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Stiffness Estimation of the Soil Built-in Road Embankment on the Basis of Light Falling Weight Deflectometer Test

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Abstract

The paper presents a method of the stiffness modulus identification of the soil built-in embankment, tested by the Light Falling Weight Deflectometer ZFG-01. The identification was carried out on the basis of displacements recorded during impact test. It was assumed that nonlinearity of the ground was described by changing in time values of the dynamic stiffness modulus. The original calculation program, based on finite difference method which enables the description of wave propagation in cylindrical soil solid under impact load, was used. The sensitivity of the dynamic stiffness modulus of the ground in the process of loading and unloading was confirmed.

Keywords: stiffness modulus of the ground, LFWD test, road embankment

1 Introduction

The Light Falling Weight Deflectometers (LFWD) are often used in engineering practice to control the stiffness modulus of soil in the embankment. First of all they are used in transportation geotechnics. The popularity of these devices is connected with the fact that the test is carried out very quickly and the results are obtained immediately. Therefore, research methodology and factors affecting measurements are now widely commented in a lot of studies, e.g. Stamp and Mooney (2013), Vennapusa and White (2009). Fundamentals of theoretical studies of the ground by means of Light Falling Weight Deflectometer are still being analysed (Adam, 2003, Asli at al., 2012; Mooney and Miller, 2009). Also, a number of standard documents and guidelines on methods of study and interpretation of results were created (ASTM E2835-11, 2011; ASTM E2583-7, 2007; ZTVE-StB 94, 1994/1997). The operation of the device is to induce reaction of the ground under the load plate. This ground reaction is caused by the falling weight through the damper spring. During the test, the results of accelerations, velocities and vertical displacements of the load plate are received. The maximum displacement obtained during impact test is usually used to control the stiffness modulus of the ground.

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The aim of the study is to evaluate the stiffness modulus of soil in the embankment. The study will present the results and methodology of non-standard evaluation of the stiffness of the subsoil, with the methodology going beyond the normal instructional procedures for use of the apparatus used in engineering practice (TP BF-StB Teil B 8.3, 2003). The analyses were carried out on the assumption that the soil is a non-linear medium. Identification of the stiffness modulus of subsoil was performed by the tangent method with the application of the author's original program of finite difference method (Gosk, 2012).

The variability of the load plate displacements in time is the basis for determining the stiffness modulus of subsoil. The problems associated with the accuracy of determining of displacements in the device during the test shall not be discussed in the article. However, the author is aware that factors such as numerical integration and low-pass filtering may affect the resulting values of the load plate displacement.

2 Subsoil Study with the use of Light Falling Weight Deflectometer

Field research was conducted in April 2015 on the embankment of European route E 67 (ViaBaltica), then being under construction, in the vicinity of the town of Zambrow. Three measurement points were located at three different sites of the analysed section of the embankment. The embankment was made of multi-graded sand and gravel mix (Sa/Gr). In each of the measurement points full waveforms of acceleration, velocity and displacement of the load plate along with the step of sampling $TP = \Delta t^{exp} = 56\,\mu s$ were recorded. The diagram of Light Falling Weight Deflectometer ZFG-01 is shown in Figure 1a. During the test, the load plate was subjected to a weight stroke by means of a shock absorber of given stiffness. The diameter of the load plate is D = 300 mm and the maximum stress obtained under it equals $\sigma_{max} \approx 100\text{kPa}$. The intention of designers of Light Falling Weight Deflectometer was to obtain a dynamic impact force P (t) which corresponds to the load conditions of the subsoil under the wheels of a moving vehicle. The movement of the load plate caused by cushioned stroke of falling weight is of multi-phase type. Figure 1b shows this movement as a schematic drawing, and also shows the character of variation of the impact force P (t) transferred to the subsoil. The primary phases of the movement are the phases of loading and unloading.

In the standard approach of the user guide of the device (TP BF-StB Teil B 8.3, 2003) the test result is the dynamic modulus E_{vd} of the subsoil used most often for quality control of the embankment compaction in the course of its construction (ZTVE-StB 94, 1994/1997). The concept of the determination of the modulus is based on the assumption that the test medium is isotropic elastic half-space, and the stiffness of the ground can be determined by using the relationship of the modulus with the static settlement of rigid circular plate. The study (Gosk, 2010) demonstrated that from the engineering point of view such significant simplifying assumptions enable obtaining solutions correct to some extent. By using the methodology of the user's guide of the device in this article the following modulus values were determined at three sites: 50.10; 51.64 and 52.19 MPa. In each of the measurement points three impact tests were carried out, each time after the initial three strokes. It is understood that the first three strokes are made to match the load plate to the subsoil. The mean value of the maximum load plate displacement obtained in three main attempts [mm] is then used to determine the dynamic modulus of the subsoil E_{vd} [MPa], which is obtained from the relationship $E_{vd} = 22{,}5 / u_{max}$.

Figure 2 shows accelerations and displacement values obtained at the measurement point 2 during the second main impact test, recorded by the author.