Study on the Correlation between the Texture Depth of Volume Replacement Method and the Texture Depth of Spectral Reproduction Method

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Abstract. Through theoretical research and actual road condition analysis, this paper establishes the simulation calculation model and the spectrum analysis model. Through the spectrum inversion, the stable road surface state is obtained, and the conversion relationship between the reconstruction depth of the spectral reproduction method and the structural depth of the volume displacement method is obtained. Through the conversion relationship of a typical single spectrum, the relationship between SMTD and TD is obtained under each type of standard waveform. Actually, in the process of sand paving, due to the presence of the exposed part, the SMTD and TD in the actual road surface are not positively correlated, thereby correcting the relationship between SMTD and TD. The acquired road surface data is modeled by MATLAB, and the analog waveform is made according to the actual waveform, and the reduced order decomposition is performed to determine the range of a. The intercept b value is determined by comparing the experimental spectra before and after sanding. This paper solves the problem that the detection mechanism needs to perform statistical correlation test in accordance with the requirements of JTG-E60 regulations to meet the requirements of pavement assessment.

1. Introduction
The pavement texture depth is a technical indicator of the surface performance of the pavement and is one of the important technical parameters for measuring the anti-sliding performance of the pavement. There are two main types of measurement methods for structural depth. One is the contact measurement method based on the volume conversion principle, that is the texture depth of volume replacement method. The other type is the non-contact measurement method based on the cross-section measurement, that is the reconstruction method of the spectral reproducibility method, which is represented by the laser texture depth meter test method. China's transportation industry standard JTG F80/1-2004 highway engineering quality inspection standard evaluation method is the texture depth of volume replacement method. The texture depth of spectral reproduction method, that is, the texture depth of laser method, is not included in the standard. With the development of electronic technology, the application of vehicle-mounted laser depth gauges has become increasingly widespread. JTG E60-2008 highway subgrade pavement field test procedures require that the correlation coefficient between the texture depth of laser method and the texture depth of volume replacement method is not less than 0.97 [1]. Therefore, the laser texture depth test must be tested by the volume replacement method. Studying the relationship between the texture depth of spectral
reproduction method and the texture depth of volume replacement method can greatly reduce the workload of construction and inspection units.

This project has mastered the technical points of the correlation between the texture depth of volume replacement method and the texture depth of spectral reproduction method. It basically overcomes the technical difficulties of the original output parameters being non-uniform and non-correlated, and realizes various calculation methods of structural depth. Unification provides a reference for the detection and acceptance of structural depth, and provides a technical basis for government departments to formulate policies.

The establishment of the texture depth of spectral reproduction method and the texture depth of volume replacement method indicates that China can also quickly evaluate the pavement by the spectral reproduction method. Because the texture depth of laser method in China has a complete traceability system, China's structural depth measurement has reached the international leading level[2].

2. Research content
In the field test procedure of JTG E60-2008 highway subgrade pavement in China's transportation industry standard, there are three kinds of test methods for pavement depth: manual sanding method, electric sanding method and vehicle-mounted laser depth gauge method. The first two are contact measurement methods, and the latter one is non-contact measurement method. There are two types of non-contact pavement texture depth calculation models: pavement texture depth measurement technology based on the spectral theory and the depth measurement technology based on the section elevation pavement structure.

2.1. Computational model of pavement texture depth measurement technology based on spectral theory
The internationally recognized definition of pavement depth is the deviation of the actual road surface profile from the ideal (reference) plane. In three-dimensional space, the specific point of the road surface is within a certain area (usually the same size as the tire grounding area). The distance (TD) between the ideal planes passing through the three highest points.

Although the ideal plane in the definition is difficult to form in actual measurement, it is more measurable than the definition of pavement depth in China. There is a certain degree of difference between the original data filtering and texture depth calculation models by various manufacturers, especially the texture depth calculation model. At present, there are mainly two types of texture depth calculation models, one is from the International Organization for Standardization (ISO) ISO13473, MPD calculation model; the other is from the British Institute of Transport and Road Research, 1974 Technical Document No. 639, SMTD calculation model.

China's original pavement laser structure depth gauge was introduced from abroad, and its corresponding calculation model is also from abroad. With the different origins of the instruments, the calculation models used are quite different. Some adopt British BS standards, and some adopt ASTM and ISO standards, some even refer to the same standard system, due to the specific technical methods selected and the special parameters used, the calculation results are also very different. For example, ISO13473 proposes four calculation methods of MTD, PD, MPD and ETD, while ASTM E1845-96 also describes MPD and ETD calculation methods, and UK SCANNER measurement system provides SMTD, MPD and RMST. Calculation method. Due to the difference of the calculation model, it is very likely that the same section data will appear and different texture depth values will be obtained. This results in low reliability and poor comparability of the pavement texture depth detection data in China, which has seriously affected the evaluation of the anti-sliding performance of pavement in China[3].

China GB/T26764-2011 "Multi-function road condition rapid detection equipment", the relevant provisions on the pavement structure depth equivalent to the TRRL method, which does not give its value traceability method, but far from the uniform value, standardizing the production purpose of
instruments and equipment. Australian equipment manufacturer ARRB uses a gear set to perform the laser calibration of the depth gauge factory calibration test. The vertical installation rotation is unstable, the gear replacement is difficult during testing, and the traceability trace chain is not clear. Due to the difference of calculation models and the lack of uniform value traceability method, the evaluation of road surface anti-sliding performance is not at the same level, which affects the scientific rationality of road quality evaluation. ISO, ASTM and related well-known scientific research institutions all define the pavement structure from the perspective of road surface spectrum. That is, the normal road surface longitudinal section is considered to be a set of continuously distributed spectra after the Fourier component decomposition. This spectrum can be quantified by different wavelengths, and the pavement structure is a set of spectra with a specific wavelength range[4].

2.2. Computational model of pavement texture depth measurement technology based on section elevation

The elevation measurement technology of pavement structure based on elevation is based on the theory of pavement spectrum. Firstly, the laser ranging technology is used to measure the elevation of the pavement profile quickly and accurately. Then, a certain calculation model is used to evaluate and describe the wavelength range of 0.5-50mm. The geometry of the road surface inside, thereby solving the measurement of the pavement texture depth. There are many different ways in the world to evaluate and describe the calculation model of pavement texture depth.

Profile Depth, PD: In a two-dimensional space, the distance between a point in the longitudinal section and the horizontal line of the highest point in the section in the interval of the tire grounding length.

Mean Profile Depth, MPD: The average of the depth of the section over a specific length interval.

Estimated Texture Depth, ETD: Using MPD as an independent variable, the conversion formula (such as ETD=0.2+0.8*MPD) is used to evaluate the depth of pavement structure.

Sensor Measured Texture Depth, SMTD: For the height series of the test points in a certain length paragraph, the calculated residual after the quadratic parabolic regression is performed. As shown in Figure 1.

\[
SMTD = \frac{\sum (y_i - \hat{y}_i)^2}{n}
\]

Among them: SMTD—the texture structure depth index, parabola regression is performed on the height data of each detection point, and the residual can be obtained. The unit is mm.

\(\hat{y}_i\)—a parabola obtained by quadratic least squares regression, which is \(a + bx + cx^2\).

Figure 1. Sensor calculation model for measuring texture depth.

For the construction depth meter, regardless of the texture depth of volume replacement method or the texture depth of spectral reproduction method, the domestic and foreign technologies are relatively mature, but in terms of output parameters, there is no correlation formula of each output parameter. The study of the correlation between the texture depth of volume replacement method and the texture depth of spectral reproduction method will further develop the laser structure depth detecting equipment and solve the problem that has not been solved in the industry for a long time.

3. Main research method
3.1. Theoretical study on texture depth conversion method
The working principle, input and output of the depth device were constructed by the spectral reproducing method to construct the depth and volume displacement method. The two parameters of the texture depth were analyzed according to the spectral theory. On this basis, the typical waveform is tested and the theoretical conversion formula of two parameters is obtained.

3.2. Test of texture depth conversion method
Firstly, the theoretical model is established, and the calculation software of different algorithms is output through MATLAB, excel and various construction depths to perform calculation and verification, and the relationship or correlation of output values of various construction depth devices is determined [5]. After completion, various types of asphalt surface materials and various road surfaces across the country are collected, modeled and calculated according to the sampled data, and the data is reproduced. Finally, the spectral data is reproduced by the scanned data to obtain a conversion formula. The main implementation plan and technical route of the project are shown in the figure.

4. Theoretical research

4.1. Brief description of spectral analysis methods

![Figure 2. Collected part of the actual road surface data and Two-dimensional spectrum of acquired data.](image)

ISO, ASTM, and well-known foreign scientific research institutions (such as TRRL) define the road surface structure from the perspective of road surface spectrum. That is, the normal road surface longitudinal section is decomposed by Fourier components and will contain a set of continuous distribution. Spectral spectrum, which can be quantified by different wavelengths, and the pavement structure refers to the deviation of the actual road surface longitudinal section from the ideal plane. Permanent International Association of Road Congresses has defined pavement construction in different wavelength ranges, which is widely recognized by the international engineering community. Since the volumetric displacement method is a computational model that aggregates points into three-dimensional measurements, the depth of the spectral reconstruction method is two-dimensional. The original research mainly uses statistical correlation, and no mathematical methods are used for research. In this study, the three-dimensional magnitude is differentiated to obtain the depth value of the two-section sanding method, and the relationship between the two is found. As shown in Figure 2 and Figure 3.

![Figure 3. Section of the texture depth of volume replacement method and the texture depth of spectral reproduction method.](image)
4.2. Conversion calculation of typical single spectrum

This paper simulates the value of a variety of basic waveforms and waveform changes. The total count value is 7 types, 116 groups, and nearly 10,000 waveform data[6]. One set of data is shown in Figure 4.

![Figure 4. Square wave basic waveform data - Simulated cement concrete groove.](image)

This paper is calculated by the standard waveform input software. Under the standard waveform, the relationship between each type of SMTD and TD is SMTD=TD*a(a>0). The SMTD and TD of each type of waveform are positively correlated, and there is only one correlation coefficient. The wavelength and amplitude of the waveform below 50 mm do not affect the value of the correlation coefficient. The correlation coefficients of different types of waveforms are different.

![Figure 5. SMTD and TD relationship diagrams of different standard waveforms](image)

Select typical data as shown in Figure 5. The red line represents the line type of one of the waveform data. The waveforms of different values and parameters are shown by the red dot in the figure. After the calculation, the intercept is extremely small and negligible. The blue dots represent different types of waveforms, and the corresponding a values are different. Each blue dot can be linearly the same as the gray one. This conclusion is consistent with the linear correlations between SMTD and TD made by various institutions in the world over the years. It also reveals that for many years, due to the uncertainty of a value, there has not been a correlation formula to convert the relationship between SMTD and TD [7].

5. Experimental research

According to the wave theory, any waveform is superposed with different waveforms, that is, the road waveform can be decomposed into waveforms of various waveforms [8]. The correlation coefficient a of the TD value and the SMTD value is also completed in a different waveform synthesis superposition. Although the value of a is different on different road surfaces, the waveform of the road surface is not extreme, and the data has certain regularity [9]. There is a range and interval. In order to determine the a-value interval, this paper has verified the theoretical and practical experiments.

5.1. Pavement waveform decompression calculation

In this paper, MATLAB is used to model the acquired pavement data, and the model is decomposed and reduced. At the same time, the simulated waveform is made according to the actual waveform, and the reduced-order decomposition is performed[10]. As shown in Figure 6.
The relationship between SMTD and TD after degrading the pavement waveform is shown in Figure 7. The horizontal axis of the coordinate system is the frequency of the wave, and the vertical axis is the amplitude[11]. According to the calculation results of different decomposition data, the value of a is basically in the range of 0.4–0.6.

5.2. The difference between the actual road surface waveform and the theoretical waveform

This paper collects asphalt surface data and actual road surface data through 3D scanner, collects and analyzes the data, and determines the range of a value[12]. The road surface and analog disk results scanned by the 3D scanner are shown in Figure 8.

Actually, the asphalt pavement cannot be completely covered by sand during the sanding process, and its partial height value is large, as shown in Figure 9. Due to the presence of exposed parts, SMTD and TD are not positively correlated in the actual road surface [13]. The SMTD still exists after the sanding section, so the conversion formula is not SMTD=a*TD in the actual process, but there is an intercept. That is, SMTD=a*TD+b.
5.3. Comparison of actual sanding and sanding theoretical values

In this paper, seven different technicians are selected to calculate the sanding of the standard disc. After each sanding, the standard disc is brushed clean and the next technician will sand again.

The experimental results show that the errors measured by different people are large during the sanding process[14]. After measuring 25 ml of sand with a balance, the density was weighed and found to have a density of 1.42, which is in line with the density range of standard sand. The theoretical sanding quality is obtained by converting the surface sand according to the density of the standard sand. Finally, the theoretical sanding results are compared with the actual sanding results, and the theoretical calculation values are basically consistent with the measured values [15].

5.4. Intercept Calculation

COOPER D R pointed out in Report No. 639: Measurement of Road Surface Texture by a Contactless Sensor that SMTD has a good linear correlation with TD, which is the main reason why the calculation model is widely adopted. The report obtained a correlation formula through a certain number of experiments: SMTD = 0.59 * TD + 0.12, and the correlation coefficient (R) was greater than 0.95[16].

Gan Baozhu, Zhang Yuguang, in the "Public Engineering" published "correlation between the sanding method and the laser structure depth gauge method to determine the depth of the pavement structure", proposed different correlation formulas and correlation coefficients. Under the condition of confidence a=0.01, the critical correlation coefficient of 96 groups of values is 0.2540, and the correlation coefficient is as high as 0.890. The formula can be used to convert the depth value of the spectral reconstruction method into the volume displacement method. The correlation formula is DTL=0.041+0.528DTS, where DTS is the volume displacement method texture depth, and DTL is the spectral reconstruction method texture depth, SMTD = 0.528*TD+0.041.

| SMTD value before sanding | SMTD value after sanding | Sanding part SMTD value |
|---------------------------|--------------------------|------------------------|
| 0.310                     | 0.073                    | 0.295                  |
| 0.440                     | 0.103                    | 0.418                  |
| 0.344                     | 0.079                    | 0.327                  |
| 0.876                     | 0.086                    | 0.831                  |
| 0.405                     | 0.093                    | 0.384                  |
| 0.867                     | 0.098                    | 0.822                  |
| 1.059                     | 0.091                    | 1.004                  |
| 0.766                     | 0.104                    | 0.727                  |
| 0.147                     | 0.053                    | 0.139                  |
| 0.845                     | 0.101                    | 0.802                  |

In this paper, the test blocks were measured before and after sanding, and the SMTD was measured as shown in Table I. Convert the contents of the table to a graph where the horizontal axis is the measured length and the vertical axis is the elevation value. The red line is the surface spectrum before sanding, the blue line is the blue spectrum after sanding, and the green line is the spectrum of the...
sanding part[17]. According to the measurement, the basic residual of SMTD after sanding is slightly less than 0.1mm, taking a certain insurance factor, taking b as 0.1mm[18].

According to the theoretical and actual measured values, the intercept b value is taken as 0.1 mm.

5.5. Calculation of Slope in Conversion Formula
In this paper, the test vehicle is used to test typical road sections, and ten typical sections are collected, totaling more than 450,000.

![Figure 10. Distribution map of typical pavement surface value a.](image1.png)

As shown in Figure 10, In the distribution map of the typical asphalt surface value a, the horizontal axis represents the range of each interval of the value a, and the vertical axis represents the number of distributions of each interval.

![Figure 11. Distribution of SMTD and TD on typical asphalt surface.](image2.png)

Figure 11 shows the distribution of SMTD and TD on a typical asphalt surface. The horizontal axis represents TD and the vertical axis represents SMTD.

5.6. Conversion Formula
According to the above conclusion, the value a is 0.55 and the b value is 0.1, so the conversion formula is SMTD=0.55*TD+0.1. The confidence interval is 40%.

6. Conclusion
In this paper, the three-dimensional magnitude is differentiated by the spectral analysis method to obtain the depth value of the sanding method of the two-dimensional section, and the relationship between the three-dimensional and two-dimensional pavement structure depth measurement is determined. Through the calculation of the conversion relationship of a typical single spectrum, it is concluded that the relationship between SMTD and TD is SMTD=TD*a(a>0) under each type of standard waveform. Actually, in the process of sand paving, due to the presence of the exposed part, the SMTD and TD in the actual pavement are not positively correlated, and the SMTD still exists after the sanding section, so the conversion formula is SMTD=a*TD+b. The acquired pavement data is modeled by MATLAB, and the model is degraded. At the same time, the simulated waveform is made according to the actual waveform, and the reduced-order decomposition is performed. The range of a
is determined to be in the range of 0.4~0.6, which is 0.55. By comparing the experimental spectra before and after sanding, it is determined that the intercept $b$ has a value of 0.1 mm. In summary, the relationship between SMTD and TD is $SMTD = 0.55TD + 0.1$.

Acknowledgments
I would like to express my gratitude to all those who helped me during the writing of this paper. I gratefully acknowledge the help of my colleagues, who have offered me valuable suggestions in the academic studies. In the preparation of the paper, they have spent much time reading through each draft and provided me with inspiring advice. Without their patient instruction, insightful criticism and expert guidance, the completion of this paper would not have been possible. I should like to express my gratitude to my beloved parents who have always been helping me out of difficulties and supporting without a word of complaint.

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