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Application of the finite element method for investigating the dynamic plate loading test

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Abstract The dynamic plate loading test using the Light Falling Weight Deflectometer (LFWD) is an innovative and very simple method used for quick assessment of the field compaction quality. The basic outcome of the LFWD test is the dynamic resilience modulus of the tested soil. This paper concisely presents the state-of-the-art for the theory and applications of the LFWD test. Moreover, an attempt is made in this study to use the finite element method for simulating the LFWD test and investigating the consequent soil response. An axisymmetric model is established to simulate a realistic case study of in-situ LFWD test. Different soil models are examined for adequately simulating the soil performance, including linear elastic, Mohr–Coulomb and Hardening-Soil models. The finite element analysis is applied to investigate the factors that probably affect the LFWD results. Furthermore, an attempt to ascertain the influence depth of the LFWD is provided.

1. Introduction

Compaction control of engineered fill or constructed subgrade has traditionally been carried out by means of in-situ density measurement tests, such as the commonly used sand cone test. Alternative methods have been employed for direct measurement of the response of the compacted soil to applied loads, such as the conventional static plate loading test (SPLT) and the dynamic plate loading test (DPLT). The dynamic plate loading test is an inventive and very simple testing method that allows for quick assessment of the field compaction quality. Simply, the mechanism of the DPLT comprises acting on the surface of the tested soil by a pulse load (i.e. falling weight) and recording the consequently induced soil movements. A testing device is used, known as the Light Falling Weight Deflectometer (LFWD). The test is predominantly designed to determine the dynamic resilience modulus (E_{vd}) of the tested material. This method has been developed during the last two decades and has already been applied in many parts of the world. It can be applied for different applications of earth works and road construction [2,4]. Many international regulations for the LFWD test procedure and for evaluating the test results have been developed, such as the German standard [1].

The DPLT using the LFWD is considered advantageous over the common SPLT because it can be performed in narrow and inaccessible areas, the test equipment is light weight and easy to handle and there is no necessity for loading truck

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Nomenclature

BEM	Boundary Element Method	h	thickness of a covering soil layer above a natural soil deposit
DPLT	dynamic plate loading test	LFWD	Light Falling Weight Deflectometer
D_{Pr}	degree of soil compaction	MC	Mohr–Coulomb soil model
E_{vd}	dynamic soil resilience modulus	SPLT	static plate loading test
E_{v1}	static modulus from loading in SPLT	s	plate deflection
E_{v2}	static modulus from reloading in SPLT	s_{max}	peak plate deflection
E_o	elastic modulus of soil deposit	t_i	duration (time) of pulse impact
E_1	elastic modulus of a covering soil layer above a natural soil deposit	σ_{max}	amplitude of pulse stress
f	frequency of pulse loading	σ_t	generated pulse stress value after time t of the pulse impact
FEM	finite element method	v	soil Poisson's ratio
HS	hardening soil model		

and settlement measurement devices. On the other side, the LFWD test may be more valuable than the customary sand cone test. This can be attributed to the sort of information obtained from the LFWD, e.g. soil response to dynamic/pulse loads, which may be more beneficial than the traditional in-situ soil density measurements. Besides, the LFWD test is non-destructive, as the soil is not excavated during the test, and it can be fruitfully used with gravelly soils where sand cones are not usually suitable. On the other side, there is a shortcoming regarding the availability of a widely accepted correlation between the LFWD test results and the soil compaction characteristics. Therefore, the application of the LFWD test is still limited.

The dynamic resilience modulus (E_{vd}), obtained from the LFWD test results, is not a direct measure of the soil compaction quality. Therefore, approaches have been proposed in the literature and relevant specifications for the indirect use of the E_{vd} modulus in assessment of the compaction quality. Some attempts have been presented in the literature to investigate the correlation between the E_{vd} modulus and the degree of soil compaction (D_{Pr}), e.g. Singh et al. [2]. An empirical E_{vd}–D_{Pr} relationship is provided in the German Guidelines for Earth Works in Road Construction [3]. Alternative contributions have been developed toward correlating the E_{vd} modulus with the static deformation moduli determined from the conventional SPLT, which are effectively linked with the degree of soil compaction, e.g. Tompai [4]. Numerical analyses have been performed in advance, based on the Boundary Element Method (BEM), to understand the soil performance during the LFWD test, e.g. Adam and Adam [5] and Adam et al. [6]. In these numerical studies, two separate mechanical models were proposed for the coupled system of LFWD and tested soil, where equilibrium and compatibility conditions of both subsystems were to be fulfilled via large iterations of BEM computations.

In this paper, a concise state-of-the-art for the theory and applications of the DPLT method is presented, focusing on the German device of the Light Falling Weight Deflectometer (LFWD). The fundamental objective of this paper was to employ the Finite Element Method (FEM) to simulate the mechanism of the LFWD test and to investigate the corresponding soil response. An axisymmetric FE model is established and verified utilizing the field measurements of an implicated case study of in-situ LFWD test. Factors that probably affect the LFWD results, as well as the LFWD influence depth, are examined using the finite element analysis.

2. Light Falling Weight Deflectometer (LFWD)

The Light Falling Weight Deflectometer (LFWD) is the testing device of the innovative technique of dynamic plate loading test (DPLT) used for compaction control of constructed subgrades and compacted soils. Two types of the LFWD have been developed in Europe; the German device and the Hungarian B & C device. The two types of the LFWD are typically associated with a very simple testing mechanism, in which a weight freely falls from a specified height to create a defined pulse force on a loading steel plate that is rested on the surface of the tested soil. The loading plate consequently settles due to the effect of the pulse force, and, thereby, the dynamic resilience modulus (E_{vd}) of the tested material is evaluated. Both the German and the Hungarian devices are similar in shape and setup; however, the latter has a loading plate of smaller diameter. The present study focuses on the widely used

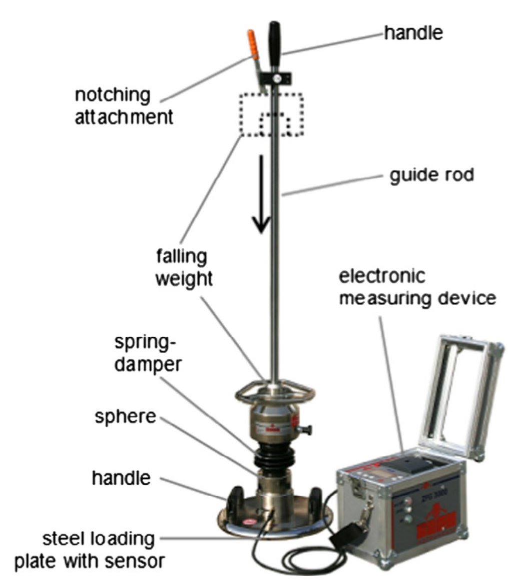

Figure 1 Details and components of the German LFWD.