinder to scoop themeasuring sand so as to not affect the uniformity of the sand density.

(3) Pour the sand over the road surface in a small pile. Repeatedly spread the sand from the inside to the outside into a circular shape with a spreader disc, and evenly spread the sand outwards by pressing slightly so that the sand fills the voids on the road surface. There shall be no sand above the highest points on the surface. Be careful not to exert excessive force or squeeze the sand outwards.

(4) Use a steel ruler to measure two perpendicular diameters across the circle of sand, and obtain their average value with an accuracy of 1mm. A special meter can also be used to directly measure the texture depth.

(5) Repeat the above method to obtain 3 test results in the same test area. All three measuring points shall be located in the wheel paths and the distance between the measuring points is 3 to 5 m. All tests in one area shall be carried out by the same technician. The test area location is referenced by the position of the middle test point.

4 Data processing

4.1 The result of thetexture depth test is calculated according to equation T 0961:

$$TD = \frac{1000V}{\pi D^2/4} = \frac{31831}{D^2} \qquad (T\ 0961)$$

In which:

V—the volume of sand (25cm^3);

D—the average diameter of the sand patch (mm).

4.2 For each testposition, take the average value of the 3 measured pavement texture depths as the test result with an accuracy of 0.01mm. If the average value is less than 0.2mm, the test result is expressed as <0.2mm.

4.3 As described in Appendix B ofJTG 3450—2019, calculate the average value, standard deviation, and coefficient of variation of the texture depth of each test section.

5 Report

The following technical information shall be included in the report:

(1) Test section information (stake number, test location, etc.).

(2) Texture depth.

(3) The average value, standard deviation and coefficient of variation of texture depth of the road section tested.

***Background*:**

The texture depth (TD) of the pavement surface is used to indicate the macrotexture of the road surface. The texture depth and the friction coefficient are both technical indicators for evaluating the skid resistance performance of a road surface. However, they have different practical implications and these two indicators cannot replace each other. Both the manual sand patch method and the electric sand patch method described in T 0962 use fine sand with controlled particle size spread over a road surface and the average depth is calculated based on the ratio of the sand volume which has filled the macrotexture on the surface to its spread area. This is a commonly used method in current engineering practice.

For the sand and measuring cylinder used in the sand patch method, the Japanese Paving Test Method Manual Section 7-7 requires that 50cm^3 sand of 0. 15 to 0. 30 mm shall be used for coarse textured surfaces while 10cm^3 sand of 0. 075 to 0. 15 mm shall be used for fine textured surfaces. Theoretically this process is more reasonable, so that the spread area of sand will not be too small or too large, but it is not easy to master in practice. To prevent confusion, China has adopted sand of 0. 15 to 0. 3 mm particle size and a cylinder with a volume of 25cm^3.

There are many reasonsthat test results may have large errors in the manual sand-patch method. For example, there is no quantitative standard for filling sand into the cylinder and how to tap it. Many people use measuring cylinders to fill sand from the sand container. The forces used to tap the measuring cylinder are different. The density and the quantity of the sand in the measuring cylinder thus vary for these reasons. In addition, the patch execution process varies from person to person as they exert different forces. This edition gives an integrated and clear explanation in the relevant clauses.

T 0962—1995 Surface texture depth of a pavement tested by the electric sand patch method

1 Applicable scope

This method is suitable for testing the surfacetexture depth of an asphalt pavement and cement concrete pavement which is not grooved in order to evaluate the skid resistance performance of the pavement surface.

2 Technical requirements for instrument and material

(1) Electric sand patch tester: by using a rechargeable DC battery, it can place the measuring sand through the sand spreader into a patch which is uniform in thickness with a width of 5 cm. The details are shown in Figure T 0962-1.

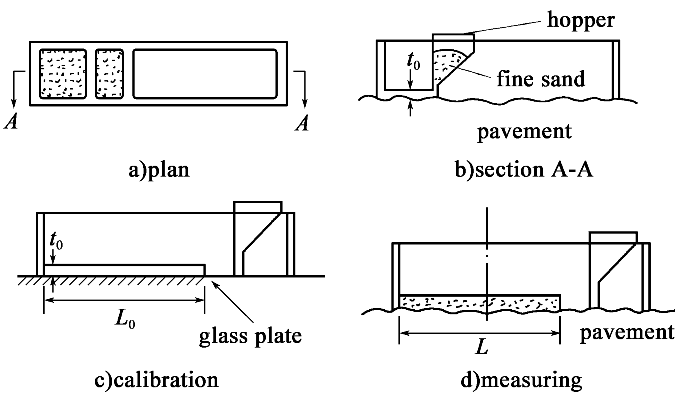


Figure T 0962-1 Electric sand patch tester

(2) Measuring sand: sufficient quantity of dry and clean homogeneous sand with a particle size of 0.15 to 0.30 mm.

(3) Standard measuring cylinder: 50mL in volume.

(4) Glass plate: Its area is larger than the sand patch tester and the plate thickness is not less than 5mm.

(5) Others: straight ruler, sand filling funnel, broom, brush.

3 Method and procedure

3.1 Preparation

(1) Preparation of measuring sand: Sieve clean fine sand after air drying. The sand must pass the 0.30 mm sieve and be retained on the 0.15 mm sieve. After sieving, place it in a proper container for later use. During the test, the measuring sand can only be used once and shall not be reused unless the material has been sieved again.

(2) Select the test positions (cross sections) at which test points shall be selected as described in T 0902 of JTG 3450—2019. The test points shall be selected in the wheel paths and more than 1m away from the pavement edge.

3.2 Calibration of the electric sand patch tester

(1) Place the sand patch tester on the glass plate and move the sand spreader to its starting position at one end of the sand patch tester.

(2) Place the sand filling funnelwith its nozzle at the level of the mouth of the measuring cylinder. Slowly fill the prepared measuring sand into the measuring cylinder through the funnel until it is heaped up above the measuring cylinder in the shape of a cone. Use a straight edge to level the mouth of the cylinder in one movement. The volume of the measuring cylinder is 50mL.

(3) Keep the funnel with its nozzle at the level of the mouth of hopper of the tester. Pour the sand evenly into the hopper through the funnel. Move the funnel back and forth during the pouring process to make the sand surface flat. It is not allowed to use any other tool to level the sand.

(4) Turn on the switch to let the hopper move slowly to the other end until all the sand is discharged so that the measuring sand is placed into a 50mm wide patch as shown in Figure T 0962-2.

(5) The patch length L0 of the measuring sand is determined by the average value of L1 and L2 and is calculated according to Figure T 0962-2 and equation T 0962-1 with an accuracy of 1mm.

$$L_0 = (L_1 + L_2)/2 \tag{T 0962-1}$$

In which:

L_0—the length of 50mL sand patch on the glass plate (mm);

L_1, L_2—paved length (mm) measured as shown in Figure T 0962-2.

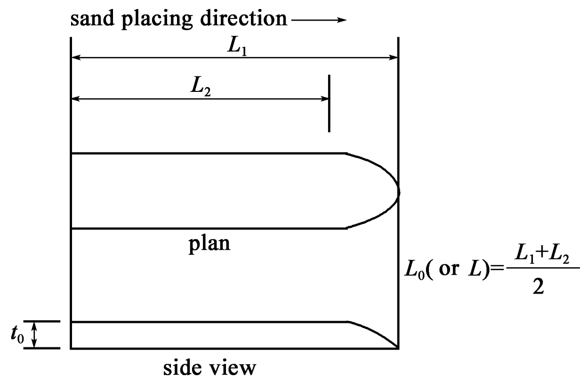


Figure T 0962-2 Method for determining L_0 and L

(6) Repeat the calibration test 3 times and take the average value to determine L_0 with an accuracy of 1mm. Calibration shall be performed before each test by using the same measuring sand and by the same technician.

3.3 Test procedure

(1) Clean the test site with a brush over an area larger than the sand patch tester.

(2) Place the sand patch tester on the road so that it is stable and in line with the longitudinal direction and move the hopper to its starting position.

(3) Follow the same steps as indicated in Clause 3.2(2) to (5), pave 50mL measuring sand over the test point and measure the paving lengths L_1 and L_2 as shown in Figure T 0962-2. Calculate L with equation T 0962-2) with an accuracy of 1mm.

$$L = (L_1 + L_2)/2 \qquad \text{(T 0962-2)}$$

Where:

L—the length of 50mL sand paved on the road surface (mm).

(4) Repeat the test at 3 test points in the same area in the wheel path. The distance between the test points shall be 3 to 5m. The test location is indicated by the position of its middle test point.

4 Data processing

4.1 Calculate the thickness t0 of the sand paved on the glass with equation T 0962-3

$$t_0 = \frac{V}{B \times L_0} \times 1000 = \frac{1000}{L_0} \qquad \text{(T 0962-3)}$$

where:

t_0—the calibrated thickness of sand paved on the glass plate (mm);

V—Volume of sand, 50mL;

B—The width of paved sand, 50mm.

4.2 Calculate thetexture depth TD with equation T 0962-4.

$$TD = \frac{L_0 - L}{L} \times t_0 = \frac{L_0 - L}{L \times L_0} \times 1000 \qquad (T\ 0962\text{-}4)$$

4.3 For each testposition, take the average value of the 3 measured texture depths as the test result with an accuracy of 0.01mm. If the average value is less than 0.2mm, the test result is expressed as <0.2mm.

4.4 As described in Appendix B ofJTG3450 – 2019, calculate the average value, standard deviation, and coefficient of variation of the texture depth of a test road section.

5 Report

The following technical information shall be included in the report:

(1) Test section information (stake number, test location, etc.).

(2) Texture depth,

(3) The average value, standard deviation and coefficient of variation of thetexture depth of the test road section.

***Background*:**

This method can avoid the shortcomings of the manual sand patch method where test results tend to be affected by human operational variations. However, the operational process of this method is more complicated than the manual sand patch method, thus it is not generally used in China.

Although the basic principle of the electric sand patch method is similar to that of the manual sand patch method, their methods are different. The manual method uses a fixed volume of sand to fill the macrotexture to calculate the average depth as the texture depth, while for the electric method the texture depth is obtained by comparing the paving length of the fixed volume of sand over the road surface with the paving length over the glass plate. Therefore, there is a difference between texture depths tested by the two methods and they shall be correlated for practical use.

The calibration of the electric sand patch method is important. To ensure the accuracy of the test results, *the same sand shall be used by the same technician in both calibration and main test processes.*

T 0966—2008 Surface texture tested by vehicle mounted laser sensor

1 Applicable scope

This method is suitable for using various vehicle mounted laser sensors continuously to measure the road surface texture depth for quality control on newly built or rebuilt roads or for collecting data under normal traffic conditions on a road without severe damage, accumulated water, snow or mud. However, it is not suitable on a grooved concrete road surface.

2 Technical requirements for instruments and materials

The test system consists ofa vehicle, distance measuring sensors, laser sensors and a main control unit. The dedicated software shall automatically control the processes of data collection, transmission, recording and data processing. The main technical requirements of the system are as follows:

(1) Maximum test speed of equipment : ≥50km/h.

(2) Sampling interval of equipment: ≤5mm.

(3) The error of the indicated elevation by sensor: ≤0.1mm.

(4) Distance calibration error: <0.1%.

3 Method and procedure

3.1 Preparation

(1) After thetest equipment is installed on the vehicle, a correlation test shall be performed as described in Clause 4 of this method.

(2) Allow the laser sensors of the test system perform a self-calibration.

(3) When installing the distance measuring sensors on site, ensure that the bolts or screws are tightened firmly.

(4) Switch on the power of the test system and start the control program. Check the operational status of each part and allow the test system to warm up.

3.2 Test procedure

(1) Stop the vehicleabout 50 to 100 m ahead of the start point, start the data collection program and set the test mode as required for the site technical conditions.

(2) The driver shall drive the vehicle within the specified speed range and avoid rapid acceleration or deceleration. The speed needs to be reduced on sections with sharp curves. The vehicle shall be driven into the test section along the normal wheel paths.

(3) On entering the test section, the operator shall start the data acquisition and recording procedure of the control unit. During the test, the start and end points of the test section and other location information shall be input into the test data record in an accurate manner.

(4) At the end of the test section, the operatorshall stop data collection and recording and restores all parts of the equipment to their initial states.

(5) Check the test data file. It shall be complete and its content shall be normal, otherwise the test needs to be repeated.

(6) Switch off the power of the test system and end the test.

4 Data processing

Calculate the average value, standard deviation, and coefficient of variation of thetexture depth of the road section tested as described in Appendix B of JTG 3450—2019.

5 Correlation test between the measuredtexture depth by the vehicle mounted laser sensor method and the manual sand patch method

(1) Select four road sections with a length of 100 meters each which have atexture depth range from 0 to 0.3, 0.3 to 0.55, 0.55 to 0.8, and 0.8 to 1.2 mm respectively. Before the test, clean the

road surface and mark the start and end points.

(2) On each test section, measure the texture depth on at least 10 points with the manual sand patch method along a wheel path and calculate the average value.

(3) Drive thevehicle with the laser sensors along the test section at a speed of 30 to 50 km/h and ensure that the laser sensor is located along the wheel path in which the sand patch tests are made. Then calculate the average value of the texture depth of the test road section.

(4) Establish a correlation relationship between the two methods. The correlation coefficient R must be equal to or greater than 0.97.

6 Report

The following technical information shall be included in the report:

(1) Test section information (stake number, test location, etc.).

(2) The average value, standard deviation and coefficient of variation of thetexture depth of the test section.

(3) If a correlation test is performed, the correlation relationship and correlation coefficient shall be included.

Background:

Currently the laser texture depth testers are generally of the vehicle mounted type. These systems are highly efficient and provide stable test results at the same time test data of other indicators such as roughness and rutting is acquired. For this reason they are popular with most inspection organizations. However, because of the mode of operation these testers cannot be used on cement concrete pavements with grooved texture or pock mark texture.

In the early days, the laser sensors on some vehicle mounted laser texture depth testers had a low response frequency during data acquisition, which resulted in a slow test speed and the advantages of a vehicle mounted tester were not fully exploited. For this reason, a minimum test speed of equipment is specified in the technical requirements. A tester shall reach or over a required minimum test speed.

Currently there are several different algorithms that express laser test results as SMTD, MPD, MTD, etc. China has adopted the SMTD algorithm. Some of the early output results ofmany imported testers were *not from the SMTD algorithm. During the procurement tender process prospective purchasers shall require that the suppliers provide output results from the SMTD algorithm.*

T 0964—2008 Friction coefficient of pavement measured by pendulum tester

1 Applicable scope

This method is suitable for testing the British Pendulum Number BPN (Pendulum Test Value, PTV) on a cement concrete pavement without grooves or asphalt pavement by using a pointer pendulum tester.

2 Technical requirements for instrument and material

(1) Pendulum tester (with a pointer): The design is shown in Figure T 0964-1. During the test, the value is directly read from the scale with a pointer. The minimum scale of the BPN value is 2.

(2) Rubber slider: The size is 6.35mm × 25.4mm × 76.2mm, and the quality of rubber shall meet the requirements in Table T 0964-1. A new rubber slider shall be used when the old one is worn more than 1.6mm in length or 3.2mm in width or when it is contaminated by oil. A new rubber slider shall be tested 10 times on a dry road surface before measurements are started. The permissible life of a rubber slider is 12 months from the date of manufacture.

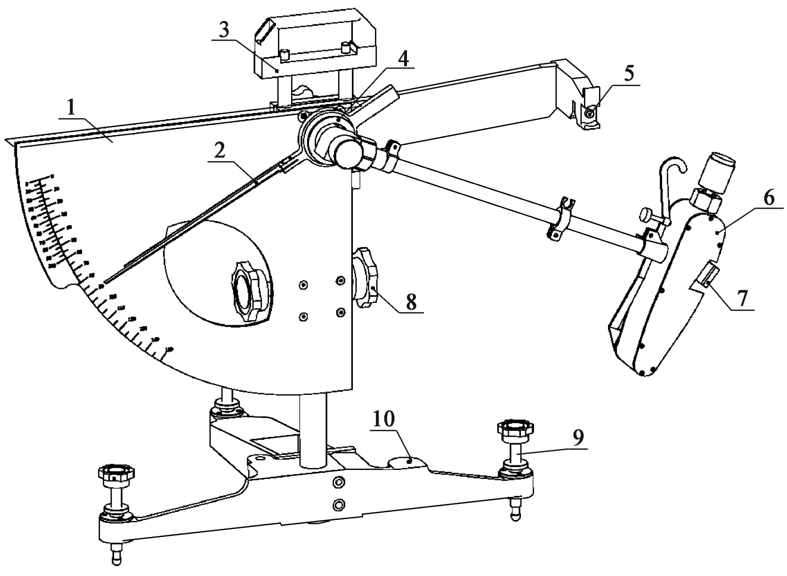


Figure T 0964-1 Illustration of a pendulum tester

1-scale; 2-pointer; 3-fastening knob; 4-zero adjustment ring; 5-release button; 6-pendulum; 7-rubber slider; 8-lifting knob; 9-level bubble; 10-leveling screw

Table T 0964-1　Technical requirements for the physical properties of the rubber

Physical property index	Temperature(℃)				
	0	10	20	30	40
Rebound value(%)	43 to 49	58 to 65	66 to 73	71 to 77	74 to 79
Hardness(HD)	55 ± 5				

(3) Sliding length gauge: the length is 126mm.

(4) Spray bottle.

(5) Road thermometer: graduations of 1℃.

(6) Others: a brush or broom, recording forms.

3　Method and procedure

3.1　Preparation

(1) Check the adjustment by zeroing the pendulum tester with the zero ring and regularly calibrate the pressure of its slider.

(2) Selecta test position as described in the method specified in T 0902 of JTG 3450—2019. Each test position has 3 testing points and the distance between the testing points is 3 to 5 m. The position of the middle testing point represents the test position. The test points shall be selected in the wheel paths at a test position (cross section) and the distances from the edge of the road shall not be less than 1m.

3.2　Test procedure

(1) Clean the road

Use a broom or other tools to clean the dust or material stuck on the road surface at the test point.

(2) Leveling the tester

①Place the pendulum tester on the test point with the swing direction of the pendulum in line with the traffic direction.

② Adjust the leveling screws on the base of the tester to center the leveling bubble.

3.2.3 Zero the pointer

①Loosen the fastening knob and turn the lifting knob to raise the pendulum so that it does not touch the road surface and is able to swing freely, and then tighten the fastening knob.

②Fix the pendulum on the right cantilever so that it is in a horizontal position. Then move the pointer to the right end by hand till it touches the pendulum rod.

③ Press the release button with the right hand to make the pendulum swing to the left and move the pointer with it. When the pendulum reaches the highest position and begins to fall, catch the pendulum with the left hand and the pointer shall point to zero.

④ If the pointer does not point to zero, repeat steps (1) to (3) until the pointer points to zero after the zero adjustment ring is adjusted by trial and error. The permissible error of zeroing is ±1.

(4) Check the sliding length

① Allow the pendulum to hang naturally and loosen the fastening knob. Turn the lifting knob to lower the pendulum. Then lift the hook of the pendulum to move the pendulum to the left and then release the hook so that the bottom face of the rubber slider is lightly in touch with the ground. Place the sliding length gauge next to and close to the slider. The left end of gauge is aligned with the position where the bottom of the rubber slider begins to touch the ground. Then lift the hook to move the pendulum to the right and release the hook to allow the bottom of the rubber slider to touch the ground lightly. Check whether the ground touching position of the rubber slider is in line with the right end of the sliding length gauge. If so, it means that the distance between two touching positions of the slider (sliding length) meets the requirement of 126mm ± 1mm. The two touching points of the rubber slider shall be the positions where the slider's longer edges touches the road surface at their earliest touching moments. Do not let the slider move by the weight of the pendulum, which will result in the calibrated sliding length being incorrect.

② If the two ground touching positions of the rubber slider are not in line with the two ends of the sliding length gauge, it can be adjusted by raising or lowering the height of the pendulum or the base of tester. Make the fine adjustment to vary the height of tester base by turning the base leveling screws. Although this is a relatively simple method, attention shall be paid that the level bubble shall be centered.

③ Repeat steps (1) and (2) until the sliding length meets the requirement of 126mm ± 1mm.

(5) Fix the pendulum on the right cantilever so that the pendulum rod is in a horizontal position and move the pointer to the right and in contact with the pendulum rod.

(6) Spray water onto the road surface at the test point with water from a spray bottle at each test.

(7) Press the release button on the right cantilever to allow the pendulum to slide over the road. When the pendulum rod falls back, catch the pendulum rod with the left hand and read the BPN, but do not record it.

(8) Allow the pendulum to pass over the road 5 times as described in Clauses 3.2.5 to 3.2.7 and read and record the pendulum value (BPN) each time. The difference between the highest value and the lowest value of the 5 pendulum values shall not be greater than 3. If the difference is greater than 3, the above operations shall be repeated until the requirements are met.

(9) Use a thermometer to record the temperature of the wet road surface at the measuring point with an accuracy of 1℃.

(10) Repeat Clauses 3.2.1 to 3.2.9 to complete the pendulum testing over 3 measuring points in one test position.

4 Data processing

4.1 Calculate the averagevalue of the 5 pendulum values of each measuring point as the pendulum value BPNT of the measuring point and round up to an integer which is then the value uncorrected for temperature.

4.2 Temperature correctionfor pendulum value

The measured pendulum value BPNTat road temperature of T (℃) shall be converted into pendulum value BPN20 at standard temperature of 20°C by using equation T 0964-1:

$$BPN20 = BPNT + \Delta BPN \qquad (T\ 0964\text{-}1)$$

Where:

BPN20—converted pendulum value at the standard temperature of 20℃;

BPNT—pendulum value measured at road temperature T;

ΔBPN—The temperature correction value fromTable T 0964-2.

Table T 0964-2 Temperature correction value

Temperature (℃)	0	5	10	15	20	25	30	35	40
Temperature correction value ΔBPN	−6	−4	−3	−1	0	+2	+3	+5	+7

4.3 Calculate the averagevalue of the 3 pendulum values at each test point as the pendulum value of the test position and round up to an integer.

4.4 Calculate the average value, standard deviation, and coefficient of variation of the pendulum value of a testroad section as described in Appendix B of JTG 3450—2019.

5 Report

The following technical information shall be included in the report:

(1) Testroad section information (stake number, test location, etc.).

(2) Pendulum value of each testposition (average value of 3 measuring points).

(3) The average value, standard deviation and coefficient of variation of the pendulum value of the testroad section.

***Background*:**
The pendulumtester (with a pointer) is a device invented by the former British Transport and Road Research Laboratory (TRRL) to test the skid resistance of a road surface. BPN is the abbreviation of British Pendulum Number, which represents the scaled values given by the pendulum tester. Over the years, this device has been widely used as a method to test the skid resistance by countries all over the world. This method is compiled by referring to commonly used test methods such as BS 598, ASTM E303, AASHTO, and Japanese Pavement Test Method Handbook 7-5.

The rubberslider used in the pendulum test has a major influence on the test results. Standards in most countries require that the rubber slider shall meet the requirements of British BS 812 for natural rubber or American ASTM E 501 for synthetic rubber. The rubber used in China is a synthetic type which was developed in China. The rubber properties conforming to the British BS 812 is adopted in this method.

Thependulum temperature correction formulas or graphs vary across the United Kingdom, the United States, Japan and other countries. Based on the results from tests carried out in China, a table with correction values was developed. The correction value of a temperature between listed values can be calculated by interpolation.

The zero calibrationof the pointer of the tester is an important procedure. However, for a long time because of restrictions in the manufacturing process and materials used by most manufacturers in China, most pendulum testers cannot control the pointer satisfactorily, which leads to incorrect test results. In order to overcome the shortcomings of the tester which gives results from a pointer, in recent years a digital pendulum tester was developed. The pendulum values are measured by sensors. The digital pendulum tester which uses sensors not only overcomes the disadvantages of the pointer type, but also avoids the human reading errors and greatly improves the accuracy of the test results.

T 0969—2019 Friction coefficient of pavement measured by digital pendulum tester

1 Applicable scope

This method is suitable forusing the digital pendulum tester to measure the pendulum friction coefficient value BPN on a cement concrete pavement without grooves or asphalt pavement.

2 Technical requirements for instrument and materials

(1) Digital pendulumtester: The design and structure are shown in Figure T 0969-1. The computing unit of the digital pendulum tester can identify the serial number of the measuring point, automatically measures, saves and displays the pendulum values and the temperature corrected results.

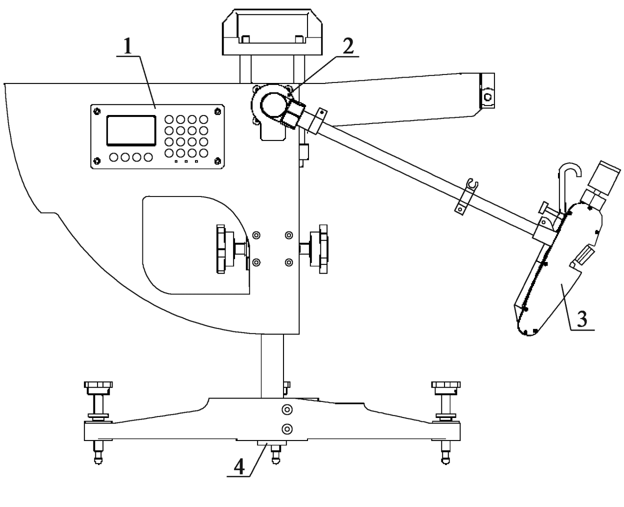


Figure T 0969-1 Illustration of digital pendulum instrument

1-computing unit; 2-rotation angle sensor; 3-pendulum; 4-temperature sensor

(2) Rubberslider: The requirements are the same as those in T 0964-2008.

(3) Sliding length gauge (the length is 126mm).

(4) Spray bottle.

(5) Brush.

(6) Pavement thermometer: thegraduations are 1℃.

(7) Others: brooms, recording forms.

3 Method and procedure

3.1 Preparation

(1) Check thezeroing sensitivity of the digital pendulum tester and regularly calibrate the pressure of the slider.

(2) Select the testposition according to the method specified in T 0902 of JTG 3450—2019. Each test position has 3 measuring points and the distance between the measuring points is 3 to 5 m. The position of the center measuring point represents the test position. The test points shall be selected in the wheel paths at the test position (cross section) and the distance from the edge of the road shall not be less than 1m.

3.2 Test procedure

(1) Clean the road

Use a broom or other tools to clean off the dust or material stuck to the road surface at the measurement point.

(2) Leveling the tester

①Place the tester on the pavement test point with the swing direction of the pendulum in line with the traffic direction.

②Adjust the leveling screws at the base of tester to center the leveling bubble.

(3) Zero calibration of the tester

①Loosen the fastening knob and turn the lifting knob to raise the pendulum so that it does not touch the road surface and is able to swing freely, and then tighten the fastening knob.

②Fix the pendulum on the right cantilever and keep the pendulum in a horizontal position.

③Switch on the power of the tester computing unit, set the test mode to "calibration" and press the release button to allow the pendulum to swing to the left. Catch the pendulum by hand when the pendulum falls back immediately after reaching the highest position. At this time the digital pendulum tester will automatically record the initial angle by the free-falling pendulum. Record this initial angle and complete the zero calibration.

4) Check sliding length

①Allow the pendulum to hang naturally and loosen the fastening knob. Turn the lifting knob to lower the pendulum. Lift the hook of the pendulum to move the pendulum to the left and then release the hook so that the bottom face of the rubber slider is lightly in touch with the ground. Place the sliding length gauge next to and close to the slider. The left end of the gauge is aligned with the position where the bottom of rubber slider begins to touch the ground. Then lift the hook to move the pendulum to the right and release the hook to allow the bottom of the rubber slider touch the ground lightly. Check whether the ground touching position of the rubber slider is in line with the right end of the sliding length gauge. If so, it means that the distance between two touching positions of the slider (sliding length) meets the requirement of 126mm ± 1mm. Two ground touching points of rubber slider shall be the positions where the longer edges of the slider touches the road surface at their earliest touching moments. Do not let the slider move further by the weight of the pendulum, which will result in the calibrated sliding length being incorrect.

②If the two ground touching positions of the rubber slider are not in line with the two ends of the sliding length gauge, it can be adjusted by raising or lowering the height of the pendulum or the base of the tester. Make the fine adjustment to vary the height of tester base by turning the base leveling screws. Although this is a relatively simple method, attention shall be paid that the level bubble shall be centered.

③Repeat steps (1) and (2) until the sliding length meets the requirement of 126mm.

(5) Attach the pendulum on the right cantilever so that the pendulum is in a horizontal position and set the test mode to "ready".

(6) Spray the road surface at the test point with water from a spray bottle to make it wet.

(7) Press the release button on the right cantilever to allow the pendulum to slide over the road. When the pendulum rod falls back, catch the pendulum rod by the left hand and read the BPN, but do not record it. Place the pendulum rod in the horizontal position again for next release.

(8) Allow the pendulum to pass over the road 5 times as described in Clauses 3.2.5 to 3.2.7 and read and record the pendulum value (BPN) each time. The difference between the highest value and the lowest value of the 5 pendulum values shall not be greater than 3. If the difference is greater than 3, this shall be investigated and the above operations shall be repeated until the requirements are met.

(9) Use a thermometer to record the temperature of the wet road surface at the measuring point with an accuracy of 1℃.

(10) Repeat procedures 3.2.1 to 3.2.9 to complete the pendulum testing over 3 measuring points in one test position.

4 Data processing

4.1 Calculate the averagevalue of the 5 pendulum values of each measuring point as the pendulum value BPNT of the measuring point and round up to an integer.

4.2 The temperature correction of the pendulum value of each test point is conducted in accordance with T 0964 of JTG3450—2019.

4.3 Calculate the average pendulumvalue of 3 test points as the pendulum value of this test position and round up to an integer.

4.4 Calculate the average value, standard deviation, and coefficient of variation of the pendulum value of a testroad section as described in Appendix B of JTG3450—2019.

5 Report

The following technical information shall be included in the report:

(1) Test section information (stake number, test location, etc.).

(2) Pendulum value of each test position (average value of 3test points).

(3) The average value, standard deviation and coefficient of variation of the pendulum value of the testroad section.

***Background*:**

The digital pendulumtester was developed based on the basic structure and working principle of the original pointer pendulum tester. By applying computer, electronic and sensor technology, a digital measurement system was developed which integrates functions of automatic display, automatic storage, and automatic temperature correction. The measurement mechanism of the digital pendulum tester has a high – precision angle sensor, an embedded pendulum value measurement system, temperature sensors, and algorithm calculation software.

The digital pendulumtester abandoned the pointer and scale (which original testers have) and its zero calibration and reading of the pendulum value are automatically made by the angle sensor and the control program, which eliminates inconsistencies and human errors in the processes of zero calibration and manual reading. The stability and accuracy of test results are thus improved.

T 0965—2008 Friction coefficient of pavement measured by one-wheel sideway force measuring system

1 Applicable scope

This method is suitable for checking the quality of a newly built or reconstructed road pavement at the time of acceptance inspection, or collecting continuously the data of sideway force friction over a road with no severe potholes or ruts under normal traffic conditions by using a one – wheel type sideway force coefficient test system.

2 Technical requirements for instrument and material

The sideway force coefficient test system consists of a vehicle, distance measuring device, sideway force test device, water supply and a main control unit, as shown in Figure T 0965. The main control unit not only controls the operations of the test device and the water supply, but also controls the process of data collection, recording and calculation. The main technical requirements are as follows:

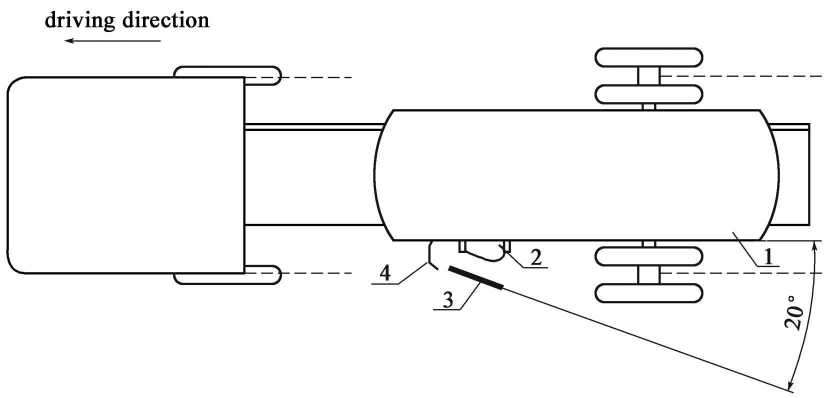


Figure T 0965　Illustration of one-wheel type sideway force coefficient test system

1-Water tank;2-Sideway force test device;3-Test wheel;4-Water supply spray

(1) The vehicle has a chassis on which the testing system and water supply system is mounted. The systems for controlling and recording allow the truck to run at a maximum speed of more than 100km/h when the water tank is full.

(2) Test tire type: smooth pneumatic tire made of natural rubber.

(3) Test tiremodel: 3.00 – 20 – 4PR.

(4) Test tire standard pneumatic pressure: 350 ± 20kPa.

(5) Test wheel inclination angle (see Figure T 0965): 19.5° to 21°.

(6) The standard static vertical load on the test wheel: 2000 ± 20 N.

(7) Non-linear error of compressiveforce sensor in test wheel axle: < 0.05%.

(8) The effective range of thecompressive force sensor: 0 to 2000N.

(9) Distance calibration error: < 2%.

3　Method and procedures

3.1　Preparation

(1) Before the start of each test or after the vehicle has tested an accumulated length of 1000km, the force sensors of the system shall be calibrated as specified and the calibrated data shall be recorded and filed.

(2) Check the tire pressures of the of the vehicle tires to ensure that they are at the standard pressure.

(3) Check the state of wear of the test tire. If its diameter is reduced by more than 6mm (that is its running surface is worn by 3mm) compared to a new tire or there is obvious damage or have cracks on the tire, the tire must be replaced. The new tire shall be run in for about 2km before the formal testing can start.

(4) Check the air pressure of the test wheel toensure it is at the requirement of 350 ± 20 kPa.

(5) Check that thefastening bolts of the test wheel are tightened. Put the test wheel in the normal test position and check that it is be able to move up and down freely along the two guiding posts on either side.

(6) Fill the water tank with sufficient clean water for the planned test distance.

(7) When the water spray is controlled by a non-automatic valve, it needs to be set to a position corresponding to the test speed. Lower the test wheel and check the spray quantity at the nozzle and the position of the sprayed area. The position of sprayed area shall be 400 ± 50mm ahead (along the driving direction) of the midpoint of where the test wheel touches the ground and the sprayed width shall be about 75mm on each side of the wheel center line.

(8) Start the control unit andconfirm that the selected function modes and technical parameters are correct.

3.2 Test procedure

(1) Before starting the test, the control unit shall be switched on for warming upover the specified time.

(2) Before entering the test section, the technician shall set the technical parameters for the test system and lower the test tire to run on the road for at least 500 meters to warm up the tire before formal testing is started.

(3) After entering the test section, the driver shallkeep a relatively uniform speed and travel along the normal wheel paths. When the water spray is controlled by a non – automatic regulation valve, the maximum speed shall not exceed the speed determined by the preset opening of the valve.

(4) During the test key points such as start and end points ofa test section and other special features shall be accurately input into the test data file by the technician.

(5) After the vehicle reaches the end of the test section, the technician shall stop the test procedure, raise the test wheel and restore all the parts of the test system to their initial states.

(6) Check to see if the data file is complete and normal, if not, repeat the test.

(7) Switch off the power of the testsystem and close the nozzle on a manual system and end the test.

4 Data processing

4.1 Speed correction of SFC value

Take the speedwhich is needed for actual purpose as the standard test speed, and the SFC value obtained at the actual test speed shall be converted to the equivalent SFC value at the standard speed by equation T 0965-1.

$$SFC_{标} = SFC_{测} - 0.22(V_{标} - V_{测}) \quad (T\ 0965\text{-}1)$$

Where:

$SFC_{standard}$—equivalent SFC value at standard test speed;

SFC_{actual}—SFC test value at actual site test speed ;

$V_{standard}$—standard test speed, km/h;

V_{actual}—actual test speed.

4.2 Temperature correction of SFC value

The standard ground temperature range of the test system is 20 ± 5℃. The SFC value measured under other ground temperature conditions must be converted to the equivalent SFC value of standard temperature by applying Table T 0965. The test system must be able to operate under a ground temperature range of 8 to 60℃.

Table T 0965 Temperature correction for SFC value

Temperature(℃)	10	15	20	25	30	35	40	45	50	55	60
Correction value	−3	−1	0	+1	+3	+4	+6	+7	+8	+9	+10

4.3 Calculate the average value, standard deviation, and coefficient of variation of the SFC value of aroad section as described in Appendix B of JTG 3450—2019.

5 Correlation test between friction coefficients tested by different types of testers

5.1 Basic requirements

Whenthe values from a braking coefficient tester or other types of lateral force tester need to be converted into SFC for actual application, a correlation test shall be carried out to establish the correlation between the results of other tests and the SFC value.

5.2 Test conditions

(1) Select 4 road sections with different friction coefficients on the basis of their SFC value ranges being 0 – 30, 30 – 50, 50 – 70, and 70 – 100 respectively. The length of a road section shall be 100 to 300 m.

(2) The surface of the test road section shall be clean and dry and the temperature of the ground shall be in the range of 10 to 30℃. The test shall be conducted in sunny weather without wind.

5.3 Test procedure

(1) The test system for SFC and the other type of tester for which the correlation test is required shall be prepared as described in Clause 3.1.

(2) Both testers shall test 4 selected test sections at speeds of 40km/h, 50km/h, 60km/h, 70km/h, and 80km/h respectively and repeat each run 3 times. The absolute difference of average value of the 3 test runs shall not be greater than 5, otherwise the test shall be repeated.

(3) Thedifference in the sampling frequencies of the two testers shall be within the limit that one shall not be more than twice of the other and more than 10 sampled values shall be obtained in each test section.

5.4 Test data processing

(1) Calculate the average value and standard deviation of the results of a road section tested from 3 repeat run at each of the 5 speeds. There are 4 test road sections. Values exceeding 3 times the standard deviation shall be discarded.

(2) Use the mathematical statistics regression analysis method to establish the correlation relationship between thetested values and their test speeds and the correlation coefficient R shall not be less than 0.95.

(3) Establish correlation equationsbetween both testers (other tester, SFC tester) measured at different speeds and the correlation coefficient R shall not be less than 0.95.

6 Report

The following technical information shall be included in the report:

(1) Test section information (stake number, test location, etc.).

(2) Test speed, temperature

(3) The average value, standard deviation and representative value of the SFC (sideway force coefficient) of the test road section.

(4) If a correlation test is performed, the correlation relationship and correlation coefficient shall also beincluded.

***Background*:**
Thesideway force coefficient test system is widely used to test the skid resistance of high – class highways. Its design, working principles and main technical parameters specified in this method are basically consistent with the British SCRIM standard. The technical parameters of the test tire generally meet the requirements by "Special test tire for measuring sideways force Friction Coefficient" (JT/T 752—2009).

Both test speed and test temperature have a great influence on the SFC test results. For this reason theprevious specifications provided conversion equations to correct the results under different speed and temperature conditions. A major change in this revision is that the standard test speed is no longer specified because the test speed may be different when used for different purposes. Since there is a speed conversion equation, for practical convenience, the desired speed can be taken as the standard speed and values tested at other speeds can be converted to the values at the standard speed.

T 0967—2008　Friction coefficient of pavement measured by dual-wheel sideway force measuring system

1　Applicable scope

This method is suitable for the acceptance test of a new or reconstructed road pavement by testing the sideway force coefficient under normal traffic conditions on a pavement without severe potholes or ruts by using a two – wheel sideway force coefficient test system.

2　Technical requirements for instrument and material

The two-wheel sideway force coefficient test system consists of a trailer, water supply system, testing unit, main control unit and calibration device. The test system is shown in Figure T 0967-1 and Figure T 0967-2. The main technical requirements are as follows:

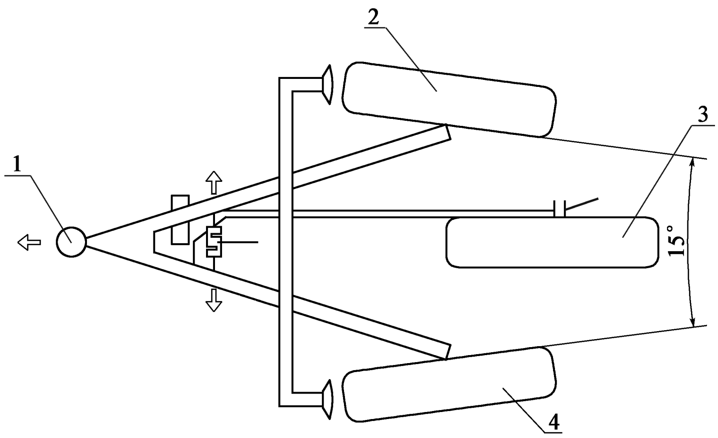


Figure T 0967-1　Plan view of Mu-meter

1-Hitching point; 2-Rotating test wheel; 3-Rear wheel

(1) The maximum speed of the towing vehicle must be greater than 80km/h. A special towing device hitch can be installed at the rear of the vehicle. The vehicle shall be equipped with warning lights and related warning signs.

(2) Total weight of the test unit: 256kg.

(3) Static standard load on a single wheel: 1.27kN.

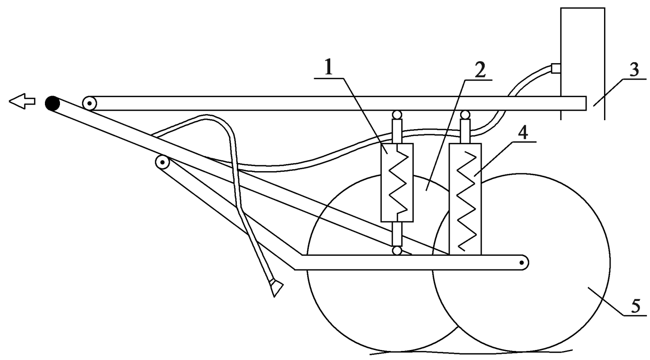


Figure T 0967-2　Side view diagram of Mu-meter

1-damping spring;2-rotating test wheel;3-recorder;4-low-speed spring;5-rear wheel

(4) Inclined angle of test wheel: 15°.

(5) Test wheel air pressure (for testing horizontal force coefficient): (70 ± 3.5) kPa.

(6) Air pressure for the rear wheel (for measuring distance): (210 ± 13.7) kPa.

(7) Test wheeltire model: 4.00/4.80 – 8 smooth tire.

(8) Thickness of sprayed water film over road surface: from 0.5 to 1.0 mm.

(9) Test speed range: 40 to 60km/h.

3　Method and procedure

3.1　Preparation

(1) The stress sensor shall be calibrated before starting the field test. Placea calibration board, which is provided as an accessory of the tester, on the ground and pull the tester across the board manually three times. The system will automatically determine whether the tester is calibrated or not and the road test will be performed only after the tester has passed.

(2) The equipment shall be warmed up for about 10 minutes before the test is started. Check that the gasoline engine for the water pump can work normally and whether the engine oil needs to be filled.

(3) Check that the tire pressure of the sideways force coefficient test wheel and the distancemeasuring rear-wheel (or sprinkler's wheel) are as specified. The tire pressure shall also be

checked during the test over a long – distance or a long time.

(4) Lower the test wheels and open the water nozzle to check that the water flow is normal and meets the requirements. Check that the indicators of the instrument are normal and then raise the test wheel.

(5) Hitch the trailer to the towing vehicle. Connect the sprinkler system (optional), the test unit and the control circuit in sequence, start the main control unit in the test mode, and start the gasoline engine at the same time. Then open the water valve and prepare for the test.

3.2 Test procedure

(1) Drive the vehicle to the test section, open the water valve about 200m in advance and lower the test wheel. The test vehicle speed is maintained at a constant speed within the range of 40 to60 km/h.

(2) During the test, the technician shall accurately enter the start and end points of the test section and other special reference points into the test data record file.

(3) After reaching the end of the test section, stop the test process, save the data file and close the valve.

4 Data processing

Calculate the average value, standard deviation, and coefficient of variation of the road surface friction coefficient of a test section as described in Appendix B of JTG 3450—2019.

5 Correlation test

The data obtainedfrom this test method shall be converted into standard SFC values as described in Sections 4 and 5 of T0965 before relevant quality examination or evaluation can be carried out.

6 Report

The following technical information shall be included in the report:

(1) Test section information (stake number, test location, etc.).

(2) Test speed and air temperature.

(3) The average, standard deviation and representative value of the road surface friction coefficient of the test section.

(4) If a correlation test is performed, the correlation relationship and correlation coefficient shall also beincluded.

***Background*:**

The results of the Mu-meter friction coefficient test equipment made in the United Kingdom belong to the category of sideways force coefficient test equipment. This type of equipment is manufactured and used in Europe and North America. In addition to a number of imported pieces of equipment, Chinese made equipment has come onto the market. The national highway engineering evaluation standards require that the test results of this type of equipment shall be converted to SFC values before being used.

T 0968—2008 Friction coefficient of a pavement from dynamic friction tester

1 Applicable scope

This method is suitable for testing the friction coefficient of the road surface by the dynamic rotating friction coefficient tester (DFtester for short).

2 Technical requirements for instrument and material

The DF tester consists of three parts: control unit, test system and watering device as shown in Figure T 0968. The technical requirements and parameters of the DF tester are as follows:

(1) Rubber slider: The fixed pressure of each rubber slider is 11.8N, the dimensions of the slider are 6mm × 16mm × 20mm and the contact pressure between the slider and the test surface is 150kPa. The Shore hardness of the slider rubber is 58 ± 2.

(2) Measurement range: simulating a driving speed in the range of 20km/h to 80km/h.

(3) Range of friction coefficient: 0 to 1.

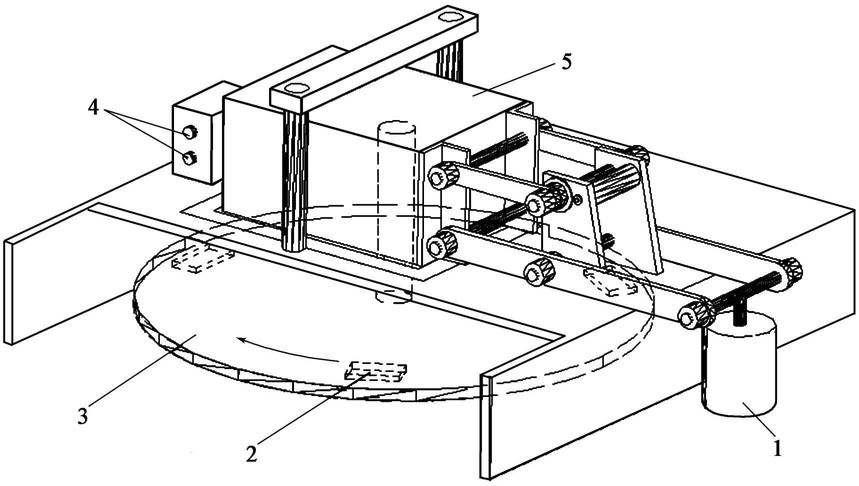


Figure T 0968　DF tester illustration

1-damper;2-motor;3-data transmission interface;4-disc;5-rubber slider

(4) On-site power supply: vehicle battery or independent battery (DC 12V).

(5) Recording device: X – Y recorder or portable computer. When using an X – Y recorder, chart paper and dedicated recording pens shall be prepared.

(6) Other appliances: buckets, brooms, thermometer.

3　Method and procedure

3.1　Preparation

(1) Tighten the screws for fixing the rubber sliders to the test disc of the DF tester. The rubber slider shall be replaced if its thickness is less than 3mm.

(2) Correctly connect the power cables of the control unit and X – Y recorder to thebattery power, switch on the power for the control unit and X – Y recorder and check that each part can work normally. Check the pen nib of the recorder and replace it if the pen nib is worn.

3.2　Test procedure

(1) Choose a relatively flat anduniform surface in the wheel path as the test point and try to avoid locations with rutting, potholes or unevenness and clean the surface of the test point. Place the DF tester on the test point. The DF tester shall be placed such that the water delivery pipe is able to deliver water to the test point.

(2) Connect the bucket filled with clean water to thewater inlet of the DF tester through a hose pipe. The bucket shall be placed higher than the elevation of the DF tester. Place the chart paper on the X – Y recorder in the correct position. When using a vehicle battery, in order to maintain a stable voltage, the vehicle shall be idling.

(3) Switch on the powerfor the control unit and X – Y recorder in sequence and set the pen nib to the origin of the coordinates of the chart paper through the X and Y coordinate adjustment.

(4) Lift and rotate the test discby operating the control switch and open the water supply valve and start spraying water onto the measuring point.

(5) When the control unit shows that the rotating speed of the disc reaches 90km/h, switch off the motor and close the valve of the water supply. Lower the test disc onto the road surface. Start the test with the recording pen plots the graph on the chart paper.

(6) While the rotation of test disc gradually slows down, the pen will continue recording on the graph paper until it returns to the origin which is the end the test.

(7) Repeat the test 3 times on the sametest point as described above. The difference between the maximum value and the minimum value of the 3 test results shall not be greater than 0.1, otherwise another test point must be selected and the test performed.

4 Data processing

4.1 Take the average of the 3 test results at each test point as the test result with an accuracy of 0.01.

4.2 Calculate the average value, standard deviation and coefficient of variation of the friction coefficient of a test section as described in Appendix B.

5 Report

The following technical information shall be included in the report:

(1) Test section information (stake number, test location, etc.).

(2) Test temperature and friction coefficient of eachtest point.

(3) The average, standard deviation and representative value of the friction coefficient of the test section.

Background:

DFtesters are used in Japan and the United States and DF testers used in China have been imported from Japan. The test result of this kind of tester is stable and the measured values from them have good correlations with other types of friction coefficient values. It is a preferred choice for testing friction coefficient at a single-point. However, currently it is not widely adopted. This method needs to be promoted.

10 Permeability

T 0971—2019 Test method for permeability coefficient of an asphalt pavement layer

1 Applicable scope

This method is suitable for testing the water permeability coefficient of an asphalt pavement layer on site with a falling head permeameter.

2 Technical requirements for instrument and material

(1) Pavement water permeability tester: Its shape and dimensions are shown in Figure T 0971. The upper part is a graduated water cylinder made of transparent plexiglass. Its volume is 600mL with graduations marked on it, and at the level of 100mL and 500mL it has thicker marks. The bottom is connected to the base of the tester through a Φ10mm tube which has a valve in the middle. The water cylinder is held on a bracket supported frame. The diameter of the inner circle of the base is Φ150mm which forms an open space and the diameter of outer circle of base is Φ220mm. The instrument is equipped with two stainless steel rings as ballast with a weight of about 5kg each and an inner diameter of Φ160mm.

(2) Collar base: a metal ring which has a tapering thickness towards its inner circle and a cutting edge at the bottom , forms a inner space with a diameter of 150mm at bottom, but its thickness at top is 5mm. It serves mainly to prevent the sealing material from being squeezed into the test surface which results in an incorrect water flow area.

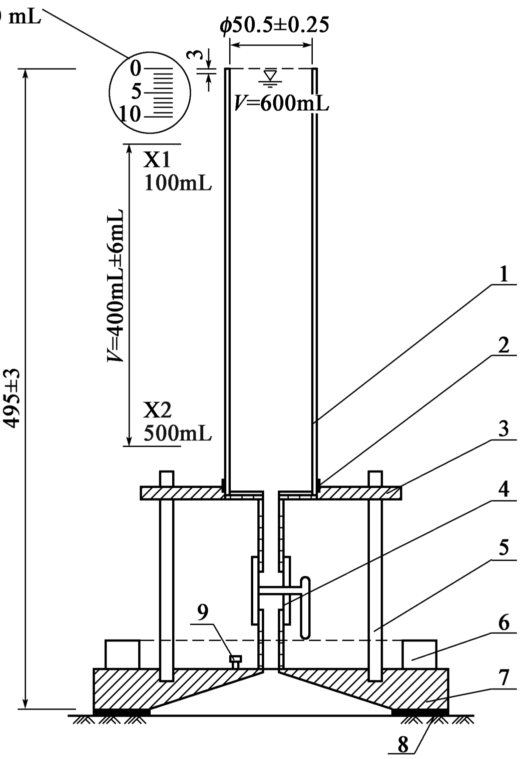


Figure T 0971 Design of water permeability tester (unit:mm)

1-Water cylinder;2-Threaded connection;3-Top plate;4-Valve;5-Column support;6-ballast;7-base;8-sealing material;9-vent hole

(3) Waterbucket and big funnel.

(4) Stopwatch.

(5) Sealing material: waterproof putty, oil putty or plasticine.

(6) Others: water, chalk, plastic ring, scraper, broom.

3 Method and procedure

3.1 Preparation

(1) Select 3 test points for each test position as described in Appendix A of JTG 3450—2019 and mark the points with chalk.

(2) Before the test, first use a broom to clean theroad surface and then use a brush to remove loose material and dust on the road surface.

(3) The waterpermeability test on a new asphalt pavement layer shall be made within 12 hours after rolling is completed.

3.2 Test procedure

(1) Placea plastic ring on the test point on the road surface and draw circles along its inner and outer circles with chalk. The part between the outer circle and the inner circle is the area that needs to be sealed with a sealing material.

(2) Seal the annular area with sealing material. Be careful not to let the sealing material protrude into the inner circle. If the sealing material accidentally enters the inner circle, it must be scraped away with a scraper. Mold the sealing material by hand into threads with the thickness of a thumb and place them in the middle part of the annular area where they shall form a complete circle.

(3) Place the collar on thetest point and ensure that the center of the collar is exactly over the drawn circles. Then slightly press the collar into contact with the surface of the threads of sealing material. Place the water permeability tester over the collar and then center it. Also press it to make it squeeze tightly against the collar and then add the ballast rings to prevent the pressure water from flowing out of the interface between the base and the road surface.

(4) Close the valve and the vent hole and fill water into the water cylinder until it is above the 100mL mark. Then open the valve and the vent hole to allow the water in the cylinder to flow downward in order to expel the air inside the open space under the tester base. When the speed of the water level in the cylinder slows down, press the tester lightly with two hands to expel all the air bubbles inside tester base completely. When the water is discharged smoothly from the vent hole (no bubbles), close the valve and vent hole and fill the cylinder with water again until it reaches the 0mL mark.

(5) Open the valve and when the water level reaches the 100mL mark, immediately start the stopwatch for timing. After 3 minutes, record the water volume and end the test. If the water level drops to 500mL before the end of 3 minutes, record the time when this happens and end the test. If the water level does not drop to the 500mL mark within 3 minutes, measure the water flow volume at the time of 3 minutes and then end test.

(6) During the test, if water seeps outfrom under the seal, the seal between the base and the road surface is deemed to be a failure and the test result is invalid. Close the valve, mend the seal with more sealing material and repeat the test by following procedure (4) and (5). If water still seeps out, select a location nearby along the transverse direction, but in the same longitudinal

position and repeat the test by following procedure (1) to (5).

(7) During the test, if waterescapes through road surface beyond the outer circle of base, the seal material can be applied manually to seal the road surface within a width of 5 cm outside the outer circle of the base and repeat the test by following procedure (4) and (5). As long as there is no water escaping from the sealed area, the test result is considered valid.

(8) Repeatprocedure (1) to (7) to test the water permeability coefficient of 3 test points.

4 Data processing

4.1 Calculate the water permeability coefficient by using equation T 0971 to an accuracy of 0.1 mL/min.

$$C_w = \frac{V_2 - V_1}{t_2 - t_1} \times 60 \qquad (0971)$$

In which:

C_w—permeability coefficient (mL/min);

V_1—Water volume at the beginning (mL);

V_2—Water volume at the end (mL);

t_1—beginning time (s);

t_2—ending time (s).

4.2 Take the average of the water permeability coefficients of the 3test points as the result of the test position to an accuracy of 1 mL/min.

5 Report

The following technical information shall be included in the report:

(1) Test location information (stake number, pavement type, etc.).

(2) Waterpermeability coefficient of test position (average value of 3 test points).

Background:

The water permeability of an asphalt pavement layer is an indirect index reflecting the gradation composition of asphalt mix and also an important indexto examine the water stability of the asphalt pavement layer. If water can penetrate through an asphalt pavement layer or layers, water will inevitably *enter into the base course or roadbed which will lead to a reduction in bearing capacity of the pavement. But if there is an impermeable layer in the pavement, the surface water may still penetrate quickly but will not result in a layer of water on the surface which is detrimental for skid resistance. Therefore, the pavement layer water permeability coefficient has become an important index to evaluate the performance of the pavement and is included in the relevant technical specifications.*

The content of this revision was enhanced based on engineering practice developed in recent years.

For the design of the permeability tester, the requirement of having a vent hole is specified. As a result, the preparatory work for the water permeability test is further improved. In the previous edition of this method, the pavement water permeability tester did not require a vent hole. However, a vent hole is provided in most testers in actual practice. Before the test is started it is necessary to open the valve of the tester and the vent hole to expel the air in the bottom of the tester. Therefore, this part of the method has been amended based on the actual applications

In the previous edition of this method, different requirements for different seepage conditions are specified. When the water level drops slowly, the seepage water volume can be measured at the time of 3 minutes; if the water level drops quickly and reaches the 500mL mark in less than 3 minutes, the time when the 500mL mark is reached is recorded; if the water level drops to a certain level and remains basically unchanged, it means that the pavement is basically impervious. However, these requirements are relatively unclear and difficult to handle by field testing personnel. The requirements in the former edition to record the water volume every 1 minute is of little practical significance. Therefore this test method has been improved in this revision by considering the actual situation to make it easier for test personnel to judge each case based on the site situations.

In the water permeability test, one of the biggest problems is the horizontal flow that may escape through the pavement surface, especially for coarse graded asphalt concrete or SMA where this kind of problem occurs. This revision considers the practical situations and requires that a seal surrounding the outer circle of tester shall be added if the water escapes through the surface. In fact, in the water permeability test, the water seepage includes vertical downward flow and horizontal flow. Adding a seal surrounding the outer circle of the tester is to increase the area of vertical downward flow so as to reduce the influence of horizontal flow on the water permeability coefficient.

The previous edition requires selecting 5 test points to test the water permeability coefficients for a test road section and their average value is taken as the test result of this section. This requirement is inconsistent with the current asphalt pavement construction technical specifications and quality inspection standards and has therefore been revised.

11 Subgrade and pavement distresses

T 0972—2019 Test method for measuring joint faulting of a concrete pavement slab

1 Applicable scope

This method is suitable for testing the faulting at the ends of structures and cement concrete slabs to evaluate the driving comfort of the pavement.

2 Technical requirements for instruments and materials

(1) Reference straight edge: 3m or 2m straight edge.

(2) Ruler

① Depth gage: with resolution of at least 0.5mm.

② Steel ruler: Its measuring range shall not be less than 200mm.

③ Steel tape: Its measuring range shall not be less than 5m.

④ Measuring wedge: The graduation shall not be greater than 0.5mm.

(3) Level or total station

① Level: with an accuracy of DS3.

② Total station: An angle measuring accuracy is 2 minutes" , ranging accuracy is of ±[2mm $+2\times10^{-6}$s(s represents measured distance in mm)].

3 Methods and procedure

3.1 Preparation

Before the test, the location shall be cleaned to ensure that there is no loose sand or debris, mud and other pollutants that may affect the test results.

3.2 Test procedure

Select the cross sections that need to be tested, record the location information and stake numbers, and describe the faulting situations at the slab joints. The test position of the faulted joint shall be selected from the places where the faulting has the largest step. Other representative positions can also be selected as required. Select from the following test methods according to the actual situation:

(1) Reference straight edge method

Position the reference straight edge at right angles across the joint on the higher side. Measure the height difference between the lower edge of the reference straight edge and the top of the lower slab with a measuring wedge or steel ruler. This is the faulting step D at this position on the joint, accurate to 1mm.

(2) Depth gage method

Place a depth gage vertically on the higherslab, press the measuring – tip until it touches the surface of the lower slab. Read the faulting step D at this position, accurate to 1mm. The selection of measuring points shall avoid the spalling or edge of cement concrete slabs.

(3) Level (or total station) method

Set up the level (or total station) on the road surface. Measure the relative elevations on both sides of a selected measuring point on the joint, accurate to 1mm. The staff (or prism) shall be placed on flat points, avoiding humps or depressions.

4 Data processing

4.1 The test results of the reference straight edge method and depth gage method are taken as the faulting step D of slab joints, accurate to 1mm.

4.2For the level (or total station) method, the absolute difference value of relative elevations between both sides of a joint shall be calculated and taken as the faulting step D of slab joints, accurate to 1mm.

Report

Thefollowing technical information shall be reported in this method:

(1) Testlocation information, (stake number, general situations of the pavement and structure, etc.)

(2) Faulting step D of slab joints.

***Background*:**

When test accuracy is ensured, the total station can be used for quick and accurate setting out or elevation measurement. Its efficiency is higher than that of the level. Therefore, the total station is added as a measuring instrument for faulting at slab joints in this edition, which can be selected according to the test situations.

In the previous edition, if three-meter straight edge method or the level method is used, the maximum elevation difference within a certain length of the faulted joint is taken as the faulting step at a slab joint within a certain range and a profile drawing is made. This method has many problems, such as a large workload, low efficiency. It is seldom used. By considering the definition of the faulting of slab joints as well as the practicability and applicability of the test methods, in this edition the reference straight edge method and the level method are simplified. The requirements for drawing the profile of the faulting at slab joints is eliminated, and the depth gage test method is included which can be selected by the user according to the actual situation.

T 0973—2019 Test method for measuring rutting on an asphalt pavement

1 Applicable scope

This method is applicable to testing rutting on a bituminous pavement.

2 Technical requirements for instruments and materials

(1) The technical requirements for a road laser rut – meter (rut measurement system) are as follows:

①Measurement error of longitudinal distance is less than or equal to 0.1%.

②Longitudinal sampling interval is less than or equal to 200mm.

③Effective test width is greater than 3.5m. There are at least 13 test points and transverse sampling spacing is less than or equal to 300mm. The elevation accuracy is 0.1mm.

④Measuring range of rut depth is 0mm to 50mm.

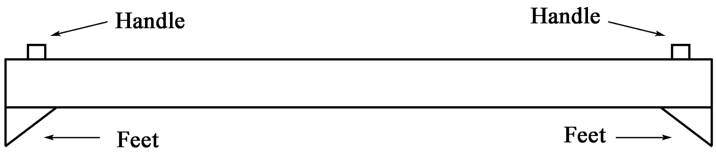


Figure T 0973-1 Cross section ruler for pavement

(2) Cross section straight edge: As shown in Figure T 0973-1, the metal straight edge has a division value of 50mm and a length which is at least the width of one lane.

The upper surface is flat and straight and the maximum permissible bending is 1mm. It has handles and feet which have a height of 100mm to 200mm at both ends. The heights of the two feet are same. It is used as a reference straight edge.

(3) Reference ruler: made of metal, with length no less than one lane width, maximum bending no more than 1mm, and has straight surfaces.

(4) Measuring instruments

①Steel tape: the measuring range shall not be less than 300mm, and the graduation value shall be 1mm.

②Steel ruler: the measuring range shall not be less than 300 mm, and the graduation value shall be 1 mm.

③Measuring wedge: graduation value shall not be greater than 0.5mm.

3 Method and procedure

3.1 The reference width for rut measurement shall meet the following requirements:

(1) For freeway and Class 1 highways, the distance between the midpoints of two lane marking lines on both sides of a lane where ruts occurred shall be taken as the reference width.

(2) For Class 2 and lower highways, when there are lane marking lines, the distance from the lane midpoint to the midpoint of the lines on both sides of a lane where ruts occurred shall be taken as the reference width; when there is no lane marking, the design width of a lane where ruts occurred shall be taken as the reference width.

3.2 Test method for cross section straight edge

(1) Preparation

First determine a road section to be tested, then select the cross-sections for testing as specified in T 0902 of this edition, and mark them out.

(2) Test procedure

①Select a cross-section for rut testing and place the cross-section straight edge at the cross-section to be tested. It shall be at right angles to the center line of road, and its feet are on either sides of the lane to be tested.

②Place a steel ruler vertically on the road surface, measure a point every 200mm along the cross-section straight edge, and read the height difference between the bottom of the cross-section straight edge and the road surface, accurate to 1mm. If the highest or lowest part of this cross section is obviously not one of the test points, the number of test points shall be increased.

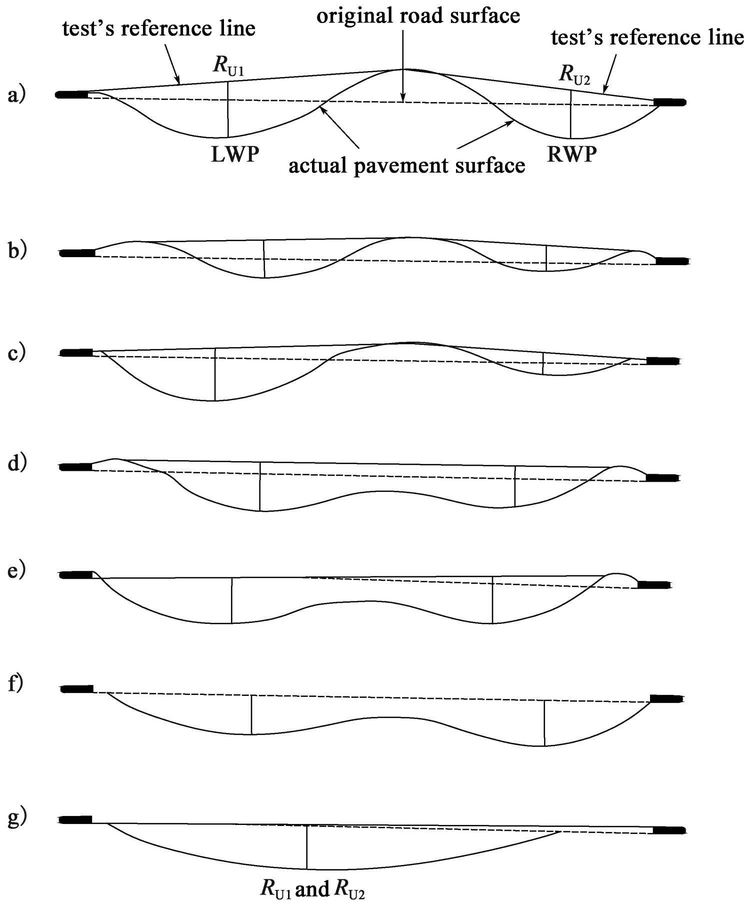


Figure T 0973-2 The illustration of road ruts with different shapesand severities

③Record the stake number, location of the tested cross section and the height differences.

Note: LWP and RWP represent left wheel path and right wheel path and RU1 and RU2 represent the rut depth of the left and right wheel path.

3.3 Reference straight edge test method

This method can be used where only the maximum rut is required instead of the complete cross section.

(1) Preparation

After determining the road section to be tested, select the cross-sections to be tested as specified in T 0902 of this version, and mark them out.

(2) Test procedure

①Select the section of the ruts which is to be tested, place the reference straight edge across the rut, at right angles to the center line of road.

②If the rut shape is being one of a), b), c) as shown in Figure T 0973-2, measure the rut depths in the left and right wheel paths respectively. Place the reference straight edge at the highest positions on both sides of a rut. Both left and right wheel path shall be checked, and visually determine the position of the maximum rut depth. Measure the height difference between the bottom of the reference straight edge and the road surface with a measuring ruler, accurate to 1mm, and record the rut depths as RU1 and RU2.

③If the rut shape is of other types shown in Figure T 0973-2, directly place the reference straight edge at the highest positions on both sides of the much-wider-rut, visually determine the maximum rut depth position of the cross-section, measure the height difference between the bottom of the reference straight edge and the road surface, accurate to 1mm, and record the rut depth as RU.

④Record the stake number, position of the tested cross-section and the rut depth of the much-wider-rut.

3.4 Test method for vehicle mounted laser rut-meter

(1) Preparation

① Identify the road section to be tested, which shall be free of accumulated water, ice/snow, and pollutants.

②Check the pressure of the tires of the test vehicle to meet the standard pressure as required and check whether the vehicle and the test equipment are functioning normally.

③Check the weather forecast as a wind speed greater than level 6 (about 13.8m/s), it is not suitable for testing.

(2) Test procedure

①The test vehicle shall be stopped at a distance ahead of the starting point of the road section to be tested to ensure that it can reach a stable testing speed. At the start of the test section, activate the test equipment to the operating mode.

②Set the parameters of the test system such as, route name, stake numbers of the road section, test lane, test direction and other information.

③Determine the test speed according to the traffic volume, pavement conditions and other actual conditions.

④The test shall be conducted lane by lane. Keep the center line of the test vehicle aligned with the center line of the lane, and the test system will automatically record the pavement rut data of the tested lane.

⑤Save the data after the test.

Data processing

4.1 The rut depth RU shall be calculated according to the cross-section shape specified in Figure T 0973-2, and the cross section and top-reference-line shall be drawn based on the test data and by following the method shown in Figure T 0973-2.

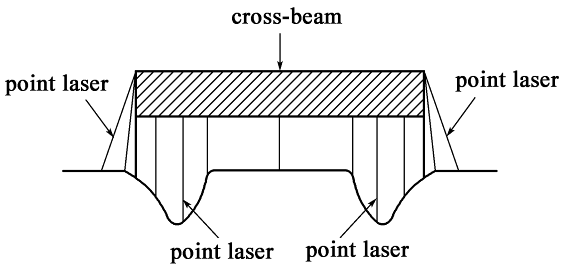


Figure. T 0973-3 The schematic diagram of point laser rut test

4.2 Determine the rut depth RU1 and RU2 on the drawing of the cross-sections, accurate to 1mm. Take the maximum value as the maximum rut depth RU of the cross-section.

4.3 Calculate the average value of the maximum rut depth at each tested cross-section along the road section as the average rut depth of the road section.

5 Report

The following technical information shall be reported for this method:

(1) Information on the tested locations (stake number, etc.).

(2) Rut depth value RU of each cross-section.

(3) The average rut depth of the tested road section.

Background:

Current Chinese manufactured automated rut meters (rut measurement system) consist of point laser rut meter or line laser rut meter. Their principles for testing are shown in Figures T 0973-3 and T 0973-4. , Ultrasonic rut meters are not being used. Ultrasonic technology was widely used in the early stage of automatic testing, but due to the limitations of low testing speed, poor accuracy, susceptibility to interference and complicated data processing, it is rarely used nowadays. Therefore, the ultrasonic rut meter is removed from this edition. In addition, the cross-sectional instruments are rarely used and sold at present, so its method is removed in this edition

The effective test width of the laser rut meter is one of the basic parameters of the instrument. The relevant domestic standards, specifications and manufacturers were investigated. The results of the investigation are shown in table T 0973. In some standards, the transverse test width has been specified as 3.5m. The transverse test width of the equipment made by most domestic and foreign manufacturers can meet the requirements of 3.5m. Therefore, the effective test width is adjusted to 3.5m in this edition.

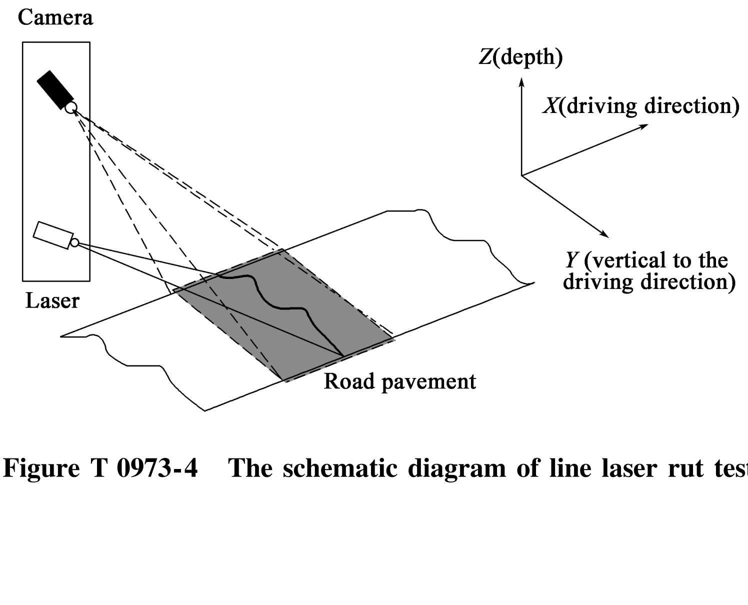


Figure T 0973-4 The schematic diagram of line laser rut test

Table T 0973 The requirements by domestic specifications on relevant parameters of laser rut meters

No.	Standards/specifications	Transverse test width (m)	Longitudinal sampling interval (m)
1	Vehicle Bearing Road Laser Rut-Meter (JT/T 677—2009)	≥3.2	≤0.2
3	Multifunctional High-Speed Highway Condition Monitor (GB/T 26764—2011)	≥3.5	≤ 0.2, 0.1mis recommended
4	Specifications of Automated Pavement Condition Survey (JTG/T E61—2014)	≥3.5	It shall be 0.1m, not more than 0.2m
5	Highway Performance Assessment Standards (JTG H20—2018)	—	The calculated length is 10m

As defined in the technical parameters of the current domestic laser rut meter and the requirements for the rut test, the measurement error of the longitudinal distance, the longitudinal sampling interval, the transverse sampling interval, the measurement range of the rut depth and the basic requirements for the test environment are specified in this edition.

The standard tire pressure referred in this method is the standard pressure specified by the manufacturer when the equipment leaves the factory.

*The unit length of calculation and output results of the rut depth of the pavement tested with a laser rut meter are clearly specified in the Highway Performance Assessment Standards (JTG H*20—2018) *and Specifications of Automated Pavement Condition Survey (JTG/T E*61—2014). *The test results can be saved in electronic form.*

When using a laser rut meter to test the rut depth, if the sun light interferes with the test results, it shall be adjusted or avoided.

When processing the rut test data, the maximum rut depth of a cross-section is determined for a cross section, and each cross-section drawing is an intermediate process in the rut calculation. In most cases, it is not necessary to present all the cross-section drawings in the report. Therefore, that 'the cross-section drawings of each test section shall be reported' in the previous edition is modified as to report the cross section drawings of required test sections..

T 0974—2019 Test method for determining pavement surface distress

1 Applicable scope

This method is applicable to record the surface distresses such as cracks, potholes and broken slabs that occurred on an asphalt pavement or cement concrete pavement, which are tested manually or through video images, so as to assess the technical conditions of the pavement.

2 Technical requirements for instruments and materials

2.1 Manual method

(1) Measuring instrument:

①Steel tape: 5m range and 50m range, with a graduation value of 1mm.

②Steel ruler: 500mm, with graduation value of 1mm.

(2) Others: chalk or paint, safety signs, etc.

2.2 Video image method

Basic parameters of a vehicle mounted distress detection system by means of a road video image:

(1) Calibrated error of distance sensor: $<0.1\%$.

(2) Effective test width: not less than 70% of the lane width.

(3) Minimum resolution of width of crack: 1mm.

(4) The accuracy of crack recognition: $\geq 90\%$.

3 Methods and procedure

3.1 Manual investigation method

Test procedure:

(1) Two techniciansform a team to record the distress on foot along the road shoulders.

(2) Measure the pavement length and width of the road section surveyed.

(3) Carefully observe and measure along the pavement, and complete the 'distress record form', with the stake number, the location, type, size and other information of the distresses of the pavement. Depending on the surrounding traffic conditions, all kinds of distress can be measured visually or with a ruler. The specific recording methods of asphalt pavement and cement concrete pavement are as follows:

① Asphalt pavement

——Cracks include longitudinal cracks, transverse cracks, irregular cracks and other independent cracks. The length and width of cracks are mainly measured with a steel tape or steel ruler. The crack width shall be the maximum value of the crack width, with t an accuracy of 1mm. The crack length shall be the cumulative length along the crack stretch. Its result shall be accurate to 0.01m.

——Other types of distress include alligator cracks,, block cracks, potholes, depression, corrugation and shoving, raveling, bitumen bleeding, repair, etc. Their areas shall be mainly considered and measured by a rectangular frame. Its length and width are the outermost sides of the rectangle which covers the distress. One of its sides is in line with the road transverse direction. Another side is at right angles to it. The survey result shall be accurate to 0.0001m2. The rectangular frame is shown in Figure T 0974-1:

② Cement concrete pavement

——If the distresses are crack, corner spalling, joint spalling, pumping, repaired cracks and others, mainly, their length shall be measured. The survey results shall be accurate to 0.01m.

——If the distresses are broken slabs, corner break, shoving, potholes, aggregate exposure, repair and others, mainly, their areas shall be measured. They shall be calculated according to the involved slabs or corners, or areas where distresses are present, and the survey results shall be accurate to 0.0001m2.

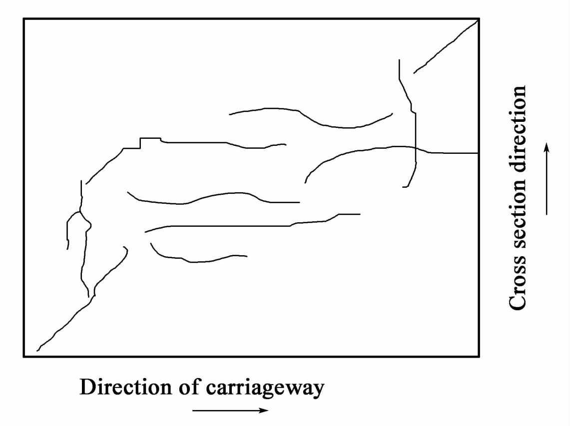


Figure T0974-1 The Rectangular Frame (Distresses inside the frame are to be Measured)

(4) If necessary, mark out with chalk or paint the distressed location, or take photos or videos, and record the corresponding stake number and photo number.

3.2 Video image test method

The video method is mainly used to automatically record the cracking distress on pavements and to deal with other pavement distress by the method of human-computer exchange.

(1) Preparation

① Start the system. Adjust the corresponding parameters of the camera system and the light source, so that the captured road image is clear.

② Determine the road section to be tested, which shall be free of water, ice and snow and pollution

(2) Test procedure

①The test vehicle shall be stopped at a distance ahead of the starting point of the test section to ensure that it can reach a stable speed required for testing. At the beginning of the test section, start the test system and adjust to operating mode.

② Set the parameters of the test system, and input the highway number, stake number of starting point, the lane being tested and other relevant information.

③ Testing shall be conducted lane by lane. The center line of the test vehicle must be aligned with the center line of lane, and the test system will automatically record the distress data of the pavement in the lane.

④ Save the data after the test.

⑤Use automation or human-computer interaction to identify the road damage images, and read the crack lengths and, distress areas.

4 Data processing

4.1 When testing the distresses of an asphalt pavement, calculate the total crack length of the tested road section and the total area of other types of distresses, and calculate the distress rate, crack rate and other indicators as required.

4.2 When testing the distresses of a cement concrete pavement, calculate the distressed length or area of the tested road section, and calculate the distress rate, shattered slab rate and other indicators as required.

The following technical information shall be reported in this method:

(1) Information on the tested road section (stake number, etc.).

(2) Distress type, its length, area and others.

(3) Distress rate, crack rate, shattered slab rate, etc.

Background:
This test method is based on "Bituminous pavement distress survey method" and "Cement concrete pavement distress survey method" that are specified in the 1995 edition of JTG 3450— 2019, and considered the definitions and classification of the distresses in the Technical Specifications for Cement Concrete Pavement Maintenance on Highways (JTJ 073. 1—2001), Technical Specifications for Maintenance of Highway Asphalt Pavements (JTJ 073. 2—2001) and Highway Performance Assessment Standards (JTG H20—2018), and also considered current actual situations of pavement distresses and the developments in testing technology. It focuses on the test method. When the distress survey is used to evaluate the pavement conditions, there are many different opinions on the calculation method, especially on how to weigh up various distresses and

their severities, so this specification has no special requirements, and relevant specifications or standards can be used for evaluation if necessary.

Whenthe manual test method is used, the relevant pavement distress record forms can be designed according to the actual needs. During the survey, the number of evaluators in each survey team shall not be less than 2, *mainly for considering the distance a person can survey, and the number of testers can also be altered according to the severity of distress. . In this method, no contaminant means that there is no sand or other debris on the road surface that can affect the ability to see the detailed distress*

Atthe time of the survey or to record the distresses on an asphalt pavement, if there is a case that a single independent crack has different severities over the same area of the pavement, and if it is difficult to distinguish them, they shall be calculated according to the most serious severe distress grade. If an independent crack passes through an area of alligator cracking or block cracking, its length in this area shall not be included in the total length of crack calculation. For the distress like potholes, ravelling, alligator cracks and block cracks on an asphalt pavement, if these distresses have different severities in the same area of the pavement, and it is difficult to distinguish them, then the most serious distress severity shall be used in the calculation. If an alligator crack area is inside a pothole (or block crack) area, its area shall be subtracted while recording the total area of potholes (or block cracks).

Cracking is one of the most important forms of pavement distress. The cracking distress statistics can be calculated separately, but the damage rate, cracking rate and other indexes on an asphalt pavement can be calculated as required.

The cracking rate of an asphalt pavement shall be calculated by using equation T 0974-1:

$$C_{\mathrm{K}} = \frac{C_{\mathrm{A}} + L \times B}{A} \qquad \text{(T 0974-1)}$$

Where, C_{K}——*cracking rate of asphalt pavement* ($m2/1{,}000m2$);

L——*total length of longitudinal and transverse cracks* (m);

C_{A}——*total area of alligator cracking and block cracking* ($m2$);

A——*pavement area ofthe road section evaluated, in* $1{,}000m2$;

B——*the effective width for converting crack length into a crack area, normally* $0.2m$

At the time of the distress surveying on a cement concrete pavement, the damage rate andshattered slab rate of cement concrete pavement can be calculated if required.

The shattered slab rate of a cement concrete pavement shall be calculated in accordance with the by *equation T* 0974-2:

$$B_{D} = \frac{S_{D}}{S} \times 100 \qquad (T\ 0974\text{-}2)$$

Where, B_D——*shattered slab rate of a cement concrete pavement* (%);

S_D——*total number of the slabs of cement concrete pavement that have been broken into two or more pieces*;

S——*total number of slabs in the test road section*

At the time of carrying out a survey for the purpose of large-scale or medium-scale maintenance to the pavement, an automated survey is usually conducted, whereas other types of pavement distress are surveyed manually as a supplement.

T 0975—2019 Test method for checking voids under a concrete pavement slab by measuring deflection

1 Applicable scope

This method is used for detecting the voids under slabs of a cement concrete pavement by means of the falling weight deflectometer (FWD) or Benckelman beam deflection device, and provides the basis for selecting maintenance treatments to a cement concrete pavement.

2 Technicalrequirements on for instruments and materials

(1) The falling weight deflectometer shall meet with the technical requirements of T 0953 in JTG 3450- 2019.

(2) Benckelman beam and loading vehicle: 5.4m Benkelman beam shall be used, and it shall meet the technical requirements of T 0951 in this version.

(3) Dial indicator and its holder.

(4) Others: steel tape, etc.

3 Methods and procedure

3.1 Falling weight deflectometer method

(1) Preparation

① Collect information about the materials, structure, layer thickness and others of the cement concrete pavement.

② Determine the stake numbers to be tested and mark out the positions of the test points. When measuring at the corner or edge of slabs, the distance between the edge of the loading plate and the longitudinal/transverse joints shall be less than 200mm. When measuring in the middle of a slab, the distance deviation between the center of the load plate and the slab center shall be less than 200mm, and the position of the load plate is as shown in Figure T 0975-1.

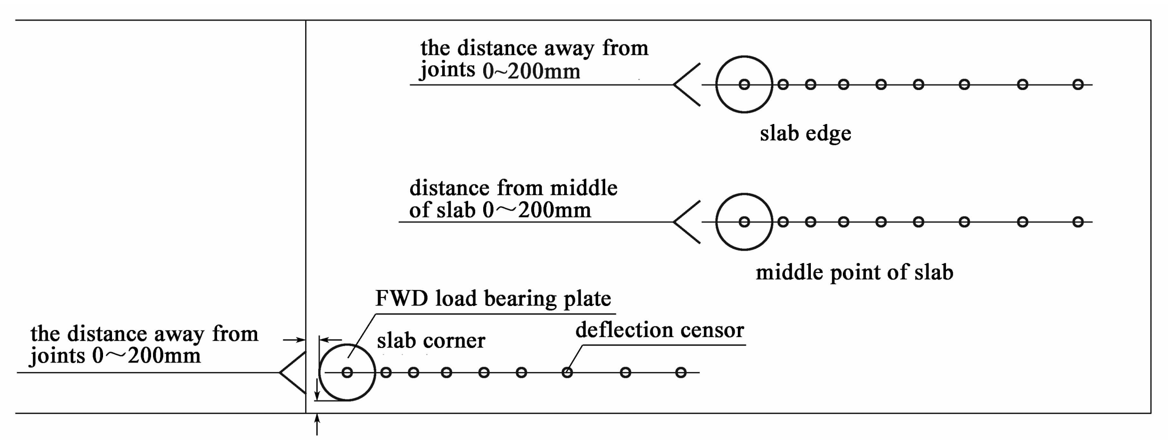


Figure T 0975-1 Schematic layout of the FWD loading plate

③ Clean the cement concrete pavement so that there is no obvious sand or mud at the test points.

④ The void detection measurements shall avoid the period of high temperature around noon on a sunny days and significant negative temperature gradient (night or early morning). Testing shall be carried out during the period when there is a small temperature difference between the upper and lower surfaces of the slabs, as in the morning or evening, or on cool cloudy and overcast days with little changes in temperatures.

(2) Test procedure

Test the deflection of the test points according to method of T 0953 in this version. When the intercept method is used to detect the voids under slabs, the corner deflection of a slab shall be tested at 3 levels of load applied to the same test point. When the deflection ratio is used to detect the voids under a slab, the same load shall be used to measure the deflection test on the slab corner, inner area and edge.

3.2 Benkelmann beam method

(1) Guidethe test vehicle to where its rear wheels are at the required test point. When testing the corner or edge of slabs, the outer edge of the rear wheel tire shall be 100-200 mm away from the longitudinal joint.

(2) When only the deflection of the corner of a slab is to be tested, the Benkelman beam probe can be placed at a distance of 50mm to100m from the joint. The supporting point and the test point of the Benkelman beam shall not be on the same slab. See Figure T 0975-2 for placement of wheels of test vehicle and Benkelman beam probe.

(3) Placethe dial gage on the top of the deflectometer, tap the deflectometer gently with fingers to check whether the dial indicator can zero in a stable manner. Record the initial reading L1 to the nearest 0.01m after the dial indicator has been zeroed.

(4) The test personnel gives the order for the vehicle to move slowly away from the concrete slab at a speed of about 5km/h, and read the final reading L2 to the nearest 0.01mm after the pointer of the dial remains constant. (1)-(4)

(5) Move the loading vehicle forward to the next test point, and repeat the above steps

(1)-(4)

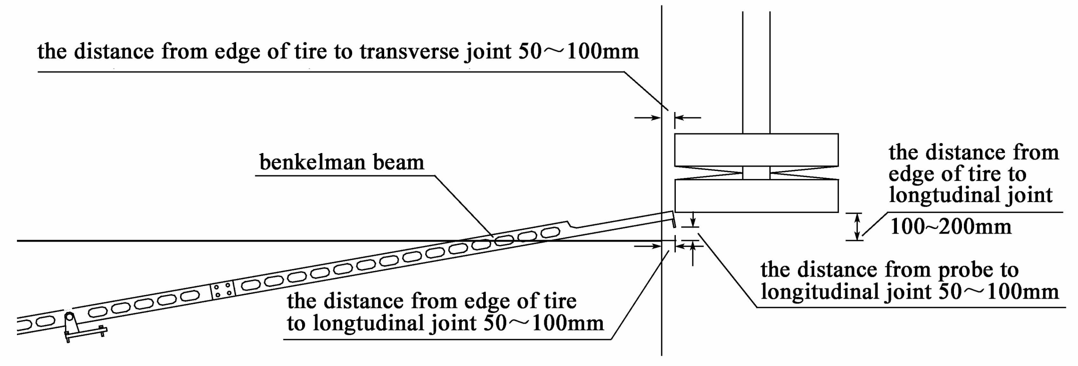


Figure T 0975-2 The layout of the wheels of the deflection measuring vehicle and Benkelman beam probe

Data processing

4.1 Falling weight deflectometer method

When the falling weight deflectometer is used for void detection, either ,the intercept method or deflection ratio method, can be used.. The detailed calculation method is as follows:

(1)The deflections at the different load levels are measured by the FWD. The regression coefficients a and b in equation T 0975-1 are calculated by the linear regression statistical method.

$$W = ap + b$$

Where, W——deflection value (0.001mm);

p——load value (kN);

a——slope of regression line;

b——intercept of regression line.

When the intercept b of the linear regression is greater than 50 μm, voids may exist.

(2) The deflection values atdifferent positions on a cement concrete slab are measured by FWD, and the deflection ratios λ_1 and λ_2 are calculated according to equatons T 0975-2 and T0975-3.

λ_1 = Wslab corner/ Wcentral slab

λ_2 = Wslab edge/ Wcentral slab

Where:

λ_1——ratio of the deflection at slab corner to the deflection in the centeral area of the slab;

λ_2——ratio of deflection at the midpoint of slab edge to the deflection in the center of the slab;

Wslab corner——deflection value at the corner of cement concrete slab (0.001mm);

Wslab edge——deflection value at the midpoint of cement concrete slab edge (0.001mm);

Wcentral slab——deflection value in the center of cement concrete slab (0.001mm).

FWD is used to measure the deflection in the center, in the middle of the edge and at the corner of the same slab. When $\lambda_1 > 3.0$ and $\lambda_2 > 2.0$, a void may exist.

4.2 Beckmann beam deflection method

The rebound deflection valueat a test point is calculated according to equation T 0975-4:

$$L_t = (L_2 - L_1) \qquad \text{(T0975-4)}$$

Where, L_t——rebound deflection value of pavement (0.01mm);

L_1——initial reading of dialgage (0.01mm);

L_2——final reading of dialgage (0.01mm).

When the rebound deflection value at a single point is used to detect a void, and its value is greater than 0.2mm, a void may exist.

5 Report

The following technical information shall be reported in this method:

(1) Falling weight deflectometer method

① Information on the test positions (stake numbers, etc.).

②Linear regression coefficient a, b or deflection ratio λ_1, λ_2 and the corresponding criteria for void detection.

③ Stake number of the positions where voids exist.

(2) Benkelman beam deflectometer method

① Information on the test positions (stake numbers, etc.).

② Deflection of each test point and the adopted criteria to detect voids.

③ Stake number of the positions where voids exist.

***Background*:**

The existence of a void under a cement concrete slab has a serious impact on the performance and fatigue life of pavement. It is also the most difficult type of distress to correct when treating distresses on an old cement pavement before it is overlaid by an asphalt layer. The first step in treating voids is to detect and locate the voids. Technical Specifications for Cement Concrete Pavement Maintenance on Highways (JTJ073. 1—2001) gives the judgment criteria for detecting voids by means of the Benkelman beam deflection method. In Specifications for the Design of Highway Cement Concrete Pavement (JTG D40—2011), it is mentioned that multiple load levels applied by the falling weight deflectometer can be used for void detection, but there is no relevant detection method in the original specification. For that reason, there is an urgent need for a unified standard to detect the voids under cement concrete pavement by means of the deflection method, in order to facilitate the application of relevant maintenance and design specifications and promote the further development of new instruments and technologies.

The temperature condition during deflectionmeasurement is particularly important for void detection. Tests have shown that when the surface temperature of the slab is higher than its bottom temperature, the central area of the slab will lift, and the slab corner will deflect downward, which *reduces the void under the slab corner. The measured value of deflection will decrease with the increase of temperature difference, thus affecting void detection. When the surface temperature of the slab is obviously lower than its bottom temperature, the slab will warp and the corner of the slab will lift off the support layer. Even if the supporting layer has no problem, voids will be apparent under the slab corner, which is incorrect. Therefore, during the void detection testing, the period with high temperature around noon on sunny days and when the temperature has a significant negative temperature gradient (night or early morning) shall be avoided. The void detection testing shall be conducted during the period with minimal temperature difference between the upper and lower surfaces of the slab, as in the morning and evening, or on the cool cloudy and overcast days with little change in temperature difference.*

The American AASHTO Pavement Design Guide uses the FWD at multiple levels of load which is analyzed by linear regression. The load levels are 6 *kilo-pounds*, 9 *kilo-pounds and* 12 *kilo-pounds. When the intercept is greater than* 50μm, *it indicates that there are voids under the slab. Combined with domestic research and practice, three levels of load for the FWD are recommended, namely* 50 *kN*, 70 *kN and* 90 *kN. Because different pavement structures and regional environmental conditions will affect the detection results, a reliable intercept value verified by experiences can be used to identify a void to meet different needs.*

*When the FWD deflection ratio is used for detecting voids, a void can be identified by referring to the Technical Specifications for Aerodrome Pavement Evaluation and Management (MHT*5024—2009). *When "deflection in the midpoint of slab edge divided by deflection in the central area of slab is greater than* 2.0", *and "deflection of the slab corner divided by deflection in the central area of slab is greater than* 3.0", *it can be accepted that there are voids.*

*According to 'the treatment of slab voids' in Technical Specifications for Cement Concrete Pavement Maintenance on Highways (JTJ*073.1—2001), *if the deflection of a cement concrete pavement that is measured with a* 5.4*m long Benkelman Beam under a BZZ*-100 *heavy duty standard vehicle exceeds* 0.2*mm*, *the slab shall be considered to have voids.*

T 0976—2019 Test pit for investigating pavement structural distress

1 Applicable scope

This method is applicable for investigating the distresses inside a pavement structure by digging out layers, which can provide the basis for developing a pavement maintenance option by considering the root cause of the distress.

2 Technical requirements for instruments and materials:

(1) Primary excavation equipment:

① Jack hammer: a hand-held pneumatic breaker equipped with various types of chisels, an air compressor, whose minimum air delivery is not less than 118L/s at a pressure of at least 0.55MPa.

② Diamond saw: motor power is more than 4kW, cutting disc or blade diameter is more than 500mm, cutting depth is more than 240mm, and advancing speed is more than 0.5m/min.

(2) Measuring instruments: 5m and 30m steel tape, 0.5m steel ruler, etc.

(3) Others: shovel, trowel, chisel, hammer, small broom or brush, air blower, etc.

3 Method and procedure

3.1 Preparations

(1) Determine a representative area based on the type of the most common pavement distresses and the purpose of the test, which shall be used as the test point

(2) Determine the number of pavement layers in the pavement structure that has to be investigated.

3.2 Test procedure

(1) If the pavement is covered by debris, a broom or brush shall be used to clean the pavement, and an air blower shall be used to blow away the dust at the location of distress.

(2) Observe and describe the visual pavement distresses at the point being tested, and record the distresses.

(3) Determine the length Llongitudinal and Ltransverse of the sides of the rectangle to be

excavated according to the severity of the distress.

Draw a line along the transverse direction of the road at the location of the distress (mainly refers to cracking or rut distress. If it is a pothole or alligator cracking distress, the test pit shall be at the side of the distress). Determine the excavation side length Ltransverse, which must cover the range of serious distresses at this cross section. Draw lines (2 lines) longitudinally from the two ends of Ltransverse and at right angles to it towards the side having distress. Determine the other side to be excavated, Llongitudinal, which shall cover the range of distresses in the longitudinal direction of the road. Finally, connect the ends of two Llongitudinal to form a rectangular frame to be excavated, the length and width shall not be less than 400mm.

(4) Use the hand-held jack hammer to carefully excavate the materials of the upper layer along the drawn lines. The excavated depth of the surface layer shall just reach the top of the next layer.

Be careful to not touch the lower layer, especially at the cracks positions.

(5) Use a jack hammer or chisel and hammer to trim the pit walls of the upper layer, shovel out the waste with a spade or trowel, clear the dust and loose material at the bottom and surrounding walls of the first layer with a brush or blower.

(6) After first layer has been excavated and tested, observe and describe the characteristics of the visible distresses on the second layer and record them.

(7) Repeat the above steps until reaching a layer with no distress. From the second layer, each side of the lower layer shall be 150 mm smaller than the corresponding side of the upper layer, that is to say, it shall be excavated into a benched shape. The width of the benches shall not be less than 100 mm. Diagrams of the elevation and plan of the excavation are shown in Figures T 0976-1 and T 0976-2

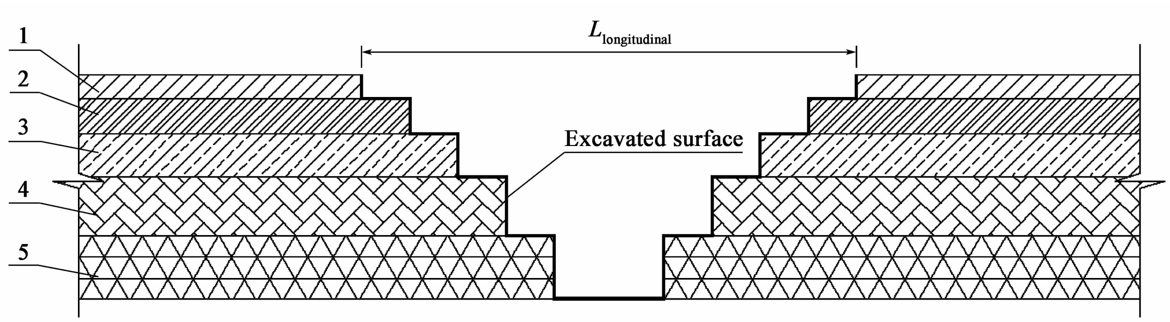


Figure T 0976-1 The schematic diagram of cross section (Note: 1, 2, 3, 4, 5 refer to each structural layer of pavement)

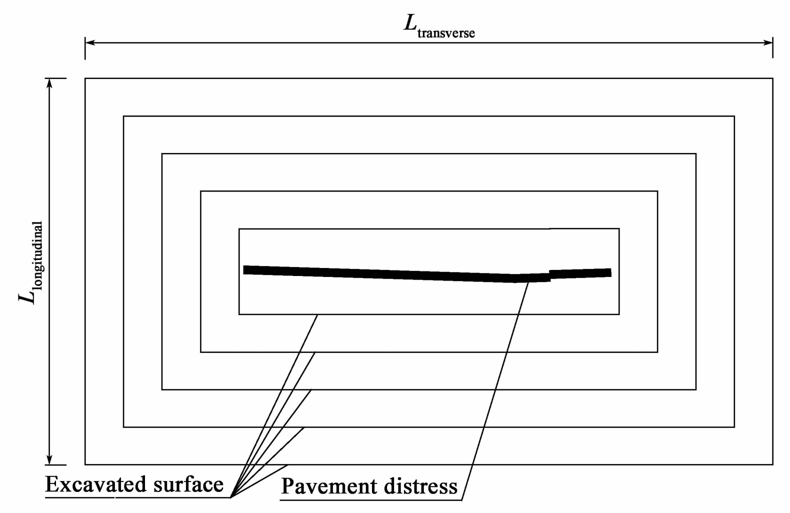


Figure T 0976-2　The schematic diagram of the test pit plan view

(8) When recording the thickness of each layer, use a 500mm steel ruler to measure the thickness at the four corners of the pit and at the midpoint of each side. Take the average value of the measured thicknesses as the thickness of the layer, accurate to 1mm. When a rut distress is being surveyed, use a diamond saw to cut the entire surface layer transversely and at right angles to the rut, so as to form a smooth profile. Use a steel ruler to measure the thickness of the upper surface layer, middle surface layer and lower surface layer at various points, accurate to 1mm.

(9) During the excavation process, the material modulus, moisture content and any other properties of the various layers can also be tested, if necessary.

(10) Excavate and test each layer until the last layer is tested and recorded. The whole test process can be photographed or videotaped if required for future reference.

4　Data processing

The distress conditions of each test location shall be summarized statistically and considered as the distress survey results of the whole survey area.

5　Report

The following technical information shall be reported for this method:

(1) Information of test location (stake number, structure type of pavement, etc.)

(2) Test record of pavement structure distresses, excavation profile and image data.

(3) The material modulus, moisture content and other indicators of various test layers.

***Background*:**

As a common method of testing structural distresses of an asphalt pavement during pavement maintenance, the test pit method, based on the research results of Shandong Academy of Transportation Science and Research, has been compiled and included in this edition by considering the actual situations of pavement distresses and conclusions from site practices.

The test pit method is considered to be a destructive test. In order to reduce the damage to the pavement or prevent causing future problems, a non-destructive method shall be used as far as possible for the testing process. The numbers of test points or test methods are given in the relevant specifications.

Currently, for distress repair, jack hammer is often used for site excavation. The excavated size and depth can be determined according to the actual situation on site. Considering that a diamond saw will produce slurry (wet cutting) or a lot of dust (dry cutting) during the cutting process, it is seldom used to cut the edges of an area to be repaired. However, when investigating the rutting distress, a blade is normally used as it has a smooth cutting face to facilitate observation.

12 Others

T 0981—2008 Test method for measuring paving temperature of hot mix asphalt

1 Scope of application

1.1 This test method is used to test the construction temperature of hot mix or warm mix asphalt mixture, including the mixing temperature of asphalt at the time of leaving the mixing plant, the temperature of the mix during paving or compaction, etc.

1.2 A probe thermometer is mainly used for the control during the construction process and is not used for arbitration testing.

2 Technical requirements for instruments and materials

(1) Probe thermometer: measurement range to 300℃, with a reading resolution of 1℃. It shall be a digital or dial type thermocouple thermometer with metal probe rod which has a length not less than 300 mm. It shall have such a recording function that will allow later checking. Glass thermometer, such as kerosene thermometer, can also be used.

(2) Non-penetration-probe thermometer: infrared thermometer or infrared camera, with reading resolution of 1℃.

(3) Other: cotton or silk soft cloth, screwdriver, etc.

3 Method and procedure

3.1 Testing on laden trucks

(1) The mixing temperature or temperatureof mix being hauled to the site shall be tested in the truck; one test per vehicle. If there is a special test-hole in the side panel of the truck (about 300 mm above the truck bed), the method shown in Figure T 0981 can be applied to directly insert the probe into the mix through the test-hole. If the truck does not have such a test-hole, the probe can be inserted from the top of either side of the mix in the truck. The mixing temperature tested at the mixing plant is the manufactured temperature, and tested at site is the site temperature.

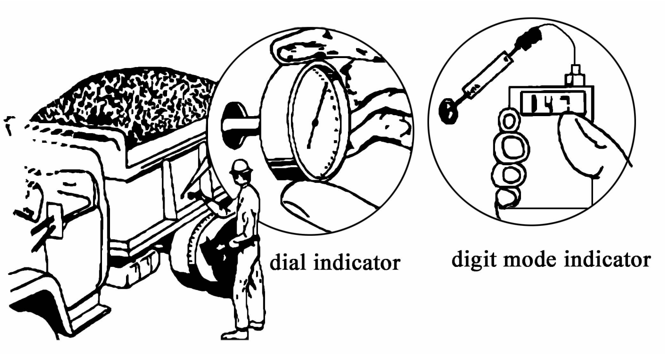


Figure T 0981 Method for testing the temperature of asphalt mixin a truck

(2) At the time of testing, the probe shall be inserted to a depth of not less than 150 mm, and the tested temperature shall be stable and not increase. The temperature shall be read and recorded to an accuracy of 1℃.

3.2 Testing at paving site:

(1) Thepaving temperature of the mix shall be tested in the mass of mix which is spread by either one of the paver's augers. Insert the thermometer probe to a depth of more than 150 mm into the mass of mix. The thermometer shall remain in the mix as the paver moves forward. If the mix at the auger is depleted, remove the thermometer and replace in the mass of the mix in front of the auger. Observe the reading until it remains constant, then read and record the temperature to an accuracy of 1℃.

(2) During the spreading process, whena truck discharges the hot material into the paver, an infrared camera can be used to test the temperature of all the hot material inside the vehicle, and save the data in the form of temperature images. Record the highest temperature, the lowest temperature, and calculate the maximum temperature difference, accurate to 1℃.

(3) The paving temperature shall be tested once per truck.

3.3 Testing the temperature during compaction process of an asphalt mix

According to requirements, select the test points for each stage of the rolling process, such as at the beginning of initial compaction, secondary compaction or final finishing compaction.

(1) By probe thermometer

Push the probe carefully into the layer of mix to a depth of half its thickness. Gently press the disturbed mix around the thermometer, monitor the change in reading until it no longer increases, read and record the temperature, accurate to 1℃. After recording the thermometer reading, immediately pull it out and insert into the mix at the next test point. When it becomes difficult to insert the probe into the mix, a small screwdriver can be used to make a hole before inserting the thermometer. When the temperature is low and the mix is hard, it is not appropriate to test with a glass thermometer or semiconductor point-thermometer with glass probe.

(2) By non-penetration infrared thermometer

A non-penetration infrared thermometer is used to test the temperature at a single point of the surface. This temperature is generally used for self-inspection by contractors or for process control during construction. When measuring temperature, it is required to aim at the surface of the asphalt mix and take more than 3 points, until the measured temperature difference of the last 3 readings is not more than 1℃. Read and record the last measurement, accurate to 1℃.

(3) By infrared camera

The infrared camera is used to test the surface temperatureof an area, and the tested temperature is generally used for construction control. During the test, the infrared camera shall be aimed at the testing area to select images for saving, and the recorded data is in the form of a temperature field image. The highest temperature and lowest temperature (in this image) are also recorded, and the maximum temperature difference is calculated, accurate to 1℃.

4 Data processing

Not less than 3 measuring points of compaction temperature shall be tested in anarea, and their average value shall be taken as the tested temperature. For the infrared camera, it is one test for an area.

5 Reports

The report of this method shall include the following technical information:

(1) Hot mix asphalt information.

(2) Test methods.

(3) Tested temperature orimages of the field tested temperature and the maximum temperature difference.

***Background*:**
*Construction temperatures of hot mix asphalt, including manufacturing temperature, spreading temperature, rolling temperature and so on, have been clearly regulated and specified in the current Technical Specifications for of Highway Asphalt pavement Construction (JTG F*40—2004). *The construction temperature of an asphalt mix will be directly related to the construction quality of an asphalt pavement and thus performance. For this reason it is one of the key items for construction quality control.*

There are two kinds of thermometers that are used inpractice. One is the penetration type, which is a thermocouple thermometer with a metal penetration probe rod and digital display or dial indicator. Another penetration type is a glass thermometer with liquid such as kerosene inside. The other type is a non-penetration one, mainly an infrared thermometer or infrared camera. The penetration types measure temperature more accurately, but with low efficiency. For this reason it is generally used as standard test method; whereas the non-contact method is mainly used to test surface temperature, but with high efficiency, and it is used more for self-inspection by contractors during the construction process. Furthermore, the infrared camera is widely used as it is more efficient, and this is often used by a third party to check the temperature variation. Therefore, considering the actual situation of temperature testing in practice in China the non-penetration method for temperature testing was added.

Currently there are many warm mix asphalt projects being constructed in China. The temperature testing methods mentioned in this chapter are also suitable for the warm mix asphalt.

T 0982—1995 Measurement method for quantity of sprayed or spread material (bitumen or aggregate)

1 Scope of application

This method is suitable formeasuring the quantity of bitumen or stone chips used in surface treatment, seal coat, penetration macadam, prime coat, tack coat, etc.

2 Technical requirements for apparatus and materials

(1) Balance with a graduation value not greater than 1 g.

(2) Tray: metal tray with an area of not less than 1000 cm^2 and a depth not less than 10 mm.

(3) Steel tape or measuring tape.

(4) Weighbridge.

(5) Paper, cloth and other splash stopper material, to prevent the bitumen material from splashing out of the tray.

3 Methods andprocedure

3.1 By tray

(1) Measure the area of the tray with a steel tape and calculate it with an accuracy to 0.1 cm^2. Place paper or cloth in the tray and weigh the tray and anti-splash material ($m1$) accurate to 1g.

(2) Based on the planned length of road section for spraying bitumen for a chip seal, a tray shall be placed anywhere transversely except in the wheel paths and at one third of the length away

from either end.

(3) The bitumen distributor shall travel at normalworking speed and in the normal working mode.

(4) Check that no bitumen is splashed out of the tray and is lost. If this happens take precautionsand remake a new test.

(5)If the bitumen has no loss by splashing, the tray with bitumen and anti-splash material shall be carefully removed and weighed (m_2), accurate to 1g.

(6) The area under the tray where bitumen was not applied shall be covered with bitumen by hand. For determining the chip application rate a clean plate will be placed on some stones after the bitumen has been sprayed and before the chip spreader passes by. The same procedure will be used as for the bitumen application rate.

3.2 Weighbridge method

(1) Before spraying or spreading the chips with the bitumen distributor or chipspreader, accurately weigh the total mass (m_3) of the distributor or spreader, including its loaded material, on a weighbridge.

(2) The total area of bitumen sprayed or chips spread shall be calculated by accurately measuring the length and width of sprayed or spread area with a measuring tape and the result shall be accurate to $1m^2$.

(3) After spraying or spreading, weigh the total mass (m_4) of the distributor or spreader together with the remaining material on a weighbridge.

4 Data processing

4.1 The application rate ofbitumen sprayed or chips spread is calculated by equation T 0982-1 when the tray method is applied.

$$Q = \frac{m_2 - m_1}{1000A_1} \qquad \text{(T 0982-1)}$$

Where:

Q——application rate ofbitumen sprayed or chips spread (kg/m^2);
m_1—— the mass of the tray together with its anti-splash material (g);
m_2—— total mass of tray, anti-splash material and bitumen or chips (g);
A_1—— area of tray (m^2).

4.2 When the weighbridge method is used, the application rate ofbitumen sprayed or chips spread is calculated by equation T 0982-2

$$Q = \frac{m_3 - m_4}{1000A_2} \quad \text{(T 0982-2)}$$

Where:

m_3—— total mass of the distributor before spraying or spreader before application (kg);
m_4—— total mass of the distributor after spraying or spreader after application (kg);
A_2—— Total area sprayed or spread (m^2)

4.3 Twice tests as a parallel test shall be made on the weighbridge. The arithmetic mean value of the two tests is taken as the test result of the application rate of bitumen sprayed or chips spread. When the difference between the two test values exceeds 10% of their mean value, the test shall be repeated.

5 Reports

The report of this method shall include the following technical information:

(1) Information of construction materials (functions, etc.).

(2) Test methods.

(3) Quantity of construction materials used.

Background:

Since chip seals use a prime coat, tack coat and chips, it is important to determine the quantity of bitumen sprayed and also chips spread. Therefore, within the scope of this method, the approach is improved.

The weighbridge method isspecified in less detail in the former edition of these Methods. In this revision, the test steps are clearer, and the calculation formula is given.

T 0984—2008 Method for checking the penetration depth of a prime coat

1 Scope of application

This method is suitable for testing the penetration depthof a prime coat to evaluate the penetration effect of a prime coat.

2 Technical requirements for apparatus and materials

(1) Pavement coring machine: hand-operated or vehicle-mounted, equipped with a water cooling device. Drill bit diameter is φ100mm or φ150mm.

(2) Chisels, screwdrivers.

(3) Base plate: A square metal tray made of sheet metal with a round hole in the center. The dimensions are same as the dimensions of the density plate in T 0921.

(4) Steelruler: measuring range not greater than 200 mm, graduated in 1 mm.

(5) Backfill material: same as the material used in the base course.

(6) Backfill tools: rammer, hammer, etc.

(7) Others: brush, protractor, cotton cloth, large metal tray, etc.

3 Methods and procedures

3.1 Preparation

(1) For stabilized materials

After the prime coat has dried, a core sample position is randomly selected from the road section to be tested, and a core sample is drilled according to the method specified in T 0903 of JTG 3450—2019. The core sample has a diameter of 100 mm or 150 mm, and its height shall not be less than 50 mm.

(2) For unstabilized materials

After the prime coat has dried, a point is randomly selected from the test road section for testing. Place the base plate on the surface of the base course, and dig a hole through the base plate to a depth not less than 50 mm. During the process of digging, the material loosened shall be taken out and placed into a large metal tray.

3.2 Test procedure

(1) For stabilized materials

① Remove dust from the surface of the core sample by gently applying water and brush clean (or use a cotton cloth).

② The core sample shall be air-dried so that the penetration of the prime coat interface can be discerned on the core sample.

③ The circumference of the top surface of the core sample shall be divided equally into eight parts with a steel ruler or a protractor, as shown in Figure T 0984. The penetration depth of the prime coat at each equal point on the circumference shall be measured to an accuracy of 0.5 mm, represented as d_i ($i = 1, 2, \cdots, 8$) respectively.

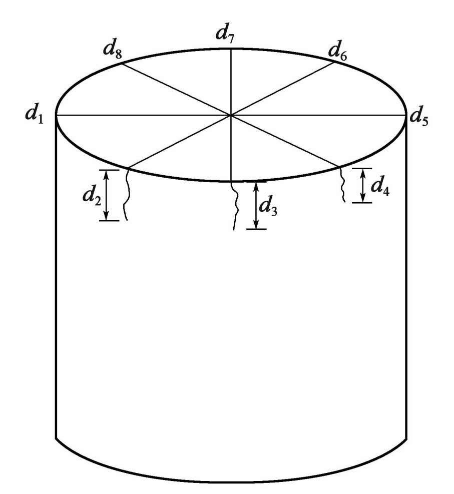


Figure T 0984 Schematic diagram formeasuring penetration depth of a prime coat

(2) For unstabilized materials

① Gently remove stones from the inner wall of the hole by hand and gently sweep it with a brush (or cotton cloth).

② The penetration depth of the prime coat is measured at 8 equally divided points on the rim of the hole to an accuracy to 0.5 mm, record them as $d_i(i=1,2,\cdots,8)$ as shown in Figure T 0984.

3.3 Backfilling

(1) For stabilized materials

Clean all loose material in thedrilled-out hole, and dry water in the hole with a cotton cloth. The same material as the base course shall be used for backfilling. Tamp and hammer until it is firm.

(2) For unstabilized materials

Clean all loose material in thedug-out hole and add to the material placed in the large metal tray to be used as backfill. Tamp and hammer it until it is firm. Should the filling material be insufficient, the same material as was used for the base shall be hand-mixed with the correct amount of water and then used to backfill the hole. Tamp and hammer until it is firm.

4 Data processing

Exclude the lowest 3 penetration depth values and calculate the arithmetic mean value of the other 5 penetration depths and record as the penetration depth at a measuring point.

5 Reports

The report of this method shall include the following technical information:

(1) Test location information (stakes, etc.).

(2) Penetration depth.

***Background*:**

According to theTechnical Specifications for Highway Asphalt Pavement Construction (*JTG F*40—2004), *the requirements for penetration depth of a sprayed prime coat over stabilized base and graded crushed stone base are specified. In recent years, graded crushed stone and other flexible bases have become popular. For this reason the test method to measure penetration depth of a prime coat in graded crushed stone base or other flexible bases is added.*

In the former edition the sampling frequency was recommended as taking a group of 3 *core samples from every* 5000 m^2 *of sprayed area and taking the arithmetic mean penetration depth to evaluate whether the prime coat complies with the requirements. As such requirements shall not be included in the context of this method, they are deleted in this revision.*

T 0985—2019　Test method for interlayer bond strength

1　Scope of application

This method is applicable for testing and evaluating the interlayer bond strength between two different material layers, namely between the upper layer, such as a seal coat, tack coat, prime coat and waterproof layer, and the structural layer, such as asphalt concrete layer, cement concrete layer, bridge deck. It can also be used to evaluate the bond strength of a composite structural layer consisting of multiple-bonded layers. .

2　Technical requirements for apparatus and materials

(1) Pull-off tester

① The pull-off tester: Any pull-off tester which can function indoors and outdoors and is capable of applying the specified load rate without obvious vibration or distortion. The tensile load rate is 25 ± 15 kPa / s.

② Pull head-plate: It is bonded to the surface of the road or core specimen to apply a tensile force. It is made of stainless steel or brass normally with a diameter of 100 mm ± 0. 1 mm. The pull head-plate can also have other special sizes as required for the test.

(2) Torsional shear testing system

① Torque meter: normal torque meter, equipped with a torsion bar, together with a torque indicator showing maximum torque. Torque range is 0 to 350 Nm, accurate to 10 Nm. The torque meter shall be equipped with slots that can facilitate installation and dismantling.

② Torsion head-plate: It is bonded to the surface of the pavement or core specimen to facilitate the installation of the torque meter for applying a torque; it is made of low carbon steel with a diameter of 95 mm ± 5 mm and a thickness of 14 mm ± 2 mm.

(3) Thermometer: resolution 0.1℃.

(4) Measuring ruler: steel ruler, Vernier caliper, etc.

(5) Stopwatch: accurate to 1s.

(6) Adhesive: To bond the head-plate to the surface of the road or core specimen, such as rapid-hardening epoxy resin.

(7) Core drill: 100 mm or 200 mm. in diameter bit.

(8) Other: scraper, etc.

3 Pull-off test method and procedure

3.1 Preparation

(1) Before testing the road construction materials must be adequately cured. Depending on the field situation, the test points are randomly selected and marked. Measure and record the surface temperature at the measuring point.

(2) For testing the bond strength between the structural layer and the upper layer, the method for installing the pull head-plate and cutting a circular groove is shown in Figure T 0985-1. First, measure the pull head-plate diameter with a Vernier caliper, accurate to 0.1 mm. Then clean the surface at the testing point, coat the bottom of the pull head-plate with a layer of adhesive, and quickly place the pull head-plate on the surface of the testing point. Allow the adhesive to cure until it is hardened completely. Once hardened, use a cutting tool to cut a circular groove around the edge of the pull head-plate to a depth reaching to the top of the lower layer.

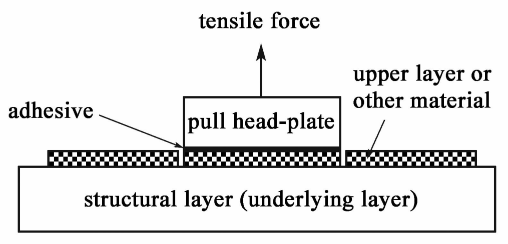


Figure T 0985-1 Schematic diagram for bonding the pull head-plate in the interlayer bond test between structural layer and upper layer

(3) When testing the interlayer bond strength of a composite structural layer – bonded to a structural layer, cut out a circular groove with a core drill and install the pull head-plate as shown in Figure T 0985-2. The ring groove is cut by a core drill to an inner diameter of 100mm to 102mm and to a depth 10 mm below the underlying layer surface. Clean the loose material inside the ring groove, then measure the inner diameter of the circular groove by Vernier caliper with an accuracy of 0.1mm. Next wash this test area and allow it to dry. Then apply the adhesive to the head-plate and place within the circular groove. Be careful that the adhesive does not spill into the circular groove. Allow the adhesive to cure until it is hardened completely. Prepare for the next step of test.

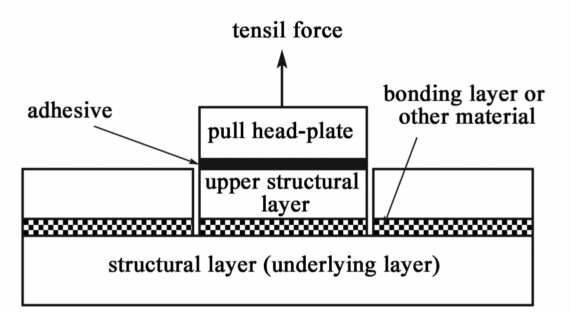


Figure T 0985-2 Schematic diagram for bonding the pull head-plate in the composite structural layer bond test

3.2 Test procedure

(1) Install thepull-off tester, start the test with tensile loading rate of 25 ± 15 kPa/s. If another loading rate is selected, it must be indicated in the report.

(2) The maximum tensile force F when the test piece has failed is read and recorded as the test result.

(3) Examine the failed surface after the test piece is broken. It shall be described in detail in the report.

(4) Three points need to be tested at each test location. Test points shall not be closer than 500 mm from each other and within an overall distance of 2 m.

4 Method and procedure of torsional shear test

4.1 Preparation

(1) The materials such as surface treatment, seal coat, tack coat, prime coat and waterproof

layer shall be fully cured before testing the bond strength on site. The interlayer temperature shall be tested before the test and given in the report.

(2) Depending on the site conditions, the test points are randomly selected and marked on the site.

(3) When the total thickness of the bonding layer and its upper layer is less than 15 mm, preparation for the test shall be carried out as shown in Figure T 0985-3. As described in subsection (2) of Clause 3.1 in this method, prepare the surface, glue the torque head-plate onto the surface, and continue with the following steps of the test. The surface of the specimen shall be horizontal.

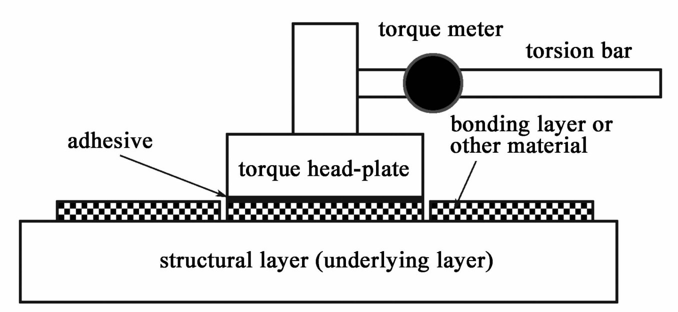


Figure T 0985-3　Schematic diagram oftorsional shear test on a thin layer

(4) When the total thickness of the bonding layer and its upper-layer is greater than 15 mm, prepare the test as shown in Figure T 0985-4. As described in subsection (3) of Clause 3.1 in this method, prepare the surface, glue the torque head-plate onto the surface, and continue with the following steps of the test.

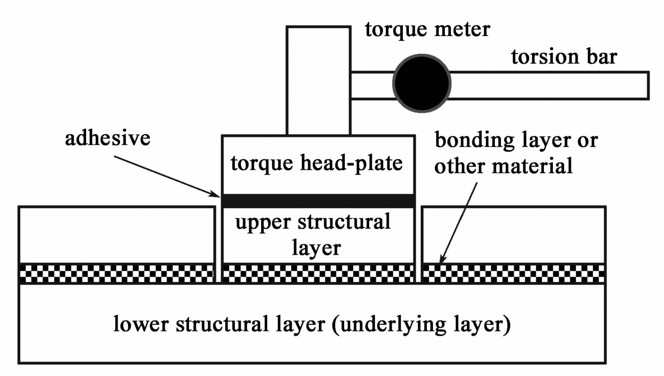


Figure T 0985-4　Schematic diagram oftorsional shear test on a thicker layer

4.2 Test procedure

(1) When theadhesive has cured, the torque meter is mounted on the torque head-plate.

(2) Measure and recordthe road surface temperature.

(3) The torsion bar is rotatedmanually at a uniform speed so that it rotates 90° within 30 s ± 5 s. During the test it is important to ensure that the torsion bar and torque head-plate are parallel to the surface of the pavement or the specimen (deviation angle less than 10°) and the maximum torque is recorded when the specimen is broken.

(4) Examine the failed cross section and describe it in detail.

(5) Three points need to be tested at eachtest location. Test points shall not be closer than 500 mm from each other and within an overall distance of 2 m.

5 Data processing

5.1 Any one of the three test values from a location shall not exceed 20 percent of their average value. Otherwise the test results for that location shall be discarded.

5.2 Thepull-off strength is calculated by equation T 0985-1 with the measured maximum tensile force and the measured diameter of the pull head-plate (or the inner diameter of the circular groove):

$$\tau_{\mathrm{TAT}} = \frac{4F}{3.14D^2} \qquad \text{(T 0985-1)}$$

Where: τ_{TAT}—— pull-off strength, MPa,

F—— maximum pull-off force, N;

D——measured diameter of pull head plate, (or the inner diameter of the circular groove), in mm.

5.3 The torsional shear strength is calculated by equation T 0985-2 with the measured maximum torque and the diameter of the torque head-plate:

$$\tau_{\mathrm{TBT}} = \frac{12 \times M \times 10^{6}}{3.14 \times D^{3}} \tag{T 0985-2}$$

τ_{TAT}:—— inter-layer torsional shear strength, kPa;

M—— Maximum torque measured by torque meter, Nm;

D ——Diameter of torque head-plate, mm.

6 Report

The report of this method shall include the following technical information:

(1) Test location information (project name, stake number, information of material and structure, etc.).

(2) Pull-off strength or torsional shear strength.

(3) Description of failed cross section.

***Background*:**

During the process of design, project transfer, certifying completion and maintenance of a pavement, problems of interlayer bond are becoming more prominent. Many pavement problems, such as corrugation, rutting and shoving of an asphalt pavement, are caused by poor interlayer bond. To better guide the activities of testing and inspection, the standard methods have been developed in detail to test the interlayer bond.

During the process of compiling this method, reference was made to the prEN 12697-48, *AASHTO T*323, *and the technical guide for the design and construction of a pavement deck on a highway steel box girder bridge.*

At present, there are many methods internationallyfor testing interlayer bonding strength, which can be classified into five categories according to the prEN 12697-48.

(1) *Torque bond testor TBT*

It is suitable for measuring bond strength on site and in the laboratory, mainly for evaluating the interlayer performance in resisting traffic load forces when accelerating or braking, or the horizontal stresses caused by thermal displacement between different layers, such as the interlayer between asphalt concrete and micro surface treatment layer, or between asphalt concrete and cement concrete surface, etc. It can be used to evaluate the interlayer bond strength between bond layer and structural layer or between structural layer and bond layer.

(2) *Shear Bond Testor SBT*

It is mainly a laboratory evaluation method, generally for evaluating the shear strength of a composite layer of a structural layer-bonded to a structural layer. The bond strength between a bond layer and a structural layer can be evaluated with the help of a bond testing molds. It mainly evaluates the interlayer performance in resisting traffic load forces during acceleration or braking, and the horizontal stress caused by thermal displacement between different paving layers, such as between asphalt concrete and a micro surface treatment layer, or between asphalt concrete and cement concrete surface, etc. In general, it is used to evaluate the bond strength of the composite layer of a structural layer bonded to a-structural layer. The bond strength between the bond layer and a structural layer can also be evaluated through an additional bond expansion test mold.

(3) *Tensile adhesion test (pull-off test)*

It is suitable for measuring bond strength on site and in the laboratory, evaluating tensile strength under vertical load, generally evaluating bond strength between bond layer and structural layer, but also evaluating bond strength between structural layer and structural layer.

(4) *Compressive shear bond test*

It is mainly alaboratory evaluation method, which is used to evaluate the interlayer shear strength under both horizontal and vertical loads.

(5) *Cyclic compressive shear bond test*

Thismethod is used to evaluate the interlayer bond strength under different temperatures, loading frequencies and stress levels. It may also be used to evaluate interlayer shear strength under horizontal and vertical loads.

The first three methods are widely used for testing, but the latter two are currently only used for scientific research.

Of the first three test methods, China mainly uses the tensile adhesion test method, while the United States mainly uses the shear bond test, and Europe mainly uses the torque bond test and the shear bond test. The torque bond test and the shear bond tests evaluate the interlayer resistance against horizontal stress, which is closer to the actual situation of pavement failure. The tensile adhesion test (pull-off test) measures the vertical load, which is different from the forces causing actual pavement failure, so it is only an indirect evaluation method.

Currently, China mainly uses the tensile adhesion test for interlayer bond strength on site, although torque bond tests are sometimes adopted. Sometimes test personnel use the shear bond test on site, but since this test is more complicated, it is seldom used. For this reason, this test method is not *included in this edition. Unlike China, the torque bond test is widely used in the EU, as it can replace the field shear bond test, and this method is easy to perform. The test procedure for laboratory molded specimens or cores taken on site that are tested in the laboratory to determine bond strength is not included as the procedure is supposed to be listed in the relevant bitumen or asphalt mix test methods.*

T 0986—2019 Measuringthe influence of the pavement on traffic noise by statistical pass-by method

1 Scope of application

This method is applicable to measuring traffic noise by statistical pass-by method to evaluate the traffic noiseinfluence of a pavement surface.

2 Technical requirements for apparatus and materials

(1) Sound level meter: meets the requirements ofa Class 1 sound level meter specified in 'Electro-acoustic sound level meter, Part 1: specifications' (GB/T 3785.1—2010), covering the frequency range of 315 to 5000 Hz. The microphone is a free-field type with a windshield.

(2) Frequency Analyzer: A 1/3 octave-band filter with a frequency rangeof 315-5000 Hz. Meet the requirements specified in 'Octave-band and fractional octave-band filters' (GB/T 3241—1998).

(3) Sound calibrator: meet the requirements of Class 1 specified in 'Sound Calibrators' (GB/T 15173—1994).

(4) Speed measuring instrument: Multi-function radar speed measuring instrument, which can measure the speed of a vehicle at the moment it passes the microphones, and its standard reliability is less than 3%.

(5) Thermometer: Thermocouple thermometer or kerosene glass thermometer with a graduation value of 1℃.

3 Preparation

3.1 Selecting test road sections

(1) The selected test section shall be straight and not less than 60 m long (not less than 100 m long inthe case that the average speed of traffic flow is not less than 100 km/h), and the longitudinal gradient is not more than 1%. The surface of the road shall be dry, without obvious pollutants. The condition of the road surface shall be good, but a section with joints shall be avoided.

(2) Newly paved roads shall not be tested for traffic noise, and shall be tested after six months of opening to traffic.

(3) The background noiseat the selected test section shall not be too large to prevent it from interfering with traffic noise measurements. The A-weighted sound pressure level of noise generated by other sources in the field is generally required to be at least 10 dB lower than the maximum sound level of traffic noise at the time of testing.

(4) The vehicle-type compositionof the traffic at the selected test section shall meet the requirements of Clause 3.5.

(5) There shall be no acoustic reflective objects, such as buildings or noise barriers, etc., within 25 m from the microphone in the selected test section.

(6) In the selected test section the influence of a guardrail on test results shall be avoided. There shall be no corrugated guardrail or concrete guardrail in the rectangular shaded area shown in Figure T 0986-1. If a section with guardrail needs to be tested, the guardrail shall either be removed or covered with sound absorbing material before testing.

(7) Loose material in the area between the microphone and the center line of the road shall be removed. Sections with tall or dense vegetation shall not be selected. When there is a side ditch or other significant low-lying area adjacent to the road, it shall be at least 5 m away from the center line of the test lane.

3.2 The test shall not be carried out on windy days (generally wind speed not more than 5 m/s) or rainy days. During the test, the ambient air temperature shall be 10℃ to 35℃ (5℃ to 30℃

when the test region falls in a "cool' climate zone). Preferably the test shall be conducted when the air temperature is about 20℃.

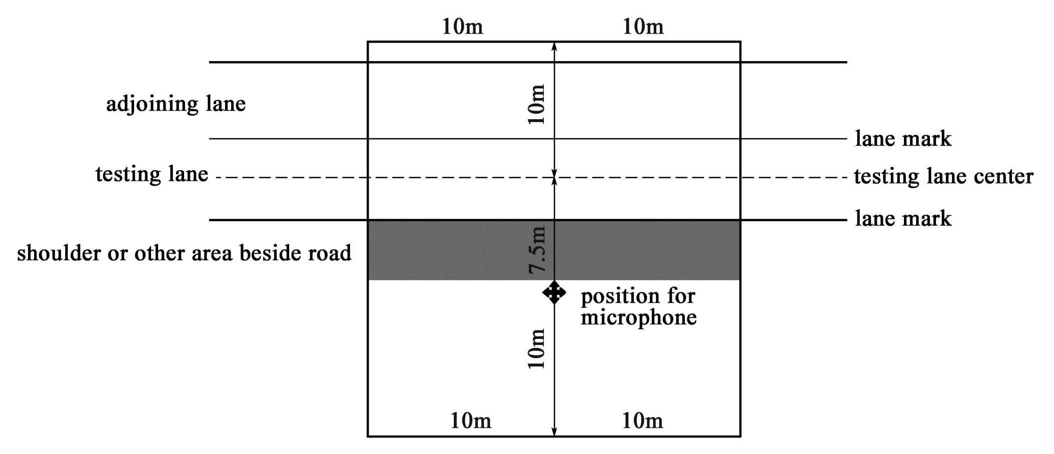


Figure T 0986-1 Requirements for minimizing the impact of a guardrail on traffic noise measurement

3.3 Microphone position

The microphone is normallypositioned to measure the noise of the right or slow lane in the driving direction. The microphone is positioned in the middle (in the longitudinal direction) of the selected test section, and shall normally be placed on the right shoulder or berm of the test lane and the horizontal distance from the center line of the test lane shall be 7.5 ±0.1 m. When the space for placing the microphone is constrained, it can be placed on the left side of the test lane after ensuring that safety is guaranteed.

3.4 Installation andinspection of noise measuring device

(1) Install the noise measuring device as required, ensuring that the microphone is at a height of 1.2 ±0.1 m above the surface of the test lane and its windshield is installed.

(2) The noise measuring device shall be switched on to check if it operates normally and if the voltage is normal. Its sensitivity shall be checked with sound calibrators.

3.5 Vehicle classification and number of vehicles to be measured

Vehicles in the trafficstream over the test section shall be classified for data processing. In this method, the vehicles in the traffic stream are divided into three categories. And the number of vehicles to be tested is as follows (other vehicles need not be tested):

Category 1: Passenger car: not less than 100 vehicles;

Category 2: Truck, bus andmotor coach with two axles: Not less than 30 vehicles;

Category 3: Truck, bus and coach with more than two axles: Not less than 30 vehicles.

The total number of vehicles in categories 2 and 3 shall not be less than 80.

4 Method and procedure

4.1 Noise andspeed tests

(1) Sound level test. Whena vehicle passes by, the maximum A-weighted sound pressure level is measured by using the time-weighted "fast" mode (" F" mode) with an accuracy of 0.01 dB.

(2) Spectrum test. 1/3 octave spectrum is recommended to be measured. The mode for average time is 'fast' mode. The spectrum is collected when the A-weighted sound pressure level reaches its highest value as a vehicle passes by.

(3) Speed testing. The vehicle speed shall be measured when the middle of the vehicle passes by the microphone, accurate to 1 km/h.

4.2 Temperaturemeasurement

Use a thermometer tomeasure the air temperature at a height of 1.0 to 1.5 m above the road surface for at least 15 s. Continuous testing is preferred. However, if the continuous test is difficult to perform, the air temperature shall be measured at least every 15 min with an accuracy of 1℃.

4.3 Checkingduring testing

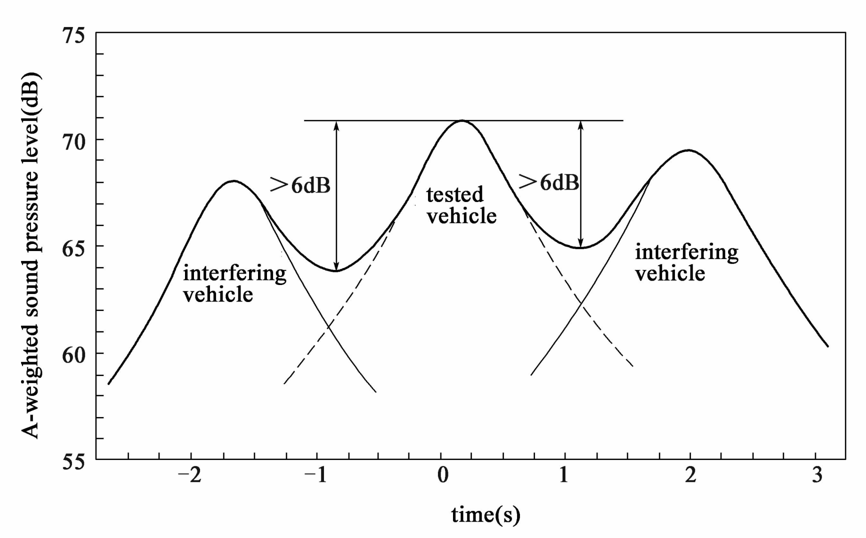
A sound calibrator is used to check the overall sensitivity of the sound measuring system (including the microphone) every 4 h and at the end of the test. Any deviation shall be recorded in the test report and all intermediate tests shall be invalid if thedeviation of the calibration reading exceeds 0.5 dB. (1)。

4.4 Situations when testing shall not take place or test results be rejected

For the followingsituations the vehicle shall not be tested or the test results shall be rejected.

(1) The A-weighted sound pressure difference between the test vehicle anda vehicle before or after as determined by Figure T 0986-3 is less than 6 dB.

(2)When the tested vehicle reaches its maximum sound pressure level, the difference between this maximum pressure level and the total sound pressure level of background noise such as other traffic vehicles is less than 10 dB.



(Thick solid lines indicate the total sound pressure level of the vehicle being tested and the vehicle before or after)

Figure T 0986-3 Diagram of signal-to-noise ratio (SNR) for a pass by vehicle

(3) The pressure levels at the test position generated by the tested vehicle and another vehicle almost reach their maximum values at the same time, which makes it difficult to differentiate the peak values.

(4) Tested vehicle with obvious abnormal noise, such as the noise caused by a malfunction of an exhaust system, or by vehicle vibrating or honking.

(5) Vehicles travelling at non-uniform speeds, or theirtransverse position clearly deviates from the center of the test lane.

(6) Vehicleswith speed less than 50 km/h.

5 Data processing

5.1 Linear regression analysis of sound-leveland vehicle speed

A datapair consists of the sound level and logarithm of vehicle speed (base 10) generated for each vehicle category is calculated and processed. A regression line of sound level and logarithm of vehicle speed (base 10) is obtained by using the least square method.

5.2 Determine thespeed group

Calculate the average speed of tested vehicles as the average speed of the traffic flow, and determine the road speed group according to the following groups:

(1) Low speed: the average speed is 45to 64 km/h;

(2) Medium speed: the average speed is 65to 99 km/h;

(3) High speed: average speed is greater than or equal to 100km/h.

5.3 Determine the reference speed ofthe traffic flow

According to the road speedgroup, the reference speed for each vehicle group is determined as shown in Table T 0986. For the speed range of the vehicle being tested, the standard speed of vehicles in vehicle category 2 and 3 shall be within the range of the measured average speeds ±1 standard deviation. The standard speed of vehicles in category 1 shall be within the measured average speed ±1.5 standard deviation.

Table T 0986 Reference speeds and typical weighting factors for each road speedgroup

Vehicle Category	Standard speed for each group of traffic flow speed, km/h					
	Low Speed		Medium Speed		High Speed	
	Reference Speed	Typical weighting factor	Reference Speed	Typical weighting factor	Reference Speed	Typical weighting factor
Category 1	50	0.900	80	0.800	110	0.700
Category 2	50	0.075	70	0.100	85	0.075
Category 3	50	0.025	70	0.100	85	0.225

5.4 Calculate the sound level at the reference speed

From the regression line as described inClause 5.1, calculate the sound level (y-coordinate) which matches the reference speed on the regression line for each vehicle category.

5.5 Calculatethe statistical pass-by noise index

Using equation T 0986-1, the pass-by index is calculated to an accuracy of 0.1.

$$\text{SPBI} = 10\lg\left[W_1 \times 10^{L_1/10} + W_2\left(\frac{V_1}{V_2}\right) \times 10^{L_2/10} + W_3\left(\frac{V_1}{V_3}\right) \times 10^{L_3/10}\right] \quad \text{(T 0986-1)}$$

Where: SPBI——statistical pass-by index, dB;

L_1, L_2, L_3——sound levels of vehicles at standard speed in vehiclecategory 1, 2 or 3, dB;

W_1, W_2, W_3——weighting factor. Based on the proportion of vehicles in category 1, 2 or 3 in the traffic flow. The sum of $W_1 + W_2 + W_3$ is 1. Typical weighting factors in Table T0986-1 were obtained from ‘Acoustic Measurement of the Influence of Road Surfaces on Traffic Noise Part 1: Statistical Pass-By Method.’ (GB/T 20243.

1—2006). These values can be adopted when the data required for the weighting factor is not available.

v_1, v_2, v_3——Standard speed of vehicles in vehicle category 1, 2, or 3, km/h.

6 Report

The report of this method shall include the following technical information:

(1) Test section information (stake number, lane position, type of road tested, surface condition, surrounding reflective objects, etc.)

(2) Test time, weather conditions during the test period, air temperature, test equipment and microphone position.

(3) Weighting factors by road speedgroup and by vehicle category.

(4) Data of measured sound level and speed, regressionline of sound-level and speed, sound level at standard speed and statistical pass-by index.

***Background*:**
Since traffic noise is greatly affected by the external environment, testing is a complex process. At present, the evaluation methods of road noiseused in the world are mainly the far-field method and the close-proximity method. The far-field method includes the control pass-by method (CPB) and the statistical pass-by method (SPB).

(1) *Controlpass-by method (CPB)*
This methoduses a specified combination of standard vehicles/tires to test the peak noise as vehicles pass by and is therefore called the control pass-by method. Depending on application, the test will be carried out under different test conditions, such as vehicles that run at a constant speed, or vehicles are coasting, or engines are switched off, or just testing the noise from tires; the vehicle speed can also be decided depending on the actual situation. Currently, there are two main CPB standard testing methods: BRRC method and the French-German method. Both methods require the vehicle to run with engine switched off when close to the microphone to test the tire noise, i. e., coasting past the microphone. The BRRC approach uses a single vehicle. The French-German method uses a specified combination of four vehicles/tires, mainly used on lightly trafficked roads.

(2) *Statisticalpass-by method (SPB)*
The noise measurement methodused in the statistical pass-by method (SPB) is similar to that of the

control pass-by method (CPB), but the traffic flow is different. CPB method uses the specified combination of standard vehicles/tires, while SPB selects 180 *or more vehicles for testing from the free traffic flow with a speed greater than* 50*km/h.*

Figure T 0986-5 Set up of traffic noise test under far-field method

In the ISO standards, the statistical pass-by method is the only standard belonging to the far-field method. It is ISO 11819-1, Acoustic Measurement of the Influence of Road Surfaces on Traffic Noise Part 1: Statistical Pass-By Method. No CPB standard was found. In the EU standard, there is also only EN ISO 11819-1 'The standard of statistical pass-by method', which is equivalent to the international standard ISO 11819-1 method. China also has the standard for the statistical pass-by method, GB 20243.1 being equivalent to ISO 11819-1.

Currently, the statistical pass-by method by the far-field method is mainly used in highway traffic noise measurement, and it is also used as a highway EIA (Environment Impact Assessment) standard. This method used ISO 11819-1 and GB 20243.1 as reference for compiling. It can be used to compare the traffic noise of different roads under different traffic flow conditions. It is applicable to a traffic flow with a constant speed, that is, free traffic flow with a specific speed greater than or equal to 50km/h. Under other driving conditions, i.e., non-free traffic flow conditions, such as at intersections or congested traffic, noise from the road surface is less important.

If on a two-way multi-lane highway it is not possible to position the microphone on the right hand side of the road since the shoulder is too narrow or for other reasons, the microphone can be placed on the left hand side of the test lane. If it is a two-way two lane road, then measure the traffic noise from the outer lane. If it is a two-way road with three or more lanes in each direction, the traffic flow can be directed to the inner first lane to test the traffic noise.

In order to ensure that the number of vehicles tested still meet the requirements ofClause 3.5 after the vehicles specified in Clause 4.4 are removed, it is normally necessary to increase the number of measured vehicles during the test.

The typical value of the weighting factor is determined according to the time period and day or night in different regions of China. Typical weighting factors in Table T 0986 were obtained from Table 1 in GB/T 20243-1-2006, representing the most typical case. With the same weighting factor, the influence of road surface on traffic noise is relatively comparable. If necessary, a weighting factor suitable for local conditions can also be adopted as the basis for calculation.

T 0987—2019 Road and tire noise emission assessment by CPX (with trailer)

1 Scope of application

The close-proximity method (CPX) is suitable for testing tire noise of a pavement surface with a trailer and is used to evaluate the influence of different pavement types on vehicle tire noise.

2 Technical requirements for apparatus and materials

(1) *Sound level meter: same asClause* 2.1 *in T* 0986 *of JTG* 3450—2019

(2) *Frequency analyzer: same asClause* 2.2 *in T* 0986 *of JTG* 3450—2019.

(3) *Sound calibrator: same asClause* 2.3 *in T* 0986 *of JTG* 3450—2019

(4) *Speed measuring instrument: theaccuracy is better than* 1%. *If it is to be attached to a tire, it shall not be on the driving wheels.*

(5) *Position measuring instrument: Beidou satellite or other positioning system.*

(6) *Thermometer: Thegraduation is* 1℃; *Infrared thermometers are used for pavement temperature. Contact thermometers are used for air temperature.*

(7) *Axle load measuring instrument: The maximum allowable error is* 5%.

(8) *Tire pressure gauge*: *the maximum allowable error is* 4%.

(9) *Test Vehicle*

① *The test vehicle unit* (*hereinafter referred as test vehicle*) *is composed of a towing vehicle and a trailer. One or more test wheels are mounted on the trailer. A screen shall be provided around the test wheels to protect the microphones from background noise interference.*

② *The test vehicle shall meet the following acoustic performance requirements*:

——*Sound reflection conditions inside the acoustical screen chamber*: *the sound reflection inside the screen chamber* (*excluding the reflection from test tires and road surface*), *shall not have a sound pressure level difference of* 1/3 *octave within* 315*Hz to* 5000*Hz greater than* 3*dB.*

——*For the background noise generated by the complete vehicle unit*, *the total A-weighting sound pressure level difference shall not be less than* 10*dB when the test vehicle is tested on its the acoustic performance*, *and the sound pressure level difference of* 1/3 *octave within* 500*Hz to* 5000*Hz shall not be less than* 6*dB*, *and the sound pressure level difference of* 1/3 *octave within* 315*Hz to* 400*Hz shall not be less than* 4*dB.*

——*The capability to resist external background noise*: *the sound pressure level difference shall not be less than* 10*dB when the test vehicle is tested on its acoustic performance.*

——*The acoustic performance of the testvehicle shall be examined when it is used for the first time. It shall also be examined when its key parts are replaced*, *and be examined routinely once every* 1 *to* 2 *years.*

③ *High power engine shall be used. The distance between the tires of the towing vehicle and the microphone shall not be less than* 3*m. When necessary*, *the rear of the towing vehicle shall be equipped with a sound insulation screen to reduce the influence of the towing vehicle noise on the microphone.*

④ *The spring stiffness and damping coefficient of the suspension system shall be similar to that of the suspension system of a passenger car. At least one test wheel shall be installed and the test wheel shall have a standard tire that meets the requirements in Clause* 2.11*of this method. Special narrow tires shall be used for the non-test wheels on the trailer. The distance between a special narrow tire and the microphones shall be as far as possible and not less than* 1.5*m. Furthermore*, *a sound insulation screen shall be installed between the non-test wheels and microphone. The test wheel cannot be mounted on the leading axle or driving axle and shall be able easily dismounted. It is better to adopt a functional design that the test wheel can be lifted off the road with no need to dismount it. If test wheels are installed on both sides of the trailer*, *their spacing* (*the distance between the midpoints of the two tire treads*) *shall be* 1.5*m to* 1.9*m. It is not advisable to install brakes on test wheels. If brakes are installed*, *the test tire shall be checked frequently for wear.*

⑤ *A screen chamber shall be installed to enclose the microphone and test wheel, and the mechanical components of the trailer shall be arranged outside the screen chamber and such as to reduce the influence of external noise on the microphones. The inner wall of screen chamber is made of lightweight sound-absorbing cotton or other materials in the shape of a pyramid, wedge or sharp wave. The total thickness of the internal sound-absorbing materials is about* 75*mm. The sound absorption coefficient must not be less than* 0.60 *in the frequency range of* 315*Hz to* 400*Hz, and not less than* 0.90 *in the frequency range of* 500*Hz to* 5000*Hz. The screen chamber shall be about* 50*mm above the ground (about* 100*mm for testing in an urban area). The lowest part of the screen chamber shall be made of soft material, which shall not move during testing. The screen chamber shall be able to be dismantled easily to be replaced. Its sensitive parts, such as for dust and water absorption, shall be foldable.*

⑥ *Within a range of* 0.3*m from the microphone, there shall be no other sound reflection surface besides the microphone fixing device, road and test wheel. Any reflective surface within the range of* 0.3*m to* 0.6*m from the microphone, such as shaft, frame, underbody, etc., shall be covered with sound absorbent cotton.*

2.10 *Positions of microphone*

①*During tire/road noise testing, a test wheel shall be equipped with two microphones at least at position* 1 *and* 2 *as shown in Figure T* 0987-1 *for simultaneous testing. If necessary, microphones can be placed at position* 3, 4, 5 *and* 6 *to measure the traffic noise.*

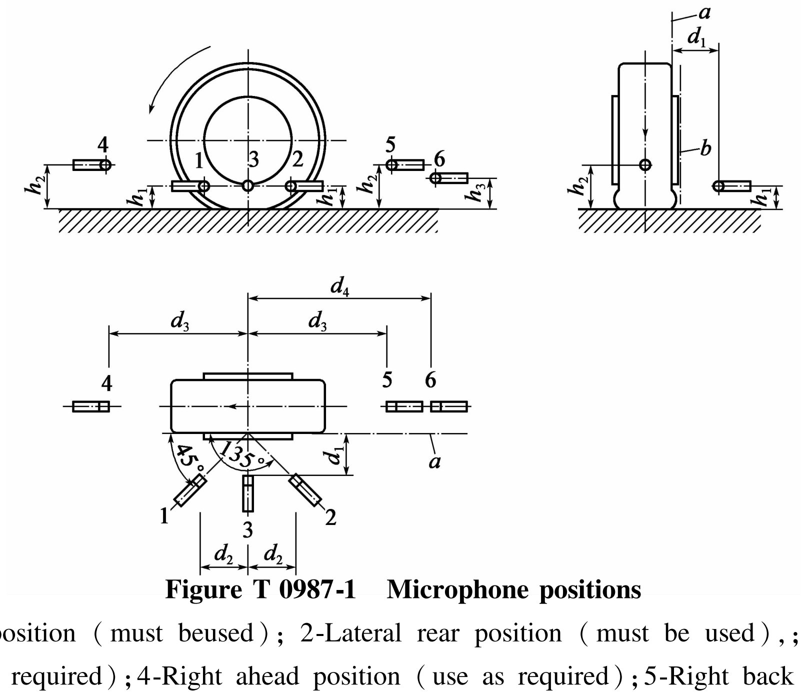


Figure T 0987-1 Microphone positions

1-Lateral front position (must beused); 2-Lateral rear position (must be used),; 3-Lateral middle position (use as required); 4-Right ahead position (use as required); 5-Right back position (use as required); 6 -The furthest rear position (use as required); a-Side wall of the tire before being deformed; b-Side wall of the tire after being deformed; d_1 = 0.20m ± 0.01m; d_2 = 0.20m ± 0.01m; d_3 = 0.65m ± 0.01m; d_4 = 0.80m ± 0.01m; h_1 = 0.10m ± 0.01m; h_2 = 0.20m ± 0.01m; h_3 = 0.15m ± 0.01m.

② The microphone shall be fixed with 5mm to10mm round steel material to reduce the impact of vibration on noise measurement during testing.

(11) Standard tires

Standard tires are divided into type P and type H. The former shall be used to evaluate noise characteristics of passenger car tireson pavements, while the latter shall be used to evaluate noise characteristics of heavy vehicle tires on a pavement. It shall be stated in the report when non-standard tires are used. Technical requirements for standard tires are shown in Table T 0987. The tread pattern of the standard tires are shown in Figure T 0987-2.

Table T 0987 Technical requirements for standard tires

Tire type	Model	Nominal width mm	Nominal diameter mm	Tire radius mm	Load Index	Speed Index	Initial tread depth	Shore hardness H_A (20℃ ±5℃)	Rim width mm
P1	P225/60R16	231	680	308	97	S	8.0 ±0.5	62-73	165.1 ±12.7
H1	195R14C	198	666	302	106/104	N	10.0 ±0.5	60-73	139.7 ±12.7

a)Type P1 b)Type H1

Figure T 0987-2 Standard tread pattern

3 Preparation

3.1 Determining test road section

(1) The effective length of the test section shall not be less than 100m, and the pavement type and pavement material over the test section shall be the same or similar.

(2) The test section shall be straight, excluding sections with a small radius curve: the radius of the curve at the test speed of 50km/h shall not be less than 250m; When the test speed is 80km/h, the radius of the curve shall not be less than 500m; When the test speed is 110km/h, the radius of the curve shall be greater than 1000m.

(3) The test road surface within 0.5mof the microphone side of the test tire shall be same or have similar surface acoustic impedance characteristics.

(4) The speed limits, curves, the longitudinal grades along the road, and the distribution of tunnel, bridge, guardrail and other structures shall be investigated in advance of testing.

3.2 Requirements forthe test environment

(1) The wind speedon site shall not exceed 10m/s during the test.

(2) Air temperature andmoisture conditions of the road surface are required to be the same as those in Clause 3.2 of T 0986 of JTG 3450—2019.

3.3 Determining test speed

(1) The standard speed specified in this method isdivided into three levels, namely 50km/h, 80km/h and 110km/h.

(2) Beforethe test, taking into account the speed limits in the test section, the average speed of the actual traffic flow and the test purpose, select a standard speed which is closest to the desired one, denoted as v_{re}.

3.4 Preparation of testequipment

(1) Test tire installation

① Standard tires shall be installed correctly by matching the marks on the tire. Camber angle shall not exceed 1.5° and static toe angle shall not exceed ±1°.

② The static load of each standard tire shall be 3200N ± 200N which can be adjusted by the ballast. During the test, the standard tire inflation pressure is 200kPa ±10kPa. Nitrogen shall be used for inflating the tire, but dry air can be used when nitrogen is not available.

③ Before a new standard tire is used for testing, it shall run a distance of at least 400km on a highway at a speed roughly the same as the test speed.

④ Before each test, check the condition of the tread area of the standard tire for aging, wear and deformation. Remove fragments of stone from the tread area. When the depth of tread wear is greater than 1.0mm, or the tire is obviously damaged or it has been used for more than 15 months, the tire shall be replaced.

⑤ A platform scale and tire pressure gauge are used to test the standard tire load and inflation pressure.

⑥ After a standard tire is installed and passed the inspection, preheat the tire by driving for at least 15min before each formal test.

(2) Installation of measurement system

① Install microphones at positions 1 and 2 in accordance with Figure T 0987-1 and be sure that each microphone is fixed firmly and does not vibrate. Enclose microphones with a windshield and acoustic shields. Confirm the positions of the microphones.

② Install the frequency analyzer, speedometer, positioning system and thermometer. The thermometer for measuring the air temperature shall be placed at a height of 1.0m to 1.5m from the ground where it is in open air. It shall be shaded to prevent direct solar radiation. The thermometer for measuring the road surface temperature shall be able to directly and vertically measure the temperature of the road surface in the wheel path which the test wheel follows.

③ Connect the data cables of all the measuring devices to the data acquisition system, turn on the power of system for warming up, and allow the sound measuring system to warm up for at least 10min.

④ Each time the system is started and warmed up and before measuring commences, the sound calibrator shall be used to check the overall sensitivity of the sound measurement system.

4 Method andprocedure

4.1 On the test road section, the test vehicle runs at the standard uniform speedaccording to Clause 3.3 of this method, and the noise at each microphone position shall be measured continuously. There shall be no braking near the test tire during noise measurements. By averaging the noise data for every 20m section the time-averaged A-weighted sound pressure level in the 1/3 octave frequency range of 315Hz to 5000Hz of each microphone will be obtained. The time-averaged A-weighted sound pressure level of 1/3 octave band of a single frequency of each 20m section is expressed as $L_{CPX:t,w,i,f,m,v_i}$.

where:

t——Test tire type, standard tireof type P or type H;

w——wheel path position which the test wheel follows, 1 is the right wheel path, 2 is the left wheel path;

r——The number of the repeat of the test, where 3 represents the third repeat;

i——The sequence number of each 20m section, where i = 3 represents the third 20m section in the test road;

f——The frequency corresponding to 1/3 octave band, ranging from 315Hz to 5000Hz;

m——Position number of microphone in Figure T 0987-1, 1 is the lateral front, 2 is the lateral rear;

v_i——Average test speed over 20m section i, km/h.

4.2 When testing traffic noise with a test vehicle, continuously measure the actual speed of the test vehicle, calculate the average speed v_i of each 20m section, and this speed shall not deviate from the standard speed V_{re} by ±15%; Also calculate the average speed of the road section which shall not deviate from the standard speed V_{re} by ±5%.

4.3 During the traffic noise test the air temperature shall be continuously measured, and the road surface temperature can also be measured as required. The measured temperatures shall be accurate to 1℃.

4.4 While measuring noise, speed and temperature, thelocation positioning system provides real-time location information.

4.5 When evaluating the traffic noise of a certain type of pavement or a certain road section, the following principles shall befollowed during the noise measurement:

(1) Select the lane next to the road shoulder and use two test wheels at the same time in the left and right wheel paths. If there is only one test wheel, it shall only measure in the right wheel path. The test wheels are all standard tires of the type P.

(2) The whole processshall be carried out twice on the same road section and in the wheel path(s) determined in (1). At least 5 short 20m sections are required for valid test values on each road section after being screened as described in Clause 4.7.

(3) If the difference in the repeated total A-weighted sound pressure levels by the same test wheel on the same road section is greater than 0. 5dB, it shall be measured two more times following steps (1) and (2), and then evaluate the four values measured.

(4) Use a type H standard tire and perform the noise test again following steps (1) to (3).

(5) Should it be necessary to measure the noise on other lanes or other transverse positions, the test can be carried out following steps (1) to (4), and noted in the report.

4.6 When evaluating traffic noise ofa road network, the following principles shall be followed for noise testing:

(1) Select the lane next to the road shoulder and use two test wheels at the same time in both the left and right wheel paths. If there is only one test wheel, the test can be made only in the right wheel path. The test wheels are all type P standard tires.

(2) The same section may be tested only once.

(3) Select a standard speed which is closest to the required one considering the speed limit in the different road sections.

4.7 Screening ofaffected traffic noise measurements

(1) When the following situations occur, the traffic noise measurements may be affected, and it is necessary to screen every short section affected by the interference:

① When the speed changed significantly in a short section, or accelerations and decelerations occurred.

② Sections with a curve radius too small or longitudinal gradients more than 6%.

③ When the external background noise does not meet the requirements, vehicles in the normal traffic pass by on the adjacent lanes during the noise measurement, or there are tunnels, bridges, guardrails and other structures less than 2m away from the microphone.

④ When the road surface has joints, potholes or other deterioration.

(2) If during the noise measurement the above situations occur this shall be flagged on the

data. If cases (1), (2) and (4) in Clause 4.7.1 of this method occurred, the measured values shall be discarded; in the case of (3), when it is found that the measured values are significantly different from the values on adjacent short sections, such measured values shall be discarded.

(3) For the situations described in Clause 4.7.1, they may also be dealt with during data processing after the test: calculate the median value of the overall total A-weighted sound pressure level, which includes all the short sections within the whole road section. For each short section compare the total A-weighted sound pressure level of the short section with the median value. If the difference is greater than 1.5 dB, then such short section had interference and is thus invalid, and the measured results shall be discarded.

4.8 During testing the overall sensitivity of the sound measuring system (including the microphone) shall be checked with the sound calibrator every 4h and at the end of the test. Any deviation shall be recorded in the test report, and if two calibration readings differ by more than 0.5dB, all intermediate measurements shall be taken as invalid.

5 Data processing

5.1 Calculate the traffic noiseover a short length of 20m

(1) Calculatethe sound pressure levels of one test wheel at different frequencies according to equation T 0987-1, accurate to 0.1:

$$L'_{\mathrm{CPX}:t,w,r,i,f,v_i} = 10\lg[0.5(10^{0.1L_{\mathrm{CPX}:t,w,r,i,f,1,v_i}} + 10^{0.1L_{\mathrm{CPX}:t,w,r,i,f,2,v_i}})] \quad (\mathrm{T\ 0987\text{-}1})$$

Where: $L'_{\mathrm{CPX}:t,w,r,i,f,v_i}$ —— Average value of sound pressure level of one test wheel at frequency 'f', dB;

$L_{\mathrm{CPX}:t,w,r,i,f,1,v_i}$ —— Sound pressure level at frequency 'f' measured by a lateral front microphone, dB;

$L_{\mathrm{CPX}:t,w,r,i,f,2,v_i}$ —— Sound pressure level at frequency 'f' measured by a lateral rear microphone, dB

(2) Sound pressure level modificationby using equation T 0987-2, accurate to 0.1:

$$L_{\mathrm{CPX}:t,w,r,i,f,v_i} = L'_{\mathrm{CPX}:t,w,r,i,f,v_i} + C_{\mathrm{d},f} \quad (\mathrm{T\ 0987\text{-}2})$$

Where, $L_{\mathrm{CPX}:t,w,r,i,f,v_i}$ —— is the average modified value of sound pressure level at frequency 'f', dB;

$C_{\mathrm{d},f}$ —— The noise coefficient of the test vehicle relating to frequency 'f'.

(3) Calculate the total A weighted sound pressure level of 1/3 octave bands by equation T 0987-3, accurate to 0.1:

$$L_{CPX:t,w,r,i,v_i} = 10\lg\left(\sum_{f=315}^{5\,000} 10^{0.1 L_{CPX:t,w,r,i,f,v_i}}\right) \quad (T\ 0987\text{-}3)$$

In theequation: $L_{CPX:t,w,r,i,v_i}$——Total A-weighted sound pressure level in the frequency range of 315Hz to5000Hz for each 20m short section, Db.

(4) Use equation T 0987-4 to modify the total A-weighted sound pressure level by test speed, temperature and tire hardness with an accuracy of 0.1:

$$L_{CPX:t,w,r,i,v_{re}} = L_{CPX:t,w,r,i,v_i} - B\lg\left(\frac{v_i}{v_{re}}\right) - \gamma_t(T - T_{re}) - \beta_t(H_A - H_{re}) \quad (T\ 0987\text{-}4)$$

Where: $L_{CPX:t,w,r,i,v_{re}}$——total A-weighted sound pressure level of each short 20m section at standard temperature/ speed, dB;

B——Speed coefficient, 25 fora newly constructed asphalt pavement or asphalt pavement with its void ratio (voids with no intruded dust) greater than 18%, 35 for cement concrete pavement and 30 for other pavements (such as AC\SMA and thin-layer pavement);

v_{re}——Standard speed, km/h;

γ_t——Temperature modification factor, dB/℃. For type P and H standard tires, the temperature modification coefficient is as follows: -0.08 + 0.0004 v_{re} for newly built asphalt pavement or asphalt pavement with a void ratio (voids with no intruded dust) greater than 18%; the cement concrete pavement is -0.10 + 0.0004 v_{re}; the other pavement types are -0.14 + 0.0006 v_{re}.

T——Temperature measured on site during test, ℃;

T_{re}——Standard temperature, 20℃;

β_t——Tire hardness modification coefficient, 0.2dB for type P and H standard tires;

H_A——The measured Shore hardness of the tire at 20℃ ±5℃;

H_{re}——The standard Shore hardness of the tire at 20℃ ±5℃, which is 66.

5.2 Calculate the traffic noise of the whole test road section

(1) Calculate the averaged overall total A-weighted sound pressure level of the whole road sectionby using equation T 0987-5, accurate to 0.1.

$$L_{CPX:t,v_{re}} = \frac{1}{n_r}\sum_{r=1}^{n_r}\left[\frac{1}{n_i}\sum_{i=1}^{n_i}\left(\frac{1}{n_w}\sum_{w=1}^{n_w} L_{CPX:t,w,r,i,v_{re}}\right)\right] \quad (T\ 0987\text{-}5)$$

Where: $L_{\mathrm{CPX}:t,v_{\mathrm{re}}}$——The averaged overall total A-weighted sound pressure level of the whole road section at standard speed v_{re} with type 't' standard tire, dB;

n_w——A value relating to the number of wheel paths being tested; it is 2 when both left and right wheel paths are measured; when only right wheel path is measured, it is 1;

n_i——The total number of valid short sections tested over the whole road section;

n_r——The number of repeated tests, normally 2 or 4.

(2) Calculate the traffic noise index of the whole sectionby using equation T 0987-6, accurate to 0.1.

$$L_{\mathrm{CPXI}:v_{\mathrm{re}}} = 0.5L_{\mathrm{CPX}:\mathrm{P1},v_{\mathrm{re}}} + 0.5L_{\mathrm{CPX}:\mathrm{H1},v_{\mathrm{re}}} \quad (\mathrm{T\ 0987\text{-}6})$$

Where: $L_{\mathrm{CPXI}:v_{\mathrm{re}}}$——Traffic noise index at standard speed v_{re}, dB;

$L_{\mathrm{CPX}:\mathrm{P1},v_{\mathrm{re}}}$——Average total A-weighted sound pressure level of the whole road section at the standard speed v_{re} tested with type P standard tire, dB;

$L_{\mathrm{CPX}:\mathrm{H1},v_{\mathrm{re}}}$——Average total A-weighted sound pressure level of the whole section at the standard speed v_{re} tested with type H standard tire, dB.

(3) Calculate the variance of traffic noiseover the whole road section by using equation T 0987-7, accurate to 0.1.

$$S_{\mathrm{CPX}:v_{\mathrm{re}}} = \frac{\frac{1}{n_r}\sum_{r=1}^{n_r}\left(\frac{1}{n_w}\sum_{w=1}^{n_w} S_{\mathrm{CPX}:\mathrm{P},w,r,v_{\mathrm{re}}}\right) + \frac{1}{n_r}\sum_{r=1}^{n_r}\left(\frac{1}{n_w}\sum_{w=1}^{n_w} S_{\mathrm{CPX}:\mathrm{H},w,r,v_{\mathrm{re}}}\right)}{2} \quad (\mathrm{T\ 0987\text{-}7})$$

Where, $S_{\mathrm{CPX}:v_{\mathrm{re}}}$——variance of traffic noise over the whole road section at standard speed v_{re}, dB;

$S_{\mathrm{CPX}:\mathrm{P},w,r,v_{\mathrm{re}}}$——variance of all $L_{\mathrm{CPX}:t,w,r,i,v_{\mathrm{re}}}$ measured 'r' repeated number of times on wheel path 'w' over the whole road section with the standard speed v_{re} and type P standard tire, dB;

$S_{\mathrm{CPX}:\mathrm{H},w,r,v_{\mathrm{re}}}$——variance of all $L_{\mathrm{CPX}:t,w,r,i,v_{\mathrm{re}}}$ measured 'r' repeated number of times on wheel path 'w' on the whole section with the standard speed v_{re} and type H standard tire, dB;

5.3 In the evaluation of road network traffic noise, the test is made only once ($n_r = 1$). In order to improve the reliability of the evaluation, 5 consecutive and valid 20m short sections shall be taken as one 100m section. The average total A-weighted sound pressure level of each 100m section shall be calculated according to Clause 5.2.2 as the measurement result of traffic noise.

6 Report

The report of this method shall include the following technical information:

(1) Test section information (time of testing and weather conditions during testing, road surface conditions).

(2) Test equipment type (standard tire information, noise factor of test vehicle, background noise level generatedby test vehicle and ability of test system to dampen external background noise).

(3) The standard speed, lane and wheel path, number of times the test was repeated, the position of the microphone and the calibration results of the microphone.

(4) Modification coefficient of speed and temperature, $L_{CPX:t,w,r,i,v_{re}}$ of each valid 20m section, actual speed, standard speed and temperature, averaged overall total A-weighted sound pressure level of the whole road section $L_{CPX:t,v_{re}}$, close-proximity traffic noise index $L_{CPXI:v_{re}}$ and traffic noise variance of the whole section $S_{CPX:v_{re}}$.

(5) If necessary, use a graph to show the $L_{CPX:t,w,r,i,v_{re}}$, and actual speed corresponding to each stake number.

***Background*:**
At present, theinternational road noise evaluation methods mainly include the far-field method and close-proximity method. The far-field method has been used to measure the noise of the actual traffic flow, and it can accurately describe the noise source and its propagation effects by considering various vehicle types and actual traffic composition. However, this method is time-consuming and can only be measured at one location. Due to the large difference between different road sections, it causes significant variations. Strict requirements are also in-force for selecting road sections. Besides it is difficult to evaluate the differences in traffic noise between different sections or different lanes/ wheel paths. Consequently, it is also difficult to evaluate the overall traffic noise conditions of a road.

The close-proximity method (CPX), also known as tire/road noise measurement, is a supplement to the far-field method. A photograph of the test equipment is shown in Figure T0987-3. Compared with the far-field method, the close-proximity method can test the noise of any section, so it can evaluate consistently the noise levels from different sections and check the differences in impact of traffic noise from different lanes/wheel paths. Furthermore, the close-proximity method is more efficient and suitable for inspecting and evaluating the impact of traffic noise from a road network. However, the close-proximity method also has its limitations. For example, it is only applicable to evaluate traffic noise mainly produced by the tire/road, and it cannot take into consideration the traffic noise produced from the vehicle itself and the propagation effects of traffic noise. Although the type H standard tire is used to simulate a heavy duty tire for testing, it is still not sufficient to *represent all heavy trucks in the noise evaluation. The requirements for test vehicle and test system are very strict, and purchasing the equipment needs a large investment. The requirements on how to control the standard tire are also strict.*

Figure T 0987-3　Trailer type CPX Method

For the measurement of the impact of traffic noise, the international standard ISO and the European Union EN standard both included the close-proximity method, which is ISO 11819.2 and EN ISO 11819.2 respectively. They are equivalent. Therefore, the close-proximity method is widely used internationally.

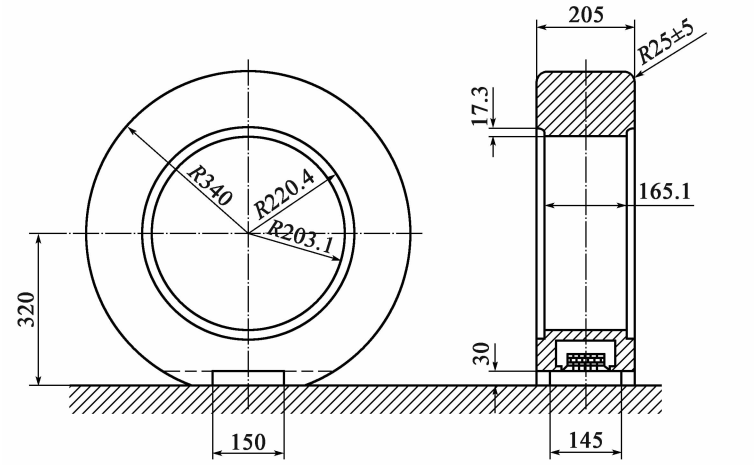
There are two types ofclose-proximity methods, namely the complete-vehicle method and the trailer method. The trailer method uses a trailer on which the test wheel is mounted, and the towing vehicle has little effect on the traffic noise, so the measured value is less affected by the background noise and the measurement accuracy is higher. Currently, China has mainly adopted the trailer method. Since there is no standard for close-proximity testing in the Chinese national standard and industry standard, this method is based on ISO 11819.2.

In order to ensure that the test vehicle meets the requirementsfor acoustic performance of Clause 2.9.2 in this method, the test vehicle generally needs to be tested for the following acoustic performance:

(1) Acoustic reflection conditions inside the screen chamber

① Remove the test wheel and tire and replace them with a tire model which has an artificial sound source. The geometry of the tire model is similar to the geometry of the test tire/wheel, and the main sound source is emitted from the front part and rear part of the tire/road contact area. The tire model with artificial sound source is shown in Figure T 0987-4.

② Install the testing system according to Clause 3.4.2 in this method and generate a white or pink noise through the artificial sound source until the sound pressure level measured by the two microphones is stable. Calculate the 1/3 octave sound pressure level of each microphone at 315Hz to 5000Hz, and calculate the mean value of 1/3 octave sound pressure level of the two microphones according to equation T 0987-1. The measurements shall be repeated. If the deviation between the two measurements is greater than 0.5dB, the measurement shall be made once more. Take the arithmetic mean value of the above two or three results (Ld, F, o).



Units: mm

Figure T 0987-4　The tire model with artificial sound source

③ Remove the screen chamber and generate a white or pink noise through the artificial sound source, until the sound pressure level measured by the two microphones is stable. At this time, there are no reflective objects other than the test vehicle within 2.0m around the microphone. Calculate the 1/3 octave sound pressure level of each microphone at 315Hz to 5000Hz, and calculate the mean value of 1/3 octave sound pressure level of the two microphones according to equation T 0987-1. The measurement is repeated. If the deviation between the two measurements is greater than 0.5dB, the measurement shall be made once more. Take the arithmetic average of the above two or three results (Ld, F, h).

④ Calculate Cd, f = Ld, f, o-Ld, f, h, that is, 1/3 octave 315Hz to 5000Hz sound pressure level difference. The results shall meet the requirements of sound reflection conditions inside the screen chamber in Clause 2.9.2. Here, 'Cd, f' denotes the noise coefficient of the test vehicle, which shall be used to correct the noise test results. When the sound pressure level difference does not meet the requirements of acoustic reflection conditions inside the screen chamber, measures shall be taken to improve it and the test shall be conducted again.

(2) Background noise generated by the complete-vehicle system

① Choose a best possible low noise pavement, such as a porous asphalt low noise surfacing.

② Lift the test tire off the road (if this is not possible, the test wheel shall be taken off), install the measuring system in accordance with Clause 3.4.2 and conduct the noise measurement.

③ Lower the test tire to make contact with the road surface (re-install the test tire) and measure the noise on the same surface as in normal operations.

④ Calculate the total A-weighted sound pressure level difference, the 1/3 octave sound pressure level difference at 500Hz to 5000Hz, and the 1/3 octave sound pressure level difference at 315Hz to 400Hz, between the measurements with the tire in contact and not in contact with the road surface. The results shall meet the requirements on background noise generated by the complete-vehicle specified in Clause 2.9.2. When the difference at each sound pressure level fails to meet the requirements in Clause 2.9.2, measures shall be taken to improve it and the test shall be repeated.

(3) Ability to dampen external background noise

① Select a representative section of road with AC or SMA pavement.

② The test vehicle is equipped as for a normal measurement, and stops on the shoulder of the selected road section. The traffic flow can pass freely on the adjacent lane. The speed of the traffic must be 70km/h ~ 90km/h, and the distance between the test vehicle and the traffic in the adjacent lane shall be no more than 1.5m.

③ When vehicles in the adjacent lane pass by, the time-weighting (F mode) is used to measure the maximum A-weighted sound pressure level and speed. More than 20 passenger cars and more than 10 heavy vehicles with two axles or more shall be measured. Take the standard speed as 80km/h and the maximum A-weighted sound pressure level at different speeds shall be converted to the standard speed by using equation T 0987-4.

④ The test vehicle is then used to measure the noise of the same section at a speed of 80km/h in the normal manner. The total A-weighted sound pressure level is calculated according to equations T 0987-1 to T 0987-5.

⑤ Calculate the difference between the total A-weighted sound pressure level measured normally on the road section and the maximum A-weighted sound pressure level measured while being stationary on the road shoulder. This difference shall meet the requirements on the ability to dampen external background noise in Clause 2.9.2. When the difference of sound pressure level does not meet the requirements, corrective measures shall be taken and test shall be repeated.

⑥ When the requirements described in '⑤' are not met, it indicates that the test vehicle is not capable of damping external background noise. During the test, it may be affected by traffic noise from adjacent lanes and reflected noise from tunnels, bridges, guardrail and other structures. Under such conditions the traffic flow may need to be controlled during noise measurement process. After the noise measurement, the test data that are affected by traffic flow or test data gathered from sections where the microphone inside the test vehicle is less than 2m away from the tunnel, bridge, guardrail and other structures shall be discarded.

Appendix A
Method for randomly selecting sampling positions of subgrade or pavement layers for site inspection or measurements

1 Scope of application

The methodfor selecting sampling positions based on random principles is applying the principle of mathematical statistics to determine test positions for site testing of road subgrade or pavement layers. This method is suitable for field test work of subgrade or pavement layers i, when selecting test positions by the random method or by a comprehensive method.

2 Technical requirements for instruments and materials

(1) Ruler: steel ruler、tape measure or range finder.

(2) Pieces of stiff paper which are numbered from 1 to 28. Altogether 28 pieces which have a size of 2.5cm × 2.5cm. These pieces of paper are kept inside a cloth bag. Another method is to use computer software which can generate random numbers (like WPS spreadsheet or EXCEL).

(3) Others: brush and chalk.

3 Preparation

Identify the road sections to be tested based on requirements by the relevant specifications for pavement construction or acceptance inspection, or method of quality evaluation. It may be a unit of work or section of road from contractor's breakdown of tasks, or a road section being a task completed in one day, or the length of whole road. For acceptance inspection, normally take 1 km as a test section.

4 The procedure to select the test intervals or sections (longitudinal position)

4.1 According to the number of intervals (subsections) given in the relevant specifications or standards the road section is divided into subsections from which sampling positions shall be selected. Number them as Interval 1 to Interval n, or as Cross section 1 to Cross section n. The total number of such intervals or cross sections is denoted as T. For tests on highway subgrade or pavement layers, these intervals or cross sections are normally divided into equal intervals. If T is more than 30, it shall be performed in stages. If computer software is used for random selection, restriction on the number is not required.

4.2 Randomly select a piece of stiff paper. The number of this piece of stiff paper becomes the Caption number in Table A-1. From this Caption, find the value in Column B which matches the number 01 to n listed in the Column A. Value A and Value B may also be generated by software. The result is that there are n groups of Value A and Value B.

4.3 Multiply the Value B (the number of such values is n) by T (the total number of intervals or cross sections), round off the results to integers by the common rule, and the serial numbers of n cross sections are obtained. From these serial numbers, actual cross sections are determined.

Example: from relevant requirements, a total of 20 cross sections must be selected from a 1 km length of a road (K36 + 000 to K37 + 000) to check their dimensions like pavement widths, elevations and cross slope. The method of selection is shown next:

(1) Divide the length of road into 20m intervals and number each of the cross sections. There are 50 cross sections in this 1km length of road (T = 1000/20 = 50) and their serial numbers are 1, 2……50.

(2) Randomly take a piece of stiff paper from the cloth bag. Let us say that the paper taken is numbered 14. It means the 14th Caption in Table A-1 shall be used.

(3) From this 14th Caption, select those numbers equal to or less than 20 from list A and their matched values from list B, multiply B by T, now 20 integer numbers are obtained by rounding off

the products. Multiply these serial numbers by the value of the interval and 20 stakes of cross sections are obtained.

This calculation procedure is shown in Table A-2.

5 The procedure to select test points (positions both in longitudinal or transverse direction)

5.1 From the relevant standards and specifications determine the number of test points (n). If n > 30, repeat the calculations several times. If selected by software than no restriction applies.

5.2 Randomly select a piece of stiff paper from the cloth bag. The number of this piece of stiff paper becomes the Caption number in Table A-1. In column A of this Caption, there are numbers 1 to n. Match each of these numbers to the values in column B and column C. Values in column B and column C can also be produced by software. Now there are n groups of values of A, B and C.

5.3 Multiply the value in column B, which matches the number in column A, by the total length of the road section Add the stake number of the starting point of the road section to the product and the longitudinal position of a test point or its stake value is obtained.

5.4 Multiply the value in column C which matches the number in column A by the width of pavement. Then subtract half of the pavement width. The distance of a test point to the center of pavement is then obtained. If the difference is positive, it means the test point is located on the right side of the center line, if negative, located on the left side.

Example: fromrelevant specifications, select 6 test points from a 1 km long road section (K36 +000 to K37 +000) to drill asphalt core samples to check their densities, bitumen contents and mix gradations. The procedure to select the drill positions is as follows:

(1) Randomly take a piece of stiff paper from the bag. The piece of paper is numbered 3.

(2) Scrolling down under the Caption of 3 there are 6 numbers which are equal to or less than 6 (there shall be 6 test points). They are 01、06、03、02、04 and 05.

(3) From Table A-1, 6 decimal numbers in list B match the numbers in list A. They are 0.175、0.310、0.494、0.699、0.838 and 0.977.

Table A-1 random numbers for normal sampling

栏号 1 Caption 1			栏号 2 Caption 2			栏号 3 Caption 3			栏号 4 Caption 4			栏号 5 Caption 5			栏号 6 Caption 6			栏号 7 Caption 7			栏号 8 Caption 8		
A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
15	0. 033	0. 578	05	0. 048	0. 879	21	0. 013	0. 220	18	0. 089	0. 716	17	0. 024	0. 863	30	0. 030	0. 901	12	0. 029	0. 386	09	0. 042	0. 07
21	0. 101	0. 300	17	0. 074	0. 156	30	0. 036	0. 853	10	0. 102	0. 330	24	0. 060	0. 032	21	0. 096	0. 198	18	0. 112	0. 284	17	0. 141	0. 411
23	0. 129	0. 916	18	0. 102	0. 191	10	0. 052	0. 746	14	0. 111	0. 925	26	0. 074	0. 639	10	0. 100	0. 161	20	0. 114	0. 848	02	0. 143	0. 221
30	0. 158	0. 434	06	0. 105	0. 257	25	0. 061	0. 954	28	0. 127	0. 840	07	0. 167	0. 512	29	0. 133	0. 388	03	0. 121	0. 656	05	0. 162	0. 899
24	0. 177	0. 397	28	0. 179	0. 447	29	0. 062	0. 507	24	0. 132	0. 271	28	0. 194	0. 776	24	0. 138	0. 062	13	0. 178	0. 640	03	0. 285	0. 016
11	0. 202	0. 271	26	0. 187	0. 844	18	0. 087	0. 887	19	0. 285	0. 899	03	0. 219	0. 166	20	0. 168	0. 564	22	0. 209	0. 421	28	0. 291	0. 034
16	0. 204	0. 012	04	0. 188	0. 482	24	0. 105	0. 849	01	0. 326	0. 037	29	0. 264	0. 284	22	0. 232	0. 953	16	0. 221	0. 311	08	0. 369	0. 557
08	0. 208	0. 418	02	0. 208	0. 577	07	0. 139	0. 159	30	0. 334	0. 938	11	0. 282	0. 262	14	0. 259	0. 217	29	0. 235	0. 356	01	0. 436	0. 386
19	0. 211	0. 798	03	0. 214	0. 402	01	0. 175	0. 647	22	0. 405	0. 295	14	0. 379	0. 994	01	0. 275	0. 195	28	0. 254	0. 941	20	0. 450	0. 289
29	0. 233	0. 07	07	0. 245	0. 080	23	0. 196	0. 873	05	0. 421	0. 282	13	0. 394	0. 405	06	0. 277	0. 475	11	0. 287	0. 199	18	0. 455	0. 789
07	0. 260	0. 073	15	0. 248	0. 831	26	0. 240	0. 981	13	0. 451	0. 212	06	0. 410	0. 157	02	0. 296	0. 497	02	0. 336	0. 992	23	0. 488	0. 715
17	0. 262	0. 308	29	0. 261	0. 037	14	0. 255	0. 374	02	0. 461	0. 023	15	0. 438	0. 700	27	0. 311	0. 144	15	0. 393	0. 488	14	0. 498	0. 276
25	0. 271	0. 18	30	0. 302	0. 883	06	0. 310	0. 043	06	0. 487	0. 539	22	0. 453	0. 635	05	0. 351	0. 141	19	0. 437	0. 655	15	0. 503	0. 342
06	0. 302	0. 672	21	0. 318	0. 088	11	0. 316	0. 653	08	0. 497	0. 396	21	0. 472	0. 824	17	0. 370	0. 811	24	0. 466	0. 773	04	0. 515	0. 693
01	0. 409	0. 406	11	0. 376	0. 936	13	0. 324	0. 585	25	0. 503	0. 893	05	0. 488	0. 118	09	0. 388	0. 484	14	0. 531	0. 014	16	0. 532	0. 112
13	0. 507	0. 693	14	0. 430	0814	12	0. 351	0. 275	15	0. 594	0. 603	01	0. 525	0. 222	04	0. 410	0. 073	09	0. 562	0. 678	22	0. 557	0. 357
02	0. 575	0. 654	27	0. 438	0. 676	20	0. 371	0. 535	27	0. 620	0. 894	12	0. 561	0. 980	25	0. 471	0. 530	06	0. 601	0. 675	11	0. 559	0. 620
18	0. 591	0. 318	08	0. 467	0. 205	08	0. 409	0. 495	21	0. 629	0. 841	08	0. 652	0. 508	13	0. 486	0. 779	10	0. 612	0. 859	12	0. 650	0. 216

continue

栏号 1 Caption 1			栏号 2 Caption 2			栏号 3 Caption 3			栏号 4 Caption 4			栏号 5 Caption 5			栏号 6 Caption 6			栏号 7 Caption 7			栏号 8 Caption 8		
20	0.610	0.821	09	0.474	0.138	16	0.445	0.740	17	0.691	0.583	18	0.668	0.271	15	0.515	0.867	26	0.673	0.112	21	0.672	0.320
12	0.631	0.597	10	0.492	0.474	03	0.494	0.929	09	0.708	0.689	30	0.736	0.634	23	0.567	0.798	23	0.738	0.770	13	0.709	0.273
27	0.651	0.281	13	0.498	0.892	27	0.543	0.387	07	0.709	0.012	02	0.763	0.253	11	0.618	0.502	21	0.753	0.614	07	0.745	0.687
04	0.661	0.953	19	0.511	0.520	17	0.625	0.171	11	0.714	0.049	23	0.804	0.140	28	0.636	0.148	30	0.758	0.851	30	0.780	0.285
22	0.692	0.089	23	0.591	0.770	02	0.699	0.073	23	0.720	0.695	25	0.828	0.425	26	0.650	0.741	27	0.765	0.563	19	0.845	0.097
05	0.779	0.346	20	0.604	0.730	19	0.702	0.934	03	0.748	0.413	10	0.843	0.627	16	0.711	0.508	07	0.780	0.534	26	0.846	0.366
09	0.787	0.173	24	0.654	0.330	22	0.816	0.802	20	0.781	0.603	16	0.858	0.849	19	0.778	0.812	04	0.818	0.187	29	0.861	0.307
10	0.818	0.837	12	0.728	0.523	04	0.838	0.166	26	0.830	0.384	04	0.903	0.327	07	0.804	0.675	17	0.837	0.353	25	0.906	0.874
14	0.905	0.631	16	0.753	0.344	15	0.904	0.116	04	0.843	0.002	09	0.912	0.382	08	0.806	0.952	05	0.854	0.818	24	0.919	0.809
26	0.912	0.376	01	0.806	0.134	28	0.969	0.742	12	0.884	0.582	27	0.935	0.162	18	0.841	0.414	01	0.867	0.133	10	0.952	0.555
28	0.920	0.163	22	0.878	0.884	09	0.974	0.046	29	0.926	0.700	20	0.970	0.582	12	0.918	0.114	08	0.915	0.538	06	0.961	0.504
03	0.945	0.140	25	0.939	0.162	05	0.977	0.494	16	0.951	0.601	19	0.975	0.327	03	0.992	0.399	25	0.975	0.584	27	0.969	0.811

栏号 9 Caption9			栏号 10 Caption10			栏号 11 Caption11			栏号 12 Caption12			栏号 13 Caption13			栏号 14 Caption14			栏号 15 Caption15			栏号 16 Caption16		
A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
14	0.061	0.935	26	0.038	0.023	27	0.074	0.779	16	0.078	0.987	03	0.033	0.091	26	0.035	0.175	15	0.023	0.979	19	0.062	0.588
02	0.065	0.097	30	0.066	0.371	06	0.084	0.396	23	0.087	0.056	07	0.047	0.391	17	0.089	0.363	11	0.118	0.465	25	0.08	0.218
03	0.094	0.228	27	0.073	0.876	24	0.098	0.524	17	0.096	0.076	28	0.064	0.113	10	0.149	0.681	07	0.134	0.172	09	0.131	0.295
16	0.122	0.945	09	0.095	0.568	10	0.133	0.919	04	0.153	0.163	12	0.066	0.360	28	0.238	0.075	01	0.139	0.230	18	0.136	0.381
18	0.156	0.430	05	0.180	0.741	15	0.187	0.079	10	0.254	0.834	26	0.076	0.552	13	0.244	0.767	16	0.145	0.122	05	0.147	0.864

continue

栏号 9 Caption9			栏号 10 Caption10			栏号 11 Caption11			栏号 12 Caption12			栏号 13 Caption13			栏号 14 Caption14			栏号 15 Caption15			栏号 16 Caption16		
25	0. 193	0. 469	12	0. 200	0. 851	17	0. 227	0. 767	06	0. 284	0. 628	30	0. 087	0. 101	24	0. 262	0. 366	20	0. 165	0. 520	12	0. 158	0. 365
24	0. 224	0. 672	13	0. 259	0. 327	20	0. 236	0. 571	12	0. 305	0. 616	02	0. 127	0. 187	08	0. 264	0. 651	06	0. 185	0. 481	28	0. 214	0. 184
10	0. 225	0. 223	21	0. 264	0. 681	01	0. 245	0. 988	25	0. 319	0. 901	06	0. 144	0. 068	18	0. 285	0. 311	09	0. 211	0. 316	14	0. 215	0. 757
09	0. 233	0. 338	17	0. 283	0. 645	04	0. 317	0. 291	01	0. 320	0. 212	25	0. 202	0. 674	02	0. 340	0. 131	14	0. 248	0. 348	13	0. 224	0. 846
20	0. 290	0. 120	23	0. 363	0. 063	29	0. 350	0. 911	08	0. 416	0. 372	01	0. 247	0. 025	29	0. 353	0. 478	25	0. 249	0. 890	15	0. 227	0. 809
01	0. 297	0. 242	20	0. 364	0. 366	26	0. 380	0. 104	13	0. 432	0. 556	23	0. 253	0. 323	06	0. 359	0. 270	13	0. 252	0. 577	11	0. 280	0. 898
11	0. 337	0. 760	16	0. 395	0. 363	28	0. 425	0. 864	02	0. 489	0. 827	24	0. 320	0. 651	30	0. 387	0. 248	30	0. 273	0. 088	01	0. 331	0. 925
19	0. 389	0. 064	02	0. 423	0. 540	22	0. 487	0. 526	29	0. 503	0. 787	10	0. 328	0. 365	14	0. 392	0. 694	18	0. 277	0. 689	10	0. 399	0. 992
13	0. 411	0. 474	08	0. 432	0. 736	05	0. 552	0. 571	15	0. 518	0. 717	27	0. 338	0. 412	03	0. 408	0. 077	22	0. 372	0. 958	30	0. 417	0. 787
30	0. 447	0. 893	10	0. 475	0. 468	14	0. 564	0. 357	28	0. 524	0. 998	13	0. 356	0. 991	27	0. 440	0. 280	10	0. 461	0. 075	08	0. 439	0. 921
22	0. 478	0. 321	03	0. 508	0. 774	11	0. 572	0. 306	03	0. 542	0. 352	16	0. 401	0. 792	22	0. 461	0. 830	28	0. 519	0. 536	20	0. 472	0. 484
29	0. 481	0. 993	01	0. 601	0. 417	21	0. 594	0. 197	19	0. 585	0. 462	17	0. 423	0. 117	16	0. 527	0. 003	17	0. 520	0. 090	24	0. 498	0. 712
27	0. 562	0. 403	22	0. 687	0. 917	09	0. 607	0. 524	05	0. 695	0. 111	21	0. 481	0. 838	20	0. 531	0. 486	03	0. 523	0. 519	04	0. 516	0. 396
04	0. 566	0. 179	29	0. 697	0. 862	19	0. 650	0. 572	07	0. 733	0. 838	08	0. 560	0. 401	25	0. 678	0. 360	26	0. 573	0. 502	03	0. 548	0. 688
08	0. 603	0. 758	11	0. 701	0. 605	18	0. 664	0. 101	11	0. 744	0. 948	19	0. 564	0. 190	21	0. 725	0. 014	19	0. 634	0. 206	23	0. 597	0. 508

continue

栏号 9 Caption9			栏号 10 Caption10			栏号 11 Caption11			栏号 12 Caption12			栏号 13 Caption13			栏号 14 Caption14			栏号 15 Caption15			栏号 16 Caption16		
15	0.632	0.927	07	0.728	0.498	25	0.674	0.428	18	0.793	0.748	05	0.571	0.054	05	0.787	0.595	24	0.635	0.810	21	0.681	0.114
06	0.707	0.107	14	0.745	0.679	02	0.697	0.674	27	0.802	0.967	18	0.587	0.584	15	0.801	0.927	21	0.679	0.841	02	0.739	0.298
28	0.737	0.161	24	0.819	0.444	03	0.767	0.928	21	0.826	0.487	15	0.604	0.145	12	0.836	0.294	27	0.712	0.368	29	0.792	0.038
17	0.846	0.130	15	0.840	0.823	16	0.809	0.529	24	0.835	0.832	11	0.641	0.298	04	0.854	0.982	05	0.780	0.497	22	0.829	0.324
07	0.874	0.491	25	0.863	0.568	30	0.838	0.294	26	0.855	0.142	22	0.672	0.156	11	0.884	0.928	23	0.861	0.106	17	0.834	0.647
05	0.880	0.828	06	0.878	0.215	13	0.845	0.470	14	0.861	0.462	20	0.674	0.887	19	0.886	0.832	12	0.865	0.377	16	0.909	0.608
23	0.931	0.659	18	0.930	0.601	08	0.855	0.524	20	0.874	0.625	14	0.752	0.881	07	0.929	0.932	29	0.882	0.635	06	0.914	0.420
26	0.960	0.365	04	0.954	0.827	07	0.867	0.718	30	0.929	0.056	09	0.774	0.560	09	0.932	0.206	08	0.902	0.020	27	0.958	0.356
21	0.978	0.194	28	0.963	0.004	12	0.881	0.722	09	0.935	0.582	29	0.921	0.752	01	0.970	0.692	04	0.951	0.482	26	0.981	0.976
12	0.982	0.183	19	0.988	0.020	23	0.937	0.872	22	0.947	0.797	04	0.959	0.099	23	0.973	0.082	02	0.977	0.172	07	0.983	0.624

栏号 17 Caption17			栏号 18 Caption18			栏号 19 Caption19			栏号 20 Caption20			栏号 21 Caption21			栏号 22 Caption22			栏号 23 Caption23			栏号 24 Caption2		
A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
13	0.045	0.004	25	0.027	0.290	12	0.052	0.075	20	0.030	0.881	01	0.01	0.946	12	0.051	0.032	26	0.051	0.187	08	0.015	0.521
18	0.086	0.878	06	0.057	0.571	30	0.075	0.493	12	0.034	0.291	10	0.014	0.939	11	0.068	0.980	03	0.53	0.256	16	0.068	0.994
26	0.126	0.990	26	0.059	0.026	28	0.120	0.341	22	0.043	0.893	09	0.032	0.346	17	0.089	0.309	29	0.100	0.159	11	0.118	0.400
12	0.128	0.661	07	0.105	0.176	27	0.145	0.689	28	0.143	0.073	06	0.093	0.180	01	0.091	0.371	13	0.102	0.465	21	0.124	0.565
30	0.146	0.337	18	0.107	0.358	02	0.209	0.957	03	0.15	0.937	15	0.151	0.012	10	0.100	0.709	24	0.11	0.316	18	0.153	0.158

continue

栏号 17			栏号 18			栏号 19			栏号 20			栏号 21			栏号 22			栏号 23			栏号 24		
Caption17			Caption18			Caption19			Caption20			Caption21			Caption22			Caption23			Caption2		
05	0.169	0.470	22	0.128	0.827	26	0.272	0.818	04	0.154	0.867	16	0.185	0.455	30	0.121	0.774	18	0.114	0.300	17	0.190	0.159
21	0.244	0.433	23	0.156	0.440	22	0.299	0.317	19	0.158	0.359	07	0.227	0.227	02	0.166	0.056	11	0.123	0.208	26	0.192	0.676
23	0.270	0.849	15	0.171	0.157	18	0.306	0.475	29	0.304	0.615	02	0.304	0.400	23	0.179	0.529	09	0.138	0.182	01	0.237	0.030
25	0.274	0.407	08	0.220	0.097	20	0.311	0.653	06	0.369	0.633	30	0.316	0.074	21	0.187	0.051	06	0.194	0.115	12	0.283	0.077
10	0.290	0.925	20	0.252	0.066	15	0.348	0.156	18	0.390	0.536	18	0.328	0.799	22	0.205	0.543	22	0.234	0.480	03	0.286	0.318
01	0.323	0.490	04	0.268	0.576	16	0.381	0.710	17	0.403	0.392	20	0.352	0.288	28	0.23	0.688	20	0.274	0.107	10	0.317	0.374
24	0.352	0.291	14	0.275	0.302	01	0.411	0.607	23	0.404	0.182	26	0.371	0.216	19	0.243	0.001	21	0.331	0.292	05	0.337	0.844
15	0.361	0.155	11	0.297	0.589	13	0.417	0.715	01	0.415	0.457	19	0.448	0.754	27	0.267	0.990	08	0.346	0.085	25	0.441	0.336
29	0.374	0.882	01	0.358	0.305	21	0.472	0.484	07	0.437	0.696	13	0.487	0.598	15	0.283	0.440	27	0.382	0.979	27	0.469	0.786
08	0.432	0.139	09	0.412	0.089	04	0.478	0.885	24	0.446	0.546	12	0.546	0.640	16	0.352	0.089	07	0.387	0.865	24	0.473	0.237
04	0.467	0.266	16	0.429	0.834	25	0.479	0.080	26	0.485	0.768	24	0.550	0.038	03	0.377	0.648	28	0.411	0.776	20	0.475	0.761
22	0.508	0.880	10	0.491	0.203	11	0.566	0.104	15	0.511	0.313	03	0.604	0.780	06	0.397	0.769	16	0.444	0.999	06	0.557	0.001
27	0.632	0.191	28	0.542	0.306	10	0.576	0.859	10	0.517	0.290	22	0.621	0.930	09	0.409	0.428	04	0.515	0.993	07	0.610	0.238
16	0.661	0.836	12	0.563	0.091	29	0.665	0.397	30	0.556	0.853	21	0.629	0.154	14	0.465	0.406	17	0.518	0.827	09	0.617	0.041
19	0.675	0.629	02	0.593	0.321	19	0.739	0.298	25	0.561	0.837	11	0.634	0.908	13	0.499	0.651	05	0.539	0.620	13	0.641	0.648
14	0.680	0.890	30	0.692	0.198	14	0.748	0.759	09	0.574	0.699	05	0.696	0.459	04	0.539	0.972	02	0.623	0.271	22	0.664	0.291
28	0.714	0.508	19	0.705	0.445	08	0.758	0.919	13	0.613	0.762	23	0.710	0.078	18	0.560	0.747	30	0.637	0.374	04	0.668	0.856
06	0.719	0.441	24	0.709	0.717	07	0.798	0.183	11	0.698	0.783	29	0.726	0.585	26	0.575	0.892	14	0.714	0.364	19	0.717	0.232
09	0.735	0.040	13	0.820	0.739	23	0.834	0.647	14	0.715	0.179	17	0.749	0.916	29	0.756	0.712	15	0.730	0.107	02	0.776	0.504
17	0.741	0.906	05	0.848	0.866	06	0.837	0.978	16	0.770	0.128	04	0.802	0.186	20	0.760	0.920	19	0.771	0.552	29	0.797	0.548

continue

栏号 17			栏号 18			栏号 19			栏号 20			栏号 21			栏号 22			栏号 23			栏号 24		
Caption17			Caption18			Caption19			Caption20			Caption21			Caption22			Caption23			Caption2		
11	0.747	0.205	27	0.867	0.633	03	0.849	0.964	08	0.815	0.385	14	0.835	0.319	05	0.847	0.925	23	0.780	0.662	14	0.823	0.223
20	0.850	0.047	03	0.883	0.333	24	0.851	0.109	05	0.872	0.490	08	0.870	0.546	25	0.872	0.891	10	0.924	0.888	23	0.848	0.264
02	0.859	0.356	17	0.900	0.443	05	0.859	0.835	21	0.885	0.999	28	0.871	0.539	24	0.874	0.135	12	0.929	0.204	30	0.892	0.817
07	0.870	0.612	21	0.914	0.483	17	0.863	0.220	02	0.958	0.177	25	0.971	0.369	08	0.911	0.215	01	0.937	0.714	28	0.943	0.190
03	0.916	0.463	29	0.950	0.753	09	0.883	0.147	27	0.961	0.980	27	0.984	0.252	07	0.946	0.065	25	0.974	0.398	15	0.975	0.962

栏号 25			栏号 26			栏号 27			栏号 28			栏号 25			栏号 26			栏号 27			栏号 28		
Caption 25			Caption 26			Caption 27			Caption 28			Caption 25			Caption 26			Caption 27			Caption 28		
A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
02	0.039	0.005	16	0.026	0.102	21	0.050	0.952	29	0.042	0.039	05	0.126	0.658	20	0.136	0.576	07	0.197	0.013	03	0.210	0.054
16	0.061	0.599	01	0.033	0.886	17	0.085	0.403	07	0.105	0.293	14	0.161	0.189	05	0.158	0.228	16	0.125	0.363	23	0.234	0.533
26	0.068	0.054	04	0.088	0.686	10	0.141	0.624	25	0.115	0.420	18	0.166	0.040	10	0.216	0.565	08	0.222	0.520	13	0.266	0.799
11	0.073	0.812	22	0.090	0.602	05	0.154	0.157	09	0.126	0.612	28	0.248	0.171	02	0.233	0.610	13	0.269	0.477	20	0.305	0.603
07	0.123	0.649	13	0.114	0.614	06	0.164	0.841	10	0.205	0.144	06	0.255	0.117	07	0.278	0.357	02	0.288	0.012	05	0.372	0.223
15	0.261	0.928	30	0.405	0.273	25	0.333	0.633	26	0.385	0.111	19	0.420	0.557	19	0.510	0.207	27	0.587	0.643	14	0.483	0.095
10	0.301	0.811	06	0.421	0.807	28	0.348	0.710	30	0.422	0.315	21	0.467	0.943	03	0.512	0.329	12	0.603	0.745	12	0.507	0.375
24	0.363	0.025	12	0.426	0.583	20	0.362	0.961	17	0.453	0.783	17	0.494	0.225	15	0.640	0.329	29	0.619	0.895	28	0.509	0.748
22	0.378	0.792	08	0.471	0.708	14	0.511	0.989	02	0.460	0.916	09	0.620	0.081	09	0.665	0.354	23	0.623	0.333	21	0.583	0.804
27	0.389	0.959	18	0.473	0.738	26	0.540	0.903	27	0.467	0.841	30	0.623	0.106	14	0.680	0.884	22	0.629	0.076	22	0.587	0.993
03	0.625	0.777	26	0.703	0.622	18	0.670	0.904	16	0.689	0.339	01	0.841	0.726	21	0.870	0.435	03	0.844	0.511	19	0.896	0.464
08	0.651	0.790	29	0.739	0.394	11	0.711	0.253	06	0.727	0.298	29	0.862	0.009	28	0.906	0.397	30	0.858	0.289	18	0.916	0.384
12	0.715	0.599	25	0.759	0.386	01	0.790	0.392	04	0.731	0.814	25	0.891	0.873	23	0.948	0.367	09	0.929	0.199	01	0.948	0.610
23	0.782	0.093	24	0.803	0.602	04	0.813	0.611	08	0.807	0.983	04	0.917	0.264	11	0.956	0.142	24	0.931	0.263	11	0.976	0.799
20	0.810	0.371	27	0.842	0.491	19	0.843	0.732	15	0.833	0.757	13	0.958	0.990	17	0.993	0.989	15	0.939	0.947	24	0.978	0.636

(4) The length of road section is 1000m. Multiply 1000 with the decimal numbers. Six products are obtained, namely 175m、310m、494m、699m、838m and 977m respectively. (These are the distances of selected test points from the starting point of the road section).

(5) From Table A-1, 6 decimal numbers in list C match the numbers in list A. They are 0.647、0.043、0.929、0.073、0.166 and 0.494.

(6) The pavement width is 10m. Multiply 10 with the decimal numbers. Six products are obtained, namely 0.647、0.043、9.29、0.73、1.66 and 4.94m. Subtract half of pavement width and six transverse positions of the test points are obtained. They are 1.47m (right), 4.57m (left), 4.29m (right), 4.27m (left), 3.34m (left), 0.06m (left).

The above procedure is shown in Table A-3.

TableA-2 Example calculation table for randomly selecting cross sections for testing (longitudinal positions)

Serial number	List A of Caption 14	List B	B × T	Determined serial number	stake
1	17	0.089	4.45	4	K36 + 080
2	10	0.149	7.45	7	K36 + 140
3	13	0.244	12.2	12	K36 + 240
4	08	0.246	13.2	13	K36 + 260
5	18	0.285	14.25	14	K36 + 280
6	02	0.340	17.05	17	K36 + 340
7	06	0.359	17.95	18	K36 + 360
8	14	0.392	19.60	20	K36 + 400
9	03	0.408	20.40	20	K36 + 420
10	16	0.527	26.35	26	K36 + 520
11	20	0.531	26.55	27	K36 + 540
12	05	0.787	39.35	39	K36 + 780
13	15	0.801	40.05	40	K36 + 800
14	12	0.836	41.8	42	K36 + 840
15	04	0.854	42.7	43	K36 + 860
16	11	0.884	44.2	44	K36 + 880
17	19	0.886	44.3	44	K36 + 900
18	07	0.929	46.45	46	K36 + 920
19	09	0.932	46.6	47	K36 + 940
20	01	0.970	48.5	49	K36 + 980

Table A-3 Example calculation table for randomly selecting longitudinal and transverse test points

Caption 3			The length of road section			Pavement width 10m	6Test points
Serial number	List A	List B	Distance from starting point	Stake	List C	Distance from edge of pavement	Distance from center line
NO. 1	01	0. 175	175	K36 + 175	0. 647	6. 47	(right)1. 47
NO. 2	06	0. 310	310	K36 + 310	0. 043	0. 43	(left)4. 57
NO. 3	03	0. 494	494	K36 + 494	0. 929	9. 29	(right)4. 29
NO. 4	02	0. 699	699	K36 + 699	0. 073	0. 73	(left)4. 27
NO. 5	04	0. 838	838	K36 + 838	0. 166	1. 66	(left)3. 34
NO. 6	05	0. 977	977	K36 + 977	0. 494	4. 94	(left)0. 06

***Background*:**
Selecting test points randomly is an important method for determining test location for field testing and quality control, as it can minimize interference by field staff. The field staff interference factors may affect the representativeness of the test results. It has been widely used abroad but not in China. One of the reasons is that the various construction specifications or quality evaluation standards and test methods are not clear. The other reason is that the testing technology develops quickly permitting the use of continuous and high efficiency test equipment. Since the sampling frequency of test data is increased by a hundred times that makes it possible to test the full section rather than a sample with the result having higher representativeness than randomly selecting samples.

There are still some field tests in the highway industry which are performed by sampling. With the relevant specifications and standards becoming more refined, the method of randomly selecting test points is still useful in some cases. The method of taking a piece of stiff paper from a cloth bag for calculating test positions based on a table was created by referring to various USA specifications which were practiced widely for many years. It is also included in 'Technical Specifications for Construction of Highway Roadbases' (JTG/T F20—2015). Since the procedure for this method is laborious, and computer technology is widely used, it is easy to obtain the random values. The way to obtain random values by software for selecting test positions is allowed in addition to this method.

Appendix B
Statistical methods for evaluating data collected from a section of road

1 Scope of application

This method specifies how to calculate the average value, standard deviation, coefficient of variation, the difference between measured value and design value and representative value of test results generated from a road section. This method is suitable for the statistical analysis required in the Standard. Other test data statistics may also be used as reference.

2 Calculation

2.1 Calculate the difference between the measured value and the design value using equation B-1

$$\Delta X_i = X_i - X_0 \tag{B-1}$$

where: ΔX_i——the difference between measured value X_i and design value X_0

X_i——measured value at ith test point;

X_0——design value

2.2 Calculate the average value, standard deviation and, coefficient of variation of test results using equations B-2 to B-4

$$\overline{X} = \frac{\Sigma X_i}{N} \tag{B-2}$$

$$S = \sqrt{\frac{\sum_{i=1}^{N}(X_i - \overline{X})^2}{N-1}} \tag{B-3}$$

$$C_v = \frac{S}{\overline{X}} \times 100 \tag{B-4}$$

Where: X_i——measured value at ith test point

N——the number of test points in a road section

$\overline{X}$——average value of measured values in a road section

S——standard deviation of measured values in a road section

CV——coefficient of variations of measured values in a road section(%)

2.3 Calculate the representative value of measured values in a road section, using equation B-5 for a one-tailed test, or using equation B-6for a two-tailed test.

$$X' = \overline{X} \pm S\frac{t_\alpha}{\sqrt{N}} \tag{B-5}$$

$$X' = \overline{X} \pm S\frac{t_{\alpha/2}}{\sqrt{N}} \tag{B-6}$$

where: X'——the representative value of measured values in a road section,

t_α or $t_{\alpha/2}$——coefficients in t distribution table which vary with degree of freedom (N-1) and confidence level α(reliability), see Table B. The reliability level shall be determined from the relevant specifications.

3 Report

3.1 Based on the practical demands and requirements of relevant specifications, prese 测点。nt a table which lists all the measured values, the average value, standard deviation, coefficient of variation and representative value. Show the results which have been discarded as being outlier test points.

3.2 If there are no special demands, outlier data shall be rejected by following the rule of ‘ k times of standard deviation’. Measured values outside the range of $\overline{X} \pm kS$ shall be rejected, and the calculations repeated without the outlier. If the test data N is being 3、4、5、6, the value of ’k’ shall be 1.15, 1.46, 1.67 and1.82 respectively. If N equals or is more than 7, the value of ‘k’ shall be 3.

Table B the values of $\frac{t_{\alpha/2}}{\sqrt{N}}$ and $\frac{t_{\alpha}}{\sqrt{N}}$

Test number	Two tailedconfidence level		Single tailconfidence level	
	95% reliability	90% reliability	95% reliability	90% reliability
	$\alpha/2$	$\alpha/2$	α	α
2	8.985	4.465	4.465	2.176
3	2.484	1.686	1.686	1.089
4	1.591	1.177	1.177	0.819
5	1.242	0.953	0.953	0.686
6	1.049	0.823	0.823	0.603
7	0.925	0.716	0.716	0.544
8	0.836	0.670	0.670	0.500
9	0.769	0.620	0.620	0.466
10	0.715	0.580	0.580	0.437
11	0.672	0.546	0.546	0.414
12	0.635	0.518	0.518	0.392
13	0.604	0.494	0.494	0.376
14	0.577	0.473	0.473	0.361
15	0.554	0.455	0.455	0.347
16	0.533	0.436	0.436	0.335
17	0.514	0.423	0.423	0.324
18	0.497	0.410	0.410	0.314
19	0.482	0.398	0.398	0.304
20	0.468	0.387	0.387	0.297
21	0.454	0.376	0.376	0.289
22	0.443	0.367	0.367	0.282
23	0.432	0.358	0.358	0.275
24	0.421	0.350	0.350	0.269
25	0.413	0.342	0.342	0.264
26	0.404	0.335	0.335	0.258
27	0.396	0.328	0.328	0.253
28	0.388	0.322	0.322	0.248
29	0.380	0.316	0.316	0.244
30	0.373	0.310	0.310	0.239
40	0.320	0.266	0.266	0.206
50	0.284	0.237	0.237	0.184

continued

Test number	Two tailedconfidence level		Single tailconfidence level	
	95% reliability	90% reliability	95% reliability	90% reliability
	α/2	α/2	α	α
60	0.258	0.216	0.216	0.167
70	0.238	0.199	0.199	0.155
80	0.223	0.186	0.186	0.145
90	0.209	0.277	0.173	0.136
100	0.198	0.166	0.166	0.129

***Background*:**

At the time of quality evaluation of highway subgrade and pavement layer, a road section is normally considered as a unit. It shall be selected based on practical demands and requirements of relevant specifications. Based on the results of each test point (test area) in this road section, statistical calculations may be made by following this Appendix to evaluate the quality of the work of this road section.

Some formulas defining absolute error/precision were deleted in this revision, as they are no longer used, and is not compatible with the terminology of engineering calculations in China.

Appendix C
Correlation test method

1 Scope of application

This method specifies the general requirements and processing procedures for using the linear regression method to determine the correlation between two different groups of test data. This method is suitable for converting results which are from different test methods but giving a certain technical index.

2 General requirements

2.1 The same technical index can be tested by different methods. To meet the needs for quality verification by the results from a different test method, a correlation equation can be built between the results to convert them.

2.2 There shall be at least four data points to perform the correlation test. The measured values shall be uniform and stable. The range shall be evenly distributed and cover the measured values found during daily production.

2.3 When performing a correlation test, the average value of multiple results from repeated tests shall be adopted to do the regression analysis.

2.4 When an earlier test could affect the measured value of a later test, the time interval between the two tests shall be suitably prolonged.

2.5 For a technical method which is sensitive to the test environment, necessary measures shall be adopted to ensure stable test conditions for repetitive tests. The use of modified data from the environment shall be avoided in regression analysis.

3 Data processing

3.1 Normally the least squares method is used to do regression analysis for two groups of test data. The correlation equation may be represented as follows:

$$Y = AX + B, R = \times.\times\times\times\times, C = x_{min} \sim x_{max} \quad (C\text{-}1)$$

where: Y——converted value, written in the form of ' symbol of the technical index$_{\text{title of test method}}$ ', dimensionless.

X—— value to be converted, written in the form of ' symbol of the technical index$_{\text{title of test method}}$ ', dimensionless.

A——slope, B—intercept, R— correlation coefficient, keep 4 significant figures;

C——measured range.

x_{min}——minimum value of test data to be converted

x_{max}——maximum value of test data to be converted.

3.2 The calculation equation for each characteristic parameter in the least squares method are as follows:

$$A = \frac{n\sum xy - \sum x \sum y}{n\sum x^2 - (\sum x)^2} \quad (C\text{-}2)$$

$$B = \bar{y} - A\bar{x} \quad (C\text{-}3)$$

$$R = \frac{\overline{xy} - \bar{x}\,\bar{y}}{\sqrt{(\overline{x^2} - \bar{x}^2)(\overline{y^2} - \bar{y}^2)}} \quad (C\text{-}4)$$

where: y——the converted value of test data

x——the value of test data to be converted

3.3 Correlation coefficient R shall satisfy the requirements for a specific technical index.

4 Report

The report of this method shall contain but not be limited to two groups of test data, correlation equation and graphs of the regression analysis.

***Background*:**

With the development of testing technology, there are many cases of highway field tests where different test methods are used for a certain technical index. To ensure consistency between the quality evaluation results, normally a relationship between two test methods is developed to convert the results between each other for quality evaluation. This is called a correlation test. As the conversion relationship built from a correlation test will be applied during data processing on daily test data, it is important for the correlation to be representative and reliable. The requirements for test conditions, testing elements and number of samples are strict and are specified. As many correlation test methods are provided for many technical indexes in the Standard to avoid repetition, this Appendix is added in this revision to generalize the requirements and data processing methods, so that engineers can have a global view of correlation testing. The special requirements for a specific index, such as requirements for correlation coefficient, measured elements and test conditions remain in the clauses about correlation tests under their original method titles.

Correlation tests have an inherent error component. For that reason it cannot replace the calibration performed by certain institutions of metrology.

Wording Explanation for the Standard

1 The strictness in execution of the Specifications is expressed by using the wording as follows:

1) MUST—A very restrict requirement in any circumstances.

2) SHALL—A mandatory requirement in normal circumstances.

3) SHOULD—An advisory requirement.

4) MAY—A permissive condition. No requirement is intended.

2 Expressions used for reference to standards are explained as follows:

The standards for which a year is added to the standard number shall be the specific versions to be used. Otherwise they shall be the latest available versions.