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Structural Performance of Plastic Cell filled Concrete Block Pavement for Low Volume Roads

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Abstract

This paper presents a systematic full scale field study on the structural performance of Plastic Cell filled Concrete Block Pavement (PCCBP) for different cell thicknesses subjected to live traffic conditions. Five test sections of various thicknesses *viz.*, 50 mm, 80 mm, 100 mm, 120 mm and 150 mm of PCCBP over 100 mm thick water bound macadam (WBM) sub-base layer has been constructed at the approach road towards Indian Institute of Technology Guwahati (IIT Guwahati), India, from National Highway 31 (NH 31). Further, in order to optimize the cost of pavement construction, an attempt has been made to use waste stone dust (byproduct of aggregates crushing) in place of the traditional river sand. Structural performance of PCCBP was evaluated using a custom fabricated Falling Weight Deflectometer (FWD) by measuring the surface deflections at specified radial distance from the load center. Genetic Algorithm (GA) based backcalculation program (Reddy *et. al.*, 2002) was used for backcalculating the layer moduli of the PCCBP test sections using pavement surface deflection data obtained through FWD. For the thicknesses tested, elastic layer modulus of PCCBP (~1995 MPa for 50 mm thick) has been seen to increase linearly with increasing thickness (~90% increase in elastic modulus was observed for 200% increase in thickness).

To evaluate the structural performance of PCCBP with traffic passes, surface deflections data using FWD were collected at regular intervals. It has been observed that for the initial 38,000 ESAL passes the degradation in layer modulus of PCCBP is of the range ~3-20%, however there appears to be a stabilization after 38,000 ESAL passes with the degradation dropping to ~1-7% (from 38,000 to 62,000 ESAL passes).

Keywords: Distress; Pavement condition index; Plastic Cell filled Concrete Block Pavement (PCCBP); Low volume roads; Falling Weight Deflectometer (FWD).

1. Introduction

During the last few decades, road infrastructures have been given high priority by the Government of India for faster socio-economic growth of the far flung rural inhabitants. In order to speed up the development process, the Ministry of Rural Development, Government of India, has launched a rural road development program called *Pradhan Mantri Gram Sadak Yojna* (PMGSY) for connecting unconnected rural inhabitants with all weather roads (PMGSY, 2010). Developing countries such as India faces a challenging task for providing all-weather road connectivity to their rural inhabitants. Whilst conventional flexible pavement

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with a thin cover of premix bituminous carpet is normally adopted for rural roads, frequent maintenance are required (to maintain both functional and structural efficiencies) due to damages caused by poor drainage conditions, overloaded vehicular traffic, iron wheeled bullock carts etc. As a result such pavement incurs huge maintenance cost. To offset such expensive maintenance cost, concrete pavements are increasingly used in rural road connectivity in India because of their durability. However it not only involves high initial cost but can also fail due to various reasons like day and night variations in warping stresses, seasonal changes in the modulus of sub-grade reaction etc. [Srinivas et. *al*., 2007]. Although pre-cast concrete block pavement (Panda, B.C. and Ghosh, A.K., 2002(a); Panda, B.C. and Ghosh, A.K., 2002(b) and Ryntathiang, 2005) provides more flexible response (depending upon the dilantancy of the jointing sand) as compared to the normal concrete pavement mentioned above, there is a tendency for block movements under braking or accelerating force of the vehicular traffic and the interlocking caused by the jointing sand needs frequent maintenance which may not be practical for rural roads.

As an alternative, for better structural performance and low maintenance, a new pavement technology called Plastic Cell Filled Concrete Block Pavement (PCCBP) was developed in South Africa (Visser, 1994, 1999; Visser and Hall, 1999, 2003). In PCCBP, diamond shaped heat welded plastic cells (Figure 1) are used to encase concrete blocks. It may be noted that this type of plastic cell formwork has been successfully used for canal lining, reinforced earth treatment etc. (Visser and Hall, 1999). The cells are tensioned and spread across the foundation layer and concrete is filled and compacted into the cells. Upon compaction the cell walls get deformed resulting in interlocking of adjacent individual concrete blocks (Figure 2). Flexibility is induced into cement bound (rigid) surface and Visser (1999) termed these pavements as Flexible Concrete Pavements.

In India, limited studies on PCCBP technology have been reported by Ryntathiang (2005), Ryntathiang *et. al.*, (2005), Pandey (2006), Sahoo *et. al.*, (2006), Roy *et. al.*, (2009, 2010) and Shivaprakash, (2011) on the cost effectiveness and feasibility for rural roads. Albeit their studies were confined to selected PCCBP thicknesses e.g., 40 mm (Roy *et. al.*, 2009, 2010), 75 mm (Ryntathiang *et. al.*, 2005) and 100 mm (Ryntathiang *et. al.*, 2005, Roy *et. al.*, 2009, 2010, Shivaprakash, 2011), it was observed that PCCBP can provide sufficiently high elastic modulus with low initial and maintenance cost. From the review of literatures available, no attempt has been made to study the effect of PCCBP thickness on the structural performance of pavement. It may also be mentioned that as most reported studies on PCCBP were not performed for live traffic conditions, their suitability for actual field conditions need to be observed. Lack of the above information has hindered the development of design standards, at least in the Indian road context

The present work aims to conduct a systematic field study on the structural performance of PCCBP for various cell thicknesses subjected to live traffic (low volume) conditions. Five test sections of different thicknesses *viz.*, 50 mm, 80 mm, 100 mm, 120 mm and 150 mm of PCCBP over a proposed 100 mm thick water bound macadam (WBM) sub-base layer has been constructed at the approach road towards Indian Institute of Technology Guwahati (IIT Guwahati), India from National Highway 31 (NH31). Further in order to optimize the cost of pavement construction, an attempt is made to use stone dust (byproduct of aggregates crushing) in place of the traditional river sand. It may be noted that with increasing infrastructure development in road projects, housing sector and other major concrete structures etc. demand for crushed stone aggregates (~approximately 20% of crushed stone goes as waste stone dust) has increased resulting in more waste stone dust (Tripathy and

Barasi, 2006). The use of waste stone dust in the construction of rural roads is also expected to solve the scarcity of construction materials like river sand in remote far flung rural areas, and help in cost cutting where the cost of transporting sand is relatively expensive. Thus efforts in this work are directed towards evaluating the structural performance of PCCBP under live traffic condition by using linear elastic layer theory based moduli backcalculation computer code BACKGA (Reddy *et al.*, 2002) from the surface deflection data obtained through a custom fabricated Falling Weight Deflectometer (FWD).

2. Materials used for the construction of PCCBP

2.1 Low Density Polyethylene (LDPE) Plastic Cell

The plastic cell formwork used in the present study is made of Low Density Polyethylene (LDPE) sheet of thickness 0.49 mm. Flexible translucent water delivery LDPE pipe having diameter of ~101.6 mm (Figure 3a) which is available in the local market of Guwahati, Assam, India was used for preparation of cell formwork. The pipes were cut into required strips (50 mm, 80 mm, 100 mm, 120 mm and 150 mm) and heat bonded using paddle sealing machine (Figure 3b) which on stretching forms diamond shaped pockets of size 150 mm x 150 mm (Figure 3c).

2.2 Cement

Fly ash based portland pozzolana cement (PPC) conforming to IS 1489 (1991), was used for casting concrete blocks. The cement (TOPCEM cement) for the whole work was procured in a single consignment and stored properly. The standard consistency and specific gravity of the PPC cement was found to be 31% and 3.15. The initial and the final setting time were found out to be 102 and 372 minutes respectively.

2.3 Stone dust

Stone dust collected from a stone crusher factory located nearby IIT Guwahati, Assam, India was used as fine aggregates for casting concrete blocks. The particle size distribution of stone dust obtained from the sieve analysis is shown in Table 1, and it is found to be closely conforming to Zone II of IS 383 (1970). Water absorption and specific gravity of the stone dust as per IS 2386 (1963a) was obtained to be 0.73% and 2.63 respectively. Fineness modulus of the stone dust was found to be 2.3 which lie within the specified limit of 3.37-2.10 for Zone II of IS 383 (1970).

2.4 Coarse Aggregate

The crusher run coarse aggregates were obtained from the same stone crusher factory from where the stone dust was collected. These coarse aggregates were crushed from hilly stone boulders brought from Dewdwar quarry, Baicharali, Guwahati, Assam, India. The physical properties of the coarse aggregates for concrete as per IS 2386 (1963a, 1963b) were given in Table 2. Single size stone aggregates of 22.4 mm (i.e. passing 26.5 mm sieve and retained on 13.2 mm sieve) as per specification of MORTH (2001) were selected for casting the concrete in the study.

2.5 Soil\

The soil used for backfilling the sub-grade for the test pavement was brought in from a nearby hill slope excavation. The grain size distribution of sub-grade soil as per IS 2720 (1985a) is given in Table 3. The specific gravity was obtained as per IS 2720 (1980) and found to be ~2.63. From Table 3 it can be seen that percentage of fine fraction passing 75 micron sieve is ~41%, and the soil can be classified as coarse grain soil as per ASTM 2487 (2006). The liquid

limit was found to be 35% with no significant plastic limit (IS 2720, 1985b). The laboratory soaked and un-soaked California Bearing Ratio (CBR) values of the soil used for backfilled were found out to be 5% and 7% respectively (IS 2720, 1987).

3. Laboratory investigations

Laboratory investigations were carried out to determine an appropriate construction technique which would be labour intensive, cost effective and appropriate for execution by semi-skill villagers so as to generate employment for the economically challenged rural inhabitants. Two different types of construction techniques were tested. 1)*Premix technique*: It is a type of construction where the plastic cell formwork are spread and tensioned over a prepared foundation layer and the concrete is placed into the cells and compacted (Ryntathiang *et. al*., 2005; Pandey, 2006; Roy *et. al.,* 2009,2010 and Shivaprakash, 2011). 2)*Grouting technique*: Here, plastic cell formworks are spread and tensioned over the foundation layer as done in the previous case and cells are filled with coarse aggregates and mortar (slurry) is vibrated into the voids between coarse aggregates (e.g., using a plate vibrator) (Visser, 1994, 1999; Visser and Hall 1999, 2003).

In order to check the suitability of the above mentioned techniques, laboratory concrete cube (150 mm x 150 mm x 150 mm) compressive strength tests for both premix and grouting techniques were carried out using nominal single size 22.4 mm coarse aggregates (for better grouting of mortar into voids between aggregates) and different cement:stone dust (c:sd) mix proportions *viz.*, 1:1.0, 1:1.25, 1:1.5, 1:1.75 and 1:2.0. For the initial study on grouting technique coarse aggregates were first filled into the cube mould, then cement mortar with three different water cement ratios (w/c) of 0.4, 0.5, and 0.6 were placed and vibrated into the voids between coarse aggregates using table vibrator. It has been observed that for the grouting technique, mortar with w/c ratio = 0.4 was too dry to grout into the voids in between the coarse aggregates whilst a w/c ratio of 0.6 produced a high workability. An intermediate w/c ratio of 0.5 exhibited moderate workability resulting in better compaction of the concrete. To check the feasibility of grouting technique in the field, a small trial test pit of size 2 m x 2 m was prepared and plastic cells of each pocket size 150 mm x 150 mm x 120 mm was laid and stretched on a prepared 100 mm thick WBM sub-base course. Crushed nominal single size stone aggregates 22.4 mm were filled into the pockets of plastic cells and mortar having c:sd ratio = 1:1.25 was vibrated using a plate vibrator into the voids between the coarse aggregates. It has been seen that core samples taken out after curing the concrete for 7 days showed incomplete penetration of mortar for ~30% of thickness. Although it might have been possible to get better compaction using needle vibrator, it is expected that its implementation in the field with large number of plastic cells may be prohibitive. Visser, 1994, 1999; Visser and Hall 1999, 2003 reported grouting technique using cement sand slurry (and hence ‘very high’ slump), however it is important to note that increasing water/cement ratio will lead to reduction in the compressive strength as well as segregation of concrete. Thus for the present field study, premix technique has been adopted with a moderate w/c ratio of 0.50. The variation of 7 days average cube compressive strength as per IS 516 (1959) of premix concrete (three samples were considered for each c:sd ratio) with c:sd ratios is presented in Figure 5. From Figure 5, it can be seen that c:sd ratio = 1:1.25 gives the highest compressive strength (~ 18 MPa). As this 7-days cube strength is more than 15 MPa which is required for opening to the heavy traffic (Visser and Hall, 1999), c/sd ratio of 1:1.25 is adopted for casting PCCBP in the field.

4. Structural evaluation of PCCBP test sections

4.1Test section

A full scale field study on the structural assessment of different thicknesses of PCCBP (50 mm, 80 mm, 100 mm, 120 mm and 150 mm) over 100 mm WBM sub-base course was carried out at IIT Guwahati main approach road from the National Highway, NH31. A section of the existing bituminous pavement, measuring 15 m in length and 7 m in width was selected for construction of five different thicknesses of PCCBP test sections. A schematic plan and sectional view of the test sections is shown in Figure 6. Based on the preliminary survey it has been observed that the traffic passing on the selected road stretch consists mainly of heavy trucks carrying construction materials, dumpers, buses and light moving vehicles like cars etc. The road can be considered as a low volume road as the average daily traffic was estimated to be about 250-300 vehicles/day.

4.2 Excavation of the existing pavement

Taking due care the problems of rain during construction work and the effect of the rain water on the strength of the sub-grade layer, the excavation of the existing bituminous pavement for the construction of PCCBP test section was done during October 2009 using an earth excavator. The upper layers of the existing pavement were removed and a trench measuring 15 m in length and 7 m in width and approximately 450 mm depth was excavated (Figure 7) till sub-grade soil layer. After excavation the loose materials were properly removed and the natural soil was properly levelled. It was observed that the existing pavement consists of 20 mm premix carpet, 75 mm thick bituminous macadam over 350 mm thick sub-base course (200 mm thick WBM course and 150 mm granular sub-base). The dry density and field moisture content of the sub-grade soil in place by core cutter method as per IS 2720 (1975) was found to be 1730 kg/m^3 and 13.80% respectively. The laboratory soaked CBR value obtained for the sub-grade soil collected from the excavated site was found to be 6% (IS 2720, 1987).

4.3 Preparation of the sub-grade soil

The trench was backfilled with selected soil collected from nearby hill slope whose properties are given in Section 3.2.5. Laboratory compaction test was conducted to determine optimum moisture content (OMC) and maximum dry density (MDD) of the soil as per IS-2720, 1987). Compaction was done at the optimum moisture content (~12%) using a 100 KN three wheeled roller in three layers of 100 mm each, maintaining cross and longitudinal slopes. After compaction the surface was levelled manually to bring the surface to the required profile for each thickness (Figure 6). The field density and the moisture content of the compacted sub-grade soil was determined by core cutter method (IS 2720, 1975) and were found to be 1880 Kg/m^3 and ~12 % respectively. The percentage field compaction was found to be ~98% of the standard laboratory compaction value.

4.4 Water Bound Macadam (WBM) Course

In the present study 100 mm thick WBM sub-base course was provided above the prepared sub-grade soil layer. Crushed stone aggregates and screenings conforming to Grading 1 and Grading A respectively as prescribed by MORTH (2001) were used for WBM course. The particle size distribution and properties of water bound macadam sub-base course are given in Table 4. The materials were manually placed and spread uniformly over the prepared sub-grade soil. Laying and compaction (Figures 8a and 8b) was done as per MORTH (2001). Rolling with copiously sprinkling of water and sweeping with brooms for WBM was continued until the slurry that is formed will, after filling the voids between aggregates form a

wave ahead of the moving roller indicating that the voids are fully filled and the layer is properly compacted (CPWD, 1996).

4.5 Laying and concreting of the plastic cells

After preparation of the WBM course, plastic cell formwork 5.5 m x 2.7 m for each test sections were laid, maintaining the cross fall (~ 2.5%) and longitudinal (~ 0.05%) slopes such that the new and the old pavement surfaces are in the same level. A gap of 750 mm on the edges and 300 mm (to provide space for tensioning plastic cells) between adjacent sections of PCCBP (Figure 9 and 10a) were left. A reusable wooden frame (Figure 10a) with hook arrangements was used for tensioning the plastic cell formwork. It also acts as side restrain for casting concrete. This wooden frame was to be removed after casting one section and for reusing it for another section (Figure 10b). The plastic cell formwork, after tensioning forms diamond shaped (150 mm X 150 mm) pocket size (Figure 10a).

From the laboratory test results, premix concrete with cement:stone dust:coarse aggregates ratio of ~1:1.25:2.0 by volume having 28-days cube compressive strength of ~32 MPa was selected for casting PCCBP. Mixing of the concrete was done by a diesel operated mixer machine and amount of water was maintained at w/c ratio = 0.5. The test section was constructed sequentially from the higher thickness (150 mm) and proceeded towards the lower thickness giving a gap of 300 mm in between two adjacent sections as shown in Figure 3.9. After casting the next section, the previous gap was filled with concrete and levelled. The remaining gaps between the edges of the road were also filled with concrete and level. Compaction was done using a plate vibrator and a locally fabricated wooden beam straight edge rammer. The finished surface was levelled properly; care was taken to make the new construction (test section) in the level with the existing bituminous pavement.

4.6 Curing of the PCCBP test section

Casting of the whole test section was completed in a single day and the concrete was allowed to set overnight. Longer lane closure to ensure curing is a criticism for concrete pavement. Water curing was done for 21 days, however Roy *et. al.,* (2009) reported 14 days curing using wet jute gunny bags to be sufficient for quick opening of the traffic. After removing water the pavement was clean properly and marking was done for different PCCBP sections (Figure 11) and initial surface deflection data of the test sections (using FWD) were collected before opening to the regular traffic. Core samples collected from the test sections shows that the compaction is proper and the thickness of each section is maintained properly. The PCCBP test section was opened to normal traffic (Figure 12) after 25 days from the day of casting.

4.7 Traffic survey

In order to evaluate the structural performance of the test sections with traffic passes, daily traffic volume data was collected from the IIT Guwahati security check gate. Axle load survey was carried out using a portable load pad (calibrated and checked in the laboratory) which can measure up to a maximum of 10 tones wheel load. Following the recommendation of IRC (2007) the axle load survey for the present study was carried out considering only the motorized commercial vehicle with gross laden weight of 3 tonnes and above (i.e. heavy and medium commercial vehicles). The universal ‘fourth power damage formula’ (AASHTO, 1962) is used to convert the number of repetitions of vehicles of various axle loads into Equivalent Single Axle Load (ESAL) repetitions of 80 kN. An equivalent axle load factor called Vehicle Damage Factor (VDF) has been calculated from the axle load distribution data, which when multiplied by the monthly volume of commercial vehicle repetitions, would convert into monthly ESAL repetitions.

Figure 13 shows the monthly ESAL with month for the data collected from 25th December 2009 to 24th November 2010 (i.e., ~ 11 months period). The initial high ESAL values up to the month of April is attributable to several earth filling and constructional activities in and around IIT Guwahati campus, which get reduced during the rainy season i.e., May till July. It can be seen that at the end of about 11 months (i.e. up to 24th November 2010) the total ESAL repetitions has reached 62,000 approximately. It may be mentioned that in Indian rural roads, tractor-trailers ferrying farming products during harvesting periods, and people and materials during local festivals / marriages constitute major commercial traffic. Considering a traffic volume of 20 vehicles per day, and rear axle load of a loaded tractor-trailer as ~ 60 kN (Roy *et al.*, 2010), the yearly average ESAL repetitions is about 2300. So, the cumulative ESAL repetitions of 62,000 are equivalent to ~ 25 years of service for a typical rural road in India.

5. Structural evaluation of PCCBP test section

A custom fabricated Falling Weight Deflectometer (FWD), a non-destructive test (NDT) equipment which simulates the short duration loading of the fast moving wheel was used to record the surface deflection data of the test pavement (Figure 14). BACKGA (Reddy *et. al.*, 2002), a Genetic Algorithm (GA) based back calculation software was used to calculate the pavement layer elastic moduli from the recorded surface deflection data.

5.1 Falling Weight Deflectometer (FWD)

FWD produces an impulse load by dropping a free fall mass over a loading plate with spring system which transmits the load on to the pavement. The instantaneous surface deflection of the pavement is measured at various radial distances from the center of the load by using a number of geophones as shown schematically in Figure 15.

The FWD used in the present study is mounted on a trailer for better mobility. The equipment consists of a loading platform with load plate (300 mm in diameter) for dropping load and a geophone beam with geophones to measure the pavement surface deflection. The load platform along with the geophone beam can be lowered and kept in contact with the pavement using two hydraulic cylinders. The height of fall can be adjusted and impulse load in the range of 20 kN to 100 kN can be applied on the pavement. The load applied is measured with a load cell provided under the load plate and the pavement surface deflections are measured with the geophone. Analog Input Modules (AIM) was used to acquire data from the load cell and geophones (NI, 2009). The AIM, data acquisition and voltage output from geophones are controlled and accessed through LabVIEW software (LabVIEW, 2009).

The load cell and geophone readings are calibrated and processed to determine the magnitude of load in kilo-Newton and deflection in millimeter. For evaluation of PCCBP test section, the FWD was positioned in the interior of the test pavement in such a way that the load plate along with geophone beam aligns along the longitudinal direction of the road. Care was taken to ensure that each geophone knobs touches the pavement surface properly. For each test section the load was dropped 3-4 times and surface deflection data were collected on either side of the load plate at radial distances of -500 mm, -300 mm, 0 (zero), 300 mm, 600 mm, 900 mm and 1200 mm. The surface deflections were then normalized to a load of 40 kN (IRC, 2007) and average of three deflection readings were taken for structural evaluation of the pavement.

5.2 Backcalculation of layer modulus using BACKGA

Backcalculation is an analytical procedure in which the surface deflection data collected through FWD test are used to predict the elastic moduli of different layers of pavement. The back calculation procedure involves theoretical calculations of the deflections produced under a known applied load using an assumed set of layer moduli. The theoretical deflections are then compared with those measured during the field test. In case of differences between the theoretical and the measured deflection, the assumed pavement layer moduli are adjusted and the process is repeated until the differences between the theoretical and measured values fall within acceptable limits.

In this work, GA based BACKGA program developed by Reddy *et. al.,* (2002) was used for backcalculating the layer moduli of the PCCBP. In BACKGA a systematic search of the solution space defined by the ranges of moduli selected by the user is conducted. Detail explanation of the BACKGA technique is available in Reddy et al., (2002) and Rakesh *et al.,* (2006). The objective function of the BACKGA was to minimize the differences between the measured and the computed surface deflection of the pavement. Layer thickness, surface deflection, locations at which the deflections were measured, loading details and Poisson's ratios of the pavement were used as main inputs to the BACKGA program. In the present study the range of moduli and the material properties considered for the BACKGA analysis are shown in Table 5. The upper and lower limits of layer modulus are chosen based on heuristic approach considering possible practical values. It has been observed by Reddy *et al.,* (2002) that slight variation in the values of Poisson's ratio (within a practical range) do not significantly affect the critical stresses and strains, hence as a first approximation a Poisson's ratio value of 0.35 (Sahoo *et al.,* 2006 adopted 0.30 as Poisson's ratio) was considered based on an average of the values of both concrete (~ 0.20) and LDPE (~ 0.43). For each set of layer moduli selected within the search space, surface deflection at radial distances of 0, 300, 600, 900, 1200 mm (measured from the center of the load plate) are computed using linear elastic layer theory. The computed deflections are compared with the measured deflections and the fitness of the moduli set under given range is evaluated (Rakesh *et. al*., 2006). The elastic layer moduli computed through BACKGA program using the surface deflection data obtained by FWD are used for structural evaluation of pavement. The validation of the layer elastic modulus obtained through BACKGA program was done using two different layer elastic analyses based computer program code KENLAYER (Huang, 2010) and Finite Element (FE) analysis based ABAQUS software (ABAQUS, 2009).

6. Results and discussions

6.1 Surface deflections

A comparison of surface deflections of PCCBP (100 mm thickness) with those obtained from the literature on similar studies *viz.,* Roy *et. al.,* (2009) and Ryntathiang *et. al.,* (2005) is presented in Figure 16. It can be seen that the present study showed higher peak deflection as compared to that obtained by Roy *et. al.,* (2009) and almost agrees with Ryntathiang *et. al*., (2005). The lower value of deflection of Roy *et. al.,* may have resulted from: 1) higher grade of concrete with compressive strength of 38.5 MPa (i.e. an increase of 18% from the present study) and 2) higher sub-grade soaked CBR value (~ 8%) as against the lower soaked CBR value (~5%) of the sub-grade used in the present work. In the case of Ryntathiang *et al.,* (2005) while the concrete used has lower compressive strength (~25 MPa), the testing was done in laboratory using sand (conforming to Zone II of IS 383 (1970) and with a higher

soaked CBR of (~8%) in a brick wall confined pit of size 3 m x 2 m, which may have resulted in higher deflection.

Figure 17 shows a plot of the surface deflection profiles for various PCCBP thicknesses *viz.*, 50 mm, 80 mm, 100 mm, 120 mm and 150 mm. It can be seen that with increase in thickness of the PCCBP, there is decrease in overall deflection (i.e. size of deflection bowl). The deflection bowl is seen to be significant up to an approximate radial distance of twice the load plate diameter (~600 mm) from the center of the load. The peak deflections are identified from Figure 17 and plotted in Figure 18. It can be observed that the decrease in peak deflection with increasing PCCBP thickness is nearly linear (R^2 = 0.97), with 200% increase in thickness from 50 mm thick PCCBP, there is a decrease of ~48% (0.8481 mm for 50 mm thick PCCBP) in deflection.

6.2 Layer elastic modulus

The variation of PCCBP layer elastic moduli with increase in their thickness is shown in Figure 19. A nearly linear (R^2 = 0.97), variation in elastic moduli has been observed, with an increase of ~90% in elastic modulus from 1958 MPa (for 50 mm PCCBP thickness) when the thickness is increased from 50 mm to 150 mm (i.e. 200% increase in thickness). The present results agree with the laboratory observation made by Visser (1994) where a linear (R^2 = 0.987) increase of moduli (from 40 MPa to 100 MPa) for 200 % increase in thickness (from 50 mm to 150 mm) was reported. However, the present observation is in contrast to the non-linear relationship (*ln* (PCCBP layer modulus) = 0.012 x (PCCBP thickness in mm) + 2.852; for support stiffness of 20 MPa) proposed by Visser (2003), where there is a 'rapid' increase of layer modulus with increasing thickness. However, the above relationship is linear if we consider semi-log scale for the same. The variations in sub-base and sub-grade elastic moduli with PCCBP thickness are shown in Figures 20 and 21 respectively. It can be seen that there is no significant variation of sub-base elastic modulus and lies in the range 240-300 MPa for different thicknesses considered. It may be noted that the present results are approximately twice the values (Sub-base modulus = sub-grade modulus x 0.2 x (thickness in mm)$^{0.45}$ = 111 – 158 MPa) suggested by Shell (1978). From Figure 21 it can be seen that sub-grade moduli lies within the range 70 - 100 MPa for the thicknesses considered. The computed sub-grade moduli values (i.e. range of 14-20 x CBR) lie in between those predicted by Shell (1978) i.e. 10 x CBR and Visser *et al.*, (2003), i.e. range of 1-100 x CBR.

7. Performance of PCCBP with load repetitions

In order to evaluate the performance of PCCBP test sections with load repetitions, Falling weight deflectometer was used to measure the surface deflections at regular interval of load repetitions i.e. 0 load repetition (before opening traffic), ~38,000 ESAL repetitions (~ 6 months after opening traffic), ~62,000 ESAL repetitions (~ 11 months after opening traffic). Based on the surface deflection data obtained through FWD, layer elastic moduli of each test sections were computed using a layer backcalculation programme code BACKGA (Reddy *et. al.*, 2002). Figures 22 - 24 show the variation of elastic layer moduli of PCCBP, sub-base and sub-grade layers respectively for 3 (three) different load repetitions. A decrease of 8% to 20% can be observed for 50 mm, 80 mm, 100 mm, 120 mm and 150 mm thick PCCBP surface layers, after ~62,000 ESAL repetitions (Figure 22). In general, the rate of decrease is comparatively higher in the initial 38,000 passes, which is then appears to be stabilized thereafter. From Figure 23 it can be seen that sub-base layer elastic moduli also decreased with increasing traffic passes, but with a comparatively steeper gradient in the initial 38000

ESAL passes. In the initial stage (zero load repetition) the results of sub-base modulus for 50 mm thick sub-base are seen to be slightly higher as compared to that of other PCCBP thicknesses, which then drops to results closer to that of 80 mm thick PCCBP. This observation may have resulted from local variation in sub-base/ sub-grade compaction. The decrease of sub-grade moduli with number of ESAL repetitions can also been seen (Figure 24), however in contrast to PCCBP surface layer and sub-base layers, the decrease in moduli of sub-grade layer is comparatively higher during 38000 – 62000 ESAL repetitions range, converging to a of modulus value to ~ 60 MPa for all the thicknesses considered. The initial decrease in moduli of PCCBP layer and sub-base layers (i.e. during 0 – 38000 passes) may be related to the decrease in stiffness of the PCCBP layer due to distressing.

8. Conclusions

The main conclusions drawn from the present study are:

1. An increase in the size of surface deflection bowl was observed for decreasing PCCBP thickness. The deflection bowl has been observed to be significant up to an approximate radial distance of twice the load plate diameter from the center of the load (~600 mm).
2. Peak surface deflections decreased with increasing PCCBP thickness linearly, with 200% increase in thickness from 50 mm thick PCCBP, a decrease of ~48% (0.8481 mm for 50 mm PCCBP) in deflection was observed.
3. A thin PCCBP of about 50 mm over thin sub-base can result in sufficiently high elastic moduli (> 1900 MPa) of PCCBP to be used for rural roads.
4. Elastic modulus of PCCBP increases with increasing thickness, approximately in a linear manner for the thicknesses tested, 90% increase in elastic modulus was observed for 200% increase in thickness.
5. It has been observed that for the initial 38,000 ESAL passes the degradation in layer modulus of PCCBP is of the range ~3-20%., however there appears to be a stabilization after 38,000 passes with the degradation dropping to ~1-7% (from 38,000 to 62,000 ESAL passes).
6. The lowest thickness of PCCBP (50 mm) has shown a high elastic modulus (~1800 MPa) even after a wheel load repetition of 62, 000 passes.

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Table 1: Particle size distribution of stone dust

Sieve size (mm)	Percentage passing by weight (%)	Specified limit of passing (%) for Zone II
10	100	100
4.75	98.4	90-100
2.36	91.5	75-100
1.18	70.3	55-90
0.6	52.3	35-59
0.3	35.7	8-30
0.15	21.4	0-10

Table 2: Physical properties of coarse aggregates for concrete.

Properties	**Value**
Los-Angeles abrasion value	26.58%
Aggregate flakiness index	9.2%
Specific gravity	2.700
Water absorption	0.3%

Table 3: Grain size distribution of sub-grade soil.

Sieve size (mm)	**Percentage passing (%) by weight**
4.75	98.1
2.8	97.3
2.36	94.8
2.0	94.5
1.0	85.2
0.6	76.6
.425	69.6
0.3	65.7
0.15	49.7
0.075	41.6

Table 4: Particle size distribution and properties of water bound macadam sub-base course

Particle size distribution			Aggregate properties			
Sieve size (mm)	Percentage passing (%)	Specified limit for Grading I (% passing)	SG	WA (%)	CE & FI (%)	LAAV (%)
125	100	100	2.716	0.23	32.8	14.1
90	91.7	90-100				
63	44.93	25-60				
45	7.6	0-15				
22.4	1.71	0-5				

Note: SG = Specific Gravity; WA = Water Absorption; CE & FI = Combined Elongation and Flakiness Index; LAAV = Los-Angeles Abrasion Value.

Table 5: Selection of limits of Pavement (new construction) material properties.

Pavement layer		**Elastic modulus (MPa)**		**Poisson's ratio**
		Lower limit	**Upper limit**	
PCCBP	50 mm	200	2000	0.35
	80 mm	200	2600	
	100 mm	200	3000	
	120 mm	200	3500	
	150 mm	200	3800	
Sub-base		20	300	0.40
Sub-grade		10	100	0.40

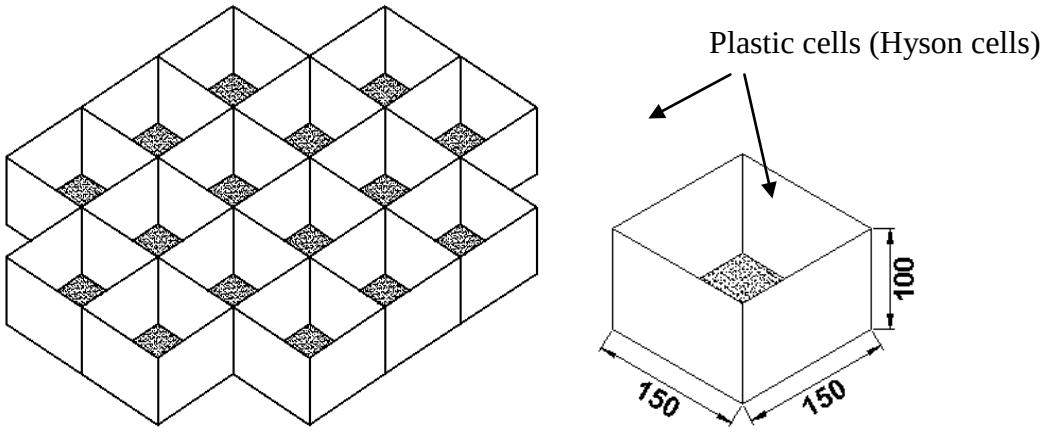


Figure 1: Schematic diagram of typical plastic cells (Hyson cells) formwork with pocket size 150 mm x 150 mm.

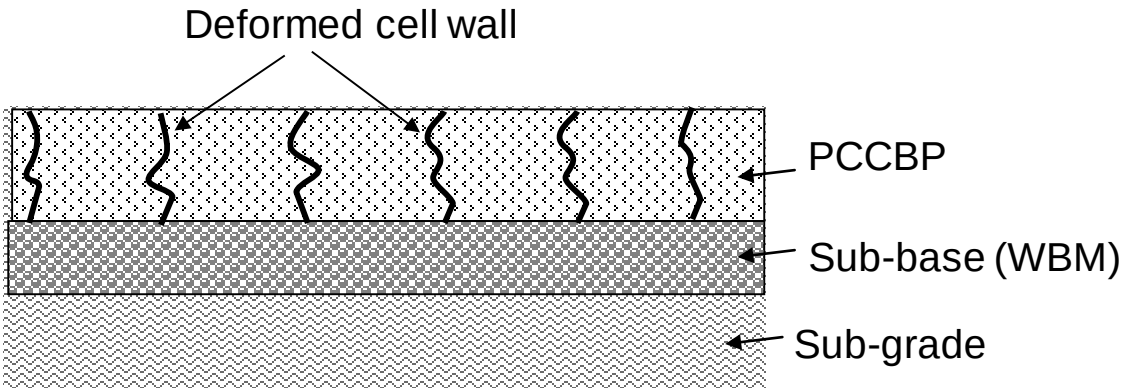


Figure 2: Schematic diagram of deformed cell walls of PCCBP.

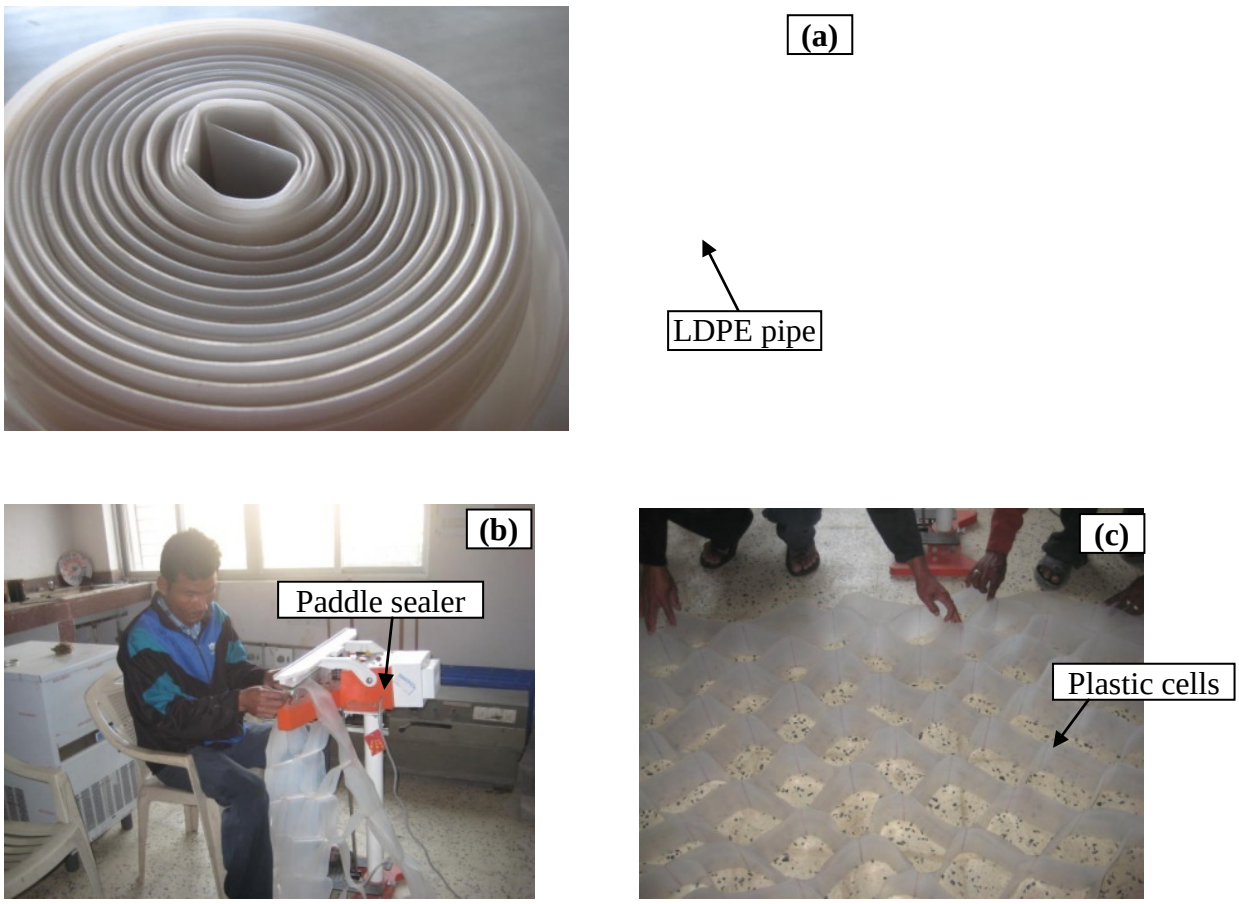


Figure 3: a) Low Density Polyethyline (LDPE) pipe (0.49 mm thick and 101.6 mm in diameter), b) Sealing of plastic cell formwork using paddle sealer, and c) Finished plastic cell formwork.

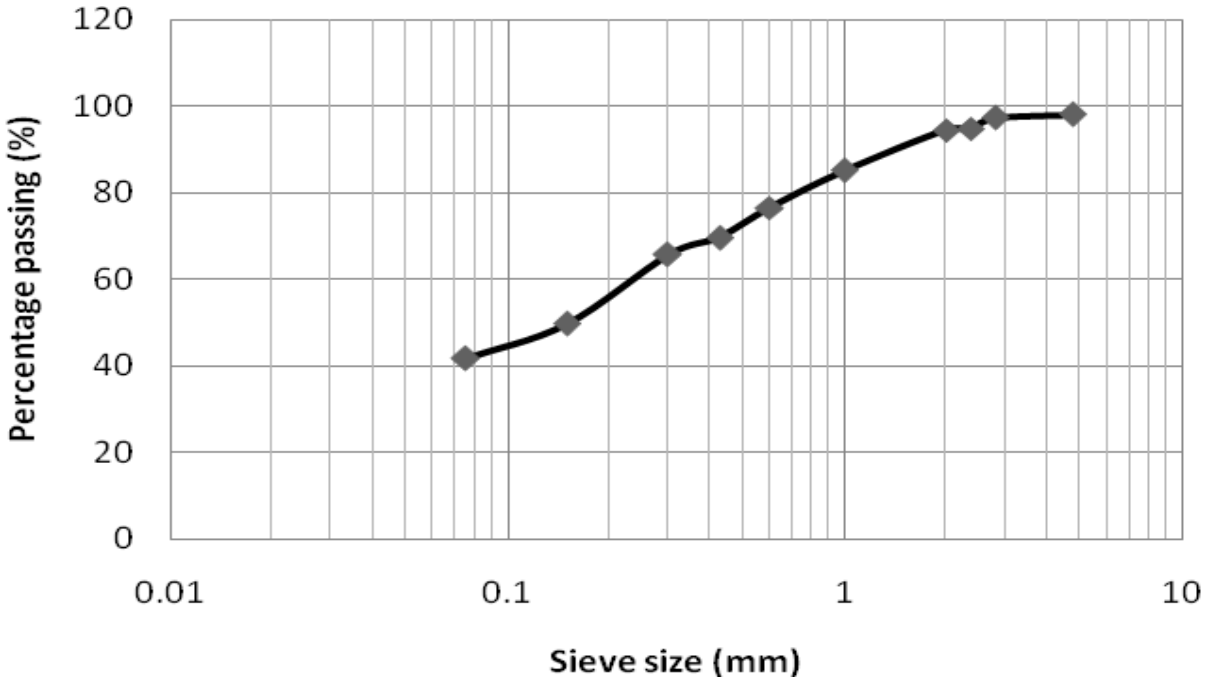


Figure 4: Particle size distribution of soil (sub-grade).

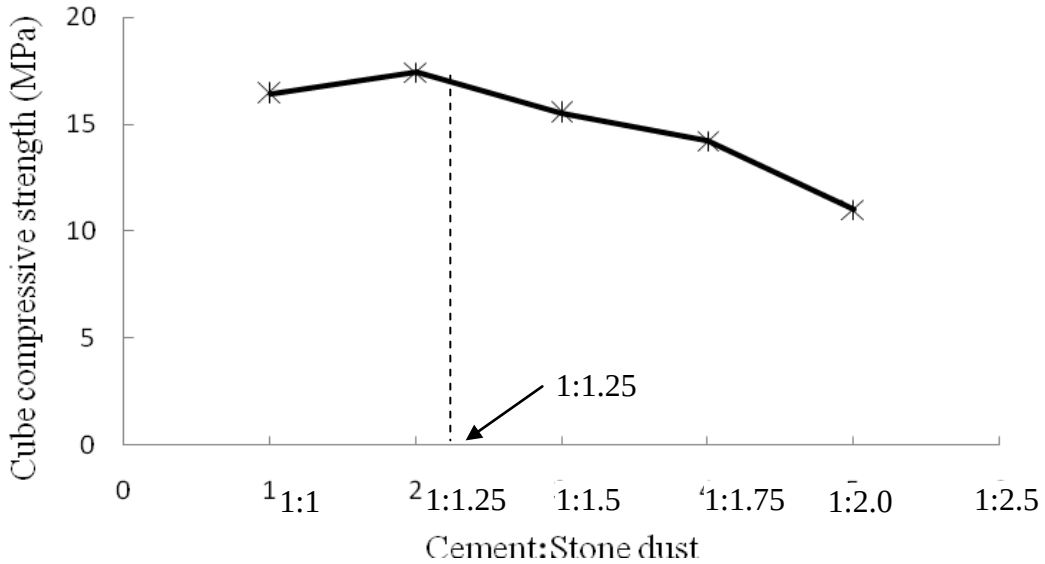


Figure 5: Variation of 7 days concrete compressive strength with cement:stone dust ratio.

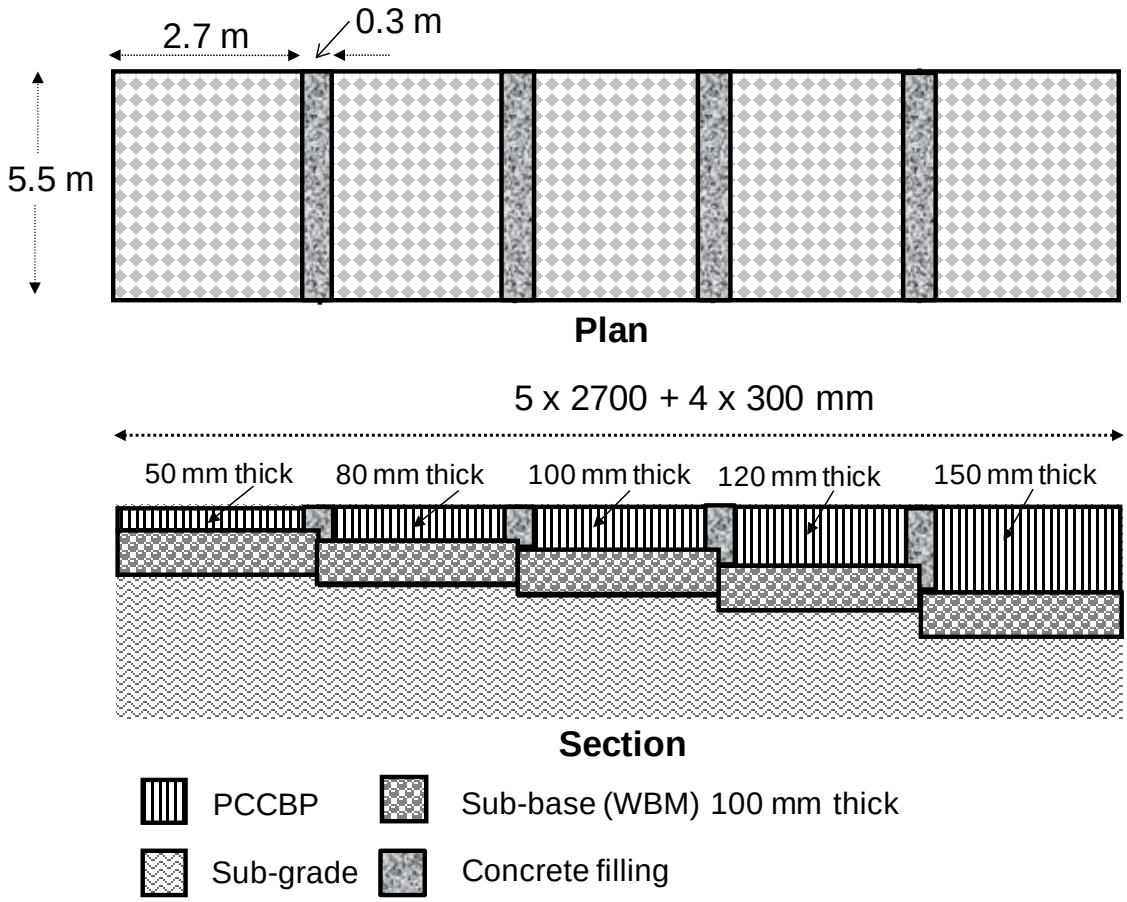


Figure 6: Schematic plan and sectional view of the test section showing different thickness of PCCBP.



Figure 7: Excavation and removal of the top layers of the existing bituminous pavement.



Figure 8: a) Laying, and b) Compaction of the WBM course.

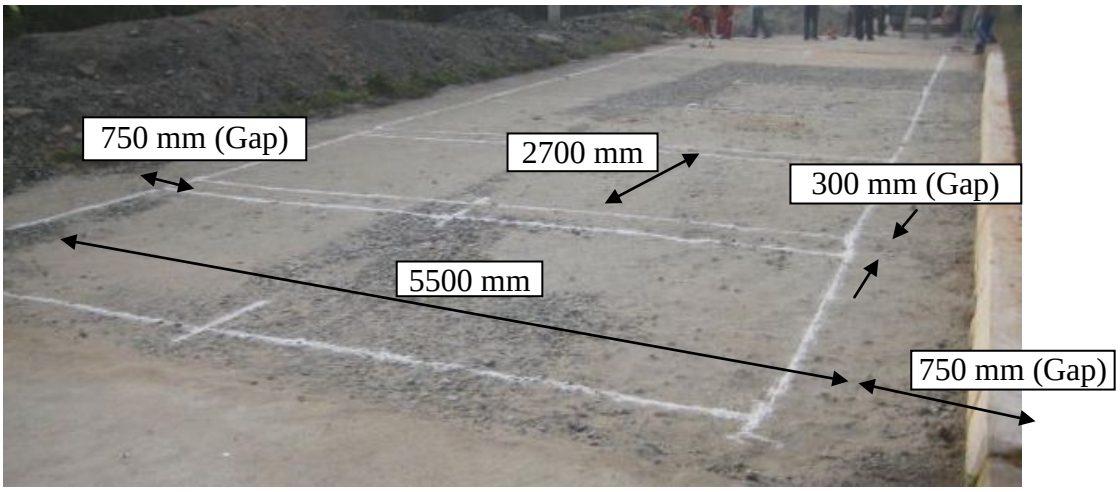
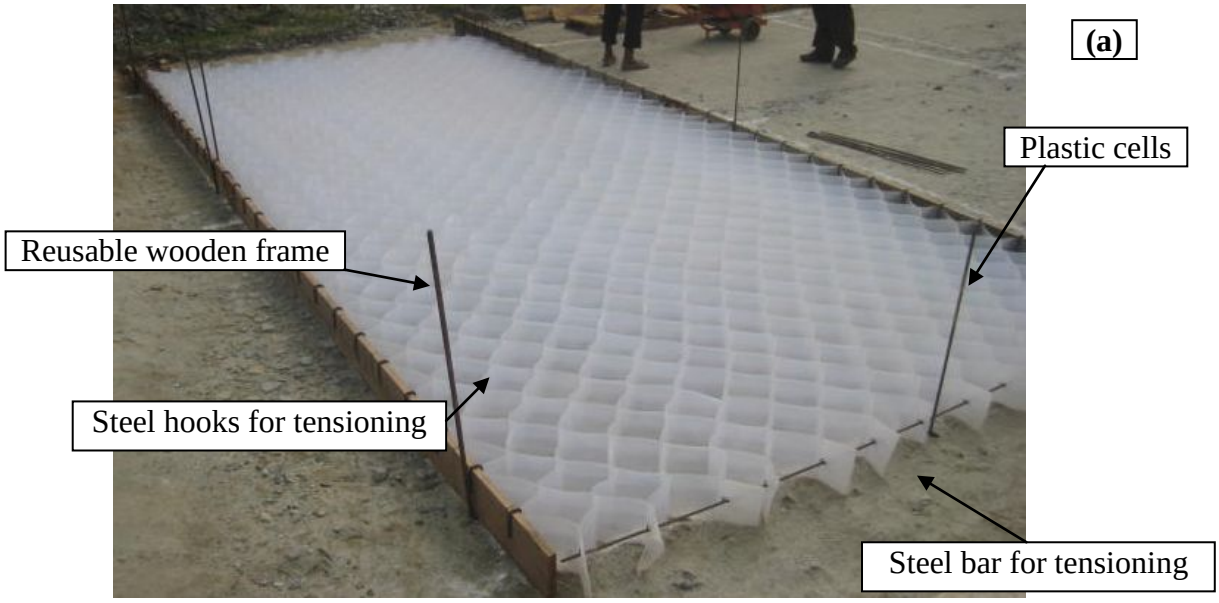


Figure 9: Layout for different sections of PCCBP.





(b)

Figure 10: a) Casting of the PCCBP, and b) Laying of plastic cell formwork for next PCCBP section.

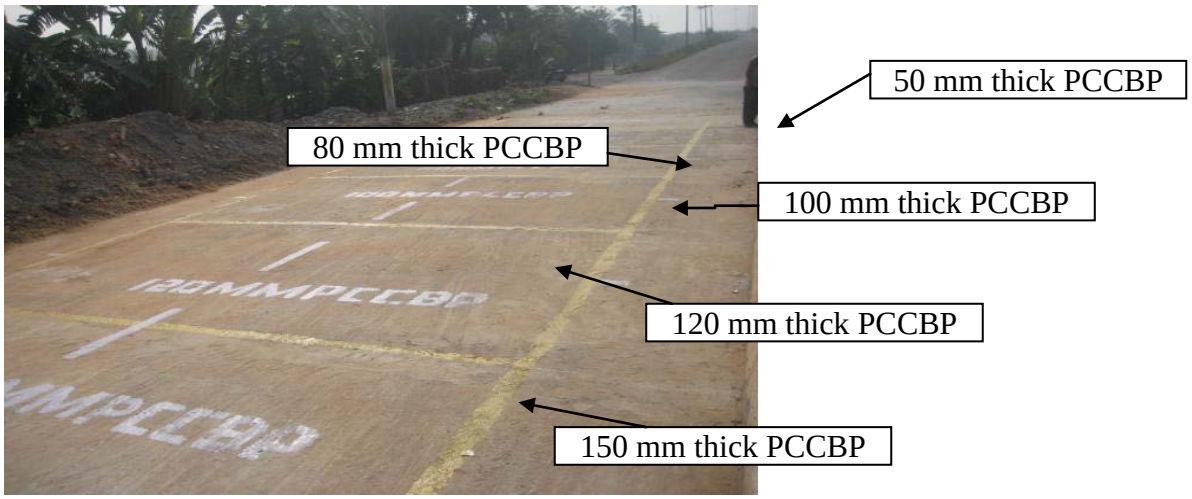


Figure 11: Completed PCCBP test road with markings for different test sections.



Figure 12: Completed PCCBP test opened to regular traffic.

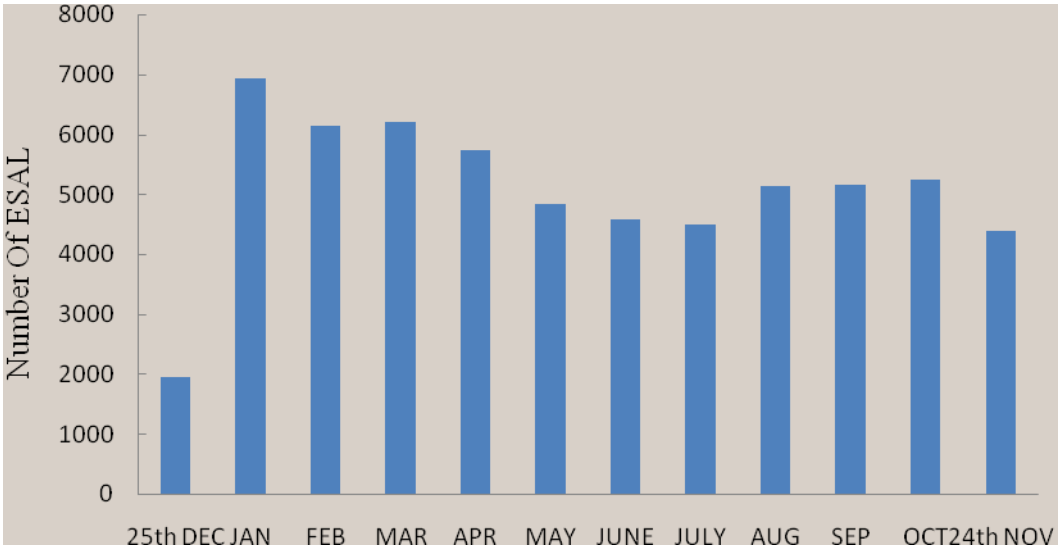


Figure 13: Monthly number of ESAL (Equivalent Single Axle Load) passing on the test pavement.

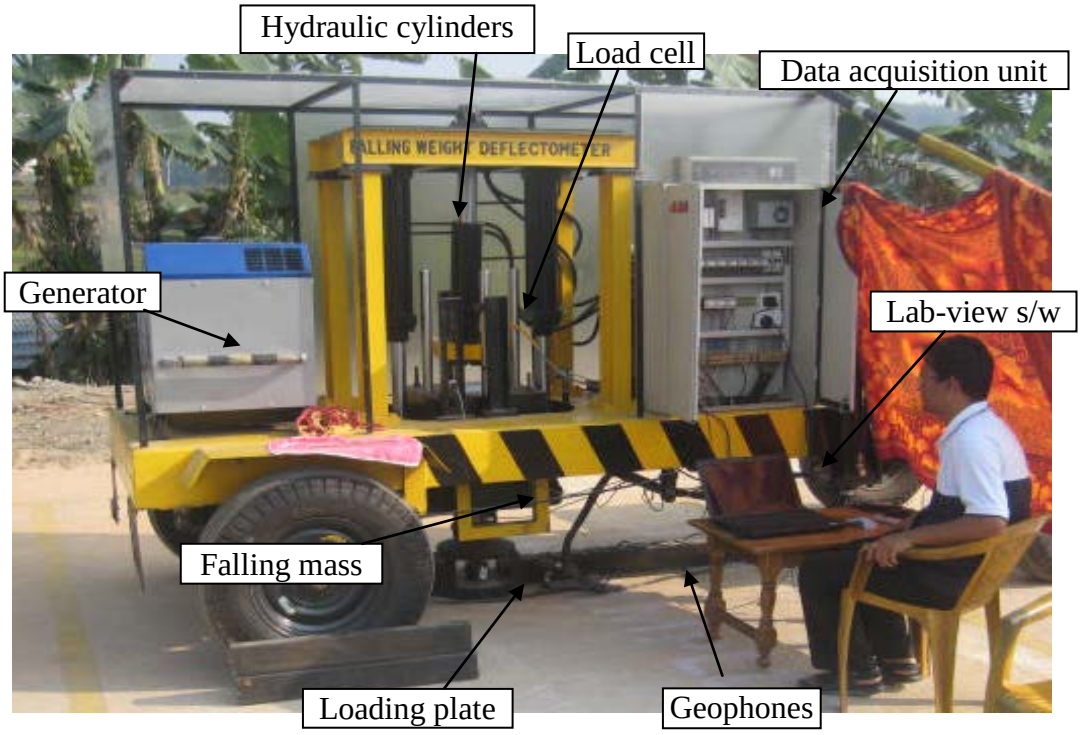


Figure 14: Custom fabricated FWD for the present study

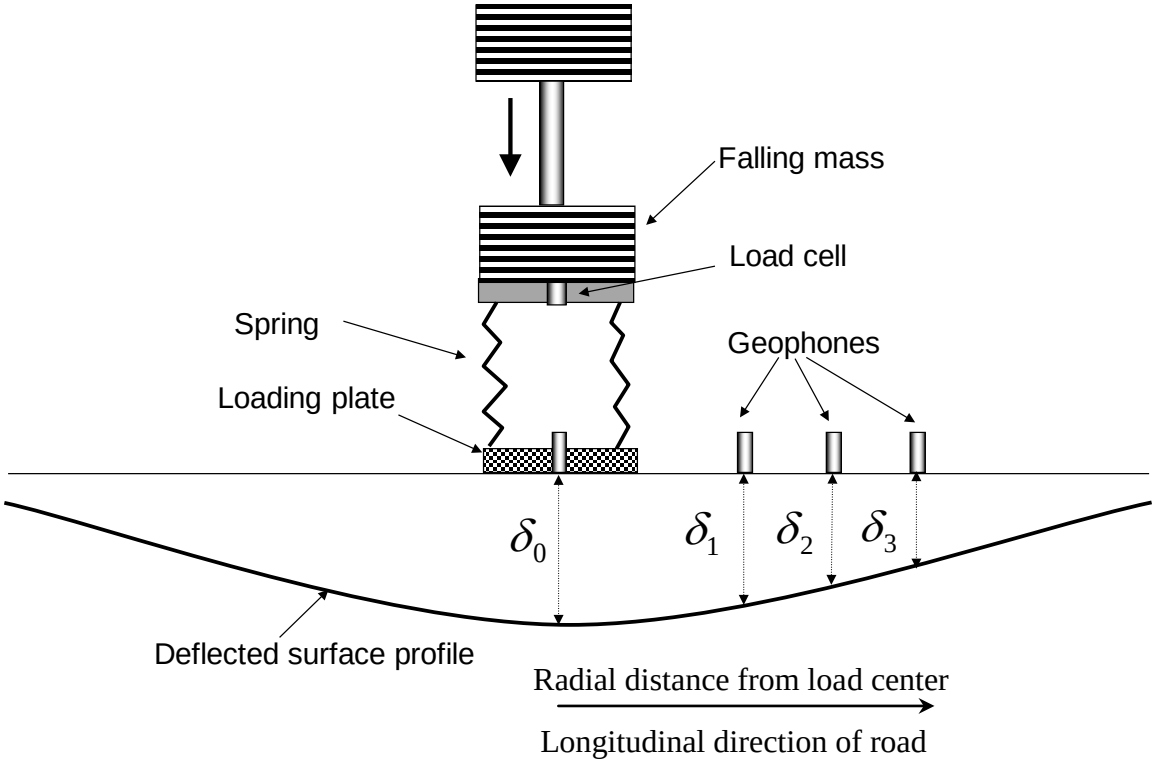


Figure 15: Schematic diagram showing surface deflection measurement using FWD at different radial distances from load.

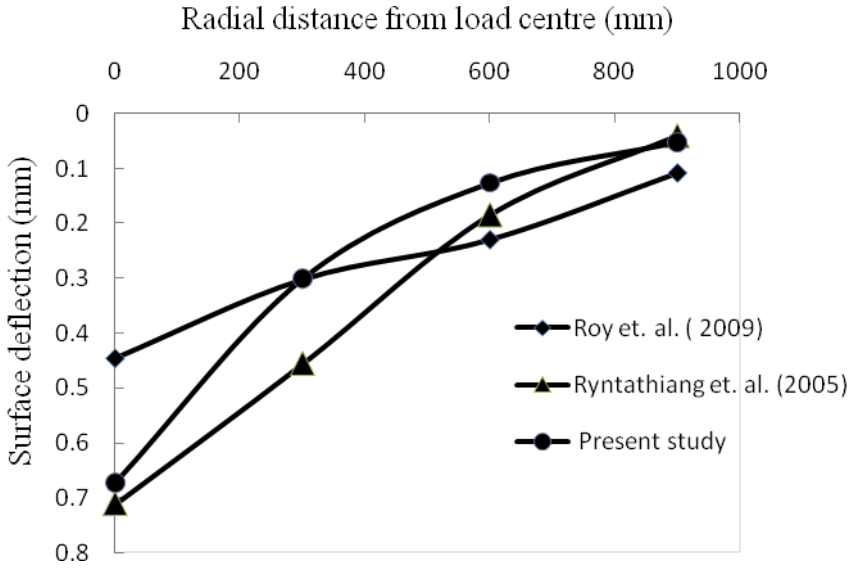


Figure 16: Comparison of the present study with similar studies on PCCBP (thickness equal to 100 mm) in India.

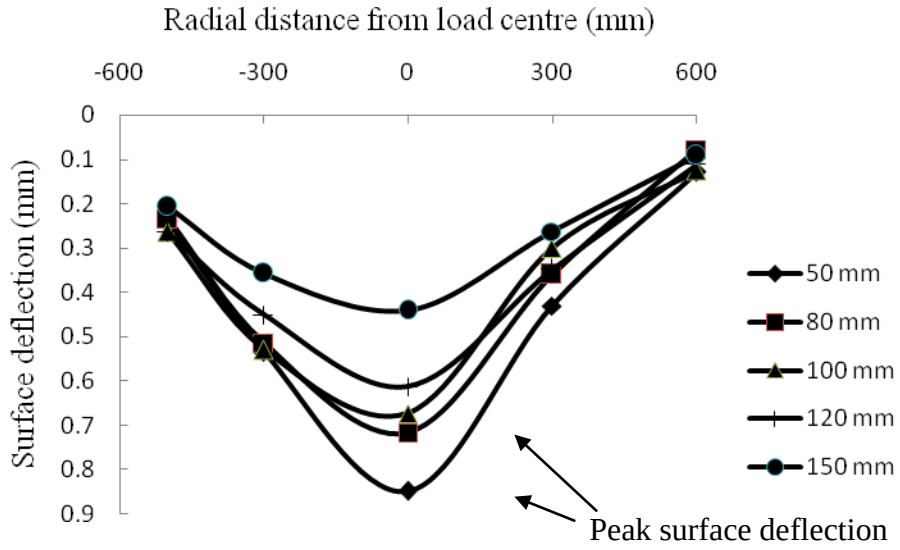


Figure 17: Surface deflection profiles for different thicknesses of PCCBP.

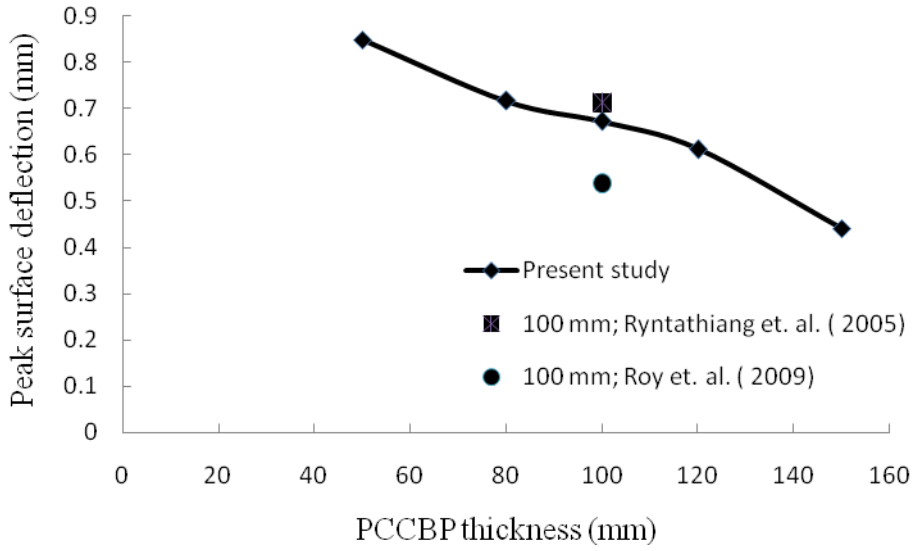


Figure 18: Variation of peak surface deflection with PCCBP thickness.

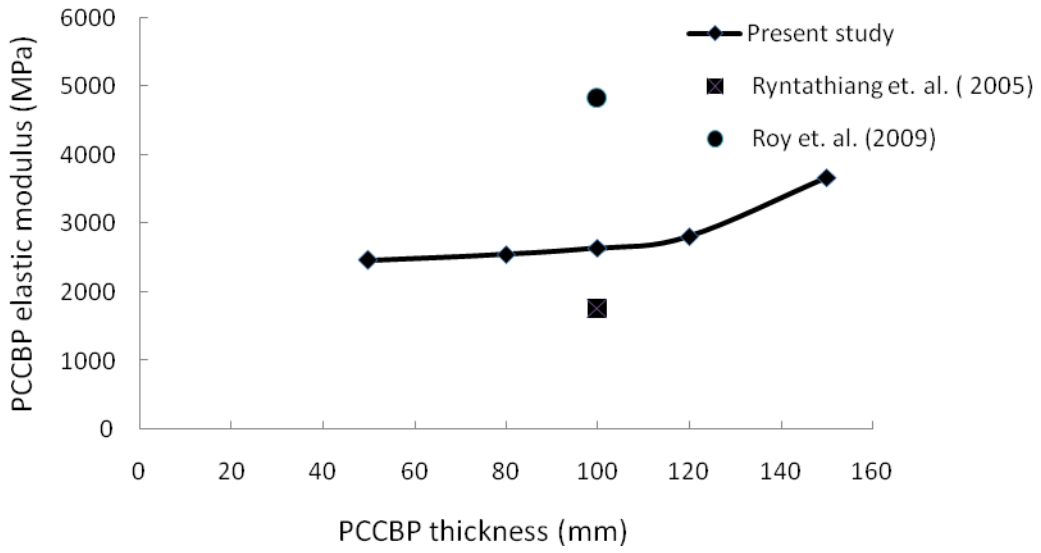


Figure 19: Variation of PCCBP elastic modulus with PCCBP thickness.

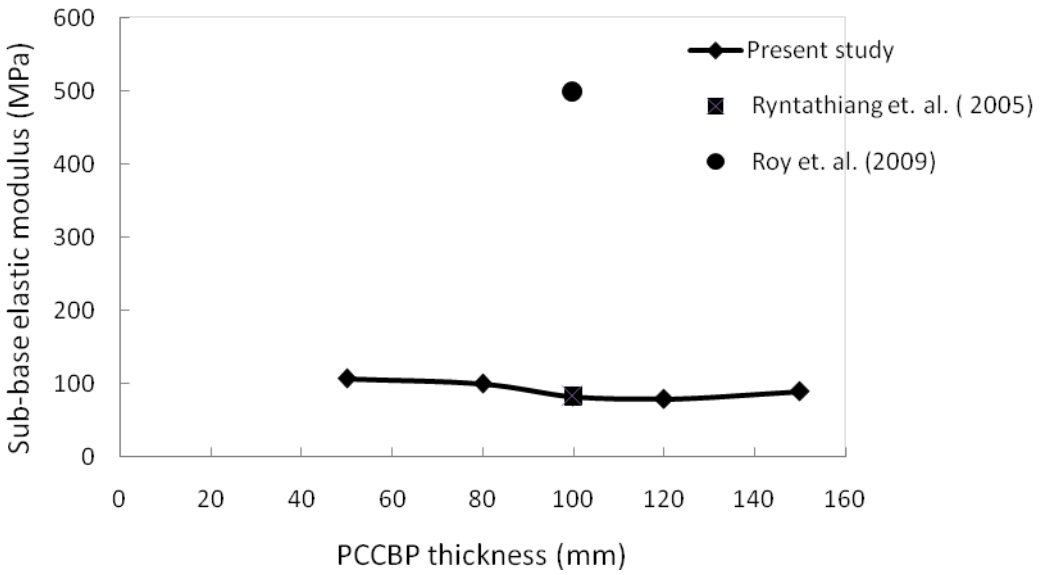


Figure 20: Variation of Sub-base elastic modulus with PCCBP thickness.

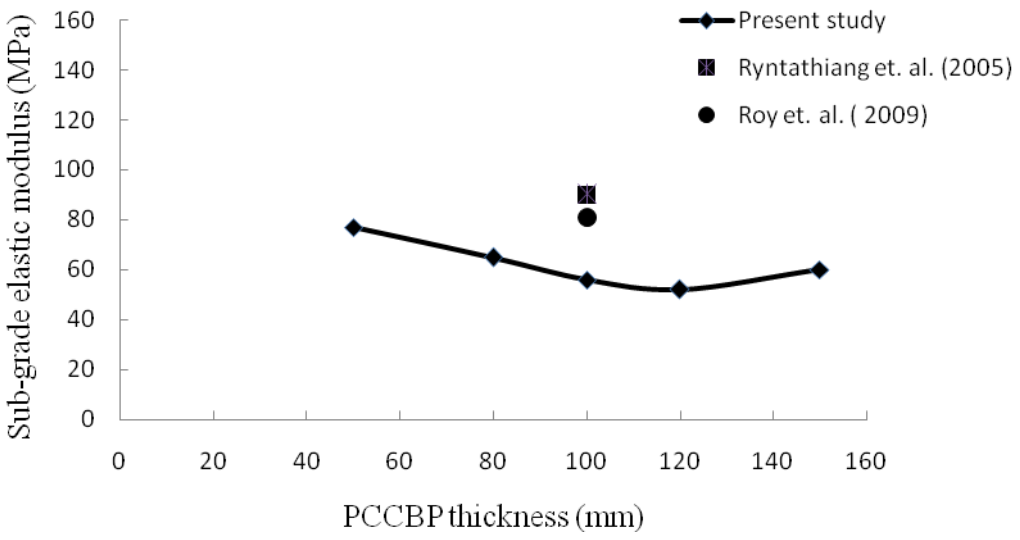


Figure 21: Variation of Sub-grade elastic modulus with PCCBP thickness.

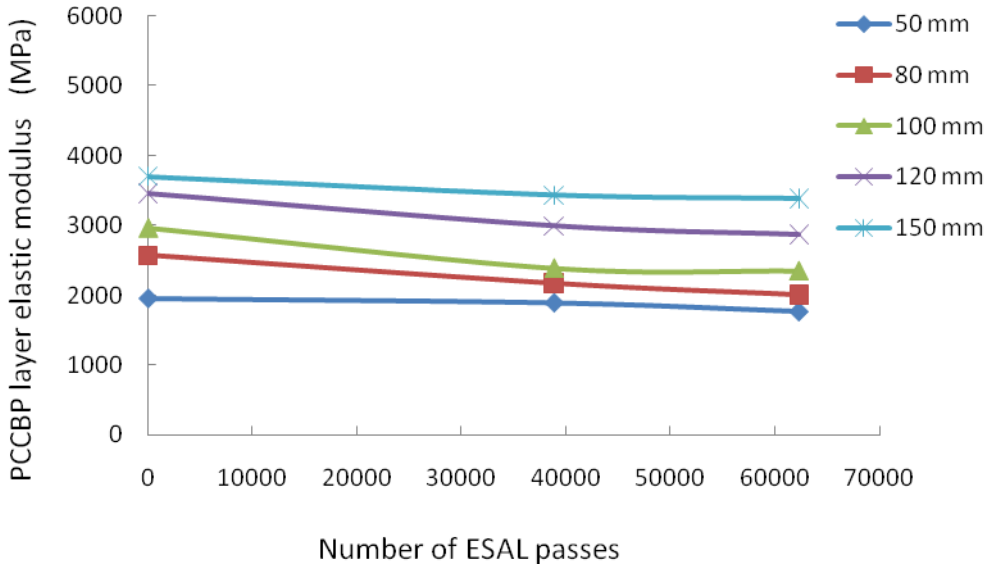


Figure 22: Variation of PCCBP elastic layer modulus with number of ESAL passes for different thicknesses of PCCBP.

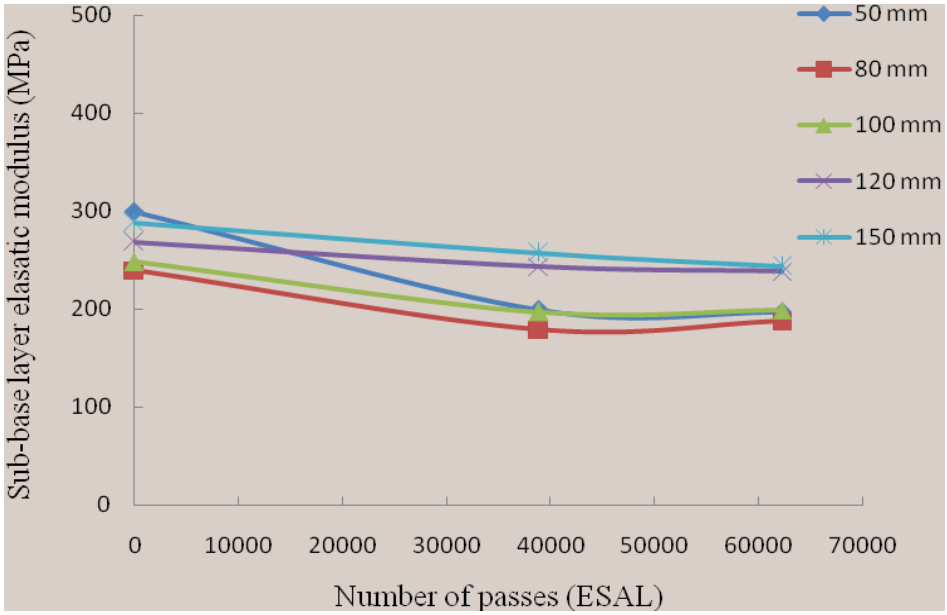


Figure 23: Variation of sub-base layer elastic modulus with number of passes (ESAL), for different thicknesses.

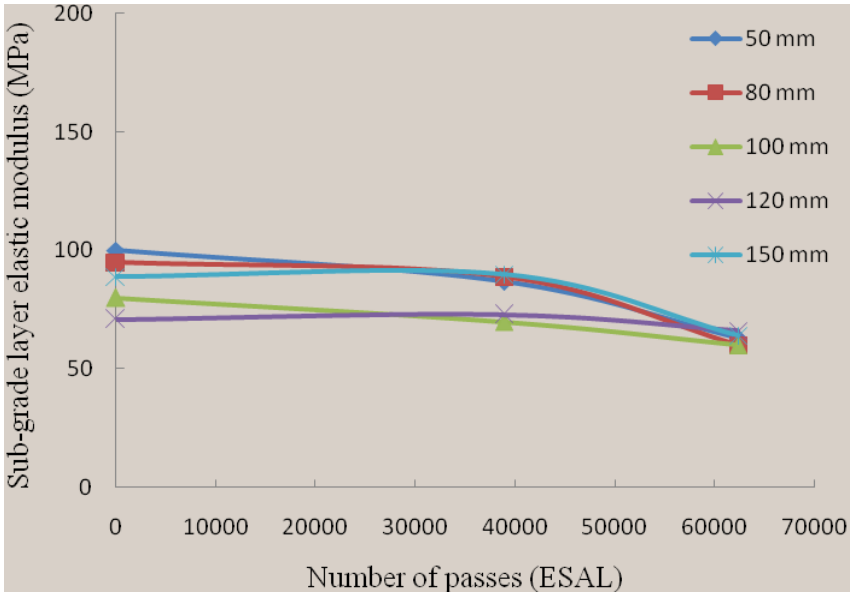


Figure 24: Variation of sub-grade layer elastic modulus with number of passes (ESAL), for different thicknesses.