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RESEARCH ARTICLE

Comparison of pavement surface texture determination by sand patch test and 3D laser scanning

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Abstract

A modern highway must be capable of proving traffic safety, comfort to passengers as well as efficient and economical transportation. In view of the increase in the number of traffic accidents due to the developments in automotive industry, the traffic safety has gathered too much consideration in recent years. Skid resistance, on which road safety depends, is closely related to the pavement surface texture. The deterioration due to the traffic loads, especially polishing effect, involves a change in surface texture. In recent years, efforts are needed to develop more advanced technologies for evaluating pavement surface texture. In this study, the 3D laser scanner was utilized to quantify the mean profile depth (MPD) of a pavement at a static location. The surface texture of asphalt concrete pavements was scanned at 31 different locations and the results have been compared with the results of sand patch test. It was found that there is a good correlation between MPD as measured by 3D laser scanning and the mean texture depth (MTD) as measured by volumetric method (sand patch test).

Keywords

Pavement surface texture · laser scanner · sand patch test · macro texture · mean profile depth

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1 Introduction

As travel safety and efficiency of the road system are of increasing importance to highway agencies, friction measurements have become an important tool in the management of pavement surfaces. The friction-related properties of a pavement depend on its surface texture characteristics.

Pavement texture is defined as the deviations of the pavement surface from a true planar surface [1]. Macro texture is characterized by wavelengths between 0.5 to 50 mm and peak to peak amplitudes usually between 0.1 to 20 mm. Microtexture is characterized by wavelengths shorter than 0.5 mm and with peak to peak amplitudes usually between 0.001 and 0.5 mm [2, 3]. Texture wavelength (Fig. 1) is defined as the minimum distance between periodically repeated parts of the curve in its direction along the surface plane [3]. Both microtexture and macrotexture influence the skid resistance of a pavement.

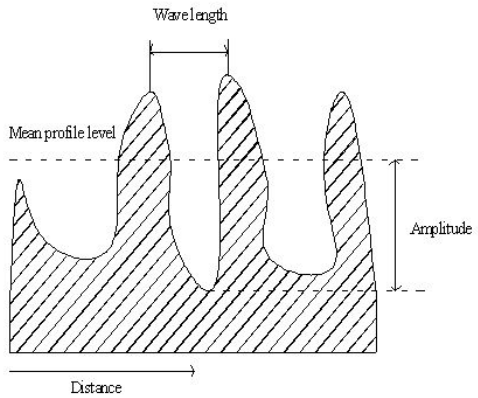

Fig. 1. Representation of surface texture characteristics.

It is widely recognized that pavement surface texture influences many different pavement–tire interactions. Fig. 2 illustrates the ranges of texture wavelengths affecting various vehicle–road interactions, including friction, interior and exterior noise, splash and spray, rolling resistance, and tire wear.

Adequate macrotexture is important for quick dispersion of water accumulated on the surface of a pavement to prevent hydroplaning. Hydroplaning occurs when a layer of water builds between the rubber tires of the vehicle and the road surface,

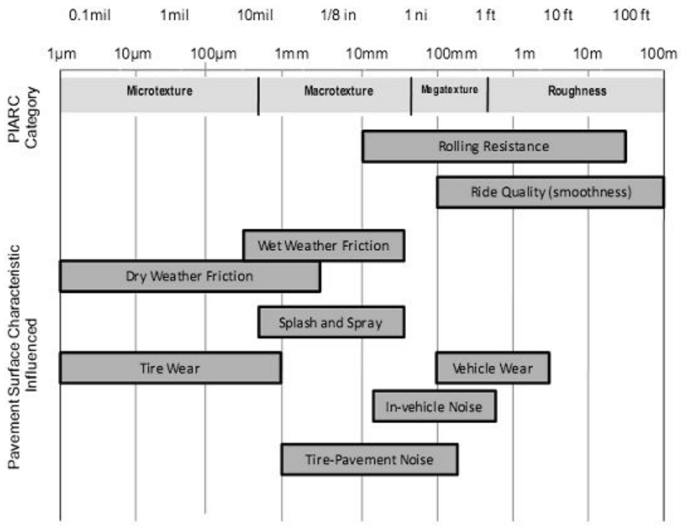

Fig. 2. Pavement surface characteristics classification and their impact on pavement performance measurements.

leading to the loss of traction and thus preventing the vehicle from responding to control inputs such as steering, braking or accelerating. Macrotexture aids for the development of hysteresis component of friction that is related to energy loss as the tire deforms around macro asperities and consequently increases pavement friction [4, 5].

A number of studies related skid resistance with surface texture. Britton et al. studied the influence of texture on tire and road friction. Skid numbers were governed by six texture parameters. The three macrotexture parameters and three microtexture parameters were expressed in terms of texture size, spacing or distribution, and shape [6]. Moore defined three parameters for characterizing a surface texture; size, interspace (or density) and shape [7]. Ergun et al. developed a friction-coefficient prediction model which is based on texture profiles measured by using an image capturing technique [8]. Bond et al. showed how differences on microtexture and macrotexture of pavement surfaces influence peak brake coefficients of a standard test tire [9]. Leu and Henry demonstrated how skid resistance tests taken from different pavement surfaces are different based on their microtexture and macrotexture [10].

Measuring the pavement macrotexture and relating these measurements to pavement skid resistance has been a major concern for pavement researchers. Macrotexture measuring techniques include sand patch method [11], outflow meter test [12], and circular texture meter [13]. In the past decade, significant advances have been made in laser technology, in computational power and in speed of computers. As a result, several systems can measure surface texture even at traffic speeds: The mini-texture-meter developed by British Transport and Road Research Laboratory [14], the Selcom laser system developed by researchers at the University of Texas at Arlington [14, 15] and the noncontact high speed optical scanning technique developed by the researchers at Pennsylvania State University [16] are the examples of these systems.

The primary indices used to characterize the texture with the above mentioned techniques are the mean texture depth (MTD) and the mean profile depth (MPD). While stating in the international PIARC (World Road Association) Road Experiment that the best parameter for determining the speed constant of the international friction index (IFI) is MPD, good predictive capabilities were also observed for MTD.

The objective of this study is to identify the MPD of the pavement surfaces using 3D laser scanner and to compare the results with MTD obtained by traditional method which is sand patch test.

2 Experimental

2.1 Test methods

2.1.1 The sand patch test

The test procedure used for the study follows the procedures contained in ASTM E965 [11]. It uses a volumetric approach of measuring pavement macrotexture. The principle is fairly obvious that the greater the texture, the more the sand will be taken up by it and the smaller the circle that can be achieved from the standard quantity of sand. In this study a known volume of glass spheres (24.6 mL) was spread evenly over the pavement surface to form a circle, thus ?lling the surface voids with glass beads. The diameter of the circle was measured on four axes and the value averaged. This value was used to calculate the MTD in mm (Eq. (1)).

$$MTD = \frac{4V}{\Pi . D^2 avg} \tag{1}$$

Where

V = the exact volume of glass spheres in, mL

D_{avg} = the average diameter of the sand patch in, mm

2.1.2 3D Laser scanning

Since the volumetric method (sand patch test) is impractical, slow and has poor repeatability, the work has been initiated with the aim to develop an alternative measurement device to the sand patch test. Improvements of measuring devices in recent years make the measurement techniques faster and more reliable. New data acquisition techniques include interferometry [17], terrestrial laser scanner that acquires three dimensional spatial data [18], as well as various 2D and 3D profiling methods with new calibration techniques and the Scanning Laser Position Sensor (SLPS).

In this study, the Metris Model Maker D100 3D laser scanner (class 2M) including enhanced sensors was utilized to inspect full range of colours and depths on the selected asphalt pavement surfaces. The laser equipment was mounted on a portable vehicle attached to a computer as presented in Fig. 3. The Model Maker D with true digital camera technology includes several groundbreaking innovations such as second generation Enhanced Sensor Performance (ESP2). This device provides a better trade off between resolution and efficiency in texture data collection.

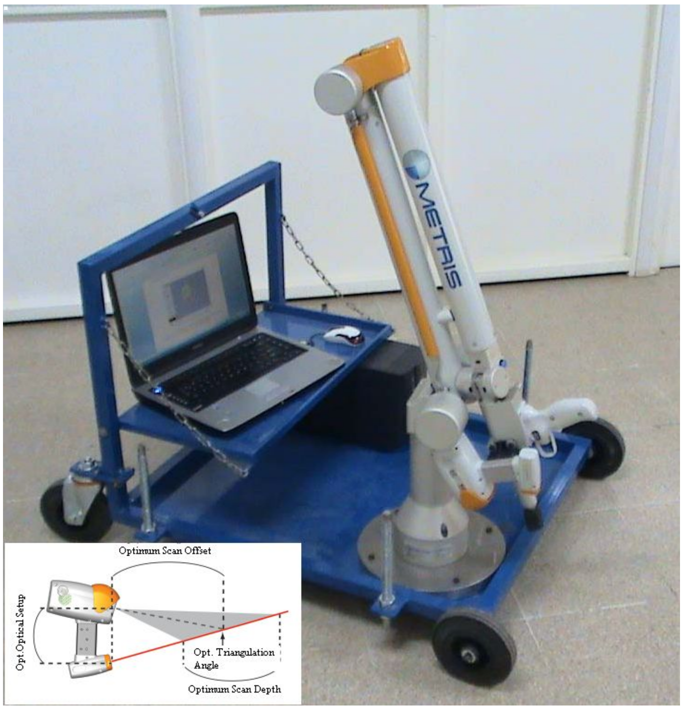

Fig. 3. 3D Laser scanning device.

As shown in Fig. 3, the device measures texture by means of laser light. Laser intensity output is controlled by the processing unit to maintain a constant level of light on the detector. The possible angle of incidence will depend on the measured material and on the surface geometry. The sensor consists of a light source and a detector integrated with optics and electronics. It is insensitive to ambient light. When the light source projects a beam to hit a pavement surface, a scattered reflection will occur. This light spot on the surface is viewed by a camera mounted inside the sensor. Depending on the distance between the laser head and the measured spot, the image of the light spot will be reflected to focus on a certain position on the detector.

As the resolution depends on the range to the object, in the field studies the scanners' enhanced sensor was established to provide an optimum resolution of 15μ m in the lateral direction and an optimum resolution of 10μ m in the vertical direction. The other important measure of the usefulness of the laser scanner is the accuracy (bias). This parameter determines how well the data represent the actual geometry of the scanned scene of object. For the 3D laser scanner utilized, the accuracy is expressed in terms of standard deviation of the ten measurements made on the same test surface. The standard deviation related to the calibration surface was found as 0.04 mm.

The Model Maker D is capable of sampling 1000 texture elevation points across a 100 mm wide laser line at 150 Hz as it scans the road surface at about 0.1 m/s. More importantly, the result is a 3D texture profile along a 100 mm wide swath of pavement surface.

The laser scanner adapts its laser power to suit the surface characteristics of pavement through enhanced scanning performance. During scanning process, laser device automatically tracks changes based on the surface conditions (both colour and reflectivity of the bitumen as well as some minerals) parallel to the direction of the moving traffic and adapts laser power and sensor settings. Fig. 4 exhibits the different textured surfaces taken by the 3D laser scanner.

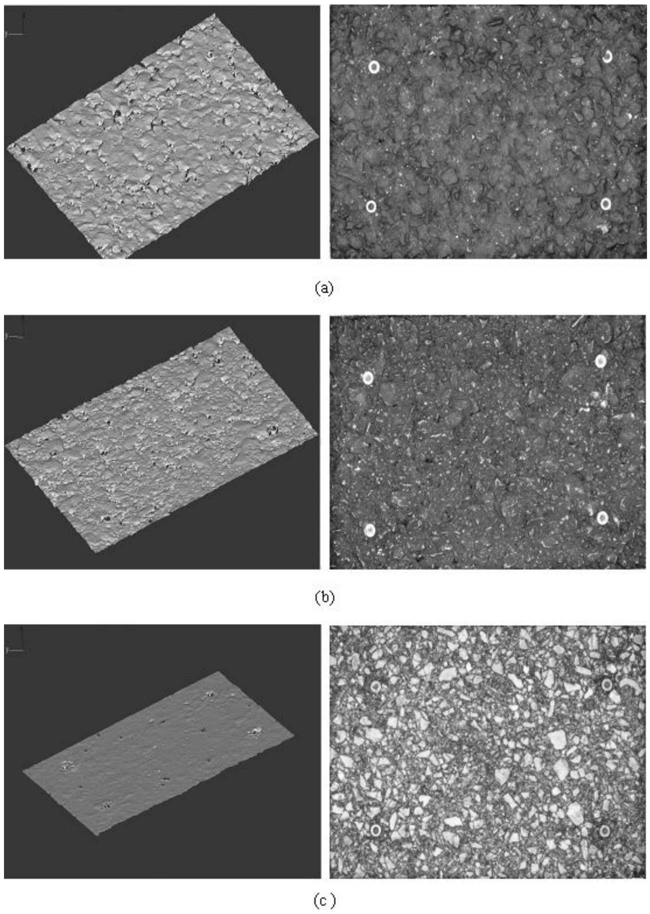

Fig. 4. The images of different textured asphalt pavement surfaces (laser scanned images on left-images captured by 12.1 Mp CCD camera on right).

The surfaces scanned with the Model Maker D were also captured by 12.1 Mp CCD camera as illustrated in Fig. 4.

The Model Maker D laser scanner are also supplied with a data acquisition software (Kube) which is integrated and specifically designed for capturing and processing the laser stripe data.

Following the acquisition procedure of the set of surface (Fig. 5 (a)) and cross-section (Fig. 5 (b)) of pavement samples with Kube software, it is necessary to characterize them with appropriate indicators such as mean profile depth (MPD).

A standard method for computing the profile depth of the pavement surface texture from the surface cross section was established in ASTM E 1845 [19] and utilized within this study. MPD is expressed as the average profile depth (the difference between the profile and a horizontal line through the highest peak within a distance along the surface of the same order of length as a tire/pavement interface) over a 100 mm long base line.

In order to investigate the cross-section in detail and compute the MPDs, the cross sections were taken in every 6 mm (Fig. 5 (b)).

Based on descriptions given in ASTM E 1845 standard, before computing the MPD, the surface profile was filtered by applying a low pass filter in order to remove wavelengths ≤ 2.5 mm followed by suppressing the profile slope by subtracting a regression line from the profile. The MPD was computed from a sample baseline divided into two equal half as presented in Fig. 6. The peak level in each half was determined and the average of the two peaks was termed as MPD.

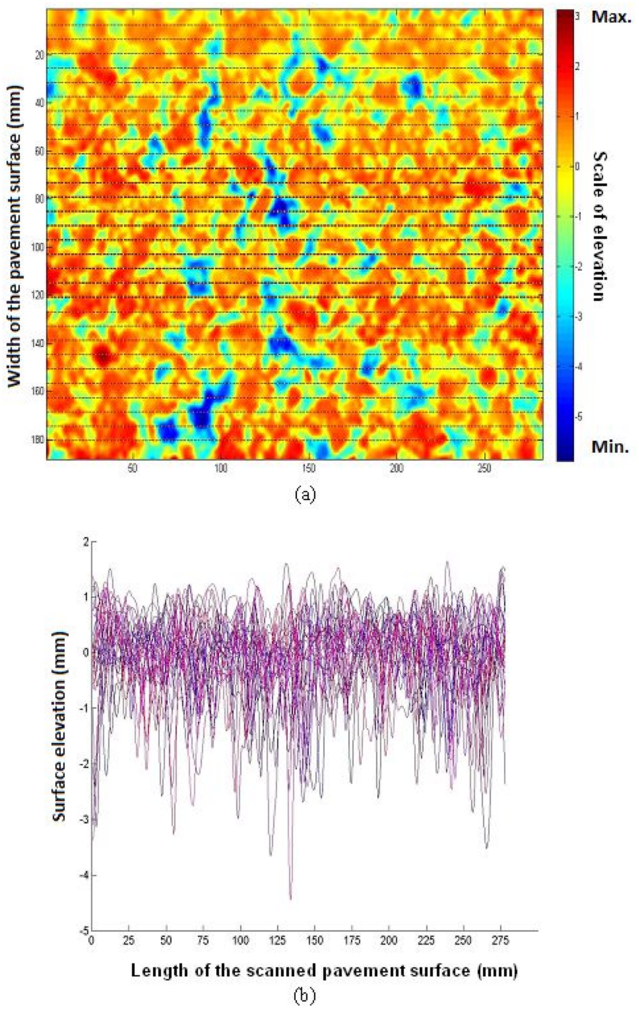

Fig. 5. The profile and a cross section example of an asphalt pavement surface.

2.2 Test track

The study was conducted on alignment sections of main arterials in Izmir/Turkey. The sections in question were picked to produce a range of surface textures. The total number of investigated flexible pavement section is 31 .Aggregate type used on the sections included limestone aggregate both in fine and coarse fraction. Each experimental section is exposed to the same environment but different traffic loading conditions.

3 Results and Discussion

The irregular road surface causes time dependent loading which depends on the characteristic of the road [20]. The characteristic of a road surface is determined by its texture and it is

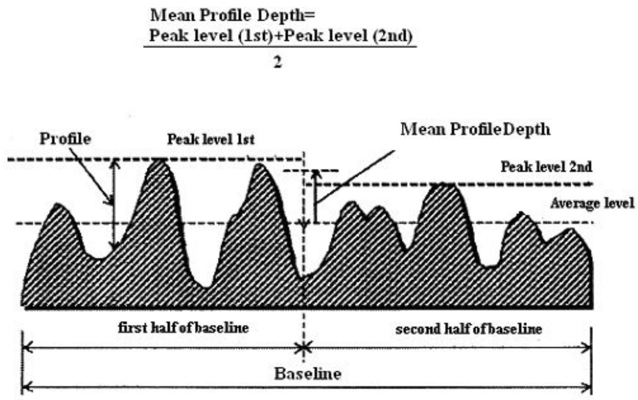

Fig. 6. Standard method used for calculating MPD [19].

directly related to safety and driving comfort. It is the aim of the study to find a measured value which can replace the MTD as a single-value representation of surface texture. The comparisons with sand patch test were presented to show that the laser method is also much more sensitive to both coarse and fine textures.

Fig. 7 exhibits MPD as obtained from 3D laser scanning, plotted alongside the MTD as obtained from the sand patch test. The data in the figure represent the average of the five tests by each method.

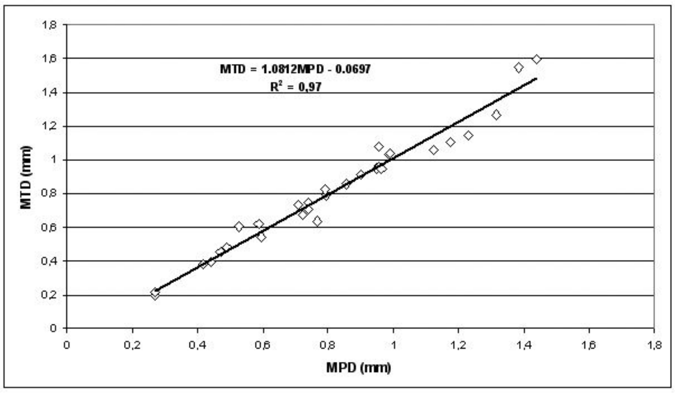

Fig. 7. Relationship between MPD and MTD.

The correlation coefficient indicates a strong relationship (R^2=0.97) between the MPD and MTD. The regression statistics are also presented in Tab. 1 and Tab. 2.

As presented in the tables, it is clear that both intercept and the MPD variable are significant. As a result, MTD values can be predicted by using the regression formula given below:

$$MTD = 1.0812MPD - 0.0697 \quad (2)$$

The measured and estimated values of MTD are compared with each other (Fig. 8).

As indicated in Fig. 8, the regression line adopted for comparison is almost identical with the line of equality which indicates the efficiency of the above presented equation.

Tab. 1. Statistics of Regression Analysis Between MPD and MTD

Coefficient of correlation r	Coefficient of determination R^2	Adjusted R^2	Standard Error	Observations
0,98	0,97	0,96	0,06	31

Tab. 2. ANOVA of Regression Analysis Between MPD and MTD

	Degrees of freedom (df)	Sum of squares (SS)	Mean Square (MS)	MS Regres./ MS Resid. (F)	Significance F
Regression	1	3,328453	3,328453	826,945785	7,21549E-23
Residual	29	0,116724	0,004024		
Total	30	3,445177			
	Coefficients	**Standard Error**	**T Stat**	**Probability of T statistic (P-value)**	
Intercept	-0,069721	0,032711	-2,131419	0,041655	
MPD (mean)	1,081236	0,037599	28,756665	7,21549E-23	

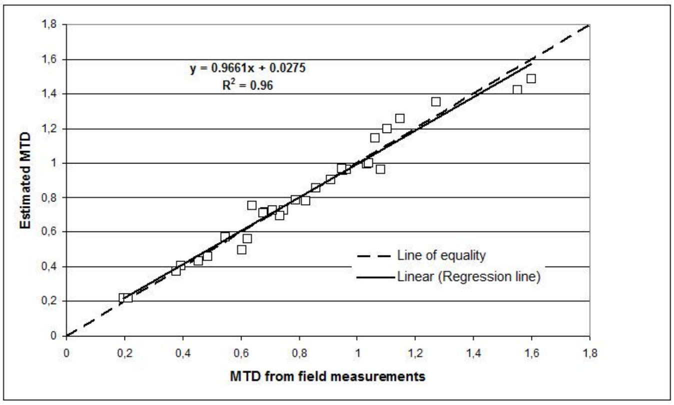

Fig. 8. Relationship between measured MTD and estimated MTD.

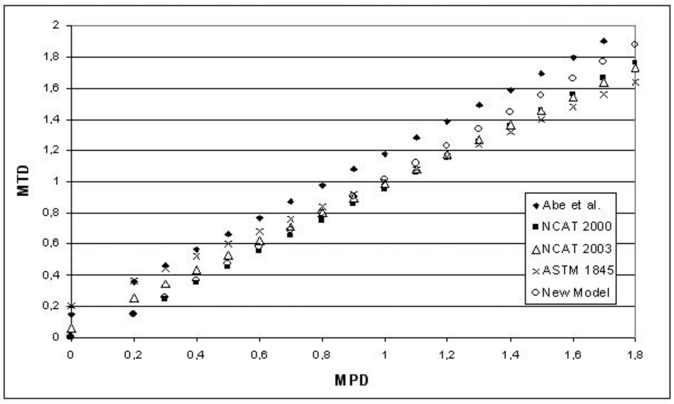

Fig. 9. Comparison of different MPD-MTD models.

Line of equality is an ideal line which indicates that the observed and the estimated values are assumed to be the same. Regression line's closeness to the line of equality is a clear indicator of how the estimated model works.

Previous work by Abe et al. suggests the following relationships between the MPD and MTD [21].

$$MTD = 1.03MPD + 0.15 \tag{3}$$

Detailed investigations were also performed in the National Center for Asphalt Technology at 2000 and 2003 to identify a relationship between MPD and MTD. The equations produced from 2000 and 2003 studies are respectively presented below [22].

$$MTD = 1.0094MPD - 0.056 \tag{4}$$

$$MTD = 0.9265MPD - 0.0633 \tag{5}$$

The following estimated mean texture depth-MPD relationship is also presented as a part of ASTM E1845 [19].

$$MTD = 0.8MPD + 0.2 \tag{6}$$

All the models presented above are compared with the model suggested in this study by the Eq. (2) (Fig. 9). It is clear that all models give quite close results but the model suggested by Abe et al. give higher MTD estimated values with respect to the other presented models.

4 Conclusion and Recommendations

In this study, surface texture measurements performed by the 3D Laser Scanning and the Sand Patch Test are conducted on different textured asphalt pavement sections. The 3D Laser Scanning produces results comparable with the ASTM E 965 Sand Patch Test. A strong relationship ($R^2 = 0.97$) is obtained between the MTD and MPD of the investigated pavement surfaces. The suggested model in this study is also closely related with the previously developed models.

This study also demonstrated the feasibility of assessing the surface texture of the pavements by means of laser scanned image analysis. Regarding the very fine dimensions of the pavement surface texture, the main advantage of the utilized 3D laser scanning system is the acquisition time and accuracy as compared with the sand patch test, which is considerably fast for scanning highly densed roads. 3D laser scanning would give an accurate and detailed assessment of pavements' changing surface texture level.

The conclusion of this study covers the determination of MPD and MTD. Frictional characteristics of the pavements should also be investigated by various friction devices and the correlations must be made between the friction and texture characteristics.

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