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Research Paper

Evaluation of Subgrade Resilient Modulus and Modulus Ratio for Geotextile Reinforced Water Bound Macadam Road using Full-Scale Laboratory Accelerated Pavement Testing Set Up

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ABSTRACT

Resilient modulus (MR) is a very important parameter for designing the flexible pavements. In the mechanistic pavement design, MR of pavement materials is used as an input parameter. In most of the studies, the MR values are usually obtained by conducting laboratory repeated load triaxial test. However, due to the complexity, cost, and need for well-trained personnel associated with it; the researchers have tried to find out several alternative tests. This paper aims to investigate the resilient modulus of subgrade soil for the full-scale geotextile reinforced and unreinforced pavement by using the indigenously developed full-scale laboratory accelerated pavement testing set up. The MR of unreinforced pavement section was verified by comparing it with the laboratory repeated load triaxial test and found to be comparable. The paper also aims to investigate the variation in modulus ratio for geotextile reinforced and unreinforced pavement sections. The modulus ratio and resilient modulus of unreinforced pavement were compared with the empirical equation suggested by Indian Road Congress (IRC) 37-2012 and provided reasonably good agreement. It can be concluded that the full-scale accelerated pavement testing set up has provided an alternative to repeated load triaxial test for the determination of resilient modulus.

1 Introduction

The design of flexible pavement is mainly based upon the characteristics (stiffness) of subgrade soil. The stiffness (stress-strain relationship) of subgrade soil and unbound pavement materials is called Resilient Modulus (M_R). By definition, it is the ratio of applied peak deviator stress to a recoverable axial strain of the material subjected to a cyclic axle load [1]. M_R is an important parameter that characterizes the subgrade's ability to withstand repetitive stresses under traffic loading [2]. In most of the current pavement design procedures, the resilient modulus is used as a key input parameter. It is an essential input

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to mechanistic pavement response models used to compute stresses, strains, and deformations induced in the pavement structure by the applied traffic loads [2]. Therefore, an accurate measurement of M_R is needed to ensure the efficiency and accuracy of the pavement design [3].

Resilient modulus can be measured by various means such as laboratory Repeated Load Triaxial (RLT) test, dynamic testing on field by using Falling Weight Deflectometer (FWD), and use of empirical correlations. Most of the researchers are using the RLT test, however, this test requires expensive laboratory equipment and well-trained personnel, in addition, this test generally performed on small specimen size hence are subjected to scale effect. However, in practice due to the testing equipment's needs and complexity involved in the test, empirical relations are generally used to estimate the M_R of subgrade soils [4]. The most common empirical equation is based on the California Bearing Ratio (CBR), which was first introduced by Heukelom and Klomp [5] and thereafter by Powell et al. [6]. However, these empirical equations are having questions on their accuracy because of the quasi - statics nature of the CBR test and the absence of stress parameters in the expressions [4].

Hence, to furnish some of the limitations of the RLT test and empirical relations, in the present study an inexpensive laboratory full-scale accelerated pavement testing set up is developed to find out the MR of a subgrade soil for specially constructed full-scale pavement section under the controlled loading conditions. The obtained results were compared with the laboratory RLT test as well as with the empirical equation suggested by IRC 37 [7]. The present study also investigated the benefit of geotextile reinforcement in terms of modulus ratio.

2 Full scale laboratory accelerated pavement testing set up

Figure 1 shows the developed full-scale laboratory accelerated pavement testing set up, which applies the cyclic load with the help of hydraulic jack and power pack units. A crosshead consisting of 2- ISMB 250 beams which act as a reaction beam, spanning the width of the pavement. The crosshead is bolted to the bottom side of the ISMB 350 connecting beam.

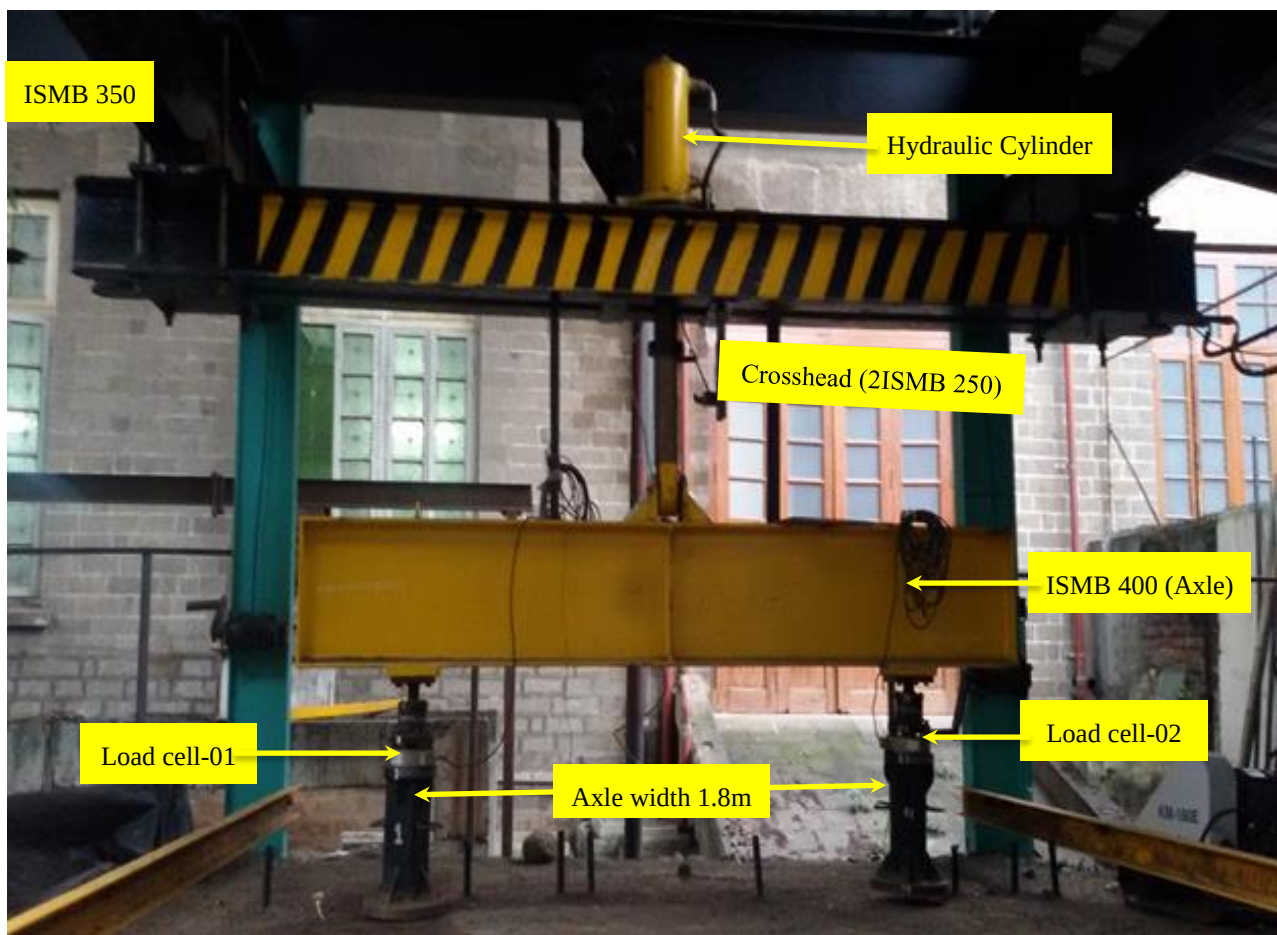


Fig.1 – View of full- scale laboratory accelerated pavement testing set up.

A double acting hydraulic cylinder (300 mm diameter and 450 mm height) of 200 kN capacity with a stroke of 200 mm is positioned in the middle of the crosshead (2-ISMB 250). A spindle of 50 mm diameter extended from the piston of the cylinder and the bottom end of it is connected to the ISMB 400 beam of 2.5m length which serves as a rear axle of the truck. The hydraulic cylinder bolted to the crosshead at its center, applies cyclic load through the spindle over the center of the beam (ISMB 400). Thus, the axle load gets divided equally into two parts. The spindle connection provides flexibility to ISMB 400 similar to the real axle of the truck, to accommodate the uneven pavement deformation at the left and right circular steel plates. A standard axle load of 80 kN applied over the center of the Indian Standard Medium Weight Beam (ISMB 400) which is connected to a pair of 300 mm diameter circular steel plates, 1.8 m apart, simulating the truck wheel base. The area of circular plate simulates the equivalent tire contact area of dual tire assembly of on-highway truck [8]. A pair of load cells of each of 200 kN capacity, are placed between the swivel joint and vertical prop which sense the actual applied load on each circular plate. The data logger logs this actual load.

The area of circular plate simulates the equivalent tire contact area of dual tire assembly of on-highway truck [8]. A pair of load cells of each of 200 kN capacity, are placed between the swivel joint and vertical prop which sense the actual applied load on each circular plate. The data logger logs this actual load. Table 1, shows the special characteristics of the full-scale laboratory accelerated pavement testing set up.

Table 1 – Special characteristics of the full-scale laboratory accelerated pavement testing set up

Sr. No	Element	Description
1	Loading axle	300 mm diameter steel plates spanning 1.8 m c/c
2	Load cell	2 No each of 200 kN capacity
3	Loading wave form	Trapezoidal or Triangular
4	Spindle stroke length	200 mm
5	Control panel	Frequency - 0.11 Hz to 0.25 Hz
6	Swivel Joint	To cater to uneven rutting
7	Winch	Forward and backward movement of the crosshead (2-ISMB 250) along the traffic direction

The testing set up applied cyclic loading in a trapezoidal waveform of 0.2 Hz frequency. The loading cycle is a force controlled where the load is increased gradually from zero to a target value and then it is maintained constant for a certain period of time before the load decreased to zero.

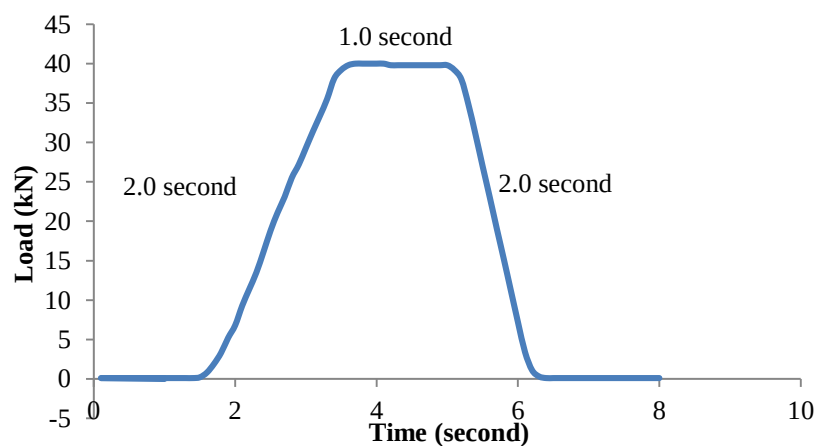


Fig.2 - Typical trapezoidal waveform showing period of constant loading of 1.0 second, loading- unloading periods of 2.0 seconds each and rest period of 2.0 seconds [9].

Figure 2 shows the typical response of loading cycle, the loading wave linearly increases to a peak load of 40 kN in 2.0 seconds, followed by a period of 1.0 second of constant loading of 40 kN, decreases linearly to zero in 2.0 seconds and remain

zero for next 2.0 seconds of rest period. This load pulse corresponds to 0.2 Hz frequency, which simulates the vehicle speed of 0.36 m/s.

3 Experimental Investigation

The Experimental investigation using developed laboratory accelerated pavement testing set up was performed on full-scale Water Bound Macadam (WBM) geotextile reinforced and unreinforced pavement sections. In the case of reinforced pavement section woven geotextile was placed at the base- subgrade interface and to simulate the geotextile anchorage a shoulder of 500mm width was constructed on either side of the pavement. The performance study of these pavement sections was carried out for limited 50000 standard axle loading cycles.

Pavement response such as stress and deformation were obtained by installing the calibrated instruments such as earth pressure cell and Linear Variable Displacement Transducer (LVDT); these instruments were installed at the base-subgrade interface. Figure 3 shows the typical cross-section of WBM reinforced model pavement showing the layout of the instruments embedded into it. In each model pavement section, five numbers of hydraulic earth pressure cells and eight numbers of LVDTs are installed. One pressure cell is placed beneath the loading plate viz. EP-08 and EP-11 (shown in Figure 3) and the others are kept at a 325 mm distance on either side of the loading plate along the axle i.e., ISMB 400. In the present study, the stress detected by the earth pressure cells (EP-08 and EP-11) is observed as deviator stress at the base-subgrade interface. In both the model pavement sections, instruments were installed at identical locations. This will ensure a justifiable comparison of the test results between these pavement sections.

The LVDTs sensed the magnitude as well as nature of total deformation at the base-subgrade interface. From the observed LVDT data, the resilient, as well as permanent deformation was computed. The resilient deformation was computed for each loading cycle which was further used to compute the resilient strain.

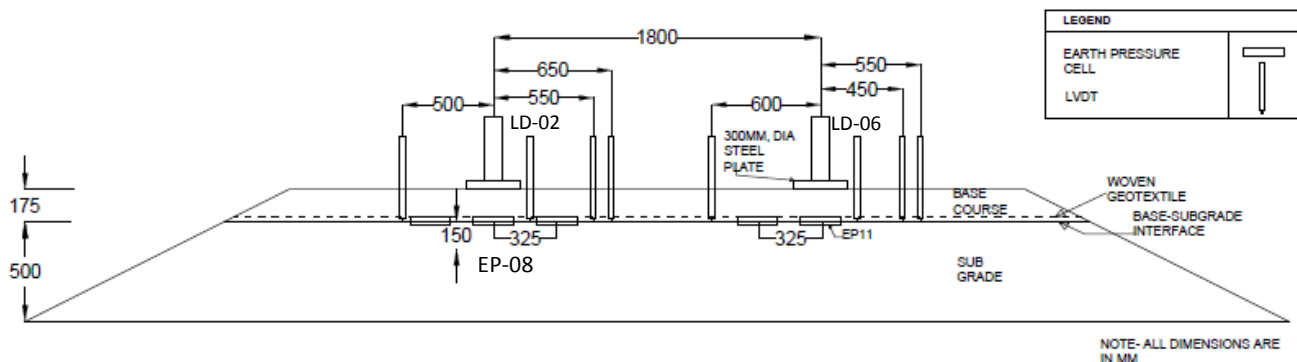


Fig.3 – Typical layout of instrumentation embedded in the model of reinforced pavement [9].

4 Results and Discussion

4.1 Resilient Modulus

By definition resilient modulus is a ratio of deviator stress (σ_d) to the resilient strain. In this study, the deviator stress is measured as the vertical stress detected by the earth pressure cell (EP-08 and EP-11) positioned below the circular steel plate at the base-subgrade interface (shown in Fig. 3). While the resilient strain was computed from the observed subgrade deformation data for the LVDT located at 50 mm from the edge of the loading plate (LD-02 and LD-06 as shown in Fig. 3). The other LVDTs data are useful to observe the subgrade deformation profile for reinforced and unreinforced pavement sections. The resilient strain is calculated for various numbers of loading cycles for geotextile reinforced and unreinforced WBM pavement sections.

Figure 4 shows the variation of a resilient strain of reinforced and unreinforced WBM pavement sections with the number of loading cycles. In both pavements initially, the resilient strain increases as increased in loading cycles. In unreinforced pavement, it increases at a faster rate and after 18000 cycles the resilient strain becomes almost constant. While in the

reinforced pavement, after 26000 cycles the resilient strain is decreased, this is attributed to the mobilization of tensioned membrane effect, however, after 35000 loading cycles, it becomes almost constant.

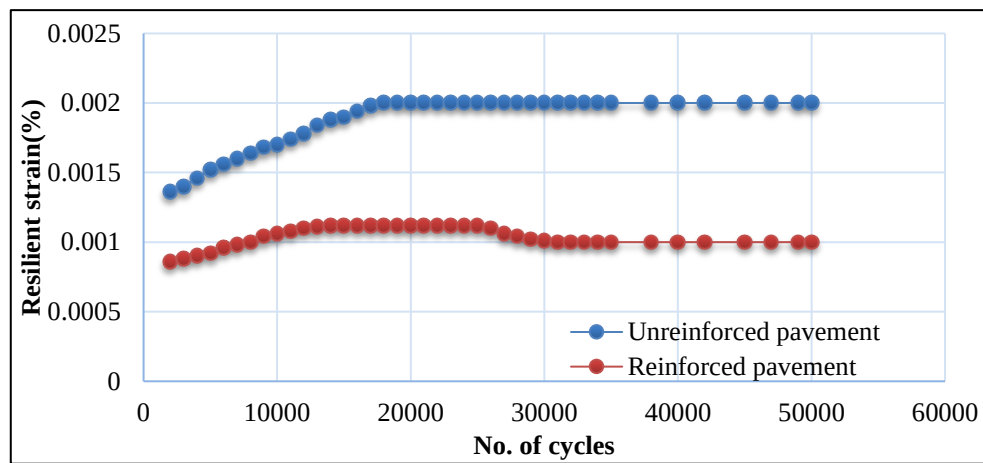


Fig.4 – Variation of resilient strain with number of loading cycles for reinforced and unreinforced pavement sections at 50 mm from the edge of the loading plate.

The resilient modulus is then computed for the various numbers of loading cycles. Figure 5 shows the variation of resilient modulus of reinforced and unreinforced WBM pavement with the number of loading cycles. The reinforced pavement section shows an almost 17% increase in resilient modulus as compared to the unreinforced pavement section throughout all the loading cycles.

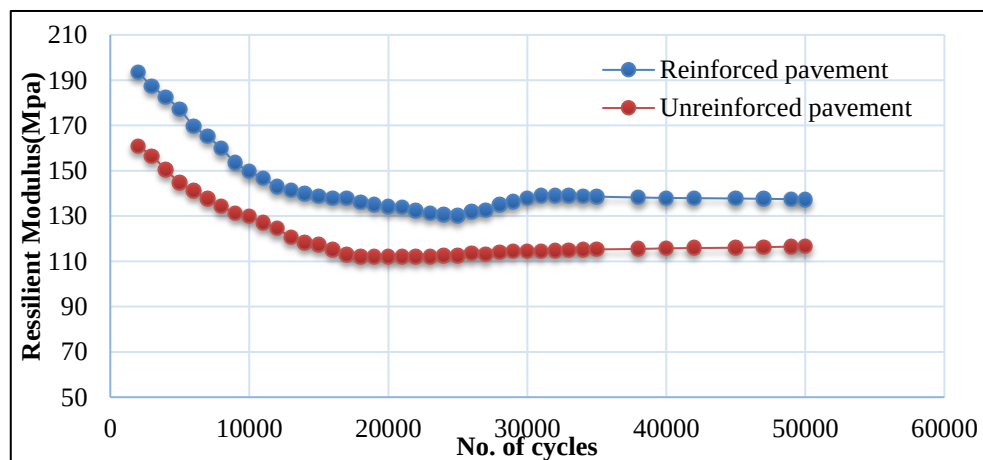


Fig.5 – Resilient modulus variations with loading cycles for unreinforced and reinforced pavement sections.

In both pavement sections initially, the resilient modulus decreases as increased in loading this may be attributed to rearrangement of grains in the pavement matrix. In the unreinforced pavement section after 18000 cycles, the resilient modulus becomes almost constant. This finding is in agreement with Qian Yu et al. [10]. In the reinforced pavement section, after 26000 cycles the resilient modulus shows a slight increase, this may be attributed to the tensioned membrane effect, while after 35000 cycles the resilient modulus approached a stable value, this is consistent with the resilient strain results.

4.1.1 M_R for Unreinforced pavement

The average value of resilient modulus for the unreinforced pavement section is found to be 117.4 MPa. For comparison purpose, the subgrade resilient modulus of the unreinforced pavement section is obtained in the laboratory by performing the Repeated Load Triaxial test.

The RLT test was performed on a similar subgrade soil sample as used during the construction of full-scale geotextile reinforced and unreinforced pavement sections. The test was performed on two different sample size viz. 75mm and 100mm. For the identical stress condition, the resilient modulus for 75 mm specimen size yields (108.45 MPa) slightly higher than the 100 mm specimen size (100.08 MPa) this may be because of higher confinement of the particles in the smaller size of the specimen. This finding is an agreement with Kandhal and Brown [11] and Saleh M.F. and S.J.Ji [12]. Hence, the average resilient modulus obtained through the RLT test is to be 104.2 MPa.

The resilient modulus is also calculated by using the following empirical equation suggested by IRC 37 [7], which is similar to the equation suggested by Powel et al. [6].

$$M_R = 17.6 \times (CBR)^{0.64} \quad (1)$$

where CBR is Effective California Bearing Ratio for subgrade soil.

The field CBR tests were performed over the prepared subgrade of reinforced and unreinforced pavement sections at four different locations (shown in Figure 6) and the average unsoaked CBR of the compacted subgrade was found to be 19.2%.

Since the field CBR of 19.2% is comparable to laboratory unsoaked CBR of 21.13 %, laboratory soaked CBR may be considered as field soaked CBR which is 13.5%.

Hence

$$M_R = 17.6 \times (13.5)^{0.64} \Rightarrow M_R = 93.07 \text{ MPa}$$

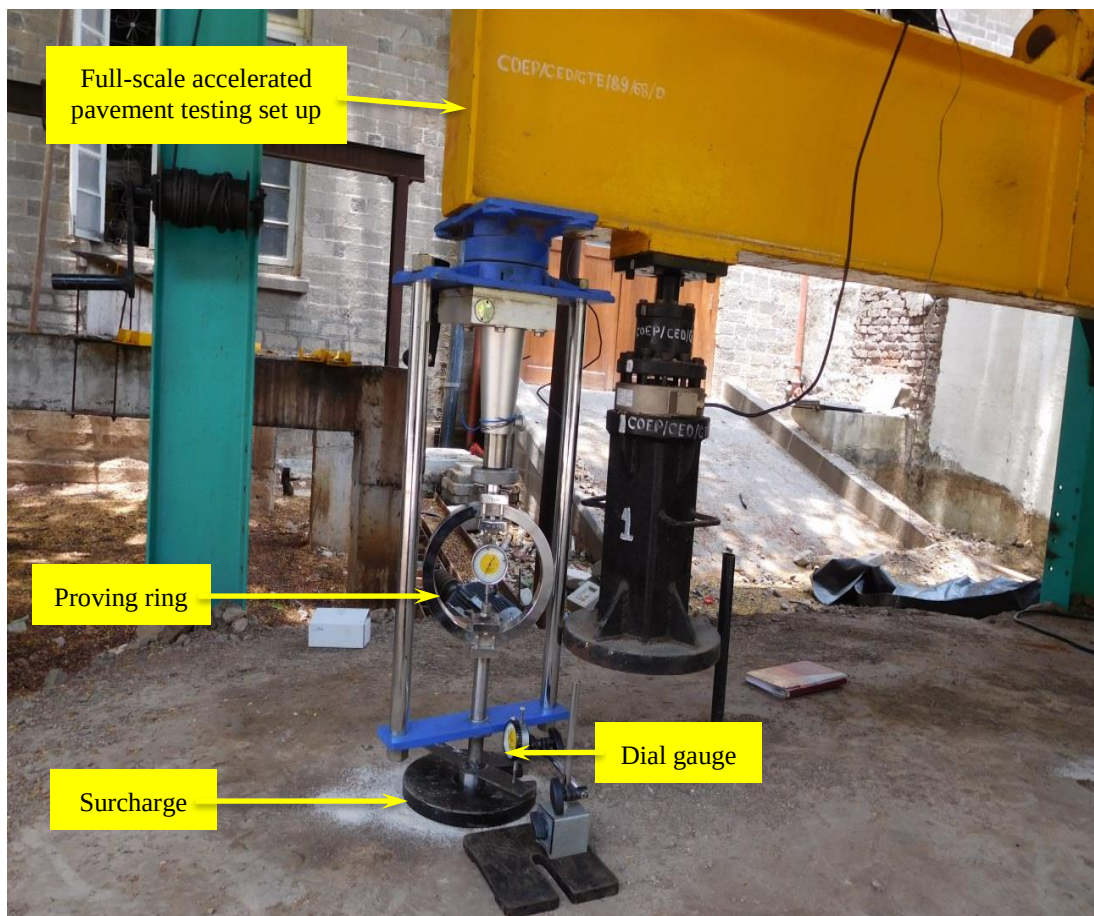


Fig. 6 – View of Field CBR test.

Table 2, Summarizes the resilient modulus value for unreinforced pavement obtained by different techniques.

Table 2- Resilient modulus for unreinforced pavement obtained by different techniques

Sr. No.	Technique/Method	Resilient Modulus of unreinforced WBM pavement (MPa)
1	Full-scale laboratory accelerated pavement testing set up	117.4
2	Repeated Load Triaxial test (RLT)	104.2
3	Empirical equation suggested by IRC 37 (2012)	93.07

The relationship between the resilient modulus values of unreinforced pavement section those obtained from full-scale laboratory accelerated pavement testing set up are found to be comparable with the RLT test and the equation suggested by IRC 37 [7]. As compared to the laboratory RLT test, the full-scale pavement testing set up provides an 11.0 % higher value of the resilient modulus. This may be because of variation in the state of stress, number of cycles, and the scale effect. Overall, the difference in the resilient modulus values observed is not large therefore it is reasonable to say that the resilient modulus obtained by using the developed full-scale accelerated pavement testing set up are similar to the RLT test.

4.1.2 M_R for Reinforced pavement

From Figure 5, the average resilient modulus for reinforced pavement is found to be 142.74 MPa. Using this resilient modulus value, the effective *CBR* of subgrade soil is calculated as per equation (1).

For $M_R = 142.74 \text{ MPa}$ (reinforced pavement); the Effective *CBR* is = 25.4 %.

Hence, for geotextile reinforced pavement, the effective *CBR* of subgrade soil is increased by 46 %. As per IRC-SP 20 [13]; the corresponding base course thickness for 25.4 % *CBR* is 135 mm, hence reduction in base course thickness for geotextile reinforced pavement is by 40 mm.

4.2 Modulus ratio

Similar to the equivalent *CBR* concept the benefit of geotextile reinforcement may also be considered in terms of modulus ratio, which is a ratio of base course modulus to subgrade modulus which is evaluated using Odemark's- Boussinesq theory. Before Odemark's method Ullidtz [14], is used, the equivalent thickness of two layers (subgrade and base course) is calculated by using the following Boussinesq equation.

$$\sigma = q \left[1 - \left\{ \frac{1}{1 + \left(\frac{r}{h_e} \right)} \right\}^{3/2} \right] \quad (2)$$

where, σ : observed vertical stress beneath the loading plate at base-subgrade interface (kPa)

q : surface stress (kPa);

r : radius of equivalent tire contact area (m) and

h_e : the equivalent thickness

The variation of equivalent thickness for reinforced and unreinforced pavement sections is shown in Figure 7.

To use Odemark's method, the following two conditions should be encountered [14];

- 1) The upper layer must have a higher modulus than the lower layer. Preferably the ratio of the upper layer to the lower layer is recommended to be greater than 2.0
- 2) The equivalent thickness should be greater than the radius of the loading plate

The test condition of the present study meets the preferred requirement for Odemark's method.

The modulus ratio is computed by using the following Odemark's equation

$$h_e = h^3 \sqrt{\frac{E_{bc}(1-\mu_2^2)}{E_{sg}(1-\mu_1^2)}} \quad (3)$$

where, h : thickness of base course (m), h_e : equivalent thickness (m), E_{bc} : elastic modulus of base course (MPa), E_{sg} : elastic modulus of subgrade (MPa), μ_1 : Poisson's ratio of base course ($\mu_1 = 0.40$ selected in this study), μ_2 : Poisson's ratio of subgrade ($\mu_2 = 0.35$ selected in this study).

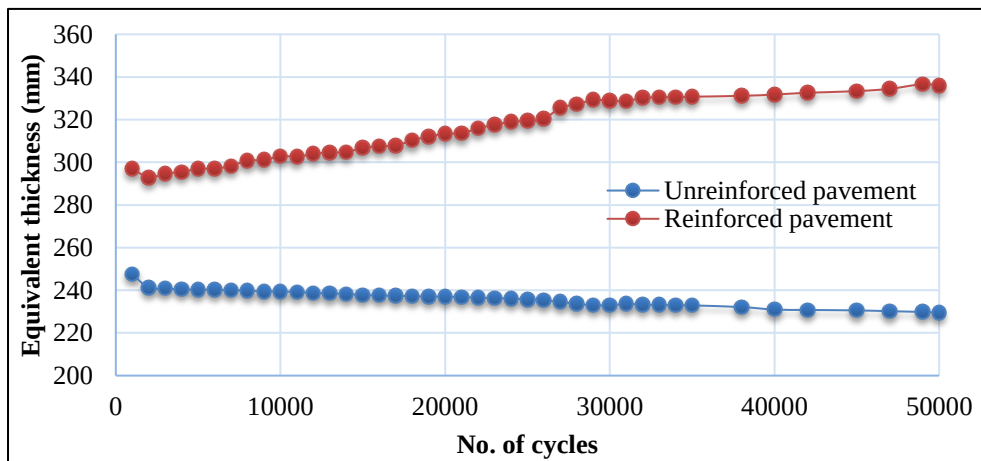


Fig.7 – Equivalent thickness variations with loading cycles for unreinforced and reinforced pavement sections.

Figure 8 shows the variation of the calculated modulus ratio with the number of loading cycles for reinforced and unreinforced pavement. In the unreinforced pavement, the modulus ratio is decreased from 2.57 to 2.04, while in the reinforced pavement it is increased from 4.40 to 6.42. This improvement in modulus ratio is attributed to the geotextile reinforcement.

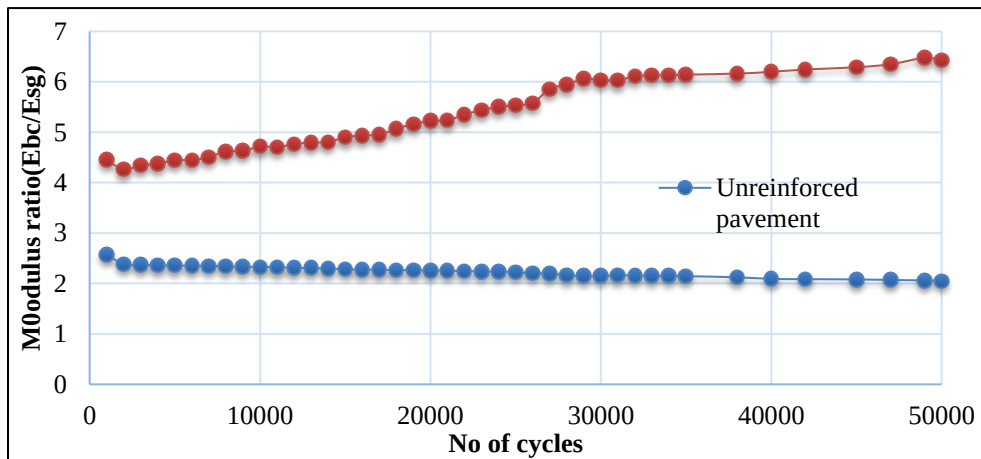


Fig.8 – Modulus ratio variation of reinforced and unreinforced pavement sections with number of loading cycles.

The above modulus ratio result of unreinforced pavement is compared with the empirical equation suggested by IRC 37 [7] as follows;

$$\frac{M_{R\text{Subgrade}}}{M_{R\text{base course}}} = 0.2h^{0.45} \quad (4)$$

where, h : base course thickness (175mm)

$$\text{Modulus ratio} = 2.04$$

In the present study, the modulus ratio obtained for unreinforced pavement is laying in between 2.57 to 2.04, which is comparable to the modulus ratio calculated by the equation suggested by IRC 37 [7]. In Giroud and Han (2004) method the maximum modulus ratio for unreinforced pavement is considered up to 5.0, which may increase beyond 5.0 by the introduction of geosynthetics material in the pavement. In the present study, the introduction of geotextile in pavement increased the modulus ratio from 4.40 to 6.42. This confirms the correctness of the conducted experimental work.

5 Conclusions

From the experimental investigation, it is concluded that the subgrade resilient modulus is increased by 17% for geotextile reinforced pavement section, therefore, increased in the effective CBR of subgrade soil by 46%, which leads to a reduction in base course thickness by 40 mm. The present research also confirms an increase in the modulus ratio to more than 5.0, for geotextile reinforced pavement section, as estimated by Giroud and Han (2004). The modulus ratio obtained for unreinforced pavement is laying in between 2.57 to 2.04, which is comparable to the modulus ratio calculated by the equation suggested by IRC 37 (2012). The agreement of experimentally determined results of resilient modulus with those determined using repeated load triaxial test and IRC 37 (2012) confirms the accuracy of the designed full-scale accelerated pavement testing set up. Hence, the inexpensive full-scale accelerated pavement testing set up has provided an alternative to repeated load triaxial test for determination of resilient modulus of the pavement materials which composite with other materials such as geosynthetics.

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