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A Hong Kong Case Study on the Combined Usage of In-situ and Laboratory Test Devices for Road Foundation Assessment

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Abstract. Recently the Hong Kong Road Research Laboratory (HKRRL) was engaged by a major highway contractor to evaluate the pavement subgrade condition of an existing access road at the Peak on Hong Kong Island. Due to the narrow and unique nature of the road, large scale tests such as Falling Weight Deflectometer (FWD) and On-Site California Bearing Ratio tests were difficult to be carried out. The difficulty was further exacerbated by the limited time of lane closure allowed by the authorities. Because of the various constraints, the HKRRL adopted a more comprehensive solution by making use of various in-situ (small scale) and laboratory test techniques for the subgrade assessment exercise. The combined site and laboratory test results successfully demonstrated that the stiffness of the subgrade material was becoming progressively lower towards the western portion of the road alignment and were able to give expert advice to the contractor on the extent for further detailed examination. The test results also agree well with the site observation of the geological outcrops.

Keywords: LWD, DCP, Repeated Load Test, Resilient Modulus, Pavement Subgrade

1. Introduction

Due to the uncertainty of the existing subgrade condition which may affect the compaction quality for the future resurfaced asphalt material of a narrow access road (Lugard Road), a major highway contractor has engaged the Hong Kong Road Research Laboratory (HKRRL) in conducting an onward evaluation and on the provision of expert advice. The evaluation works were conducted recently and this paper aims to present and conclude the major findings.

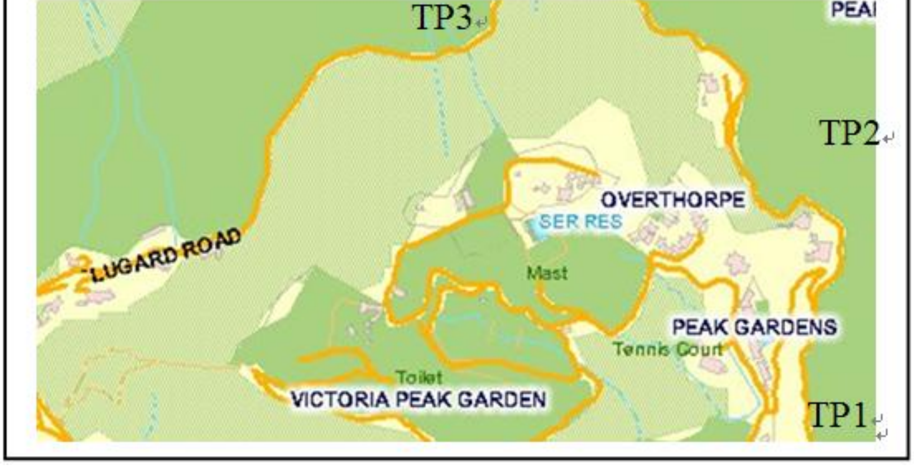

Fig. 1: Site Location (Lugard Road, The Peak)

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Lugard Road is a narrow access road (about 3.2 m wide) surrounding the Victoria Peak Garden. The exact site location is indicated in Fig. 1. The major scope of the evaluation works comprised the following items:

Excavation of shallow trial pits – 3 nos. trial pits (TP1 –TP3), approximately 0.5m x 0.5m on plan, for exposing of the pavement subgrade material, execution of field tests as well as to facilitate collection of disturbed and undisturbed soil samples.

In-situ field tests - Light weight deflectometer (LWD) tests and dynamic cone penetration (DCP) tests.

Laboratory tests - Determination of soil properties such as moisture content, soil densities, particle size distribution, atterberg limits and repeated load tests on the evaluation of resilient modulus.

2. Observation of Geological Outcrops

Based upon the site observation, the majority of the road was formed by the slope cutting. The outcrops on the slope surface indicate that more rocky materials were present near the location of TP1 and the amount of rock diminishes towards TP3. This agrees well with the exposed soils surface at the trial pits (TP1-TP3), which indicated that the pavement subgrade was majorly consisted of highly decomposed volcanics (HDV) at TP1 to completely decomposed volcanics (CDV)) at TP2 and TP3.

3. Basic Soil Properties

3.1. Moisture content

Soil samples were retrieved separately from the three trial pits. They were stored in airtight plastic bags and were subsequently delivered to the laboratory for moisture content determination. The summarized results as shown in Table 1 indicates that the subgrade moisture content falls in the range of approximately 15% to 20% along the road, being the highest at TP1. The slightly higher moisture content of the soil at TP 1 is considered to be due to the presence of an impermeable layer at shallow depth as identified by the DCP test results. The moisture contents at TP2 and TP3 are relatively lower.

Table 1: Moisture Contents of Soil Samples

Trial Pit No.	Average Moisture Content
TP 1	20.7%
TP 2	17.2%
TP 3	15.1%

In general, the results are considered reasonable as the natural soil moisture contents of the soils lie very much close to the “Plastic Limit” (i.e. 19%).

3.2. Atterberg limits

The Atterberg Limits of the soil were determined in accordance with GeoSpec 3 (Model Specification for Soil Testing, CEDD, HKSAR, 2001) [1]. Soil particles with sizes smaller than 425 μm were adopted for Atterberg Limits test.

The test results indicate that the plastic limit (PL) and the liquid limit (LL) of the subgarde soils are 19 % and 27.5 % respectively, with a plasticity index of 8.5 % (PI = LL - PL)). It implies that the material owns a “*low plasticity property*”, which means it is unlikely to compress unduly under load, nor do they shrink excessively when dried, and once they have acquired a firm consistency, near the plastic limit, they are quite stable.

4. In-Situ Test Results

4.1. LWD Test results

Light weight deflectometer (LWD) (Prima 100) was adopted to evaluate the subgrade stiffness. Prima 100 owns a falling weight of 10 kg which impacts a rubber spring to produce a load pulse of 15-20 ms, with an applied stress of 120 - 140 kPa (by using 300 mm diameter loading plate). Fig. 2 shows an on-going LWD test.

The LWD typically measures a single deflection (via geophone) at the centre of the bearing plate under a load pulse. The derived measurement is often named as the "composite" stiffness (E_{comp}) because the measured deflection relates to the influence of more than one layer. Based on elastic half-space theory (Bousseineq half space), the stiffness measured can be calculated from the following equation 1 [2], [3]:

$$E_{comp} = \frac{A \times P \times r \times (1 - \mu^2)}{d} \quad \text{(MPa)} \qquad (1)$$

Where

A = plate rigidity factor (π/2 assuming a rigid plate)

P = applied stress (kPa)

R = plate radius (m)

μ= Poisson's ratio

d=deflection (mm)

Fig. 2: LWD test being carried out at trial pit

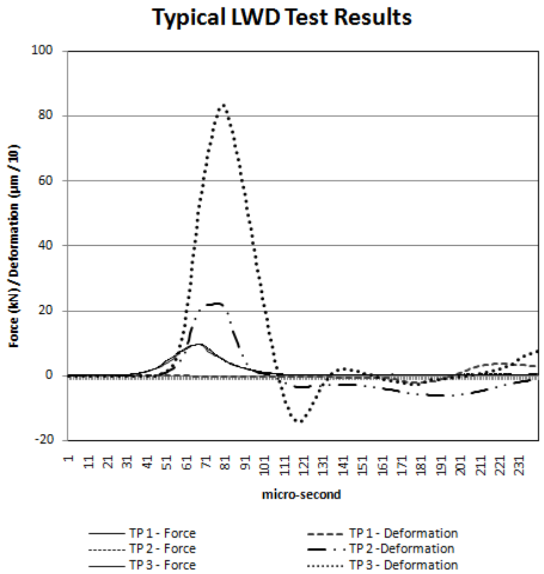

Fig. 3: Typical graphical plots of LWD test results

The results as summarized in Table 2 provide a clear indication that the E_{comp} was particularly high at TP 1 (with an average stiffness of 604 MPa). It validates the findings of the DCP test which a hard stratum is present at shallow depth. Results at TP 2 (with an average stiffness of 112 MPa) compares closely with results of the repeated load test. Soil stiffness was found to be particularly low at TP 3 (average stiffness of 31 MPa). Typical force-displacement plots for the LWD tests are presented in Fig. 3.

Table 2: Summary of LWD Test Results

Trial Pit	Drop No.	Max. Applied Load (kN)	Max. Deflection (µm)	E_{comp} (MPa)
TP 1	No. 1	9.48543	35.67	745
	No. 4	9.82243	48.94	562
	No. 5	10.0737	56	504
TP 2	No. 2	8.97539	226.65	110
	No. 3	9.20281	230.63	112
	No. 4	9.39809	232.22	113
TP 3	No. 1	9.5736	832.85	32
	No. 3	9.54888	852.79	31
	No. 6	9.70708	893.31	30

4.2. DCP Test results

The dynamic cone penetration (DCP) tests were also carried out at the locations of the trial pits. DCP test results (as indicated in Fig. 4) indicate that hard stratum was present at very shallow depth of the subgrade at TP 1. It agrees well with the site observation which indicates that the exposed subgrade comprised of gravel and highly decomposed volcanic materials (HDV). The DCP test results at TPs 2 and 3 illustrate that subgrade materials were generally much weaker than the one at TP 1, and it is envisaged that completely decomposed volcanic (CDV) may be present under the depth of the subgrade being tested (i.e. approximately 750 mm).

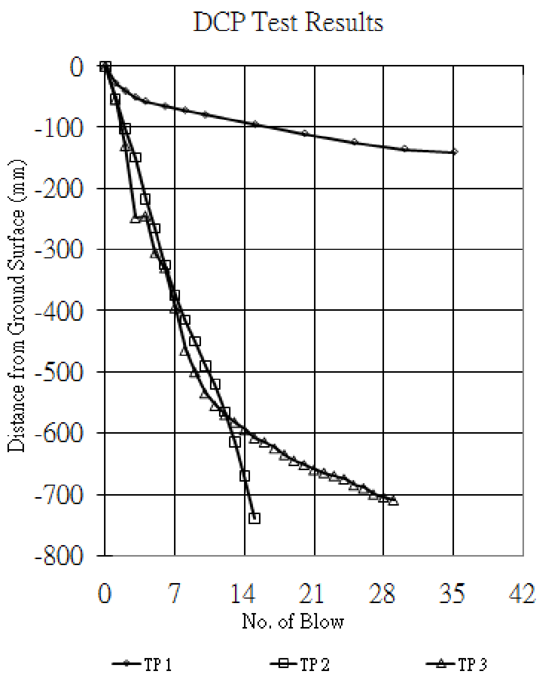

Fig. 4: Graphical plots of DCP test results

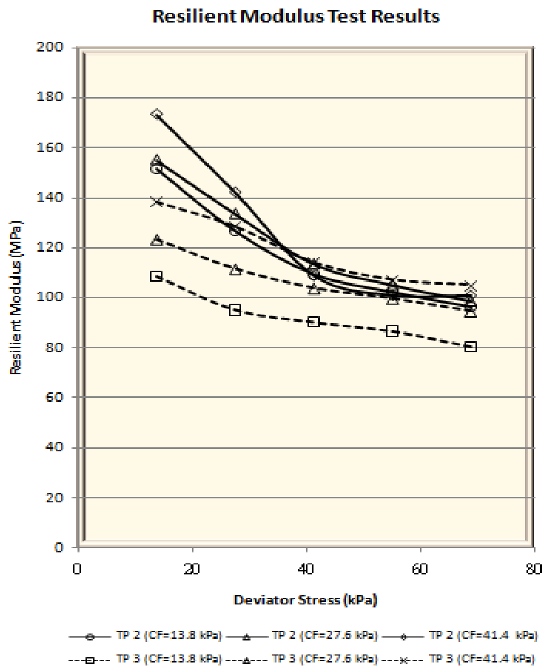

Fig. 5: Graphical plots of Repeated Load test results

In order to obtain the relationship between DCP value and resilient modulus (M_R), two sets of correlations were adopted and compared. The first correlation set comprises equation 2 developed by Kleyn and Van Harden [4] and equation 3 which is commonly adopted by the Hong Kong highway industry [5]. The second set of correlation comes from the findings of the researches by Webster [6] and Powell [7], which is presented as equations 2 and 3.

Kleyn and Van Harden,

$$\text{Log CBR}(\%) = 2.628 - 1.273 \times \text{Log (DCPI)} \tag{2}$$

$$M_R = 10 \times \text{CBR} \quad \text{(for granular soil)} \tag{3}$$

Webster and Powell,

$$\text{CBR} = 292 / \text{DCPI}^{1.12} \tag{4}$$

$$M_R = 17.58\,(\text{CBR})^{0.64} \tag{5}$$

The analysis results indicate that the first set of correlation (Kleyn and Van Harden; RD/GN/017) generally yields a lower bound and upper bound values for stronger and weaker soils respectively. Vice versa, the second set of correlation (Webster and Powell) does the opposites, which provides an upper bound and lower bound values for stronger and weaker soils respectively as shown in Table 3. Pursuing the averages of the two could achieve some meaningful relationships with the LWD test results.

Table 3: Summary of Estimated CBR and M_R Values

Trial Pit No.	Layer No.	Depth (mm)	DCPI mm/blow	M_R (MPa) (2)(3)	M_R (MPa) (4)(5)
TP 1	1	0-50	15	135	95
	Average:			**115**	
	2	50- 130	3	1050	303
	Average:			**677**	
	3	130 - 140	2	1100	405
	Average:			**753**	
TP 2	1	0-730	50	29	40
	Average:			**35**	
TP 3	1	0-250	83	15	28
	Average:			**22**	
	2	250- 550	50	29	40
	Average:			**35**	
	3	550-710	8.5	280	143
	Average:			**212**	

5. Repeated Load Test Results

Repeated Load Test (RLT) was conducted on the U100 soil samples retrieved at TPs 2 and 3. The retrieval of U100 soil sample at TP 1 was not successful at the time due to the presence of hard stratum at shallow depth. On the other hand, the soil sample (at TP 2) as extruded from the U100 sampling tube was very much intact, whereas the soil sample from TP 3 was found to be disintegrated during extrusion and hence remoulded sample (to simulate the field density) was made for the subsequent repeated load test.

5.1. Apparatus

Repeated load machine (NU-14) was adopted to determine the resilient modulus (M_R) of the soil samples. The apparatus is equipped with a triaxial system comprising a confining air chamber, an internal submersible load cell and external displacement transducers. The confining air system is capable to generate a confining air pressure up to 500 kPa. The loading system can simulate a load form induced by moving vehicle (a haversine shaped load form) with a standard load duration of 0.1 second and a rest period of 0.9 second.

A repeated loading test schedule was established with reference to the AASHTO Standard: T307-99 (2003): *Determining the Resilient Modulus of Soils and Aggregate Materials* [8], and the resilient modulus (M_R) were determined from the last five load cycles of each test. The test schedule for both soil samples are presented in Table 4 below.

Table 4: Repeated Load Test Sequence

	Deviator Stress (kPa)				
Confining Pressure	13.8	27.6	41.4	55.2	68.9
	No. of Load Cycle				
13.8 kPa	100	100	100	100	100
27.6 kPa	100	100	100	100	100
41.4 kPa	100	100	100	100	100

5.2. Resilient modulus

The test result exhibit a general trend that the resilient modulus (M_R) of the soil material decreased as the deviator stress increased. The amount of decrease in M_R was particularly remarkable at lower deviator stress levels and the change became relatively mild at the higher deviator stresses. At the highest end of the deviator stresses, the M_R tended to become a constant value. Such trend was observed for all the tests carried out at different confining pressures and being one higher than the other for a higher confining pressure, as illustrated in Fig. 5. The M_R of soil sample at TP 3 was found to be slightly lower than the one for the soil sample at TP2. However the results for TP3 soil sample may not be regarded as absolutely representative due to the tested sample was remoulded in nature. Overall, the test results agree well with the findings of other typical granular soils in Hong Kong [9].

Due to the fact that the bituminous surface layer was very thin in nature (about 40 mm), and no sub-base layer is found to be present, the existing confining pressure for the subgrade is considered likely to be at the lower end and whereas the deviator stress is likely to be at the higher end.

6. Conclusions

In summary, the subgrade materials underneath Lugard Road were found to be consisted of in-situ volcanic materials (i.e. Highly Decomposed Volcanics (HDV) in the vicinity of TP 1 and Completely Decomposed Volcanics (CDV) in the vicinity of TPs 2 and 3). The soil material is granular in nature and its fine particles possess a “low plasticity” property. The combined site and laboratory test results successfully demonstrated that the stiffness of the subgrade material was becoming progressively lower towards the western portion of the road alignment. Hence the contractor was advised to pay particular attention on the subgrade condition underneath the road portion near TP 3 during their future possible re- surfacing works based on the following findings, and preferably, more thorough examination is required.

Subgrade Condition at Trial Pit No. 1 - The in-situ test (both DCP and LWD) results indicate that a hard stratum is present at a shallow depth of subgrade (It shows that the stiffness is in an approximate range of 600 MPa – 700 MPa).

Subgrade Condition at Trial Pit No. 2 - The LWD test results at TP 2 agrees well with the findings of the repeated load test which demonstrate the stiffness of subgrade is approximately 100 MPa. The particular lower value of stiffness as estimated by the DCP correlation is probably due to the encountering of local weak spot.

Subgrade Condition at Trial Pit No. 3 – Both the DCP and LWD test results show that the subgrade possesses a low stiffness (i.e. approximately 30 MPa at shallow depth). The result of the repeated load test can only be treated as a reference due to the remoulded nature of the soil sample.

7. Acknowledgements

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