LATEST DEVELOPMENT OF THE MOBILE LOAD SIMULATOR (MLS) IN CHINA AND THE TECHNICAL FEATURES OF THE CHINESE NATIONAL STANDARDS ON THE ACCELERATED PAVEMENT TESTING USING MLS

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ABSTRACT

At present, China has the most full-scale and 1/3-scale Mobile Load Simulators (MLS) in the world. There are over 100 million loading applications tested by MLSs from the east to the west, and the north to the south of China. They have been applied in the transportation laboratories of universities, research institutes and vocational colleges. A great number of research reports and papers were published internally and internationally.

The MLS is an innovative advanced technology product with the original patent (90/9054) registered in South Africa. In December 2016, the South African Bureau of Standards (SABS) officially published the National Standard for the Determination of permanent deformation and moisture sensitivity in asphalt mixes with the MLS11, also known as MMLS3 (SANS 3001-PD1: 2016). Compared with other simulators used in the world, the MLS has several advantages with the lower capital costs per load application; less dependency on overloading for acceleration; lower operation cost indoors and outdoors; greater flexibility for testing protocols; etc.

There are two categories of technical standards in China: one is the provincial level and the other one is the national level. This paper introduces the latest development and applications of the MLS technology in China. It mainly reports the technical features of Chinese national standards on MLS systematic applications and the schedule to work on this standard.

Keywords: Mobile Load Simulator (MLS), Full-Scale MLS, 1/3-Scale MLS, Chinese Standards, Accelerated Pavement Testing (APT).

1. BACKGROUND

With the vigorous development of China's transportation infrastructure in recent years, the highway traffic network has become denser, and its efficiency and local convenience

effects have become more obvious. Since the reform and the opening up, China's transportation infrastructure construction has developed rapidly. By the end of 2020, the length of expressways in mainland China had reached 161 000 kilometres, with a total lane length of 723 100 kilometres, ranking first in the world, and the total national highway length is 5 198 million kilometres. With the increasing volume of road transportation and the sharp increase of large-tonnage vehicles, especially the channelized operation of high-grade road traffic, the fast-developing road transportation industry has accelerated the fatigue and structural damage of road surfaces.

2. PROBLEM STATEMENT

In order to study the structure and damage mechanism of the pavement and reduce the construction and maintenance costs, the life cycle of the road and the long-term performance of the pavement should be fully considered in the early stage of road design and construction, so as to optimize the road performance indicators. The design service lives of expressways and primary and secondary asphalt pavements in China are 15 years and 12 years respectively. Compared with advanced countries in the world, the design years stipulated in China are quite short. The design service lives of their pavement structures are shown in Table 1.

Table 1: Design service life of the pavement structures

Country	USA	UK	Germany	France	Canada	South Africa	Japan
Years of Design Life	30 ~ 50	≥40	30 ~ 40	30 ~ 40	30 ~ 40	20 ~ 40	20 ~ 40

Therefore, most of the high-grade roads in China are usually overhauled once every 10 years or so. Experience shows that large-scale highway construction is followed by large-scale highway maintenance and repair. A considerable number of highways have early damages such as ruts, cracks, waves, potholes, etc. After a few years of heavy traffic conditions, serious structural damage has occurred even within 3 to 5 years, which affects the service performance and service life of the road surface, and causes huge economic losses to the road construction industry. By carrying out research on the fatigue performance and anti-skid performance of asphalt mixture and pavement structure, improving the service performance of asphalt pavement, transportation authorities can prolong the service life of the pavement, save construction and maintenance costs, and greatly improve the social and economic benefits.

For heavy load, low speed and other traffic conditions, it has become a serious problem for road researchers to study the internal mechanical response characteristics of the pavement structure and its variation laws, as well as the damage mechanism of the pavement structure through the simulation test of the pavement structure. So, the accelerated pavement testing (APT) for long term performance and overloading conditions had been applied in South Africa and globally. The APT can save time and costs for the road authorities.

3. ACCELERATED PAVEMENT TESTING (APT) WITH THE MOBILE LOAD SIMULATORS AND THEIR ORIGINAL DEVELOPMENT IN SOUTH AFRICA AND TECHNOLOGY EXCHANGES GLOBALLY

As the long-term actual observation test is carried out in the life cycle of the road, the accuracy and reliability of the data will be high, but the data collection period is too long, the test results are seriously delayed, and huge manpower, material and financial resources are consumed. In addition, at different driving speeds, the dynamic load of the wheel caused by the uneven road surface is different at variable driving speeds. This kind of variable load is related to various factors such as vehicle axle load, vehicle speed, and road surface smoothness. Therefore, the collected data is difficult to accurately evaluate the pavement structure performance in order to meet the needs of the current road construction and the rapid development of traffic. However, the traditional sampling indoor testing method cannot truly simulate the actual running conditions of the vehicle on the road, the accuracy, authenticity, practicability and real-time performance of the test data are poor, and the error of the analysis results is also large. In view of the heavy load, low speed and other traffic conditions, how to study the internal mechanical response characteristics of the pavement structure and its variation laws, as well as the failure mechanism of the pavement structure through the simulation test of the pavement structure, has become a challenge for road researchers.

The use of APT can properly solve the problems mentioned above. It needs high investment but also gets higher benefits. According to the evaluation by relevant experts of the South African Department of Transport and the CSIR, the actual economic benefit ratio of the APT is 12.8 times. The advantages of innovation and scientific progress are obvious also.

From the 1990s to the early 2000s, South Africa's mobile load simulators (MLS) invented by Prof. Fred Hugo and Mr. Johan Muller, had been a useful tool of the APT. It has presented the advantages of faster loading speed, shorter test period, lower test cost, and more convenient movement. The MLS system applies 4 or 6 sets of axle loads, simulates the actual vehicle load at high speed, and adopts a non-contact linear induction linear motor system to effectively reduce and eliminate the fatigue and wear of drive transmission. Figure 1 shows the full-scale mobile load simulator with two series as MLS30/33 and MLS66/69 and Figure 2 indicates the 1/3-scale mobile load simulator (MLS11) indoor.

Figure 1: Full-Scale MLS

Figure 2: 1/3-Scale MLS

In June 2017, the MLS Users Alliance was established during the first Beijing World Transport Convention (WTC). And the International Society of the MLS (ISMLS) is a professional society and non-profit organization, which was co-established in Pretoria, South Africa, the administrative capital of South Africa in November 2018. The main partners consist of the South Africa-China Transport Co-operation Center (SACTCC), China-Africa Transport Strategy Research Institute (CATSRI) at Chang'an University, China with the University of Pretoria, South Africa and the PaveTesting Limited / MLS Test Systems (Pty) Ltd. with other international scientific research institutions and consulting firms.

In February 2019, the ISMLS participated in the "Belt and Road" Transport Technology Conference in Kathmandu, the capital of Nepal. It exchanged views at the Seminar of the MLS Big Data and Standards held in Pretoria, the administrative capital of South Africa in July of the same year. In October 2020, during the 6th China-Europe Functional Pavement Workshop, a China-UK-South Africa MLS technical standard and big data seminar was held. In July 2021, the 3rd Seminar on MLS Technical Standards and Big Data was held at the Delft University of Technology in the Netherlands. Technical exchanges in this field have promoted more applications in the world.

4. CURRENT STATUS OF MOBILE LOAD SIMULATORS IN CHINA

4.1 Tongji University, Shanghai

In 2007, the Key Laboratory of Road and Traffic Engineering, Ministry of Education under Tongji University imported the MLS66 full-scale pavement acceleration load simulator (Figure 3) and two one-third scale MLS11 pavement acceleration load simulators (Figure 4) from the South African MLS Test Systems (Pty) Ltd. The full-scale MLS adopts the patented cyclic loading mode of the loading frame and the method of using a linear motor to drive the loading wheel so that the full-scale loading speed can reach 6000 wheel loads/h. It can load the road with actual tires in a short time and under controllable conditions, simulate the loading of vehicles on the road for decades, and apply various indicators on the road. And the one-third scale MLS loading speed can reach 7200wheel loads/h.

Figure 3: MLS66 at Tongji University

Figure 4: MLS11 at Tongji University

Tongji University has implemented two 1/3-scale mobile load simulators and one full-scale mobile load simulator at same time. More than 40 million wheel load tests have been carried out under various geographical and climatic conditions, including Hong Kong-Zhuhai-Macao Major Bridge deck pavement. These tests performed the accelerated

loading tests on pavement structures in the field. Under the conditions of the simulated environment (water, temperature), through the continuous actions of repeated loads and the influence of the simulated environment (water, temperature), the pavement structure was accelerated to damage in a short time, and the simulation obtains its performance in the simulated environment.

Heating tests are commonly used to evaluate asphalt pavements. The deformation is usually within 125mm of the upper layer. Therefore, even if the maximum aggregate particle size is less than 25mm, the use of 1/3 scale MLS accelerated loading test can simulate the actual situation. Several reports and papers were published by this university. It supplies a deep foundation for the Chinese national standards on the APT.

4.2 Liaoning Provincial Institute of Transportation Research

In 2009, Liaoning Provincial Institute of Transportation Research imported the South African road accelerated loading test systems MLS66 and MLS11 which had been based on the "Key Laboratory Construction Project of Expressway Maintenance Technology and Transportation Industry" and established an accelerated loading testing platform.

The MLS66 presents the most advanced full-scale linear movable pavement accelerated loading test system in the world, and it is the first equipment of this type in the world because it closely simulates the reality, has high loading efficiency and convenient movement. There were more than 40 million load applications in this province. It serves the cold regional data for the technical standards of China. Figure 5 and Figure 6 show the full scale and 1/3 scale MLS systems in Liaoning Province.

Figure 5: MLS66 in Liaoning Province

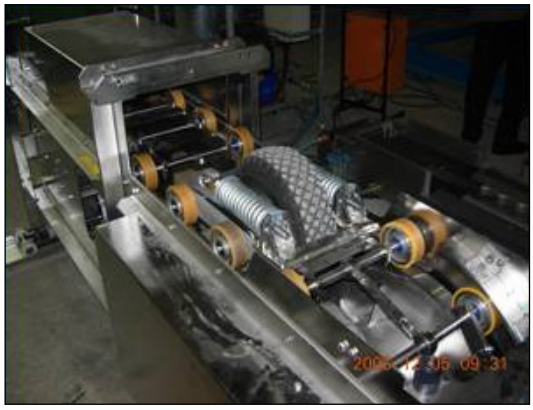

Figure 6: MLS11 in Liaoning Province

4.3 Jiangsu Transportation Research Institute (JSTI) and Southeast University

Jiangsu Transportation Research Institute (JSTI) and the National Road New Materials Engineering Laboratory of Southeast University have also owned the MLS platform. Field tests had been completed on two expressways in Jiangsu Province and roads in Guangxi Region. Their research reports were presented at the 6th China-Europe Functional Pavement Workshop in October 2020, the 8th China-Africa Transportation Cooperation Forum in July during the SATC2021 and the 3rd Seminar of the Mobile Load Simulator Standards and Big Data in July 2021, which conducted academic sharing for this national standards compilation.

Figure 7: MLS66 at Southeast University

Figure 8: MLS11 at JSTI

4.4 Changsha University of Science and Technology (CSUST)

In 2019, the National Engineering Laboratory of Highway Maintenance Technology of Changsha University of Science and Technology (CSUST) bought the accelerated pavement testing system of the PaveMLS69 series, which is currently the longest testing length in the world (Figure 9). The system can be used to verify and evaluate the construction quality of new roads and the service life of existing roads or newly designed pavements. The PaveMLS69 accelerated loading system can simulate heavy traffic volume and can simulate up to 144 000 times 15t truck wheel rolling per day. Take the loading of highway asphalt pavement with a design life of 15 years and a design heavy-traffic volume (15 million trucks) as an example, which can be completed in 3 to 4 months through the system. The PaveMLS acceleration loading system can record a variety of data (load, temperature, rutting, monitored mechanical response, etc.) in real-time, which can be used to analyze the performance of the road surface in detail. This PaveMLS69 joined into MLS family for linking the standards and their applications. Also, 1/3-scale MLS11 system has been used in CSUST over more than 10 years.

Figure 9: PaveMLS69 at CSUST

Figure 10: MLS11 at CSUST

4.5 Applications of the 1/3-scale Mobile Load Simulators in China

There are eighteen 1/3-scale Mobile Load Simulators MLS11 applied in China currently. They are members of the MLS series with the data collected from each user. About 30 million load repetitions have supported the Chinese standards of the MLS system. Table 2 shows the list of the 1/3-scale Mobile Load Simulators MLS11 in China.

5. Features of Chinese Standards of the Mobile Load Simulators (MLS)

5.1 Investigations of the Data Collection for the MLS Testing

From the perspective of compiling standards, the main issues to be investigated are as follows:

- Investigate domestic and foreign literature, standards, specifications, etc. related to the test technology of highway mobile pavement acceleration loading system.
- Investigate the application fields and status quo of accelerated loading technology at home and abroad.

Table 2: List of the 1/3-Scale Mobile Load Simulators in China

No.	Users	No.	Users
1	Tongji University	10	Hebei University of Technology
2	Tongji University	11	Chang'an University
3	Research Insitute of Highway (RIOH), Ministry of Transport, PR China	12	Chongqing Transport University
4	China Academy of Transportation Science	13	Changsha University of Science and Technology
5	Liaoning Provincial Institute of Transport Research	14	Heilongjiang Provincial Institute of Transport Research
6	Shanxi Provincial Institute of Transport Research	15	Chongqing Transport Research Institute, China Merchant
7	Southeast University and Jiangsu Provincial Transport Institute	16	Guangdong Hualu Transport Technology, Co., Ltd
8	Inner Mongolia University of Agriculture	17	Yunnan Provincial Institute of Transport Research
9	Inner Mongolia University of Technology	18	Yunnan Vocational College

5.2 Methods of the Research and Analyses

5.2.1 Literature Searches

Through literature searches, the panel collect Chinese and international technical standards, specifications and papers regarding the "Technical Regulations for Highway Mobile Pavement Accelerated Loading System", and can comprehensively and systematically grasp the current status of industry technology, learn from good experience and practices, and strive to improve the content of this regulation and meet actual needs by the national standards.

5.2.2 Analysis of Existing Relevant Standards and Norms

The list of relevant standards and specifications that have been investigated and obtained so far is as follows:

- Jiangsu Provincial Local Standard. DB32/T3821-2020 Technical Specification for Drainage Asphalt Pavement for Highway Maintenance Engineering (Waterproof Pavement Applied One-third Scale MLS Test Standard).

- South African National Standard--2016. SANS 3001-PD1 Civil Engineering Test Methods (Part PD1: Determination of Permanent Deformation and Moisture Sensitivity in Asphalt Mixes with the MMLS3).

5.3 Core Structures of the Full-Scale MLS

MLS has a high degree of automation. The types and quantities of its components are relatively large, and the assembly of more than ten thousand components makes the high density of the entire equipment sensitive. The full-scale MLS is mainly composed of a power supply system, hydraulic system, cooling system, electrical control system, loading system and road heating system. Relying on the MLS core component shown in Figures 11 and 12, the loading units apply the load to the road surface to carry out the testing. MLS is equipped with a total of 6 loading units, which are connected through hinges and connected to form a ring mechanism, relying on the chain shaft and the steel guide wheel on the loading unit to move in one direction along the elliptical track fixed inside the equipment frame. The specifications for the core structures are detailed in this standard.

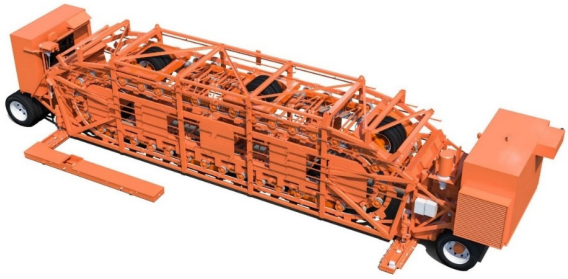

Figure 11: Main Frame of the MLS

Figure 12: Maglev system chains with wheels

5.4 Features of Chinese National Standards of the Full Scale Mobile Load Simulators

5.4.1 Test verification items, quantities and schemes

Focusing on the content formulated in the "Technical Specifications and Standards for the Testing of Highway Mobile Pavement Accelerated Loading System", the test and verification items are to be carried out are as follows:

Test verification of key technical points of the full-scale mobile accelerated loading system MLS (MLS69, MLS66, MLS33 and MLS30) (mainly outdoor tests, indoor tests are supplemented in a targeted manner, striving to achieve the best combination and cost-saving description, Figures 11 and 12 is MLS66 Large-scale accelerated loading test device).

5.4.2 Test Purpose

Verifying the feasibility, reliability and repeatability of the relevant technical clauses of this regulation.

5.4.3 Test Section

Select 1 newly built or renovated and expanded expressway, and select 3 test loading positions on the expressway with a certain distance interval, but with the same pavement structure and material composition.

5.4.4 Test Items
Including the Asphalt mixture fatigue test, high-temperature performance test, low-temperature performance test, water damage resistance test and anti-skid performance test.

5.4.5 Number of Tests
Each type of test item is done once in 3 loading positions, a total of 5×3=15 times.

5.4.6 Test Result Processing
For different types of test items, extract the data of each type of test parameter under different loading times. Compare and analyze the test data of each type of test to provide the basis for the revision of the corresponding technical clauses.

5.5 Features of Chinese National Standards of the 1/3-Scale Mobile Load Simulators

1/3-scale mobile load simulator MLS11 has kept the key technical points for testing verification.

5.5.1 Test Purpose
Verifying the feasibility, reliability and repeatability of the relevant technical clauses of this regulation.

5.5.2 Specimen Requirements
According to the Marshall test method of asphalt mixture, one group of GAC16 asphalt mixture specimens (meeting the specification requirements) may be formed, and each group of 9 specimens are assembled in the test tank at one time, a total of 2×9=18 specimens.

5.5.3 Test Items
Asphalt mixture fatigue test, high-temperature performance test, low-temperature performance test, water damage resistance test and anti-skid performance test.

5.5.4 Number of Tests
For the needs of comparative analysis, each type of test item needs to form 2 sets of test pieces, a total of 2×9×5=90 test pieces need to be formed and loaded 5×2=10 times.

5.5.5 Test Result Processing
For different types of test items, the technician should extract the data of each type of test parameter under different loading times. Comparing and analyzing the test data of each set, the technicians should provide the basic data support for the revision of the corresponding technical clauses.

5.5.6 Coring in-Situ and Transport to the Lab for Testing
For the properties of pavement materials, the technician should core in-situ (Figure 13) and transport to the laboratory for comprehensive testing (Figure 14).

Figure 13: Coring samples in-situ

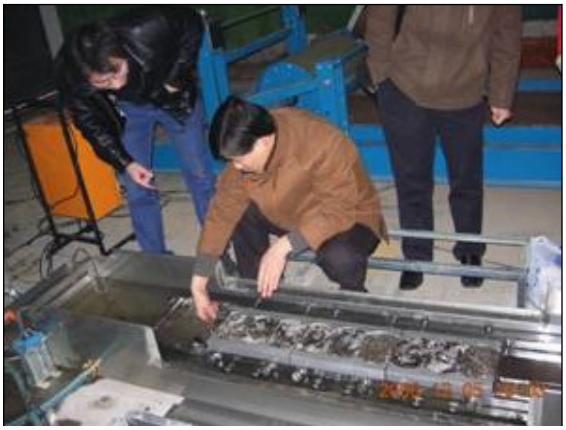

Figure 14: Testing the samples indoors

5.6 Scheme of Chinese Standards of the Mobile Load Simulators (MLS)

The panel had worked on a feasibility study from 2019 to 2020. The national steering committee's chair raised the comments in Oct. 2021. A high-level technical meeting at the national level was held for the working committee in Dec. 2021. The draft of the standard should be compiled by mid-2022.

Guangdong Hualu Transport Technology Co., Ltd, Chang'an University, The International Society of the Mobile Load Simulators (ISMLS), TIPTOP China Limited and Guangdong Jiaoke Testing Center are key members of compiling the standards. CECS is the Chinese national authority for approving and publishing this standard.

6. CONCLUSIONS

- This standard has based on the real requests for accelerated pavement testing (APT) on sites and indoors in China. It consists of the full-scale MLS and 1/3-scale MLS.

- From this standard, the technical authorities may obtain from the related tests according to this test procedure which is consistent among multiple sets of testing results at different test locations in the same test site, thus indicating that the use of the MLS system to carry out related test research has the better repeatability.

- The performances and durability of the new and existing pavement structures and materials may be evaluated by the Chinese national standards on MLS testing. The service life of structures and materials based on factors such as experimental big data and environmental changes may be analyzed for owners and institutional references.

- Through systematically analyzing existing highway pavement structures and materials, the authorities may combine the application of newly developed high-performance and environmentally friendly materials to improve the design and maintenance innovation of highway service life to 30-40 years.

- Combining the South African national standard on MLS testing and the Chinese national standards on MLS testing, an international standard on MLS testing will be formed by the ISMLS and related specialists around the world.

7. ACKNOWLEDGEMENTS

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