SUITABILITY OF CAST IN-SITU CONCRETE BLOCK PAVEMENT FOR LOW VOLUME ROADS

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SUMMARY

Cast in-situ concrete block pavement (CISCBP) consists of interlocked concrete blocks formed by placing zero slump concrete into the formwork of polyethylene cells placed over a compacted subgrade or subbase and compacted with a roller. CISCBP can also be constructed by filling up the cells with single size aggregates and grouting of cement-sand mortar into the aggregates by a plate vibrator. Scanty literature is available on application of CISCBP. This paper presents the findings of a research work carried out for the laboratory evaluation of cast in-situ concrete block pavement for low volume roads. Results of the investigation on proportioning of mixes and the evaluation of strength of the mixes are presented. The formwork of plastic cells of depths 75mm and 100mm forming square of sides of 150mm by 150mm was placed over the bed of an Accelerated Pavement Test Facility (APTF). For the construction of the 75mm CISCBP, grouting method was adopted while cement, sand, aggregates and the required quantity of water were premixed and poured into the 100mm plastic cells for further compaction. During the compaction, the cell walls get deformed and causing interlocking among the concrete blocks, which bring about greater load spreading ability of the blocks.

On repeated application of the 40kN dual wheel load in the accelerated pavement test, the pavements sections showed very less rutting along the wheel path. Falling Weight Deflectometer (FWD) test on the pavement sections indicated that the equivalent elastic modulus of the cast in-situ concrete block layer can be over 2500MPa. Cores taken after the accelerated test revealed that premixed concrete blocks had fewer voids than those formed by grouting cement-sand mortar into the aggregates. A design chart was made where an equivalent elastic modulus of 2500MPa was adopted for the concrete block layer. The vertical subgrade strain was selected as the criterion for the design and a reliability of 50% (AASHTO, 1993) was considered for producing design charts for low volume roads. The design chart was made at different repetitions of standard axle load with different subgrade CBR.

1. INTRODUCTION

The Ministry of Rural Development of the Government of India launched a major rural road programme, called the Pradhan Mantri Gram Sadak Yojana (PMGSY) in the year 2000 to bring about all weather rural connectivity so as to encourage growth due to faster transportation. The all-weather road can be surfaced or un-surfaced depending upon the volume of traffic. Thin bituminous surfacings such as premix carpet and surfacing dressing (IRC, 2002) that are usually provided on low volume roads deteriorate fast due to poor drainage resulting in raveling and pothole formation. Such roads need frequent maintenance. It is desirable to have a concrete surface needing little maintenance but a normal cement concrete pavement requires high initial investment.

A new type of pavement called the cast in-situ concrete block pavement developed in South Africa (Visser and Hall, 1999; Visser, 1994, 1999, 2003) appears to be most appropriate for India also. This type of pavement consists of a formwork of polyethylene cells 150mm by 150mm in size with thicknesses varying from 50mm to 150mm or greater (Figure 1). The formwork of plastic cells is stretched over the carriageway under tension, filled with single size aggregates and rolled with static or vibratory roller. A mortar of cement and sand is placed over the compacted aggregate and vibrated into the voids by a plate compactor. Alternatively, the cells can also be filled with concrete and compacted. The concrete in the cells upon compaction (Figure 2) forms interlocking blocks after curing and have a good load spreading behavior (Ryntathiang et al., 2005).

The present paper deals with a study on behavior of cast in-situ concrete block pavements constructed in the bed of an accelerated pavement test facility. Details of materials used, laboratory investigation on proportioning of mixes by volume, evaluation of cube strength of the mixes and construction procedures are also presented. The flexible pavements were subjected to different wheel load repetitions. Equivalent elastic moduli of the cast in-situ block layer as well as rutting along the wheel path were evaluated at different repetitions.

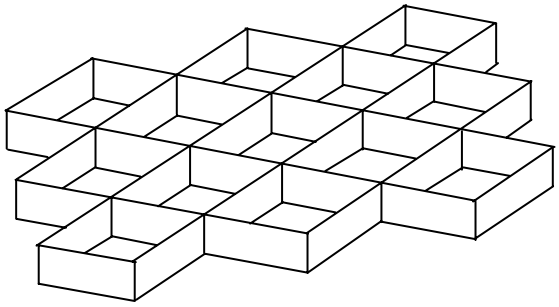


Figure 1: Plastic cell after tensioning over prepared subbase

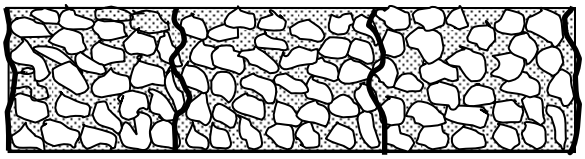


Figure 2: Deformed plastic cell walls after compaction bringing about interlocking

2. TYPES OF CONSTRUCTION WITH CAST IN-SITU CONCTERE BLOCK PAVEMENT

Following three alternate methods can be used for construction of cast in-situ concrete blocks in the field:

Type 1

Single size aggregates are filled into the cells and compacted by a static/vibratory roller. Cement-sand grout is spread and vibrated into the voids of the compacted aggregates.

Type 2
A low slump concrete mix of Portland cement, sand and aggregate having optimum moisture content (water content varying from 6% to 8%) is filled into the plastic cells. The concrete is compacted by 80 to 100kN static/vibratory roller.

Type 3
A high slump concrete with super plasticizer (Visser, 2003) is filled into the cells whose walls are initially deformed to ensure interlocking.

Types 1 and 2 appear to be most promising for adoption in rural area in India because of less requirement of highly trained manpower.

3. MATERIALS

3.1 Plastic cell
Readily available low density polyethylene (LDPE) sheets of thickness 0.49mm were cut in widths 75mm and 100mm respectively and they were heat welded to form a cell size 150mm x 150mm with depth of 75 and 100mm respectively on stretching.

3.2 Cement
Ordinary Portland cement of grade 43 meeting the requirements of Indian Standard (BIS, 1988) was used for casting concrete blocks.

3.3 Sand
The sand was obtained from the bed of the river Kasai located near Kharagpur. Particle size distribution shown in Table 1 indicates that it corresponds to Zone III (BIS, 1970).

Table 1. Particle size distribution of sand

Sieve Size (mm)	10	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Gradation (% Passing)	100	97.5	93.3	82.8	68.3	22.8	3.8	0.02
Zone III of Indian Standard	100	90-100	85-100	75-100	60-79	12-40	0-10	

3.4 Coarse aggregate for concrete blocks
The coarse aggregates classified as dolerite were obtained from Chandil quarry in Jharkhand. Single size aggregate of nominal size 26.5mm and 22.4mm as per the specification of Ministry of Road Transport and Highway (MORTH, 2001) were selected for the cells of 100mm and 75mm depth respectively so that the maximum aggregate sizes were about one third the depth of the concrete blocks. The apparent specific gravity of aggregates of nominal size 26.5mm and 22.4mm were 2.68 and 2.64 respectively. The single size aggregates had an average flakiness index of about 36 percent (BIS, 1963a) and Los Angeles Abrasion value (BIS, 1963b) was found to be 13.1 percent.

3.5 Coarse aggregate for subbase
Wet Mix Macadam (WMM) meeting the specifications of Ministry of Road Transport and Highway (MORTH, 2001) was used as the granular subbase. Dolerite aggregates obtained from Chandil quarry were blended to meet the gradation requirement and its engineering properties were evaluated and given in Table 2.

Table 2. Blended particle size distribution and properties of WMM subbase

Sieve Size (mm)	53	40	22.4	11.2	4.75	2.36	0.6	0.075
Specified Limit	100	95-100	60-80	40-60	25-40	15-30	8-22	0-8
Blended (% Passing)	100	96.15	66.44	58.62	33.75	17.59	10.95	4.11

Aggregate Properties	App Sp. gr	W.A (%)	CE & F (%)	LAAV (%)	AIV (%)	DD kg/m^3	OMC %
	2.42	0.424	38.84	13.11	12.69	2171.4	8

Note: App. sp. gr - Apparent specific gravity; WA - Water absorption; CE&F - Combined Elongation and Flakiness; LAAV - Los Angeles Abrasion Value; AIV – Aggregate Impact Value; DD - Dry Density; OMC - Optimum Moisture Content

3.6 Subgrade

Sand having the following particle size distribution is used as subgrade for the present study. Laboratory study under modified compaction showed that it has a density of 1653kg/m^3 at optimum moisture content of 12%.

Table 3. Particle size distribution of subgrade sand

Sieve Size (mm)	1.18	0.7	0.6	0.425	0.3	0.25	0.18	0.15	0.125	0.09	0.075
% Passing	100	99.79	99.65	99.54	97.11	80.48	29.04	7.08	4.35	1.68	0.94

4. MIX COMPOSITION AND STRENGTH OF CONCRETE BLOCKS

Cubical moulds of steel of dimensions 150mm x 150mm x 150mm (BIS, 1959) were used for determination of strength of different mix proportions. Aggregates of nominal sizes 26.5mm and 22.4mm (MORTH, 2001) were used in the investigation. For one series of investigation, 22.4mm singe size pit run gravel was also investigated to explore its use for low volume roads since the material is cheap and available in plenty in many places. The Los Angeles Abrasion value (BIS, 1963b) of the gravel was 42 percent.

The cubical mould was filled with single size aggregate and cement sand mortar was placed at the top of aggregate and the mortar was vibrated into the voids by mean of a pan vibrator. Additional mortar was vibrated to fill up all the voids of the aggregate. Excess mortar was removed by means of a straight edge. The cement-sand ratios of 1:1, 1:1.5 and 1:2 by volume were adopted for different experiments and water cement ratio was varied from 0.4 to 0.5. Volume by batching was adopted since this method is easy to adopt in rural areas in India. The cube strength was determined after 7 days of curing in water. Some cubes were cast after premixing the above aggregates, cement, sand and water keeping their proportions same as that adopted for grouting method. A brief description of the different methods adopted for the study is explained below.

a). Dry single size coarse aggregates were filled into the cubical mould and vibrated. Weight of the mould and the aggregates were determined to find out the void in the mineral aggregates. Cement-sand mortar having different proportions of cement and sand by volume were placed over the compacted aggregates and vibrated into the aggregates. Excess amount of mortar was struck off.
b). The aggregates, cement, sand and water were mixed together and compacted into a mould.

Laboratory investigation on mix compositions and strength of concrete blocks using different methods mentioned above are shown in Tables 4 and 5 respectively. In all of the above cases, cube strength was determined after 7days of curing in water. The 7days strength is mean of three cube samples

Table 4. Laboratory study of coarse aggregate of nominal size of 26.5mm and 22.4mm with different cement (C) sand (S) ratios at different water cement (w/c) ratios

Condition	26.5mm Aggregate				22.4mm Aggregate			
	C/S	w/c	Void in agg.	7 days Strength MPa	C/S	w/c	Void in agg.	7 days Strength MPa
(a) Compacted dry aggregates and cement sand mortar grouting	1:1	0.5	43.54	17.56	1:1	0.5	39.82	15.56
	1:1.5	0.5	44.80	18.22	1:1.5	0.5	44.14	22.2
	1:2	0.5	43.54	13.33	1:2	0.5	44.14	11.8
	1:1	0.45	38.78	16.44	1:1	0.45	44.14	20.8
	1:1.5	0.45	37.47	17.33	1:1.5	0.45	44.14	20.5
	1:2	0.45	-	-	1:2	0.45	-	-
(b) Cement sand and aggregates Premixed	1:1	0.4	-	23.71	1:1	0.4	-	24.16
	1:1	0.45	-	19.7	1:1	0.45	-	23.28

Table 5. Laboratory study of nominal size of 22.4mm gravel with different cement (C) sand (S) ratio at different water cement (w/c) ratios

Condition	C/S	w/c	Void in agg.	7 days Strength MPa
Grouting of cement-sand mortar into Compacted gravel aggregates	1:1	0.5	33.02	18.44
	1:1.5	0.5	32.28	14.89
	1:2	0.5	33.63	11.11
	1:1	0.45	33.92	19.22
	1:1.5	0.45	32.51	20.11
	1:2	0.45	-	-

Table 4 indicates that the mixes having cement-sand ratios of 1:1 and 1:1.5 by volume at water cement ratio of 0.45 and 0.5 have, in general, the necessary 7 days compressive strength to resist the damaging effect of low volume traffic since the blocks will be under compression only.

It is seen that the strength of mixes made by vibrating the cement-sand mortar into aggregates shows wide variation. This is due to the fact that the aggregates are flaky in nature with flakiness index of about 36 percent. The penetration of mortar into the aggregates is not same for different samples because of flaky aggregates. It may be mentioned that 28 and 90 days strength are 1.35 and 1.63 times higher respectively than 7 days strength (MORTH, 2001).

Row (b) of Table4 indicates that when mixture of aggregates, cement, sand and water were compacted into cubical moulds, a higher strength was obtained because of effective coating of mortar.

As seen from Table 5, the rounded low cost pit run gravels grouted with cement-sand mortar at water cement ratios of 0.45 and 0.5 are as strong as grouted flaky aggregates (row a) of Table 4. The aggregates used in Table 4 are twice as costly as the gravels used in Table 5.

5. CONSTRUCTION OF TEST PAVEMENT

In the present investigation, two test pavements with thicknesses of 75mm and 100mm of cast in-situ concrete blocks were constructed in the test area of Accelerated Pavement Test Facility (APTF) of IIT Kharagpur (Ryntathiang, 2005). Since the APTF can accommodate pavement width of 2.0m only, the size of each of the test pavements was 2.1m by 2.0m. The sectional detail of the two-test pavement is shown in Figure 3. The subgrade for both the test sections (Table 3) was laid at the optimum moisture content and compacted by a plate vibrator to a minimum dry density of 98% of modified proctor (MORTH, 2001). The existing undisturbed lateritic soil formed the foundation of the sand subgrade. The sand subgrade was covered with a plastic sheet to, i) prevent loss of moisture from the subgrade and ii) to control intrusion of aggregates into the sand subgrade. WMM subbase described in section 4.5 is laid in thickness of about 100mm. The details of the construction of the two concrete blocks pavement are described by Ryntathiang et al. (2005).

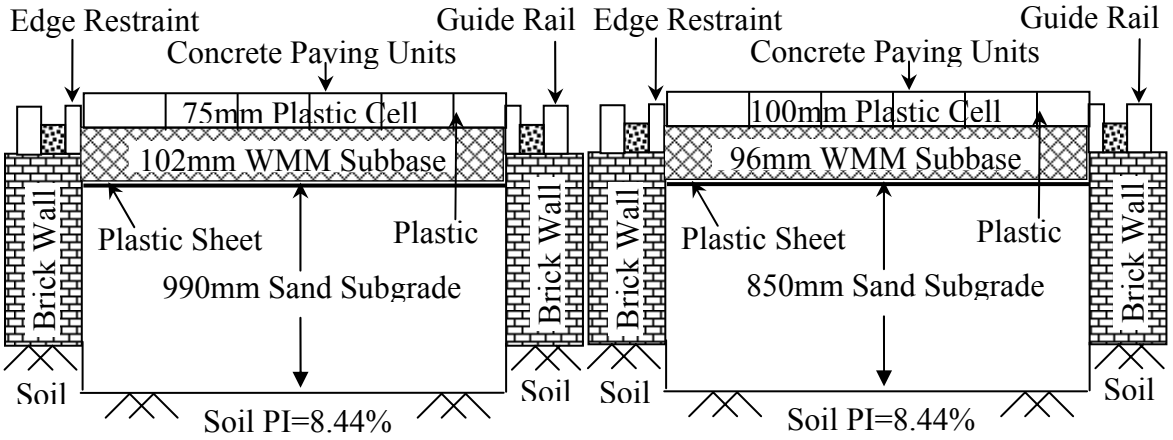


Figure 3: Cast in-situ concrete block pavement of 75mm and 100mm

6. TESTING PROCEDURE

6.1 Accelerated test

Total numbers of repetitions of 40kN dual wheel load for both test sections (75mm and 100mm of concrete blocks) were 11000passes. During the test, rutting along the wheel paths and deflections under FWD were measured at regular intervals of load repetition. The dual wheel was moving to and fro over the same path without lateral wander.

6.2 Falling weight deflectometer (FWD) test

A Falling Weight Deflectometer fabricated in the Transportation Engineering section of Civil Engineering Department was used for evaluation of cast in-situ concrete block pavement laid on the bed of Accelerated Pavement Test Facility. The details of the equipment are reported elsewhere (Reddy, 2003).

6.3 Measurement of rutting

Rutting was measured after every 1000 passes, the total number of passes being 11000. Figure 4 shows the surface of the two CISCBP of thicknesses of 100mm and 75mm after 6000 repetitions of accelerated pavement test.



Figure 4. Condition of CISCBP of thickness of 100mm and 75mm after 6000 repetitions

Cores were taken from each of the two pavements after accelerated pavement and FWD tests (Figure 5). It was found that both the cores had a uniform structure with little honeycombing. However, cells filled with a premix concrete appeared to have less void than the ones in which mortar was vibrated into the aggregates because of flaky aggregates. The cores also revealed that the vertical cell walls became deformed after casting indicating that interlocking among the neighboring blocks would develop in such pavements.

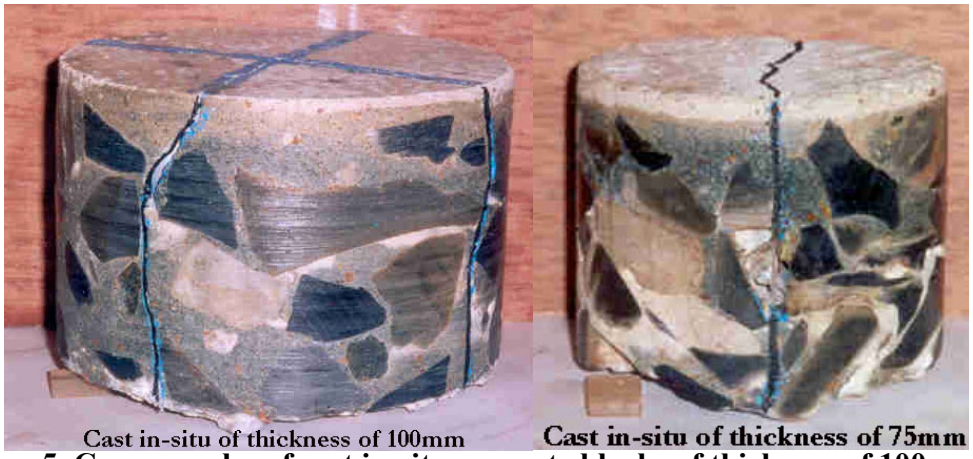


Figure 5. Core samples of cast in-situ concrete blocks of thickness of 100mm and 75mm.

7. TEST RESULT

7.1 Rutting

Permanent deformation was measured under each of the dual wheels with reference to a fixed datum and the average of the two readings was taken as the rutting of the pavement. A hollow square bar was used as a straight edge and depressions were measured at the centers of each of the dual tires as well as distances of 0mm, 300mm, 600mm, and 900mm on either side of center of the dual wheel system. Figure 6 shows the rutting for the two pavements of CISCBP. Rutting along each wheel path was measured and the average was taken as the rutting of pavement in Figure 6.

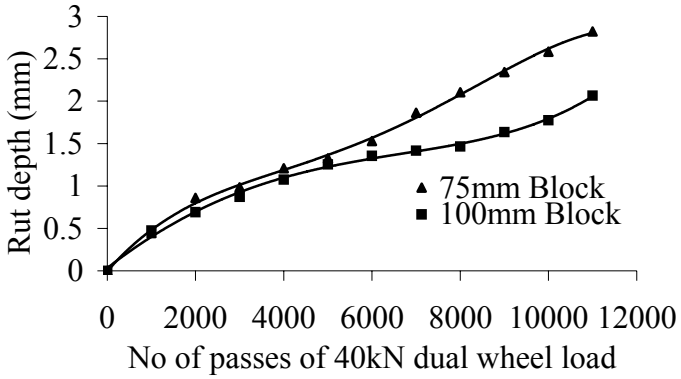


Figure 6. Rut depth of CISCBP upto 11000 passes

Figure 6 shows that even after 11000 passes of a 40kN dual wheel load, the rutting along the wheel path is less than 3mm. The curve for the 75mm cell filled CISCBP shows a decreasing trend in rutting whereas the 100mm blocks show an increasing trend though the subgrade and the subbase are nearly identical. The increasing trend of the 100mm blocks may be due to experimental errors in measurement though the overall trend is very clear. Rutting takes place faster up to 2000 repetitions and there after it increases by about 1.5mm to 2mm for additional 9000 repetitions. Rutting would be around 15 to 20m after 100,000 repetitions. A rural road in India carry low volume of traffic and the axles with wheel load approaching a magnitude of 40kN may not be too many for most roads. The test pavement had a rutting of less than 3mm even after 11000 repetitions of 40kN when there is no lateral wander. In the field rutting would be much less because of lateral wander. Considering that the allowable rut depth may be 25mm to 50mm (AASHTO, 1993) for low volume roads, the experimental pavements under test appear to be sufficiently strong. It is further noticed that the rate of increase of rut depth decreases with repetitions up to 6000 passes and there after it may remain constant. Because of low amount of rutting, cast in-situ pavements are suitable for low volume road since there is always a lateral wander of wheel loads even for a single lane two-way carriageway (Reddy and Pandey, 1995) and if this is taken into account, the number of repetitions of standard axle loads for rut depth of 50mm may be very large considering the experimental data gathered in the this investigation.

7.2 Deflections under FWD

Deflection tests were carried out on the two cast in-situ concrete block pavements by a Falling Weight Deflectometer (FWD). Surface deflections were determined at radial distances of 0mm, 300mm, 600mm and 900mm from the center of the loading plate after every 1000 repetitions of wheel load up to 6000 repetitions. These measured deflections were used for evaluation of pavement layer moduli. The modulus values of different layers were evaluated by a computer program available in Transportation Laboratory. Though the dimensions of the test were about 2.14m by 2m, the backcalculation from the FWD data may yield a reasonable estimate of the elastic modulus of CISCBP. Results of the FWD test are reported elsewhere (Ryntathiang et al., 2005). Considering the model pavements to be a three layer elastic system consisting of cast in-situ concrete block as the top layer, WMM as the subbase layer and sand as the subgrade, layer moduli were computed using the deflection data and the backcalculation software, BACKGA (Reddy et al., 2000). The results are shown in Table 6.

The table indicates that modulus of 75mm cast in-situ concrete block layer is about 18 percent higher than the 100mm concrete block layer though the subgrade and subbases for both the pavements are

practically identical. On further examination, it was found that the granular subbase of 75mm thick blocks had a bulk density of 2305 kg/cm^2 whereas the subbase of 100mm blocks had a value of 2256kg/cm^2. Thus, the block modulus may be dependent upon the subbase modulus.

For the above types of pavement, a modulus value of 2500MPa which is lower of the two values for the cast in-situ concrete block layer may be adopted for pavement design.

Table 6. Elastic modulus of pavement layers of CISCBP

No of Repetitions	100mm PLASTIC CELL			75mm PLASTIC CELL		
	Concrete	Subbase	Subgrade	Concrete	Subbase	Subgrade
2000	1766	82	90	2978	181	94
3000	1598	80	89	2988	202	92
4000	2378	82	77	2990	216	90
5000	2337	80	80	2966	184	94
6000	2542	72	76	2995	180	97

8. CONSTRUCTION OF A CISCBP ROAD IN FIELD

After the success of laboratory investigation, a 250-meter CISCBP pavement 3.75m wide and 100mm thick was constructed in the field using zero slump concrete. A water cement ratio of 0.30 was used during the compaction by an earth rammer. The subbase consisted of 100mm of murrum, a low grade soft lateritic aggregate. The subgrade had a CBR of 5.0. After 30 days of casting, falling Weight Deflection test was done and the back calculated modulus of the concrete blocks was obtained as 3500MPa. Further investigation is under progress.

9. PERFORMANCE CRITERIA

Plate bearing and accelerated pavement tests on concrete block pavement (CBP) have established that such pavements performed in a manner which is similar to flexible pavement (Shackel, 1980, 1982; Seddon, 1980; Miura et al., 1984; Houben and Jacobs, 1998). The performance behaviour of cast in-situ concrete block pavement (CISCBP) was also found to be similar to the CBP pavements (Visser and Hall, 1999).

A large number of in-service pavements in India were examined for rutting and a criterion for rutting was developed for 84% reliability for design of flexible pavements in India (IRC, 2001). A vertical subgrade strain (ε_z) was considered as an indicator of the rutting behaviour of flexible pavement. A high ε_z is indicative of the fact that on the subbase also, the vertical strain would be high. Controlling ε_z on the subgrade would limit the vertical strain on the subbase also. For design of CBP and CISCBP pavements, use of ε_z has been selected by the authors as design criterion in the present investigation. A reliability level of 50% (AASHTO, 1993) is adopted for producing design charts for low volume roads. After examination of performance of flexible pavements in India, Reddy and Pandey (1992) proposed following performance based vertical subgrade strain criterion for 50% reliability considering 20mm as the limiting value of rutting along the wheel path.

$$N = 3.0599 \times 10^{-7} \left(\frac{1}{\varepsilon_z} \right)^{4.5337} \quad (1)$$

Where N = Cumulative repetition of standard axle
ε_z = Vertical subgrade strain
Equation 1 was used for selecting thickness of subbase for developing a design chart.

10. ELASTIC MODULI OF PAVEMENT LAYERS

10.1 Concrete block layer
Tests on cast in-situ concrete block pavements in the bed of the APTF and in the field indicate that a value of an equivalent elastic modulus of 2500MPa can be used for pavement design pending further verification from field tests.

10.2 Subbase modulus
Because of limited study by the authors, SHELL's equation (Claessen et al., 1977; Dormon and Metcalf, 1965) given below was adopted in the present investigation for assigning moduli to a granular layer.

$$E_2 = k \times E_3 \quad (2)$$

Where $k = 0.2(h_2)^{0.45}$

E_2 and E_3 = Elastic modulus values of granular layer and subgrade respectively and

h_2 = Thickness of granular layer in mm.

10.3 Subgrade modulus
The following equations of subgrade modulus (M_R) given by Lister and Powell (1987) was adopted for the thickness design.

M_R (MPa) = 10 x CBR for CBR of ≤ 5 percent (3)
M_R (MPa) = 17.6 x $(CBR)^{0.64}$ for CBR of > 5 percent (4)

11. DEVELOPMENT OF DESIGN CHART

Based on the available literature and the data obtained in the present research, design charts for low volume roads having $5x10^4$ to $2x10^6$ repetitions of standard axles are proposed. Several combinations of pavement sections were analysed using the computer program FPAVE developed by IIT Kharagpur (Das, 1998) to determine the vertical subgrade strain (ε_z). Values of ε_z were computed at the top of subgrade, vertically below the center of standard dual wheel loads (40kN) for tyre pressure of 0.56MPa. The Poisson's ratios of the top layers (cast in-situ concrete blocks), subbase layer and subgrade were taken as 0.3, 0.35 and 0.35. The subgrade modulus was calculated as given by Equations 3 and 4 and the subbase modulus were obtained from the Equation 2.

Since the thicknesses of concrete blocks were kept constant, the thickness of granular material was varied so that the computed limiting vertical strain (Equation 1) for rutting for different levels of traffic was equal or less than that given by Equation 1. Figure 6 shows the design chart of cast in-situ concrete block pavement (CISCBP).

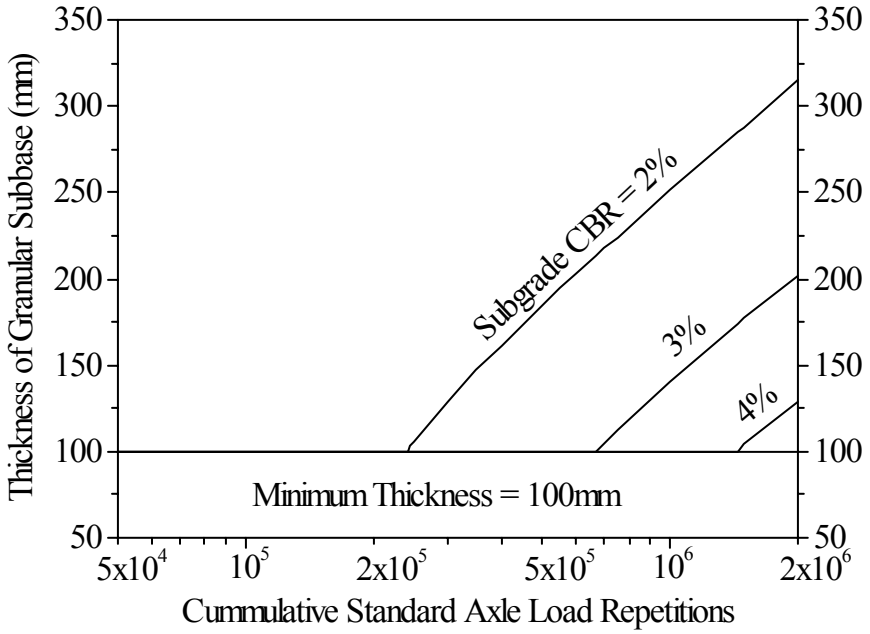


Figure 6. Design chart for cast in-situ concrete block pavement (CISCBP)

11. CONCLUSIONS

- Laboratory investigations demonstrate that, premixing the coarse aggregates, cement, sand and water and compacted in cubical mould of side of 150mm have higher strength than the grouted cement-sand single size coarse aggregates.
- Cast in-situ concrete block pavement of thickness of 100mm has less rutting than cast in-situ concrete block pavement of thickness of 75mm.
- Core samples taken from pavements showed that the cement concrete blocks obtained by premixing and compacting cement, sand and single size coarse aggregates had lower voids than the ones in which cement-sand mortar was grouted into the voids of the single size coarse aggregates.
- For a traffic load repetitions of 5 x 10^5 of standard axle, it can be seen that a pavement with cast in-situ concrete blocks can be laid directly on subgrade with CBR of 4 percent or higher (Figure 6)
- From drainage considerations, a minimum granular layer of 100mm of thickness is recommended before laying cast in-situ concrete block pavements. However, in low rainfall area, granular layer may be dispensed with for low traffic.

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