Analysis and Design Study of Concrete Paver Blocks with Feedback Loop

Raman, Rahul Sikka, Bhawna Arora

***Abstract*— Concrete block pavement (CBP) can be an alternative pavement to asphalt and concrete pavements. CBP is formed from individual concrete paving blocks (CPBs) that fit next to one another on a suitable sub base leaving a specific joint space among them to be filled with jointing sand.**

CBP differ from other pavements according to their mechanical behaviour, manufacturing technique, structural design, installation technique and structural behaviour. For a serviceable pavement all of these subjects have to be studied. This study aims to design the paver blocks of specified strength and to eliminate the defects arose during the life of the paver blocks.

For this purpose, several designs mixes with different cement contents and W/C ratios were designed and the one meeting all the required criterion is selected. However, even after getting desired strength and other required properties some defects arises in the lifespan of the blocks. These defects are then further studied by collecting data of all the defects.

Defects arising in the paver blocks include mainly edge breaking and lesser strength of the blocks. Recorded data is used for further modification in the design of the blocks and better quality control of material and manufacturing process is obtained. The compressive strength, tensile splitting strength, abrasion resistance, density and % water absorption tests were performed on each mix at 7, 14, 28 days.

This study concludes that with better control at the quality of the materials and in the manufacturing process better products can be made. All the defects arising in the blocks are eliminated with the re-design of the blocks by data collection studies for the defects of blocks

***Index Terms*— Concrete paving block, concrete block pavement, re-design, quality control**

I. INTRODUCTION

CBP/ICBP consists of a surface layer of small-element, solid un-reinforced pre-cast concrete Paver blocks lay on a thin, compacted bedding material which is constructed over a properly profiled base course and is bounded by edge restraints/kerb stones. The block joints are filled using suitable fine material. A properly designed and constructed CBP/lCBP gives excellent performance when applied at locations where conventional systems have lower service life due to a number of geological, traffic, environmental and operational constraints. Many number of such applications for light, medium, heavy and very .heavy traffic conditions are currently in practice around the world.

Manuscript received July 15, 2017

In India, research and development work in this field started at Central Road Research Institute in the nineties. Currently the Indian Institute of Technology (IIT), Kharagpur, has joined in the research and development efforts. Application of CBP/lCBP technique is finding increasing popularity around the country, especially in metropolitan cities as well as in large and medium towns.

LITERATURE

The surface of ICBP comprises concrete blocks bedded and joined in sand .It transfer the traffic loads to the substructure of the pavement .The load spreading capacity of concrete blocks layer depends on the interaction of individual blocks with joining sand to build up resistance against applied load. The shape, size, thickness, laying patterns are important block parameters which influences the block parameters.

Some early plate load studies (Knapton 1976, Clark 1978) suggested that load spreading ability was not significantly affected by block shape. Latter accelerated trafficking studies (Shackle 1993) established that shaped blocks exhibited smaller deflection than rectangular blocks of similar thickness installed in same laying pattern under same applied load. (Shackel 1980, Jacobs and Houben 1988) found that, in their early life, block pavements stiffen progressively with an increase in load repetitions. However Shackel clarified that the progressive stiffening did not influence the magnitude of resilient deflection of ICBP. Elastic deflection is decreased with an increase in number of load repetition, rather than an increase, as observed in flexible and rigid pavements.

DESIGN OF CONCRETE PAVER BLOCKS

- **IS Method of Design of Concrete Paver Blocks**

We have designed the blocks using the Indian Standard method of design. This helped us achieving the goal of strength of tiles in minimum specified strength. Use of admixture aided in the higher strength of the blocks in lesser time.

Design of Paver Blocks

The following materials are used for mix proportioning of grade of Paver Blocks:

Materials in use for Design: Type of cement used Shree Cement OPC -43 Grade, Maximum nominal size of aggregate-20mm, Minimum cement content-330kg/m^3, Maximum water-cement ratio-0.40, Workability-100mm, Exposure conditions-Severe, Method of transporting and placing-Manual, Type aggregate-Crushed Angular Aggregate, Maximum cement content-450kg/m^3, Admixture used-Super plasticizer.

Test results Obtained for Design Mix: Cement used-Shree cement OPC-43 grade, Specific gravity of cement-3.10, Chemical Admixture- Super plasticizer, Specific gravity of coarse aggregate-2.74 and Fine aggregate-2.8, Water absorption of coarse aggregate-0.5% and Fine aggregate-1.0%

Sieve analysis:

1) Coarse aggregate (Test result)

Table 4.1: Coarse Aggregate

IS Sieve Sizes mm	Analysis of Coarse Aggregate Fraction		Percentage of Different Fractions			Remarks (Results)
	I	II	I	II	III	
20	100	100	60	40	100	Conforms to IS 383
10	10	71.20	0	28.5	28.5	
4.75	-	9.60	-	4	3.7	
2.36	-	0	-	-	-	

2) Fine aggregate (Test Results)

Text in Bolds shows our test results.

Table4.2: Fine Aggregate Zoning.

IS SIEVE DESIGNATION	PERCENT PASSING FOR			
	Grading zone I	**Grading zone II**	**Grading zone III**	**Grading zone IV**
10 mm	**100**	100	100	100
4.75 mm	**90-100**	90-100	90-100	95-100
2.36 mm	60-95	75-100	85-100	95-100
1.18 mm	30-70	**55-90**	75-100	90-100
600 micron	**15-34**	35-59	60-79	80-100
300 micron	5-20	8-30	12-40	15-50
150 micron	**0-10**	0-10	0-10	0-15

Results shows that the fine aggregates belongs to the Grading Zone-I.

Target Strength for Mix Proportioning of Paver Blocks

Assumed Standard Deviation (N/mm^2), s =5N/mm^2 for Grade of Concrete M-35

Therefore, target strength =35 + 1.65 x 5 =43.25 N/mm^2

SELECTION OF WATER-CEMENT RATIO

Selected Minimum cement-content, Maximum water-cement ratio and Minimum Grade of concrete for Severe Exposure with Normal Weight Aggregate of 20mm Nominal maximum size. Maximum water-cement ratio = *0.45*. Based on practical data, adopt water-cement ratio as 0.40. **0.40<0.45 Hence, OK.**

SELECTION OF WATER CONTENT

Maximum water content 186 litre (for 25 to 50 mm slump range) for 20 mm aggregate. Estimated water content for 100mm slump =186+186x6/100 =197 litre. As super-plasticizer is used, the water content can be reduced up 25 per cent and above. Hence, the arrived water content =197 x 0.75 =147.75 litre.

CALCULATION OF CEMENT CONTENT

Water-cement ratio= 0.40, Calculated Cement content =147.75/0.40=369.375 (370Kg Approx.). Minimum cement content for 'severe' exposure condition = 320 kg/m^3.

PROPORTION OF VOLUME OF COARSE AGGREGATE AND FINE AGGREGATE CONTENT

Volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (Zone I) for water-cement ratio of 0.50 =0.60. In the present case water-cement ratio is 0.40. Therefore, volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As the water-cement ratio is lower by 0.10. The proportion of volume of coarse aggregate is increased by 0.02 (at the rate of -/+ 0.01 for every ± 0.05 change in water-cement ratio). Therefore, corrected proportion of volume of coarse aggregate for the water-cement ratio of 0.40 = 0.62. Volume of fine aggregate content = 1 - 0.62 =0.38.

MIX CALCULATIONS

The mix calculations per unit volume of concrete shall be as follows:

a) Volume of concrete =1 m^3

b) Volume of cement = $\frac{Mass of Cement}{Specific Gravity Of Cement} \times \frac{1}{1000}$

$= \frac{370}{3.10} \times \frac{1}{1000}$

$= 0.119 m^3$

c) Volume of Water = $\frac{Mass Of Water}{Specific Gravity Of Water} \times \frac{1}{1000}$

$= \frac{147.75}{1000} = 0.147 m^3$

d) Volume of chemical Admixture (Super-Plasticizer) @3% by mass of cement content =

$\frac{Mass of Chemical Admixture}{Specific Gravity Of Admixture} \times \frac{1}{1000}$

$= \frac{11.1}{1.21} \times \frac{1}{1000} = 0.009 m^3$

e) Volume of all in aggregate= 1-(0.119+0.147+0.009)= 0.725m^3

f) Mass of coarse Aggregate= 0.725x0.62x2.74x1000= 1231.63 kg

g) Mass of Fine Aggregate= 0.725x0.38x2.8x1000= 771.4kg

MIX PROPORTIONS FOR TRIAL NUMBER 1

Cement-370kg, Water-147.75litre, Fine aggregate-771.4kg, Coarse aggregate-1231.63kg, Chemical admixture-11.1kg, Water-cement ratio-0.40.

MIX PROPORTIONS FOR TRIAL NUMBER 2

Cement-375kg, Water-150litre, Fine aggregate-780.4kg, Coarse aggregate-1220.63kg, Chemical admixture-10.1kg, Water-cement ratio-0.40.

QUALITY CONTROL/ASSURANCE IN MANUFACTURING OF BLOCKS

Quality control is the use of techniques and activities to achieve sustain and improve the quality of the paver blocks produced. It involves integrating techniques and activities specification of all the materials and final paver block required.

Quality Control Measures adopted in the Materials:

- **Tests on aggregate Sieve Analysis Results (Coarse Aggregate)**

Table 6.1: Test on Aggregate Sieve Analysis Result

IS Sieve	Percentage Passing Through Sieve (Results)	Percentage of Passing Through Sieve (Indian Standard Requirements)
40mm	100	100
20mm	96	95 to 100
16mm	77	-
12.5mm	48	-
10mm	27	25-55
4.75mm	8	0-10
2.36mm	2	-

Results shows the aggregate is *well graded* and conforms to the IS Specifications.

- **Specific Gravity of Aggregates:** Coarse aggregate-2.75 and Fine aggregate-2.79
- **Tests on Cement:** Specific gravity of the cement is tested. And results of the random sampling and testing are conforming to the values used in the mix design of the paver blocks. Specific Gravity of cement: 3.10

Quality control measures in the manufacturing process:

- **Decrease in reject rate and increase in product quality.**
  The nos of the rejected paver blocks after the final product is manufactured decreased upto 60%. Visual inspection of the product showed promising increase in the quality of the blocks.
- **Reduction in price of products hence better value for money.**
  The price of the expensive materials used is the major factor which increases the overall price of the product. Since we designed the product and blocks are manufactured in totally controlled environment and methods the overall price of the commodity is reduced upto15%.
- **Increase in product yield which should make economic mass production possible.**
  This is the one of the factor by which we can benefit a lot. However at this point we don't required mass production. But still this method can be used to benefit when mass production is required.

TESTING OF PAVER BLOCKS

- **Compressive Strength Test**
  Compressive strength of paver blocks shall be determined as per the Indian Standard methods. Paver blocks strength need to be specified in terms of 28 days compressive strength. In case the compressive strength of paver blocks is determined for ages other than 28 days, the actual age at testing is to be reported. The compressive strength of the blocks is the major factor which governs the usage and durability of the blocks. Sampling of the blocks is done as per the IS requirements and the blocks are tested. 8 blocks are randomly selected and sample is then taken to the laboratory.

Area of the Paver Block: Plan Area of paver blocks 28300mm^2

Table 7.2: Compressive Strength as per IS 15658:2006

S. No.	Tiles Area mm^2	Max Load (N)	Compressive Strength N/mm^2	Corrected Com. Stg. After applying Correction factor N/mm^2	Corrected Average Comp. Strength N/mm^2
1.	28300	919500	32.49	38.34	40.82
2.		963000	34.03	40.16	
3.		999000	35.3	41.65	
4.		1010500	35.71	42.14	
5.		981000	34.66	40.9	
6.		962500	34.01	40.13	
7.		1006500	35.57	41.97	
8.		990000	34.98	41.28	

Criteria for passing of the concrete blocks as per IS 15658:
Average Strength of the blocks as observed in the tests results: 40.82 N/mm^2.According to the IS specifications average strength should be: = 35 + 0.825x5 = 39.125N/mm^2.And our resulting strength of the blocks is 40.82 which is greater than the requirements of IS Specifications.

Correction Factor to be used for testing the Compressive Strength.

- **Tensile Splitting Test**

The tensile splitting strength of paver blocks should be determined as per the method given in the Indian Standard Code IS 15658 (Annex-F).

The Flexural strength of the blocks is determined and found to be:

Result of Splitting test:

Table 7.4: Average Flexural Strength (N/mm^2)

S. No.	Maximum Load at Splitting (N)	Flexural Strength (N/mm^2)	Average Flexural Strength(N/mm^2)
1	8490	3.97	4.07
2	8540	4.00	

3	8710	4.08	
4	8455	3.96	
5	8765	4.10	
6	8805	4.12	
7	8950	4.19	
8	8915	4.17	

The average flexural strength of the blocks is less than that of the requirement as per the Indian Standard.

4.14 N/mm^2 (Required Flexural Strength ≥ 4.07 N/mm^2 (Observed Flexural Strength of the specimens)

This sample doesn't conform to the specifications of the Indian Standard code; hence the design needs to be modified.

LIFE OF BLOCKS AND FEEDBACK FROM PAVER BLOCK USAGE

In the life of the paver blocks many defects may arise and they have an adverse effect on the remaining life of the paver blocks. These effects need to be detected and the control measures can be adopted for these in the mix design and in the manufacturing process of the blocks. Some of these defects are identified in this study and the measures to control these defects are adopted. The design is modified and remedial controls are also applied in process.

Defects identified:-

- **Corner Breakage**: Tiles with broken corner with more than 5mm in any length of the tile is considered broken. All such blocks are identified and data is recorded for further studies.
- **Tiles breaking**: Any block which is broken in shear is considered broken in this study. Such blocks are not fitted for the traffic and must be removed. Lesser the numbers of the failed blocks higher the reliability of the paver blocks. All such paver blocks are identified and the data is recorded for further modification in the design or in the process of the making of the blocks.

Data collection studies

Table 8.2: Defective Piece(Broken Corner)

S. No.	No. of tiles Observed	Defective Pieces (Broken Corners)
1.	10000	340
2.	10000	230
3.	10000	310
4.	10000	290

These defects can be removed once the design of the paver blocks is modified.

Table 8.3: Broken Paver Blocks

S. No.	No. of laid tiles Observed	Broken Paver Blocks
1.	50000	15
2.	50000	21
3.	50000	19
4.	50000	23

RE-DESIGNING: USE OF FEEDBACK DATA IN DESIGN MODIFICATION

Design of Paver Blocks

First of all, the cement slurry topping in the paver blocks is increased by the 1mm since it is mainly responsible for the wear and tear of the blocks mostly. Hence, Area of blocks 283cm^2.The topping requirement 3mm thick. Hence the volume of the cement slurry required for the one block is 283x0.3= 84.9cm^3.Now the modification in the design and quality control in manufacturing is required to eliminate the numbers of the failed paver blocks.

The design of the blocks is modified as below:

The following materials are used for mix proportioning of grade of paver blocks:

Materials in use for Design: Type of cement used Shree Cement OPC -43 Grade, Maximum nominal size of aggregate-20mm, Minimum cement content-330kg/m^3, Maximum water-cement ratio-0.38, Workability-100mm, Exposure conditions-Severe, Method of transporting and placing-Manual, Type aggregate-Crushed Angular Aggregate, Maximum cement content-450kg/m^3, Admixture used-Super plasticizer.

Test results Obtained for Design Mix: Cement used-Shree cement OPC-43 grade, Specific gravity of cement-3.10, Chemical Admixture- Super plasticizer, Specific gravity of Coarse aggregate-2.74 and Fine aggregate-2.8, Water absorption of Coarse aggregate-0.5% and Fine aggregate-1.0%

Sieve analysis:

Table 9.1: Coarse Aggregate

IS Sieve Sizes Mm	Analysis of Coarse Aggregate Fraction		Percentage of Different Fractions			Remarks (Results)
	I	II	I	II	III	
20	100	100	60	40	100	Conforms to IS 383
10	10	71.20	0	28.5	28.5	
4.75		9.60		4	3.7	
2.36		0				

2) Fine aggregate (Test Results)

Text in Bolds shows our test results.

Table 9.2: Fine Aggregate Zoning

IS SIEVE DESIGNATION	**PERCENT PASSING FOR**			
	Grading zone I	**Grading zone II**	**Grading zone III**	**Grading zone IV**
10 mm	**100**	100	100	100
4.75 mm	**90-100**	90-100	90-100	95-100
2.36 mm	60-95	75-100	85-100	95-100
1.18 mm	30-70	**55-90**	75-100	90-100
600 micron	**15-34**	35-59	60-79	80-100
300 micron	5-20	8-30	12-40	15-50
150 micron	**0-10**	0-10	0-10	0-15

Results shows that the fine aggregates belongs to the Grading Zone-I.

Target Strength for Mix Proportioning of Paver Blocks

Assumed Standard Deviation (N/mm^2), s =5N/mm^2 for Grade of Concrete M-35 **Therefore, target strength =35 + 1.65 x 5 =43.25 N/mm^2**

SELECTION OF WATER-CEMENT RATIO

Selected Minimum cement-content, Maximum water-cement ratio and Minimum Grade of concrete for Severe Exposure with Normal Weight Aggregate of 20mm Nominal maximum size. Maximum water-cement ratio = *0.45*. Based on practical data, adopt water-cement ratio as 0.38.

SELECTION OF WATER CONTENT

Maximum water content 186 litre (for 25 to 50 mm slump range) for 20 mm aggregate. Estimated water content for 100mm slump =186+186x6/100 =197 litre. As super-plasticizer is used, the water content can be reduced up 25 per cent and above. Hence, **the arrived water content =197 x 0.75 =147.75 litre.**

CALCULATION OF CEMENT CONTENT

Water-cement ratio= 0.38, Calculated Cement content =147.75/0.38=388.375 (389Kg Approx.). Minimum cement content for 'severe' exposure condition = 320 kg/m^3.Hence, OK.

PROPORTION OF VOLUME OF COARSE AGGREGATE AND FINE AGGREGATE CONTENT

Volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (Zone I) for water-cement ratio of 0.50 =0.60.In the present case water-cement ratio is 0.40. Therefore. volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As the water-cement ratio is lower by 0.10. The proportion of volume of coarse aggregate is increased by 0.02 (at the rate of -/+ 0.01 for every ± 0.05 change in water-cement ratio).Therefore, corrected proportion of volume of coarse aggregate for the water-cement ratio of 0.38 = 0.624.Volume of fine aggregate content = 1 - 0.624 =0.376

MIX CALCULATIONS

The mix calculations per unit volume of concrete shall be as follows:

h) Volume of concrete =1 m^3

i) Volume of cement = $\frac{MassofCement}{SpecificGravityOfCement} \times \frac{1}{1000}$

$$= \frac{389}{3.10} \times \frac{1}{1000}$$

$= 0.125m^3$

j) Volume of Water $= \frac{MassOfWater}{SpecificGravityOfWater} \times \frac{1}{1000}$

$= \frac{147.75}{1000} = 0.147m^3$

k) Volume of chemical Admixture (Super-Plasticizer) @3% by mass of cement content $= \frac{MassofChemicalAdmixture}{SpecificGravityOfAdmixture} \times \frac{1}{1000}$

$= \frac{11.1}{1.21} \times \frac{1}{1000} = 0.009m^3$

l) Volume of all in aggregate= 1-(0.125+0.147+0.009)= $0.719m^3$

m) Mass of coarse Aggregate= 0.719x0.624x2.74x1000= 1229.63 kg

n) Mass of Fine Aggregate= 0.719x0.376x2.8x1000= 756.4kg

MIX PROPORTIONS FOR FINAL DESIGN

Cement-389kg, Water-147.75litre, Fine aggregate-756.4kg, Coarse aggregate-1229.63kg, Chemical admixture-11.1kg, Water-cement ratio-0.38.

ELIMINATION OF DEFECTS

Our re-designed product eliminates most of the commonly occurring defects in the paver blocks. Defects which showed up early in the life of the blocks now no longer exist. The tests results and site performance both supports our study. This makes it a successful case of the studying defects and elimination of them with experimental studies.

RESULT/CONCLUSION

The aim of the study was to determine the better design mix for paver block's longevity. In this study we determined the design mix for our requirements and defects occurring in the lifespan of the blocks are then identified. These identified defects needed to be removed from the blocks. A study is then carried out to determine the possible causes of those defects in the paver blocks. A second mix-design is then carried out keeping in mind those identified defects. After the design of the blocks studies are again carried out to determine the elimination of the defects. If that mix-design doesn't solve our problems, then, a third iteration could be carried to possibly eliminate all still occurring defects.

Out study shows that with better knowledge of the practical usage of the blocks and better knowledge of the defects occurring in the blocks a very suitable mix-design can be carried out to eliminate all the problems occurring in the interlocking paver blocks.

Data of corner breaking and compressive failure of the blocks is accumulated from the different sites of same mix-design. This helped us to proceed and determine the failures occurring in the blocks. Hence, with enough knowledge of the usage and defects occurring in the blocks a very well worked out design mix for making concrete paver blocks is possible for maximum lifespan of the blocks.

REFERENCES

1. Interlocking Concrete Blocks- An easy approach in road construction pavement
2. Authors: Dr. S D Sharma, Journal/Seminars/Conferences: New Building Material & Construction World, Vol.15, Issue 3, Sep. 2009, Published in: Journal, Date: 1 September 2009
3. IRC SP 062: Guidelines for the Design and Construction of Cement Concrete Pavement for Low Volume Roads (First Revision)
4. Shackel B. (1993)," Design and constructions of interlocking concrete block pavement". First International Conference on Concrete Paving, Newcastle-upon-time,U.K,113-120
5. Barber, S.D., and Knapton, J. (1976) "An experimental investigation of the behavior of a concrete block pavement". Cement Concrete Association, U.K.
6. ICPI "Design guidelines for Interlocking concrete block pavement". (Part 1 to Part 10).
7. IS 10262 (2009) Guidelines for concrete mix design proportioning
8. IS 383 (1970): Specification for Coarse and Fine Aggregates From Natural Sources For Concrete IS 456 (2000): Plain and Reinforced Concrete - Code of Practice