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Stress Distributions under Portable Falling Weight Deflectometer Tests

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This paper summarizes the study on stress distributions induced by Light Weight Deflectometer (LWD) tests on typical road subgrade soil masses in Hong Kong and they were subsequently compared with the ones from mechanistic and finite element analyses. The key findings are as follows.

The vertical stresses were observed to have a more rapid reduction within the upper region (400 mm approx.) of the soil mass along the centre-line under the applied load. An inflexion point exists of stress change occurs at a depth of approximately 400 mm (1.5 times load plate diameter) . Beyond the inflexion point, the rates of deterioration in stresses were found to be considerably lower. Both MePaDs and SIGMA/W analyses showed similar findings. For example within the coarse subgrade material with the applied stress of 132 kPa (i.e. full drop-height), 81% and 90% of stress reductions were resulted from the MePaDs and SIGMA/W analyses respectively in the upper region and the actual measurements yieled about 78% of reduction.

Along the centre line under the applied load, the horizontal confining stresses decreased dramatically within a very shallow region of the subgrade material. The measurements exhibited most of the confining stress deterioration occurred at the top 300 mm (1 times load plate diameter) whereas both MePaDs and SIGMA/W analyses showed a distnctive inflexion point of change in stresses, being located at approximately 250 mm and 150 mm respectively. Over 95% of the confining stresses diminished beyond the inflexion point and the levels of stress were observed to marginally increase near the bottom of the container.

The LWD moduli yielded against the two classic stress ratios: (1) deviator stress / confining stress ratio, and, (2) bulk stress / deviator stress ratio followed similar patterns of the ones for resilient moduli obtained by RLT tests. This has formed important breakthroughs in explaining the ways which in-situ stresses induced by the LWD tests may cause alterations in E_{LWD} as previously investigated by other researchers in this area.

Set-up and Schedule of Test

Subgrade materials adopted and test schedule

Three typical subgrade materials comprising coarse (C), medium (M) and fine (F) completely decomposed granitic soils under the optimum moisture content (OMC) and wet side of OMC were utilized for the tests. The soil materials were compacted inside the metal container by vibratory compactor in eight separate layers (i.e. 100 mm for each layer). The associated moisture contents and compacted densities are shown in table 1 below.

Table 1 Summary of soil materials adopted under LWD tests

Soil no.	Soil type	Moisture content (%)	Density (Mg/m^3)	Relative to OMC
1	coarse	13.6	1.82	OMC
2	coarse	15.4	1.80	OMC+2%
3	fine	14	1.70	OMC
4	fine	17.8	1.71	OMC+2%
5	medium	8	1.88	OMC
6	medium	11.9	1.96	OMC+2%

Instrumentations and data acquisition

A large scale test set-up was established to cater for the utilization of the 300 mm load plate. The test container was tailor made and it sized 1,000 mm in diameter and 800 mm in height. It was able to split in half by unbolting the sides to allow for soil removal. Being similar to the set-up of the preliminary tests, the Toyko Sokki mini SPGs were allocated at the depths of 100 mm, 200 mm, 300 mm, 400 mm and 700 mm respectively to measured vertical and horizontal stresses. Examples of the SPG installation are shown in Figure 1. The data measurements were captured by the National Instruments (NI)' data acquisition system, as shown in Figure 2.

Fig. 1. Set-up of mini SPGs

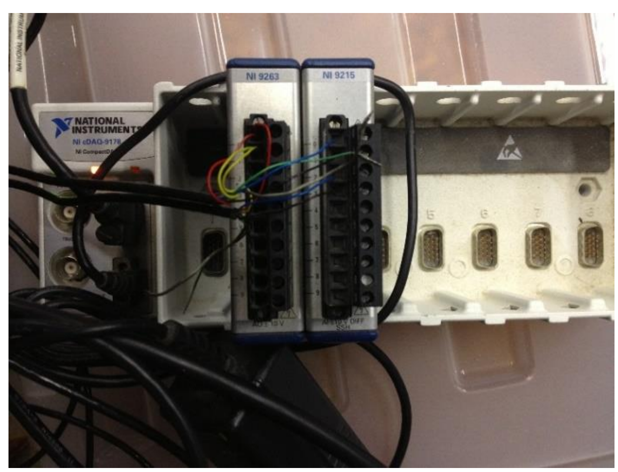

Fig. 2. NI data acquisition system

PFWD tests were conducted on top of the soil mass with four different drop heights (i.e. x 0.25, x 0.5, x 0.75 and x 1.0). The load plate of 300 mm in diameter was adopted.

Test Results

Figures 3 and 4 graphically illustrate the vertical and horizontal stress characteristics (at the momentary maximums) against the drop height ratios under different distances (i.e. 100 mm to 700 mm and 100 mm to 400 mm respectively) from the source of applied load.

The results show several key findings. Firstly the magnitudes of vertical and horizontal stresses rised as the drop height ratio increased, and secondly, it was evident that the relationships between both the magnitudes and rates of change in vertical and horizontal stresses against dop height ratios were progressively more sensitive when the distances were closer to the load source (Steeper gradients in vertical and horizontal stresses towards the load source as shown in the graphs). Lastly, the magnitudes and changes in the horizontal stresses tended to drop more rapidly than the vertical stresses in terms of distances from load source. For instance, it was negligible at a distance of 300mm below the load source. This corresponds to one times the load plate diameter of the PFWD.

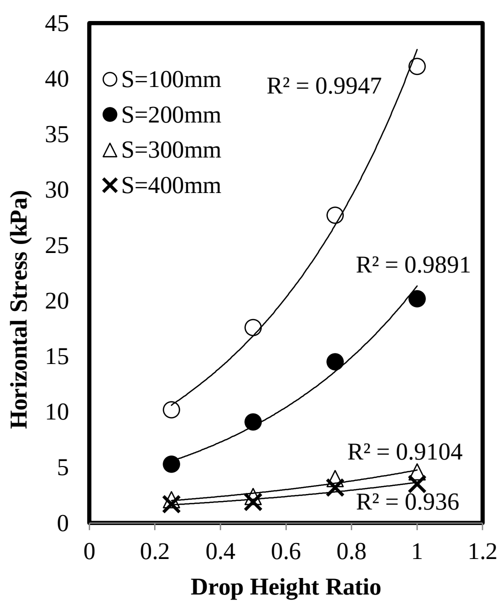

Fig. 3. Drop height ratio vs horizontal stress

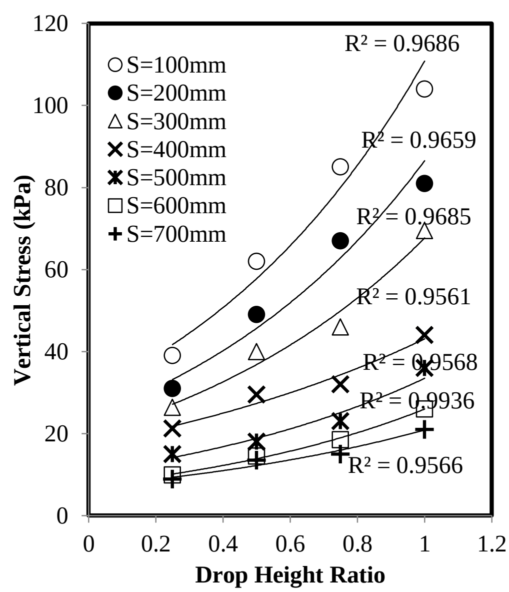

Fig. 4. Drop height ratio vs vertical stress

Comparison between Mesaured and Theoretical Stresses

The stress measurements along the centre-line under the applied LWD load from the tests were compared with the ones generated by the MePaDs and SIGMA/W softwares. In general, trends for both measured vertical and horizontal confining stresses, were found to be comparable to the ones produced by the two computer programmes. The associated characteristics, similarities and major deviations are described here and graphically presented in Figures 5 to 8.

Vertical Stress

The vertical stresses were observed to reduce more rapidly within the upper region (400 mm approx.) of the soil mass along the centre-line under the applied load. An inflexion point seems to exist at the depth of approximately 400 mm. Beyond the inflexion point, the rates of deterioration in stresses were found to be considerably lower. Both MePaDs and SIGMA/W analyses showed similar findings and such characteristic was showed slightly less distinctive by the real measurements. For example within the NC subgrade material with the applied stress of 132 kPa (i.e. full drop-height), 81% and 90% of stress reductions were resulted from the MePaDs and SIGMA/W analyses respectively in the upper region and the actual measurements yieled about 78% of reduction.

Horizontal Confining Stress

Along the centre line under the applied load, the horizontal confining stresses decreased dramatically within a very shallow region of the subgrade material. The actual measurements exhibited most of the confining stress deterioration occurred at the top 300 mm whereas both MePaDs and SIGMA/W analyses showed a distnctive inflexion point of change in stresses, being located at approximately 250 mm and 150 mm respectively. Over 95% of the confining stresses diminished beyond the inflexion point and the levels of stress were observed to marginally increase near the bottom of the container. It is envisaged that such slight increases of stress was due to the boundary effect from the bottom edge. These observations were consistent to all applied stress levels within different subgrade materials tested under the schedule.

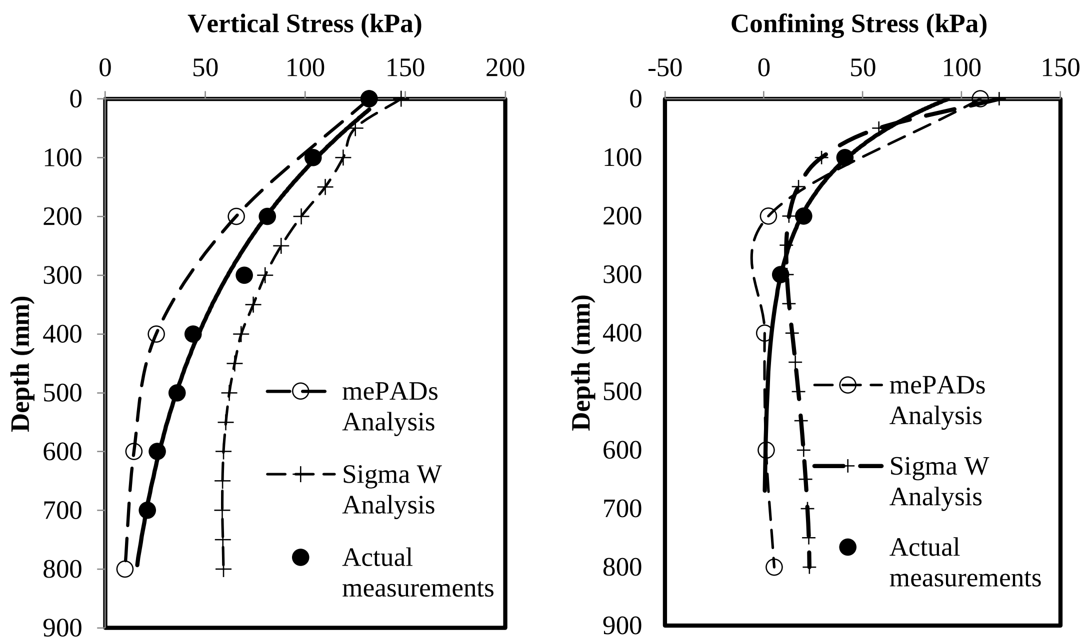

Fig. 5(a) & (b) Comparison of theoretical and measured stresses (full drop height) – coarse soil

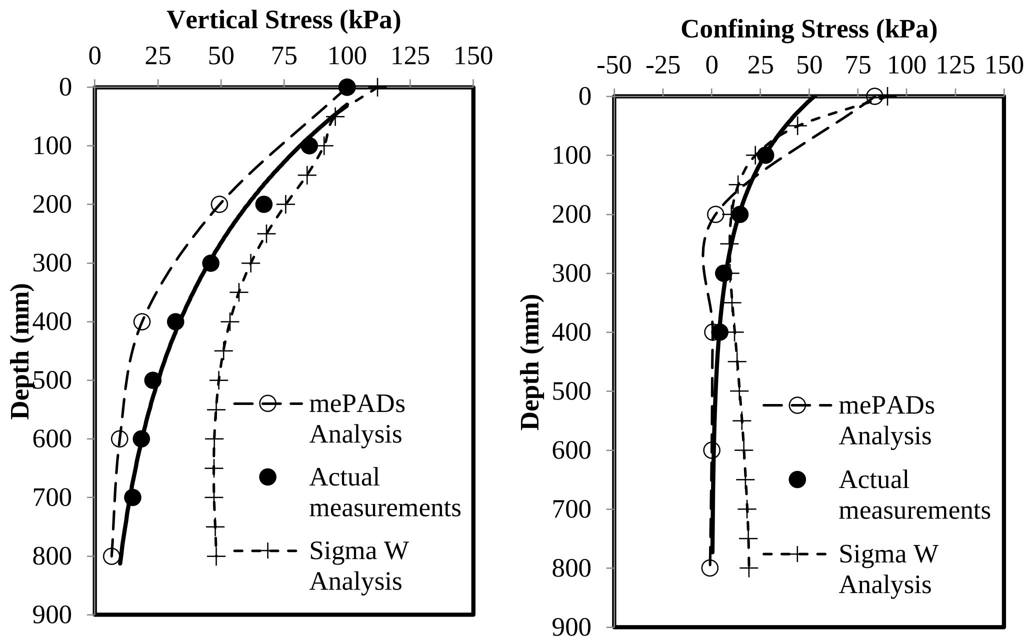

Fig. 6(a) & (b) Comparison of theoretical and measured stresses (0.75 drop height) – coarse soil

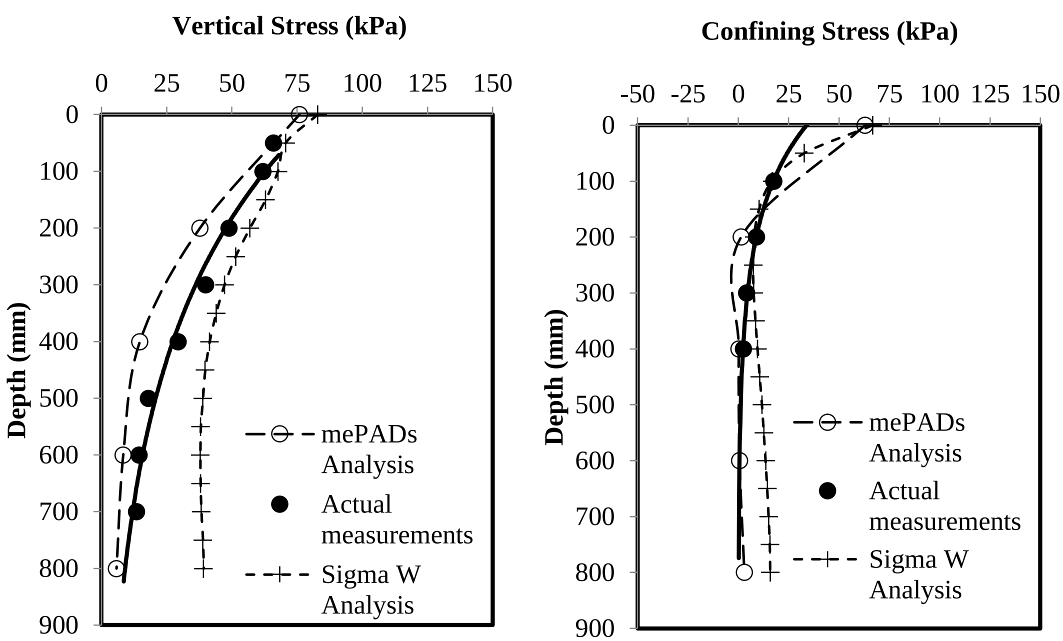

Fig. 7(a) & (b) Comparison of theoretical and measured stresses (0.5 drop height) – coarse soil

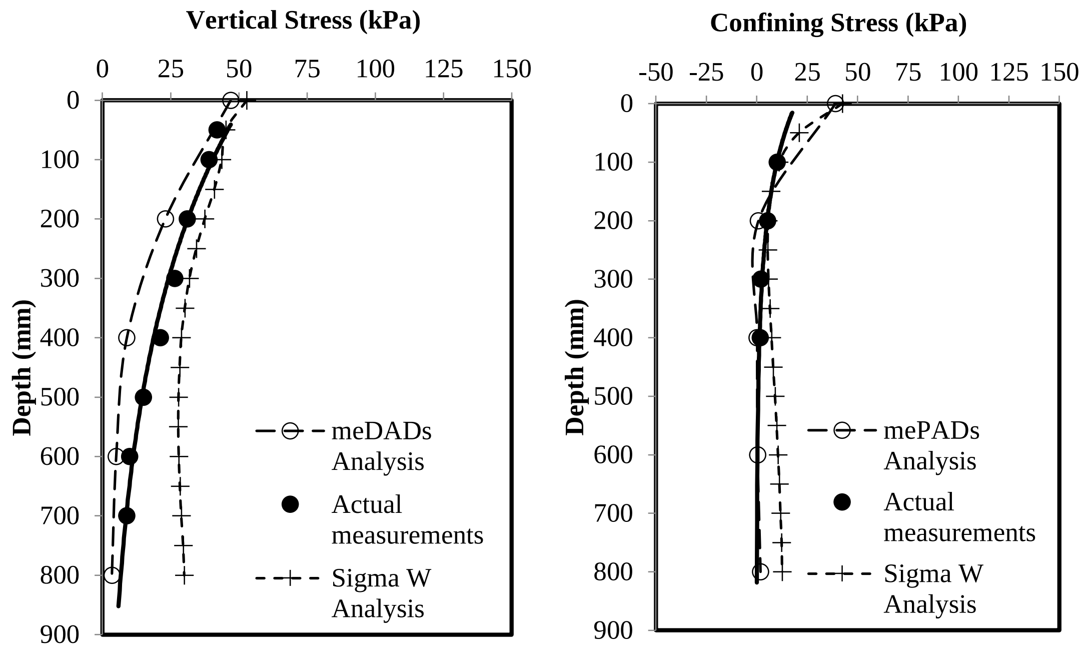

Fig. 8(a) & (b) Comparison of theoretical and measured stresses (0.25 drop height) – coarse soils

The Influence of Stresses on Light Weight Deflectometer Moduli

As the LWD tests progressed, the associated light weight deflectometer moduli (E_{LWD}) were obtained, and the ways which the in-situ stresses within the soil mass induced by the LWD tests may influence the E_{LWD} were evaluated. The results show a clear trend that the E_{LWD} increased as the vertical stress, confining stress and deviator stress rised (as illustrated in Figure 9). These findings are consistent to the ones obtained under the preliminary studies as covered in previous publication. Besides, E_{LWD} values were also plotted against the two stress variants, (1) deviator stress to confining stress (as in Figure 10) and, (2) bulk stress to deviator stress (as in Figure 11). Both stress variants follow the power relationships to the E_{LWD} (i.e. negative power relationship to the first variant, and positive power relationship to the second variant) as follows:

$$E_{LWD} = k_1 (\theta / Pa)^{k2}$$

Where,

θ = bulk stress ($\sigma_1+\sigma_2+\sigma_3$) at centre line under the applied load

$$E_{LWD} = k_1 (\sigma_d / Pa)^{k2}$$

Where,

σ_d = deviator stress at centre line under the applied load

These relationships were found to be highly comparable to the classic K-θ (by Seed et al (1967)) and deviator stress models (by Moossazadeh and Witczak (1981)) developed for resilient modulus of subgrade soils under repeated triaxial load (RTL) test, which the parameters k_1 and k_2 depend on the properties of the soil materials. This finding indicates that the material behaviours under RTL and LWD tests and the influences of in-situ stresses to the associated moduli produced share significant similarities. This also forms breakthroughs in explaining how and why ELWD alters under different applied stress (e.g. change in drop heights or load plate diameters) as mentioned by other previous researchers.

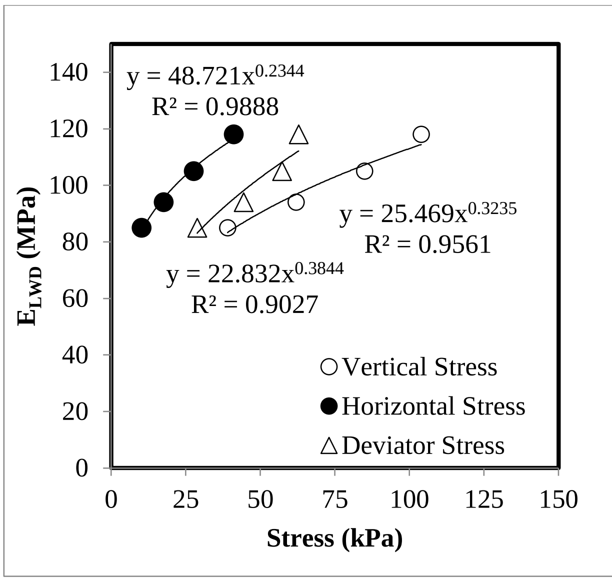

Fig. 9 E_{LWD} vs vertical, horizontal and deviator stresses

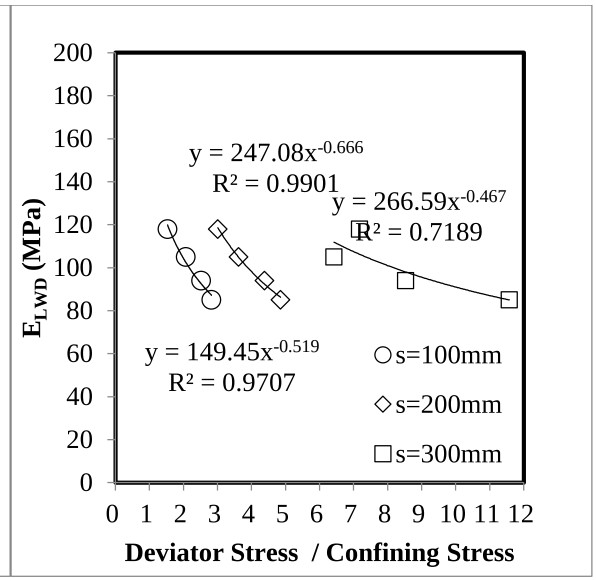

Fig. 10 E_{LWD} vs deviator stress / confining stress ratio

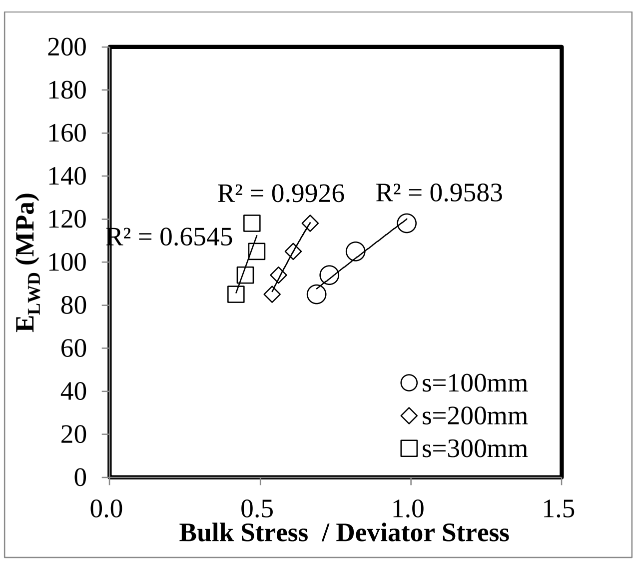

Fig. 11 E_{LWD} vs bulk stress / deviator stress ratio

Conclusions

This paper has summarized several key findings for the typical stress distributions induced by the LWD tests within the local subgrade materials and the influences of in-situ stresses that may have to the E_{LWD}. The LWD moduli yielded against the two classic stress ratios: (1) deviator stress / confining stress ratio, and, (2) bulk stress / deviator stress ratio followed similar patterns of the ones for resilient moduli obtained by RLT tests. This has formed important breakthroughs in explaining the ways which in-situ stresses induced by the LWD tests may cause alterations in E_{LWD} as previously investigated by other researchers in this area.

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