Laboratory testing of static and dynamic deformation characteristics of small scale model of pavement subgrade

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Abstract. Interaction system vehicle-pavement represents actual problem in terms of structural, life service and environmental requirements. Experimental measurements with real vehicles and pavements are time consuming and bring high complexity of the inputs, relations and other boundary conditions which need to be identified to achieve reliable outputs. Inevitable uncertainties related to the real structure can be controlled when scale models with identified boundary conditions are prepared. Determination of the characteristics of the individual components of the vehicle-pavement interaction system at controlled conditions is then possible. The subgrade is an important part of the pavement structure. A laboratory and numerical simulations based on the static and dynamic testing methods were used to determine the deformation parameters of the subgrade. A viscoelastic mass was selected as a subgrade for the small scale model of the pavement. Its characteristic allows the simulation of the dynamic effects of the vehicle on pavement structure. A short-time dynamic loading of the subgrade occurs when the vehicle moves on the pavement. Therefore, the response of the subgrade should be also characterized with the dynamic parameters. The results obtained by the experimental observations in-lab will be used for the evaluation of the traffic effect on the pavement structure and surrounding objects such as buildings.

1. Introduction
Observation of the vehicle-pavement system with the real vehicle and pavement is affected by the numerous factors, which many of them cannot be fully controlled within the analysis because of its stochastic nature and complexity also based on mutual influence [1-3]. Small scale model seems to be reliable in terms of controlled observation at given or known boundary conditions. Of course, detailed comparison of model results and real system outputs should be realized to verify the reliability of the small scale model.

Because of small thickness of the pavement, subgrade represents very important part of the structure. Pavement loading is mainly spread in stiffer upper layers but some portion of the loading is transferred to the subgrade and then further to the environment.

Considering this, we selected the material based on the gelatine which should represent the behaviour of the subgrade under dynamic conditions.
In engineering practice is gelatin commonly used to model seismic activities such as earthquakes. One of the important parameters is the properly model scale ratio. Here it is necessary to correctly determine the gelatin material parameters and after that these values can be interpolated to real situations. In this article we focus on the possibility of using a small scale gelatin model for dynamic vehicle-pavement interaction. The tested gelatin consists of animal origin obtained from collagen using hydrolization. Based on the measured experimental results we want to determine the suitability of use for vehicle-pavement interaction [4-6].

This paper presents the results of the static and dynamic loading tests of the subgrade material to estimate its deformation characteristics.

2. **Subgrade material**

A gelatine like material was selected as a subgrade material. Its viscoelasticity allows to simulate the behaviour under dynamic loading and can be related to the softer subgrade soils or small scale simulations.

Gelatine is protein of animal origin obtained from collagen using hydrolization [7, 8]. In this case, the collagen was prepared from ossein of beef-cattle. Solution containing glycerine was boiled until became liquid and poured into the steel tank. After cool down, a compact mass with flat surface was created.

Poisson's ratio $\mu = 0.5$ corresponding to the soft materials is assumed for the testing at a compound and air temperature of 22°C.

3. **Subgrade testing**

In real scale conditions, various methods were developed to determine the deformation characteristics of the pavement layers [9]. Despite the small scale, we decided to test the subgrade via conventional methods such as plate load test (PLT) and hammer drop test (HT) which are common in engineering practice.

Using the same methods for the real structures and model allows us to determine the scale relation between calculated quantities.

3.1. **Testing stand**

The scheme of the tank and PLT and hammer drop tests is plotted in figure 1.

![Figure 1. Scheme of the testing stand (dimensions in mm),](image)

a) detail of the PLT test, b) hammer drop test.
3.2. Plate load testing
Plate load testing consists of measurement of the plate settlement at given load acting on the plate. At known plate radius \( r \) and Poisson's ratio \( \mu \) of tested material, we can calculate the modulus of elasticity \( E \) for the given pressure interval under the plate \( \Delta p \) and corresponding elastic plate settlement \( y_e \) [10].

\[
E = \left[ 0.5 \cdot \pi \cdot (1 - \mu^2) \cdot \Delta p \cdot r \right] y_e^{-1}
\]

A plexiglass plate of thickness of 2.5 mm with the diameter of 215 mm and the weight of 131 g was used for the loading. The plate was rigid and light-weight as well. Additionally, sliding deformeter acts with the weight of 102 g on the plate as a result of pressure of the measurement tip. On each loading stage, 44 or 46 g weight was placed in the middle of the plate, figure 1a. After 30 minutes, all weights were removed and actual settlement was read to calculate the elastic part of the settlement.

This elastic part only corresponds to the effect of the weights because removing of the deformeter and plate is impossible during the test. A 30-minute restriction was selected due to viscous nature of the gelatine when the settlement grows up within the time. Moreover, dynamic load of the vehicle wheel acts only for the short period of time and longer loading stage gives underestimated values of modulus of elasticity.

A total of 5 loading/unloading cycles were realized during each of the 3 PLT tests.

3.3. Hammer drop testing
When a loading plate (typically during lightweight deflectometer test – LWD) is placed on the gelatine, it sticks with the surface and removing is very complicated and cannot be done without some damage of the gelatine mass surface. Stiffness of the plate and the damper influence the recorded values, when the weight impacts the damper on the plate.

To exclude these uncertainties, a hammer drop test based on the Clegg Impact Soil Tester (CIST) was adopted [11]. Wooden cylinder of diameter \( d = 25 \) mm with weight \( m = 39 \) g slides along the leading aluminium rod from the height \( h \) and hits the gelatine surface. Accelerometer attached to the cylinder records the deceleration \( a \) during the impact, figure 1b. When the peak deceleration is known, modulus of elasticity \( E \) is calculated as follows [12]:

\[
E = m \cdot a^2 \cdot (1 - \mu^2) \cdot (d \cdot h \cdot g)^{-1}
\]

Gravitational acceleration is \( g = 9.81 \) m·s\(^{-2}\).

4. Results and discussion
Typical propagations of the load/settlement for the PLT test and the time/acceleration for the hammer drop test are plotted in figures 2 and 3.

![Figure 2. Load/settlement curve for PLT test.](image1)

![Figure 3. Time/acceleration curve for hammer drop test.](image2)
Calculated values of modulus of elasticity according to equation (1) varies in interval from 5.7 to 2.6 kPa with decreasing of its values with increasing vertical load. Significant drop in $E$ values was observed in the first loading/unloading stage when first 46 g weight was applied (“weights” part of the curve in figure 2). After second cycle, $E$ values oscillate around 2.6 to 3.1 kPa in 3rd to 5th cycle. Final value of the PLT $E$ modulus lies within this interval.

Relation between calculated modulus $E$ and corresponding hammer drop $h$ is plotted in figure 4.

![Figure 4. Values of modulus $E$ depending on the hammer drop height.](image)

As shown in figure 4, overall trend of the $E$ values is clearly visible when with increasing hammer drop height $E$ values also increase. Unfortunately, the spread of the data points is very large. Reliability coefficient is $R = 0.74$ for the second degree polynomial relation of the trend line. Despite this, we assume that sufficient large set of test results allows to determine reliable value of $E$ modulus from the hammer drop test.

It’s also obvious that $E$ modulus from hammer drop test is significantly larger than $E$ modulus from PLT test. Considering the trend line, the $E$ value lies within the interval from 10.6 kPa to 40.4 kPa which gives the dynamic multiplier between PLT and hammer drop values of modulus $E$ from 4.1 to 13.0. The $E$ values from hammer drop test appear to be a “dynamic values”. This statement should be verified by the physical and numerical modelling when the subgrade response to the dynamic load of the pavement will be investigated.

Hammer drop testing method was originally developed for determination of the static values but considering the dynamic nature of the pavement loading and the dynamic effect of the hammer, this method is still suitable for the testing in the model. Determination of the pressure interval on the subgrade is necessary to calculate the $E$ modulus related to the deformation response of the gelatine. The surface tension of the gelatine when the stiffness grows up with increasing impact energy represents problem that can be solved when actual pressure acting on the model subgrade during the vehicle wheel pass will be known. Drop height and hammer weight can be then calibrated to obtain required response of the gelatine.

5. Conclusions
Testing of the gelatine materials is complicated because of its viscoelastic nonlinear nature. Static tests proved that gelatine can swallow up objects after few hours or days depending on the weight and shape of the objects. Time restriction for the static tests was then set to achieve as realistic values of $E$ modulus as possible. Dynamic characteristics of the gelatine strongly depend on the stress state on the subgrade surface. Only exact knowledge of this quantity allows reliable estimation of the $E$ modulus related to the dynamic behaviour of the subgrade.
A large dispersion of the $E$ modulus values during hammer drop test should be minimized when a larger set of data will be available. Other methods, such as resonant testing or dynamic excitation, can be combined to describe the behaviour of the gelatine under dynamic conditions. Based on measured experimental results, we can conclude the possibility of re-evaluating the mixing ratios of gelatin. In this case, we can change the material parameters of the small scale model. However, it is necessary to state that correct identification of gelatin properties is very complicated and complex [13].

Together with the above mentioned statements, dynamic deformation characteristic will be a background for further small scale physical and numerical modelling of the interaction system vehicle/pavement and surrounding objects.

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