LABORATORY AND FIELD STUDY ON INTERLOCKING CONCRETE BLOCK PAVEMENT (ICBP) FOR SPECIAL PURPOSE PAVING IN INDIA

T. Muraleedharan, P.K. Nanda
Central Road Research Institute
New Delhi, India

Summary

In India, there are many paving applications in which the adoption of prevailing practice of bituminous/asphaltic concrete pavement construction results in less durable pavements, such as bus stops/terminals, highway intersections/roundabouts, container terminals, freight handling areas, port areas and industrial estates. In world-wide experiments, the Interlocking Concrete Block Pavement (ICBP) has been proved to be a durable alternative for such locations. The widely applied ICBP technique for special purpose paving has only recently been introduced in India. And so far no laboratory study to understand the engineering behaviour of ICBP seems to have been conducted here. The Central Road Research Institute (CRRI) has for some time been working to create awareness of this new technique among the practising engineers, and has been experimenting with this technique in the laboratory as well as in the field. The paper gives a summary of the laboratory experiments just completed and in progress, field studies on ICBP on a seasonal snow-bound road in the Western Himalayas, and facilities currently being set up at CRRI for wholesale production of coloured blocks and construction of in-service ICBPs.

Introduction

The ICBP technique for special purpose paving has aroused considerable interest among researchers, engineers, architects, contractors, airport planners and concrete associations throughout the world, as is evident from the four international conferences on Concrete Block Paving (CBP) held since 1980 and the 5th conference presently being held in Israel.

In India, use of ICBP has started recently with the availability of high-tech block-making machines. The paper summarises the recently completed and ongoing efforts of the Central Road Research Institute (CRRI), New Delhi, to familiarise Indian users with the technique through laboratory and field experiments, as well as to create infrastructural facilities and expertise for wholesale production of blocks and construction of ICBP.

Laboratory Study on ICBP

In-House Testing Facility

A test bed facility measuring 15 m X 6 m is available at CRRI, with a compacted subgrade, and facility for construction of test pavement of thickness upto 60 cm. Water Bound Macadam (WBM) base course of 10 cm thickness is existing on the subgrade. A load reaction beam made of reinforced concrete, capable of being electrically moved on rails to different testing positions, and giving a maximum reaction of 40 tonnes, is also installed in the test bed.

Objective of Present Study (Phase-I)

The main objective of the Phase-I study was to construct an ICBP test section in the test bed facility using 60 mm thick blocks of UNIPAVE design paved on bound (lean concrete) and unbound (Water Bound Macadam - WBM) base courses, and to conduct static plate load tests and dynamic load tests using Falling Weight Deflectometer (FWD).

Construction of Test Section

The infrastructural facilities available in the Institute, including a Block Making Machine procured from Germany, were used for production of blocks. The blocks used had an average 28-day compressive strength of 50.8 MPa. In the total test bed area, a sub-section measuring 6 m by 3.75 m was available for construction of the ICBP test section, the remaining section being occupied by other experimental constructions. The subgrade consisted of low plasticity clay (CL), with plasticity index of 9. Standard proctor compaction test gave a maximum dry density (MDD) of 1.84 Mg/cu.m. (1.84 gm/cc) at an optimum moisture content (OMC) of 13.6 per cent. The soil had been compacted to a thickness of 90 cm in two layers of 60 and 30 cm thickness. The lower layer was compacted at MDD and OMC. The upper layer was given extra compaction to obtain a modified AASHO density of 1.965 Mg/cu.m. (1.965 gm/cc). The in situ CBR of the compacted subgrade was 16 per cent, which was in close agreement with the average in situ CBR of 20 per cent obtained under field conditions in Delhi. The material below the compacted subgrade consisted of partially disintegrated rock formation.

WBM base course was prepared by digging up the existing WBM layer (which was dislocated due to constant movement of testing equipment) and recompacting the same to the desired extent, so as to obtain a uniformly copmacted base course layer. This was especially important as the block pavement is known to ultimately reflect, on its top, the profile of the base course below. Compaction was effected with a vibrating plate compactor having an impact force of 20 kN.

Lean concrete base course was prepared using concrete of nominal mix 1:4:8. A compacted thickness of 10 cm was obtained. Hand-compaction had to be adopted due to malfunctioning of

compaction equipment. The compacted lean concrete was air-cured for 24 hours. Thereafter it was covered with a thin layer of sand and water-cured for 6 more days. Tests on hand-compacted cubes gave an average 28-day compressive strength of 1.75 MPa (17.5 kg/sq.m.). Due to hand-compaction, the strength obtained was lower than what could be achieved under vibratory compaction. Following construction, plate load tests on the two types of base courses were completed. Edge restraints were provided by fixing concrete beams along the boundary.

Coarse bedding sand of Fineness Modulus 3.3 was provided to 25 mm thickness as bedding sand. The Interlocking Concrete Blocks (ICBs) were manually paved on the bedding sand layer in herringbone pattern. The paved blocks were compacted using vibrating plate compactor, applying an impact force of 20 kN. Optimum compaction was achieved after 6 passes. A mixture of fine sand and lime (5 per cent by volume) was used for sealing of joints. A cross-section of the test section is shown in Fig. 1.

Static Plate Load Tests

An electro-hydraulically operated Load Alternator was used for conducting plate load tests. Plate load tests using 30 cm dia plates were conducted on both types of base courses and on the block layer paved on them, as per the Indian Standard (IS):9214-1979 [1]. An initial seating load of 0.5 tonne was applied in all tests. Load was gradually increased and deflections were noted at increments of 0.5 tonne loading. In the case of base courses, a maximum load of 3.5 tonnes, and for ICBP a maximum load of 5 tonnes, were applied. The analytical results of the plate load tests on base courses and ICBP are summarised in Table 1.

The average total deflection of WBM base course for an applied pressure of 0.495 MPa was 2.140 mm, of which 1.284 mm (i.e., 60 per cent) was permanent deformation and 0.856 mm (40 per cent) was recoverable deflection. This corresponds to a stiffness value of 0.536 MPa/mm. The resilient modulus calculated as per Burmister's two layer theory was 347 MPa.

Compared to the performance of WBM base course, for the same applied pressure the lean concrete base course exhibited a total deflection of 4. 013 mm for the maximum load, which is almost twice that obtained under WBM base course. Also, no recoverable deflection was observed, indicating failure of the test point. Hence the stiffness and resilient modulus values of the lean concrete base course could not be assessed. As mentioned earlier, the bound base course could not achieve its optimum strength as manual compaction had to be employed.

The average total deflection of ICBP over WBM base course for an applied pressure of 0.707 MPa was 2.298 mm, of which 1.999 mm (i.e., 87 per cent) was permanent deformation and 0.298 mm (13 per cent) was recoverable deflection. This corresponds to a stiffness value of 2.37 MPa/mm. The resilient modulus of ICBP layer over WBM base course was estimated as 1424 MPa.

Table 1 : Summary of analysis of plate load tests on base courses and ICBP

	Test Surface			
	WBM Base Course	Lean Concrete Base Course	ICBP over WBM	ICBP over Lean Concrete
Maximum Load (P) (kN):	35	35	50	50
Applied Pressure (MPa):	0.495	0.495	0.707	0.707
Ave. Total Deflection under Loading Plate (mm):	2.140	4.013	2.298	2.832
Permanent Deformation (mm):	1.284	4.014	1.999	2.265
Recoverable Deflection (mm):	0.856	0	0.298	0.567
Stiffness (MPa/mm):	0.536	--	2.37	1.25
Resilient Modulus (MPa):	347	--	1424	748

The average total deflection of ICBP over lean concrete base course for an applied pressure of 0.707 MPa was 2.832 mm, of which 2.265 mm (i.e., 80 per cent) was permanent deformation and 0.567 mm (20 per cent) was recoverable deflection. This corresponds to a stiffness value of 1.25 MPa/mm. The resilient modulus of the ICBP layer over lean concrete base course was estimated as 748 MPa.

Thus in the present experiments, contrary to the deflection behaviour of flexible pavement, the newly constructed ICBP pavement indicated a higher order of permanent deformation. This is in conformity with the observed behaviour of such constructions elsewhere, and is due to the gradual embedment of blocks into the bedding sand. The ICBP test section presently under analysis has the limitation that no trafficking could be simulated by actual running of vehicles, to see the effect of gradual development of interlock.

Estimation of Pavement Capacity

The total effective thickness of the pavement on WBM base course is: 10 cm WBM + 6 cm ICBs. Experience indicates an equivalency factor in the range of 1.5 to 2.0 for stabilised base course in terms of granular base course, and a range of 2.5 to 2.85 for concrete blocks in terms of base course [2]. Considering an equivalency factor of 2.5 for the blocks in the present case, the equvalent granular thickness of the ICBP test section works out to (10 + 15) cm, i.e., 25 cm. The CBR of the subgrade is 16. From the C curves for flexible pavement design [3], it can be assessed that the thickness corresponds to that required for a traffic of 450 to 1500 commercial vehicles per day.

Dynamic Impulse Load Tests using Falling Weight Deflectometer

Dynamic impulse load tests were conducted by using a Falling Weight Deflectometer (FWD). The test results were recorded using the software (ISSE M4, Ver. 10.2) supplied by the manufacturers (Denmark). The data were analysed using the ELCON programme to arrive at the E moduli or stiffness of the structural layers of the pavement. Tests were conducted at two locations each on ICBP over WBM base course and ICBP over lean concrete base course. While selecting test points care was taken to leave out the failure point on lean concrete base course.

In analysing the test results using the ELCON progromme, the following parametric values were used:

Block thickness	: 60 mm (Actual)
Base Course thickness	: 100 mm (Actual)
Design Period	: 10 years
Design Traffic	: 10 million Std. Axles
Season	: 1 (From 12 options)
Temperature	: 25 deg. C
Equivalent Depth of Stiff Layer	: Varies from 805 to 923 mm (as calculated by the programme)

Comparison of Experimentally Obtained Moduli with Ideal Ranges

Representative ranges of material layer properties obtained for block pavements, based on world-wide experimental and theoretical studies, have been reported by Shackel [2]. These are compared with the experimentally obtained values in the present case, as given in Table 2.

The E values for block layer and WBM base course obtained by the plate load test compares well with the representative range of values indicated by Shackel [2].

In the ELCON programme, as in Burmister's two layer theory, the subgrade is assumed to be an infinitely thick linear elastic material. Real pavements are founded on stress-sensitive subgrades often underlain by stiff layers or even bedrock. In the present case a stiff layer was encountered at a depth of 80 to 90 cm from the top of the the subgrade, as shown in records. This clearly indicates that the results of FWD tests have been adversely affected by the presence of the rocky layer immediately below the subgrade.

In addition, there is also another factor to be considered. The freshly constructed block pavement was having a coarse sand layer below the block layer, effecting some discontinuity between the block layer and the base course, and thus affecting the results of the programme. In the case of in-service pavements this effect is largely nullified, as the block layer surface reflects the profile of the base course after about 6 months of trafficking.

Table 2 : Comparison of Experimental Results with representative ranges of material layer properties for ICBP

Material	Modulus (E) (MPa)		
	Representative Range as per Shackel	Experimental Value (Plate Load Test)	Experimental Value (FWD Test)
Dentated Blocks	900 - 7500	Blocks over WBM : 1424 Blocks over Lean Concrete:748	Blocks over WBM: 368 Blocks over Lean Concrete:1282
Crushed Rock Base	200 - 800	347 (WBM)	250 (WBM)
Stabilised Base	1000 - 30000	---	300 (Lean Concrete)

Thus it is concluded that the FWD test results are at variance with the plate load tests. This is to be expected, as the former method employs dynamic impulse loading of pavement, whereas the latter method involves static loading. However, the involvement of a number of inderminable factors in the ELCON programme and the assmptions made by the programme regarding these factors may limit the reliability of the FWD test results in the present case.

Phase-II Study

In the Phase-II part of this study, the pavement section was completely inundated for 24 hours. Water was then drained out and the pavement was recompacted using heavy duty plate vibrator. Static and repetitive plate load tests were then conducted till failure occurred. This experiment has indicated some interesting results, which are being analysed.

Field Study on ICBP Constructed on a Seasonal-Snow Bound Road in the Himalayas

Background

For the past few decades, the Border Roads Organisation, (BRO), under the Ministry of Defence, Govt. of India, and CRRI have been working jointly in solving the problems connected with providing durable and economically viable roads along the border regions. Recently BRO and CRRI jointly undertook a field project for application of ICBP technique on seasonal snow-bound road in the Western Himalayas (Jammu & Kashmir). Details of the work have been published elsewhere [4]. Given in subsequent paras is a summary of the work and findings.

Site Conditions

The mountain road connecting Srinagar to the cold-desert districts of Kargil and Leh, which forms the life-line for the latter, has been built along the historic silk route from China to India. A good portion of the road has been provided with durable pavement. However, the 13 km stretch of the road known as ZOJILA PASS, at altitudes of above 3500 m, has remained a challenge to the civil engineer, due to many problems occurring in the region. These include : snowfall, avalanches, snow drift, snow melt and icing problems, inhospitable climate and working conditions, single-lane pavement with limited periods of traffic movements possible during summer, and, on top of all, heavy traffic movement for enabling adequate winter storage of essential items for people in the hill districts.

Choice of ICBP as a Construction Option

The problems of the Zojila Pass were studied afresh by CRRI and it was decided to construct an experimental ICBP section as an alternative. In the summer of 1993, a transit factory was set up in the foothills of the Himalayas and blocks required for about 4000 sq. m. of paving were produced. Also, in order to further reduce the in situ construction period, it was planned to produce specially designed interlocking edge restraint blocks (ERBs) as well as a limited number of precast concrete base blocks (CBBs) for paving. The objective was to complete the work during one working season so that the performance of the section can be monitored during subsequent years and modifications needed, if any, can be incorporated during subsequent construction.

Design Considerations & Quality Control

Subgrade in the region varies from hard rock, thin laminated rock and schists, to gravel or boulders mixed with varying proportions of silts and plastic fractions. Laboratory study indicated soaked CBR in the range of 5 to 7 per cent. A design traffic of 1000 to 1500 commercial vehicles per day was considered. Subsequent laboratory investigations of soil samples collected along the route indicated that the design assumption regarding the bearing capacity of the soil was somewhat conservative. UNI-PAVE block of 120 mm thickness was selected for mass production. The ERBs had the dimensions of 30 cm X 30 cm X 32 cm. Rectangular Concrete Base Blocks (CBBs) having the dimensions of 46 cm X 23 cm X 15 cm were also used for a limited length of the section. In situ cement concrete base course was provided for the remaining length. The precast products were cured in water only for 10 days due to constraints on working period. As testing facilities were available only at a place 300 km from the production unit, quality control testing was limited to randomly selected samples of ICBs and cubes. The tests indicated that for ICBs, the 28-day compressive strength obtained was of the order of 35.3 MPa, with around 10 per cent variation. For ERBs and CBBs, the same was around 30 MPa. The in situ concrete used in base course had

an estimated 28-day compressive strength of 20 MPa. The strength obtained for ICBs was lower than expected, due to the reduced curing period, which was dictated by shortage of time.

Construction

The blocks were transported to the construction site which was 70 km from the production unit. The thickness of coarse bedding sand used was 30 mm. The elements of the ICB pavement structure are detailed in Fig. 2. The three-in-one experiment consisted of the following:

Experiment-I: In situ concrete base course over which 30 mm compacted bedding of coarse sand was provided, and the Interlocking Concrete Blocks (ICBs) were paved in STRECHER pattern.

Experiment-II: In situ concrete base course over which 30 mm compacted bedding of coarse sand was provided, and the ICBs were paved in HERRINGBONE pattern.

Experiment-III: Precast concrete base blocks (CBBs) paved on 30 mm bedding sand, on top of which additional bedding sand layer of 30 mm thickness was provided, and the ICBs were paved in HERRINGBONE pattern.

The test section, which was initially 30 m long, was subsequently extended to 100 m.

Evaluation

By the time construction of the section was completed in October '93, the road had been closed to regular traffic as snowfall had started in the higher reaches of the mountain. The road was opened to traffic in June, 1994, after completion of snow-removal operations. Measurement of profiles indicated that the pavement had settled, by and large uniformly, by 4 to 5 mm due to the gradual embedment of blocks into the bedding sand caused by the overburden of snow which stood to about 25-30 m height over the section during the snowing period. During subsequent summer months, the average heavy vehicle traffic on the route was of the order of 600 vehicles per day, with a peak traffic of 700 vehicles. Observations indicated that the height of the ERBs can be somewhat reduced to avoid fouling of dozer blade while carrying out summer snow clearance operations. It was also noted that the proper drainage is essential for good performance of the technique. No other distress of pavement was noticed, neither was any maintenance work needed. The technique proved to be an appropriate solution for the problem existing on the mountain ranges of the Himalayas.

Facilities for Mass Production of Blocks and Application of ICBP for In-Service Pavements

The Institute has presently set up infrastructural facilities for mass production of coloured ICBs and is poised to take up construction of in-service ICBPs.

Acknowledgement

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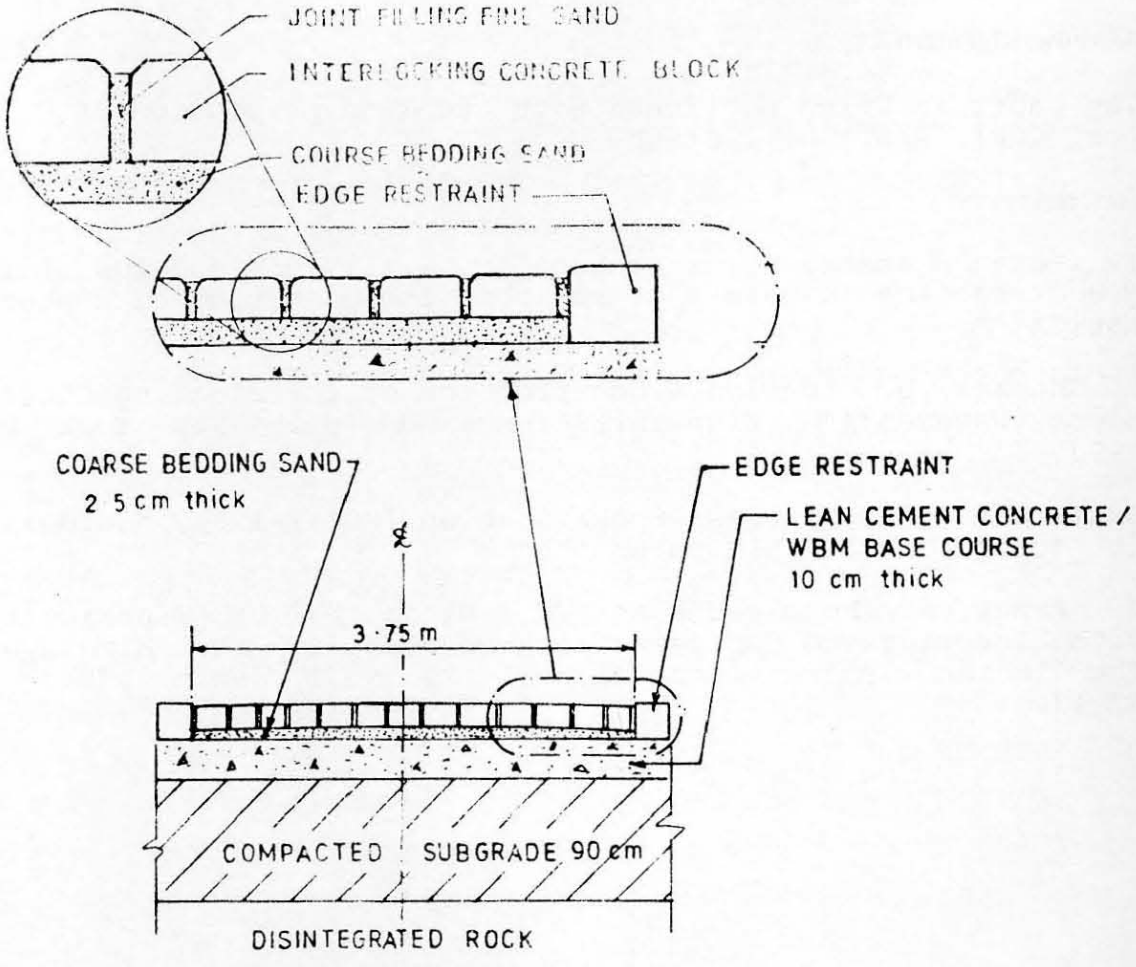


Fig. 1 : In-House ICBP structure

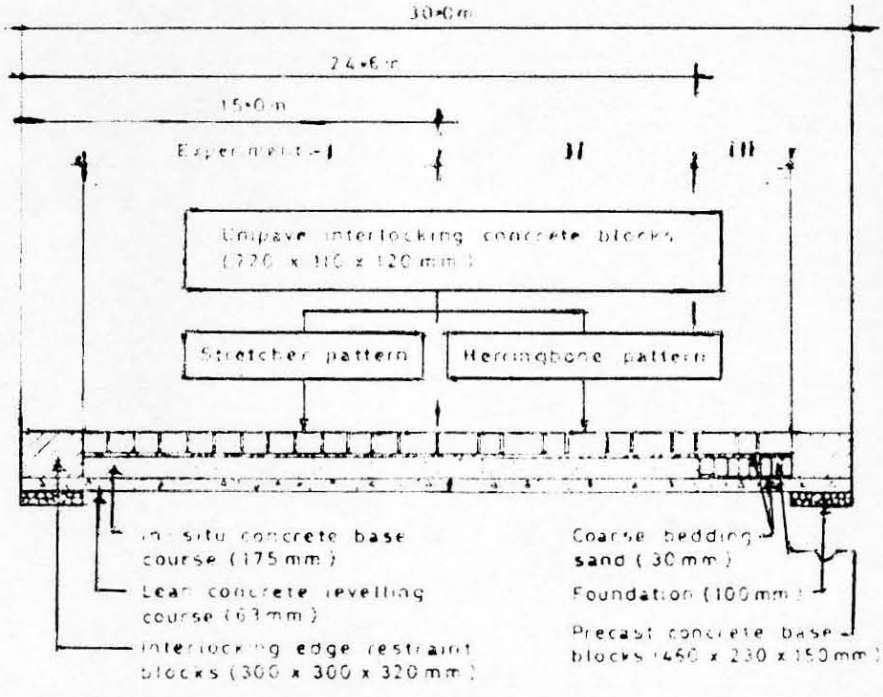


Fig. 2 : Structure of experimental ICBP in the Himalayas