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THE STUDY OF HEAVY LOAD IMPACT ON ROAD PAVEMENT

Atis Zarins

[1]*Riga Technical University, Kaļķu str. 1, LV-1658 Riga, Latvia. E-mail: atis.zarins@rtu.lv*

Abstract. Road transport efficiency is dependent on a number of factors. The most significant of them are: guaranteed capacity of cargo traffic and impact of this traffic load on road structures. Latvian road operation experience show several problems associated with heavy goods transport and their impact on road pavements. A large proportion of the paved road network has seen strong rutting, which the reason is cited - the overloaded heavy freight traffic.
To find the impact of heavy loads, and in particular - timber haulage transport, on road pavement deformations and evaluate their prevention possibilities, as well as to investigate the efficiency of freight transport, for example by increasing the authorized amount of the cargo, and establish conditions that will allow it to do, a study was carried out.
The research methodology was based on dielectric constant measurements in a road structure using percometer. Measurements were made in the various pavement structure layers in different depths, with different loading schemes and in different moisture/temperature conditions. The obtained results confirmed the theoretically expected, that the load effect on road structures was reduced by increasing the contact area of load, measured between tire and road surface. Increasing of contact area was established by using the Central Tire Inflate system (CTI), which was installed on the test car. The study led to the relatively cheap and simple method for determining pavement response, behavior and for impact studies.

Keywords: road pavement, bearing capacity, dielectric permittivity, CTI, load impact.

1. Introduction

When designing or evaluating operating parameters of an existing road structure, methods and solutions based on theoretical considerations are commonly used. Thus a specific situation has to be associated with certain fixed parameters. But usually engineer has limited amount of such standard parameters and situation may not necessarily be appropriate to the relevant and well investigated standard case. Therefore, in practice often have to make a direct study of the situation, which usually have to be associated with sophisticated equipment and methods. It is therefore important to put into practice research methods, which require lower cost required for the study and its implementing consequences. One such possibility is to fix and analyse the change of dielectric parameters of road material with percometer.

The first indications of such a tool in research of road construction are available from the 1995th when percometer used in tube suction test by Saarenketo and Scullion (1995) and Scullion and Saarenketo (1997).

There are several studies about dielectric properties of road materials and soils with regard to operational characteristics: Saarenketo *et al*. (1998), Saarenketo *et al*. (2000). These studies were conducted under laboratory conditions. Research on road operating parameters considering impact of frost heave, during which dielectric properties of the environment under study are analyzed is published by Saarenketo *et al.* (2000) and Saarenketo and Aho (2005). There is pointed to the possibility of use of dielectric value under load as parameter and characteristic of loading impact on the road body.

This study will examine the feasibility of using dielectric conductivity parameters of the road materials, for the evaluation of road pavement response under full scale loading in situ.

2. Dielectric properties of road material

Dielectric permittivity $E_r(\omega)$ for soil or road material can be expressed with relationship:

$$E_r(\omega) = \frac{E(\omega)}{E_0}, \qquad (1)$$

where: $E(\omega)$ –absolute dielectric permittivity of material, which depends on frequency and is complex value, E_0 – dielectric constant of material, or the relative permittivity of a material for a frequency of zero.

Permittivity describes how much is the resistance of media to the electric field. Dielectric permittivity of soil materials determined by intensity of various processes in material structure: 1) ionic and 2) dipolar polarisation and relaxation of water solution molecules and 3) atomic and 4) electronic resonances in material media due to voltage applied to. Character of each of those processes determines different measurement frequency to review them. Because for road body medium first two of mentioned processes are more actual, the measurements can be carried out using frequencies that are common for them – about 2kHz for detecting of ionic and domain polarisation processes, and about 40-50 MHz for molecular level polarisation processes. However, possibly the whole spectrum of frequencies, or at least both mentioned together, can make an interest in soil material studies.

Parameter measured with percometer is the real part of the complex relative dielectric permittivity value (1).

Measurement of E_r for natural materials, including soils and granular building materials is relatively complicated. In order to avoid the impact of environmental heterogeneity of conductivity parameters to measurements, choice of right frequency of measurement and location of sensors has an importance. Also of importance is a correct understanding of the influence of water to the physical processes, and of their structure and mechanism. Conductivity of the natural media largely depends on its moisture. But much more on the electrochemical properties of water solution, i.e. salt content in water, as well as on electrochemical properties of media particles. It is possible to use empiric relationships between the conductivity E_r and the proportion of water in material, or moisture W. In generally relation $E_r = f(W)$ at different moisture levels and water electrical properties is non-linear, and depend on water and soil particle interactions. Most of typical materials have fixed inherent values of the W_v and E_r.

Main process, which can be analysed with respect to road material response to loading, is change of polarisation in water solution in interaction with soil particles and voids during loading and consecutive volume change. Polarization reduces the electric field in dielectric media, because of the increasing of polarization charge density on particle surface. Consequently, the surface parameters of the media constituent material and their molecular structure must be taken into account while evaluating measured dielectric data. The latter applies especially to the quantity of water solution, density and its chemical structure. In order to compare measurements made in different media, influence of all of the parameters must be precisely identified and evaluated. However, two different measurements taken at the same media can be assumed as comparable, even without knowing these parameters, with the assumption that they have been the same in both comparable measurements. Electrical losses in soil results from the inherent heat loss, loss from process of polarization of water molecules and the loss in electrochemical processes between clay mineral particles. This phenomenon is the result of a complex, frequency dependent dielectric permittivity. The real part of the dielectric permittivity for natural environments changes in the range of 1 for air, up to 81 for water. Water is that component of natural environment, including unbound road materials, which in great degree affect both the dielectric permeability, as well as its mechanical properties, for example - bearing capacity of pavement structure. Note however that this effect also depends on other factors, for example: environmental moisture conditions, etc.. Road structure can contain adsorption (hygroscopic) water, capillary (matrix) water and free water. Dielectric permeability of water within soil or road material depends on the total soil particle surface area available for water molecules, as well as from the polarization of water molecules, as well as the density of the soil. Thus, change of material conductivity and hence the dielectric permittivity resulting from load, or an compression, can be explained with the releasing of colloidal particles and ions from the clay particle surface and their suspension in the free and matrix water. An others factors causing this effect is due to the 1) suction and 2) pumping phenomenon in capillary material, as a result of cyclic loading. Loss of dielectric capacity of soil and road material also can be explained with suction, when free water from the upper layers is temporarily withdrawn to the lower layer in result of the compression and subsequent release of the pavement structure.

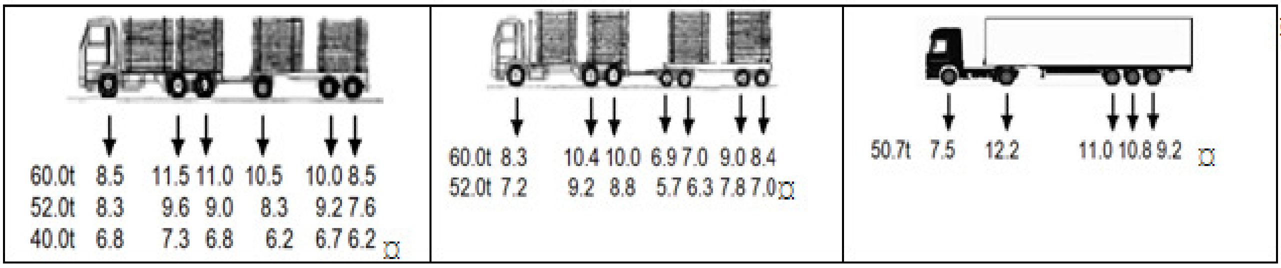

Fig 1. Load distribution schemes of test vehicles

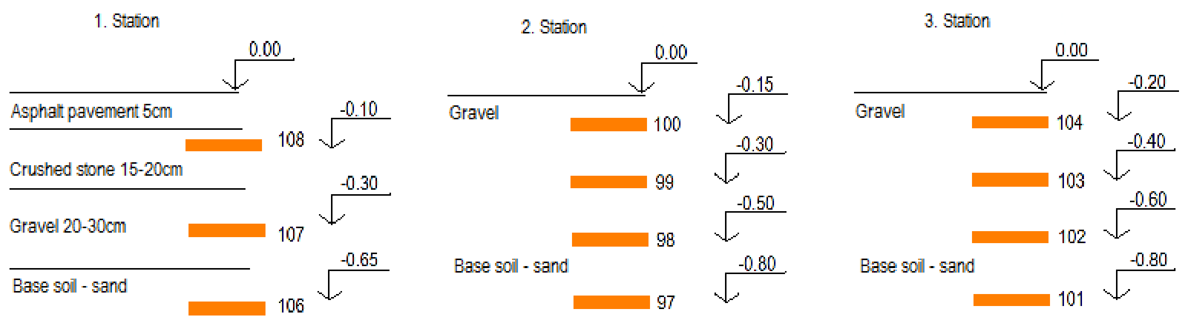

Fig 2. Sensor configuration in test stations

3. Methodology

The essence of the study is based on a comparison - the impact on the road structure from reference vehicle which consider conventional loads and dimensions, in comparison with the impact of vehicle with dimensions

by following the appropriate legislative vehicle and load parameters Three basic vehicle configurations with different load distributions was used in tests (see Fig 1.). The standard six axle timber haulage vehicle was equipped with CTI system and load tests were carried out both: with a standard tire pressure (0.8MPa), and with a reduced pressure using a CTI system (0.35MPa) results of which in graphs below are marked as “with CTI”.

Test equipment consists of percostation (3 stations each equipped with 3-4 sensors), 4 channel data logger and portable weighing-machine.

The research methodology is based on a road structure dielectric constant measurements using percometer. Measurements were carried out in different layers of pavement structure at various depths, and during different loads were applied. Measurements included the following sessions: 1st - before freezing, (late November), when the pavement structure has a maximum moisture due to autumn rainfall, but coverage is not yet frozen (autumn slush), 2nd after the surface thaw,(April) when the pavement bottom has not yet been thawed, and the road structure is saturated with water (spring slush), 3rd dry structure (late May) and 4th - after summer rainy season (August). Overall, 165 proper readings – response diagrams, were obtained from the single sensor at the time of full loading tests. Road pavement response study is based on the consideration that dielectric permittivity change of an unbound pavement material under the load correlates with the amount of applied impact. So measurements of E_r in equal media conditions for different loads can be used for impact evaluation. Therefore it can be assumed, that induced parameter changes within a single measurement session (in equal conditions) are comparable.

Assuming, that changes of dielectric parameters in road materials affecting from load impact, in greater extent depends on matrix water, in tests the measurements was carried out using frequency – 2kHz for detecting E_r. Samples of E_r have been taken using sampling rates 200 – 1000 Hz.

Stations of tested road structures were configured as drawn in Fig 2.

and load combinations under research. The effect of using a reduced pressure in the tires was also considered.

The aim is to find out - whether it is possible to characterize the capacity and response of road structure using dielectric parameters during full loading test.

The reference vehicle (40t, 6 axles) was determined

Duration of measurement cycle was provided such that it includes both - the loading, and recovering of the structure under test. Loading was applied with speed 15-25 km/h, so vehicle crosses test section of road in approx. 5 seconds. Recovery time depends on the water and material condition, and may be from 10 s to several minutes. Necessary length of data logging was fixed during test by following the measurement.

All the test stations is located on functioning roads. Fist one in section of asphalt paved road, third – on the same road section with gravel pavement and second one on low volume forest road, with just renovated drainage.

From obtained records, the change of dielectric value ΔE_r has been evaluated with purpose to express pavement response (see Fig3).

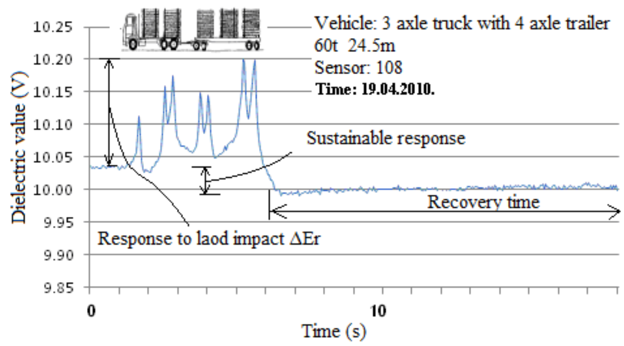

Fig 3. Sample of test record and parameters to be evaluate

4. Test results

The overall results confirm hypothesis that dielectric value change of an unbound pavement material under the load correlates with the amount of applied impact. This follows from graphs presented (see. Fig 4-6). Coefficient of correlation varies from 0.7 to 0.9, however amount of data evaluated can be treated as insufficient for statistical analysis, because of assumption, that only data from certain station and certain measurement session can be compared in such way. So we were able to make no more than only one cross for each load distribution scheme per session.

Fig 7 shows pavement response differences in 1st station (asphalt pavement). This comparison confirms that elongated vehicle (24.5 m, 7 axles) with cargo load 52 t makes nearly equal impact, as the reference vehicle with 40 t. In turn, using reduced tire pressure (52 t with CTI), reduces impact almost twice. If weight increases (60t), response to upper layers of pavement increases proportionally (fig 4 to 6). However, as it can see, this effect maintains only in top layers of pavement. On lowest sensor the difference disappears (Fig 6 and 7).

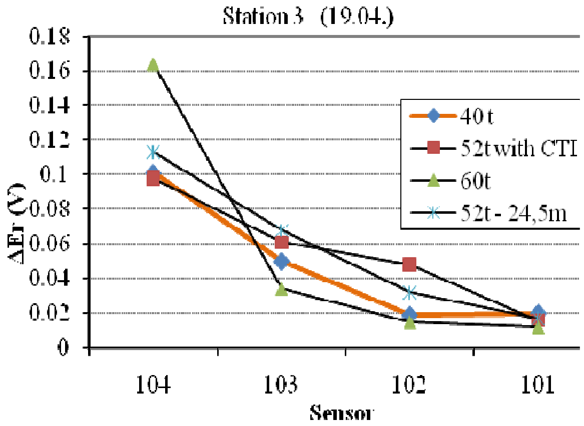

Fig 4. Differences of *Er* for Station 3 (9.04.2010)

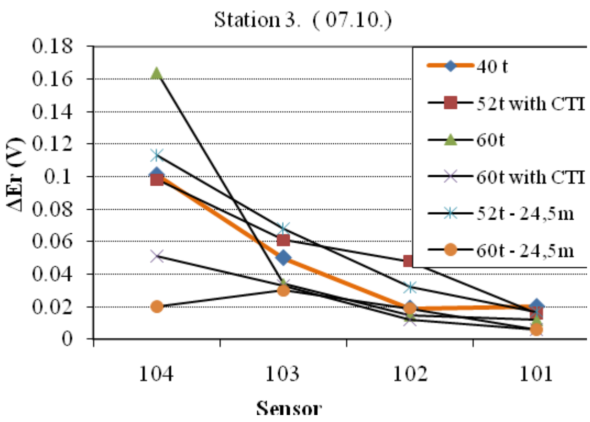

Fig 5. Differences of *Er* for Station 3 (07.10.2010)

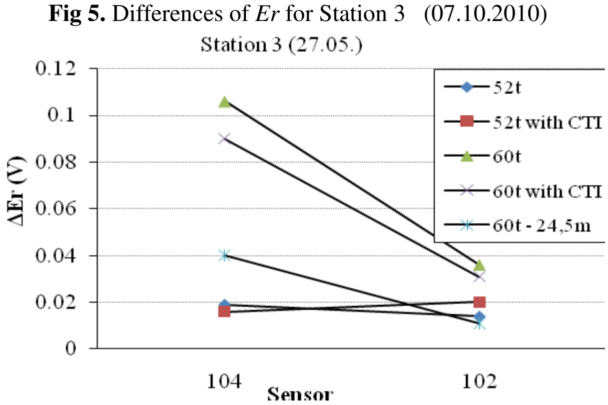

Fig 6. Differences of *Er* for Station 3 (27.05.2010)

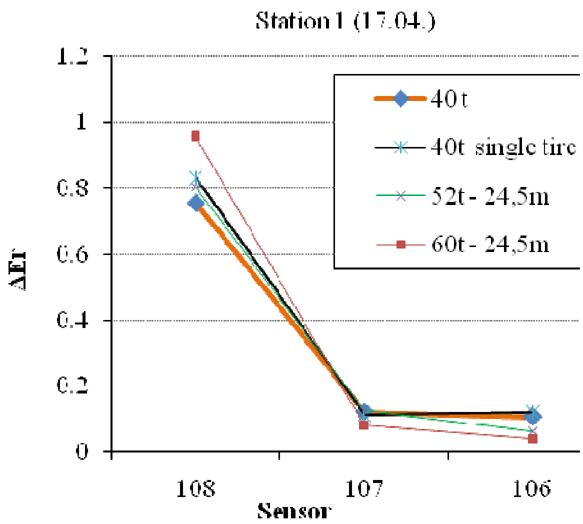

Fig 7. Differences of *Er* for Station 1 (17.04.2010)

Test results show that 40t vehicle equipped with single tires on asphalt pavement cause slightly stronger response than reference vehicle (see Fig 8). In turn - situation on gravel road (Fig 9.) shows that single tire load leaves significantly greater impact, than double tired vehicles with the same cargo weight.

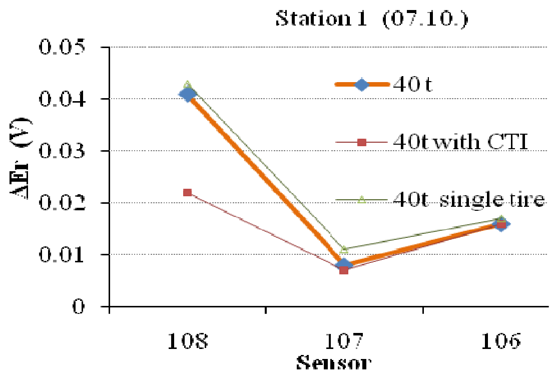

Fig 8. Differences of *Er* for Station 1 (07.10.2010)

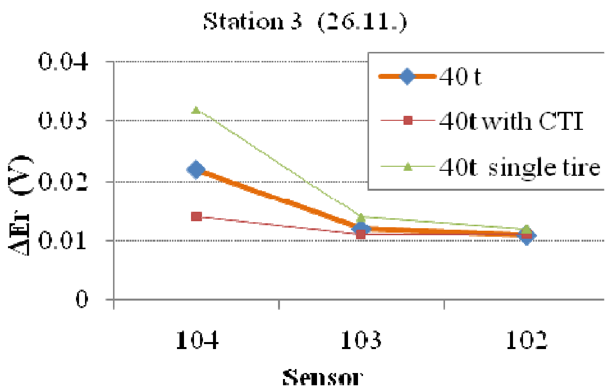

Fig 9. Differences of *Er* for Station 3 (26.11.2010)

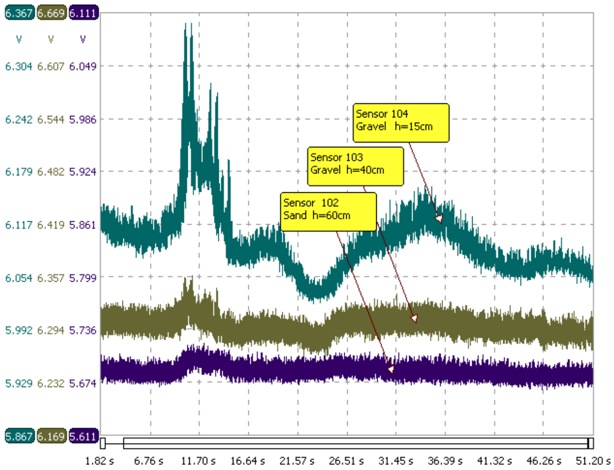

Fig 10. Dielectric response *Er* in station 3. Vehicle 52 t (26.11.2010) (vertical axes between sensors are shifted)

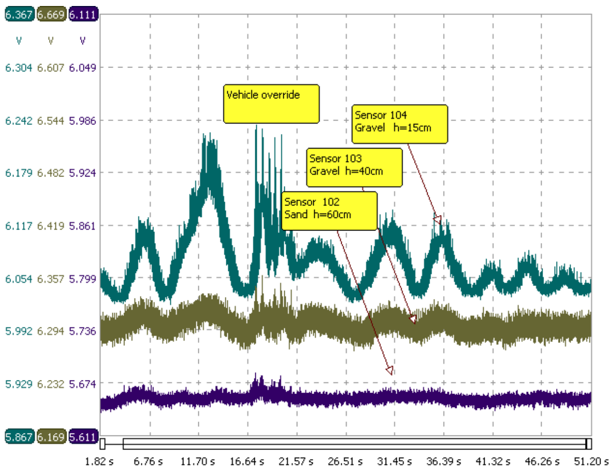

Fig 12. Dielectric response *Er* in station 3. Vehicle 24.5 m, 52 t (26.11.2010) (vertical axes between sensors are shifted)

An interesting phenomenon of dielectric value fluctuation appears in records, which were done in early spring and late autumn sessions (see Fig 10 and 11.). Records done in other sessions didn't show this. In Fig 10 appears that loading initiates such waving. In turn, Fig 11shows that waving precedes vehicle movement and appears even before vehicle passes test section. Moreover – fluctuation has a distinct frequency. In this case it was about 5s. Time of full quieting lasts about 2 minutes. This means that there exists a particular soil determined natural frequency of fluctuations. Also apparently that fluctuation initiates by the definite axle load configuration and other parameters (axle weight, speed, etc.). As it is seen in records, fluctuation prevails in upper layers and quiets down at lowest part of pavement. This can be explained by the proximity of the upper sensor to the free surface. It is obvious (Fig 11) that impact from fluctuation is close or equal with the impact from the applied load and must be properly evaluated.

Fluctuation described can be explained with water pumping phenomenon which prevails in wet road condition, and obviously has a base frequency depending on road material.

Other phenomenon fixed during tests is an opposite response, when dielectric value drops down under the load.

This was detected with lowest sensor of asphalt pavement (see fig 12) while upper sensors show positive response, and this reminds in all sessions. And it was observed also in well drained upper part of forest road (see Fig13).

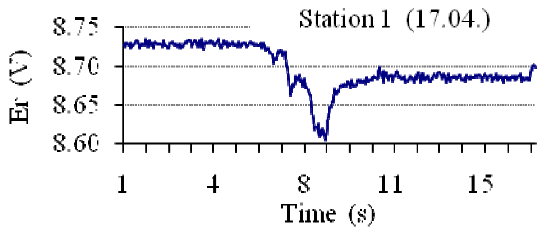

Fig 11. Oposite dielectric response *Er* in station 1

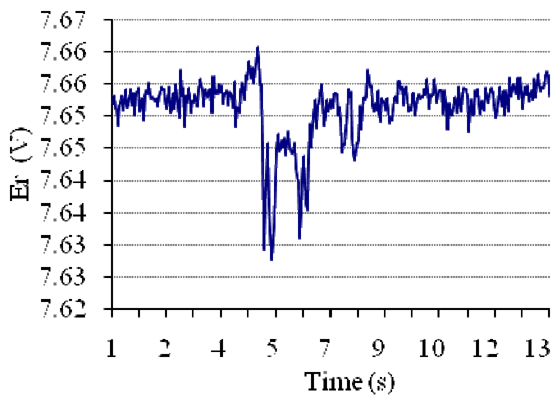

Fig 13. Oposite dielectric response *Er* in station 2

During tests the recovery time of dielectric value, or time of media stabilization after loading induced response, also was studied. Unlike to study of Saarenketo and Aho (2005) were recovery time is defined in different way, and was measured in ionic level spectrum part, in current study it was defined as time while dielectric conductivity value returns in initial position (see Fig 3), and was measured in 2kHz frequency. According to this definition, the recovery time in most cases did not fixed, because of they exceeds of 10-15 min or more, or was not tended to return in initial position at all. This can be explained with unstable character of molecular level water movement in wet road material.

5. Conclusions

Water movement and condition in road material and soil can be characterised using dielectric permitivity measured within two frequecy intervals - that are common for them – about 2 kHz for detecting of ionic and domain polarisation processes, and about 40-50 MHz for molecular level polarisation processes. This study was carried out in lowest frequency interval. However results show that some response parameters, i.e. – recovery time, can be researched with higher frequency, because of its more ionic level character.

This study shows, that it is possible to characterize the capacity and response of road structure using dielectric parameters of road material or subsoil during full loading test. However it is clear that without additional researches and definng soil dielectric propertiis and water regime in road structure, only relative analysis shall be possible within one measurement station and session.

It was concluded, that reduced pressure in tires significantly reduces an impact on top layers of pavement. However in depth of base layer (>30cm), this effect disappears. In addition, it was fixed, that the impact reducing effect in greater extent refers to unbounded pavements. A similar effect also applies to single tires.

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