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Distress Evaluation of Plastic Cell Filled Concrete Block Pavement

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Abstract: This paper describes a systematic full scale experimental study to evaluate various distresses of plastic cell filled concrete block pavement (PCCBP) of different thicknesses (50 mm, 80 mm, 100 mm, 120 mm and 150 mm) based on pavement condition index (PCI) methodology. 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, the Interlocking Concrete Pavement Distress Manual, published by the International Concrete Pavement Institute (ICPI), Toronto, Canada, has been adopted. Four distresses, viz., 1) damage pavers, 2) depression, 3) faulting, and 4) rutting, as mentioned in the ICPI distress manual, and four new distresses specific to PCCBP, viz., 1) edge spalls, 2) scaling, 3) exposed cells, and 4) cell opening are identified. Distress evaluation of PCCBP test sections (after 62,000 equivalent single axle load (ESAL) passes of 80 kN) based on the ICPI distress manual showed that the test sections can be rated as ”fair” (50 mm thick) to “very good”" (150 mm thick). A relatively high elastic modulus (1,800 MPa) was observed for the thin PCCBP layer (50 mm thick), even after a wheel load repetition of 62, 000 passes, suggesting that PCCBP with “waste stone dust” as replacement for the traditional river sand can be a promising alternative for rural roads.

***Key words**: Distress; Falling weight deflectometer (FWD); Low volume roads; Pavement condition index; Plastic cell filled concrete block pavement (PCCBP).*

Introduction

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. Especially for rural roads, there is a need to innovate construction technology appropriate for local conditions and suitable for generating employment. While conventional flexible pavement with a thin cover of premix bituminous carpet is normally adopted for rural roads, frequent maintenance activity is required (to maintain both functional and structural efficiencies) due to damage caused by poor drainage conditions, overloaded vehicular traffic, iron wheeled bullock carts, etc. As a result, such pavements incur high maintenance costs. To offset such expensive maintenance, concrete pavements are increasingly used in rural road connectivity in India because of their durability. However, concrete pavements not only involve 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. [1]. Although pre-cast concrete block pavement [2-4] provides a more flexible response (depending upon the dilantancy of the jointing sand) as compared to the normal concrete pavement mentioned above, there is a tendency for block movements under braking or accelerating force of the vehicular traffic, and the interlocking caused by the jointing sand needs frequent maintenance which may not be practical for rural roads.

As an alternative, for better structural performance and low maintenance, a new pavement technology called plastic cell filled concrete block pavement (PCCBP) was developed in South Africa [5-8]. In PCCBP, diamond shaped heat welded plastic cells (see Fig. 1) are used to encase concrete blocks. This type of plastic cell formwork has been successfully used for canal lining, reinforced earth treatment, etc. [7]. 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 Fig. 2). Flexibility is induced into cement bound (rigid) surface and Visser [6] termed these pavements as Flexible Concrete Pavements. In India, limited studies on this PCCBP technology have reported on the cost effectiveness and feasibility for rural roads [4, 9-12]. Although their studies were confined to selected (100 mm) PCCBP thicknesses, it was observed that PCCBP can provide sufficiently high elastic modulus with low initial and maintenance cost. To the best of the 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 [6] and Vissar and Hall [7]. As such, an experimental study has been attempted to report various types of distresses and their severity level for different thicknesses of PCCBP under live traffic condition for low volume roads.

The present work aims to identify and evaluate the various pavement distresses on different thicknesses of the PCCBP test section based on the pavement condition index (PCI) methodology. This method for pavement evaluation has been widely accepted, as it offers a method to objectively rate pavement condition. 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 were constructed at the approach road towards the Indian Institute of Technology Guwahati, India (IIT Guwahati) from National Highway 31 (NH31). To optimize the cost of pavement construction, an attempt was made to use waste stone dust (byproduct of aggregates crushing) in place of the traditional river sand. Axle load survey and traffic volume count

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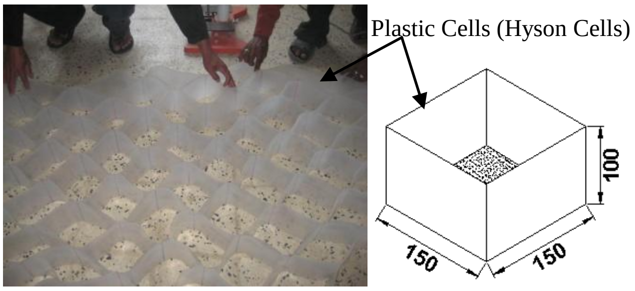

Fig. 1. Schematic Diagram of Typical Plastic Cells (Hyson Cells) Formwork with Pocket Size 150 mm x 150 mm.

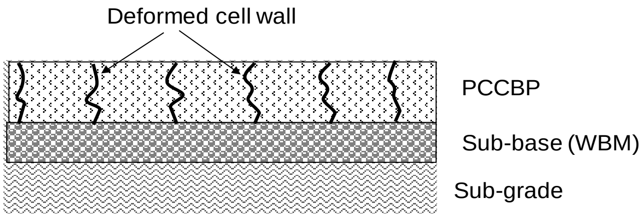

Fig. 2. Schematic Diagram of Deformed Cell Walls of PCCBP.

was performed to estimate the rate of surface deterioration with number of axle load passes. 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, the Interlocking Concrete Pavement Distress Manual [13], published by the International Concrete Pavement Institute (ICPI), 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 the ICPI manual [13], 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 [13] 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, construction of test section, observed distresses and evaluation of PCI for PCCBP test sections are presented, with reference to various distress terminologies from ICPI [13] and the American Society for Testing and Materials (ASTM) [14].

Materials Used for the Construction of PCCBP

Low Density Polyethylene Plastic (LDPE) Cell

The plastic cell formwork used in the present study is made of a low density polyethylene (LDPE) sheet with a thickness of 0.49 mm. Cell formwork was prepared with flexible translucent water delivery LDPE pipe having a diameter of 101.5 mm, which is available in the local market of Guwahati, Assam, India. The pipes were cut into required strips (50 mm, 80 mm, 100 mm, 120 mm and 150 mm) and heat bonded using paddle sealing, which on stretching forms diamond shaped pockets with a size of 150 mm x 150 mm (see Fig. 1).

Cement

Table 1. Particle Size Distribution of Stone Dust.

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

Fly ash based Portland pozzolana cement (PPC) conforming to Indian Standard (IS) 1489 [15] was used for casting concrete blocks. The cement (TOPCEM cement) for the whole project was procured in a single consignment and stored properly.

Stone Dust

Stone dust collected from a stone crusher factory located nearby Indian Institute of Technology (IIT) Guwahati, Assam, was used as fine aggregate for casting concrete blocks. The particle size distribution of stone dust obtained from the sieve analysis is shown in Table 1, and it can be seen that the gradation conforms best to Zone II of IS 383 [16]. Water absorption and specific gravity of the stone dust as per IS 2386 [17] was obtained to be 0.73% and 2.63 respectively. The fineness modulus of the stone dust was found to be 2.3, which lies within the specified limit of 2.10-3.37 for Zone II of IS 383 [16].

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. The values of Los Angeles abrasion value, aggregate flakiness index, specific gravity, water absorption as per IS 2386 [18] were obtained as 27%, 9%, 2.7, and 0.3% respectively. Single size stone aggregates of 22.4 mm (i.e., wholly passing 26.5 mm sieve and wholly retained on 13.2 mm sieve) as per specification of Ministry of Shipping, Roads Transport and Highways (MORTH) [19] were selected for casting the concrete in the present study.

Soil

The soil used for backfilling the sub-grade for the test pavement was brought in from a nearby hill slope excavation. A plot between the particle size and the percentage passing based on wet sieve analysis [20] is shown in Table 2. The specific gravity was obtained as per IS 2720 [21] and found to be 2.63. Table 2 shows that percentage of fine fraction passing 75 micron sieve is 41%. The liquid limit was found to be 35% with no significant plastic limit [22]. The soil can thus be classified as SM-ML, as per ASTM 2487 [23]. The laboratory soaked and un-soaked California Bearing Ratio (CBR) values of the soil used for backfill were found out to be 5% and 7% respectively [24].

Table 2. Grain Size Distribution of Sub-grade Soil.

Sieve Size (mm)	Percentage Passing (%) by Weight
4.75	98.1
2.8	97.3
2.36	94.8
2	94.5
1	85.2
0.6	76.6
0.425	69.6
0.3	65.7
0.15	49.7
0.075	41.6

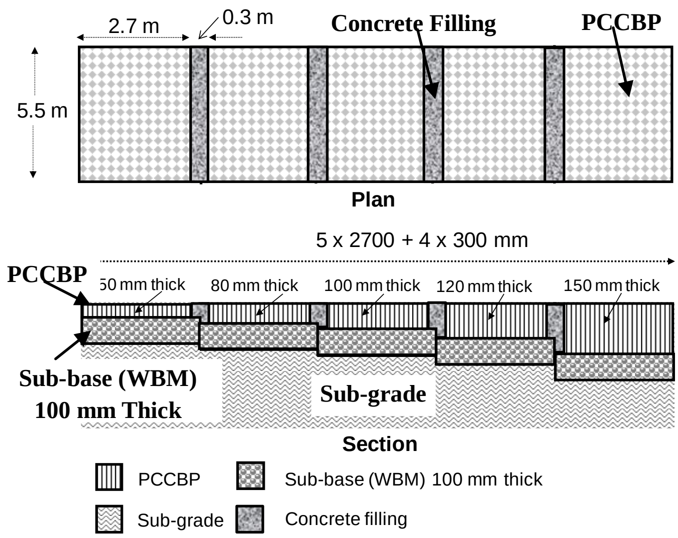

Fig. 3. Schematic Plan and Sectional View of the Test Section Showing Different Thickness of PCCBP.

Field investigations

Test Section

A distress study based on PCI methodology was performed on different thicknesses of PCCBP (50 mm, 80 mm, 100 mm, 120 mm and 150 mm) at the 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 Fig. 3. Based on the preliminary survey, the traffic along the road stretch considered consists mainly of heavy trucks carrying construction materials, 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.

Excavation of the Existing Pavement

Taking due care of 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 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 to the sub-grade soil layer. The existing pavement consisted of 20 mm premix carpet, 75 mm thick bituminous macadam over 350 mm thick sub-base course (200 mm thick WBM course over 150 mm granular sub-base). The dry density and field moisture content of the sub-grade soil estimated by core cutter method as per IS 2720 [25] was found to be 1,730 kg/m^3 and 13.80% respectively. The laboratory soaked CBR of the soil sample collected from the field was found to be 6% as per IS 2720 [24].

Preparation of the Sub-grade Soil

The trench was backfilled with selected soil collected from nearby hill slope. After excavation, the surface of the existing ground was level, and the backfilled soil was spread uniformly. Compaction was done at the optimum moisture content (12%) using a 100 KN three wheeled roller in three layers of 100 mm each. After compaction, the surface was leveled manually to bring the surface to the required profile for each thickness (Fig. 3). The field density and the moisture content of the compacted sub-grade soil were determined by core cutter method [25] and found to be 1,880 Kg/m^3 and 12.04% respectively. The percentage field compaction was found to be 98% of the standard laboratory compaction value.

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 [19], were used for WBM course. The particle size distribution and properties of WBM sub-base course are given in Table 3. The materials were manually placed and spread uniformly over the prepared sub-grade soil. Construction and compaction were performed by MORTH standards [19]. Rolling and compaction of WBM were continued until the slurry (after filling the voids between aggregates) formed a wave ahead of the moving roller.

Laying and Concreting the Plastic Cells

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

From the laboratory test results, premix concrete with cement:stone dust:coarse aggregates ratio of 1:1.25:2.0 by volume (28-days cube compressive strength = 32 MPa) was selected for casting PCCBP. Concrete mixing was done by a diesel-operated mixer machine, and the amount of water was maintained according

Table 3. Particle Size Distribution and Properties of Water Bound Macadam Sub-base Course.

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

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

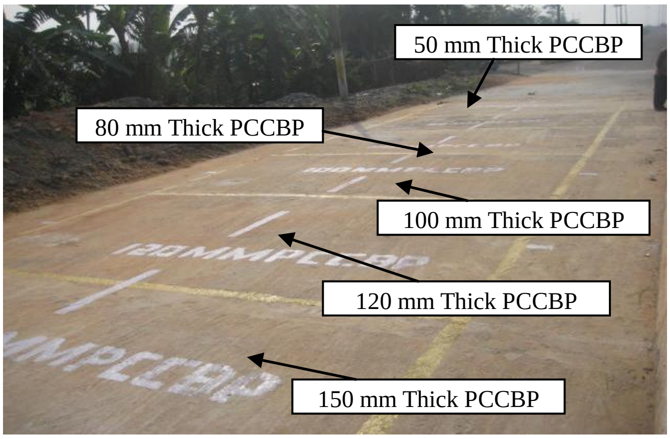

Fig. 4. Completed PCCBP Test Road with Markings for Different Test Sections.

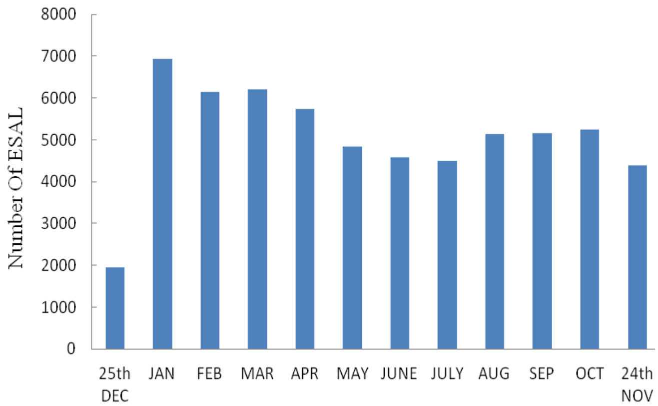

Fig. 5. Monthly ESAL with Month (~11 Months).

to w/c ratio of 0.5. The test section was constructed sequentially leaving a gap of 300 mm between two adjacent sections. After casting the adjacent section, the gap was filled with concrete and leveled. The remaining gaps between the edges of the road were also filled with concrete and leveled. Compaction was done using a plate vibrator and a locally fabricated wooden beam straight edge rammer. The finished surface of the test pavement was leveled in accordance with the existing bituminous pavement. Casting of the whole test section was completed in a single day and the concrete was allowed to set overnight. Water curing was done for 21 days; however, Roy *et al*, [11] reported 14 days curing using wet jute gunny bags to be sufficient for quick opening to traffic. After removing water, the pavement was cleaned properly and marked for different PCCBP sections (Fig. 4). Initial surface deflection data of the test sections (using falling weight deflectometer (FWD)) were collected before opening to regular traffic. Core samples collected from the test sections showed that the compaction was proper and the effective cell height was reduced and concrete layer of 6% to 10% (i.e. 10 mm – 15 mm for 150 mm thick PCCBP) of the cell height can be seen on top of the cell formwork. The PCCBP test section was opened to normal traffic 25 days after casting.

Traffic Survey

In order to evaluate the structural performance of the test sections with traffic passes, daily traffic volume data was collected from the IIT Guwahati security check gate. An 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 a 10-ton wheel load. Following the recommendation of the Indian Road Congress (IRC), [26] the axle load survey for the present study was carried out considering only the motorized commercial vehicle with gross laden weight of 3 tones and above (i.e. heavy and medium commercial vehicles). The universal "fourth power damage formula" [27] was used to convert the number of repetitions of vehicles of various axle loads into equivalent single axle load (ESAL) repetitions of 80 kN. An equivalent axle load factor called Vehicle Damage Factor (VDF) was calculated from the axle load distribution data, which when multiplied by the monthly volume of commercial vehicle repetitions, would convert into monthly ESAL repetitions.

Fig. 5 shows the monthly ESAL with month for the data collected from December 25, 2009, to November 24, 2010 (i.e., 11 months period). The initial high ESAL values up to the month of April are due to several earth filling and construction activities in and around IIT Guwahati campus, which were reduced during the rainy season (May to July). At the end of about 11 months (i.e. up to 24th November 2010), the total ESAL repetitions had reached approximately 62,000. On Indian rural roads, tractor-trailers ferrying farming products during harvesting periods and people and materials during local festivals / marriages constitute major commercial traffic. Considering a traffic volume of 20 vehicles per day, and a rear axle load of a loaded tractor-trailer as 60 kN [12], the yearly average ESAL repetitions is about 2,300. So, the cumulative ESAL repetitions of 62,000 are equivalent to 25 years of service for a typical rural road in India.

Performance of PCCBP with Load Repetitions

In order to evaluate the performance of PCCBP test sections with

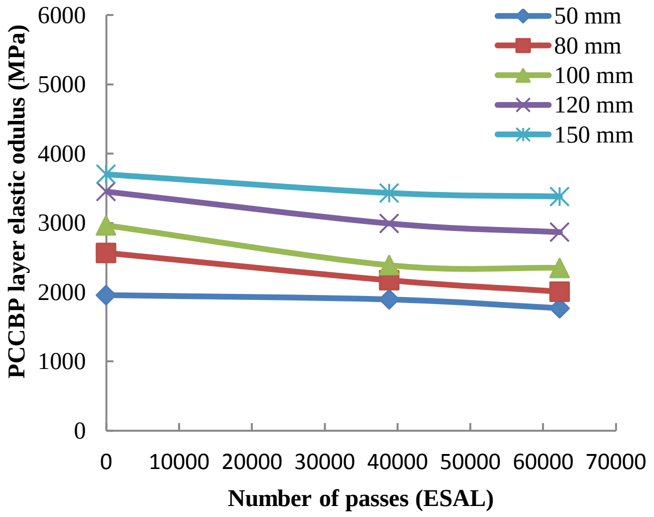

Fig. 6. Variation of PCCBP Layer Elastic Modulus with Number of Passes (ESAL), for Different Thicknesses.

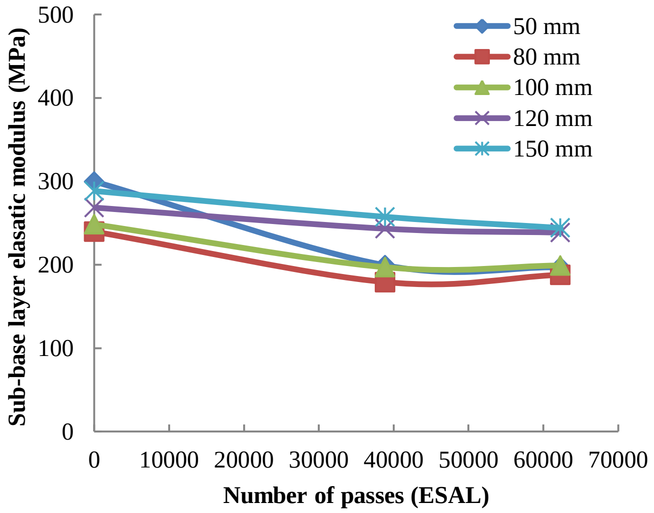

Fig. 7. Variation of Sub-base Layer Elastic Modulus with Number of Passes (ESAL), for Different Thicknesses.

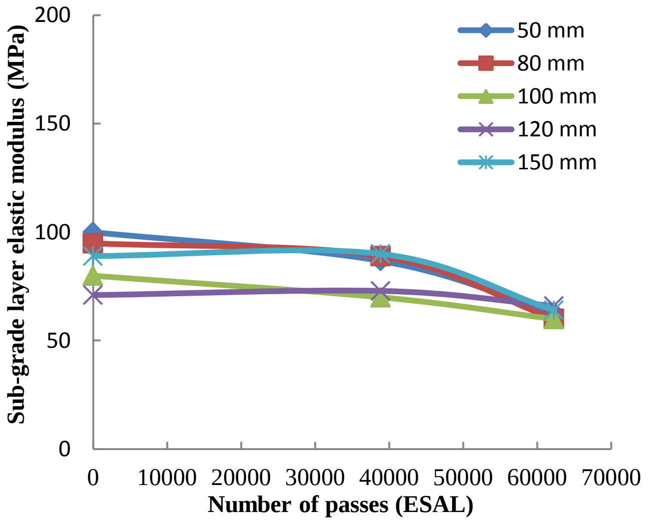

Fig. 8. Variation of Sub-grade Layer Elastic Modulus with Number of Passes (ESAL), for Different Thicknesses.

load repetitions, FWD was used to measure the surface deflections at regular interval of load repetitions, i.e., 0 load repetition (before opening traffic), 38,000 ESAL repetitions (6 months after opening traffic), 62,000 ESAL repetitions (11 months after opening traffic). Based on the surface deflection data obtained through FWD, layer elastic moduli of each test sections were computed using a layer back-calculation program code BACKGA [28]. Figs. 6 - 8 show the variation of elastic layer moduli of PCCBP, sub-base, and sub-grade layers respectively for 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 (Fig. 6). In general, the rate of decrease was comparatively higher in the initial 38,000 passes, which then appeared to stabilize thereafter. Fig. 7 shows that sub-base layer elastic moduli also decreased with increasing traffic passes, but with a comparatively steeper gradient in the initial 38,000 ESAL passes. In the initial stage (zero load repetition), the results of sub-base modulus for 50 mm thick sub-base were slightly higher as compared to that of other PCCBP thicknesses, which then dropped to results closer to that of 80 mm thick PCCBP. This observation may have resulted from local variation in sub-base/sub-grade compaction. The decrease of sub-grade moduli with number of ESAL repetitions can also been seen (Fig. 8); however, in contrast to PCCBP surface layer and sub-base layers, the decrease in moduli of sub-grade layer was comparatively higher during the 38,000 – 62,000 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 – 38,000 passes) may be related to the decrease in stiffness of the PCCBP layer due to distressing.

Distress Evaluation

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) 2,500 mm closer to the inner portion of the test section (total road width is 7 meter), as shown in Fig. 9. Visual evaluations as well as field measurements were done at 0 (zero), 23,000, 50,000, and 62,000 ESAL passes (Fig. 10). Fig. 10 shows the gradual surface degradation through edge spalls and exposure of plastic cells of different test sections with number of load repetitions (ESAL).

Distress Types Similar to Interlocking Concrete Block Pavement Distress Manual [13]

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

a) Rutting:

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

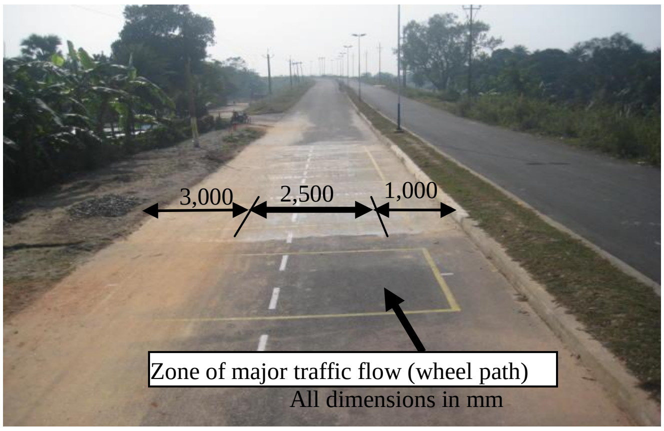

Fig. 9. Zone of Traffic Flow (Visual Inspection).

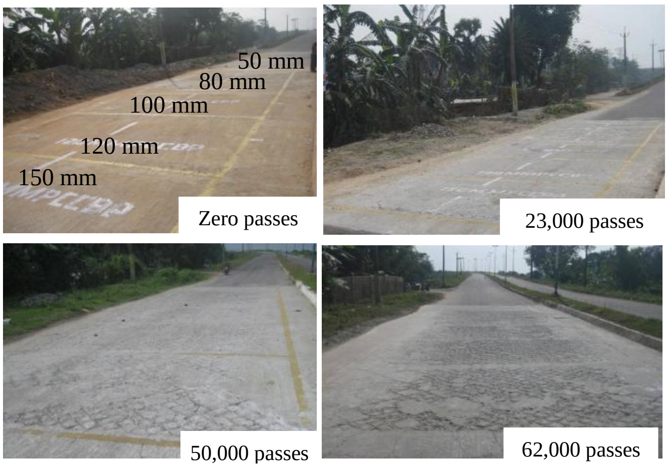

Fig. 10. Surface Degradation of the Test Sections with Traffic Passes (ESAL).

Fig.11. Rutting in 50 mm PCCBP Test section.

Table 4. Severity Levels of Distresses on PCCBP.

a) Rutting [1]	
Severity Level	Maximum rut Depth in mm
Low	5 – 15
Medium	15 – 30
High	> 30
b) Damaged Pavers [1]	
Severity Level	Criteria
Low	Individual Cracks, Spalls or Weathering.
Medium	Advanced Cracking, Spalling or Weathering
High	Blocks are in Multiple Pieces or are Disintegrate.
c) Depression [1]	
Severity Level	Maximum Depression Depth in mm
Low	5 – 15
Medium	15 – 30
High	> 30
d) Faulting [1]	
Severity level	Elevation Difference in mm
Low	4 – 6
Medium	6 – 10
High	> 10
e) Edge Spalls	
Severity level	Spall Depth in mm
Low	< 10
Medium	10 -30
High	>30
f) Scaling	
Severity Level	Scale Depth in mm
Low	4 – 6
Medium	6 – 10
High	> 10
g) Exposed Cells	
Severity Level	Exposed Depth in mm
Low	< 5
Medium	5 -10
High	>10
h) Cell Opening	
Severity Level	Sides of Individual Blocks in mm
Low	< 300
Medium	300 – 600
High	> 600

loading. Rutting can be located by visual assessment and measuring with a straight edge along wheel paths (Fig. 11). Fig. 11 shows rutting in the 50 mm PCCBP test section. 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 was measured using a steel tape in millimeters. The severity of the rut can be defined by the maximum rut depth in mm. The level of severity for rutting is given in Table 4(a).

After about 62,000 ESAL passes, the rut depths were measured (at intervals of 0.5 m along the road and 0.2 across the road) on each of the PCCBP section and were used to plot surface profile in the form of contour in Fig. 12. It can be seen that in the central portion (2,500 mm) near to the inner edge of the road a zone of permanent deformation/rutting can be identified, in agreement with the visual observation shown in Fig. 9. 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 Fig. 13, variation of average rut along the test sections are plotted with radial distance from the centerline of the road. Fig. 13 shows that the maximum depth of rutting (~20 mm) was observed in 50 mm and 80 mm thick PCCBP, whereas for the 150 mm thick PCCBP, it was around 10 mm after 62,000 ESAL passes. For 100 mm thick PCCBP, the average maximum rut depth was around 15 mm, and this was in

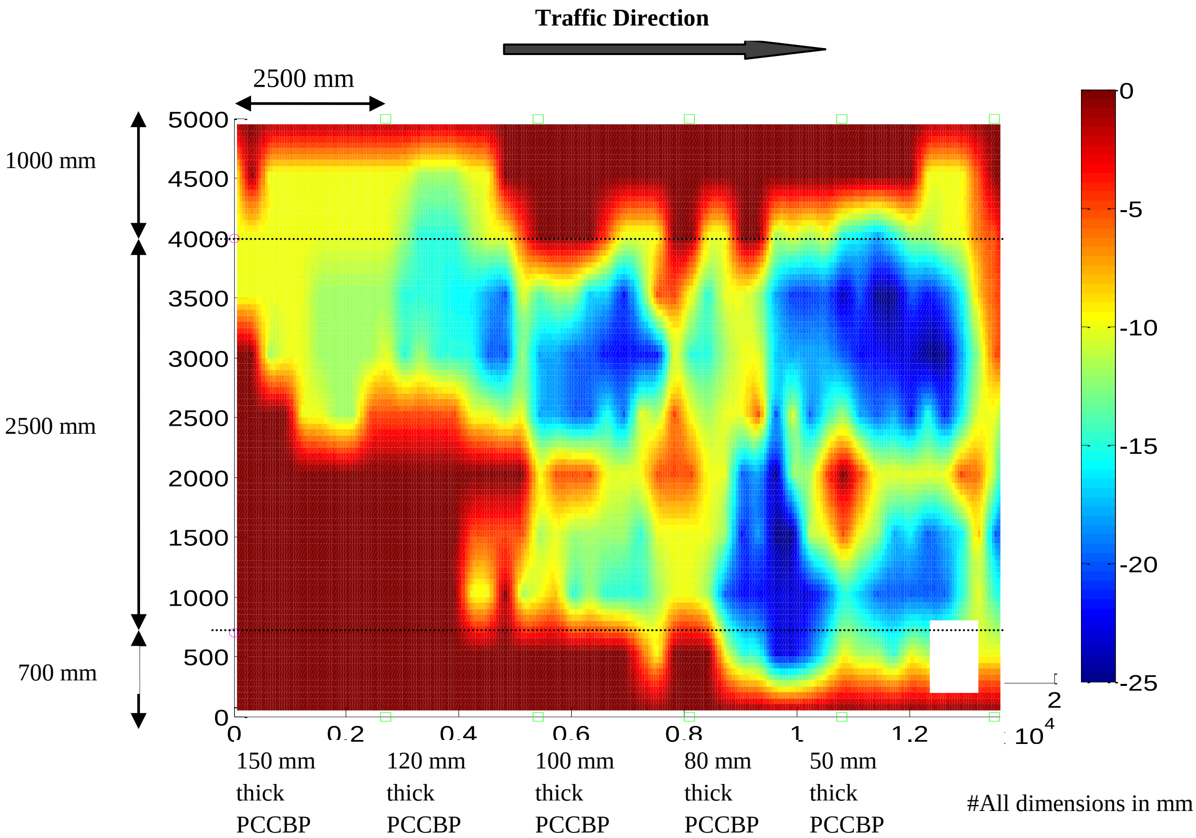

Fig. 12. Surface Profile Contour of theTest Pavement after ~62000 ESAL Passes.

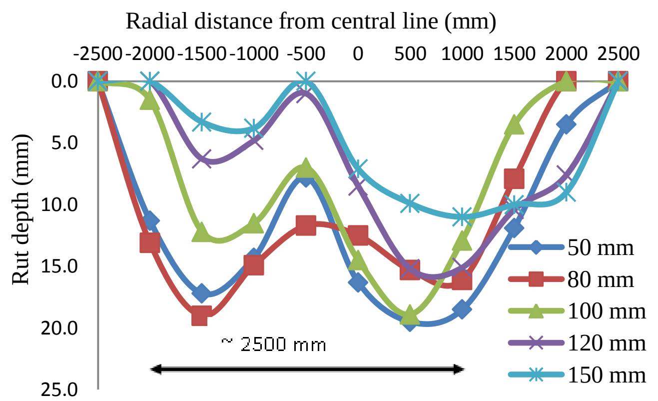

Fig. 13. Avereage Rut Depth of Different Test Sections after ~ 62,000 ESAL Passes.

Fig. 14. Damaged Pavers Observed in 120 mm Thick PCCBP Test Section.

agreement with the result of 16 mm (extrapolated linearly for 62,000 ESAL repetitions) reported by Roy *et al*, [12] for 100 mm PCCBP over 100 mm thick soil-cement as sub-base layer. The allowable rut depth is 50 mm for a design traffic of 1 million ESAL during the design life (10 years) for low volume rural roads [26, 29]. Although it appears that around 40% of the allowable rut depth was 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.

b) Damaged paver:

Damaged pavers describe the condition of the cast-in-situ cell filled concrete blocks due to load related damages. Damaged pavers would include paver distresses such as partial or full block damage, chip, cracks, etc. Minor cracks on blocks with little to no opening are considered to have less significant effect on performance. Fig. 14 shows damaged pavers observed in the 120 mm thick PCCBP test section. Damaged blocks were counted as number of blocks in a particular test section in the present study. Its severity was evaluated by degree of distress and is given in Table 4 (b).

c) Depression:

Depressions are areas of the PCCBP surface that have lower elevations compared to those 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 they can lead to water ponding. 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 was measured using a steel tape.

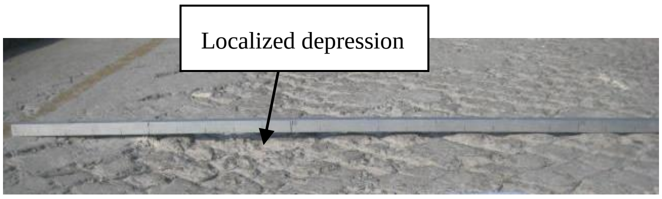

Fig. 15. Measurement of Depression (80 mm Thick PCCBP) Using a 3 Meter Long Straight Edge Alluminium Bar.

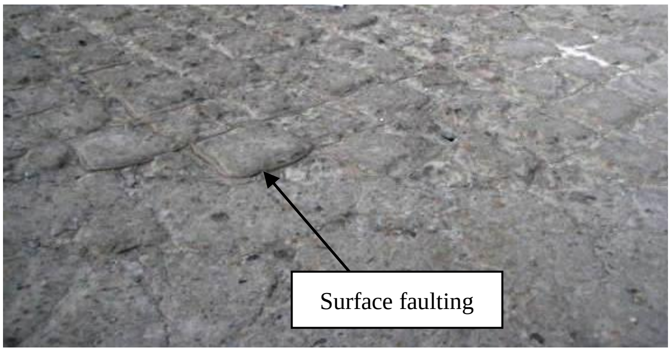

Fig. 16. Surface Faulting (100 mmTthick PCCBP).

Depressions were measured in number of blocks in the test section. The severity was defined by the maximum depth of depression. Fig. 15 shows a medium severity depression in 80 mm thick PCCBP test section. Its severity was evaluated by degree of distress and is given in Table 4 (c).

d) Faulting:

Faulting is an area 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 taller than others. Faulting can cause roughness on a pavement surface, leading to an uncomfortable ride. Fig. 16 shows the faulting of blocks in the 100 mm thick PCCBP test section. This distress is often combined with other distresses such as settlement, heave, rutting, etc. Faulting is measured in number of blocks affected in the present case. Its severity is defined by the maximum elevation difference. The proposed severity level for faulting is given in Table 4 (d).

Distresses Specific to PCCBP

New distresses observed specially in PCCBP pavements are: 1) edge spalls, 2) scaling, 3) exposed cells, and 4) cell opening. Brief descriptions of the new distresses based on visual observations and in conjunction with similar distresses as highlighted by ICPI [13] are presented below:

a) Edge spalls:

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 are different from edge breaking in that the spalls occur at an angle to intersect the joint, whereas the break extends vertically through the slab. Fig. 17 shows different stages of edge spalls of the concrete blocks in PCCBP. Edge spalls are identified by the edge breakage of blocks, with breakage plane meeting the joint at an angle. If one or more edge spalls with the same severity level are in a block, the block is counted as one block. The proposed severity level of edge spalls is based on the depth of spall. Table 4 (e) shows the severity level of edge spalls of blocks in the present study.

Fig. 17 shows the gradual development of edge spalls and exposure of plastic cells. Formation of a similar pattern of cracks along edges was also reported by Roy *et al*, [11] and Shivaprakash [30]. It may be noted infiltration of surface water from precipitation can take place through such cracks [31].The possible mechanism of the formation of edge spalls is depicted in Fig. 18. An initially vertical plastic cell wall of specific height becomes deformed (resulting in shortening its height) during concrete compaction.

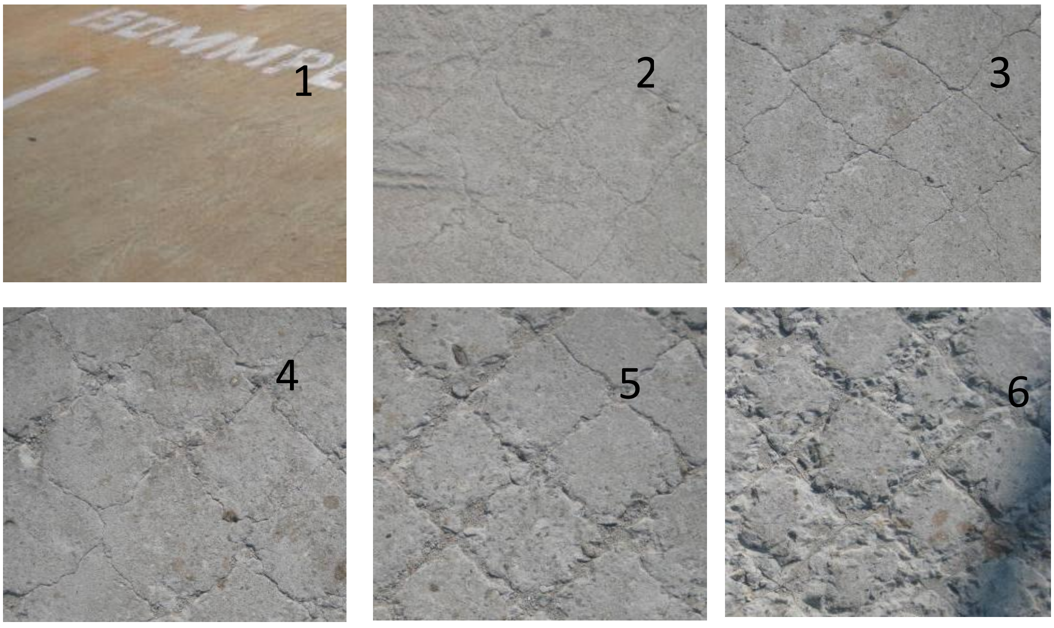

Fig. 17. Different Stages of Development of Edge Spalls of PCCBP Blocks.

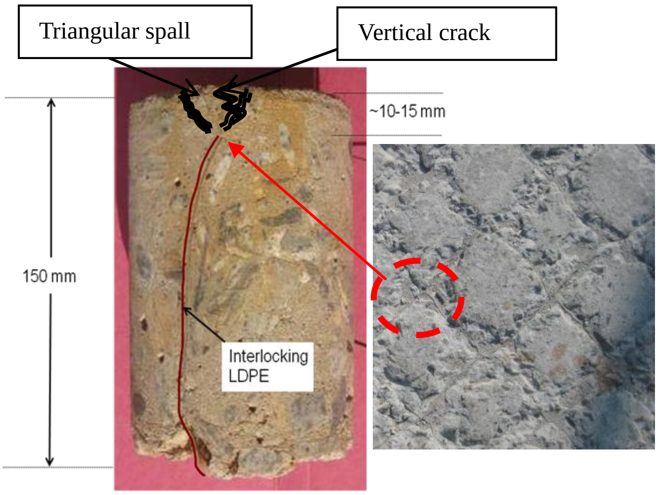

Fig. 18. Edge Spalling Mechanism.

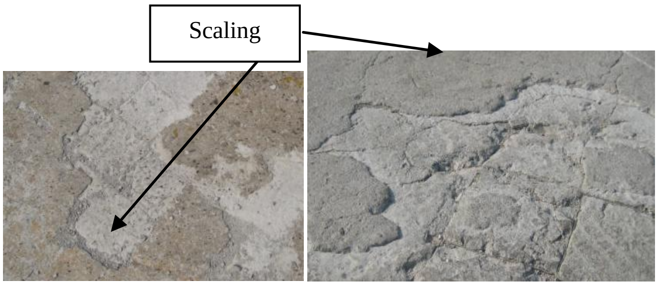

Fig. 19. Scaling of 100 mm thick PCCBP Surface.

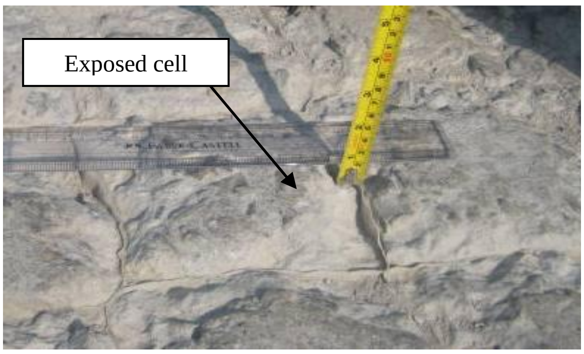

Fig. 20. Exposed Cells Wall in 80 mm Thick PCCBP Test Section.

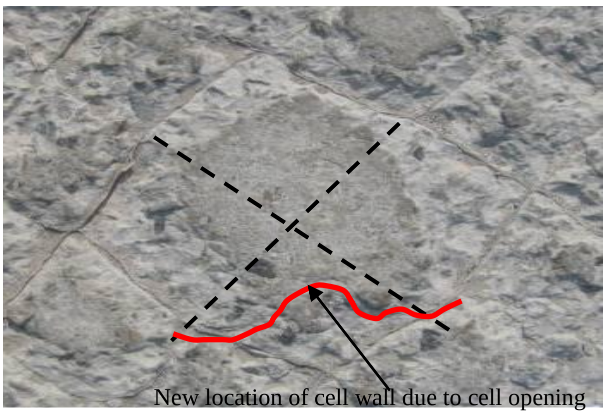

Fig. 21. Cell Opening in 100 mm Thick PCCBP Test Section.

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 [6]. 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; 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 an extra layer of concrete above the deformed plastic cell walls was also seen in the work of Sahoo *et al*, [4]. The extra concrete layer above the plastic cell formwork caused the edge spalling due to the relative block movement under traffic. The edge spalling mechanism consisted 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 until 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 (Fig. 17) at the end of 62,000 ESAL passes exceeded 1 mm (a limiting deflection criterion suggested by Visser and Hall [7] for no spall formation).

b) Scaling:

Scaling is the peeling of thin leveling cement mortar layer from the pavement surface. Thin cement mortar is applied to even out local undulations, and if there is a time lag between concreting and placing the mortar, there are chances of concrete and mortar separating during trafficking. Scaling may also arise from bleeding of the concrete for reasons such as over-compaction and excessive water. Fig. 19 shows the scaling of the 100 mm thick PCCBP surface. Scaling is normally 3 mm to 10 mm in depth, with the occurrences measured in square meters. Scaling can be measured in square meters of surface area. The proposed severity level is given in Table 4 (f).

c) Exposed cells:

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. Fig. 20 shows exposed cell wall in the 80 mm thick PCCBP test section. Exposed plastic cells can be identified by visual observation of the cell walls. Exposed cells can be measured in mm of depth. The severity level can be expressed in the amount of depth of plastic exposure. Table 4 (g) shows the proposed severity level of exposed cells.

d) Cell opening:

The length of the block sides can be increased due to opening of the sealing in the plastic cell formwork. Opening of sealing can occur while concreting. These 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. Fig. 21 shows a cell opening in the PCCBP test section. Normally the opening cells are identified based on the size of the block sides. Cell opening can be measured in mm for the sides of blocks. The severity level can be expressed as the size of the block sides in mm. The proposed severity level is given in Table 4 (h).

Evaluation of PCI

The measuring technique adopted in the present study follows the

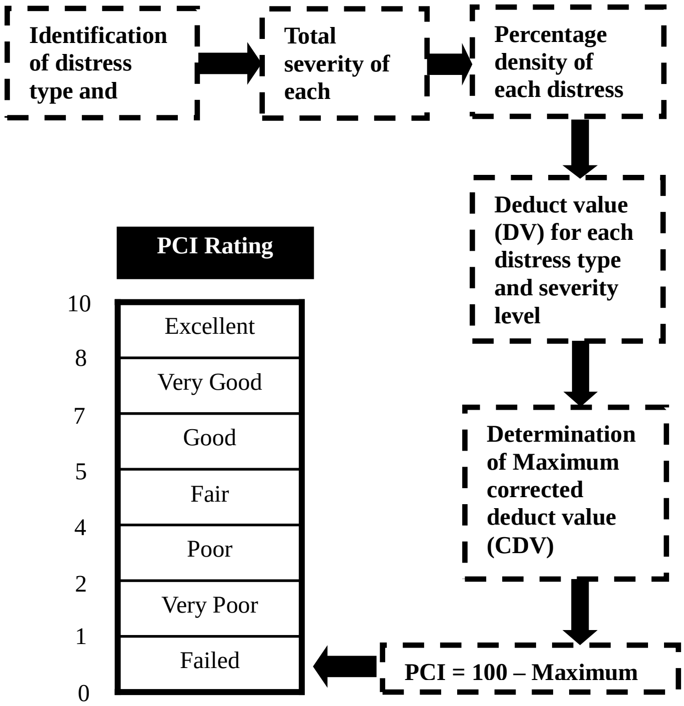

Fig. 22. Flow Chart for Calculation of PCI.

guidelines laid down by ICPI [13] for distress measurement of interlocking concrete block pavement. Linear measurements were done using a measuring tape (30 m). However, as the size of the test pavement is small, instead of measuring the distress areas, the affected number of blocks was counted. Hollow square aluminum pipe of 50 mm x 5 mm (~ 2" x 2") and 3 m (10 ft.) 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 in). Depressions and ruts were measured to where the straight edge meets the pavement surface. For each test section, the quantities of different distresses and their severity levels were recorded based on visual justification. Where multiple severities existed within the outer boundary of a distress, an outline of each severity was identified, and a running subtotal of each of the severities was noted.

A flow chart showing the calculation of PCI for the PCCBP test section is given in Fig. 22. The area to be surveyed (different test sections) was marked properly and the survey was performed using a pavement condition survey data sheet prepared by ICPI. Table 5 shows the different types of distress and their severity levels that were observed in different PCCBP test sections. The total severity of each distress type was recorded in number of affected blocks and the percentage density was calculated as a fraction of total number of blocks in the sample unit. The deduct value was then calculated from the deduct curves for each type of distress [13]. For calculation of the maximum corrected deduct value (CDV), the iterative method described by ICPI [13] 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 [13]. The PCI for each test section was calculated by subtracting the maximum corrected deduct value (CDV) from 100: 100 – Maximum CDV = PCI. The overall condition rating of the section was evaluated from the PCI rating chart given in Fig. 22. Table 6 shows the PCI value and overall rating of each test section.

Table 5. Distress Type and Their Severity Condition for Different Thicknesses of Pavement (ICPI, 2007).

Distress Number and Type

101: Damaged Pavers 102: Depressions 103: Faulting 104: Rutting

L = low; M = Medium; H = High.

Sample Area = ~336 Blocks

Distress / Severity	Quantity (Blocks) PCCBP Thickness (mm)				
	50	80	100	120	150
L-101	6	12	6	8	9
L-102	-	-	-	20	-
M-102	27	28	24	-	-
L-103	154	82	48	85	45
L-104	-	-	-	48	45
M-104	56	55	40	-	-

Table 6. Pavement Condition Rating of Different Thickness of PCCBP Test Section (ICPI, 2007).

PCCBP Thickness in mm	Maximum CDV	PCI -(100 - Max CDV)	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

Discussions

Studies on various types of distress carried out as per ICPI distress guide lines [13], based on the deduct value and PCI values, showed that different thicknesses of the PCCBP test section can be rated as Fair to Very Good (Table 6). 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 [6] reported an initial slight spalling (because of high deflection), but observed later that the spalling did not deteriorate further after 15 months. It may be noted that Visser and Hall [8] also mentioned edge spalls and scaling, but no detail study was reported. Performance evaluation needs to be done for a longer duration, and deduct curves need to be developed for better understanding of PCCBP.

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 [13], and four new distresses specific to PCCBP *viz.*, 1) edge spall, 2) scaling, 3) exposed

cells, and 4) cell opening are suggested.
2. The distress evaluation of PCCBP test sections (after 62,000 ESAL passes) based on the ICPI [13] distress manual showed that the test sections can be rated as 'Fair' (50 mm thick) to 'Very Good' (150 mm thick).
3. A relatively high elastic modulus (1,800 MPa) was observed for the thin PCCBP layer (50 mm thick), even after a wheel load repetition of 62,000 passes, suggesting that PCCBP with waste stone dust as replacement for the traditional river sand can be a promising alternative for rural roads.

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