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Development of a Predictive Model for Cement Stabilised Roadbase

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Abstract

Cement stabilisation is a common method for stabilising recycled road base material and provides a longer pavement life. With cement effect, the increment of stiffness in the stabilised layer would provide better load transfer to the pavement foundation. The recycling method provides an environmentally option as the existing road base materials will not be removed. This paper presents a case study of a trial section along the North-South Expressway in West Malaysia, where the Falling Weight Deflectometer (FWD) was implemented to evaluate the compressive strength and in-situ stiffness of the cement stabilised road base material. The improvement in stiffness of the cement stabilised base layer was monitored, and samples were tested during the trial. FWD was found to be useful for the structural assessment of the cement-stabilised base layer prior to placement of asphalt layers. Results from the FWD were applied to verify the assumed design parameters for the pavement. Using the FWD, an empirical correlation between the deflection and the stiffness modulus of the pavement foundation is proposed.

INTRODUCTION

Falling Weight Deflectometer (FWD) has been widely accepted as a non-destructive tool for assessing the condition of pavements in Malaysia. FWD has been used during pavement construction for assessing the performance of pavement foundations along an expressway in West Malaysia. Chai and Faisal (2000) demonstrated that, when FWD tests are performed on the pavement foundation, information can be collected from the FWD deflection basin [1]. The FWD deflection measurements can be used directly to validate design assumptions such as the level of compaction and recommended material stiffness. This approach may also serve to provide a supplementary performance specification to sub-grade construction in highway projects.

The practice of cement bound aggregate is recognised in Malaysia for the construction of concrete and flexible composite pavements. The terminology used to describe the cement bound aggregate may differ internationally. In the United Kingdom, the term "cement-bound material" or "CBM" [2] applies to mixtures from gravel-sand, a washed or processed granular material, crushed rock, all-in-aggregate, blast-furnace or any combination of these. Austroads (2004) gives a simple description as "cemented material" [3]. In Malaysia, the common terminology is "cement-stabilised base" or "CTB" [4].

This paper describes field tests conducted using FWD on a flexible composite pavement test section on the

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Southbound Carriageway of the North-South Expressway in West Malaysia. The pavement rehabilitation involved in-situ stabilisation of the existing road base material using cement. The pavement works include the milling of the existing bituminous layers to a depth of about 175mm, in-situ cement stabilisation of the road base to a thickness of 200mm, and overlay with 230mm asphaltic concrete. Field and laboratory tests were carried out on the cement stabilised base (CTB), and core sampling formed part of the testing work.

The trial section was 100m in length and 3.65m (one lane) width. The purpose of the trial was to assess the suitability of the construction procedure for cement stabilisation. Monitoring works carried out during the trial will allow any initial problems to be identified and rectified before commencing full-scale stabilisation works. Field and laboratory tests were conducted on recycled material from the trial area, test results would verify the mix design and demonstrate compliance with the specification. The use of FWD during the trial enabled the stiffness modulus of the existing base layer to be verified before recycling. Further, the trial was intended to demonstrate that design parameters such as the in-situ effective stiffness of the CTB layer are achieved on site. Thus, based on the actual in-situ properties of the pavement, the expected design life could be determined.

CEMENT STABILISATION WORKS

The first operation involved in the in-situ recycling was milling the existing 175mm bituminous materials using a "Wirtgen-W1000". The in-situ aggregate moisture content was determined by drying a sample of aggregate in a pan at the verge of the road located next to the paved shoulder. The balance water content (the difference between the optimum and in-situ aggregate moisture contents) was then calculated. Cement was then manually spread on the surface of the existing road base material, with the rate of cement spreading being based on the mix design requirements.

A summary of the design parameters adopted in the CTB design is as follows: (i) Design water content within 4.5±0.5% of the dry mass of aggregate and cement; (ii) Design cement content was 3.5% (by mass of the dry aggregate); (iii) A minimum effective stiffness modulus of 1000MPa to be achieved after twenty-eight days of curing; (iv) The average seven days compressive strength determined from a group of five cubes of the CTB road-base shall be between 4 and 8MPa; (v) The average in-situ wet density shall not be less than 94% of the average wet density of the corresponding group of five cubes.

The in-situ recycling was then carried out to a depth of 200mm using a "Caterpillar-CAT 350" stabiliser machine. The aggregate and cement were mixed in the mixing chamber of the stabiliser machine. The CTB was then levelled using a motor grader. The measurements allowed the thickness of asphalt to be determined. Compaction of the recycled base layer was then carried out using a "Dynapac" vibratory. After a curing period of seven (7) days, bituminous materials to a nominal thickness of 190 mm were laid over the CTB base.

TESTING PROGRAM

A testing program was prepared for the purpose of monitoring the quality and performance of the stabilised pavement at various stages during and after the CTB construction. The testing comprised density measurements, FWD, and laboratory tests on the CTB cores and cube specimens prepared during construction.

Density measurements were made shortly after the CTB had been compacted using the sand replacement test. The density results were used to ensure the CTB layer had achieved the minimum 94% relative density during the stabilisation work

A FWD test was performed at 5m spacing along two runs, which were positioned approximately 0.7m from both edges of the trial area. FWD loading used at the various stages of the FWD test were computed as those expected from a standard axle loading on a completed pavement. The contact pressures adopted were 200, 350 and 700kPa for testing performed on the existing granular road base, CTB and completed asphalt surfaces respectively. For stage 1, FWD testing on the granular road base surface just before recycling was carried out to determine the initial condition of the granular road. In Stage 2 and 3, FWD tests on the CTB after three days of curing and seven days of curing were carried out to monitor the increase in stiffness of the CTB layer. A FWD test was also carried out on the asphalt layer surface at twenty-eight days after the CTB construction. The tests on the completed pavement layers would enable determination of the effective stiffness of each of the various pavement layers and verification of the assumed design parameters.

A total of twelve cores were taken from the trial section. Four cores were taken from the CTB pavement after a curing period of three days; five cores at seven days; and three cores through the combined thickness of bituminous and CTB layers at twenty-eight days, at various locations of the test site. The CTB cores were transported to the laboratory, where the recycled thickness was checked. In addition to the thickness measurement, the cores were tested for in-situ compressive strength. Twelve cube specimens were also prepared from the recycled CTB on the day of construction. The samples of the recycled CTB were taken before compaction from four locations along the length of the trial area. Cubes were prepared and tested in the laboratory for compressive strength.

ANALYSIS AND DISCUSSION

The in-situ cube compressive strength was determined from the prepared cube specimens taken at three, seven, and twenty-eight days after CTB construction and tested on the subsequent day. The results are summarised in Table 1, and indicate the average compressive cube strength of the CTB at seven days was 6.00MPa, which was within the specified requirements of 4.0 to 8.0MPa. The results of in-situ compressive strength measured from the prepared core samples are also summarised in Table 1, and indicate an average of the seven day compressive strength derived from the core samples is 6.0MPa which is equivalent to the in-situ compressive strength derived from the cube specimens.

Table 1. Compressive strength of the CTB layer

Age at test (days)	In-situ compressive strength (MPa) from core samples	In-situ compressive strength (MPa) from cube specimens
1	-	3
3	-	5.5
4	4.5	-
7	-	6.0
8	6.0	-
29	7.5	-

The FWD data acquired from the field test were normalised to a pressure 200, 350 and 700 kPa for the testing performed on the existing granular road base, CTB and completed asphalt surfaces, respectively. Seven normalised deflection readings were measured by geophones at distances (0, 300mm, 600mm, 900mm, 1200mm, 1500mm and 2100mm) from the centre of the loading plate. A FWD test carried out on the existing road base gave a centre deflection reading of 900 micron at 85 percentile value. For tests performed on the CTB, the deflections were observed to decrease between three and seven days due to curing of the CTB base. The FWD centre deflection value at 85 percentile for the three and seven days are 650 micron and 400 micron respectively. The profiles of the centre deflection parameter before and after the stabilisation have been plotted against chainage, and are shown in Figure 1.

The FWD data were back-analysed using the ELSYM5 (1986) [5] computer program to determine the effective stiffness after each stage of testing. A three-layer pavement structure was used to model the CTB base, granular sub-base, and sub-grade layers for the three and seven days' strength evaluation. For the twenty-eight days, a four layer model was used for the asphalt, CTB base, granular sub-base and sub-grade layers. The effective stiffness modulus at 85 percentile values for the various pavement layers at different stages of construction are presented in Table 2. The stiffness of the CTB layer increased from 700 MPa at three days to 1350MPa at twenty-eight days after curing. It was also noted that the stiffness of the CTB is greater than the adopted design stiffness of 1000MPa, and the CTB stiffness value had been achieved on site.

From the compressive strength and FWD deflection data gathered at the test site, a relationship between the compressive strength-deflection (*D1*) can be derived. Statistical regression analyses have been performed to establish the empirical relationship (as shown in Figures 2 and 3). The relationship for compressive strength and FWD deflection is illustrated in Equation (1).

Table 2. Effective stiffness modulus of the CTB layer

Test stages	Effective stiffness modulus(MPa) at 85 percentile values	
Pavement Layers	CTB	Road base
Granular Road base Before Recycling		280
CTB after 3 days	700	-
CTB after 7 days	1150	-
Asphalt Surface after 28 days	1350	-

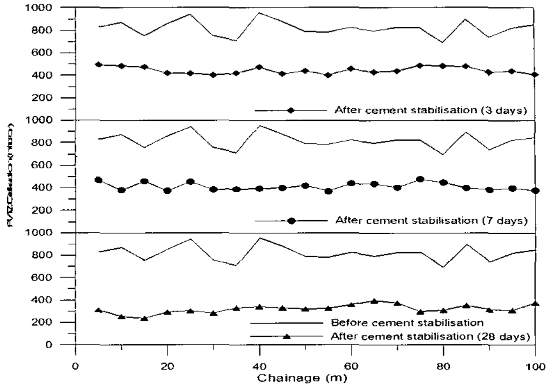

Figure 1. FWD deflection profiles before and after cement stabilisation

$$Su = -7.4543 \ln(D1) + 51.002 \qquad (1)$$

Where, Su is compressive strength of CTB (MPa), and

*D*1 is the reading from FWD deflection sensor (micron).

Another useful engineering relationship between the stiffness modulus and compressive strength of CTB is proposed in this study, and is shown in Equation (2)

$$E = -381\ Su^{0.6047} \qquad (2)$$

Where, *E* is the back-calculated stiffness modulus(Mp$_a$)

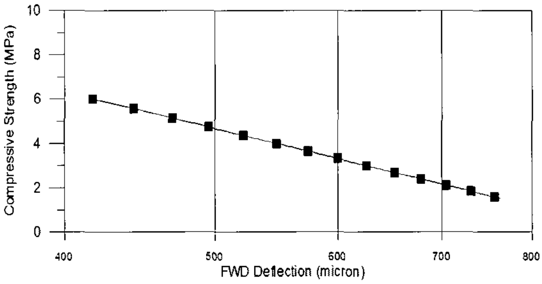

Figure 2. Compressive strength and deflection D1 relationship from FWD.

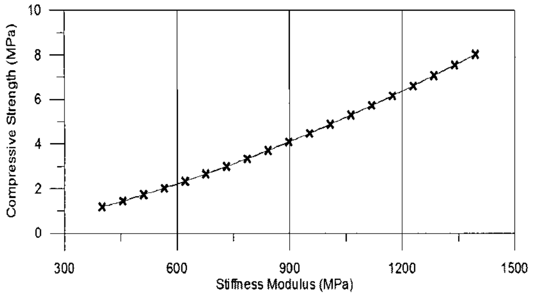

Figure 3. Stiffness modulus and compressive strength relationship from field test.

CONCLUSIONS

A pavement section of 100m in length on the Southbound Carriageway of the North-South Expressway (West Malaysia) had been rehabilitated by using cement stabilisation to strengthen existing road base. Performance of the completed pavement was examined through field (using FWD) and laboratory testing. For tests performed on the CTB, the deflections were observed to decrease between three, seven and twenty-eight days due to curing of the CTB base. The use of cement stabilised base leads to a significant improvement in the structural capacity of the pavement.

An empirical model between the in situ compressive strength and deflection of the CTB layer has been proposed. Further, this paper illustrated an empirical model between the stiffness modulus and the in-situ compressive strength of the CTB. These engineering relationships can be useful for monitoring the performance of the CTB layer when stabilisation is in progress. The significant finding from the trial test showed that, the use of FWD verifies design parameters such as the in-situ effective stiffness modulus of the CTB layer. FWD can also be used to demonstrate the required compressive strength and stiffness modulus of the CTB had been achieved on site. Thus, the expected design life (based on the actual in-situ properties of the pavement) could be determined with greater confidence.

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