periodica polytechnica

Civil Engineering
52/2 (2008) 97–102
doi: 10.3311/pp.ci.2008-2.06
web: http://www.pp.bme.hu/ci

RESEARCH ARTICLE

Conversion between static and dynamic load bearing capacity moduli and introduction of dynamic target values

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Received 2007-12-06, revised 2008-03-13, accepted 2008-12-03

Abstract

Two types of Light Falling Weight Deflectometers (LFWD) are in use in Hungary: the German device (Zorn, HMP and Wemex) and the new B & C small-plate device, which was developed by Andreas Ltd. Both devices are able to measure the dynamic load bearing capacity of subgrades, subsoils, embankment layers and backfills. Extensive application of these apparatus still has not been achieved since the dynamic modulus is not accepted in the quality assessment and quality control process of embankments and subgrade layers. Only marginal use of these devices can be noticed, mainly on areas of low importance (e.g. road shoulders) or trenches where performing a static plate load test could be complicated. For being able to use these dynamic devices on embankment layers, research for converting the measured dynamic modulus into static modulus has been initiated. First results of this research are presented in this paper. Using international and Hungarian measurement results, required target values for E_{vd} and E_d have been proposed for implementation.

Keywords

Light Drop-weight Tester · Light Falling Weight Deflectometer · B & C · subgrade modulus · static plate load test · target values · load bearing capacity

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1 Introduction

Two types of Light Falling Weight Deflectometers (LFWD) are in use in Hungary. The German device (Zorn, HMP and Wemex) appeared in the construction industry in the late 70's, while the B&C small-plate device was developed in 2003 by Andreas Ltd. These devices are similar in shape and set-up. Both are able to measure the dynamic load bearing capacity of subgrades, subsoils, embankment layers and backfills.

Extensive application of these apparatus still has not been achieved since the dynamic modulus in not accepted in the quality assessment and quality control process of embankments and subgrade layers. Only marginal use of these devices can be noticed, mainly on areas of low importance (e.g. road shoulders) or trenches where performing a static plate load test could be complicated.

For being able to use these dynamic devices on embankment layers, the research for converting the measured dynamic modulus into static modulus has been initiated. First results of this research are presented here.

2 Objectives of the research

The main objective was to determine the correlation between static and dynamic moduli. Since direct conversion formulas are not frequently used in practice, introduction of an easy-to-use table with the required static and dynamic target values has been aimed. Based on the new table, the prescribed load bearing capacity of the layers and backfills could be assessed by lightweight drop test methods.

Otherwise new quality assessment based on dynamic moduli might be able to substitute the exclusive usage of the slow and complicated static plate load test in the near future. With the help of these results, new dynamic design methods can be worked out and applied.

3 Available LFWD's in Hungary

The first LFWD used in Hungary was of *German type*. Three different companies (Zorn, HMP and WEMEX) manufactured these devices, in compliance with the relevant German standard TP BF - StB, Teil B 8.3. [1]

A 10 kg falling weight is dropped onto a 300 mm diameter plate from a height of 72 cm through guide rod; the vertical displacement of the plate (s_0) is recorded by an accelerometer built in a steel case on the top of the plate. The drop weight, drop height and plate diameter are constants, they could not be modified. The plate coefficient (c) and the Poisson's ratio (ν) are also set constant, therefore the dynamic subgrade modulus (E_{vd}) is calculated by a simplified Boussinesq equation:

$$E_{vd} = \frac{22,5}{s_0} \tag{1}$$

The Hungarian *B & C device* has a similar set-up (72 cm drop height, 10 kg drop weight), but it has a different plate diameter (163 mm). Because of the smaller diameter (R), the stress generated under the plate is assumed to be three times higher than that in case of the German device. Therefore the stress is close to that observed in the case of a static plate load testing (p=0,30-0,35 N/mm^2). The B&C device allows free selection of Poisson's ratio (ν=0,3-0,4-0,5) and plate coefficient (c=p/2 or 2), therefore the general Boussinesq formula can be used to calculate the dynamic modulus (E_d):

$$E_d = \frac{c \cdot (1-\nu)^2 \cdot p \cdot R}{s_0} \tag{2}$$

4 Conversion formulas based on earlier Hungarian results

The German device

After the first experiences gained with the German device, the Institute for Transport Sciences (KTI) launched a research program in 1995 aiming to convert the dynamic modulus obtained by that device (E_{vd}) into the well-known static plate load test modulus (E_2) obtained by conventional measurements [2].

After collecting 64 measurement results performed on different subgrade and subsoil materials, a general conversion formula was suggested. That formula (sometimes referred as "Baksay formula") is still known and appears on several laboratory records.

$$E_{vd} = 0,52 \cdot E_2 + 9,1 \tag{3}$$

Few more parallel tests were performed by KTI in 1996, but further modification of the formula was not suggested [3].

Comparative measurement results of the Hungarian Railway Company were published by Kiss et al (2003) [4], but no close relationship was found.

Contractors, including H-TPA Ltd. and EGÚT Ltd., also performed parallel measurements on different test layers, but generally on few spots and layer types. Their results remain unpublished yet.

The B&C device

Ézsiás (2005) [5] performed field measurements in order to determine the relationship between B&C dynamic subgrade modulus (E_d) and static subgrade modulus. His results related to incineration slag (Eq. 4) showed good correlation, while those related to silty fine sand were relatively poor (Eq. 5).

$$E_d = 1,4397 \cdot E_2 + 7,3819 (R^2 = 0,98) \ \textit{incineration slag} \tag{4}$$

$$E_d = 0,6426 \cdot E_2 + 19,796 (R^2 = 0,38) \ \textit{silty fine sand} \tag{5}$$

Almássy and Subert (2006) [6] published their results after performing 58 measurements on sandy gravel subgrade during the implementation of the M7-M70 highway project. They found a correlation (see Eq. 6), but did not suggest the wider use of it.

$$E_2 = 8,906 \cdot E_d^{0,5238} (R^2 = 0,76) \tag{6}$$

5 International conversion formulas

The German device

Several correlation results between E_2 and E_{vd} are available in the international literature. The most relevant results are summarized in Fig. 1.

Direct conversion equations are not frequently used in practice, generally limit values are given for both E_2 and E_{vd}. Four different German standards give similar limit values, these are also presented in Fig. 1 (bold dash lines).

Fig. 1 shows that the value of the static plate load test modulus clearly exceeds at least two times that of the E_{vd} modulus. Some of the results show even higher ratios. Only two publications give a ratio less than two, but both of them are based on modulus values measured only at few points and within small intervals.

It can be clearly observed too that all German standards specify the required dynamic values around the correlation line reflecting the ratio of two. This means that all known standards apply the lowest conversion ratio (or even a bit less) for specifying the limit values of the E_{vd} dynamic modulus.

5.1 The B & C device

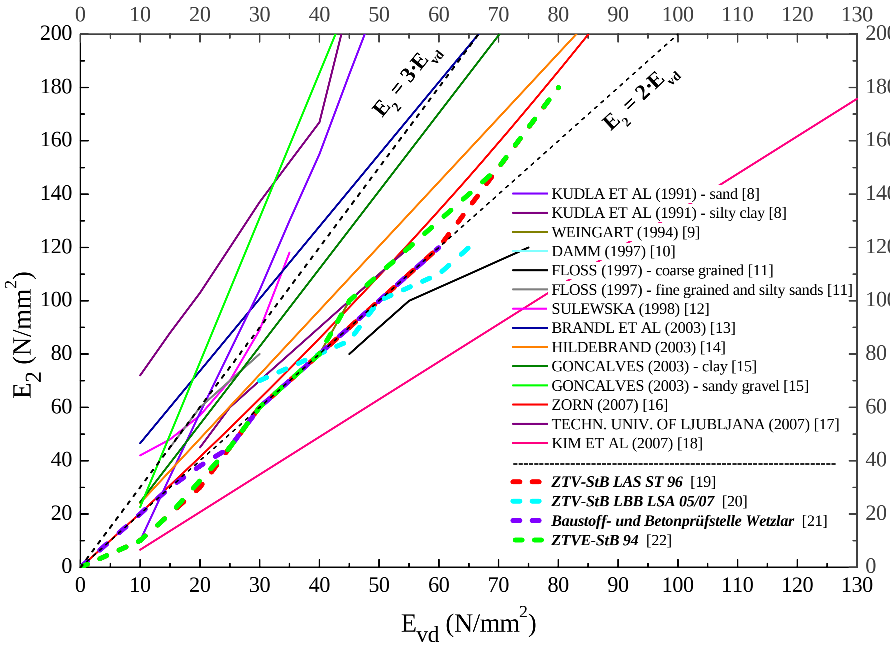
Only one publication deals with the conversion between E_d and E_2. Boujlala (2007) [7] found a conversion rate of $E_d \approx 0,6 \cdot E_2$ after performing parallel tests in 4 locations on a coarse grained subgrade layer, in the Northwestern part of Switzerland.

6 New conversion formulas for static and dynamic moduli

After collecting and assessing the available measurement results, more accurate and simple conversion formulas were defined (Fig. 2 and Fig. 3).

These formulas can be used to convert the measured E_{vd} or E_d dynamic moduli values into conventional static E_2 moduli values. In case of E_1, the coefficient of correlation is definitely low, but the formula of E_2 gives a value of R^2 = 0,67-0,69, which seems to be acceptable in geotechnical testing.

Fig. 1. Correlation results found in international literature



Accordingly, the suggested modification of the "Baksay formula" is as follows:

$$E_{vd} = 0,62 \cdot E_2 \tag{7}$$

After differentiating the data by subsoil and subgrade layer types, the formulas in Table 1 are proposed to be used for calculation.

7 Target values for dynamic moduli

Direct conversion between dynamic and static moduli is not frequently used in practice. Generally target values are given for different embankment and subgrade layers, most often depending on the required degree of compaction of the tested layer. Direct conversion is allowed in Austria, while required E_2 and E_{vd} modulus target values are fixed in Germany, Slovenia and some other countries.

Based on international and Hungarian experiences, a table of target values can be introduced. Different E_{vd} and E_d values are given for required E_2 values in Table 2. In case the defined dynamic modulus is achieved on site, the required static modulus for the layer can be justified. Interpolation between given values is acceptable.

8 Direct conversion between E_{vd} and E_d

Based on field tests on sandy gravel and laboratory tests on silty fine sand, the following direct relationships can be used for conversion between the two dynamic moduli (test results are shown in Fig. 4 and Fig. 5).

$$E_d = 1,41 \cdot E_{vd} \quad \text{(sandy gravel)} \tag{8}$$

$$E_d = 2,37 \cdot E_{vd} \quad \text{(silty fine sand)} \tag{9}$$

A more or less reasonable correlation can be observed in case of field test on sandy gravel ($R^2 = 0,54$), and good correlation in case of silty fine sand ($R^2 = 0,81$)

9 Summary and conclusions

The possibility of reliable conversion between values of two dynamic moduli (E_{vd}, E_d) obtained by using a Light Falling Weight Deflectometer and the static E_2 modulus is briefly presented and justfied.

Parallel measurements carried out by different Hungarian contractors, laboratories and research institutes have been collected and assessed in this respect. Based on the results, new conversion formulas have been set up and modification of the old "Baksay formula" is proposed. Based on extensive field and laboratory tests executed on sandy gravel and silty fine sand, direct conversion between E_{vd} and E_d has been calculated.

Using international and Hungarian measurement results, required target values for E_{vd} and E_d have been proposed for implementation.

The new dynamic target values could open up the opportunity to perform the quality control and assess the bearing strengths of the tested layer, not only by static plate load test, which proved to be time-consuming and labour intensive, but by dynamic devices too. Meanwhile more detailed statistical analyses should be performed since more measurement sites and data are needed to increase the reliability of the proposals.

The widespread use of mentioned dynamic devices referred to above, may facilitate for contractors, laboratories and engineers in the highway and railway construction industry to perform quick and continuous quality control of embankments, subgrade and subsoil layers and backfills.

Fig. 2. Relationship between E_1, E_2 and E_{vd}

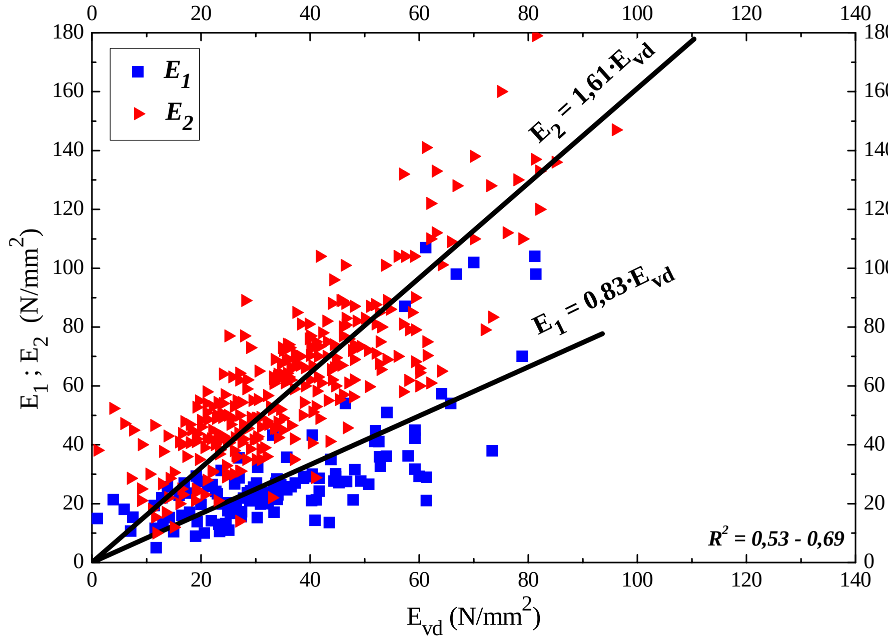
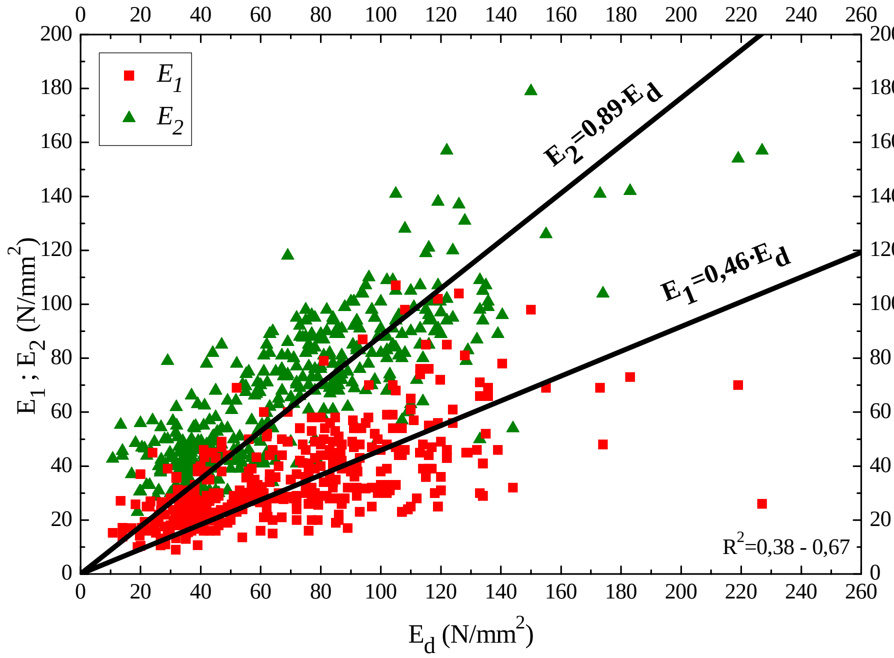


Fig. 3. Relationship between E_1, E_2 and E_d



Tab. 1. Conversion formulas for different subsoil and subgrade layers

Type of subsoil or subgrade layer	Conversion formula E_{vd}	Conversion formula E_d	Correlation R^2	
			E_{vd}	E_d
Coarse and fine grained soils	$E_2 = 1{,}58 \cdot E_{vd}$	$E_2 = 0{,}90 \cdot E_d$	0,55	0,73
Silty soils	$E_2 = 1{,}30 \cdot E_{vd}$	$E_2 = 0{,}80 \cdot E_d$	0,72	0,25
Crushed stone subgrade layers, mechanically stabilized base courses	$E_2 = 1{,}69 \cdot E_{vd}$	$E_2 = 0{,}93 \cdot E_d$	0,67	0,39

Tab. 2. Target values for different subsoil and subgrade layers

E_2 (N/mm^2)	E_{vd} (N/mm^2)		E_d (N/mm^2)	
	Coarse and fine grained soils, crushed stone subgrade layers, mechanically stabilized base courses	*Silty soils*	*Coarse and fine grained soils, crushed stone subgrade layers, mechanically stabilized base courses*	*Silty soils*
120	100	100	170	250
100	80	80	140	200
80	70	75	120	140
60	50	55	90	100
40	35	40	60	65
25	25	20	20	30

Fig. 4. Conversion of E_{vd} and E_d (field tests – sandy gravel)

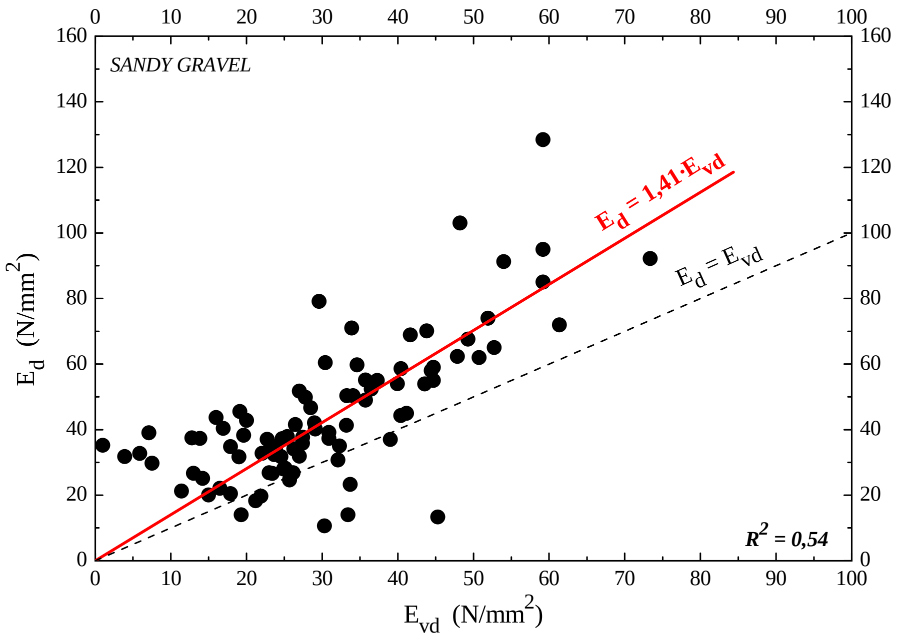
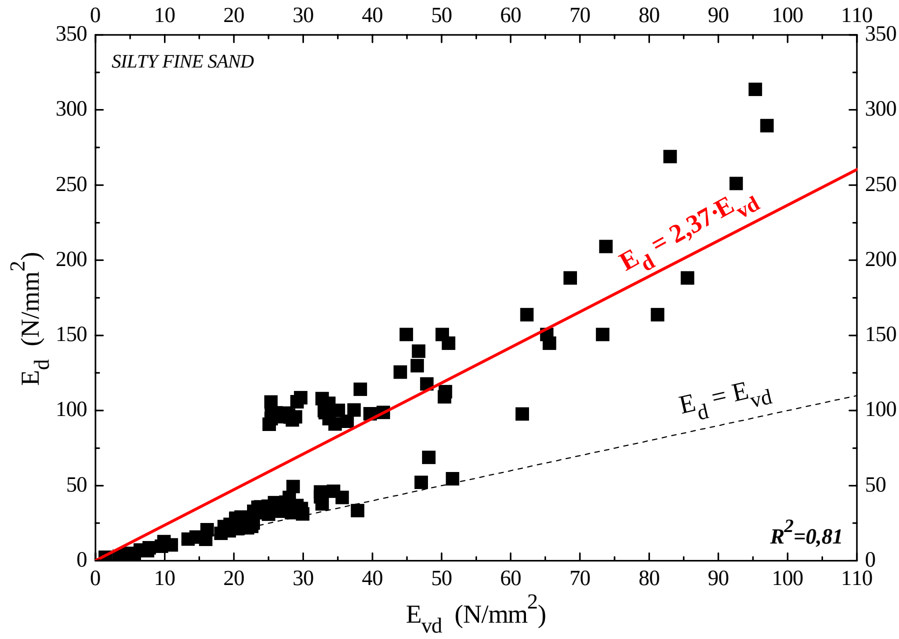


Fig. 5. Conversion of E_{vd} and E_d (laboratory tests – silty fine sand)



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