

A Study on Plastic Cell Filled Concrete Block Pavement for Low Volume Rural Roads

A thesis submitted for the degree of Doctor of Philosophy

By

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Declaration

I hereby declare that the work embodied in this thesis entitled '***A Study on Plastic Cell Filled Concrete Block Pavement for Low Volume Rural Roads***' has been carried out by me in the Department of Civil Engineering, Indian Institute of Technology Guwahati, India, under the supervision of **Drs. Teiborlang Lyngdoh Rynthiang and Konjengbam Darunkumar Singh.**

In keeping with the scientific tradition, due acknowledgements have been made, wherever the work described is based on the findings of other investigators.

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Certificate

This is to certify that the thesis entitled '*A Study on Plastic Cell Filled Concrete Block Pavement for Low Volume Rural Roads*' being submitted by *Mr. Yendrebam Arunkumar Singh* to the *Indian Institute of Technology Guwahati, India* for the award of the degree of *Doctor of Philosophy* is a record of bonafide research work carried out by him under our supervision.

The thesis work, in our opinion is worthy of consideration for the award of degree of *Doctor of Philosophy* in accordance with the regulations of the Institute.

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To my brother
(L) Yendrembam Sonachand Singh



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Guwahati/Dated

Yendrembam Arunkumar Singh



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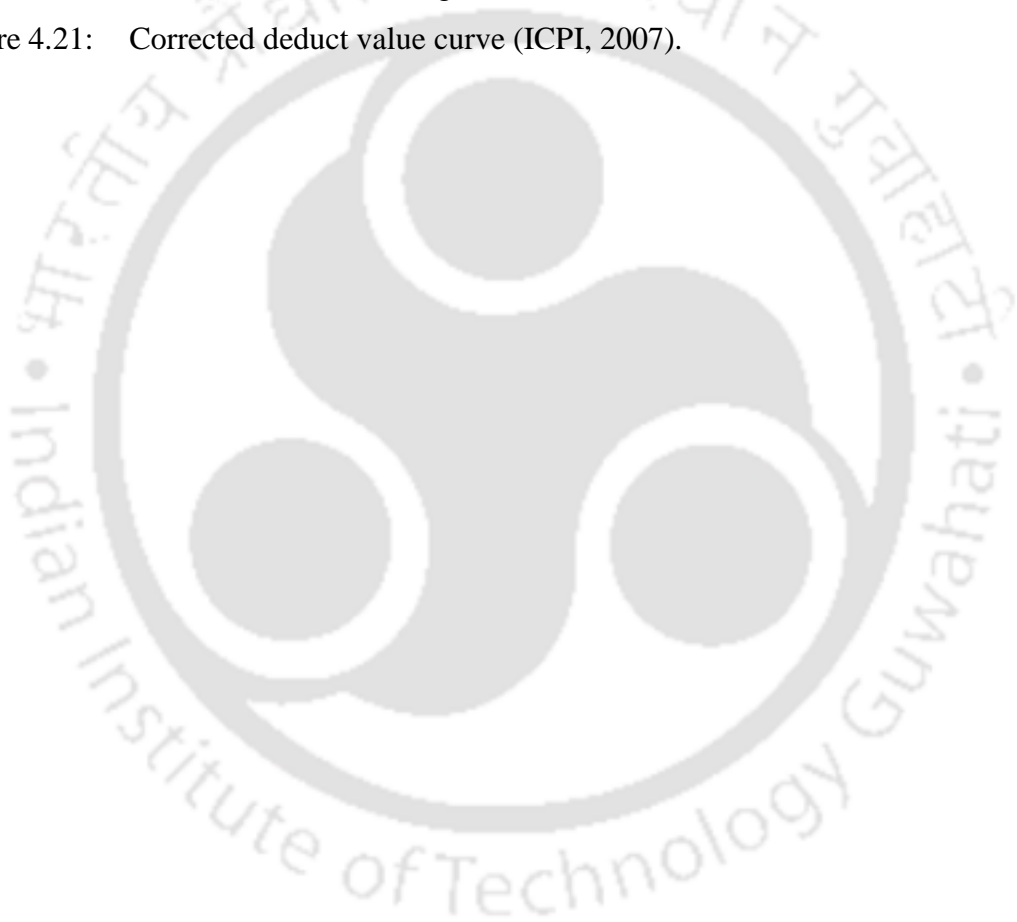
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Nomenclature

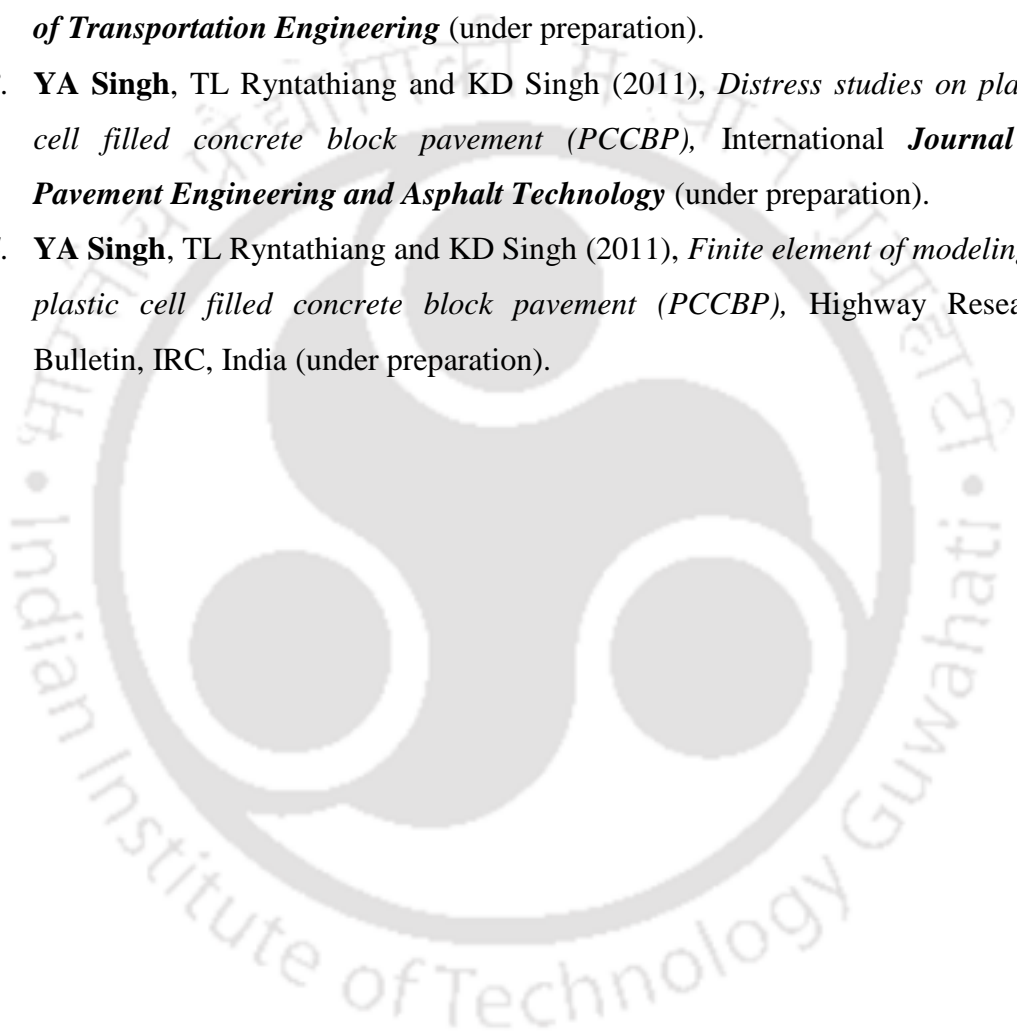
ϵ_z	Vertical Sub-grade Strain (micro strain)
AASHTO	American Association of State Highway and Transport Officials
AIM	Analog Input Modules
ANN	Artificial Neural Network
ASTM	American Society for Testing and Materials
BIS	Bureau of Indian Standards
CBR	California Bearing Ratio
DCP	Dynamic Cone Penetration
DD	Dry Density
DV	Deduct Value
CDV	Corrected Deduct Value
E	Elastic Modulus
$E_{\text{sub-base}}$	Layer Elastic Modulus for Sub-base
E_{subgrade}	Layer Elastic Modulus for Sub-grade
EPM	Electro Permanent Magnet
ESAL	Equivalent Single Axle Load
FE	Finite Element
FWD	Falling Weight Deflectometer
GA	Genetic Algorithm
HCV	Heavy Commercial Vehicle
ICPI	Interlocking Concrete Pavement Institute
IRC	Indian Road Congress
kN	Kilo Newton
LDPE	Low Density Polyethylene
MCV	Medium Commercial Vehicle
MDD	Multi Depth Deflectometer
MPa	Mega Pascles
NDT	Non Destructive Test
NH	National Highway

OMC	Optimum Moisture Content
PCCBP	Plastic Cell Concrete Block Pavement
PCI	Pavement Condition Index
PMGSY	Pradhan Mantri Gram Sadak Yojana
VDF	Vehicle Damage Factor
WBM	Water Bound Macadam



Publications based on the work in the thesis

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INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
DEPARTMENT OF CIVIL ENGINEERING

ABSTRACT

Doctor of Philosophy

A study on plastic cell filled concrete block pavement for low volume rural roads

By

Yendrebam Arunkumar Singh

A systematic full scale experimental study on the structural performance of Plastic Cell filled Concrete Block Pavement (PCCBP) for various cell thicknesses subjected to live traffic conditions is presented in this research work. Five test sections of different 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). In addition, to check the feasibility of PCCBP overlay to strengthen the existing old bituminous pavement, 50 mm thick PCCBP overlay test section was also constructed. 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. Custom fabricated Falling Weight Deflectometer (FWD) was used to evaluate the PCCBP by measuring the surface deflections at specified radial distance from the load center. In this work, 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. 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, surface deflections data using FWD were collected at regular intervals of 0 passes, 38,000 passes (~6 months) and 62,000 passes (~11 months). 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). It has also been seen that there is a significant improvement (~230% increase) in elastic layer modulus when PCCBP is used as overlay as compared to that of bituminous overlay.

Efforts have been made to assess pavement distresses of PCCBP test section using distress guidelines developed by Interlocking Concrete Pavement Institute (ICPI, 2007) based on Pavement Condition Index (PCI) for similar distress types observed. The distress type and severity level of each test section was recorded and PCI value of each section was calculated using the deduct curves given in the distress manual. From the PCI value, the rating of the test section was found to be in the range from Fair to Very Good condition even after a load repetition of 62,000 ESAL passes. Specific distresses observed for PCCBP are also reported. From the feasibility study of PCCBP overlay, it was observed that the performance is Excellent even after 62,000 ESAL passes.

Economic evaluation of PCCBP vis-a-vis conventional flexible and rigid pavements was also carried out. In the absence of design guidelines for PCCBP, rutting criteria as per IRC (2001) was adopted to design the PCCBP pavement. Conventional flexible and rigid pavements were design as per IRC (2007) and IRC (2004). The construction and maintenance cost were estimated based on Government of Assam schedule rate 2007-08 (PWD, 2007) and guidelines for the estimation of the maintenance cost for construction of the rural roads (IRC, 2002; PMGSY, 2010). Suitable cost escalation factor to bring to the year 2010 market rate were considered based on monthly wholesale price index (OEA, 2010). Economic evaluation (considering construction cost and maintenance cost for 5 years) shows that cost of flexible and rigid pavements are higher by ~43% and ~141% respectively as compared to that of PCCBP. Hence, PCCBP with waste stone dust as replacement for the traditional river sand for both concrete and WBM can be an economical option for rural roads.

CHAPTER 1

Introduction

1.1 General

Designing sustainable rural roads with reasonable riding quality and low life cycle cost has always been one of the major challenges for pavement engineers and researchers. The research effort in this direction has become far-reaching pertinent in India as the share of low volume (< one million Equivalent Single Axle Loads (ESAL) in a life cycle as per IRC, 2007 and AASHTO, 1993) rural road is about 80% of the total road length (NHAI, 2011). Whilst conventional flexible pavement 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 Rynthathiang, 2005) provides more flexible response (depending upon the dilatancy 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 (see Figure 1.1) is 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 (see Figure 1.2). Flexibility is induced into cement bound (rigid) surface and Visser (1999) termed these pavements as “Flexible Concrete Pavements”. Whereas, in the case of pre-cast concrete block pavements, concrete pavers are set in bedding sand and the spaces between the individual paving units is filled with clean quality joint sands, PCCBP are cast-in-situ concrete blocks where there is interlocking between the individual blocks with plastic between the blocks. The PCCBP has good load spreading capacity with competitive lifecycle cost with conventional pavement types (Visser, 1994, 1999). Although construction of PCCBP can be mechanized, significant amount of hand labour may be utilized making it labour intensive with possibilities of generating employment opportunities for the rural inhabitants.

In India, limited studies on PCCBP technology have been reported by 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). A 50 mm thick PCCBP overlay is also constructed on the existing old bituminous surface to explore the possibility of PCCBP as overlay and to compare it with the bituminous overlay which was constructed (three) months ahead by other agency. 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). In additional, attempts have also been made to carry out distress studies of PCCBP test sections based on pavement condition index (PCI) methodology. Economic evaluation of PCCBP vis-a-vis conventional flexible and concrete pavements was also carried in order to know the advantages of constructing rural roads with PCCBP over the conventional flexible and rigid pavements.

1.2 Objectives

The main objectives of the present study are:

1. To evaluate structural behavior of different thicknesses of PCCBP (using waste stone dust as fine aggregates) over 100 mm thick water bound macadam (WBM) sub-base.
2. To explore the possibility of laying PCCBP as overlay on existing old bituminous pavement.

3. To study the various distresses of PCCBP based on pavement condition index.
4. Economic assessment of PCCBP vis-a-vis conventional flexible and rigid pavements.

1.3 Thesis organization

The thesis consists of seven chapters as mentioned below:

- An introduction to PCCBP along with a brief description about various chapters of the thesis is presented in Chapter 1. The key objectives of the study are also enumerated in the same chapter.
- In Chapter 2, a review of relevant work carried out by different researchers on PCCBP, stone dust as a replacement of sand in concrete and distress studies on PCCBP have been presented.
- Field investigations on structural behavior of different thicknesses and overlay (over existing old bituminous pavement) PCCBP constructions have been discussed in Chapter 3. Variations in layer moduli of PCCBP with traffic passes are also presented.
- Chapter 4 describes the distress studies of the PCCBP test sections with traffic passes.
- Economic evaluation of PCCBP vis-a-vis conventional flexible and concrete pavement is presented in Chapter 5.
- Summary and conclusions of the present study are presented in Chapter 6.
- Recommendations for possible future work are presented in Chapter 7.

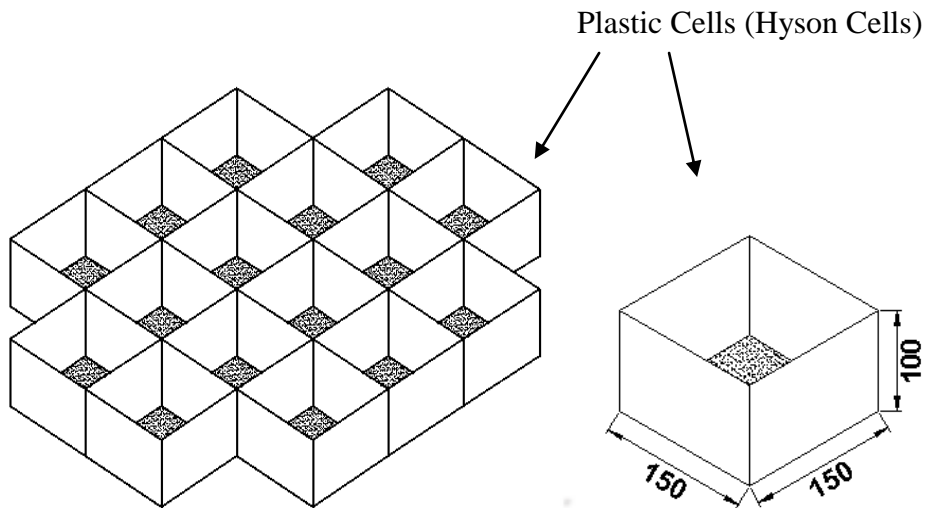


Figure 1.1: Schematic diagram of typical plastic cells (Hyson cells) formwork with pocket size 150 mm x 150 mm.

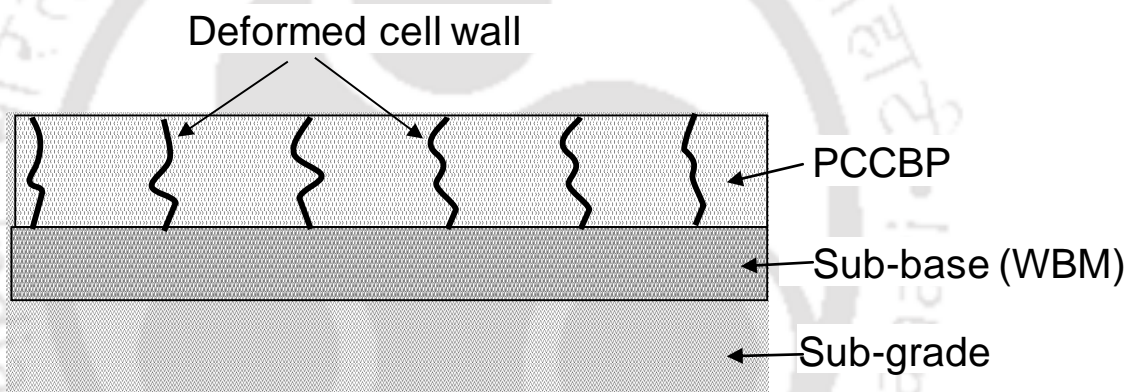


Figure 1.2: Schematic diagram of deformed cell walls resulting in interlocking of PCCBP.

CHAPTER 2

Literature Review

2.1 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. As mentioned in Chapter 1, with rural roads constituting bulk of the total road length in India (NHAI, 2011), it has become important to explore innovative cost-effective (without compromising performance) pavement technology with a good load spreading capacity and long life. In this context, PCCBP which is a flexible concrete block pavement using a locally developed welded plastic cell (Hyson-cells) pioneered by Visser (1994) can be a promising alternative for low volume rural roads where highly mechanized construction and strict quality control may not be possible. The technology has not been used by any other investigators throughout the world except some limited studies carried out in India (Roy *et. al.*, 2009, 2010, Sahoo *et. al.*, 2006 and Ryntathiang, 2005). The following sections provide an introduction on low volume roads followed by review of literatures pertaining to PCCBP. Reviews of using stone dust as fine aggregates in concrete are also discussed. In the absence of any prior systematic studies on distresses of PCCBP, reviews on relevant distresses studies on pre-cast interlocking concrete block pavements are addressed.

2.2 Low Volume Rural Roads – definition

In India, Other District Roads (ODR) and Village Roads (VR) are considered to be rural roads and the traffic volume on these roads is comparatively low; however as mentioned in Chapter 1, they constitute about 80% of the total road network (~ 3.34 million km (MORT&H, 2011)). The traffic on rural roads mostly comprises of two wheelers, three wheelers (Sinha, 2010), with tractor-trailer transporting farm products constituting major commercial traffic (Roy *et al.*, 2010). These roads are short in length and connect homes and farms to nearby markets, and forest and mines to mills. These roads also provide public access to essential health, education, civic and outdoor recreational facilities, and link to the highway transportation system. In the literature, several definitions of low volume rural roads are given based on maximum traffic flow in terms of vehicles per day. Gourley and Greening (1999) defined low volume roads to be those with an average daily traffic of less than 200 vehicles per day with an upper bound of 1 million ESAL during their life of 20 years. However, according to Gerald (2010), AASHTO (1993), Federal Highway Administration (FHWA, 1992), Sawanson (1994), the maximum average daily traffic are set at 400, 400, 500, 300-1700 respectively. Thus it can be seen that there are multitudes of maximum limit of average traffic proposed by various researchers for low volume roads. As per Indian Road Congress (IRC, 2007), considering a design life of 10 (ten) years, the maximum number of ESAL applications considered for design of low volume rural roads is 1 million ESAL applications.

2.3 Plastic Cell Filled Concrete Block Pavement

2.3.1 Review of previous work carried out in South Africa

Initial investigations on the possibility of placing the PCCBP (plastic cell concrete slab) directly on the compacted in-situ soil was attempted by Visser (1994) by studying the load transferring capability of a 1200 mm by 800 mm cell slab over 20 mm thick rubber mats, having different shore hardness of 38, 50 and 70. The load

transferring capability of different thicknesses of slab of 50, 75, 100 and 150 mm were tested under an applied load of 40 kN load (legal dual wheel load) on a 300 mm diameter load plate. The slabs were cast in the plastic cell formwork and tested after three weeks. It was observed that the equivalent elastic modulus of cell slab, found out using a linear elastic program code, ELSYM (Visser, 1994), showed decreasing trend with decrease in slab thickness. The lowest value corresponding to the 50 mm thick slab was 100 MPa. The stiffness of the slab with greater resilience rubber mat was found to be higher than that with lesser resilience. Further, good load spreading capability (slab action) through interlocking between blocks was also reported.

Visser and Hall (1999) carried out experimental tests to develop a design catalogue for PCCBP for low volume roads. Based on the success of laboratory tests, three field trial sections were constructed using grouting method on a road carrying 300 laden five axle trucks daily. In the grouting method, plastic cell formworks were spread and tensioned over the foundation layer and cells were filled with coarse aggregates and mortar was vibrated into the voids between coarse aggregates (e.g., using a plate vibrator). The sections were constructed on compacted granite unpaved road having wearing course thickness of 250 mm and in situ California Bearing Ratio (CBR) of 150%. Based on the performance of the field test with 150 mm thick PCCBP using cement: sand ratio of 1:1, it was concluded that for heavy traffic the concrete compressive strength of 15 MPa was adequate for opening to normal traffic and for light traffic the road can be open within 24 hours. Tests were also conducted by placing 150 mm thick PCCBP on compacted Kalahari sand using single size 50 mm round river pebbles grouted with a similar 1:1 cement : sand and observed that the test pavement served well even after 4 years compared to conventional concrete pavement which deteriorates after 2 years of service. Further field trial with 50 mm thick PCCBP with a similar mix was found that it performed well, and hence suggested that 50 mm thick PCCBP could be used for lightly traffic access roads. The economic evaluation showed that PCCBP is highly competitive with flexible pavement and more economical than block pavement. Design guide and catalogue for low volume streets based on type of street, traffic loading, material considerations, environment, etc. was also proposed.

Visser (1999) evaluated the performance of PCCBP under ultra heavy traffic condition up to 100 tonnes axle loads, by constructing test sections with Reddy mix concrete of compressive strength of 49 MPa (28th day). The test sections were subjected to traffic by trucks and reach stackers. Structural responses of different layers of test panels were monitored using multi depth deflectometers (MDD). It was concluded that although 100 mm thick PCCBP layer can be structurally adequate for ultra heavy loading condition, 150 mm layer would be preferred. The PCCBP blocks were left unaffected when tested using turning wheel of reachstacker and point loads of stacked containers, thereby showing the three dimensional interlocking behavior. Laser level survey showed limited permanent deformations (~ 3 – 6 mm) for PCCBP with stronger underlying layers of mine sand and 53 mm crushed stone suggesting that PCCBP can be an option even for ultra heavy traffic.

Visser and Hall (2003) observed that an increase of stiffness of the PCCBP layer with increasing support layer (i.e., sub-grade layer) stiffness. A linear relationship between the thickness of the PCCBP layer and logarithm of the slab stiffness was also proposed for a given support stiffness. For a support stiffness of 20 MPa the relationship was found to be:

$$\ln(\text{PCCBP stiffness in MPa}) = 0.012(\text{slab thickness in mm}) + 2.852 \quad (2.1)$$

Structural design catalogue was also proposed based on the relationship between vertical sub-grade strain and stiffness of soil for a range of PCCBP thickness. It is also reported that the cost saving in the road construction using PCCBP was up to 50% and no maintenance was required for eight years, suggesting that its adequacy for low volume roads. Using this PCCBP technique Visser and Hall (2003) made a significant contribution in improving the quality of life of rural communities particularly in remote and often poor regions of South Africa.

2.3.2 Review of previous work carried out in India

In India, the first attempt on the study of PCCBP was made by Rynthiang (2005) by investigating its structural performance in the laboratory. Rynthiang (2005) adopted grouting technique for casting 75 mm thick PCCBP and premix technique for casting 100 mm thick PCCBP. It was observed that sufficient compressive strength for resisting the damaging action of low volume traffic could be obtained after seven days of casting, using a mix of 1:1.5 cement:sand (by volume). The mix made up of premixed cement, sand and coarse aggregates was found to have higher seven days compressive cube strength than grouting cement sand mortar into the voids of coarse aggregates. Core sample from the test pavements showed that premixed concrete had less voids than the grouted concrete blocks. It was also observed that PCCBP of thickness 100 mm had better interlocked faces than the 75 mm blocks. Accelerated test on blocks have shown rutting as low as 3 mm after 11,000 repetitions of standard 80 kN for 75 mm thick blocks. The moduli for 75 mm and 100 mm PCCBP layer were obtained as 2995 MPa and 2542 MPa respectively. Economic evaluation of PCCBP vis-à-vis conventional flexible and pre-cast concrete block pavement shows that conventional flexible pavement is 1.22 times the cost of pre-cast concrete block pavement and 1.62 times PCCBP.

Sahoo *et. al.*, (2006) constructed 250 meter long PCCBP pavement over 150 mm compacted thickness of moorum sub-base to test its feasibility on field for low volume roads. The premixed cement concrete mix used for filling the pockets of plastic cell was mixed in the proportion 1:1.5:3 (cement: fine aggregate: coarse aggregate) by volume. The result obtained from the investigation showed that the elastic modulus of cell filled concrete layer were in the range 2486 to 6850 MPa and that of foundation layer (sub-base and sub-grade) were in the range 123 to 161 MPa which are sufficiently high for low volume roads.

Roy *et. al.*, (2009) constructed four test sections each of size 2.5 m x 2.5 m to study the behavior of roller compacted cell filled concrete pavement over moorum and laterite boulders as sub-base layers. The different test sections consisted of 1) 100 mm

thick PCCBP layer filled with roller compacted concrete laid over 150 mm thick moorum sub-base, 2) 100 mm thick PCCBP layer filled with roller compacted concrete laid over 150 mm thick laterite boulder sub-base, 3) 150 mm thick PCCBP layer filled with 110 mm thick soil-cement and 40 mm thick with cement concrete laid over 100 mm thick moorum sub-base, 4) 150 mm thick PCCBP layer filled with 110 mm thick sand-cement and 40 mm thick with cement concrete laid over 100 mm thick moorum sub-base. The layer moduli of cell pavement were found to be sufficiently high (~1215-4969 MPa), suggesting that soil-cement and sand-cement with a topping of thin roller compacted concrete can serve as strong pavement.

Roy *et al.*, (2010) investigated the structural performance of PCCBP placed over 1) soil-cement, and 2) sand-cement laid over a) moorum and b) soil-cement; using thin recycled plastic as cell walls and roller compacted concrete. It was found that moduli values of the surface layer was in the range ~ 1524 – 6014 MPa, the highest being associated with 100 mm thick PCCBP over 100 mm thick soil cement (10% cement by weight of dry soil) base course. The pavements were tested on simulated village traffic (~1500 passes of loaded truck equivalent to 3 years of village traffic) and found that no distress signs and negligible rutting (~1.91 mm), suggesting that such construction could be a cost effective proposition for locations with scarcity of aggregates. Based on the long term performance considering FWD test results and live traffic condition, of the field tests (100 mm thick cell filled pavement laid over 100 mm compacted moorum) for five years under heavy rainfall condition, it was found that the PCCBP showed excellent performance.

To economize the cost of construction Shivaprakash (2011) adopted a dual-layer concreting method by placing a lower strength (concrete compressive strength = 10 MPa) below a higher strength concrete (concrete compressive strength = 30 MPa) into the same PCCBP cell of 100 mm thickness; for a pilot project of a village road of length = 40 km.

2.4 PCCBP as Overlay Construction

Plessis and Visser (2001) investigated the behavior of PCCBP overlay placed on the deteriorated Portland cement concrete container terminal pavement. An experimental section of 500 m² at City Deep container terminal consisting of 300 mm thick concrete pavement (heavy duty pavement) was selected for overlaying with PCCBP of thicknesses 150 mm and 200 mm. The selected section had been in service for about 20 years and shows severe cracking. It was observed that both the thicknesses showed significant reduction in deflection and strain (with 200 mm thick showing lower values of deflection and strain) as compared to the section without overlay under similar load condition. The author concluded that the hypothesis that cell filled concrete overlay leads to improve behavior of the pavement is accepted. A significant improvement of the overlaid pavements life to 38 and 158 million reach stacker repetitions were observed in the 150 mm and 200 mm overlay section respectively.

2.5 Stone dust as replacement of sand in concrete

In order to optimize cost of construction and to solve the scarcity of river sand in the remote villages, an effort has been made to replace river sand with waste stone dust in concrete production. Different researchers (Sahu *et. al.*, (2003), river sand with stone dust; Reddy and Reddy (2007), river sand with rock flour; Safiuddin *et. al.*, (2007), natural sand with quarry waste fines etc.) reported possibilities of replacement of sand in concrete. A review of previous works on the replacement of sand in concrete and its effect of fresh and harden properties of concrete is presented in this section.

Sahu *et. al.*, (2003) carried out suitability of partial and fully replacement of natural sand in concrete with crusher stone dust. Based on two types of fine aggregates i.e., 20% and 40% replacement of river sand with stone dust, it was observed that there is a significant increase in compressive strength, modulus of rupture and split tensile strength. However, it was reported that addition of stone dust decreased the workability of concrete mix significantly.

Reddy and Reddy (2007) carried out laboratory investigations on rock flour as replacement of sand and ceramic scrap as replacement of coarse aggregates in

concrete. It was observed that rock flour can be effectively used as full replacement of river sand in concrete resulting in increase of compressive strength, split tensile strength and modulus of rupture.

Safiuddin *et. al.*, (2007) tested fresh and harden state of concrete by 20% replacement of natural river sand with quarry waste fine aggregates. The test result showed that quarry waste fine aggregates enhanced the slump and slump flow of the concrete. The use of quarry waste fine aggregates marginally improved the dynamic modulus of elasticity of concrete due to reduced difference between moduli of aggregates and hydrated cement paste. However, a decrease in the compressive strength of concrete by 7% to 9% was observed.

Ilangovana *et. al.*, (2008) conducted test on concrete cubes for full replacement of natural sand with quarry rock dust in concrete. Durability study was carried out to investigate the drying and shrinkage studies, deterioration, and water absorption for both conventional concrete and quarry rock dust concrete as per codal provisions. It was observed that physical and chemical properties of quarry rock dust satisfies code provisions of fine aggregates and gives equal or better (an increase of 10 to 15 percent) compressive and flexural strength of concrete. The overall workability and permeability value of quarry rock dust concrete was found to be less compared to conventional concrete.

Manasseh, J., (2010) carried out laboratory test on fresh and harden concrete to replace river sand with crushed granite fines (CGF) for use in concrete pavement. The compressive and tensile strength values of 40.70 N/mm² and 2.30 N/ mm² respectively were obtained, with the partial replacement of river sand with 20% CGF, as against values of 35.00 N/mm² and 1.75 N/ mm², obtained using river sand as fine aggregates in concrete production.

2.6 Distresses in PCCBP

To obtain a composite indicator of pavement deterioration caused by loading, construction shortcomings, environmental causes, etc., Pavement Condition Index (PCI) methodology is generally adopted (e.g., ASTM, 2009, 2010, Hein and Burak, 2007, 2009, ICPI, 2007). ASTM (2009) defines PCI as a numerical rating that ranges from 0 – 100 with 0 being the worst possible condition and 100 being the best possible condition of pavement. Based on the specific distress types, in the past, several pavement management tools were developed by Shackel (1998), Geller (1996), Rada (1993), Netherlands (1993) etc., however the PCI assessment for asphalt (flexible) and concrete pavement evaluation published by US Army Construction Engineering Research Laboratory in the 1970s for US Air Force (Shahin, 1994) became one of the most popular and widely used guidelines. These procedures were adopted by American Public Works Association, Federal Aviation Administration, and with modification for collecting data by ASTM (2009).

The pavement condition evaluation guidelines for flexible and rigid pavements proposed by US Army Corps of Engineers (MicroPaver distress guide) were adapted by Interlocking Concrete Institute (ICPI, 2007, Hein and Burak, 2009) for interlocking concrete pavements. The guidelines include 1) preparation of detailed survey for types of distresses with photographs, 2) determination of the influence of each of the distresses on the pavement performance through consultation with industry and design engineers, 3) computation of ‘deduct’ values based on influence functions for each distress type and severity, and 4) calculation of overall pavement condition index (PCI) by summing all the ‘deduct’ values. Shackel (1998) developed pavement management system for interlocking concrete block pavement in Australia by considering five primary distress types: rutting, horizontal creep, spalling, cracking and slippage and suggested that other distress like joint width, staining etc may insufficiently affect the performance of the pavement. In the Australian methodology, the individual distresses are categorized and quantified, multiplied by their individual weight and extent and then summed to determine an overall ‘deduct value’. This deduct value is then subtracted from 100 to determined the overall PCI. ICPI (2000) adapted a distress measuring system proposed by Stephanos and Rada (1992), and identified several interlocking concrete block pavement distresses such as

1) loss of sand in joints, 2) inconsistent joint widths, 3) corner or edge Spalling, 4) cracked blocks, 5) joint seal damage, 6) disintegration, 7) depression, 8) settlement or faulting. Each distress is identified by type with severity rating ranging from low to high. ICPI (2000) further adapted the work done by Stephanos to develop an overall pavement condition index for interlocking concrete pavements. For each distress, deduct values were assigned to three levels of severities based on the type of distress and its expected impact on the overall pavement condition. The density level of distress was based rather five levels of distress density viz., 1) few – up to 5 % of the surface, 2) intermittent – up to 15 % of the surface, 3) frequent – up to 35 % of the surface, 4) extensive - up to 65 % of the surface, and 5) throughout – 100 % of the surface. Higher values of the deduct value will have greater impact of that the particular distress, severity and extent on the overall condition of the pavement. Further advancement was made by Hein and Burak (2007, 2009) and ICPI (2007) in developing a pavement distress guide for interlocking concrete pavement based on exhaustive literature review, consultation with industry experts, and analysis of several pavements sites throughout North America, by classifying eleven types of distresses, its extent and severity level were identified viz., 1) damaged pavers, 2) depressions, 3) edge restraint, 4) excessive joint width, 4) faulting, 5) heave, 6) horizontal creep, 7) joint sand loss, 5) missing pavers, 6) patching, and 7) rutting.

Surface polishing and permanent deformation up to 100 mm (resulting from poorly compacted underlying soil) was reported for a PCCBP thickness of 150 mm (75,000 laden trucks passes) by Visser (1994). After 15 months of trafficking by ultra heavy wheel loads (~ 100 tonnes axle loads), 150 mm thick PCCBP showed no deterioration except for initial slight spalling (Visser, 1999). The weakest section of the test section having mine sand as the underlying material showed 13 mm permanent deformation, without significant visual changes observed later on. Based on visual distress inspections on PCCBP by Vissar and Hall (1999) some evidences of edge spalling were found, although that none of the cells had cracked through blocks. In some locations where thin leveling layer was placed on top of the already placed concrete layer, scaling of concrete surface was observed. The roughness of the pavement surface was reported to perfectly adequate for low volume roads. In some portion of the road section disintegration of block was observed which was due to the improper penetration of the concrete grouting. Visible cracks on the block edges with minor

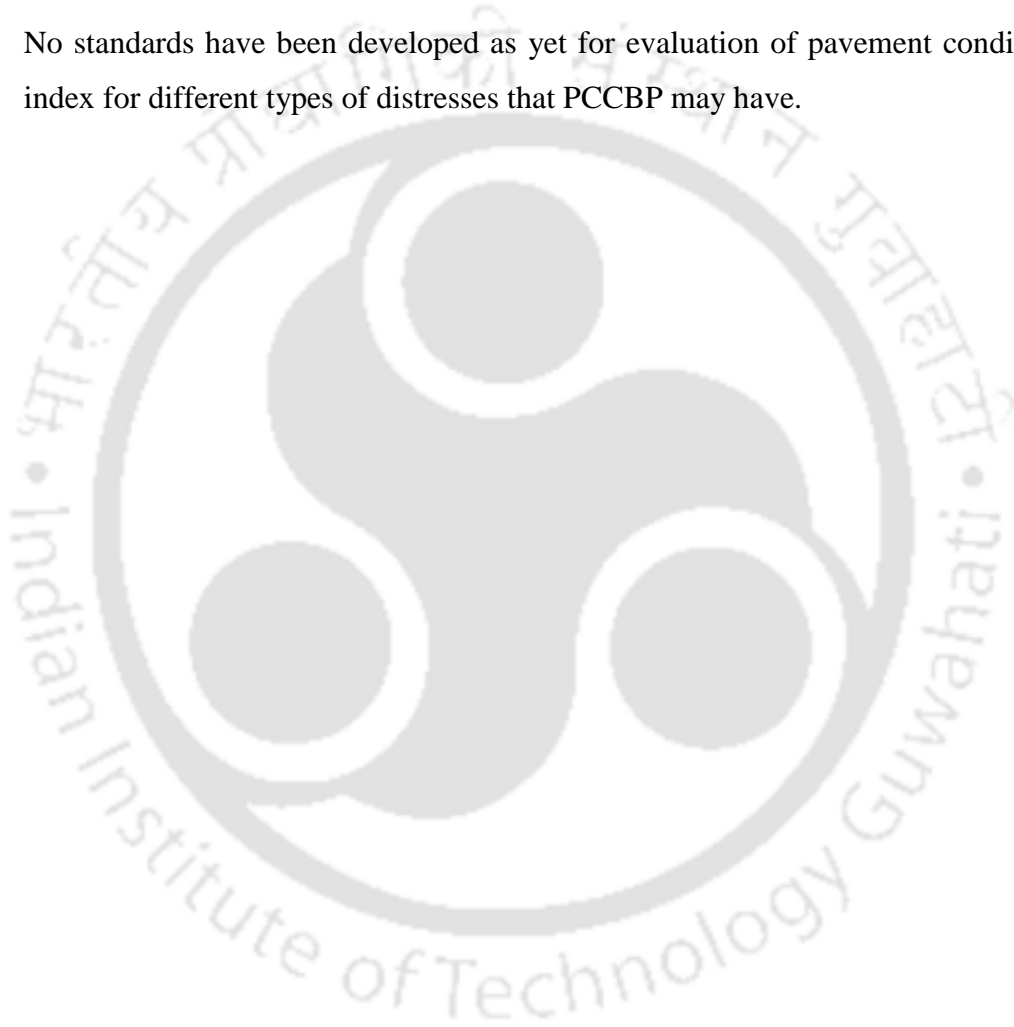
spalling were also reported on 150 mm thick PCCBP overlay over deteriorated (severe block cracking and crocodile cracking were present) concrete pavement of 300 mm thickness, when subjected to ultra heavy wheel loads in container ports (Plessis and Visser, 2001). For simulated village traffic (1500 passes of loaded truck equivalent to 3 years of village traffic) on 100 mm thick PCCBP over underlying soil-cement, moorum, sand-cement bases it was found that no observable distresses were observed by Roy *et al.*, 2010. On the other hand, edge cracking along cell wall locations was seen on 100 mm thick PCCBP over 100 mm thick compacted moorum after four years of service traffic with 4/5 loaded trucks per day. Appearance of surface cracks was observed within few days of road opening of a main village road using dual concrete layer (mentioned previously) 100 mm thick PCCBP by Shivaprakash (2011), indicating the vertical yielding of pavement due to heavy loaded truck traffic. However, to the best of author's knowledge, no systematic study and hence standard guidelines for evaluation of distresses on PCCBP have been reported in the literature.

2.7 Summary of literature review

An assessment of the reviewed literature indicates that limited researches on PCCBP, use of stone dust as replacement of sand in concrete and distress studies on PCCBP have been conducted. The popularity of PCCBP is confined mainly to South Africa and no investigators throughout the world have used this technology except few attempts carried out in India to gain further understanding. The summary of the previous investigations related to present work are summarized below:

1. PCCBP is suited for low volume roads.
2. The life cycle cost of PCCBP is comparatively lesser than conventional flexible and rigid pavement constructions.
3. Interlocking between concrete blocks results in good load spreading capacity of the pavement.
4. Concrete compressive strength of 15 MPa was adequate for opening to normal traffic and for light traffic the road can be open within 24 hours.

5. Very limited information is available on the variation of elastic modulus of the blocks with block thickness.
6. Limited tests suggest that PCCBP can be used as overlays over concrete pavements.
7. Replacement of natural sand with waste stone dust in concrete showed mixed compressive strength results *i.e.*, it may or may not increase as compared to that of normal concrete with natural sand only.
8. No standards have been developed as yet for evaluation of pavement condition index for different types of distresses that PCCBP may have.



CHAPTER 3

Structural Behaviour of PCCBP

3.1 Introduction

In this chapter, a systematic experimental study of the structural performance of PCCBP for various cell thicknesses subjected to live traffic conditions is presented. Five test sections of different 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, India (IIT Guwahati) from National Highway 31 (NH31). Further, to explore the feasibility of using PCCBP as overlay layer for strengthening old bituminous surfaced rural roads, 50 mm thick PCCBP overlay section has also been constructed adjacent to the PCCBP test section. For optimizing the cost of pavement construction, an attempt is made to use waste 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 river sand in remote rural areas, and help in cost cutting where the cost of transporting sand is relatively expensive. To evaluate the structural performance of PCCBP, elastic layer moduli of different layers of the test pavement have been calculated using a linear elastic layer theory based moduli backcalculation computer code BACKGA (Reddy *et al.*, 2002) from the surface deflection data obtained through Falling Weight Deflectometer (FWD). Variation of layer moduli are also presented for varying traffic passes. To validate the results obtained through BACKGA, finite element analysis have been carried out using ABAQUS (2009). A comparison between the deflection profiles obtained

through Falling Weight Deflectometer (i.e. experimental) and FE modeling using ABAQUS was also carried out using another elastic layer based software KENLAYER (Huang, 2010) using the layer moduli obtained through BACKGA as inputs.

3.2 Materials used for the construction of PCCBP

3.2.1 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 3.1a) 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 3.1b) which on stretching forms diamond shaped pockets of size 150 mm x 150 mm (Figure 3.1c).

3.2.2 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.

3.2.3 Stone dust

Stone dust (Figure 3.2) 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 3.1, 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).

3.2.4 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 3.2. 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.

3.2.5 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 3.3. The specific gravity was obtained as per IS 2720 (1980) and found to be ~2.63. From Table 3.3 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).

3.3. 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 (Figure 3.3) of construction techniques were tested (Visser, 1994):

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 (Figure 3.4) 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 3.5. From Figure 3.5, 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.

3.4 Structural evaluation of PCCBP test sections

3.4.1 Test 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 3.6. 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.

3.4.2 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 3.7) till sub-grade soil layer. After excavation the loose materials were properly removed and the natural soil was properly leveled. 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).

3.4.3 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 leveled manually to bring the surface to the required profile for each thickness (Figure 3.6). 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.

3.4.4 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 3.4. The materials were manually placed and spread uniformly over the prepared sub-grade soil. Laying and compaction (Figures 3.8a and 3.8b) 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).

3.4.5 Laying and concreting of the plastic cells

3.4.5.1 PCCBP – new construction

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 3.9 and 3.10a) were left. A reusable wooden frame (Figure 3.10a) with hook arrangements was used for tensioning the plastic cell formwork. It also acts as side restraint for casting concrete. This wooden frame was to be removed after casting one section and for reusing it for another section (Figure 3.10b). The plastic cell formwork, after tensioning forms diamond shaped (150 mm X 150 mm) pocket size (Figure 3.10a).

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 leveled. 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 leveled properly; care was taken to make the new construction (test section) in the level with the existing bituminous pavement.

3.4.5.2 PCCBP - overlay construction

PCCBP overlay test section measuring 2.7 m in length was also constructed leaving a gap of 350 mm from the 50 mm thick PCCBP test section. It may be mentioned that the bituminous road section on which the overlay is to be laid was left while the road stretch was resurfaced by other agency 3 (three) months ahead of construction of the new PCCBP test pavement (Figure 3.11). The material specifications adopted for the bituminous overlay construction is given in Table 3.5.

A 50 mm thick PCCBP overlay section was laid over the existing 445 mm thick (Section 3.4.2) old bituminous pavement surface. The old surface was clean properly and surface preparation was done so as to achieve good bonding between old bituminous surface and the new PCCBP overlay surface. On the prepared old bituminous surface, adhesive material 'Gellix' was applied (Figure 3.12). The properties of Gellix are given in Table 3.6. After application of Gellix (@ 1 liter per square meter as per specification), the plastic cell formwork (50 mm cell thickness) was stretched and spread over the pavement surface. The concreting of the overlay section was done while the coating of Gellix is still tacky (Figure 3.13). The finished surface was compacted and level properly so that the finished surface of 50 mm thick PCCBP overlay section is level with the 50 mm thick newly resurfaced bituminous road surface. A schematic diagram showing the PCCBP overlay and the bituminous overlay laid over the existing old bituminous pavement is shown in Figure 3.14.

3.4.6 Curing of the PCCBP test section

Casting of the whole test section (both new and overlay constructions; Section 3.4.5) 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 3.15) 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 (Figure 3.16). Figure 3.17 shows a core sample with deformed LDPE cell walls with a layer of concrete on top of the plastic cells. Due to deformation resulting from compaction, the effective cell height was reduced and concrete layer of 6% to 10% (i.e. 10 mm – 15 mm for 150 thick PCCBP) of the cell height can be seen on top of the cell formwork (Figure 3.17). Similar observation (5 mm reduction in cell height) was also reported by Visser (Visser, 1999). The PCCBP test section was opened to normal traffic (Figure 3.18) after 25 days from the day of casting.

Traffic survey

In order to evaluate the performance of the test sections with traffic passes, daily traffic volume data was collected from the IIT Guwahati security check gate (all vehicles passing the test pavement also passes the 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 (Figure 3.19). The wheel load recorded by the portable load pad was then double to evaluate the axle load of the vehicles. 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. HCV and MCV). The registration number, type of vehicles and goods carried by the vehicle were also recorded during the axle load survey. The load pad was placed on hard surface closed to the edge of the road with enough care being taken to ensure that the level of two wheels on either side of the axle are kept at the same level for uniform distribution of the load on both the wheels. The vehicles were stop at a suitable distance before negotiating the load pad. Proper instructions were given to the driver to ensure that the vehicles move slowly and the wheel is placed centrally over the load pad. The stable reading (wheel load in Tonne) shown by the digital display unit of the load pad was recorded. The universal 'fourth power damage formula' (AASHTO, 1962) which relates axles repetitions, N_1 (with W_1 axle weight) and N_2 (with W_2 axle weight) for the same extent of damage, is used to convert the number of repetitions of vehicles of various axle loads into Equivalent Single Axle Load (ESAL) repetitions of 80 kN (Equation 3.1).

$$\frac{N_1}{N_2} = \left(\frac{W_2}{W_1} \right)^4 \quad (3.1)$$

From axle load survey, the axle load and the corresponding traffic volume was obtained. 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. VDF is the weighted average of the damages caused by the individual axle load group with respect to the corresponding volume of traffic of each

group and has been calculated using Equation 3.2 (using standard axle load of 8.16 tonnes as the basis for India).

$$VDF / Axle = \frac{V_1 \left(\frac{W_1}{W_s} \right)^4 + V_2 \left(\frac{W_2}{W_s} \right)^4 + V_3 \left(\frac{W_3}{W_s} \right)^4 + \dots}{V_1 + V_2 + V_3} \quad (3.2)$$

where, $W_1, W_2, W_3 \dots$ are the median values of the various axle load groups, V_1, V_2, V_3 are the respective traffic volumes, and W_s is standard axle load (Chakraborty and Das, 2003). In the present study, VDF was calculated from the axle load survey data for the commercial vehicles passing the test section and is found to be 2.51 (considering standard truck of two axle). The detail calculation of VDF is presented in **Appendix A**.

Figure 3.20 presents variation of monthly ESAL repetitions on the test pavement for 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. Figure 3.21 shows the cumulative ESAL with month for the data presented in Figure 3.20. 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. Assessing in an accelerated manner, 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 (accelerated performance) for a typical rural road in India.

3.6 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

3.22). 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.

3.6.1 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 3.22.

The FWD used in the present study is mounted on a trailer for better mobility. The power supply for the equipment is through a DC generator mounted along with the equipment. Provisions are also made for direct AC power supply so that the equipment can also be operated electrically depending on the availability of power supply on the site. 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. Electro Permanent Magnet (EPM) operated with an input current of 0.6 Ampere and maximum lifting capacity of 500 kg, is provided with the equipment for lifting and dropping the falling mass. 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. The calibration data along with the calibration factor for geophone is given in **Appendix B**. 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 (Figure 3.23). 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.

3.6.2 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. The various parameters input to BACKGA followed those considered by Pandey and Reddy, (2005), Rakesh *et al.*, (2006), Sahoo *et al.*, (2006), Roy *et al.*, (2009, 2010), Ryntathiang *et al.*, (2005), Reddy *et al.*, (2000, 2002) *viz.*, 1) Size of population = 60, 2) Number of generations = 60, 3) Cross over probability = 0.74, and 4) Mutation probability = 0.10. An optimal set of layer moduli is selected (defining upper and lower bounds) as input to the program in such a way that the measured deflections match closely with those computed from the selected layer moduli. In the present study the range of moduli and the material properties considered for the BACKGA analysis are shown in Table 3.7. 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). Sample input and output annotated files using BACKGA program are given as **Appendix C**. 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) as discussed in Sections 3.6.3 and 3.6.4.

3.6.3 Deflection computation using KENLAYER

The KENLAYER (Huang, 2010) is elastic multi layer system based software for flexible pavement analysis with a circular loading area. It can be used to determine surface deflections based on input parameters such as Young's modulus, Poisson's ratio and layer thickness etc., assigned to different elastic layers. In the present study, the layer modulus (presented later in Section 3.7) obtained through BACKGA using pavement surface deflections (FWD) as input, was validated using KENLAYER by comparing the KENLAYER surface deflections with that of experimental deflections obtained through FWD. A detail discussion is given in Section 3.7. (Flow chart of KENLAYER is presented in **Appendix D**)

3.6.4 Deflection computation using ABAQUS

Validations of the BACKGA results (layer moduli) have been performed using finite element (FE) software ABAQUS (2009) (linear-elastic-static analyses). Figure 3.24

shows the schematic diagram of a typical PCCBP geometry adopted for the finite element study. PCCBP model of plan size 2400 mm x 2400 mm has been chosen such that the distance of the edge from the center of load is 1200 mm (Figure 3.24c). Similar to the experimental construction, the inputs to ABAQUS (2009) are taken as 50 mm, 80 mm, 100 mm, 120 mm and 150 mm for PCCBP layer thickness with a fixed sub-base (WBM) layer of 100 mm. However, the thickness of the sub-grade layer has been taken as 5000 mm following the work of Huurman (1997) and is considered to be sufficient for the analyses of interest. The layer moduli obtained through BACKGA have been used as inputs of the FE analyses. The Poisson's ratios considered for PCCBP, sub-base and sub-grade layers in the analysis are given in Table 3.7. Due to symmetry of the PCCBP pavement with respect to the center of loading plate, only one quarter domain has been modeled (Figure 3.24c). Roller boundary conditions are applied on all the four sides allowing only vertical displacements, and the bottom part is restrained. The load has been applied as pressure of 0.565 N/mm^2 on top of a steel loading plate (quarter plate is considered in the present case) having radius 150 mm (Young's modulus = $2 \times 10^5 \text{ N/mm}^2$ and Poisson's ratio = 0.3). The contact of the loading plate with the top of PCCBP has been modelled as rigid body contact. Figure 3.25 shows a typical finite element mesh using C3D8R (Eight noded Continuum 3D solid elements with reduced integration, ABAQUS, 2009). The typical model consists of 25,738 nodes and 22,805 elements. Comparison of the FE surface deflection results with that of experimental values (FWD) are discussed in the Section 3.7.

3.7 Results and discussions

3.7.1 Thickness effect of PCCBP test pavement

3.7.1.1 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 Rynthiang *et. al.*, (2005) is presented in Figure 3.26. 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 Rynthiang *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 3.27 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 3.27 and plotted in Figure 3.28. 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.

3.7.1.2 Layer elastic modulus

The variation of PCCBP layer elastic moduli with increase in their thickness is shown in Figure 3.29. 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 3.30 and 3.31 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 $\times 0.2 \times (\text{thickness in mm})^{0.45} = 111 - 158$ MPa) suggested by Shell (1978). From Figure 3.31 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 \times CBR) lie in between those predicted by Shell (1978) i.e. 10 \times CBR and Visser *et al.*, (2003), i.e. range of 1-100 \times CBR.

3.7.1.3 Validation with FE and KENLAYER

As highlighted in Sections 3.6.3 and 3.6.4, moduli values obtained from BACKGA (Figures 3.29-3.31) are used as input to both ABAQUS and KENLAYER to validate the moduli results from BACKGA, by comparing output surface deflections with experimental values (FWD). It may be noted that FE analysis allows simulation of rigid plate contact of the loading plate whereas analytical analysis based KENLAYER program uses flexible plate contact. Figure 3.32 shows a typical vertical displacement contour for PCCBP test pavement from FE analysis. Figure 3.33a and 3.33b shows the comparison of surface deflection of different PCCBP thicknesses (plotted as a function of the radial distance from the center of the load plate) obtained through FE analysis, KENLAYER analyses and experiment results (FWD). It can be seen from Figure 3.33a and 3.33b that peak deflection predicted by KENLAYER nearly matches with the experimental peak deflections. However, FE under predicts peak deflections, as compared to the experimental deflection values and KENLAYER deflection values, by $\sim 38\%$, 36% , 33% , 30% and 28% for 50 mm, 80 mm, 100 mm, 120 mm and 150 mm PCCBP thicknesses respectively. It may be noted that in FE analyses the loading plate is modeled as rigid plate, simulating the steel load plate used in FWD for dropping load, hence it is expected to predict lesser deflection than that predicted by KANLAYER analysis, which is based on flexible plate loading (to simulate rubber tire loading). This observation agrees with the report that a reduction of 21% in surface deflection under a rigid plate as compared to that of flexible plate (Yodar and Witzak, 1975). At distances beyond ~ 450 mm (i.e., 1.5 times the loading plate diameter), there is a reasonable agreement (although lower than the experimental values) between the surface deflection profiles predicted by FE and KENLAYER. It can also be seen that the influence of load on the surface deflection bowl is much

shorter (the deflection is ~ 0.05 mm at the distance of 900 mm from the load center, for all the PCCBP thicknesses considered) for experimental results as compared to that of FE and KENLAYER results (~ 0.2 mm of surface deflection has reached at a similar radial distance of 900 mm). This may be due to the reduced load transfer as a result of the presence of plastic cells, as compared to the continuous layer idealization in FE and KANLAYER analyses. However, deflection value at other radial distances from center of the load, under prediction can be seen with KENLAYER and FE analysis (both are based on elastic theory). In the first instance, the over estimation of FE and KENLAYER surface deflection values (as compared to experimental values) at radial distances away from center of the load may be due to the idealized continuum assumption (linear elastic, isotropic and homogenous properties) of the various composite layers. However, in the absence of sophisticated analyses (considering in-homogeneity, complex stress interaction at the cell walls, etc.), the moduli predicted by BACKGA based on elastic layer theory and ANN, can best be considered, within the scope of the present research effort, as appropriate for qualitative observation, rather than the exact numerical match. As such, in the present work, the results from BACKGA are presented and discussed.

3.7.1.4 Comparison with other similar studies

Figure 3.34 shows a comparison of elastic layer moduli of the test pavement (i.e. PCCBP surface, WBM sub-base and sub-grade layers) with the values obtained from literature on similar studies. Higher elastic moduli values for Roy *et al.*, (2009) may be related to the lower deflections as presented in Section 3.7.1.1. In the case of Rynthathiang *et al.*, (2005) the deflection is higher than the present study and correspondingly the elastic moduli is also lower as compared to the present study. Good agreement can be seen with the result obtained by Rynthathiang *et al.*, (2005), this may be related with similar thicknesses of WBM (~ 100 mm) considered. Whereas Roy *et al.*, (2009) considered a thicker sub-base (~ 150 mm) over better sub-grade soil CBR value ($\sim 8\%$) and hence the possibility of getting a higher sub-base elastic modulus (~ 498 MPa). From Figure 3.34 it can be seen that sub-grade moduli lies in the range 63 – 48 MPa for the thicknesses considered. Elastic moduli values are closer for both Roy *et al.*, (2009) and Rynthathiang *et al.*, (2005) but slightly higher than the

present study, consistent with higher soaked CBR values as compared with the present study.

3.7.2 PCCBP as overlay construction

3.7.2.1 Surface deflections

Figure 3.35 shows variation of surface deflection with radial distance from load center for 50 mm thick PCCBP and bituminous overlays, for similar thicknesses of underlying base and sub-base layers (Figure 3.36). It can be seen that for the same thickness of overlays, there is an overall decrease (~ 20%) in surface deflections when PCCBP is used instead of bituminous overlay. Comparing with deflection profiles of Figure 3.35 and Figure 3.27, it can be observed that an increase in ~ 345% in WBM thickness results in ~47 % decrease in peak deflections of PCCBP.

3.7.2.2 Layer elastic modulus

The surface deflections shown in Figure 3.35 are given as inputs in BACKGA to obtain layer moduli values. In this case the cross-section is idealized into three layers system, by combining premix bituminous base courses, WBM sub-base course and granular sub-base course as one layer of thickness 445 mm laid over sub-grade soil (Figure 3.36). The material properties adopted in BACKGA is given in Table 3.8. It may be noted that the upper limit of layer modulus for sub-base is increased to 600 MPa, as compared to that given in Table 3.7 (upper limit = 300 MPa), considering the thicker (~445 mm) sub-base layer. The Poisson's ratio for bituminous layer is also maintained at 0.35 (Shell, 1978). It is worth noting that the effect of Poisson's ratio is not that significant on the moduli computation (Huang, 2010). Figure 3.37 shows the comparison of layer moduli for surface course (PCCBP/Bituminous overlays), sub-base and sub-grade. An increase of ~235% in surface layer modulus is observed when PCCBP is used instead of bituminous layer (Overlay PCCBP layer modulus = 1982 MPa). The sub-base and sub-grade moduli for both the overlays i.e. with PCCBP and bituminous surface layers, are observed to be ~240-350 MPa and ~99 MPa respectively. Compared with the new PCCBP construction (Figures 3.29, 3.30 and 3.31), it can be seen that for comparable PCCBP thickness of 50 mm, there is a

marginal increase (~1.5%) in surface layer modulus for overlay construction, but comparable sub-grade layer modulus of ~99 MPa. However an increase of 16% in sub-base layer modulus has been observed for overlay construction compared to that of new construction. This may be due to higher thickness of sub-base (445 mm) as compared to the 100 mm for the new construction.

3.7.3 Performance of PCCBP with load repetitions

3.7.3.1 Different thickness of PCCBP test section

In order to evaluate the effect of load repetitions on PCCBP test sections, surface deflections were measured at three different 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, layer elastic moduli of each test sections were computed using BACKGA program as explained in previous sections. Figures 3.38 - 3.40 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 3.38). 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 3.39 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 be seen (Figure 3.40), 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) and thereafter followed by sharp decrease in sub-grade modulus (38,000-62,000 passes)

may be related to the decrease in stiffness of the PCCBP layer due to distressing (see Chapter 4). Due to distress in the PCCBP layer, the sub-grade modulus of all the pavement section might have converged to modulus value ~60 MPa.

3.7.3.2 PCCBP as overlay construction

Figures 3.41-3.43 show the effect of load repetitions on the moduli for PCCBP and bituminous overlay constructions. It can be observed from Figure 3.41 that the decrease of moduli for PCCBP and bituminous overlays are 0.9% and 3% respectively after 62,000 ESAL repetitions. This may be due to thicker, well compacted and consolidated underlying base/sub-base courses of the existing old pavement. From Figures 3.42 and 3.43 it can be observed that there is no significant variation in layer moduli of both sub-base and sub-grade layers with increase in passes of traffic. Again, the reason may be well compacted and consolidated underlying layers of the existing pavement.

3.8 Conclusions

A study has been made to investigate experimentally into the structural assessment of different thicknesses (50 mm, 80 mm, 100 mm, 120 mm and 150 mm) of Plastic Cell filled Concrete Block Pavement (PCCBP) over 100mm thick sub-base layer of Water Bound Macadam (WBM) course, using 'waste' stone dust in place of the traditional river sand as fine aggregates in concrete. To explore the possibility of PCCBP as overlay construction, 50 mm thick PCCBP overlay layer was also constructed. Layer elastic moduli of different layers of PCCBP have been calculated using a backcalculation computer program code BACKGA (Reddy *et al.*, 2002) from the surface deflection data obtained through a custom fabricated Falling Weight Deflectometer (FWD). Based on the investigation the following main conclusions are summarized:

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% (0.84 mm for 50 mm PCCBP) in deflection was observed.
3. A thin PCCBP of 50 mm over thin sub-base of 100 mm 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. The elastic modulus for the 100 mm sub-base (WBM) was found to be in the range of 300 - 240 MPa and no significant variation in moduli could be observed for the thicknesses tested.
6. Sub-grade elastic modulus was seen to be within the range 100 – 70 MPa with marginal variation with thickness
7. 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). 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.
8. PCCBP overlay showed significant improvement (~230% increase) in elastic layer modulus when compared to that of bituminous overlay suggesting that PCCBP can be a good alternative for strengthening the existing bituminous pavements.
9. Maximum utilisation of labour (hence labour intensive) during plastic cell formwork making and construction process makes PCCBP a suitable candidate for employment generation in the rural areas.

Table 3.1: Particle size distribution of stone dust.

Sieve size (mm)	Percentage passing by weight (%)	Specified limit (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 3.2: 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 3.3: Grain size distribution of sub-grade soil.

Sieve size (mm)	Percentage passing (%) by weight
10.0	100
4.75	98.1
2.8	97.3
2.36	94.8
2.0	94.5
1.0	85.2
0.6	76.6
0.425	69.6
0.3	65.7
0.15	49.7
0.075	41.6

Table 3.4: Particle size distribution and properties of water bound macadam sub-base course.

Particle size distribution				Aggregate properties			
Type	Sieve size (mm)	Percentage passing (%)	Specified limit for Grading I (% passing)	SG	WA (%)	CE & FI (%)	LAAV (%)
Coarse Agg.	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				
Screening	13.2	100	100				
	11.2	98.84	95-100				
	5.6	24.91	15-35				
	0.180	0.35	0-10				

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

Table: 3.5: Material specifications for bituminous overlay (Institute Works, IIT Guwahati).

Type of layer	Specification
Tack coat	-Bitumen emulsion CSS-1h at the rate 0.20 kg per sqm.
Bituminous macadam (50 mm thick)	-Crushed stone aggregates with Grading -1 (40 mm nominal size) as per MORTH, 2001. -Premixed from hot mix plant (100-120 TPH) using paving bitumen of 60/70 grade. -Without anti stripping agent.
Semi-dense bituminous concrete (25 mm thick) as surfacing and profile corrective course	-Crushed stone aggregates with Grading -1 (13 mm nominal size) as per MORTH, 2001. -Premixed from hot mix plant (100-120 TPH) using paving bitumen 60/70 grade.

Table: 3.6: Physical properties of adhesive prime coat 'Gellix'.

Properties	Values
Colour	Dark brown
Adhesion to concrete	0.78N/ m ²
Specific gravity	1.05 at 25°C
Service temperature	-10°C to +100°C
Application temperature	+5°C to +50°C
Drying time	30 min at 25°C

Table 3.7: 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

Table 3.8: Selection of limits of Pavement (overlay construction) material properties.

Pavement layer		Elastic modulus (MPa)		Poisson's ratio
		Lower limit	Upper limit	
PCCBP		200	2000	0.35
Bituminous		200	600	0.35
Sub-base		20	350	0.40
Sub-grade		10	100	0.40

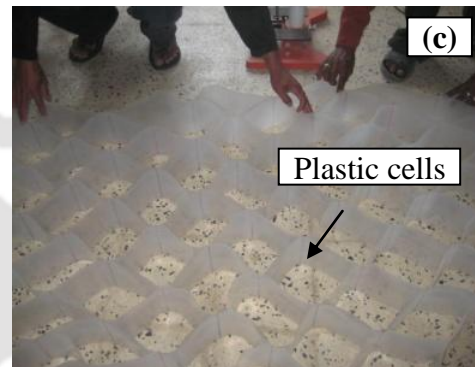
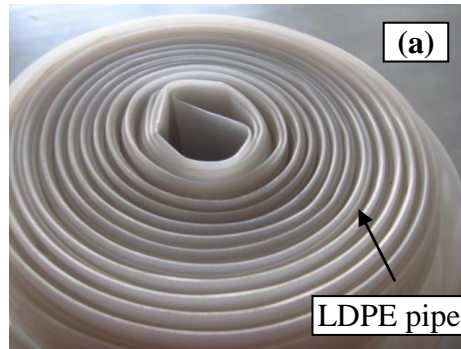


Figure 3.1: a) Low Density Polyethylene (LDPE) pipe (0.49 mm thick and 101.6 mm in diameter), b) Sealing of plastic cell formwork using paddle sealer, and c) Finished plastic cell formwork of pocket size 150 mm x 150 mm.

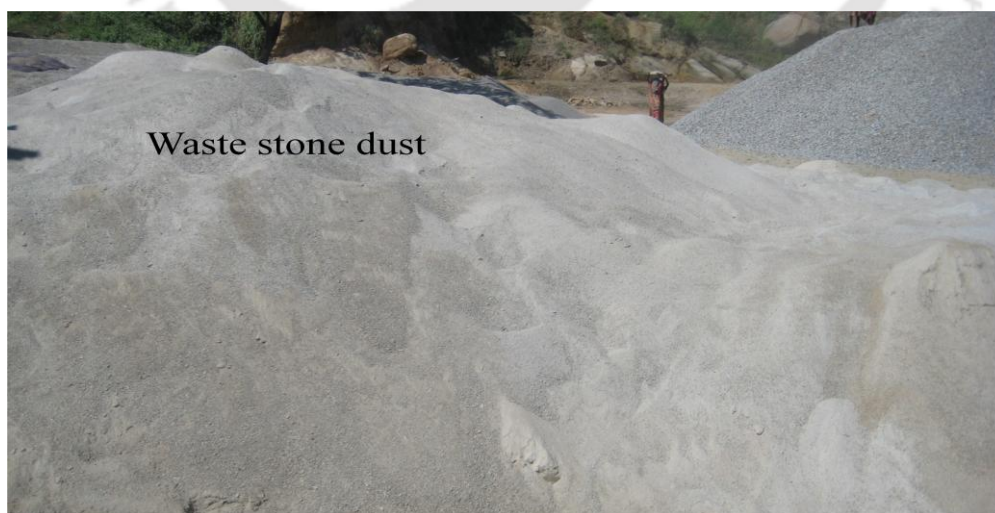


Figure 3.2: Crusher run waste stone dust (approximately 20% of the total stone crushed in the stone crusher).



Figure 3.3: Comparison between grouting and premix technique for construction of PCCBP pavement.



Figure 3.4: Incomplete penetration of mortar in grouting method.

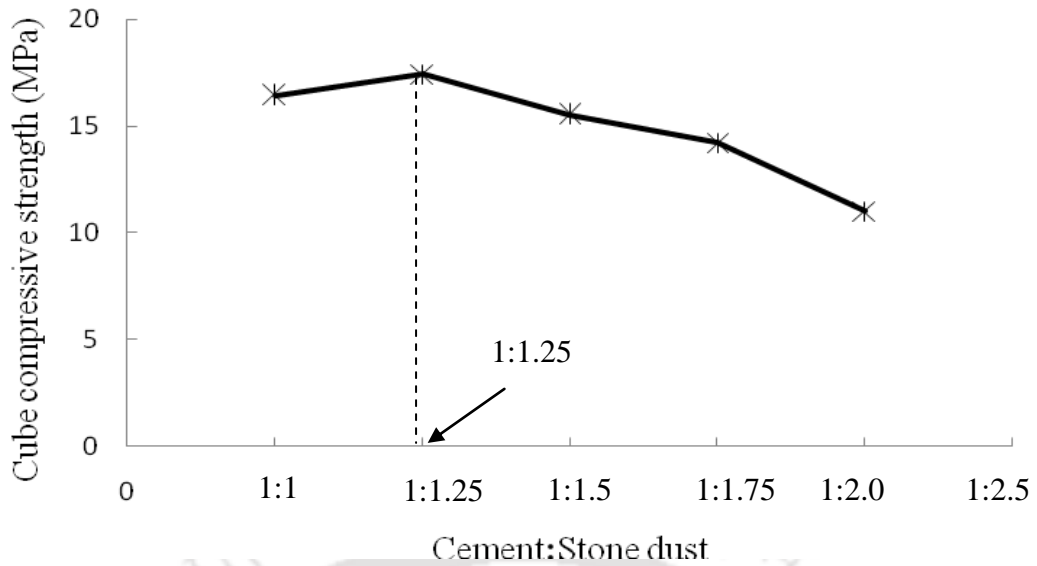


Figure 3.5: Variation of 7 days average cube compressive strength with cement:stone dust ratio for premix concrete.

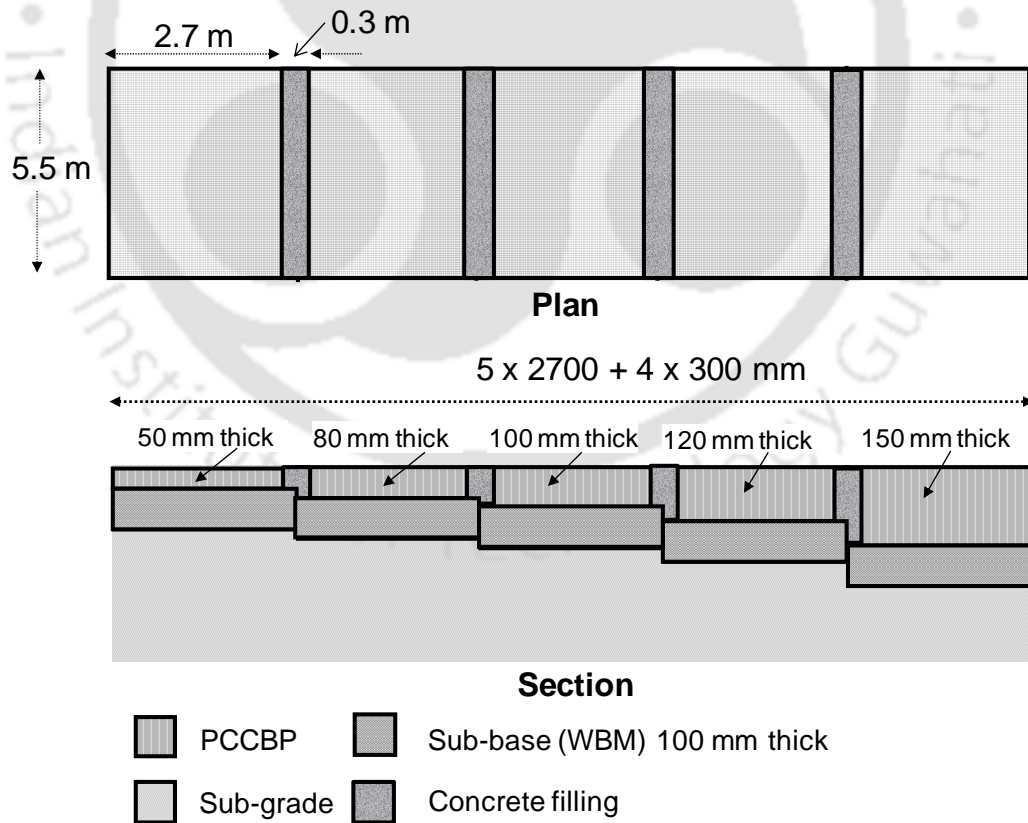


Figure 3.6: Schematic plan and sectional view of the test section showing different thickness of PCCBP.



Figure 3.7: Excavation and removal of the top layers of the existing bituminous pavement.



Figure 3.8: a) Laying and b) Compaction of the WBM course.

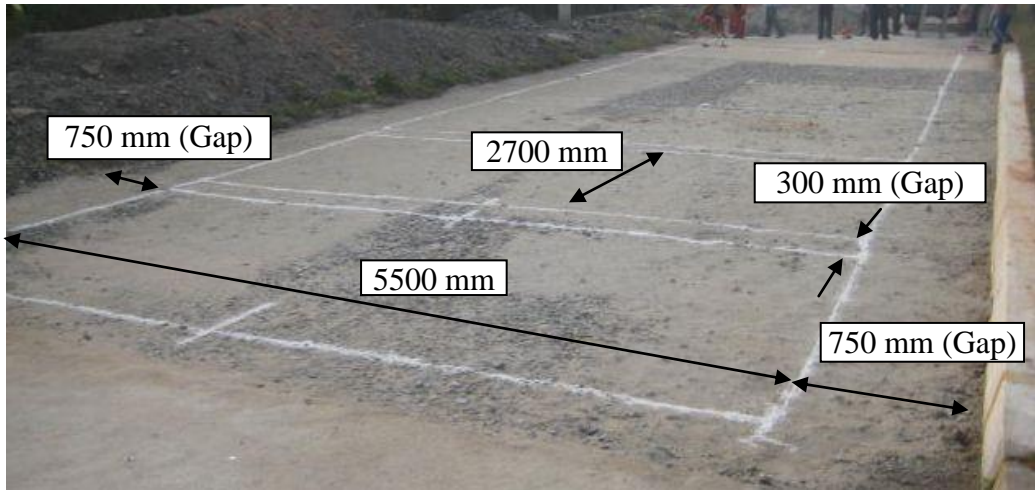


Figure 3.9: Layout for different sections of PCCBP.

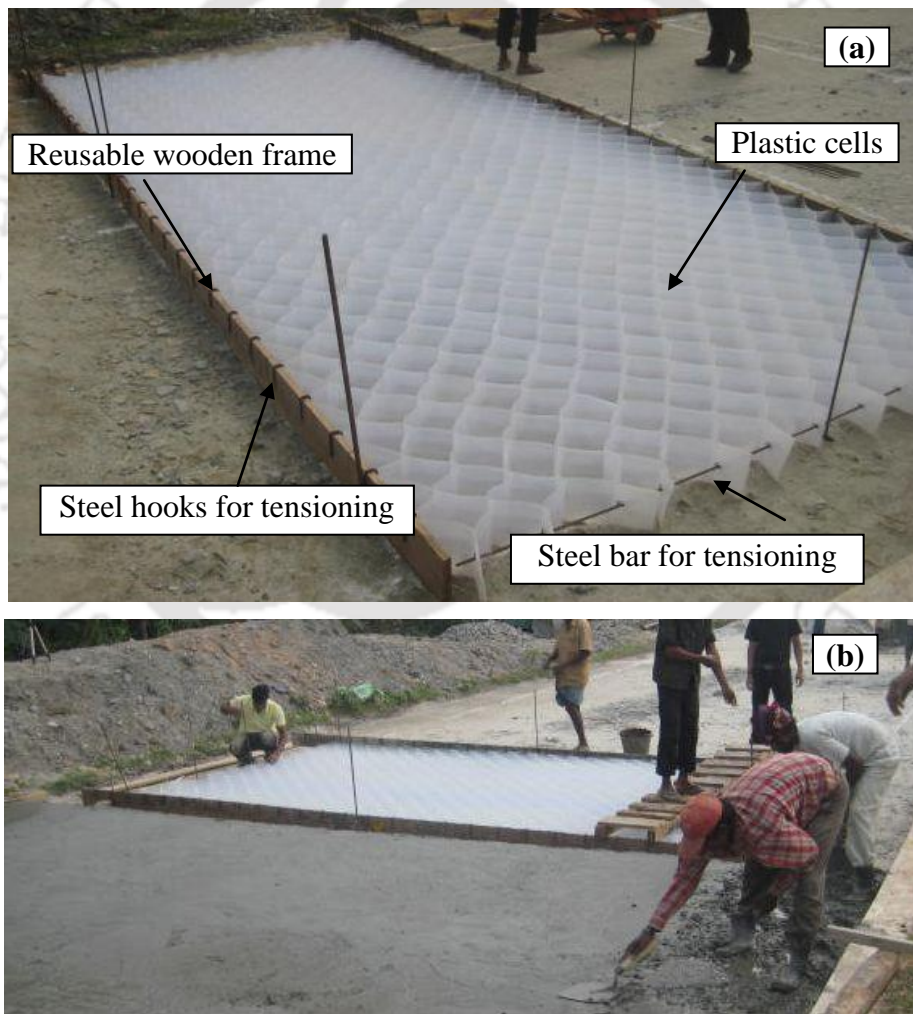


Figure 3.10: a) Casting of the PCCBP and b) Laying of plastic cell formwork for next PCCBP section.



Figure 3.11: A section of the road left behind while resurfacing the road stretch on which the test pavement was constructed.

Adhesive prime coat (*Gellix*)



Figure 3.12: Application of adhesive prime coat *Gellix* over existing bituminous pavement, after surface preparation.



Figure 3.13: Casting of the PCCBP overlay over adhesive prime coat (*Gellix*).

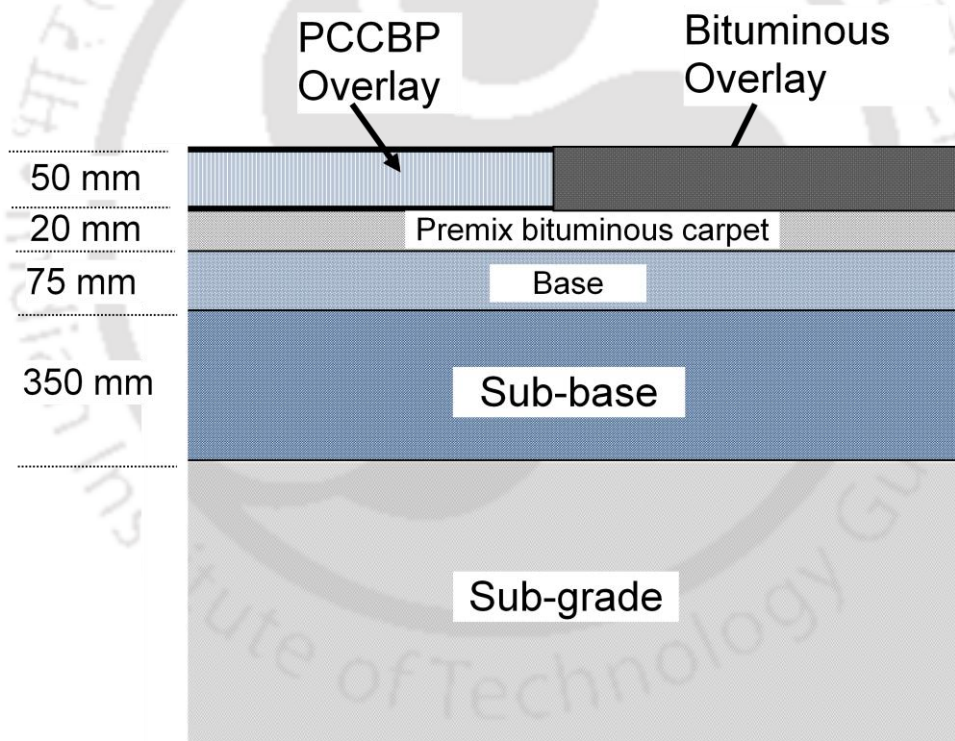


Figure 3.14: Schematic diagram of PCCBP and Bituminous overlays.



Figure 3.15: Completed PCCBP test road with markings for different test sections.



Figure 3.16: Core samples collected from test sections show good compaction and thickness of each section is maintained properly.

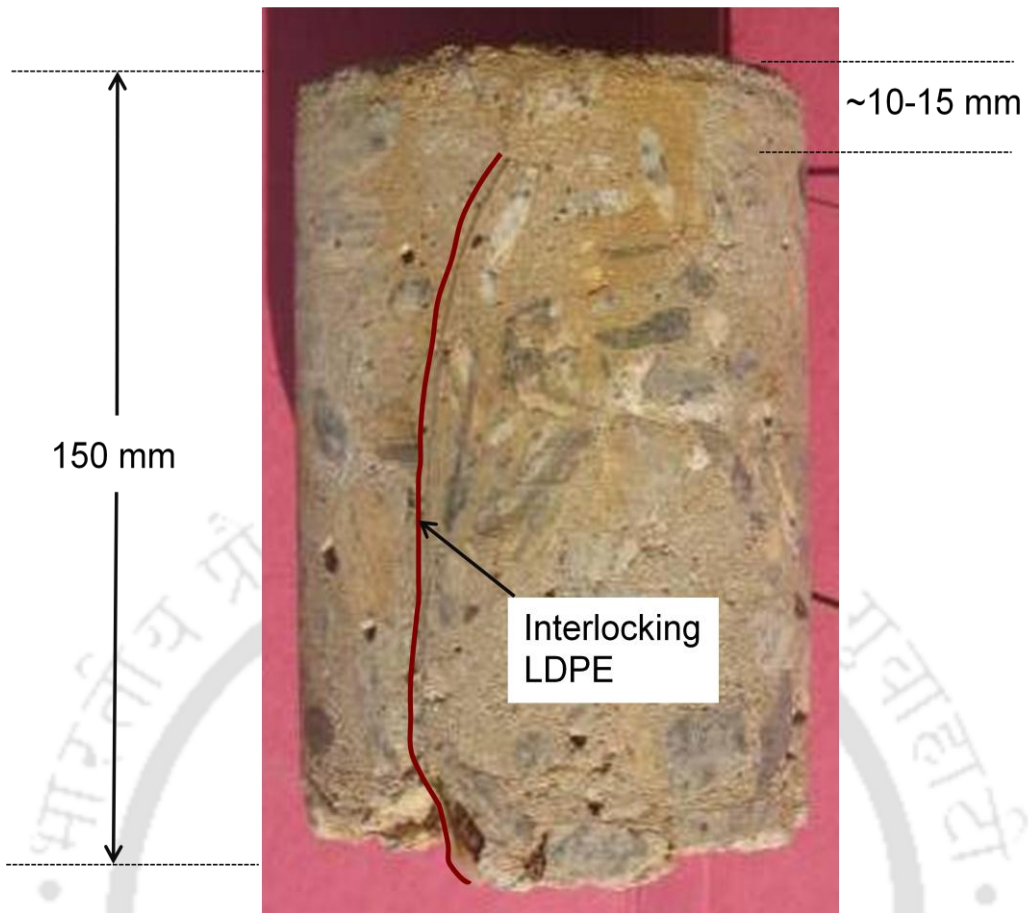


Figure 3.17: A sample core showing interlocking LDPE (red line shows its location), and layer (~10 - 15 mm) of concrete on top of plastic cells.



Figure 3.18: Completed PCCBP test sections opened to regular traffic.

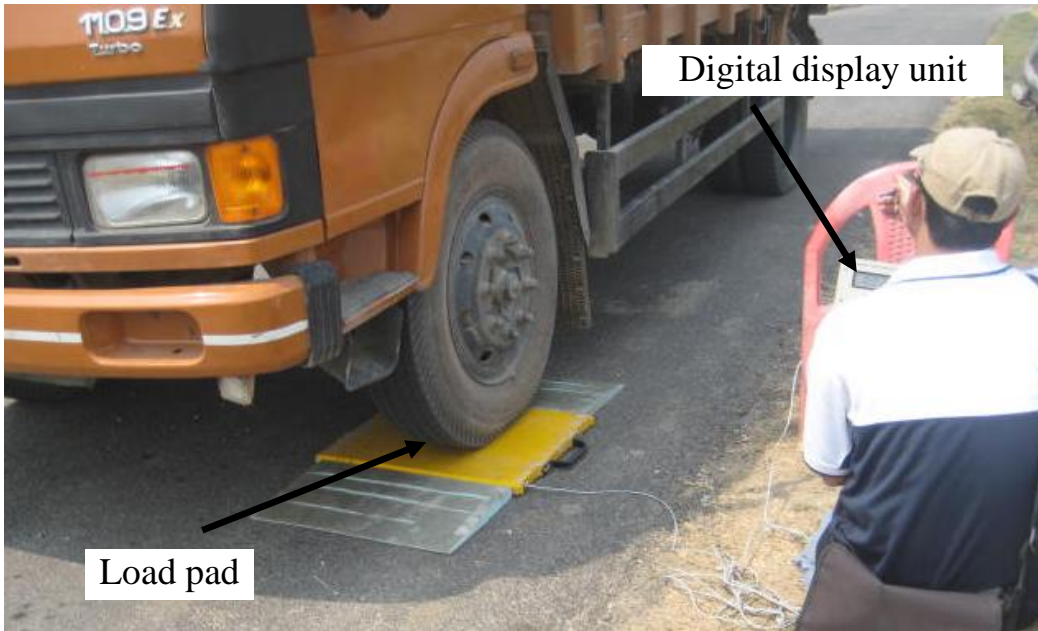


Figure: 3.19: Axle load measurement using load pad.

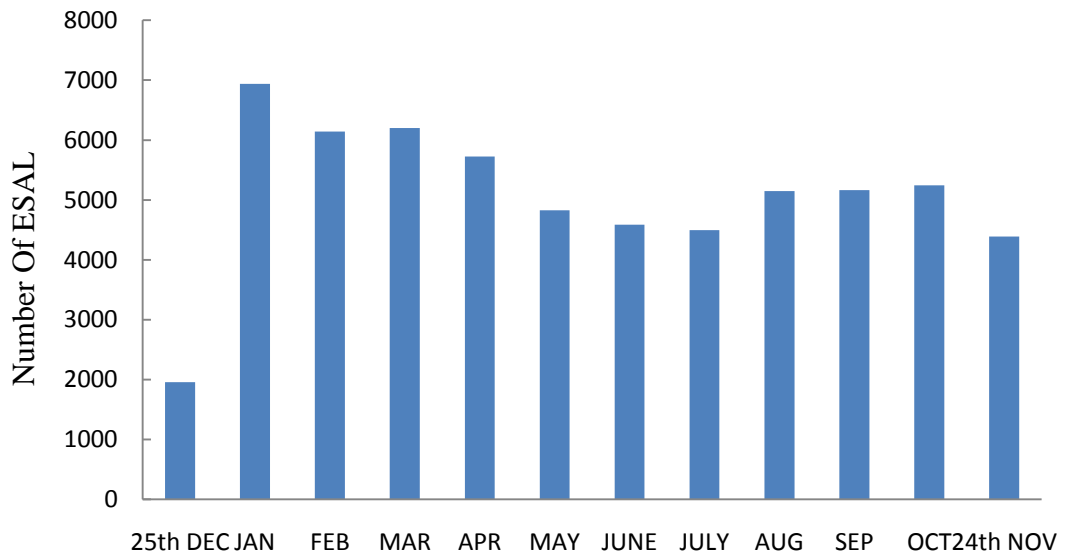


Figure 3.20: Monthly number of ESAL (Equivalent Single Axle Load) passing on the test pavement.

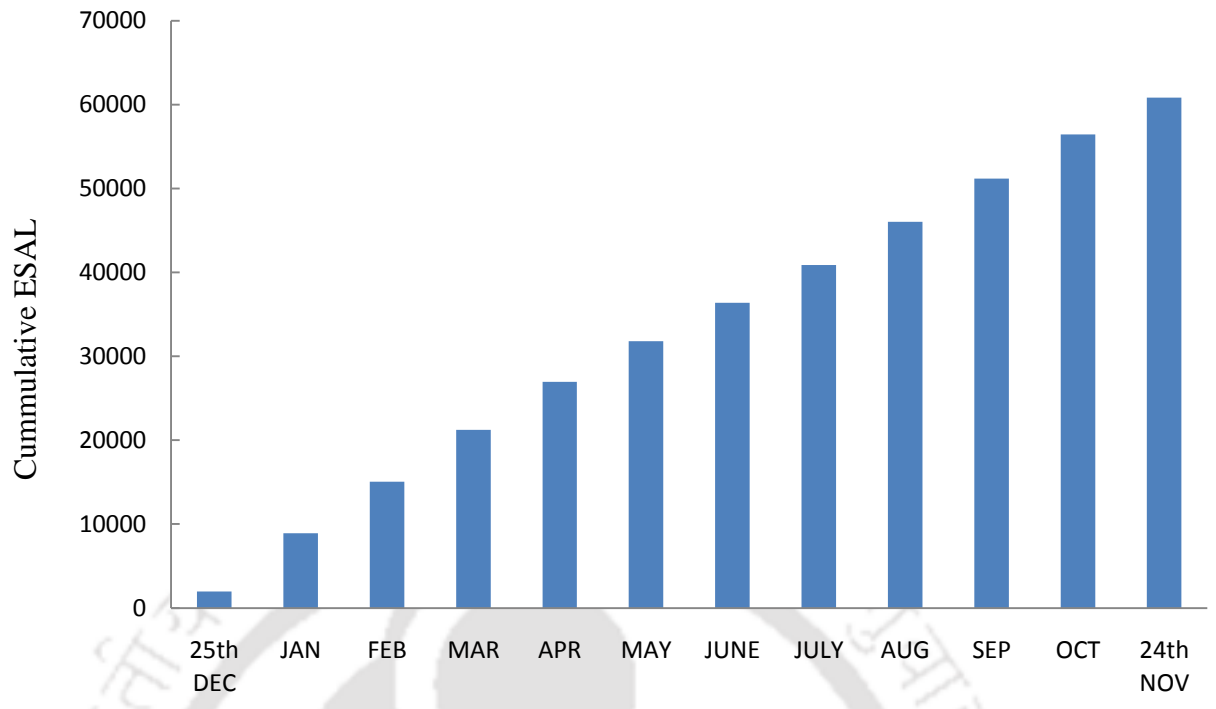


Figure 3.21: Cumulative ESAL with month (~11 months).

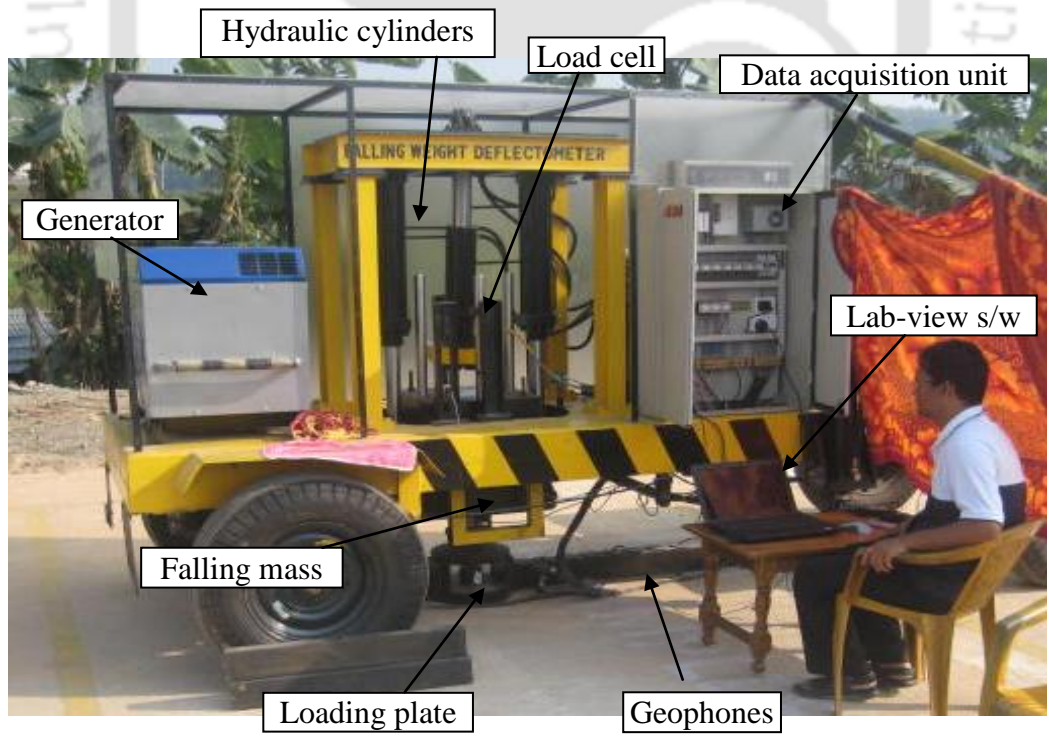


Figure 3.22: Custom fabricated FWD for the present study.

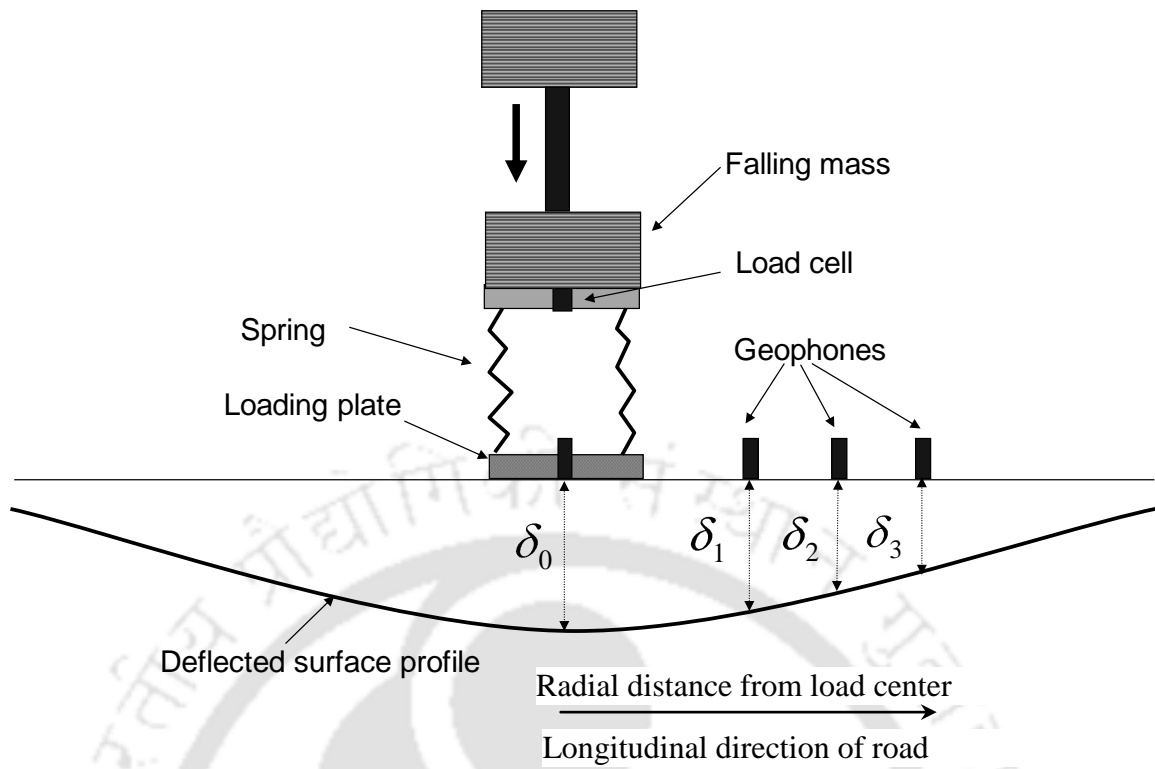


Figure 3.23: Schematic diagram showing surface deflection measurement using FWD at different radial distances from load.

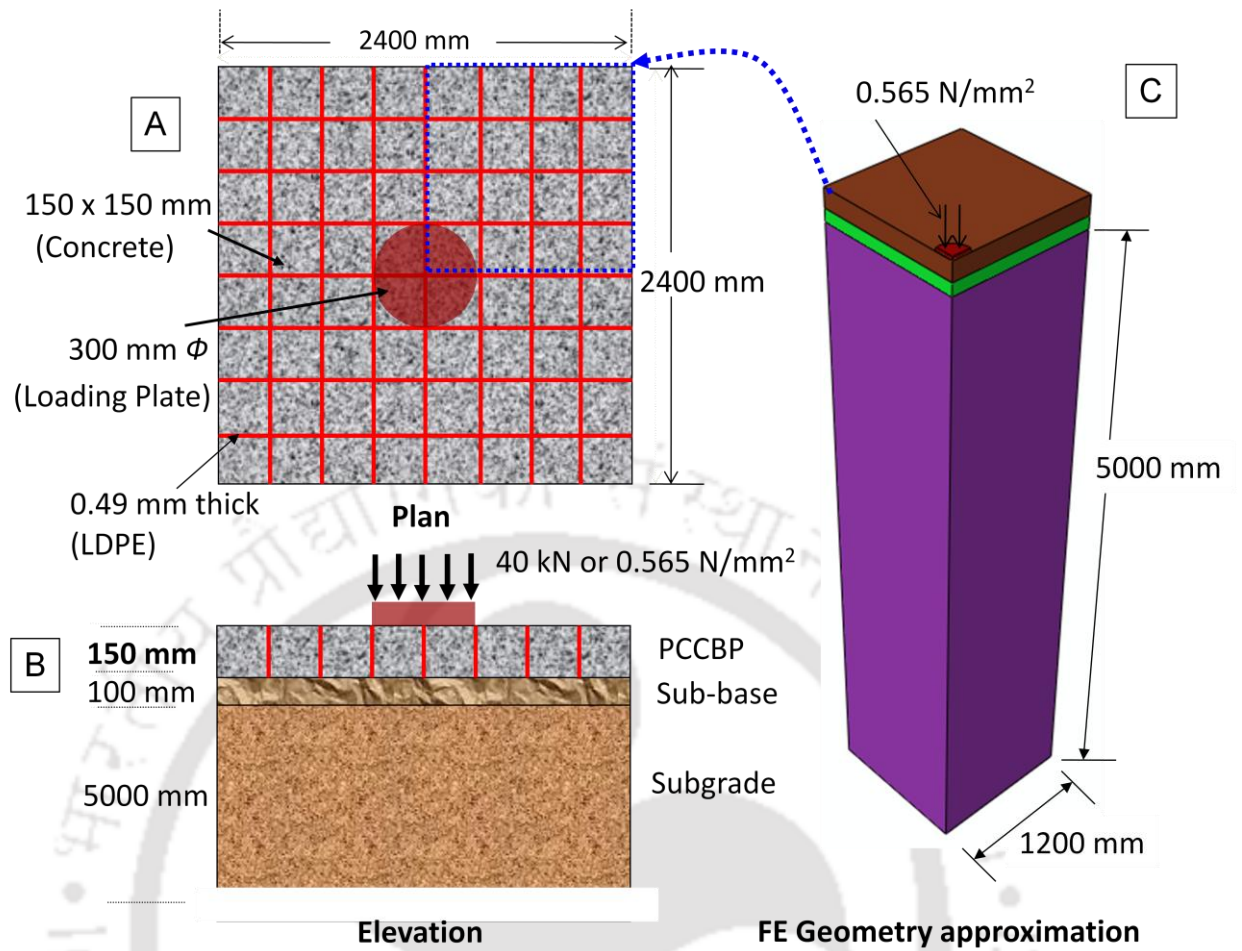


Figure 3.24: Schematic diagram showing a) top plan view of PCCBP, b) sectional elevation of PCCBP, and c) idealized geometry for finite element analysis.

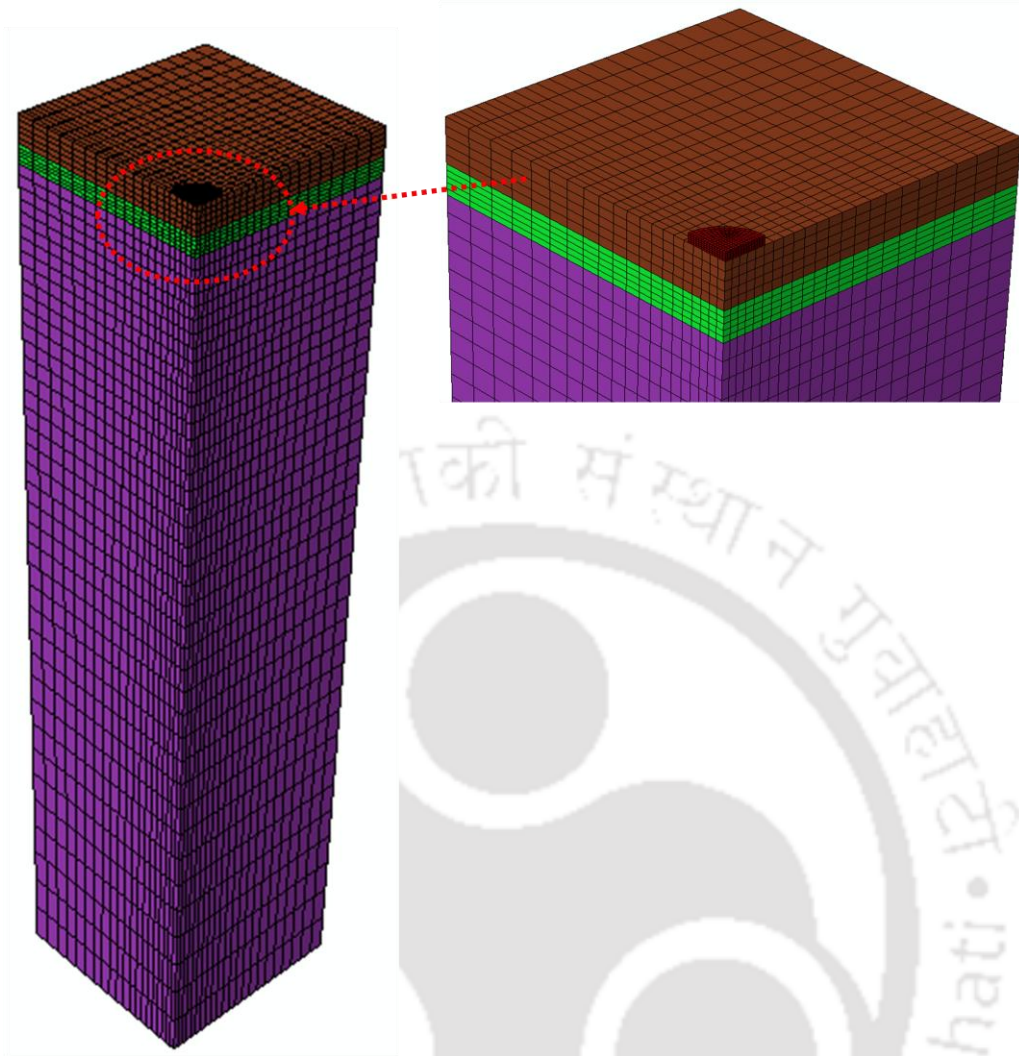


Figure 3.25: Typical FE mesh (25,738 nodes, 22,805 elements, C3D8R).

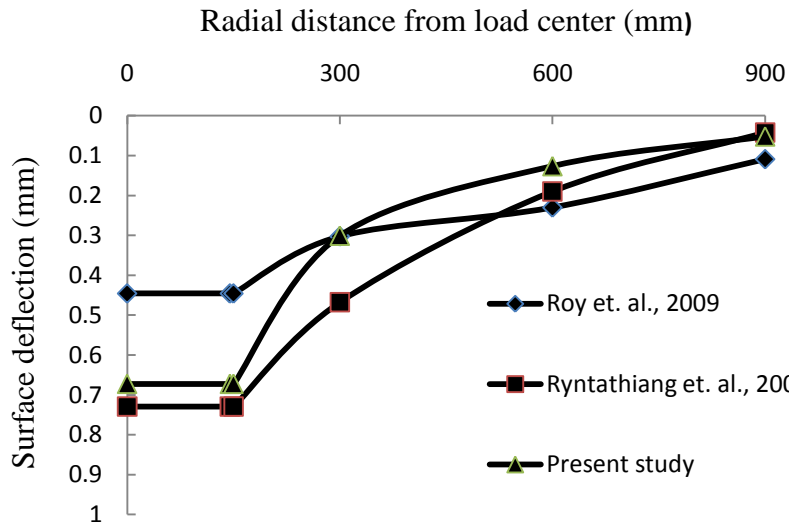


Figure 3.26: Comparison of the present study with similar studies on PCCBP (thickness equal to 100 mm) in India.

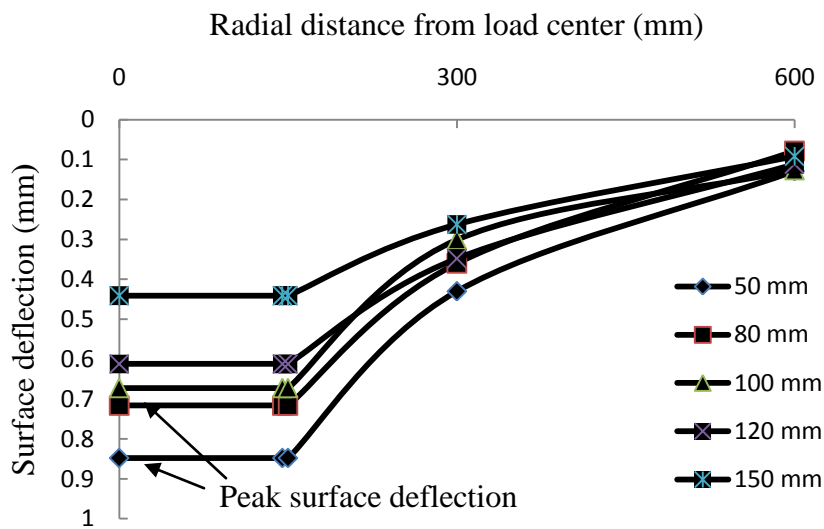


Figure 3.27: Surface deflection profiles for different thicknesses of PCCBP.

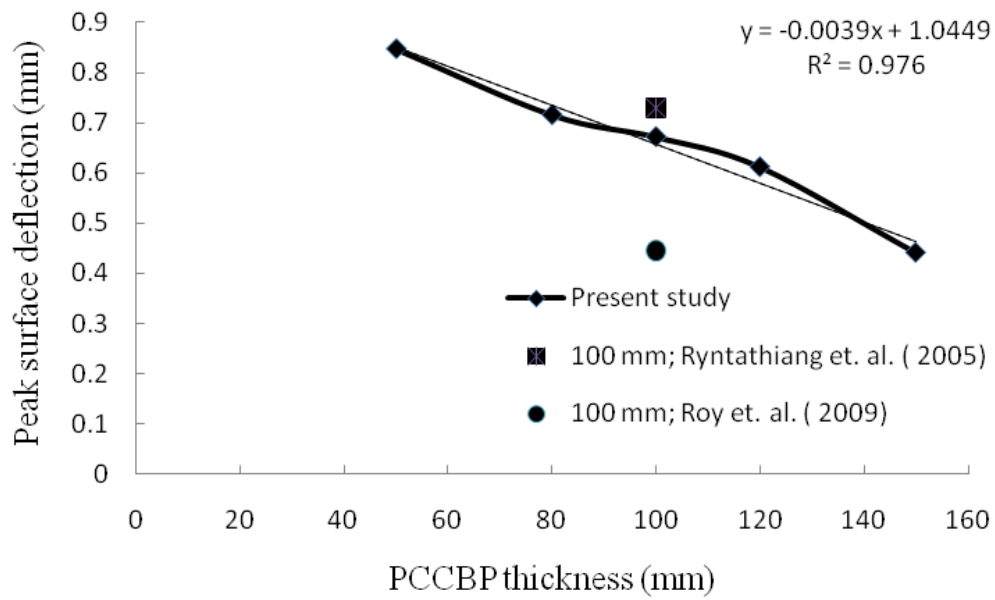


Figure 3.28: Variation of peak surface deflection with PCCBP thickness.

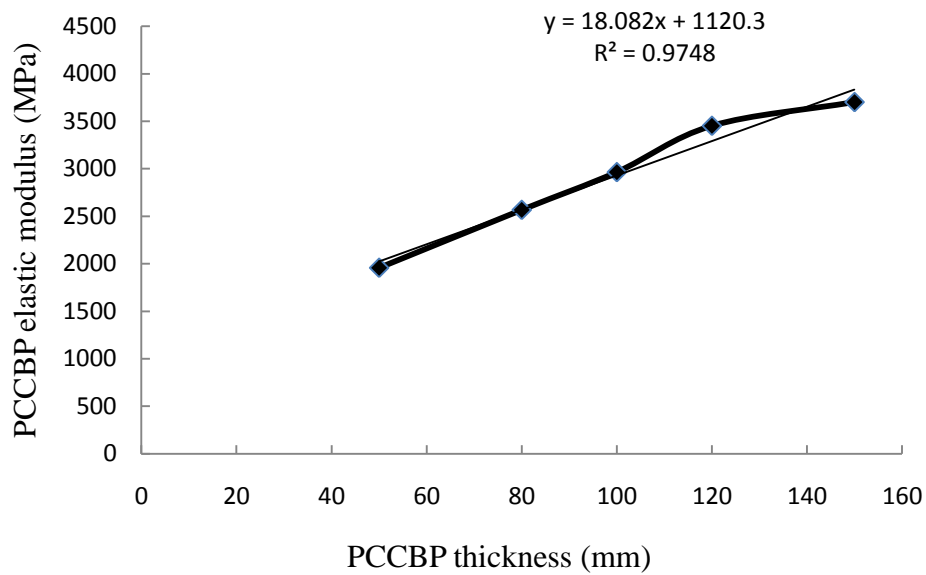


Figure 3.29: Variation of PCCBP layer elastic moduli with PCCBP thickness.

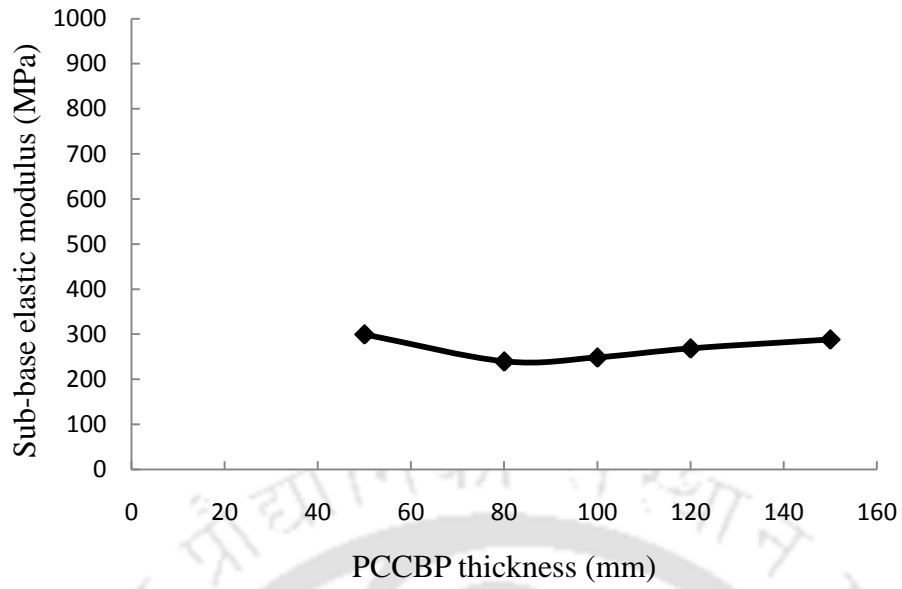


Figure 3.30: Variation of sub-base elastic moduli with PCCBP thickness.

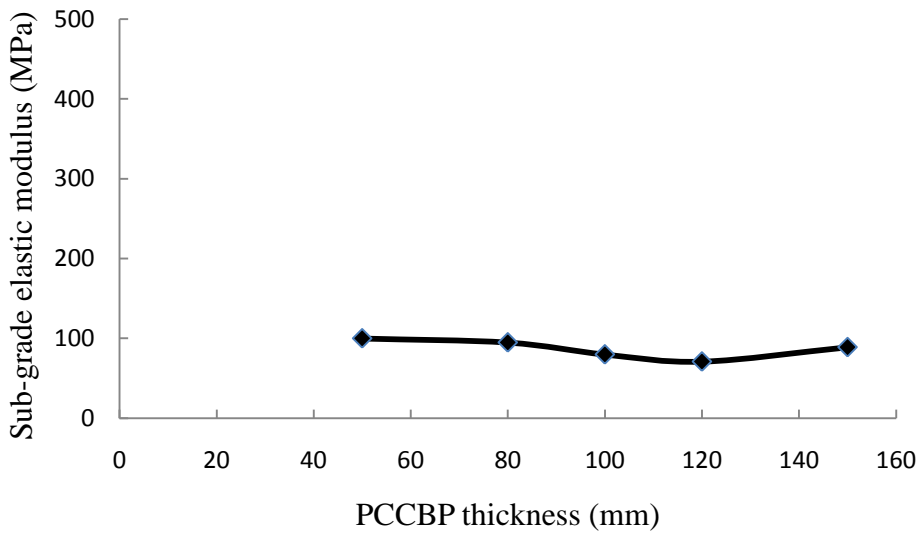


Figure 3.31: Variation of sub-grade elastic moduli with PCCBP thickness.

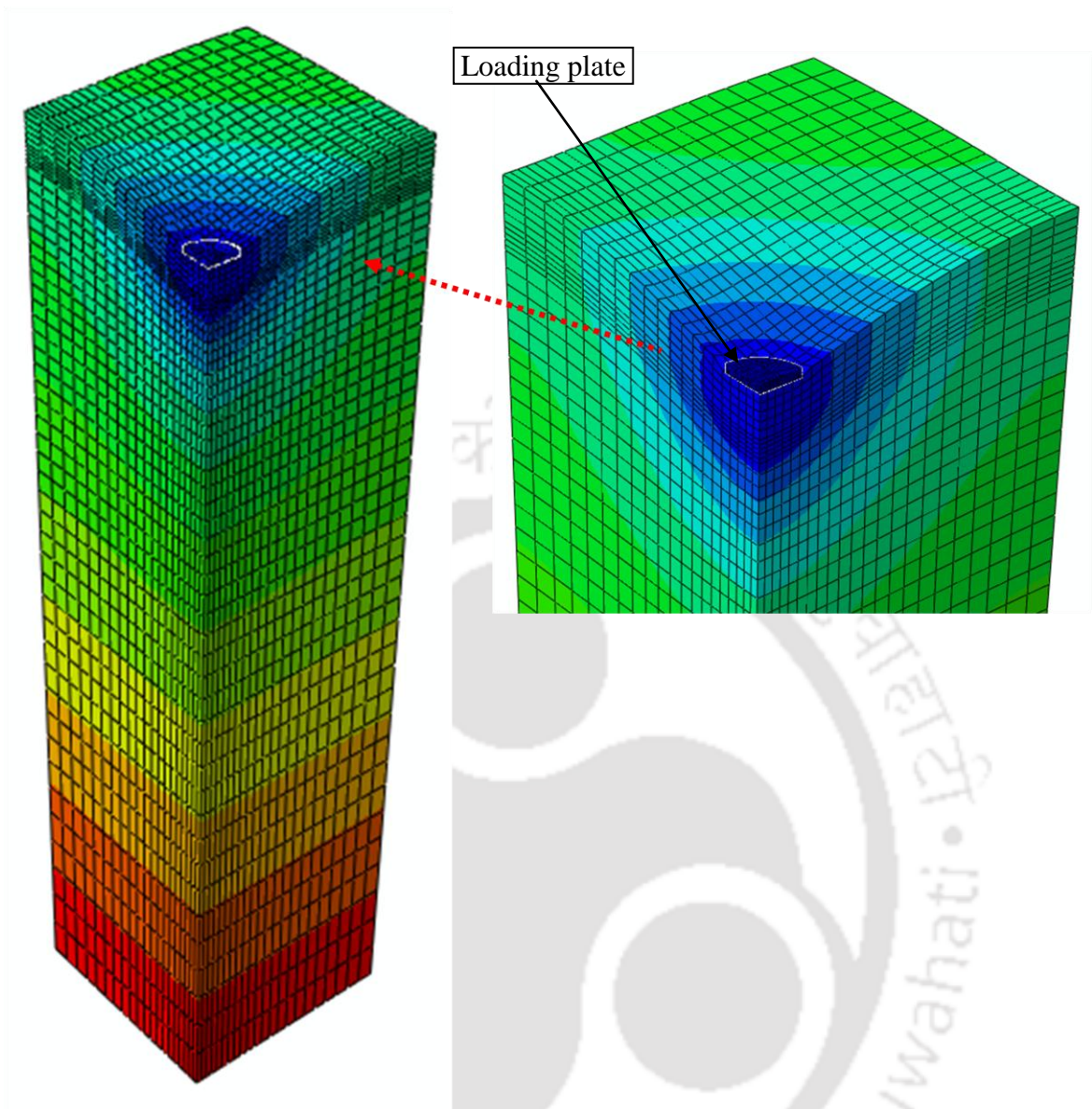


Figure 3.32: Typical vertical displacement contour for PCCBP test pavement from FE analysis.

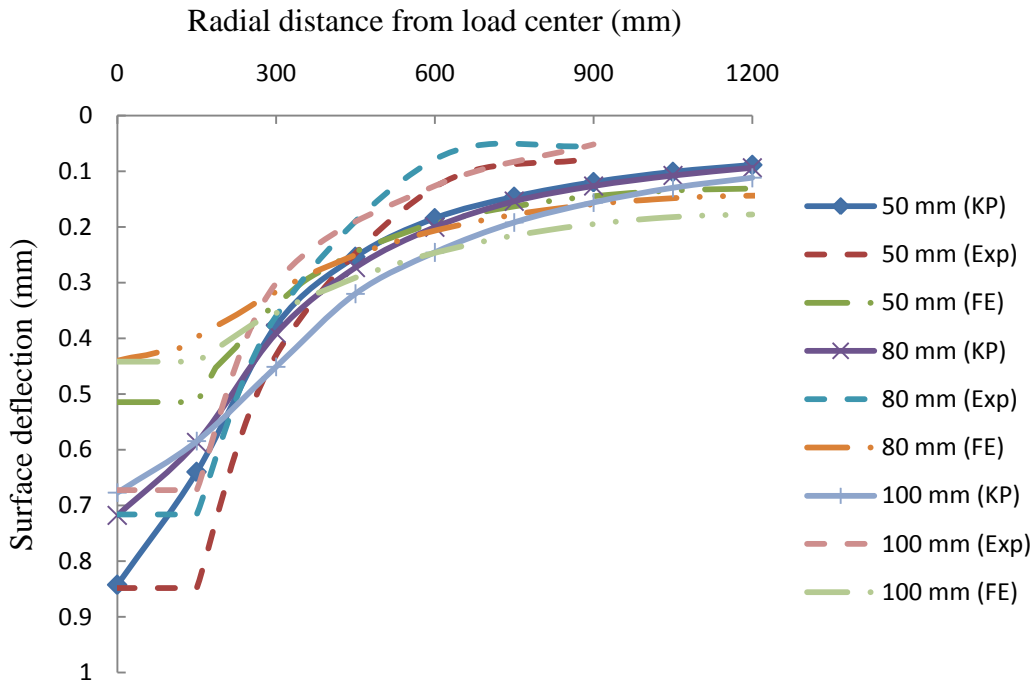


Figure 3.33a: Comparison of experimental (Exp), FE and KENLAYER (KP) surface deflection variation with PCCBP thickness (50 mm, 80 mm and 100 mm).

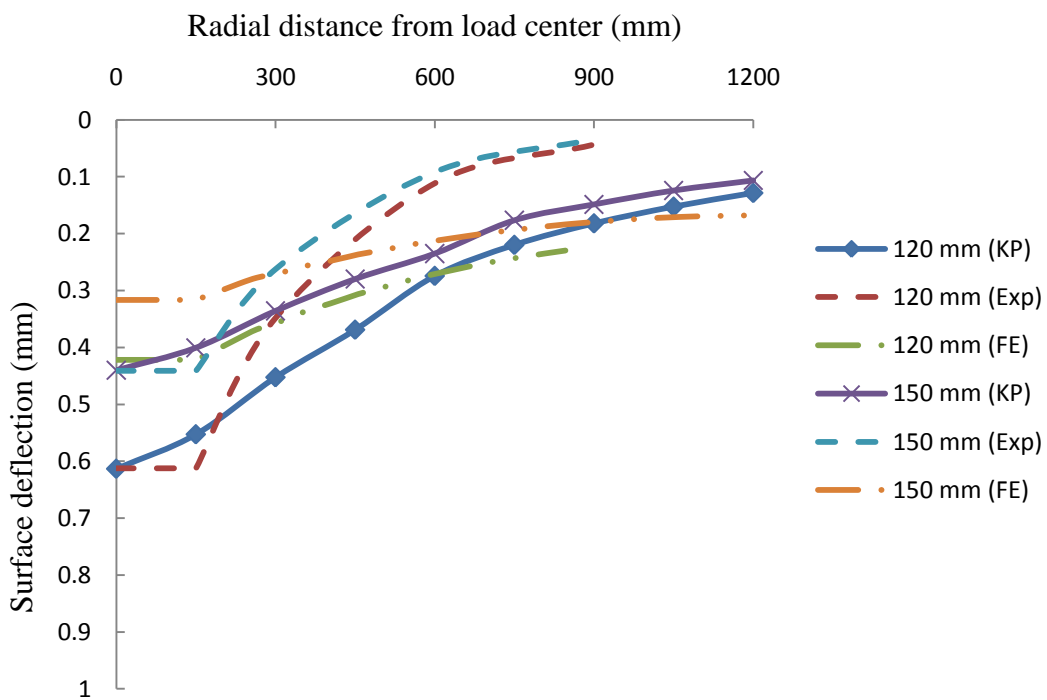


Figure 3.33b: Comparison of experimental (Exp), FE and KENLAYER (KP) surface deflection variation with PCCBP thickness (120 mm and 150 mm).

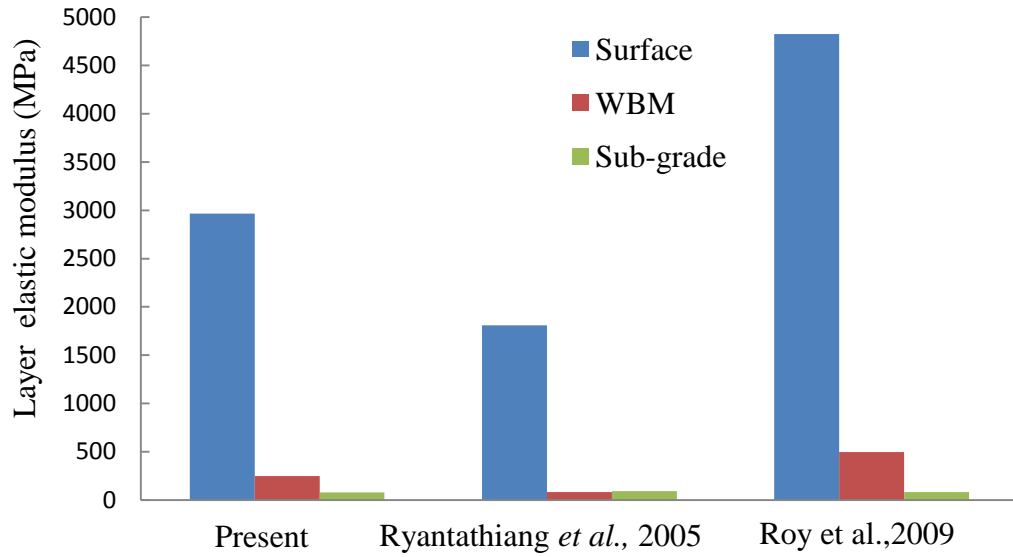


Figure 3.34: Comparison of elastic layer modulus with those from literature (100 mm thick PCCBP).

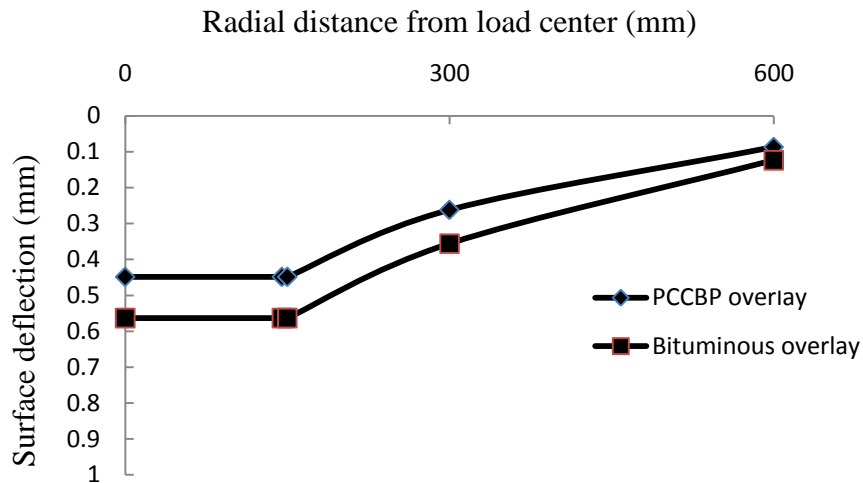


Figure 3.35: Surface profile variation for PCCBP and bituminous overlays.

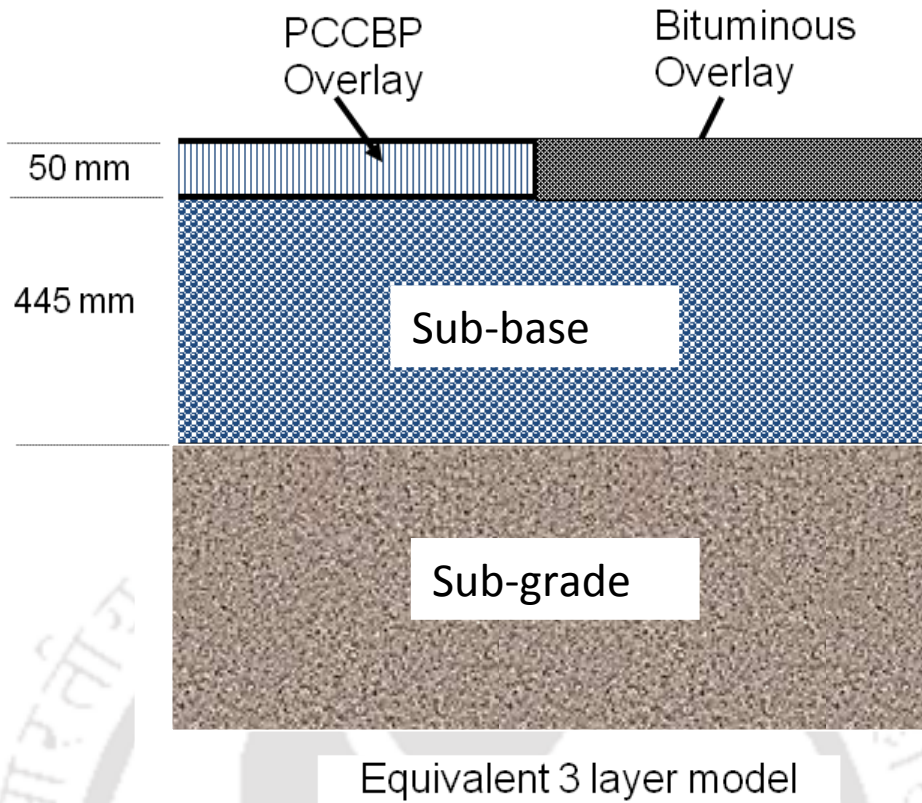


Figure 3.36: Three layer idealisation (by combining base and bituminous carpet into sub-base layer) of overlay construction.

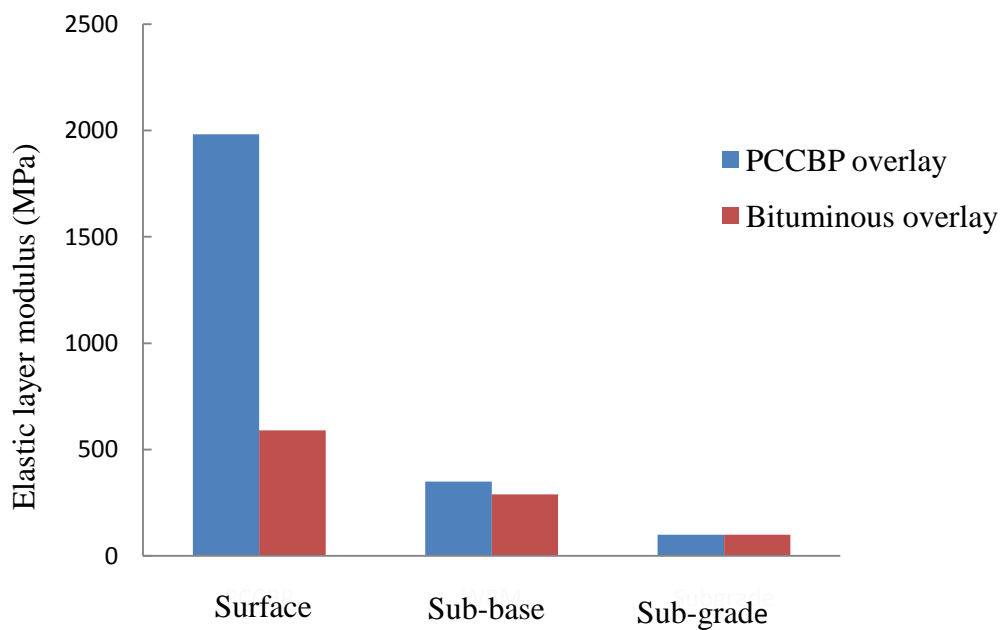


Figure 3.37: Comparison of elastic layer modulus (for surface, sub-base and sub-grade layers) for PCCBP and bituminous overlay constructions.

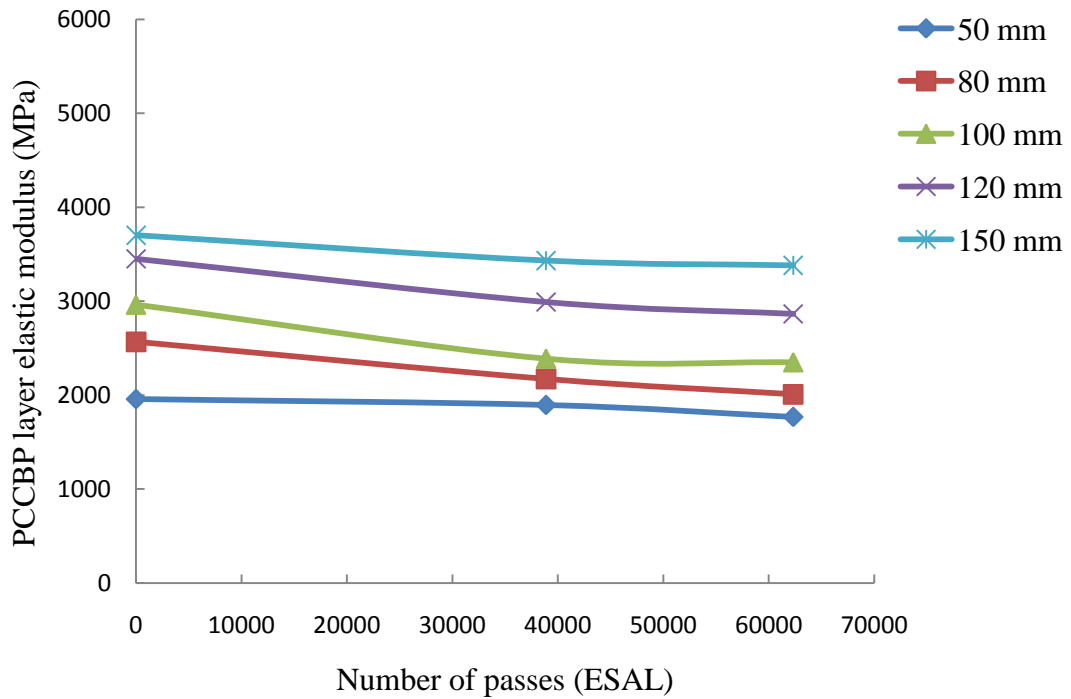


Figure 3.38: Variation of PCCBP layer elastic modulus with number of passes (ESAL), for different thicknesses.

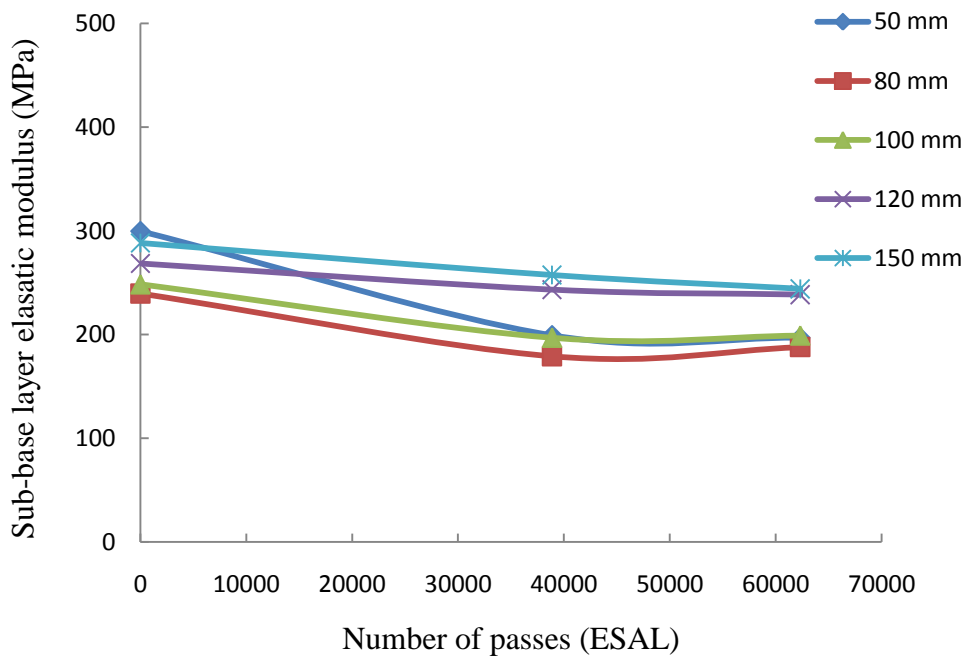


Figure 3.39: Variation of sub-base layer elastic modulus with number of passes (ESAL), for different thicknesses.

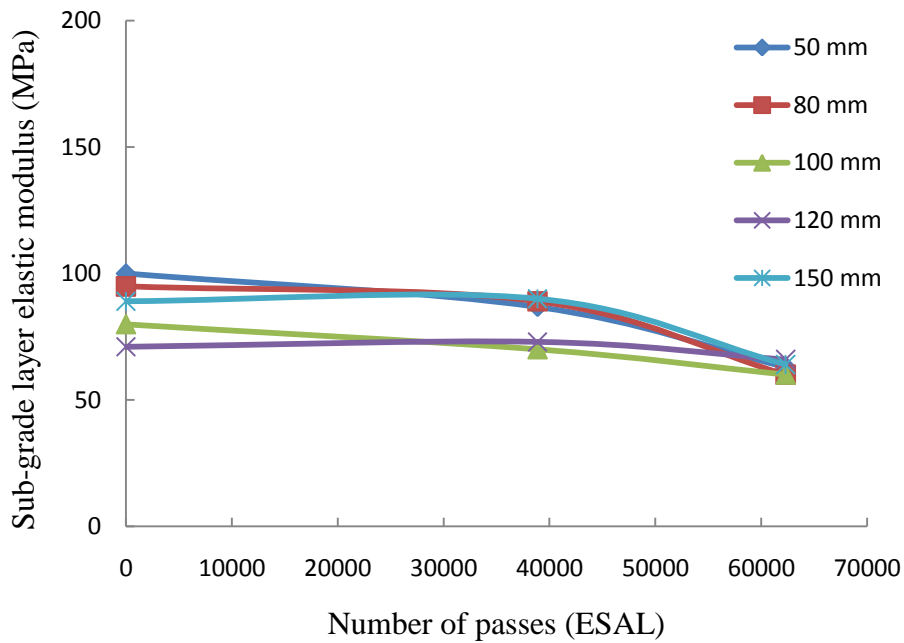


Figure 3.40: Variation of sub-grade layer elastic modulus with number of passes (ESAL), for different thicknesses.

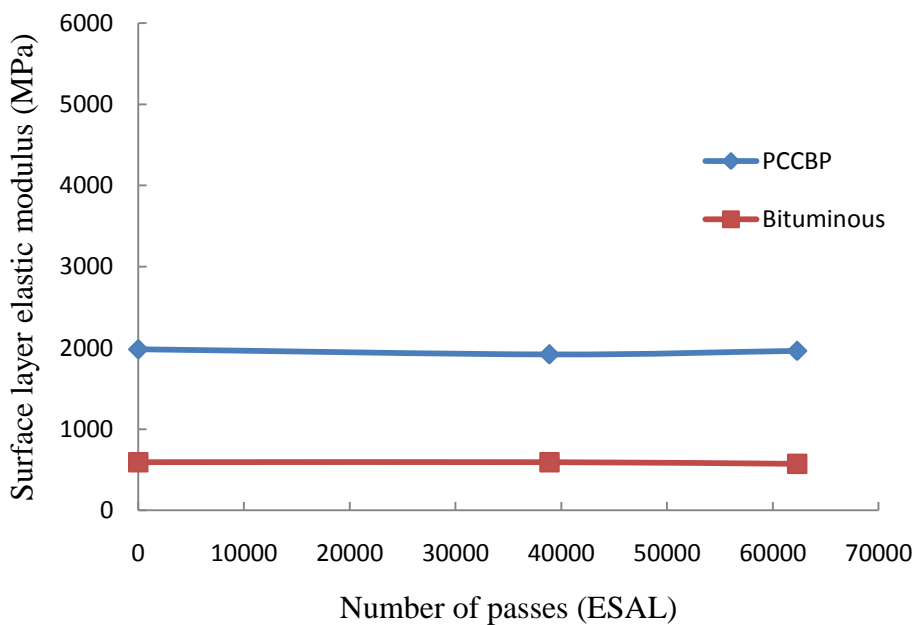


Figure 3.41: Variation of surface layer elastic modulus for surface layer with number of passes (ESAL), for PCCBP and bituminous overlay construction.

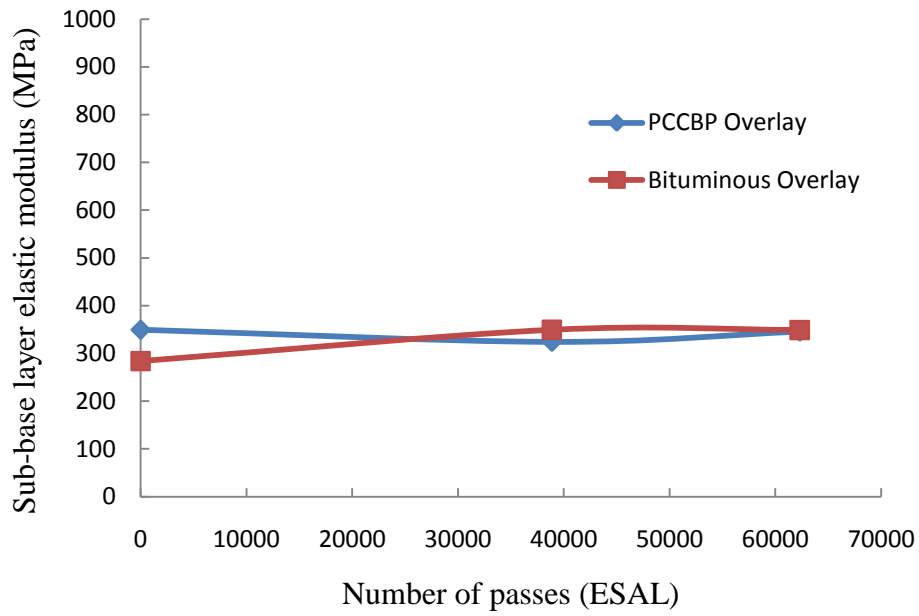


Figure 3.42: Variation of sub-base layer elastic modulus with number of passes (ESAL), for PCCBP and bituminous overlay construction.

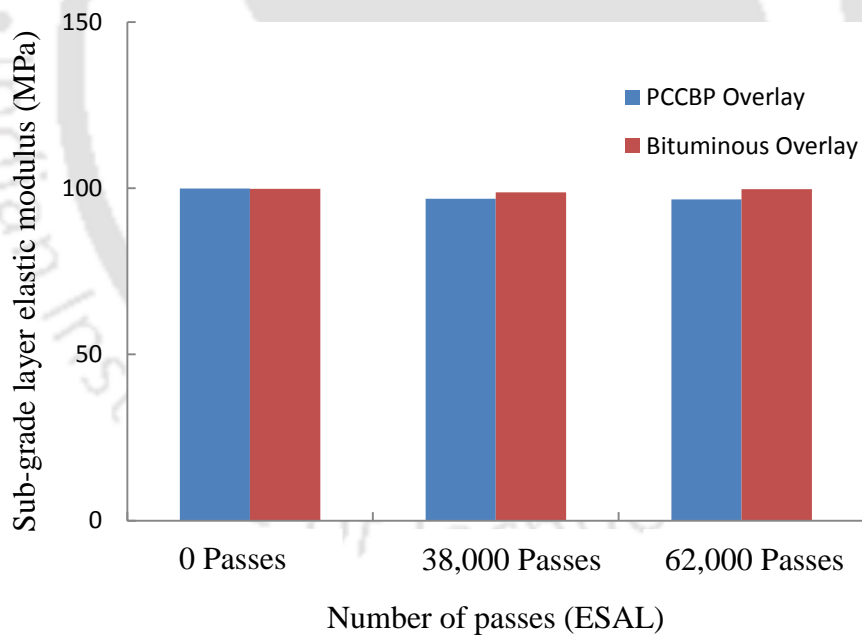


Figure 3.43: Variation of sub-grade layer elastic modulus with number of passes (ESAL), for PCCBP and bituminous overlay construction.

CHAPTER 4

Distress Study of PCCBP

4.1 Introduction

As mentioned in the literature review (Chapter 2) limited distress observations have been reported on PCCBP. To the best of author's knowledge, no systematic work is available on distress studies of PCCBP, although limited distress (e.g., edge spalling, block disintegration, scaling, permanent deformation) inspections were first reported by Vissar and Hill (1999) and Vissar (1999). As such, an attempt has been made in this chapter to report various types of distresses that are observed in the short duration (~ 11 months) of investigation. Due to the similarities in load transfer mechanism between interlocking concrete pavement and PCCBP, and in the absence of standards and guidelines for evaluation of PCI for PCCBP, Interlocking Concrete Pavement Distress Manual (ICPI, 2007), published by International Concrete Pavement Institute, Toronto, Canada, has been adopted for the present study. Four distresses viz., 1) damage pavers, 2) depression, 3) faulting and 4) rutting as mentioned in ICPI (2007) and four new distresses specific to PCCBP viz., 1) edge spalls, 2) scaling, 3) exposed cells and 4) cell opening are identified. Thus, the deduct curves developed by ICPI (2007) have been used for PCI calculation, and as deduct values have not been obtained (not in the purview of the present research) for the new distresses, their contribution to PCI calculation could not be carried out, and only their descriptions along with suggested severity levels are presented. In the subsequent sections, various terminologies (ASTM, 2009; ICPI, 2007) related to the distress evaluation in the present study are presented first, followed by observed distresses, and evaluation of PCI for PCCBP test sections.

4.2 Terminology

1) *Pavement distress:*

External indicators of pavement deterioration caused by loading, environmental factors, construction deficiencies, or a combination thereof. Typical distresses are depressions, rutting and edge spalls of the test section.

2) *Pavement Condition Index (PCI):*

It is a numerical rating of the pavement condition that ranges from 0 to 100 with 0 being the worst possible condition and 100 being the best possible condition. It may be noted that PCI does not measure structural capacity nor does it provide direct measurement of skid resistance or roughness. The basic flowchart for developing the PCI values for a section of pavement is shown in Figure 4.1

3) *Pavement Condition Rating (PCR):*

It is a description of pavement condition as a function of the PCI value that varies from failed to excellent as shown in Figure 4.1.

4) *Random Sample:*

A sample unit of the pavement section selected for inspection by random sampling techniques.

5) *Apparatus used:*

- *Data Sheets* that record at a minimum the following information: date, location, section, sample unit size, block number and size, distress types, severity levels, quantities, and names of surveyors (**Appendix E**).
- *Tape*, 100 feet long (30 m) that reads up to 1 inch.
- *Straightedge or string line*, 10 feet (~3 m), aluminum square hollow section (50 mm x 50 mm) and 3 meter in length and string line for length of distress area which are more than 3 meter.

- *Scale*, 12 in. (300 mm) that reads to 1/16 in. (1 mm) or better. Additional 12 inches. (300 mm) ruler or straightedge.
- *Layout plan*, for PCCBP test sections.

4.3 Distress Evaluation

Separate distress observations have been presented for the two types of PCCBP constructions viz., 1) new PCCBP test sections and 2) overlay construction over bituminous surface.

4.3.1 New PCCBP test section

The type and severity of PCCBP distress was assessed by direct visual inspection and physical measurement of rutting and depressions of test sections (2.7 m x 5.0 m) having different thicknesses (50 mm, 80 mm, 100 mm, 120 mm and 150 mm laid over 100 mm thick WBM course). The performance study was carried out for a short duration (~ 11 months). A preliminary visual observation shows a zone of major traffic flow (wheel path) ~2500 mm closer to the inner portion of the test section (total road width is 7 meter) as shown in Figure 4.2. Visual evaluations as well as field measurements were carried out at 0 (zero), 23000, 50000 and 62,000 ESAL passes (Figure 4.3). Figure 4.3 shows the gradual surface degradation through edge spalls and exposure of plastic cells (more discussion on Section 4.4) of different test sections with number of load repetitions (ESAL).

4.3.1.1 Distress types similar to Interlocking concrete block pavement distress manual (ICPI, 2007)

The typical distress types identified in the present study which are similar to interlocking concrete block pavement are:

1. Rutting
2. Damage pavers
3. Depression
4. Faulting

Rutting:

Description: Rutting is a permanent surface deformation that occurs along the wheel path. Rutting is typically caused by settlement of the underlying layers viz., sub-grade or sub-base courses under traffic loading.

Identification: Rutting can be located by visual assessment and measuring with a straight edge along wheel paths (Figure 4.4). Figure 4.4 shows rutting in the 50 mm PCCBP test section.

Measurement: Rutting is generally measured in square meters of pavement area. In the present study, since the area is small (~2.7 m x 5 m) for each test section, rutting was measured as number of blocks in a particular test section. The rut depth was determined by placing a straight edge across the wheel path and the depth is measured using a steel tape in millimeters. The severity of the rut can be defined by the maximum rut depth in mm.

Proposed Severity Levels: The severity level of rutting is in depth of rut. The level of severity is given in Table 4.1.

After about 62,000 ESAL passes, the rut depths were measured (at intervals of 0.5 m along the road and 0.2 m across the road) on each of the PCCBP section and are used to plot surface profile in the form of contour in Figure 4.5. The surface profile has been plotted by merging the data from all the sections including those of PCCBP and bituminous overlay, but excluding 300 mm gap in between adjacent sections. It can be seen that in the central portion (~ 2500 mm) near to the inner edge of the road a zone of permanent deformation / rutting can be identified, agreeing to the visual observation shown in Figure 4.2. Uneven surface deformation was observed, especially in the 150 mm thick PCCBP section, which could be due to the variations in sub-grade soil strength. In Figure 4.6, variation of average rut along the test sections are plotted with radial distance from the centerline of the road. It can be seen from Figure 4.6 that the maximum depth of rutting (~20 mm) was observed in 50 mm and 80 mm thick PCCBP, whereas for the 150 thick PCCBP it is around 10 mm after 62,000 ESAL passes. For 100 mm thick PCCBP, the average maximum rut depth is

around 15 mm, and this is in agreement with the result of 16 mm (extrapolated linearly for 62,000 ESAL repetitions) reported by Roy *et al.*, (2010) for 100 mm PCCBP over 100 mm thick soil-cement as sub-base layer. It may be noted that the allowable rut depth is 50 mm for a design traffic 1 million ESAL during the design life (10 years) for low volume rural roads (IRC, 2007; AASHTO, 1993). Although it appears that around 40% of the allowable rut depth has reached for 50 mm thick PCCBP (20% for 150 mm thick PCCBP), after 62,000 ESAL passes, it is difficult to comment on its increase/stabilization of rutting with further load repetitions.

Damaged paver:

Description: Damaged pavers describe the condition of the cast-in-situ cell filled concrete blocks due to load related damages. It can include distresses on the blocks such as a chip, crack etc.

Identification: Damaged pavers would include paver distresses such as partly or fully block damage, chip, cracks etc. Minor cracks on blocks with little to no opening are considered to have less significant effect on performance. Figure 4.7 shows damage paver observed in 120 mm thick PCCBP test section.

Measurement: Damaged blocks are counted as number of blocks in a particular test section in the present study.

Severity level: The severity is evaluated by degree of distress and is given in Table 4.2.

Depression:

Description: Depressions are areas of the PCCBP surface that have lower elevations as compared to that of surrounding areas due to settlement of the underlying sub-grade or granular base (WBM). Depressions can result in making the pavement rough and during rainy season it can lead to water ponding.

Identification: Depressions can be identified by using a 3 m straight edge and compare the surface elevations. In the present study, the apparent vertical depth of differential elevation below the straight edge is measured using a steel tape.

Measurement: Depressions are measured in number of blocks in the test section. The severity is defined by the maximum depth of depression. Figure 4.8 shows a medium severity depression in 80 mm thick PCCBP test section.

Severity Level: The severity is evaluated by degree of distress and is given in Table 4.3.

Faulting:

Description: Faulting are areas of the pavement surface where the elevation of some blocks differ from the surrounding blocks, caused by settlement of the sub-base or sub-grade layer. It can be identified by small areas of individual blocks standing tall of each other. Faulting can cause roughness on pavement surface, leading to uncomfortable ride.

Identification: Faulting is identified by small pocket areas of individual blocks standing tall of each other. Figure 4.9 shows the faulting of blocks in 100 mm thick PCCBP test section. This distress is often combined with other distresses such as settlement, heave, rutting, etc.

Measurement: Faulting is measured in number of blocks affected in the present case. Severity is defined by the maximum elevation difference.

Proposed Severity Levels: The proposed severity level for faulting is given in Table 4.4.

4.3.1.2 Distresses specific to PCCBP

New distresses observed specially in PCCBP pavements are: 1) edge Spalls, 2) scaling, 3) exposed cells, and 4) cell opening. Severity level is also proposed based on

visual observations and in conjunction with similar distresses as highlighted by ICPI (2007).

Edge spalls:

Description: Edge spalls are the breakdown of the edges of the individual blocks caused by the relative movement of the blocks. Edge spall occurs when there is a layer of concrete above the plastic cell top, and is generally due to bad workmanship with levels not flushed with top of plastic cells. The edge spalls is different from edge breaking in that the spalls occurs at an angle to intersect the joint whereas the break extends vertically through the slab. Figure 4.10 shows different stages of edge spalls of the concrete blocks in PCCBP.

Identification: Edge spalls are identified by the edge breakage of blocks, with breakage plane meeting the joint at an angle.

Measurement: If one or more edge spalls with the same severity level are in a block, the block is counted as one block.

Proposed severity levels: The proposed severity level of edge spalls is on the depth of spall. Table 4.5 shows the severity level of edge spalls of blocks in the present study.

Figure 4.10 shows the gradual development of edge spalls and exposure of plastic cells. Formation of similar pattern of cracks along edges was also reported by Roy *et al.*, (2009), Shivaprakash, (2011). The possible mechanism of the formation of edge spalls is depicted in Figure 4.11. An initially vertical plastic cell wall of specific height gets deformed (resulting in shortening its height) during concrete compaction. Such deformation in the plane of the cell wall (High-density polyethylene cell wall) of the order of 5 mm (reduction in cell height) was also reported by Visser (1999). Reduction in the cell height in the present study is found to be in the range of 6% - 10% of the total cell height. However, the leveling of the finished PCCBP surface (50 mm, 80 mm, 100 mm, 120 mm and 150 mm) was done in order to maintain the existing bituminous pavement surface level, and hence an extra layer of concrete (6% to 10% of total height) above the plastic cell formwork can be visible from the core

sample. Such extra layer of concrete above the deformed plastic cell walls was also seen in the work of Sahoo et al (2006). The extra concrete layer above the plastic cell formwork causes the edge spalling due to the relative block movement under traffic. The edge spalling mechanism consists of two steps, 1) formation of vertical cracks above the plastic cell tops (first stage of cracking), 2) gradual chipping of the block edges with traffic passes till the vertex of triangular spall meets the top of the plastic cell. The occurrence of edge spalls in the present study may be related to the vertical deformation (rutting) in the zone of traffic flow, where average deformations (Figure 4.6) at the end of 62000 ESAL passes exceeded 1 mm (a limiting deflection criterion suggested by Visser and Hall (2003) for no spall formation).

Scaling:

Description: Scaling is the peeling of thin leveling cement mortar layer from the pavement surface. Thin cement mortar are applied to even out local undulations and if there is a time lag between concreting and placement of the mortar, there are chances of being separated out during trafficking. Scaling may also arise from bleeding of the concrete for reasons such as over compaction and excessive water. Figure 4.12 shows the scaling of 100 mm thick PCCBP surface.

Identification: Normally 3 mm to 10 mm in depth and the occurrences is measured in square meter.

Measurement: Scaling can be measured in square meters of surface area.

Proposed Severity Levels: The proposed severity level is given in Table 4.6

Exposed cells:

Description: The plastic cell wall gets exposed either due to damaged pavers or due to edge spalling. After the loose concrete is removed the plastics are exposed and subjected to wear under traffic. Figure 4.13 shows exposed cell wall in the 80 mm thick PCCBP test section.

Identification: Exposed plastic cells can be identified by visual observation of the cell walls.

Measurement: Exposed cells can be measured in 'mm' of depth.

Proposed Severity Levels: The severity level can be expressed in the amount of depth of plastic exposure. Table 4.7 shows the proposed severity level of exposed cells

Cell opening:

Description: The length of the block sides can be increased due to opening of sealing in the plastic cell formwork. Opening of sealing can occur while concreting. This large size blocks can create unevenness due to unequal response to vertical movement, as compared with that of the original smaller sizes in the vicinity. Figure 4.14 shows cell opening in the PCCBP test section.

Identification: Normally the opening cells are identified based on the size of the block sides.

Measurement: Cell opening can be measured in term of 'mm' for the sides of blocks.

Severity Level: The severity level can be expressed as the size of the block sides in 'mm'. The proposed severity level is given in Table 4.8.

4.3.2 Overlay PCCBP test section

Figure 3.15 shows the surface condition of 50 mm thick PCCBP overlay lay over existing bituminous pavement with sub-base thickness of 445 mm. It can be observed that even after ~62000 ESAL passes, no significant distress has been observed except hairline cracks on the periphery of the blocks. Visual observation shows that unlike 50 mm PCCBP test sections laid over 100 mm thick WBM course, there is no edge spalls of the blocks in overlay section. Enhanced performance of the PCCBP overlay can be attributed to the well compacted under laying layers.

4.4 Evaluation of PCI

4.4.1 Measuring Techniques

The measuring technique adopted in the present study follows the guidelines laid down by ICPI (2007) for distress measurement of interlocking concrete block pavement. Linear measurements were done using a measuring tape (30 meter). However, as the size of the test pavement is small, instead of measuring the distress areas, affected number of blocks is counted. Hollow square aluminum pipe of 50 mm x 50 mm (~ 2'' x 2'') and 3 meter (10 feet) long was used as straightedge. Vertical measurements under a straightedge were done using a steel tape that can read up to 1 mm (1/16 inch). Depressions and ruts were measured to where the straight edge meets the pavement surface. For each test section, the quantities of different distress and their severities level were recorded based on visual justification. Where multiple severities exist within the outer boundary of a distress, outline of each severity is identified and running subtotal of each of the severities were noted.

4.4.2 Different thickness of PCCBP

The evaluation of distress in the present study was carried out based on the PCI methodology. Flow chart showing the calculation of PCI for PCCBP test section is given in Figure 4.16. The area to be surveyed (different test sections) was marked properly and the survey was carried out using pavement condition survey data sheet prepared by ICPI (**Appendix E**) following the measurement technique mentioned in Section 4.4.1. Table 4.9 shows different types of distress and their severity levels which were observed in different PCCBP test sections. The total severity of each distress type is recorded in number of affected blocks and the percentage density has been calculated as a fraction of total number of blocks in the sample unit. The deduct value is then calculated from the deduct curves (Figure 4.17 to Figure 4.20) for each type of distress (ICPI, 2007). For calculation of the maximum corrected deduct value (CDV), the iterative method described by ICPI (2007) was followed. The value of q , which is the number of deducts greater than 2 was calculated. Using the value of q and total deduct value the CDV has been calculated from the corrected deduct value curve given in Figure 4.21. The PCI for each test section was calculated by

subtracting the maximum corrected deduct value (CDV) from 100: $100 - \text{Maximum CDV} = \text{PCI}$. A sample PCI calculation sheets is given in **Appendix F**. The overall condition rating of the section is evaluated from the PCI rating chart given in Figure 4.1. Table 4.10 shows the PCI value and overall rating of each test section.

4.4.3 PCCBP overlay

Visual observation shows that there are no distinct distresses observed in the PCCBP overlay test section. However, PCI value was calculated in the similar manner and is presented in Table 4.10.

4.5 Discussions

Studies on various types of distress carried out as per ICPI distress guide lines (ICPI, 2007) based on the deduct value and PCI values showed that different thicknesses of PCCBP test section can be rated as Fair to Very Good (Table 4.10). Comparing the PCI rating with variation in layer elastic modulus of PCCBP (Figure 3.38), it has been observed that 50 mm, 80 mm and 100 mm thick PCCBP is rated “Fair” even though there is no significant reduction in elastic modulus value. The reason may be edge spalls due to extra layer of concrete (6%-10% of cell height) above the cell formwork resulted from deformation of cell wall (Figure 4.11). In addition the PCCBP test sections showed some specific distress types of low severity like cell opening, exposed cells, edge spalls etc. which are not common to interlocking concrete block pavements. The deduct curves are yet to be developed for these new distress types (not in the purview of the present research), and are not considered in the PCI calculation. In an earlier study, Visser (1999) reported an initial slight spalling (because of high deflection), but observed later that the spalling did not deteriorated further after fifteen months. It may be noted that Visser (2003) also mentioned about edge spalls and scaling but no detail study was reported. Performance evaluation need to be carried out for a longer duration and deduct curves need to be developed for better understanding of PCCBP.

4.6 Conclusions

The main conclusions drawn from the present study are:

1. Based on the distress study of the PCCBP test sections, four distresses viz., 1) damage pavers, 2) depression, 3) faulting and 4) rutting as mentioned in ICPI (2007) and four new distresses specific to PCCBP viz., 1) edge spall, 2) scaling, 3) exposed cells, and cell opening are identified.
2. Distress evaluation of PCCBP test sections (after 62,000 ESAL passes) based on ICPI distress manual showed that 50 mm thick PCCBP can be rated as Fair and highest thickness 150 mm PCCBP thickness can be rated as Very Good based on pavement condition index rating chart.
3. PCCBP as overlay construction on the existing bituminous pavement shows no significant distresses even after 62,000 ESAL load repetitions and can be rated Excellent based on PCI rating (ICPI, 2007).

Table 4.1: Severity level of rutting (ICPI, 2007).

Severity level	Maximum rut depth in mm
Low	5 – 15
Medium	15 – 30
High	> 30

Table 4.2: Severity level of damaged paver (ICPI, 2007).

Severity level	Criteria
Low	Individual cracks, spalls or weathering.
Medium	Advanced cracking, spalling or weathering
High	Blocks are in multiple pieces or are disintegrate.

Table 4.3: Severity level of depression (ICPI, 2007).

Severity level	Maximum depression depth in mm
Low	5 – 15
Medium	15 – 30
High	> 30

Table 4.4: Severity level of faulting (ICPI, 2007).

Severity level	Elevation difference in mm
Low	4 – 6
Medium	6 – 10
High	> 10

Table 4.5: Severity level of edge spalls.

Severity level	Spall depth in mm
Low	< 10
Medium	10 -30
High	>30

Table 4.6:Severity level of scaling.

Severity level	Scale depth in mm
Low	4 – 6
Medium	6 – 10
High	> 10

Table 4.7: Severity level of exposed cells.

Severity level	Exposed depth in mm
Low	< 5
Medium	5 -10
High	>10

Table 4.8: Severity level of cell opening.

Severity level	Sides of individual blocks in mm
Low	< 300
Medium	300 - 600
High	> 600

Table 4.9: Distress type and their severity condition for different thicknesses of PCCBP (ICPI, 2007).

Types of distress	Severity condition for PCCBP layer thickness (mm)				
	50	80	100	120	150
Damage paver	Low	Low	Low	Low	Low
Depression	Medium	Medium	Medium	Low	Low
Faulting	Low	Low	Low	Low	Low
Rutting	Medium	Medium	Medium	Low	Low

Table 4.10: Pavement condition rating of different thickness of PCCBP test section (ICPI, 2007).

PCCBP thickness in mm	Maximum CDV	PCI (100-maxCDV)	Rating
50	55	45	Fair
80	52	48	Fair
100	50	50	Fair
120	32	68	Good
150	30	70	Very Good
50 (Overlay)	10	90	Excellent

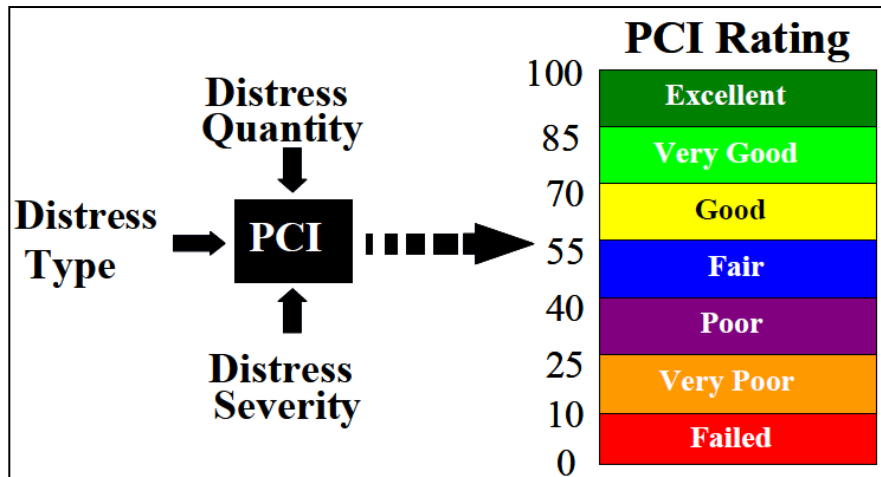


Figure 4.1: Flowchart for developing PCI values (ICPI, 2007).

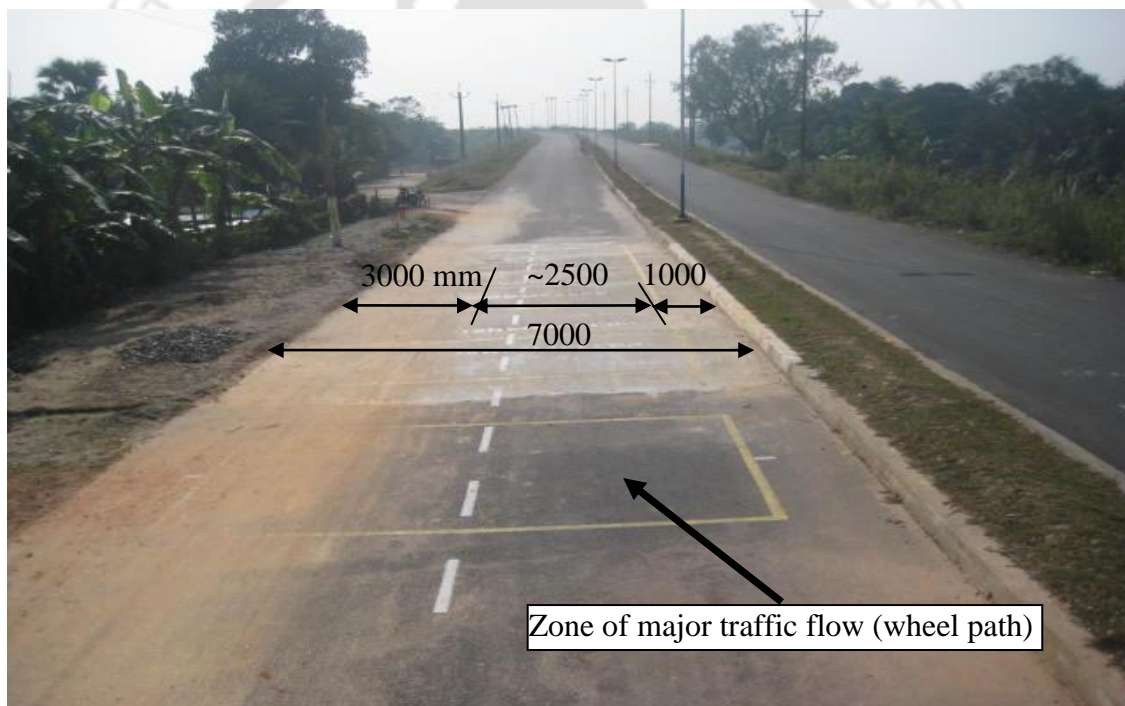


Figure 4.2: Zone of traffic flow (visual inspection).

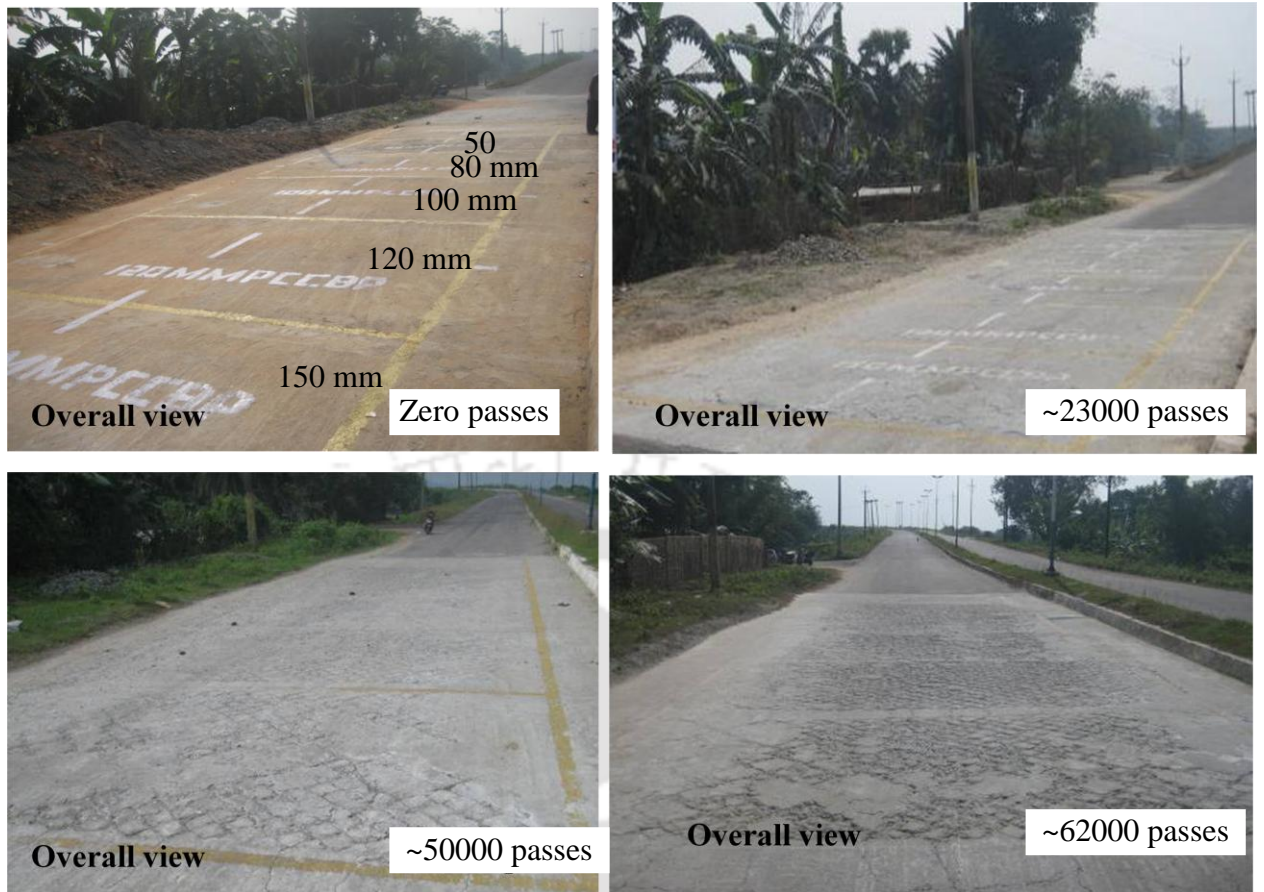


Figure 4.3: Surface degradation of the test sections with traffic passes (ESAL).



Figure 4.4: Rutting in 50 mm PCCBP test section.

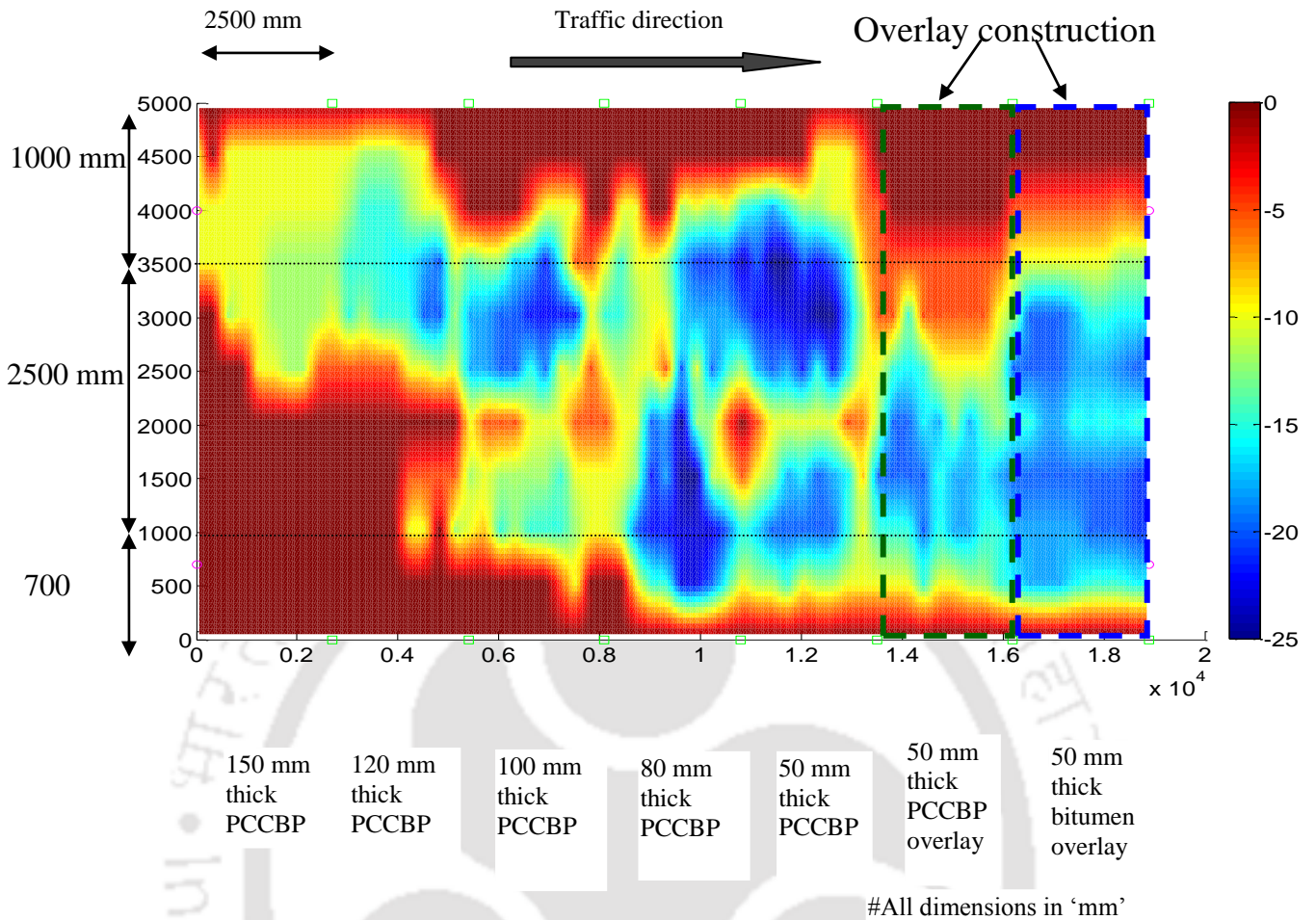


Figure 4.5: Surface profile contour of the test pavement after ~62000 ESAL passes.

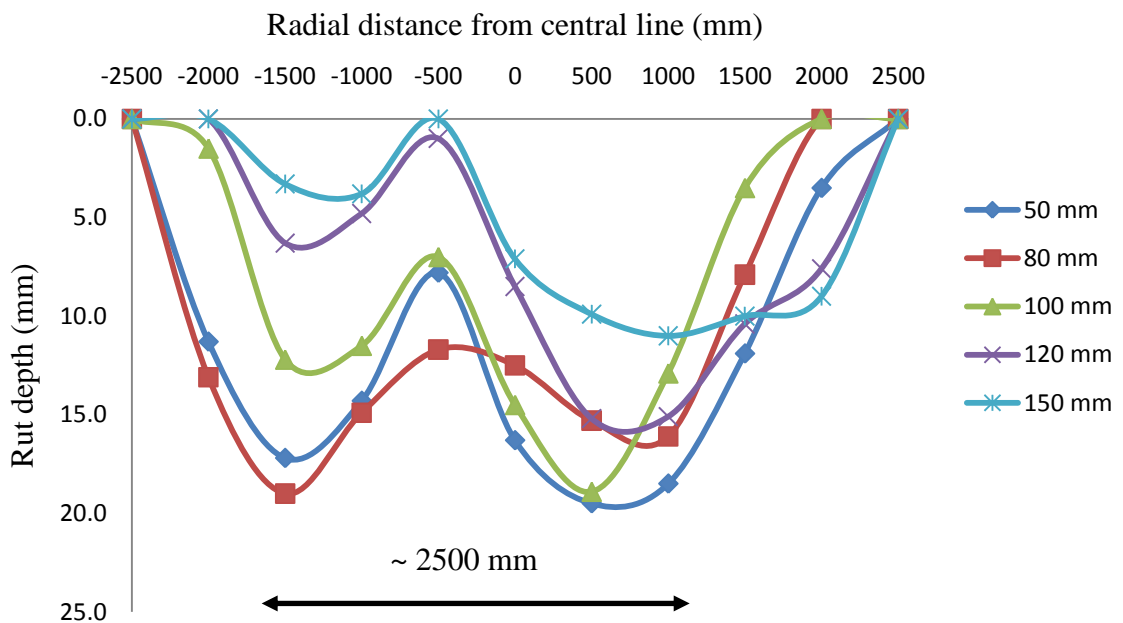


Figure 4.6: Average rut depth of different test sections after ~ 62,000 ESAL passes.



Figure 4.7: Damaged pavers observed in 120 mm thick PCCBP test section.

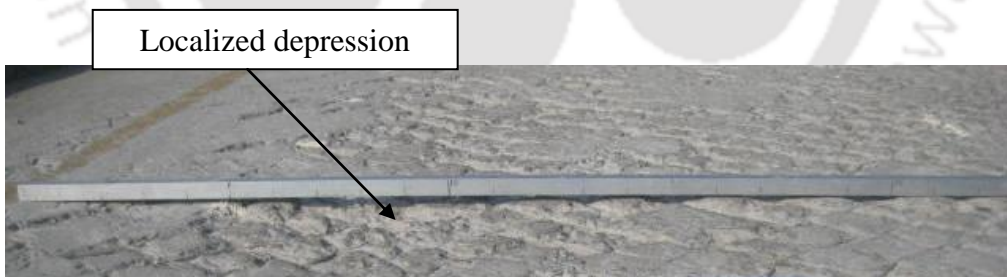


Figure 4.8: Measurement of depression (80 mm thick PCCBP) using a 3 meter long straight edge aluminium bar.

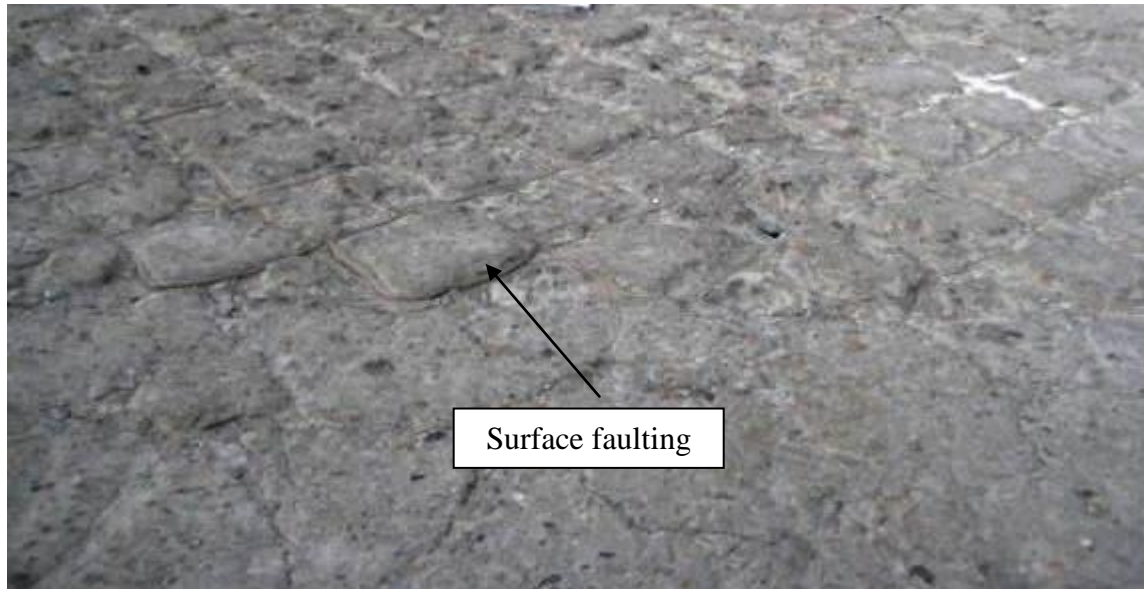


Figure 4.9: Surface faulting (100 mm thick PCCBP).

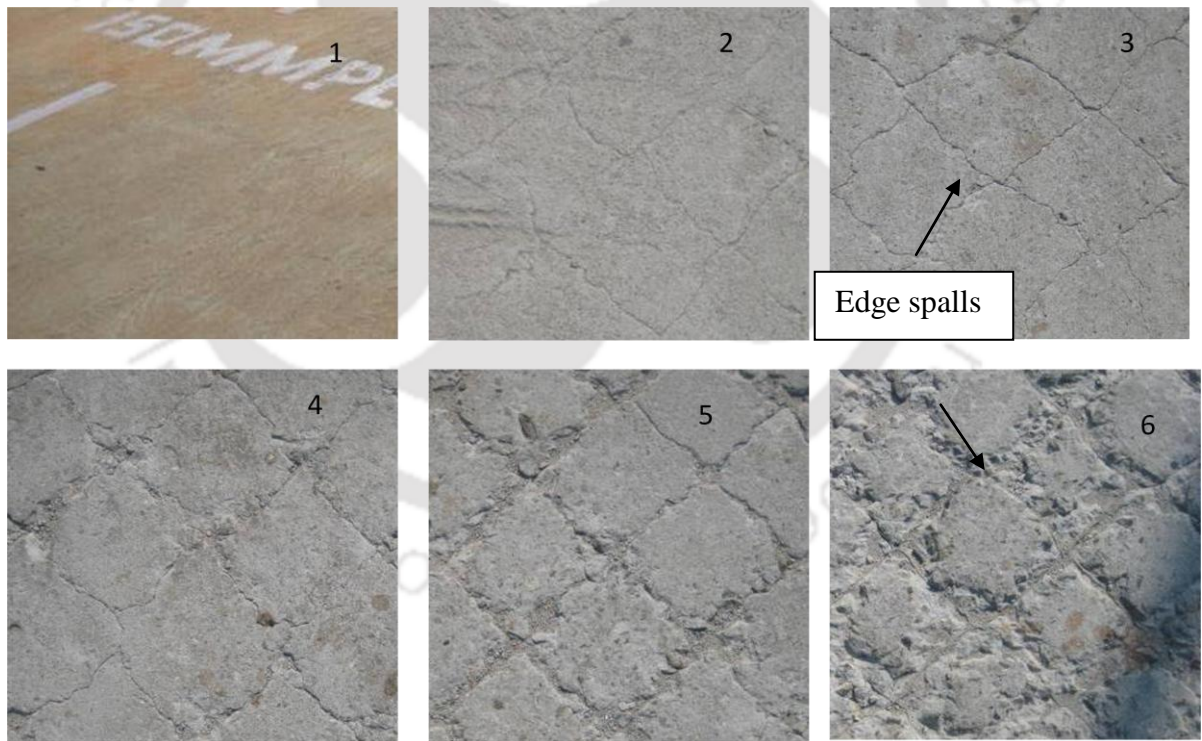


Figure 4.10: Different stages of development of edge spalls of PCCBP blocks.

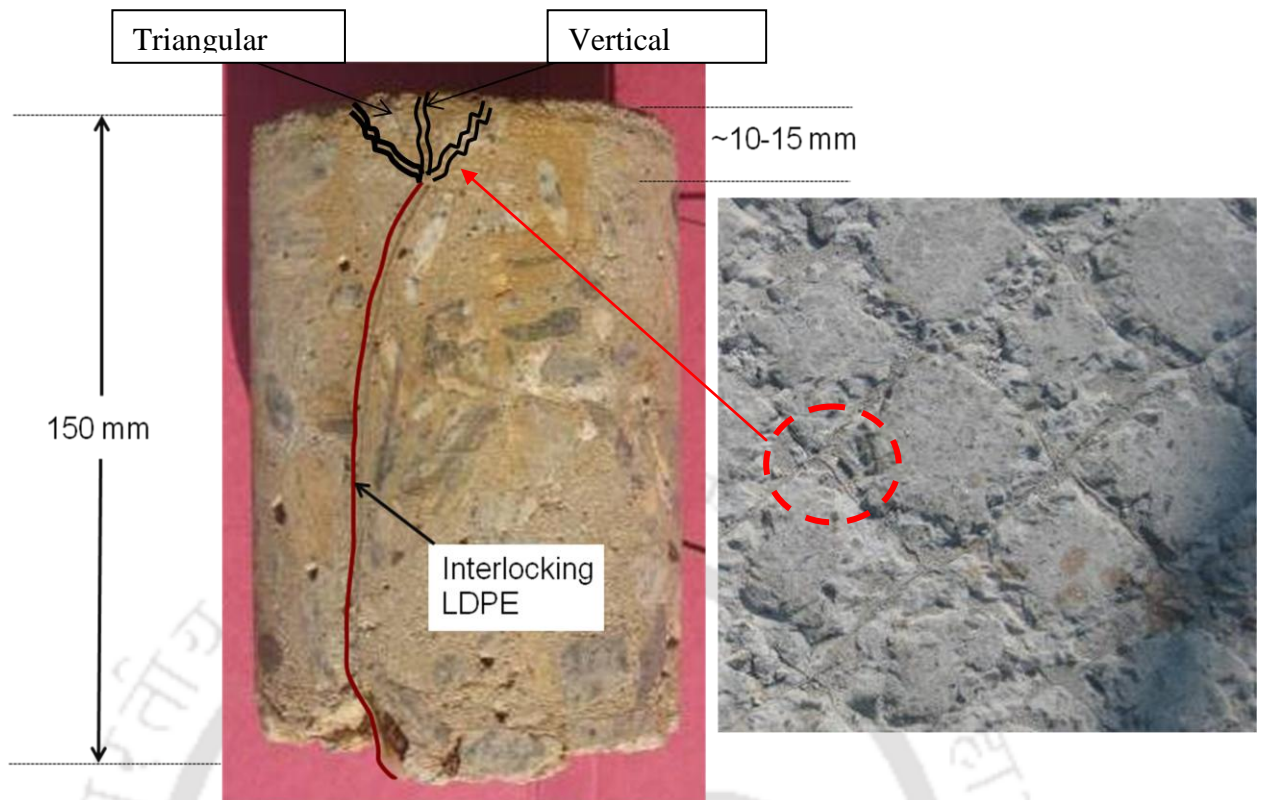


Figure 4.11: Edge spalling mechanism.

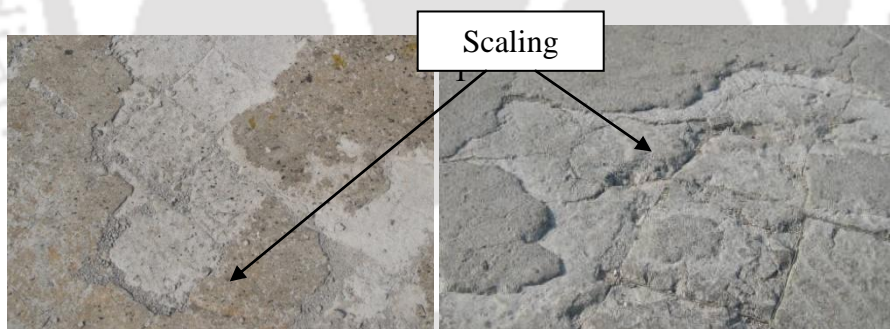


Figure 4.12: Scaling of 100 mm thick PCCBP surface.

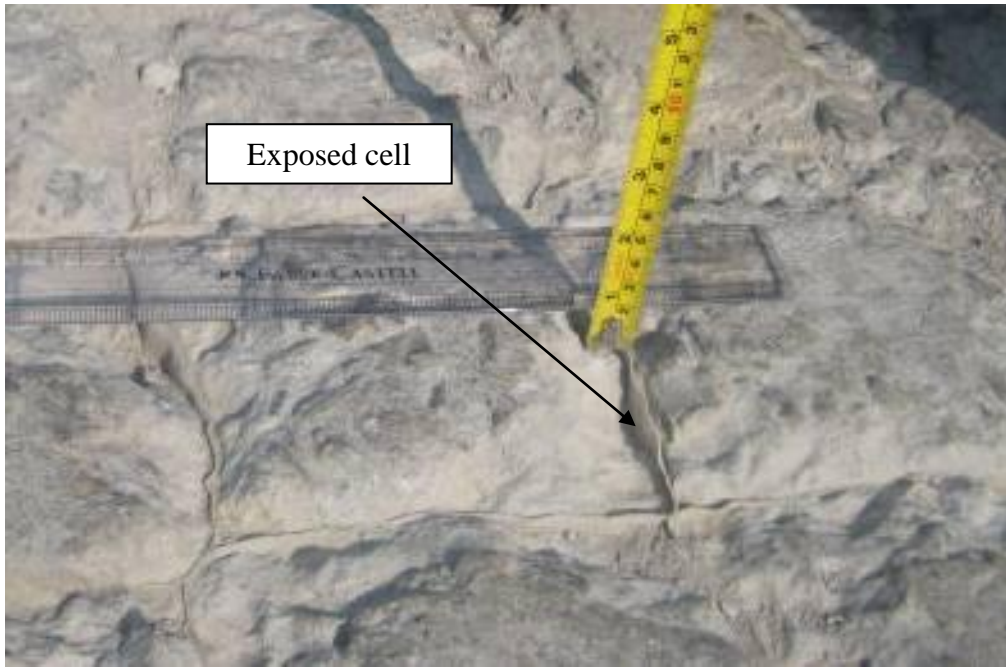


Figure 4.13: Exposed cells wall in the 80 mm thick PCCBP test section.

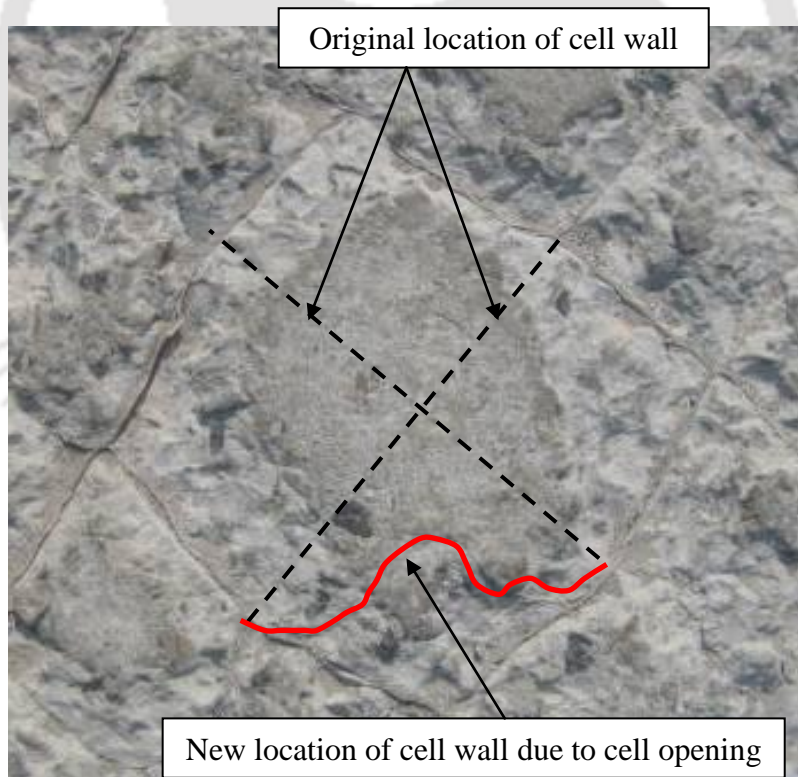


Figure 4.14: Cell opening in 100 mm thick PCCBP test section.

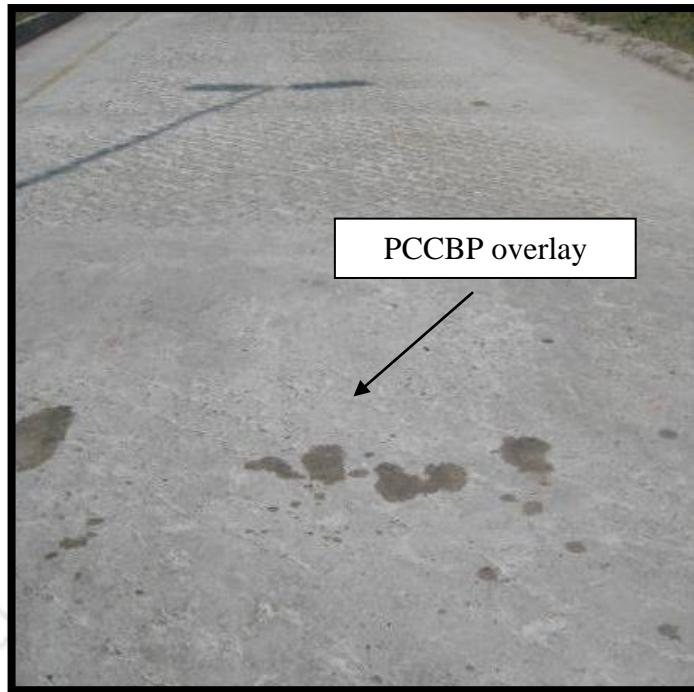


Figure 4.15: Surface condition of 50 mm thick PCCBP overlay lay over 445 mm thick existing bituminous pavement.

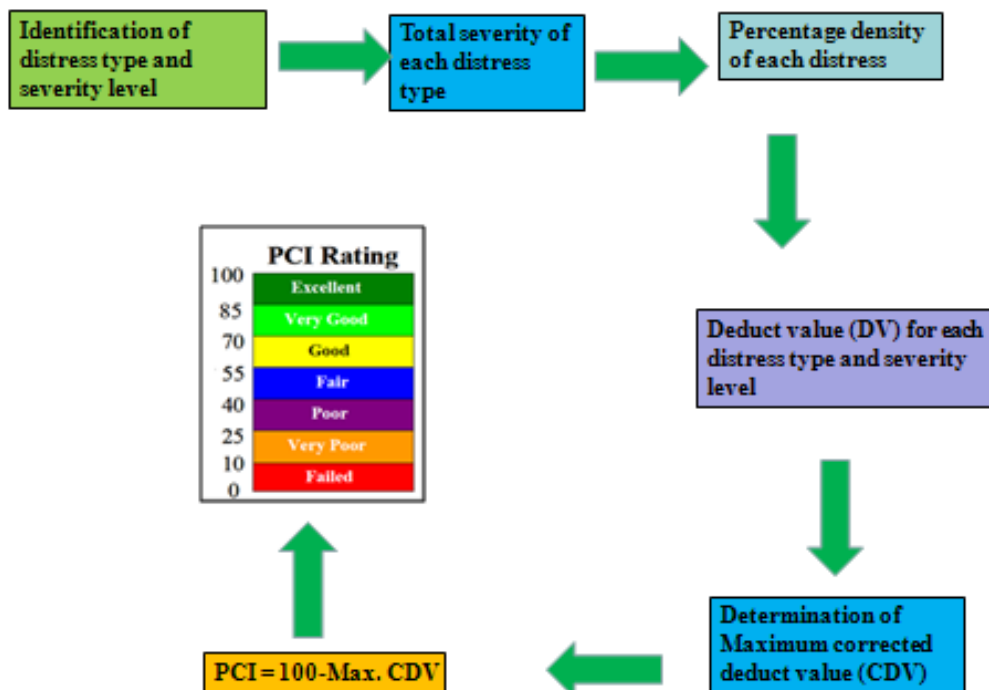


Figure 4.16: Flow chart for calculation of PCI.

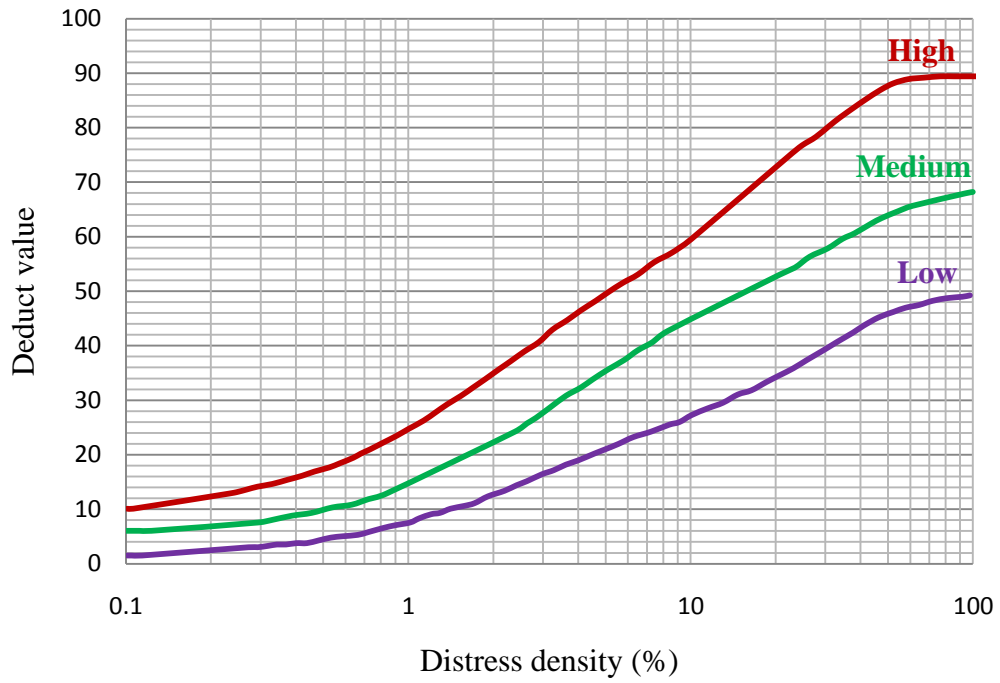


Figure 4.17: Deduct curve for rutting (ICPI, 2007).

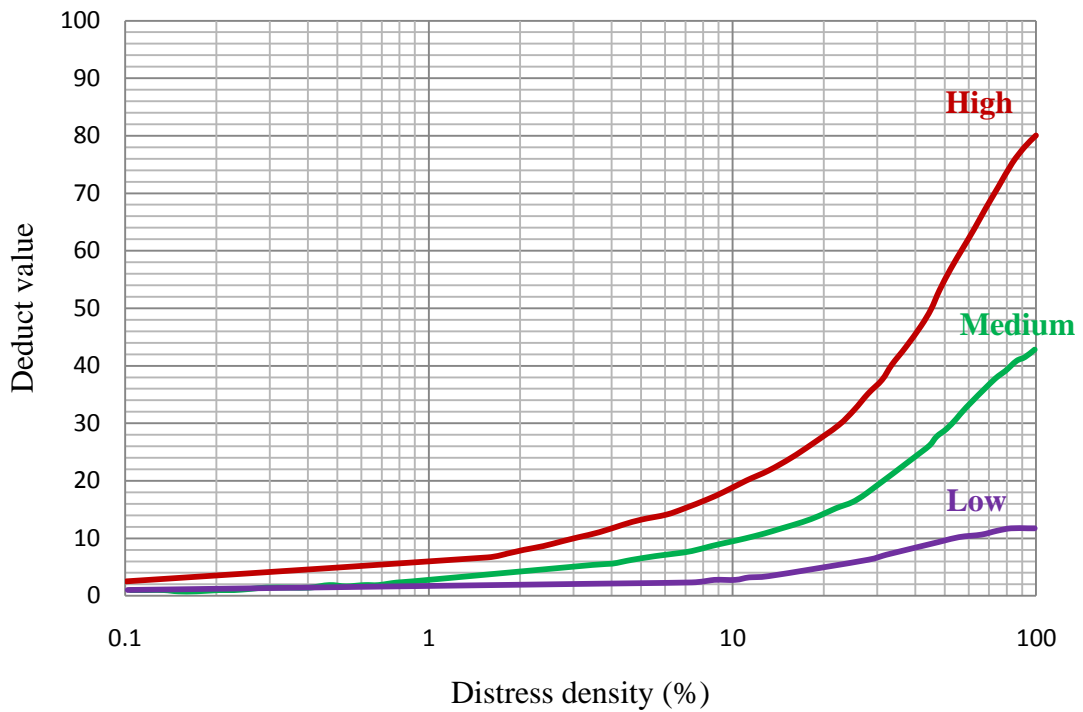


Figure 4.18: Deduct curve for damaged paver (ICPI, 2007).

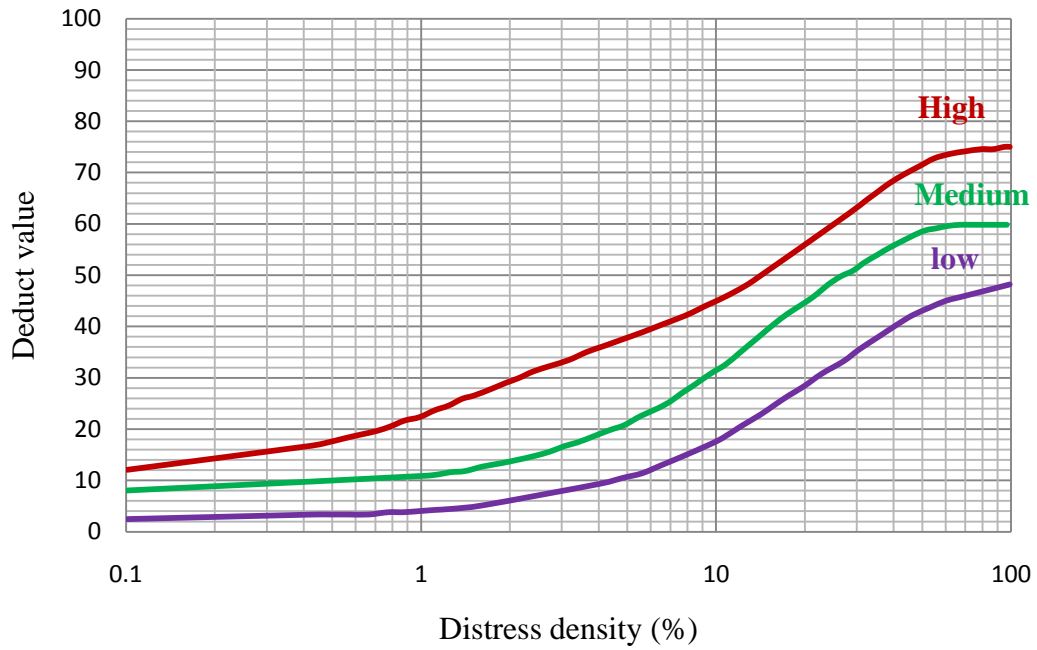


Figure 4.19: Deduct curve for depressions (ICPI, 2007).

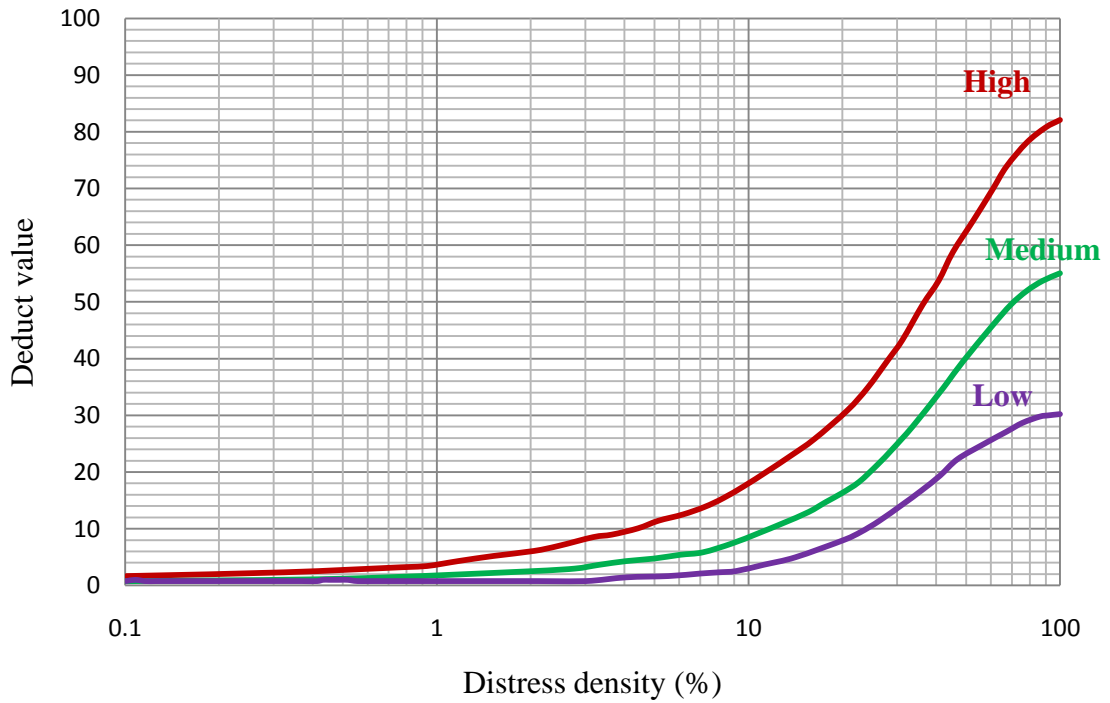


Figure 4.20: Deduct curve for faulting (ICPI, 2007).

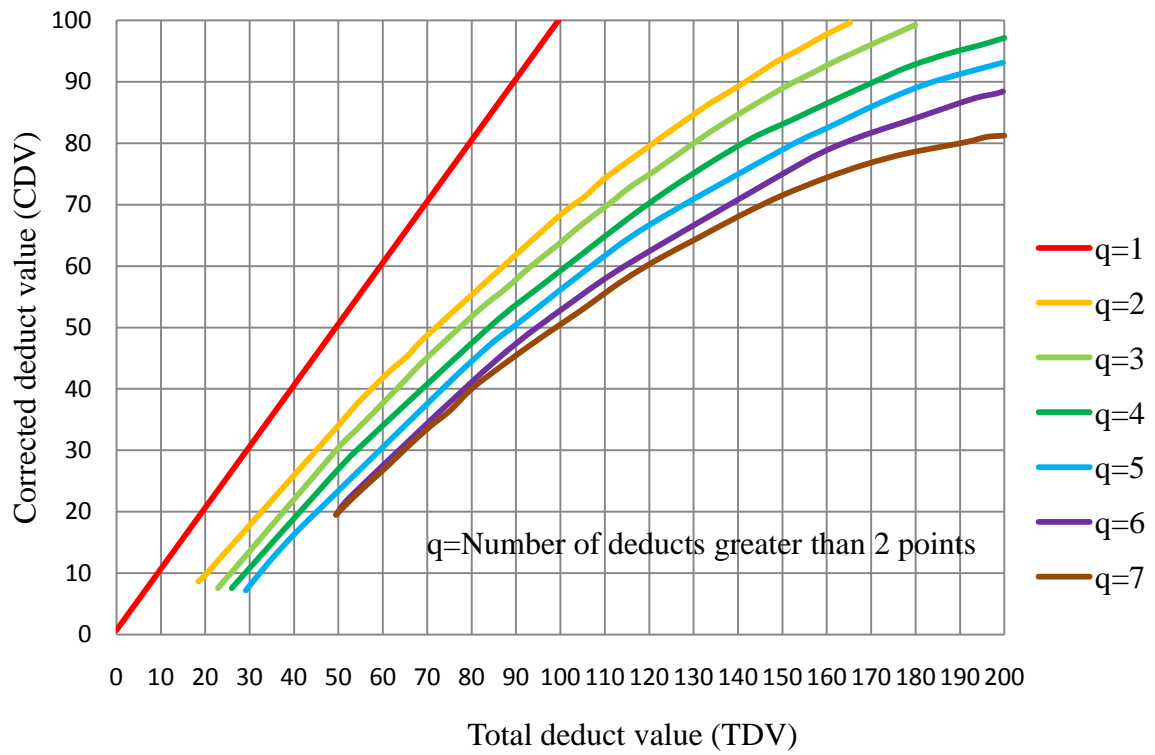
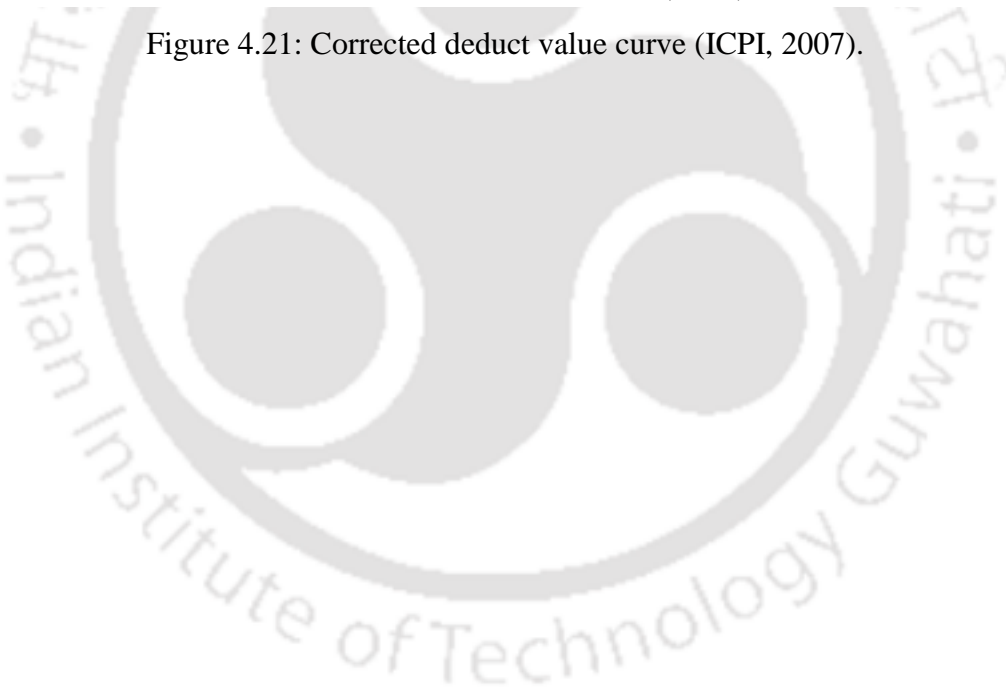


Figure 4.21: Corrected deduct value curve (ICPI, 2007).



CHAPTER 5

Economic Evaluation

5.1 Introduction

As reported earlier, in India, the proportion of low volume rural roads is about 80% of the total road length (NHAI, 2011). As such pavement engineers and researchers are concerned for designing sustainable rural roads with reasonable riding quality and with an emphasis on 'low life cycle cost'. It may be noted that conventional flexible pavement with a thin cover of premix bituminous carpet is generally constructed for rural roads, however, 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, thereby increasing the life cycle cost. To lessen such expensive maintenance cost, concrete pavements are getting popular in rural road because of their durability. On the other hand concrete (rigid) pavements require high initial cost and 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). As an alternative for better structural performance and low maintenance Plastic Cell Filled Concrete Block Pavement (PCCBP) developed in South Africa (Visser, 1994, 1999; Visser and Hall, 1999, 2003) has been investigated. As discussed in Chapter 3, in the present study of PCCBP, an attempt has been made to use waste stone dust in place of the traditional river sand, in order to optimize the cost of pavement construction. In this chapter, economic evaluation (considering construction and maintenance cost for 5 years only) of PCCBP over traditional flexible and rigid pavements is presented.

5.2 Design of Different Types of Pavement

5.2.1 Design parameters

In order to assess the economic advantage of PCCBP (using stone dust as 100% sand replacement in concrete) over conventional flexible and rigid (concrete) pavements cost comparison have been carried out considering both construction and maintenance costs for a period of 5 years. To demonstrate the cost analysis, similar design parameters adopted elsewhere (e.g., Roy *et al.*, 2009, 2010, Rynthiang, 2005) are considered:

1. Lane width = 3.75 m (single lane carriageway)
2. Sub-grade CBR = 5%
3. Design traffic = 300,000 standard axle load repetitions

5.2.2 Design of flexible pavement

The flexible pavement has been design as per IRC (2007) for the design parameters mentioned in Section 5.2.1. From the pavement design chart, Figure 4 of IRC (2007), the thicknesses of the pavement layers have been obtained as 150 mm thick granular sub-base course (CBR > 20%), 175 mm thick WBM course and 20 mm thick bituminous premix carpet as surfacing.

5.2.3 Design of rigid pavement

The rigid pavement has been design for a wheel load of 51 kN (legal limit for axle load is 102 kN) as per IRC (2004) for the design parameters mentioned in Section 5.2.1. The effective modulus (k) of sub-grade reactions (20% increased for providing 150 mm sub-base course) for 5% CBR value for sub-grade is $50.4 \times 10^{-3} \text{ N/mm}^2/\text{mm}$ as per IRC (2004).

Flexural strength of concrete:

Adopt a 28 day compressive strength of 30 MPa (f_c)

Flexural strength, $f_t = 0.7 \sqrt{f_c} = 3.834 \text{ MPa}$

Therefore, the 90 day flexural strength = $1.20 \times 3.834 = 4.6 \text{ MPa}$.

Design thickness check

Edge load stress

As per IRC (2004), the design thickness of pavement slab is 220 mm, and the corresponding edge stress is 2.35 MPa (for $k = 50.4 \times 10^{-3} \text{ N/mm}^2/\text{mm}$).

Temperature stress

The radius of relative stiffness (l) for 220 mm thick slab as per IRC (2004) = 857.36 mm.

Assuming a contraction joint spacing of 3.75 m and width of slab as 3.75 m, the edge temperature stress was calculated to be 1.35 MPa (see Table 4 of IRC, 2004 for Assam state).

Total stress

The total stress = edge stress + temperature stress = 3.7 MPa, which is less than 4.6 MPa (flexural strength of the concrete). Hence, the slab thickness is safe and can be adopted.

5.2.4 Design of PCCBP

As mentioned earlier, the interlocking of the individual blocks in PCCBP allows a limited rotation and the pavement acts as a flexible concrete pavement (Visser, 1994). Also considering the observation that PCCBP has considerably high modulus (see Chapter 3), it is unlikely to suffer significant permanent deformation. Hence, only WBM (sub-base) and sub-grade are anticipated to undergo rutting i.e., rutting may be the mode of failure in this type of pavement as observed by Ryntathiang *et. al.*, (2005) and Roy *et. al.*, (2010). Rutting along the wheel path may be caused by permanent deformation in the sub-grade and/or sub-base of the pavement. Surface rutting in the flexible pavement is generally controlled by limiting the vertical sub-grade strain. Indian Road Congress (IRC, 2001), Shell and Asphalt Institute (SHELL, 1978) have limiting sub-grade strain criteria for controlling rutting in flexible pavements. While rutting in the asphalt layer is controlled by selection of a binder, the rutting in granular as well as in the sub-grade is controlled by limiting the vertical sub-grade strain. In the present study a reliability level of 50% (AASHTO, 1993) is adopted for design of PCCBP. Reddy and Pandey (1992) proposed the following vertical sub-grade strain criterion for 50% reliability considering 20 mm as the limiting value of rutting.

$$N=3.0599 \times 10^{-8} [1/\epsilon_z]^{4.5337} \quad (5.1)$$

Where, N = Number of cumulative standard axles to produce rutting of 20 mm

ϵ_z = Vertical sub-grade strain (micro strain)

The elastic modulus of the sub-grade soil ($E_{\text{sub-grade}}$) and sub-base layer ($E_{\text{sub-base}}$) can be obtained from:

$$\begin{aligned} E_{\text{sub-grade}} &= 10 \times \text{CBR} && \text{for CBR} \leq 5 \\ &= 17.6 \times (\text{CBR})^{0.64} && \text{for CBR} > 5 \end{aligned} \quad (5.2)$$

$$E_{\text{sub-base}} = E_{\text{sub-grade}} \times 0.2 \times h^{0.45} \quad (5.3)$$

For the present study, design analysis has been carried out for 100 mm thick PCCBP laid over a sub-base layer of 100 mm thick WBM course. The elastic layer modulus of 2300 MPa for PCCBP layer obtained through BACKGA has been used. The layer modulus of sub-grade and sub-base has been calculated as, $E_{\text{sub-grade}} = 50$ MPa (i.e. 10×5 for CBR 5%) and $E_{\text{sub-base}} = 50 \times 0.2 \times (100)^{0.45} = 79.43$ MPa. Using computer program code KENLAYER (Huang, 2010), the vertical sub-grade strain is calculated to be 1.832×10^{-3} MPa (see **Appendix G**), which is lesser than allowable strain value of 2.3×10^{-3} mm (from Equation 5.1).

The design thicknesses of the different types of pavements for the cost comparison are shown in Table 5.1.

5.3 Cost comparison

5.3.1 Construction and maintenance cost

The construction and maintenance cost have been estimated based on Public Works Department, Government of Assam schedule rates 2007-08 (PWD, 2007) and the guidelines for the estimation of the maintenance cost for construction of the rural roads (IRC, 2002; PMGSY, 2010). Suitable cost escalation factor to bring to the year

2010 market rate was considered based on monthly wholesale price index (OEA, 2010). The sample calculation for cost escalation factor is enclosed as **Appendix H**. In the absence of guidelines on maintenance cost for PCCBP and considering the good performance of cell filled concrete pavement 100 mm thick over 100 mm compacted moorum sub-base course constructed for village road which withstood 5 (five) heavy monsoons without any maintenance (Roy *et. al.*, 2009), it is considered to be the same as that taken for concrete pavement. The cost calculation for economic evaluation of PCCBP vis-a-vis conventional flexible and rigid pavement is given below. The detail cost analysis is enclosed as **Appendix I**.

5.3.2 Cost estimation

i) Flexible pavement

1. Construction of 150 mm thick granular sub-base course = Rs 169/m²
2. Providing and laying 175 mm WBM course = Rs 237/m²
3. Construction of 20 mm thick premix carpet (Grade A seal coat) = Rs 201/m²
4. Add cost escalation factor to bring to present (year 2010) rate = Rs 89/ m²

Therefore, the total cost of construction for flexible pavement = Rs 696/ m²

The routine maintenance cost for 5years = Rs 46/ m²

Renewal cost of flexible pavement after 5 years = Rs 236/ m²

ii) Rigid pavement

1. Construction of 150 mm WBM base course = Rs 203/m²
2. Construction of 220 mm thick plain cement concrete slab =Rs 1193/m²
3. Add cost escalation factor to bring to the present (year 2010) rate=Rs 205/m²

Therefore, the total cost of construction for rigid pavement = Rs 1601/m²

The routine maintenance cost for 5years = Rs 16/m²

Renewal / major repair cost of rigid pavement after 5 years = Rs 26/ m²

iii) Plastic cell filled concrete block pavement (PCCBP)

1. Cost of construction for 100 mm thick WBM course = Rs 135/ m²
2. Cost of plastic cell formwork (prepared from plastic pipe) = Rs 120/ m²

3. Cost of construction for 100 mm thick cement concrete (using stone dust)
= Rs 384/ m²

Therefore, the total cost of construction for PCCBP pavement = Rs 639/ m²

The routine maintenance cost for 5years = Rs 16/ m²

Renewal / major repair cost of PCCBP pavement after 5 years = Rs 26/ m²

5.4 Discussions

The cost comparison of PCCBP vis-à-vis conventional flexible and concrete pavement considering both construction and maintenance costs is shown in Table 5.2. It can be observed from Table 5.2 that initial construction cost for both flexible and rigid pavements are higher than that of PCCBP by ~9% and ~150% respectively and the total cost (including maintenance cost for 5 years) of flexible and rigid pavements are higher by ~43% and ~141% respectively as compared to that of PCCBP. The present results are in agreement with study conducted by Roy *et al.*, (2009, 2010), in Kharagpur (using river sand as fine aggregates), where the total cost (for 5 years) of flexible and rigid pavements are reported to be higher by ~54% and ~131% respectively as compared to that of PCCBP. The economical competitiveness of PCCBP over conventional pavements *viz.*, flexible (Visser, 1994; Visser and Hall, 1999, 2003; Sahoo *et al.*, 2006), rigid (Roy *et al.*, 2009, 2010) and block (Visser, 1994; Visser and Hall, 1999; Rynthiang, 2005) pavements have also been reported in the literature. Further considering negligible or no maintenance requirement of PCCBP tested for 4, 5 and 8 years by Visser and Hall (1999), Roy *et al.*, (2009) and Visser and Hall (2003) respectively, cost saving in using PCCBP is likely to be increased. Hence PCCBP with waste stone dust as replacement for the traditional sand for both concrete and WBM can be an economical option for rural roads. Any distresses that are accrued after 15 years of service may be rectified to bring back to the normal riding quality using an overlay of 50 mm PCCBP (Roy *et al.*, 2009).

5.5 Conclusions

1. As compared to PCCBP, the initial construction costs for conventional flexible and rigid pavement are seen to be higher by 9% and 150% respectively.
2. The total cost including construction and maintenance cost for 5 years of flexible and rigid pavements are higher by 43% and 141% respectively as compared to that of PCCBP.
3. Cent percent replacement of river sand in concrete by stone dust proved to be cost cutting without significant change in the strength of the concrete. Hence, PCCBP can be a suitable alternative to the conventional flexible and concrete pavement for the construction of rural roads which is labour intensive and cost effective



Table 5.1: Design thickness of flexible, rigid and PCCBP pavement for cost comparison.

Type of Pavement	Design thickness
Flexible	20 mm Pre-mix Carpet 175 mm thick WBM course 150 mm thick granular sub-base course
Rigid	220 mm thick concrete slab 150 mm thick WBM base course
PCCBP	100 mm thick Plastic Cell Filled Concrete Block Pavement 100 mm thick WBM base course

Table 5.2: Cost comparison of flexible, rigid and PCCBP pavement

Pavement	Cost in Rs per m ²			% Difference in total cost as compared to that of PCCBP (for 5 years)
	Construction	Maintenance (for 5 years)	Total (for 5 years)	
Flexible	696	282	978	+ 43.6
Rigid	1601	42	1643	+ 141.2
PCCBP	639	42	681	

CHAPTER 6

Summary and Conclusions

In this work full scale field experimental investigation have been made to assess the structural behaviour of different thicknesses (50 mm, 80 mm, 100 mm, 120 mm and 150 mm) of Plastic Cell Filled Concrete Block Pavement (PCCBP) over 100 mm sub-base layer of Water Bound Macadam (WBM) course, using 'waste' stone dust (produced as by-product of aggregates crushing) in place of the traditional river sand as fine aggregates in concrete. The feasibility study of PCCBP as overlay construction to strengthen the existing bituminous pavement was also carried out. Layer elastic moduli of different layers of PCCBP have been calculated using a genetic algorithm based moduli backcalculation computer code BACKGA (Reddy *et al.*, 2002) from the surface deflection data obtained through a custom fabricated Falling Weight Deflectometer (FWD, a non destructive test equipment which simulates the moving vehicular wheel load on the pavement). The layer elastic moduli obtained through BACKGA have been validated using two different elastic layer analyses approaches through KENLAYER and ABAQUS. Further, effort has been made to evaluate various types of PCCBP distresses based on pavement condition index (PCI) methodology. Economic evaluation of PCCBP is also presented comparing the construction and maintenance cost (for 5 years) vis-à-vis conventional flexible and rigid (concrete) pavement. Main conclusions based on the present investigation are summarized below:

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). 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.
6. PCCBP overlay showed significant improvement (~230% increase) in elastic layer modulus when compared to that of bituminous overlay suggesting that PCCBP can be a good alternative for strengthening the existing bituminous pavements.
7. Distress evaluation of PCCBP test sections (after 62,000 ESAL passes) based on ICPI distress manual showed that 50 mm thick PCCBP can be rated as 'fair' and highest thickness 150 mm PCCBP thickness can be rated as 'very good' based on pavement condition index rating chart. Specific distresses observed for PCCBP are also reported.
8. The construction and maintenance cost (for 5 years) of flexible and rigid pavements are computed to be higher by ~43% and ~141% respectively as compared to that of PCCBP. Hence PCCBP with waste stone dust as replacement for the traditional sand for both concrete and WBM can be an economical option for rural roads. Hence PCCBP with waste stone dust as replacement for the traditional sand for both concrete and WBM can be an economical option for rural roads.

CHAPTER 7

Recommendations for future work

Although considerable understanding have been obtained in the present work for the structural behavior of different thicknesses of PCCBP using stone dust as fine aggregate in concrete, significant amount of work may be identified as future scope of work on Plastic cell filled concrete block pavement.

- 1) Studies may be carried out on the effect of varying thicknesses of WBM (sub-base) course.
- 2) The effect of soil strength (in terms of CBR) on the elastic layer moduli of PCCBP may be investigated.
- 3) Possibilities of using different sub-base materials such as lime treated, cement treated and bituminous emulsion treated sub-bases need to be examined.
- 4) Investigation can also be done for different thicknesses of plastic. Use of waste plastics can also checked for using as cell formwork.
- 5) Development of deduct curves is important for evaluation of distresses based on pavement condition index.
- 6) Studies need to be carried out to check the feasibility of PCCBP for higher traffic.
- 7) Multi depth deflectometer can be installed so that live/regular monitoring the PCCBP test pavement can be carried out.

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Appendix A

Detail Calculation of Vehicle Damage Factor for Evaluation of Equivalent Single Axle Load (ESAL)

A1. Axle load survey data sheet (2 days report)

Sl. No	Bus			Truck			Dumper		
	Front	Rear	Total	Front	Rear	Total	Front	Rear	Total
1	2.40	6.40	8.80	2.80	6.60	9.40	2.90	12.52	15.42
2	3.10	6.60	9.70	1.94	2.24	4.18	3.24	12.38	15.62
3	3.90	5.12	9.02	3.12	9.50	12.62	3.04	12.42	15.46
4	3.74	5.78	9.52	2.34	5.42	7.76	3.04	11.66	14.70
5	3.20	5.52	8.72	3.70	8.56	12.26	4.30	13.56	17.86
6	2.60	5.88	8.48	3.04	7.38	10.42	2.96	12.64	15.60
7	1.60	2.14	3.74	2.30	6.60	8.90	2.96	12.64	15.60
8	2.00	3.50	5.50	3.14	8.28	11.42	2.90	12.52	15.42
9	1.94	2.50	4.44	3.20	7.88	11.08	3.24	12.38	15.62
10	2.70	3.80	6.50	4.10	15.00	19.10	3.04	12.42	15.46
11	3.84	4.76	8.60	1.30	4.34	5.64	3.04	11.66	14.70
12	3.14	5.48	8.62	3.44	9.70	13.14	4.30	13.56	17.86
13	3.64	4.60	8.24	3.38	9.38	12.76	2.96	12.64	15.60
14	2.74	4.46	7.20	3.64	4.60	8.24	2.96	12.64	15.60
15	2.94	6.20	9.14	5.88	15.50	21.38	2.90	12.52	15.42
16	2.84	4.34	7.18	3.74	7.36	11.10	3.24	12.38	15.62
17	1.96	3.24	5.20	5.78	15.38	21.16	3.04	12.42	15.46
18	2.44	2.30	4.74	3.90	8.22	12.12	3.04	11.66	14.70
19	4.50	6.56	11.06	3.24	8.38	11.62	4.30	13.56	17.86
20	5.78	7.28	13.06	3.60	5.06	8.66	2.96	12.64	15.60
21	3.90	8.22	12.12	3.60	8.32	11.92	2.96	12.64	15.60
22	3.24	8.38	11.62	3.60	5.06	8.66			
23	3.60	5.06	8.66	3.60	8.32	11.92			
24	3.60	8.32	11.92	3.60	9.18	12.78			
25	3.04	3.50	6.54	2.80	6.60	9.40			
26	3.60	9.18	12.78	1.94	2.24	4.18			
27	3.04	3.50	6.54	3.12	9.50	12.62			
28	4.24	9.18	13.42	2.34	5.42	7.76			
29	3.64	6.86	10.50	3.70	8.56	12.26			

Sl. No	Bus			Truck			Dumper		
	Front	Rear	Total	Front	Rear	Total	Front	Rear	Total
30	2.90	7.02	9.92	3.04	7.38	10.42			
31	2.64	5.42	8.06	2.30	6.60	8.90			
32	2.44	2.30	4.74	3.14	8.28	11.42			
33	4.50	6.56	11.06	3.20	7.88	11.08			
34	3.04	3.50	6.54	4.10	15.00	19.10			
35	3.64	5.50	9.14	1.30	4.34	5.64			
36				3.44	9.70	13.14			
37				3.38	9.38	12.76			
38				3.64	4.60	8.24			
39				5.84	15.70	21.54			
40				3.54	10.52	14.06			
41				5.80	15.24	21.04			
42				2.50	6.02	8.52			
43				4.56	12.28	16.84			
44				2.80	4.40	7.20			
45				3.70	6.50	10.20			
46				2.74	5.74	8.48			

A2. Calculation of Vehicular Damage Factor (VDF)

Axle Load Range (Ton)	Mid-value of axle load (Ton)	Combined Commercial Vehicles		
		Number of Axles	Percentage Frequency	Cumulative Percentage
2-4	3	92	46.94	46.94
4-6	5	36	18.37	65.31
6-8	7	19	9.69	75
8-10	9	20	10.20	85.2
10-12	11	4	2.05	87.25
12-14	13	19	9.69	96.94
14-16	15	6	3.06	100.00
Total		196	100.00	

$$\text{VDF/Axle} = \frac{46.94 \left(\frac{3}{8.2}\right)^4 + 18.37 \left(\frac{5}{8.2}\right)^4 + 9.69 \left(\frac{7}{8.2}\right)^4 + 10.2 \left(\frac{9}{8.2}\right)^4 + 2.05 \left(\frac{11}{8.2}\right)^4 + 9.69 \left(\frac{13}{8.2}\right)^4 + 3.07 \left(\frac{15}{8.2}\right)^4}{100}$$

$$\text{VDF/Axle} = 1.254$$

Therefore, VDF for standard truck with two axle = 2.508 (~2.51)

APPENDIX-B

Calibration of geophone (sensors) using Measuring Amplifier (Bruel & Kjaer, Type-2525)

GEOPHONE-1		GEOPHONE-2		GEOPHONE-3		GEOPHONE-4		GEOPHONE-5		GEOPHONE-6		GEOPHONE-7	
Vibrati on Meter (mm)	Geopho ne Respon se (Volt)	Vibrati on Meter (mm)	Geopho ne Respon se (Volt)	Vibrati on Meter (mm)	Geopho ne Respon se (Volt)	Vibrati on Meter (mm)	Geopho ne Respon se (Volt)	Vibrati on Meter (mm)	Geopho ne Respon se (Volt)	Vibrati on Meter (mm)	Geopho ne Respon se (Volt)	Vibrati on Meter (mm)	Geopho ne Respon se (Volt)
0.0875	0.9698	0.1060	1.1387	0.1910	2.2205	0.1340	1.6400	0.1720	2.0146	0.1120	1.3901	0.1120	1.2681
0.1470	1.7654	0.1880	2.0472	0.2720	3.3121	0.2060	2.5195	0.2780	3.2015	0.1910	2.1315	0.1720	1.9961
0.1940	2.3481	0.2530	2.9594	0.3410	3.9801	0.2780	3.0145	0.3620	3.9886	0.2560	2.8754	0.2160	2.4376
0.2660	2.9920	0.3250	3.7978	0.4190	4.7843	0.3130	3.5700	0.4000	4.4590	0.3060	3.7786	0.2340	2.8264
0.3060	3.5581	0.3850	4.4767	0.5120	6.0235	0.4050	4.6552	0.4860	5.4607	0.4160	4.9524	0.2810	3.3762
CF= 0.0861		CF= 0.0865		CF= 0.0855		CF= 0.0872		CF= 0.0891		CF= 0.0843		CF= 0.0848	
R ² =0.9972		R ² =0.998		R ² =0.9986		R ² =0.9951		R ² =0.999		R ² =0.9954		R ² =0.9966	

CF= Calibration factor in mm/volt.

Appendix C

Sample Input and Output annotated BACKGA files

C1. Input file (150 mm thick PCCBP)

3					No.of parameters(layers)
30					chromosome length; size(20 for 2 layer; 30 for
3-layer)					
60					population size
60					max. # of generations
0.74					crossover probability
0.1					mutation probabilty
10 10 10					(each chromosome length)
2					units
40000 0.707					Load(Newton) Pressure(MPa)
5					No.of deflections
0.441 0.262 0.091 0.034 0.022					Deflections
0 300 600 900 1200					distances,mm
150 100					thicknesses,mm
0.35 0.4 0.4					Poisson's ratio of different layer
200 3800					range of- I layer
20 290					range-II layer
10 89					range -III layer
0.9					seed number for generating random fractions

C2. Output file (150 mm PCCBP)

population size	=	60
chromosome length	=	30
max. # of generations	=	60
crossover probability	=	.740
mutation probabilty	=	.100
seed random number	=	.900
maximum fitness	=	.92091
average fitness	=	.72588
minimum fitness	=	.38830

Accumulated statistics for generation--> 1

	x	fitness		x	fitness					
1)	.000	.000		.000	.921		513.196	228.240	83.749	.840
2)	.000	.000		.000	.911		2332.551	107.889	47.067	.780

3)	.000	.000	.000	.910		2786.510	251.466	81.895	.907
:									
:									
:									
59)	3536.070	241.701	73.710	.913		3617.009	268.622	87.842	.922
60)	3342.522	203.167	85.370	.913		3529.032	237.478	88.537	.922

Best solution so far --> **3761.290 272.317 88.923**
 Fitness = .92410 found at generation = 57

Population statistics at this generation

maximum fitness = .92354

average fitness = .89623

minimum fitness = .69909

number of crossovers = 1350

number of mutations = 10790

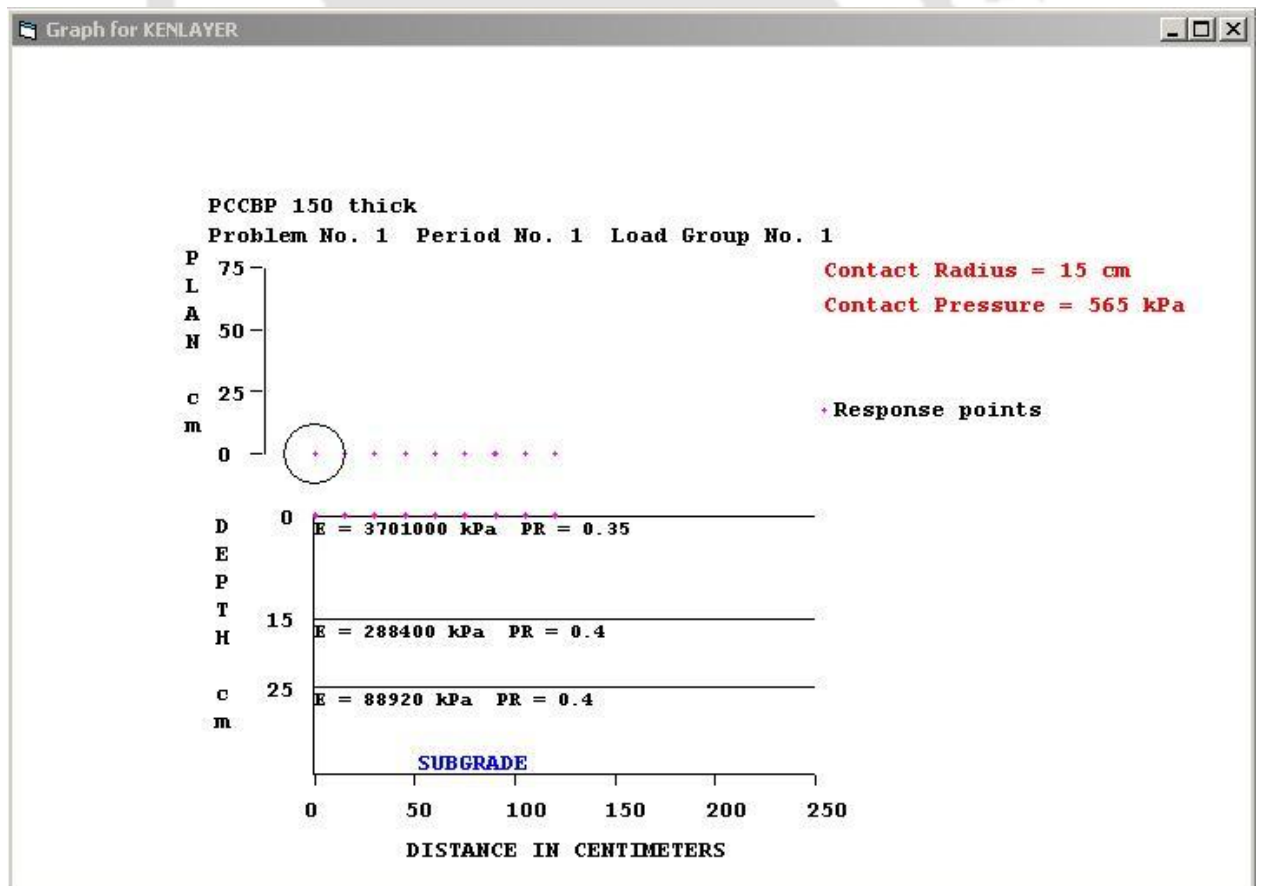


APPENDIX D

Annotated KENPAVE (KENLAYER) Input and Output files

D1. Input file (150 mm PCCBP)

1 (1)	NPROB
PCCBP 150 thick	
1 0 1 1 (3)	MATL NDAMA NPY NLG
0.001 (4)	DEL
3 1 80 1 1 (5)	NL NZ ICL NSTD NUNIT
15 10 (6)	TH
0.35 0.4 0.4 (7)	PR
0 (8)	ZC
1 (9)	NBOND
3701466 288416 88923 (11)	E
0 (13)	LOAD
15 565 (14)	CR CP
9 (16)	NR
0 15 30 45 60 75 90 105 120 (17)	RC



D2. Output file (150 mm PCCBP)

INPUT FILE NAME - F: \pccbp150.DAT

NUMBER OF PROBLEMS TO BE SOLVED = 1

TITLE -PCCBP 150 thick

MATL = 1 FOR LINEAR ELASTIC LAYERED SYSTEM

NDAMA = 0, SO DAMAGE ANALYSIS WILL NOT BE PERFORMED

NUMBER OF PERIODS PER YEAR (NPY) = 1

NUMBER OF LOAD GROUPS (NLG) = 1

TOLERANCE FOR INTEGRATION (DEL) -- = 0.001

NUMBER OF LAYERS (NL)----- = 3

NUMBER OF Z COORDINATES (NZ)----- = 1

LIMIT OF INTEGRATION CYCLES (ICL)- = 80

COMPUTING CODE (NSTD)----- = 1

SYSTEM OF UNITS (NUNIT)----- = 1

Length and displacement in cm, stress and modulus in kPa
unit weight in kN/m³, and temperature in C

THICKNESSES OF LAYERS (TH) ARE : 15 10

POISSON'S RATIOS OF LAYERS (PR) ARE : 0.35 0.4 0.4

VERTICAL COORDINATES OF POINTS (ZC) ARE: 0

ALL INTERFACES ARE FULLY BONDED

**FOR PERIOD NO. 1 LAYER NO. AND MODULUS ARE : 1 3.701E+06 2
2.884E+05**

3 8.892E+04

LOAD GROUP NO. 1 HAS 1 CONTACT AREA

CONTACT RADIUS (CR)----- = 15

CONTACT PRESSURE (CP)----- = 565

**RADIAL COORDINATES OF 9 POINT(S) (RC) ARE : 0 15 30 45 60 75 90
105**

120

PERIOD NO. 1 LOAD GROUP NO. 1

RADIAL COORDINATE	VERTICAL COORDINATE	VERTICAL DISPLACEMENT
0.00000	0.00000	0.04401
15.00000	0.00000	0.04005
30.00000	0.00000	0.03357
45.00000	0.00000	0.02797
60.00000	0.00000	0.02350
75.00000	0.00000	0.01765
90.00000	0.00000	0.01486

<i>105.00000</i>	<i>0.00000</i>	<i>0.01242</i>
<i>120.00000</i>	<i>0.00000</i>	<i>0.01065</i>



Appendix E

Data Sheet for Distress Evaluation Survey

E1. 150 mm thick PCCBP

Condition survey data sheet

PCCBP CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT			
ROAD: Plastic Cell Filled Concrete Block Pavement Test Section DATE: 24 th November'2010			
SECTION: 150 mm PCCBP		SAMPLE UNIT: 1 (one)	
SURVEYED BY: Y. Arunkumar Singh, IIT Guwahati SAMPLE AREA (No. of blocks): 336			
<u>DISTRESS NUMBER AND TYPE</u>			
101 Damaged Pavers	102 Depressions	103 Faulting	
104 Rutting			
L = Low; M = Medium; H = High			
DISTRESS/ SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
L-101	9	2.60%	1.00
L-103	45	13.39%	5.00
L-104	45	13.39%	28.00
		TDV	34.00
		CDV	30.00
		PCI	70.00
SKETCH			

E2. 120 mm thick PCCBP

Condition survey data sheet

PCCBP CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT			
ROAD: Plastic Cell Filled Concrete Block Pavement Test Section DATE: 24 th November'2010			
SECTION: 120 mm PCCBP		SAMPLE UNIT: 1 (one)	
SURVEYED BY: Y. Arunkumar Singh, IIT Guwahati SAMPLE AREA (No. of blocks): 336			
<u>DISTRESS NUMBER AND TYPE</u>			
101 Damaged Pavers		102 Depressions	103 Faulting
104 Rutting			
L = Low; M = Medium; H = High			
DISTRESS/ SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
L-101	8	2.38%	2.00
L-102	20	5.95%	8.00
L-103	85	25.30%	5.00
L-104	48	14.29%	30.00
		TDV	45.00
		CDV	32.00
		PCI	68.00
SKETCH			

E3 100 mm thick PCCBP

Condition survey data sheet

PCCBP CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT			
ROAD: Plastic Cell Filled Concrete Block Pavement Test Section DATE: 24 th November 2010			
SECTION: 100 mm PCCBP		SAMPLE UNIT: 1 (one)	
SURVEYED BY: Y. Arunkumar Singh, IIT Guwahati SAMPLE AREA (No. of blocks): 336			
<u>DISTRESS NUMBER AND TYPE</u>			
101 Damaged Pavers	102 Depressions	103 Faulting	
104 Rutting			
L = Low; M = Medium; H = High			
DISTRESS/ SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
L-101	6	1.79%	2.00
M-102	24	7.14%	28.00
L-103	48	14.29%	5.00
M-104	40	11.9%	44.00
		TDV	79.00
		CDV	50.00
		PCI	50.00
SKETCH			

E4. 80 mm thick PCCBP

Condition survey data sheet

PCCBP CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT			
ROAD: Plastic Cell Filled Concrete Block Pavement Test Section DATE: 24 th November'2010			
SECTION: 80 mm PCCBP		SAMPLE UNIT: 1 (one)	
SURVEYED BY: Y. Arunkumar Singh, IIT Guwahati SAMPLE AREA (No. of blocks): 336			
<u>DISTRESS NUMBER AND TYPE</u>			
101 Damaged Pavers	102 Depressions	103 Faulting	
104 Rutting			
L = Low; M = Medium; H = High			
DISTRESS/ SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
L-101	12	3.57%	2.00
M-102	28	8.33%	28.00
L-103	82	24.40%	5.00
M-104	55	16.37%	48.00
		TDV	83.00
		CDV	52.00
		PCI	48.00
SKETCH			

E5. 50 mm thick PCCBP

Condition survey data sheet

PCCBP CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT			
ROAD: Plastic Cell Filled Concrete Block Pavement Test Section DATE: 24 th November'2010			
SECTION: 50 mm PCCBP		SAMPLE UNIT: 1 (one)	
SURVEYED BY: Y. Arunkumar Singh, IIT Guwahati SAMPLE AREA (No. of blocks): 336			
<u>DISTRESS NUMBER AND TYPE</u>			
101 Damaged Pavers	102 Depressions	103 Faulting	
104 Rutting			
L = Low; M = Medium; H = High			
DISTRESS/ SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
L-101	6	1.79%	2.00
M-102	27	8.04%	28.00
L-103	154	45.83%	9.00
M-104	56	16.60%	48.00
		TDV	87.00
		CDV	55.00
		PCI	45.00
SKETCH			

Appendix F

Sample calculation of Pavement Condition Index (PCI) (100 mm thick PCCBP)

1. Sample unit area (number of blocks): = 336 blocks
2. Distresses present (Appendix C3):
 - i. Low severity damaged pavers (L-101) = 6 blocks
 - ii. Medium severity depressions (M-102) = 24 blocks
 - iii. Low severity faulting (L-103) = 48 blocks
 - iv. Medium severity rutting (M-111) = 40 blocks
3. Density of distresses (Percentage):
 - i. Low severity damaged pavers (L-101) = $(6/336) \times 100 = 1.79\%$
 - ii. Medium severity depressions (M-102) = $(24/336) \times 100 = 7.14\%$
 - iii. Low severity faulting (L-103) = $(48/336) \times 100 = 14.29\%$
 - iv. Medium severity rutting (M-111) = $(40/336) \times 100 = 11.9\%$
4. Deduct value (using deduct curves, Figures 4.17-20):
 - i. Low severity damaged pavers (L-101) = 2.00
 - ii. Medium severity depressions (M-102) = 28.00
 - iii. Low severity faulting (L-103) = 5.00
 - iv. Medium severity rutting (M-111) = 44.00
5. Maximum Corrected Deduct Value (Maximum CDV):

If none or only one individual deduct value is greater than 2 (two), the total value is used in place of the maximum corrected deduct value in determining PCI of the pavement.

In the present case more than one deduct values are greater than two (5.00, 28.00 and 44.00), the maximum deduct value must be determine as:

Allowable number of deducts including fraction part 'm',

$$\begin{aligned} m &= 1 + (9/98) (100 - HDV) \leq 10 \\ &= 1 + (9/98) (100 - 44.00) \leq 10 \\ &= 6.14 \end{aligned}$$

Here, less than 6.14 number of deduct values (i.e., 4 numbers) are available, all the deduct values (2.00, 28.00, 5.00 and 44.00) are used for calculation of the maximum corrected deduct value.

Total deduct value, TDV = 2.00 + 5.00 + 28.00 + 44.00 = 79.00

Again the number of deduct values greater than 2 (two), $q = 3$

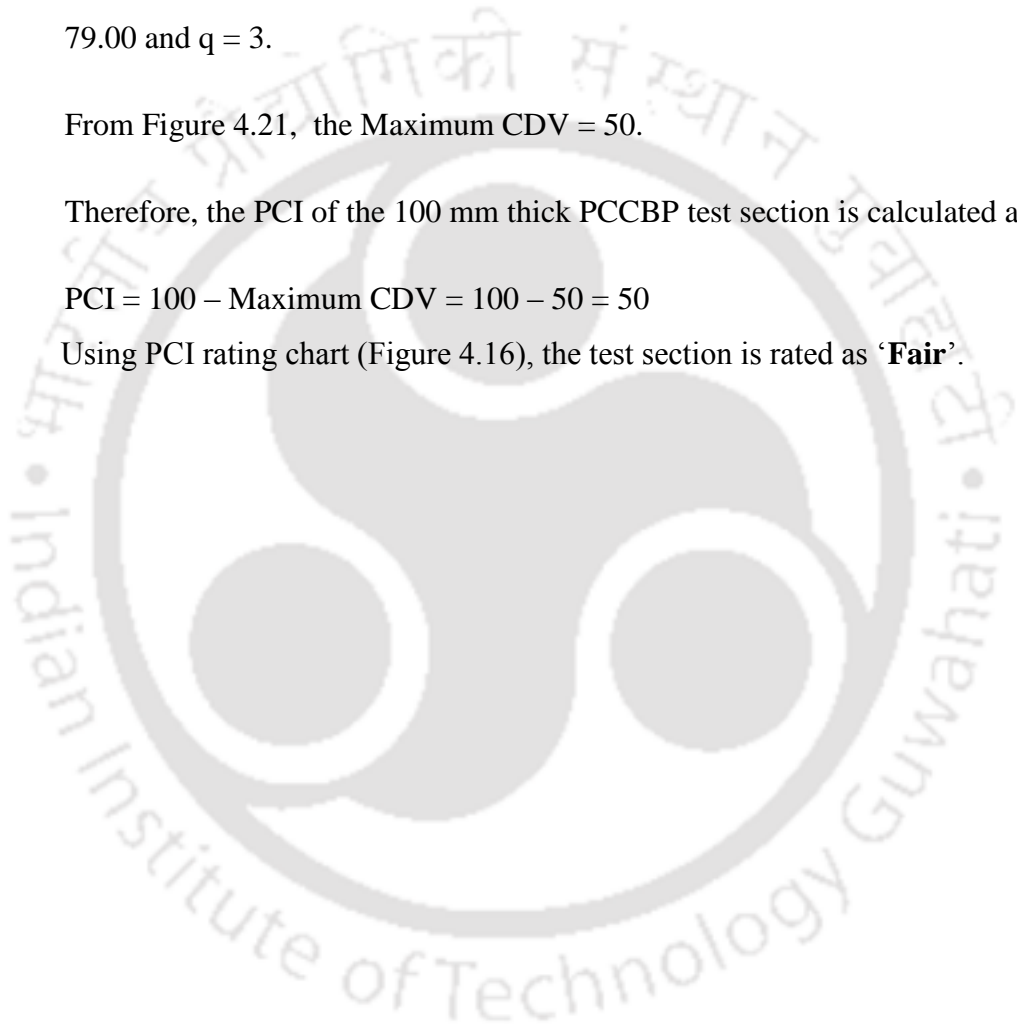
The Maximum CDV is calculated using CDV curve (ICPI-2007) for TDV = 79.00 and $q = 3$.

From Figure 4.21, the Maximum CDV = 50.

Therefore, the PCI of the 100 mm thick PCCBP test section is calculated as:

$$\text{PCI} = 100 - \text{Maximum CDV} = 100 - 50 = 50$$

Using PCI rating chart (Figure 4.16), the test section is rated as '**Fair**'.

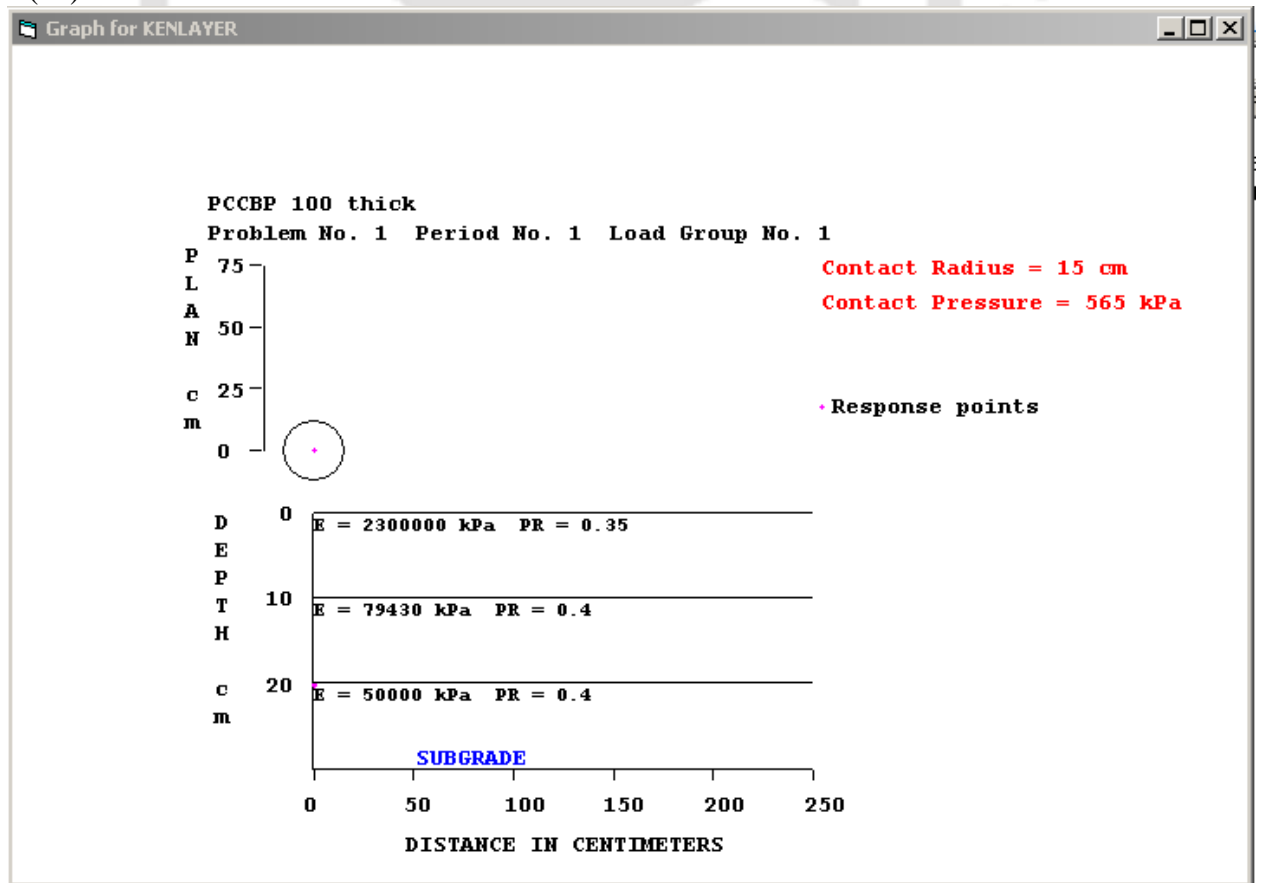


Appendix G

Annotated KENPAVE (KENLAYER) Input and Output files (Vertical Sub-grade strain)

G1. Input file (100 mm PCCBP, after 38,000 ESAL passes)

1 (1)	NPROB
PCCBP 100 thick	
1 0 1 1 (3)	MATL NDAMA NPY
NLG	
0.001 (4)	DEL
3 1 80 9 1 (5)	NL NZ ICL NSTD
NUNIT	
10 10 (6)	TH
0.35 0.4 0.4 (7)	PR
20.001 (8)	ZC
1 (9)	NBOND
2300000 79430 50000 (11)	E
0 (13)	LOAD
15 565 (14)	CR CP
1 (16)	NR
0 (17)	RC



G2. Output file (100 mm thick PCCBP)

INPUT FILE NAME -F:\ pccbp100rutshell.DAT

NUMBER OF PROBLEMS TO BE SOLVED = 1

TITLE -PCCBP 100 thick

MATL = 1 FOR LINEAR ELASTIC LAYERED SYSTEM
NDAMA = 0, SO DAMAGE ANALYSIS WILL NOT BE PERFORMED
NUMBER OF PERIODS PER YEAR (NPY) = 1
NUMBER OF LOAD GROUPS (NLG) = 1
TOLERANCE FOR INTEGRATION (DEL) -- = 0.001
NUMBER OF LAYERS (NL)----- = 3
NUMBER OF Z COORDINATES (NZ)----- = 1
LIMIT OF INTEGRATION CYCLES (ICL)- = 80
COMPUTING CODE (NSTD)----- = 9
SYSTEM OF UNITS (NUNIT)----- = 1

Length and displacement in cm, stress and modulus in kPa
unit weight in kN/m³, and temperature in C

THICKNESSES OF LAYERS (TH) ARE : 10 10
POISSON'S RATIOS OF LAYERS (PR) ARE : 0.35 0.4 0.4
VERTICAL COORDINATES OF POINTS (ZC) ARE: 20.001
ALL INTERFACES ARE FULLY BONDED

FOR PERIOD NO. 1 LAYER NO. AND MODULUS ARE : **1 2.300E+06 2**
7.943E+04
3 5.000E+04

LOAD GROUP NO. 1 HAS 1 CONTACT AREA
CONTACT RADIUS (CR)----- = 15
CONTACT PRESSURE (CP)----- = 565
RADIAL COORDINATES OF 1 POINT(S) (RC) ARE : 0

PERIOD NO. 1 LOAD GROUP NO. 1

RADIAL VERTICAL VERTICAL VERTICAL RADIAL
TANGENTIAL SHEAR

COORDINATE COORDINATE DISPLACEMENT STRESS STRESS
STRESS STRESS

(STRAIN)	(STRAIN)		(STRAIN)	(STRAIN)
0.00000	20.00100	0.09422	100.444	11.051
11.051	0.000	(STRAIN)		
1.832E-03	-6.709E-04	-6.709E-04	.000E+00	



Appendix H

Sample calculation for cost escalation

Calculation of *Cost Index* corresponding to Year (2010) is based on Assam Schedule Rate (PWD, 2007) and monthly wholesale price index (OEA, 2010):

- Material escalation = 0.55 x % increase
- Labour escalation = 0.25 x % increase
- Petrol Oil and Lubricants (POL) escalation = 0.05 x % increase

Sl no.	Item	Amount (Rs)
1	Whole sale price for material for December 2007	216.40
2	Whole sale price for material for April 2010	253.70
3	Percentage increase in the rate of material	17.23%
Cost escalation of the material		$0.55 \times 17.23 \% = 9.48 \%$
Cost escalation for material		9.48 %
Cost escalation for labour		4.38 %
Cost escalation for POL		0.81 %
Total cost index		14.67 %

Therefore, the total cost index to bring to the present market rate (April'2010) is 14.67%.

Appendix I

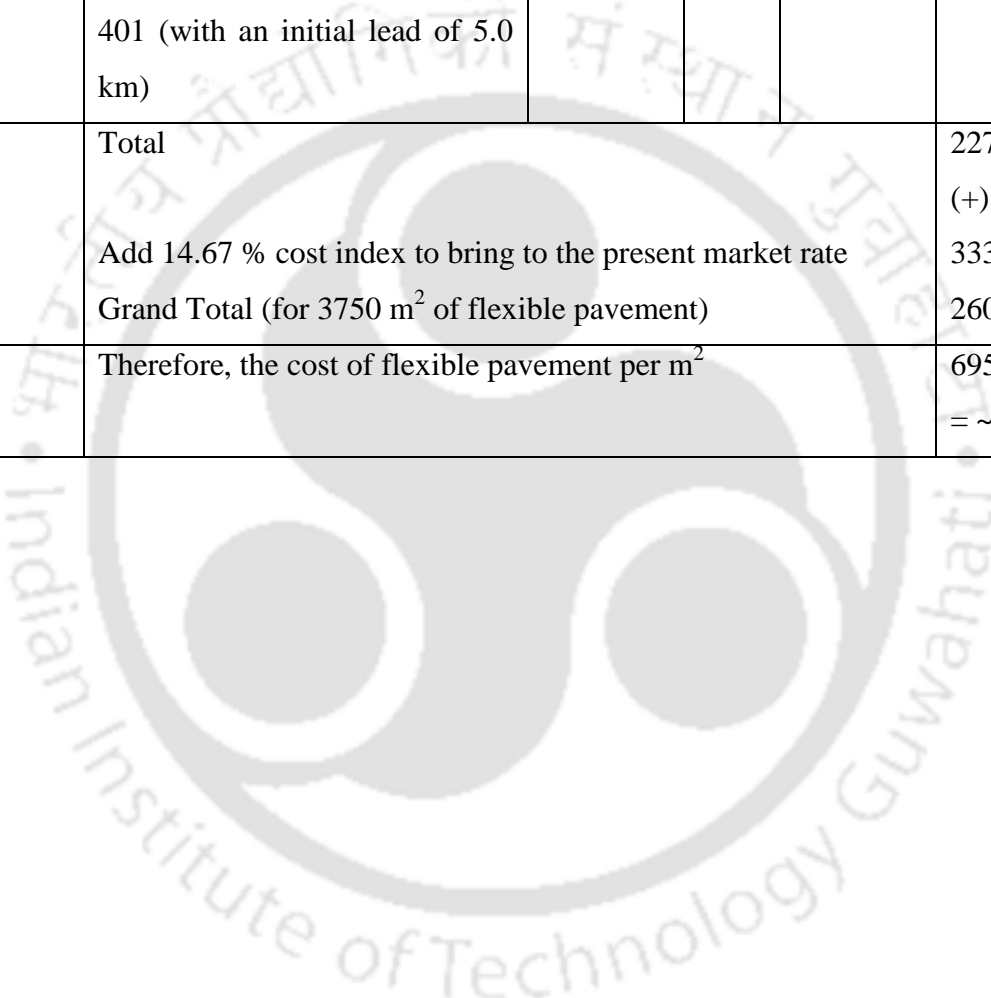
Abstract of cost for Flexible, Rigid and PCCBP pavement

I1. Abstract of cost for flexible pavement (PWD, 2007 and OEA, 2010).

Sl. no.	Particulars	Quantity	Unit	Rate (in Rs)	Amount (in Rs)
1.	Providing and applying primer coat with bitumen emulsion on prepared surface of granular base including cleaning of road surface and spraying primer at the rate of 1.00 kg/ m ² using mechanical means	3750.00	m ²	37.00	138750.00
2.	Providing and applying tack coat with emulsion using emulsion pressure distributor at the rate of 0.20 kg/ m ² on the prepared bituminous / granular surface cleaned with mechanical broom.	3750.00	m ²	13.00	48750.00
3.	Providing, laying and rolling of open- graded premix surfacing of 20 mm thickness composed of 13.2 mm to 5.6 mm aggregate either using penetration grade bitumen (60/70) or bitumen emulsion to required line, grade and level to serve as wearing course on a previously prepared base, including mixing in a suitable	3750.00	m ²	104.00	390000.00

	plant laying and rolling with a smooth wheeled roller 8-10 tonnes capacity to the required level and grade (including carriage up to initial lead of 5.0 km from quarry and carriage of mixed materials up to 10.0 km initial lead from mixing plant)				
4.	Providing and laying seal coat sealing the voids in bituminous surface laid to the specified levels, grade and cross fall using Type A seal coat (including carriage up to initial lead of 5.0 km from quarry)	3750.00	m ²	47.00	176250.00
5.	Providing, laying, spreading and compacting stone aggregates of specific sizes to water bound macadam specification including spreading in uniform thickness, hand packing, rolling with vibratory roller 8-10 tonnes in stages to proper grade and camber, applying and booming requisite types of screening / binding material to fill up the interstices of coarse aggregates, watering and compacting to the required density (with an initial lead of 5.0 km).	656.25	m ³	1353.00	887568.00
6.	Construction of granular sub-base by providing coarse graded	562.50	m ³	1127.00	633937.50

	materials, spreading in uniform layers with motor grader on prepared surface, mixing by mix in place method with rotavator at OMC and compacting with vibratory roller to achieve the desired density, complete as per clause-401 (with an initial lead of 5.0 km)				
	Total				2275255.50 (+)
	Add 14.67 % cost index to bring to the present market rate				333779.90
	Grand Total (for 3750 m ² of flexible pavement)				2609035.40
	Therefore, the cost of flexible pavement per m ²				695.70 = ~ 696.00



I2. Abstract of cost for rigid pavement (PWD, 2007 and OEA, 2010).

Sl. no.	Particulars	Quantity	Unit	Rate (in Rs)	Amount (in Rs)
1.	Construction of un-reinforced, dowel jointed, plain cement concrete pavement over a prepared sub-base with 43-grade cement @ 400 kg/ m ³ , coarse and fine aggregates conforming to IS-383, maximum size of coarse aggregates not exceeding 25mm, mixed in a batching and mixing plant as per approved mixed design, transported to the site, laid with a fixed form or slip form paver, spread, compacted and finished in a continuous operation including provision of contraction, expansion, construction and longitudinal joints, joint filler, separation member, sealant primer, sealant joint, deboning strips dowel bar, tie rods, admixture as approved, curing compound, finished to lines and grades as per drawing (including carriage of mixed materials up to 10.0 km initial lead from mixing plant.)	825.00	m ³	5422.00	4473150.00
2.	Providing, laying, spreading	562.50	m ³	1353.00	761062.50

	<p>and compacting stone aggregates of specific sizes to water bound macadam specification including spreading in uniform thickness, hand packing, rolling with vibratory roller 8-10 tonnes in stages to proper grade and camber, applying and brooming requisite types of screening / binding material to fill up the interstices of coarse aggregates, watering and compacting to the required density (with an initial lead of 5.0 km)</p>				
	<p>Total</p> <p>Add 14.67% cost index to bring to the present market rate</p> <p>Grand Total (for 3750 m² of rigid pavement)</p>				<p>5234212.50</p> <p>767858.97</p> <p>6002071.47</p>
	<p>Therefore, cost of rigid pavement per m²</p>				<p>1600.55</p> <p>= ~ 1601.00</p>

I3. Abstract of cost for Plastic Cell Filled Concrete Block Pavement (PCCBP) based on present (year 2010) market rate of Assam state.

1. Cost of plastic

Total plastic required for making plastic cell formwork of (150 mm x 150 mm x 100 mm) for an area of $2.7 \times 5.5 = 14.85 \text{ m}^2$ is $\frac{2}{3}$ of two rolls of plastic weighing 12.00 kg each.

Cost of plastic per roll (12.00Kg) @ Rs 95 per kg (12 x 95) = Rs 1140.00
Therefore, cost of plastic for 14.85 m^2 ($\frac{2}{3} \times 2 \times 1140$) = Rs 1520.00
Therefore, cost of plastic for 3750 m^2 (3.75×1000) = Rs 383838.38
Add 5% extra as transportation charges = Rs 19191.19
Total cost of plastic 3750 Sqm area = Rs 403029.57

2. Man-days required

Time taken to cutting and sealing one stripe of plastic (8 m) = 60 minutes
Number of stripes required for 14.85 m^2 ($2.7 \text{ m} \times 5.5 \text{ m}$) area = 15 stripes
Time taken for cutting and sealing plastic for 14.85 Sqm area (15×60) = 16 hours
Therefore, time taken for 3750 Sqm area (3.75×1000) = 4040.4 hours
Number of man-days required (assuming eight hours working per day) = 505.00 man-days
Assuming cost of man-days @ Rs 80 per day (80×505) = Rs 40400.00

3. Paddle Sealing Machine

Cost of electrically operated paddle sealing machine = Rs 10000.00
Therefore, total cost for preparation of plastic cell formwork for 3750 Sqm area, ($403029.57 + 40400.00 + 10000.00$) = Rs 453029.57
Therefore, cost of plastic cell formwork for one Sqm area = Rs 120.80
(Say) = Rs 120.00

4. Cost of Concreting

Volume of concrete for 100 mm thick PCCBP (3.75 X1000X0.1)	= 375 m ³
Cement (50 Kg/bag) required for 1 m ³ of concrete (1:1.25:3)	= 9.87 bags
Cement required for 375 m ³ of concrete	= 3701.25 bags
Cost of cement @ 230 per bag (230 X 3701.25)	= Rs 851287.50
Coarse aggregates required for 1 m ³ of concrete (1:1.25:3)	= 0.91 m ³
Coarse aggregates required for 375 m ³ of concrete (1:1.25:3)	= 341.33 m ³
Cost of coarse aggregates @ Rs 900/ m ³ (900 X 341.33)	= Rs 307197.00
Stone dust required for 1 m ³ of concrete (1:1.25:3)	= 0.455 m ³
Stone dust required for 375 m ³ of concrete (1:1.25:3)	= 170.66 m ³
Cost of stone dust @ Rs 200/ m ³ (200X170.66)	= Rs 34133.33
Total cost (8, 51,287.50 +3, 07,197.00 +34,133.33)	= Rs 1192617.83
Add 5% transportation charges	= Rs 59630.89
Grand total cost of concrete for 3750 Sqm area	= Rs 1252248.72
Therefore, cost of concrete per Sqm area	= Rs 333.93
Again, cost of laying and concreting 126 Sqm (18mX7m)	= Rs 6300.00
Cost of laying and concreting per Sqm area of PCCBP	= Rs 50.00
Therefore, total cost (including material cost) for concreting per Sqm=	Rs 383.93
(Say)	= Rs 384