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Predicting the Resilient Moduli of Unbound Base Material Using Field and Laboratory Light-Weight Deflectometer Tests

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Abstract **-** It is well known that unbound granular materials (UGMs) play a fundamental role as the base layer in flexible pavements. The dynamic properties, namely the resilient moduli, are quite important to characterize the unbound materials for the Mechanistic-Empirical Pavement Design Guide (MEPDG). The repeated load triaxial (RLT) test used to measure the resilient moduli is a rather expensive and time-consuming test. In this study, extensive research has been carried out to establish the relationship between the resilient moduli (Mr) measured by RLT tests and the dynamic deformation moduli (Evd) measured by a simpler technique, namely the Light Weight Deflectometer (LWD) tests, for a local type of commonly available unbound material in Sweden. To measure the dynamic material parameters using the LWD and RLT tests under similar test conditions, a series of in situ and laboratory LWD and RLT tests were carried out at different moisture contents and stress levels. The overall test results were analyzed, and a strong regression correlation (R=0.95) was found between the dynamic parameters measured from the RLT and LWD tests for the tested material.

Keywords**:** Dynamic deformation moduli (Evd), Light weight deflectometer (LWD) test, Repeated load triaxial (RLT) test, Resilient modulus (Mr), unbound granular materials

1. Introduction

In thin asphalt, surfaced, and un-surfaced pavements, the granular base and sub-base layers provide the majority of the bearing capacity. With the introduction of the concept of resilient modulus (Mr) as a measure of material stiffness, considerable attention has been paid to evaluating the behavior of unbound granular materials under repeated dynamic loading. However, because repeated load triaxial (RLT) testing is cumbersome and not readily available, the characterization of unbound granular road base and sub-base materials is still carried out using empirical methods such as the California Bearing Ratio (CBR) test [1] and [2]. Although these static tests are widely used throughout the world, they do not efficiently correlate with the dynamic response of the pavement structure under actual traffic loading from moving vehicles [3]. Therefore, it has become necessary to estimate the material properties using simple dynamic tests and to correlate the resulting material properties and behavior with the corresponding dynamic material properties evaluated using the (RLT) test. The aim of this study is to implement and evaluate methods for estimating the stability of unbound materials, which will help to reduce the gap between the required testing methods for unbound materials used in pavement design and those used in practice by contractors.

2. Tested Material Properties

A gravel material with a grain size between 0 and 32 mm was tested in this study. The specific gravity of the selected base material was tested according to SS-EN 1097-6 [4] and found to be 2.72. The results of the modified Proctor compaction tests showed that the compaction curve of the tested material is a one-and-a-half peak curve with two optimum water contents and two maximum dry densities. One of the maximum dry densities is on the dry side (at W=0%) and the other is on the wet side (at around W=6%). The maximum dry densities are 2.2 and 2.3 g/cm^3 at 0 and 5.7% water content respectively.

3. Equipment Used and Testing Procedures

A new multifunctional laboratory and in-situ Light Weight Deflectometer (LWD) equipment has been adopted in this study, as shown in Figure 1 A. In general, the LWD test is used to determine the dynamic modulus (Evd) of the tested materials. It has a basic falling mass of 10 kg, during the test the falling mass hits the plate and produces a load pulse. The conventional modulus of deformation is calculated by preloading the plate with three drops, taking into account the average

Evd of the next three drops. The magnitude of the load, the height of the load fall, and the area of impact are adjustable. The modulus of elasticity given in Equation 1 is calculated for a single-layer system based on Boussinesq theory [5].

$$\text{Evdf}=\frac{2k}{Aro}\,(1-\nu^2) \qquad (1)$$

Where: Evdf= In-situ dynamic deformation modulus, k=soil stiffness = F/δ as calculated by the LWD device, δ= Peak deformation, F= Peak impact load= Maximum applied axial load.r_o= the plate radius= 15 cm,A= stress distribution factor= 4 for stresses under point load rigid footing, ν= Poisson's ratio=0.35. For more information about LWD, see also Kuttah [6]

In addition to in-situ testing, LWD test has been designed to test pre-compacted materials in molds at the laboratories using special attachments, as shown in Figure 1 B. For compacted samples, the laboratory dynamic deformation modulus is calculated based on Eq. 2, as given below, see also Schwartz et. al. [7]:

$$\text{Evdl}=\frac{Hk}{\pi r_0^2}\left\{1-\frac{2\nu^2}{1-\nu}\right\} \qquad (2)$$

Where: Evdl= Laboratory dynamic deformation modulus, ν= Poisson's ratio = 0.35, H= height of the mold= 11.63 cm, r_o= the radius of the plate (plunger, 5 cm in this study), and k= soil stiffness, as defined in Eq.1.

Resilient modulus (MR), a measure of stiffness, has been determined in this study by repeated load tri-axial compression tests (RLT) as per SS-EN 13286-7 [8] method B for the determination of resilient modulus at high-stress levels.

The resilient modulus, see Eq.3, is determined as the ratio of the cyclic axial deviator stress to the recoverable strain.

$$MR=\sigma_d / \varepsilon_r \qquad (3)$$

Where: MR= Resilient modulus; σ_d = Applied cyclic deviator stress; and ε_r = Axial recoverable strain.

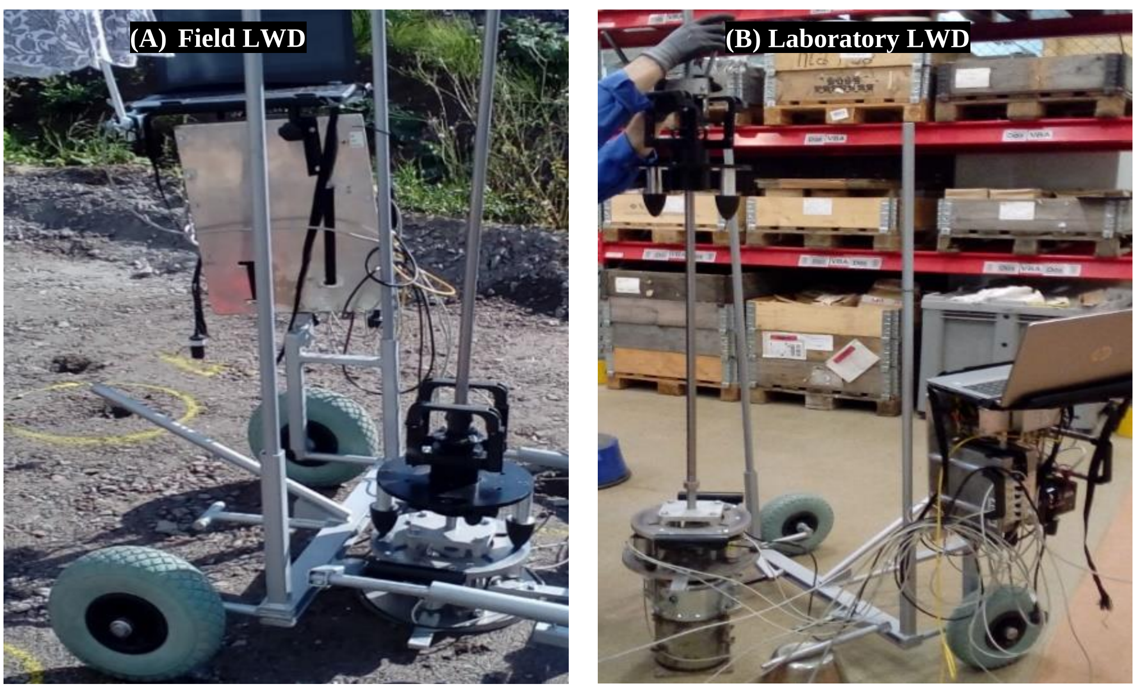

Fig. 1: Field (A) and Laboratory (B) LWD testing on unbound base material.

4. Results and Discussion

To carry out these tests, a test pit was constructed in the backyard of the Swedish Road and Transport Research Institute (VTI) in Linköping. The test pit is approximately 10 m long x 5 m wide x 1.5 m deep with sloping edges. In parallel with the in-situ LWD measurements, field NDG measurements were carried out. Resilient moduli (Mr) measured by RLT tests and dynamic deformation moduli (Evd) measured by field and laboratory LWD tests were carried out at a range of similar vertical axial stresses, compaction moisture contents, and compaction densities to establish a well-defined correlation between them for the tested base material, see Table 1.

Figure 2 and Eq. 4 below show a newly developed correlation between the elastic moduli and dynamic deformation moduli from the tests carried out on compacted base material under different applied loads and moisture content conditions.

$$MR\ (MPa) = 1.0023 * Evd\ (MPa) \quad (4)$$

The high coefficient of determination of 0.95 for Eq. 4 represents a very strong correlation between the elastic moduli (Mr) measured by RLT tests and the dynamic deformation moduli (Evd) measured by the field and laboratory Light Weight Deflectometer (LWD). This evaluation will help to improve knowledge of future requirements for the stability of unbound materials under different moisture conditions in the field.

Table 1: Results of resilient moduli (Mr) measured by RLT tests and the dynamic deformation moduli (Evd) measured by field and laboratory LWD tests.

Avg Mr (MPa)	Field and laboratory Evd (MPa)	Axial vertical stress (kPa)	WC (%)	Density (g/cm^3)
70.1	67.8	41.9	3.3	2.0
71.9	88.6	46.8	3.3	2.0
85.4	64.3	67.9	3.3	2.0
90.4	76.2	77.5	3.3	2.0
93.5	88.6	41.7	3.3	2.0
93.6	64.3	67.6	3.3	2.0
91.9	67.8	41.9	3.3	2.0
98.8	76.2	68.1	3.3	2.0
153.1	64.5	102.2	3.3	2.0
156.5	90.3	128.9	3.3	2.0
379.1	433.4	609.2	3.3	2.0
399.8	382.0	609.8	3.3	2.0
415.8	382.0	610.5	3.3	2.0
402.7	507.7	610.1	4.3	2.2
445.4	507.7	610.5	4.3	2.2
484.7	470.7	610.5	4.3	2.2
520.0	470.7	609.9	4.3	2.2
198.9	61.8	103.0	5.6	2.1
222.5	79.0	91.5	5.6	2.1
243.9	61.8	125.8	5.6	2.1
475.4	483.3	609.9	5.6	2.1
529.7	534.5	610.0	5.6	2.1
574.0	534.5	610.7	5.6	2.1

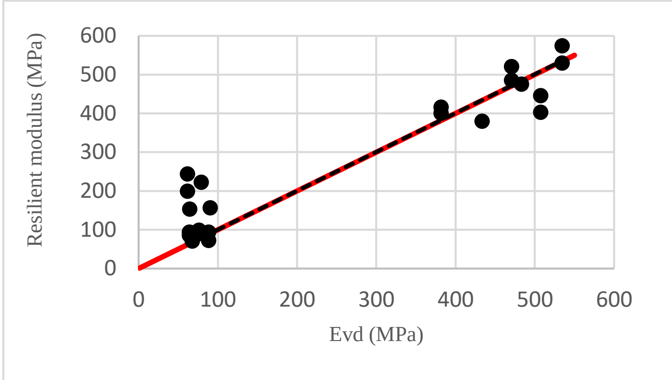

Figure 2: Correlation between the measured resilient moduli and dynamic deformation moduli

5. Conclusion

The main objective of this study was to verify the validity of using field and laboratory LWD to estimate the resilient modulus of a conventional Swedish base course material at different moisture contents and applied loads. The results show a good agreement between the Mr values measured by RLT tests and the Evds measured by laboratory LWD tests (at 600 kPa) for all moisture contents tested, with error percentages of 0.2%, 5.6%, and 1.6% only for the tests carried out at 3.3%, 4.3%, and 5.6% moisture content, respectively. For the field LWD tests (conducted at relatively lower stress levels of 45 kPa, 70 kPa, and 100 kPa), the agreement between Mr and Evd moduli was found to be highly dependent on both moisture content and applied stress levels. Error percentages of 4.5%, 23.9%, and 50% were reported between Mr and Evd moduli measured at 3.3% moisture content under applied stresses of 45 kPa, 70 kPa, and 100 kPa respectively. The highest percentage error, equal to 69%, was reported for the field LWD tests performed at the maximum stress of 100 kPa and the maximum moisture content of 5.6%. This indicates that the laboratory LWD tests may be more suitable for predicting Evd moduli closer to Mr moduli than the field LWD tests.

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