COLD IN-PLACE RECYCLING - DESIGN, PERFORMANCE AND EVALUATION

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Abstract

To improve India's highway system for ever increasing traffic, strengthening and upgrading of old roads to new road standards is gaining momentum. The Cold In-Place Recycling technique extensively used in Europe and America has recently been introduced in India. With only limited experience in actual applications, the need to share such experience as does exist in support of CIPR is vital. This paper presents experience gained on one such current project. Initial data and observations indicate, with proper evaluation of distress patterns, failure diagnosis, and appreciation of site conditions, CIPR can be used to advantage. Proper control in the design and application, and appropriate engineering judgment in construction can achieve significant upgrading and improvement in the design life of existing roads.

INTRODUCTION

India's 6000km Golden Quadrilateral National Highway development project is a most ambitious undertaking. The project improves the highway infrastructure connecting Delhi, Kolkata, Chennai and Mumbai by widening these corridors into 4 to 6 lanes at a total cost exceeding US$500 million. The Golden Quadrilateral represents approximately 15% of the total length of India's National Highways. Before the construction of this project, along with the North-South Corridor and East-West Corridor, only 3% of the National Highways were 4 lanes. Single lane roads formed approximately 30% of the NH system (Bartlett and Sharma, 2002).

One small portion of one of the Golden Quadrilateral contracts currently under construction (2001 to 2004) is located from about 117km west of Kolkata to Kharagpur in the state of West Bengal. Specifically, the existing single 2-lane carriageway is being improved into dual 2-lane carriageways. One carriageway (Kolkata to Mumbai) is newly constructed from the original ground up; the second carriageway (Mumbai to Kolkata) involves the strengthening of the existing road to carry the anticipated 80 to 100million standard axles over the next 10 years.

The intent herein is to focus on the strengthening aspects of the existing carriageway in this section and, in particular, to address a relatively new technique (in India) of pavement strengthening. The technique involves Cold In-Place Recycling (CIPR) of the existing asphalt pavement. For this particular project, the details for implementation of CIPR has happened during the construction phase of the work. During this time it has been necessary to determine the stretches for which the technique would be applied and to develop the mix design most suitable for its use.

CIPR, in the context of the current project, has limited applications as other techniques are also involved including milling with partial new pavement structure along with reconstruction (subbase, base, bituminous concrete). The technique offers the opportunity of reusing existing pavement materials (bituminous and non bituminous) by retrieving the existing aggregates, rejuvenating the oxidized bitumen, improving the road crowns and vertical profiles to a point that minimal new asphalt overlays would be required to carry low to moderate traffic. It is our view that this technique has a uniquely bright future with a potential for great benefit for India's secondary State and District roads where massive and expensive rehabilitation is not fully or even partially possible due to limited funds that might be available.

Initially, a short overview to design aspects is given. Subsequently, this paper will concentrate on the construction aspects associated with CIPR – both with respect to presenting the salient features in design/construction and in mix preparation. Evaluation of the CIPR process from standard construction placement considerations and, importantly, from a behavioral point of view, is given. The paper will identify the benefits in improved structural strength that can be achieved by CIPR. Finally, we shall present our views on the implementation of such techniques for future projects.

EVALUATION OF EXISTING CARRIAGEWAY

Background

The road segment chosen to study the CIPR application is approximately 15km in length not all of which is scheduled for CIPR strengthening. Traffic studies show that expected 20 year traffic would be in excess of 225 million standard axle loadings which would dictate an unusual and prohibitive pavement section. It was decided to address the 10 year traffic conditions of approximately 80 to 100 million standard axle loadings – still a significant traffic volume.

Detailed subsurface investigations and existing pavement evaluation studies were carried out in a systematic fashion during the design and construction phases of the project. Test pits in the existing carriageway (ECW) determined the pavement structure. The ECW's behavioral aspects were determined using Benkelman Beam deflection studies, collection of subgrade samples for laboratory soaked California Bearing Ratio (CBR) tests along with field miniature dynamic cone penetration tests to predict expected *in situ* CBR values of the subgrade soils. Detailed condition assessments of the ECW with respect to cracking, rutting, and the like were also carried out.

The existing road structure has been constructed on a clayey (CL and CI) subgrade embankment constructed from side borrow. Soaked laboratory CBR values on collected subgrade samples varied between 4 to 8%. The pavement subbase consisted primarily of lateritic moorum, brick soling and boulders of hard laterite. Locally, sand was observed between the subbase and underlying embankment. Water bound macadam (WBM) of varying thickness formed the base course onto which bituminous concrete layers of varying thickness and composition were placed. The pavement structure was not likely designed nor placed in an engineered fashion as per current construction techniques. Rather, the pavement structure likely developed as the need arose – from the placement of subbase as materials were available to a random approach of thickness and placement. The initial bituminous concrete has been overlain on a number of occasions and, in places, WBM or other granular medium was sandwiched between a then existing pavement surface and new overlay. Given the physiographic context of building on deltaic flood plain deposits, such construction techniques likely were a result of uneven embankments settlements resulting from variability from place to place of the underlying soft to firm embankment foundation soils. A typical ECW section is given in Figure 1.

The existing bituminous surface has been characterized by the presence of numerous distress patterns exhibited as alligator cracks, hungry surface, ravelling, loss of fine aggregate, longitudinal edge cracks, local loss of subgrade support and pot holes. Approximately 30 to 40 % of the road surface area was covered by these distresses. The road surface restored during April to September 2001 by crack sealing and bituminous overlay again showed similar signs of distress after 6-8 months.

Layer	Thickness (mm)	Description
	140 to 280	Cracked bituminous layers, residual bitumen content of 3 to 3.5 %
	80-230	Water bound macadam (crushed rock aggregate) base course
	125 -450	Laterite boulders, brick soling and moorum, subbase
	200-500	Clayey subgrade, CL to CI, lab CBR = 4 to 8 %, field moisture near to or higher than OMC

Fig. 1 Typical Pavement Structure

General Aspects to Evaluation of Strengthening Options

To strengthen the existing carriageway, a number of treatment options have been included in the contract, *viz*., (i) CIPR, (ii) milling and construction of subbase/base courses and (iii) pavement reconstruction. Above any of the three options, a similar bituminous concrete consisting of 170mm DBM and 40mm BC will be applied. The option to be used, especially (i) and (ii), depends on a number of factors.

The CIPR option calls for the existing pavement to be milled and immediately cold recycled in place creating a bitumen-modified base course onto which the bituminous concrete (DBM and BC) would be placed. The bituminous concrete is placed directly onto the CIPR surface unless profile correction courses of DBM are required. This implies that the CIPR option is only applicable in those locations where there is not a significant correction of the vertical profile. Otherwise, an unusually thick and expensive vertical profile correction is required.

In the milling option, the existing bituminous asphalt surface is milled to a depth of about 200mm and select subbase drainage, subbase and base courses are placed atop with their thickness depending on the difference of the existing road level to the final design road level. As the difference increases more thickness of the various courses can be placed until, in effect, the option becomes nearly the same as reconstruction.

If, in any of the areas defined under options (i) and (ii), the existing pavement is extensively damaged – severe longitudinal cracking/map (or alligator) cracking, rutting, obvious loss of subgrade support, reconstruction would be necessary. Similarly, reconstruction would be carried out in those areas inconsistent with the rational use of the other options.

PRINCIPAL FEATURES OF CIPR

CIPR is the restorative process by mixing bituminous and/or chemical additives with milled existing pavement without heating to produce a bitumen-stabilized pavement layer. CIPR consists of milling existing pavement to a specified depth, mixing additive(s) with reclaimed asphalt pavement (RAP), spreading the recycled mix and compacting it to a specified density. This is followed by placement of a new asphalt layer(s) in the form of a profile corrective course and/or asphalt courses depending on the design.

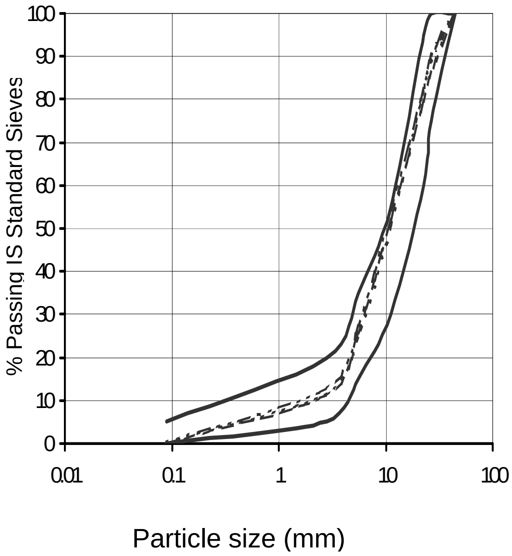
Modern recycling machines are specifically designed to have the capability of recycling a thick pavement layer (in the order of 200 mm) in a single pass for a width of 2 to 3.5m depending on the characteristics of the recycling plant. Recycling machines tend to be large and powerful. They may be crawler mounted or mounted on high floatation pneumatic tires. The core of these machines is a milling drum equipped with a large number of special cutting tools. The drum rotates to mill the material in the existing pavement. As the milling process takes place, water is sprayed into the recycler's mixing chamber from internal or external water supply tanks. The water is metered through a microprocessor controlled pumping system and is mixed thoroughly with the RAP to achieve optimum compaction moisture content.

A microprocessor controlled pumping system is also used to introduce measured quantities of fluid stabilizing agents, like bitumen emulsion, cement/water slurry, either individually or in combination directly into the mixing chamber. Powdered stabilizing agents, such as cement or lime, are normally spread onto the existing road surface ahead of the recycler. The recycler then passes over the powder, mixes it, together with water/fluid stabilizing agent into the underlying material in a single pass. Modern recyclers are usually equipped with a paving screed to uniformly lay the mixed material.

A recycling "train" using emulsion stabilizer is shown as Figure 2. It may be configured differently depending upon the recycling application and the type of stabilizing agent used. In each case the recycling machine pushes or pulls the equipment that is coupled to it by means of push rods or drawbars.

Fig. 2 CIPR in Operation

The recycling process, then, involves bituminous RAP, emulsion, water and cement as filler. The principal component is the RAP, the nature and gradation thereof. When properly milled, RAP consists of high quality conglomerates of aggregate stone(s) coated with bitumen. However, the principal concern of the RAP is the gradation - after milling this can vary. A wide variety of RAP gradations are suitable for CIPR and corrections by adding new aggregate materials is not commonly required from a material viewpoint. Additional aggregate may be added for other purposes. About the only additional material to be added would be cement filler as most RAP will be deficient in the finer sizes. Figures 3 and 4 present typical gradations of RAP – without cement and with cement filler. It is noted, too, that the rate of milling plays a large role in the gradation of the produced RAP – the slower the advancement rate in milling, the finer the material produced; the faster the advancement rate, the coarser the material. This is noteworthy in that during milling, some breakage of aggregate stone may occur. Adjusting milling speed can provide correctable RAP grading.



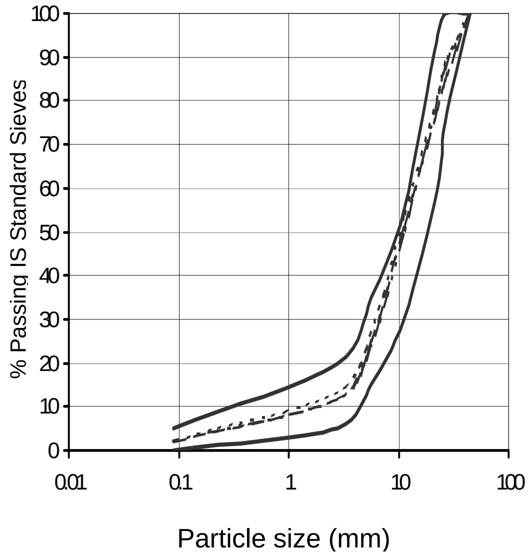


Fig. 3 Grading Of RAP (cement = 0 %) **Fig. 4 Grading Of RAP (cement = 2%)**

MIX DESIGN ASPECTS OF GRANULAR EMULSION MIXES (GEMS)

The CIPR mix design establishes the most effective method of treating the RAP materials obtained during the milling of the existing pavement. There is no apparent consensus on the details on mix design practice for stabilization with emulsion and several procedures have been put forth. Some use an initial bitumen content based on past experience or empirical formulas with the intent of adjusting this estimate during construction as needed (Asphalt Institute, 1983). Others use a more set approach based on known bituminous laboratory testing procedures such as the Marshall or Hveem methods (AASHTO *et. al*. 1998). The fundamental difference between hot mix asphalt concrete and cold recycled mix lies in the fact that cold recycled mix is a granular mix bound with a combination of bitumen and cement. Its strength is primarily derived from particle interlock and secondarily from binding capability of bitumen and cement.

Regardless of any design method adopted, past experience, engineering judgment and simple common sense are guiding principles for establishing a suitable mix. There is little to be gained by adhering religiously to a set method of design without the ability to make adjustments based on observed behaviour of the mix developed. To add additional emulsion to an already rich mix without adding counterbalancing uncoated aggregate can lead to unsatisfactory field behaviour if one simply satisfies the book. This, in fact, has happened in Rajasthan India during construction of NH-8, where 2.5% added emulsion satisfied the Marshall parameters but led to unsatisfactory field performance as a result of excess binder content in the mix (Frobel, 2000).

The mix design for this project was carried out generally in the following manner. Representative bulk samples from existing pavement to be recycled were obtained. The sample was subsequently air-dried and the chunks broken down by hand methods. Experience has shown this preparatory method to closely simulate the RAP gradation achieved during actual recycling process using a Wirtgen 2100 DCR recycler. This observation was also confirmed for this project – hand broken to actual milled gradations are similar. As noted earlier, RAP is typically short of the fines to achieve a dense grading (Figure 3).

To improve grading, 2% cement was added to the laboratory RAP mix (Figure 4). The added cement also improves the binding capability of GEMS by forming the mortar within the void spaces of the coarse aggregate. This also improves the early strength properties (important to those projects requiring a quick-on of traffic).

The main purpose for using emulsion is to obtain a mix that can be placed without heating. Slow setting emulsion was chosen to facilitate the completion of compaction operations before the emulsion can break and revert to its original viscous form. This is recommended by the Asphalt Institute for well graded mixes. A bitumen emulsion having a Saybolt-Furol viscosity of 24 to 26s (50 to 60 cSt) and an average residue content of about 60% was selected.

For maximum compactness, laboratory (heavy) compaction tests were performed (IS 2720, Part 8) on prepared RAP having varying fluid percentages but at a constant ratio of emulsion to water. The resulting compaction curve of dry density versus fluid content provided the optimum fluid content (OFC) at maximum dry density (Figure 5).

The optimum emulsion content (OEC) was obtained by determining the maximum indirect tensile strength (ITS) of compacted cement modified RAP specimens (at OFC) under soaked conditions at a number of emulsion contents (Figure 6). The preparation of the ITS sample for testing is similar to that of the Marshall Stability test with several modifications – compaction of sample under anticipated ambient temperatures, and curing temperature. The main difference between the ITS testing procedure and the Marshall testing procedure is in the mode of failure where the curved loading of the Marshall test is replaced by a flat loading surface in the ITS.

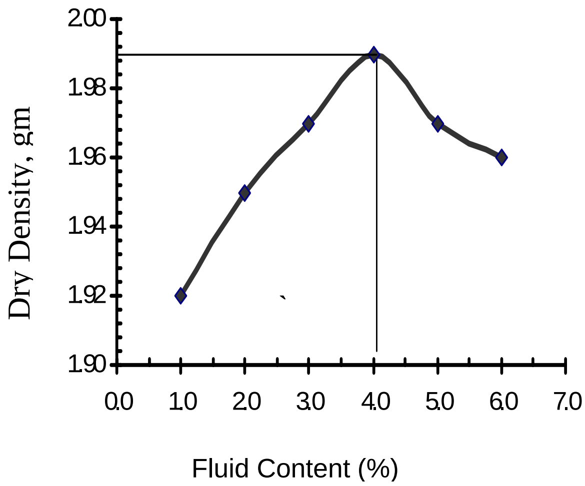


Fig. 5 Determination of OFC

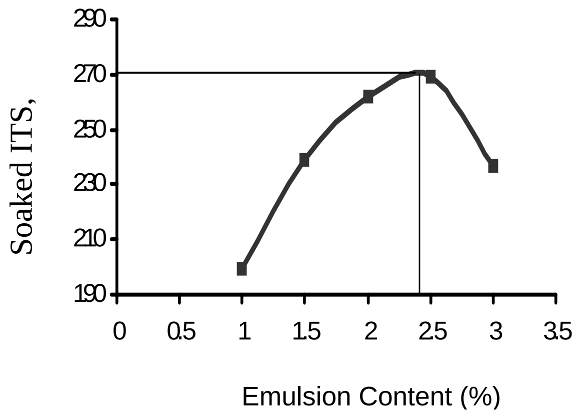


Fig. 6 Determination of OEC

CIPR CONSTRUCTION AND QUALITY CONTROL / VERIFICATION

Quality Control and Testing

To date, approximately 5.5km of CIPR have been carried out full width across the ECW. Milling width was set for 2m, which is the practical milling width for the Wirtgen 2100 DCR Recycler. Depth of cutting was set at 200mm unless the ECW exhibited thinner layers of bituminous concrete.

Our observations are that the CIPR technique is working quite well to date. Cement is placed on the existing pavement and spread to relatively uniform thickness before milling operations begin. The RAP gradation developed from milling closely follows the project's bituminous macadam (BM) specification. Adjustments have been made to the rate of milling to improve the RAP gradation. Compaction of the material has been carried out immediately by the use of a tandem vibratory smooth drum roller. Visual observations show that the material is compacting well and this has been borne out by comparing the actual compaction achieved to the same material compacted under IS 2720 Part 8. Relative compaction, in this manner, is usually in excess of 100%. Construction adopted 98% as the relative compaction to be achieved. Figure 7 shows the variation of achieved wet densities for the CIPR mix.

Samples of the material on site have also been obtained and compacted into moulds in order to carry out ITS testing on the compacted specimens. In general, the ITS values have been consistent or greater than the mix design values. These values have been well in excess of a minimum ITS value of 100kPa as proposed by others (Sabita, 1993). After consultation with Wirtgen GmbH, construction

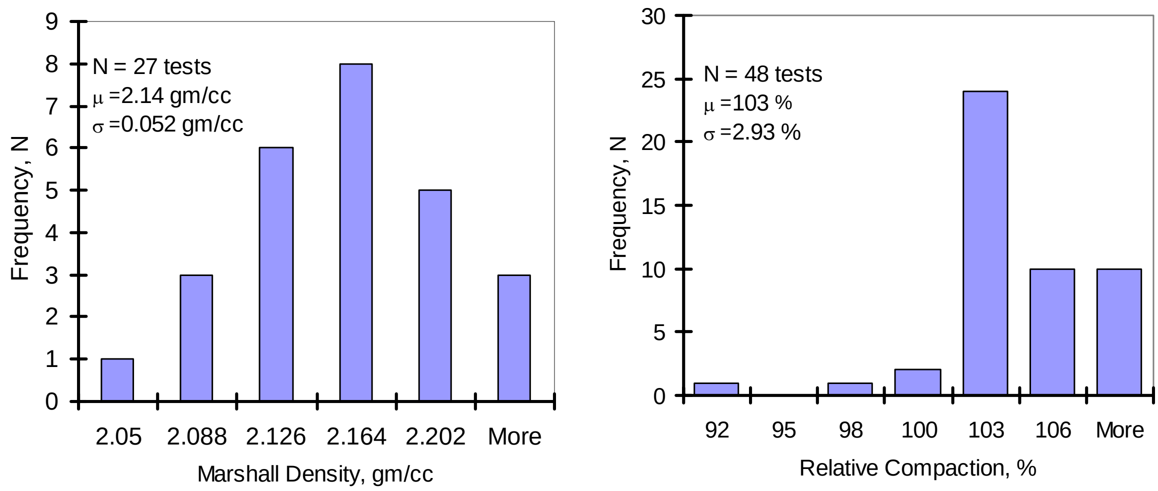


Fig. 7 Histogram of Densities

has adopted, for 7-day atmosphere cured specimens, a minimum ITS value of 200kPa. Figure 8 shows the variation in measured ITS values obtained from field samples to date.

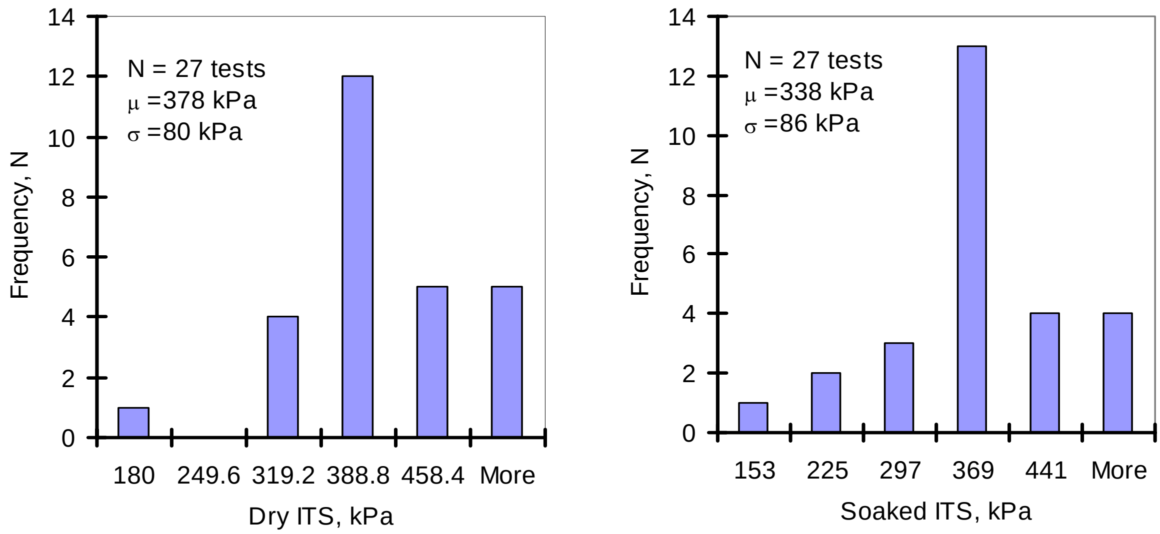


Fig. 8 Histogram of Achieved Indirect Tensile Strength

Laboratory CBR tests have been carried out on compacted samples of the CIPR mix (GEMS) to gain an appreciation as to any strength gain with curing and time. The testing data indicates that with no curing, the CBR value was approximately 30%. With curing periods of 3 and 7 days, the CBR values increased to about 50 and in excess of 90% respectively.

Further, visual and tactile examination of the recycled mix suggests that the mix is not overly rich in bitumen.

Verification of CIPR Performance

Prior to carrying out CIPR strengthening, a programme of deflection testing was initiated to assess those stretches suitable for CIPR and those areas that might require reconstruction. A number of methods were considered, namely Dynaflect and Benkelman Beam (BB). The former is based on low intensity loadings, which should be calibrated to the BB deflections (Yoder & Witzack, 1975). Given that the BB apparatus was available and simple to use under construction conditions and that the deflections determined thereby are based on loadings more in line with actual pavement loadings, the programme of testing was carried out using the Benkelman Beam (IRC:81(1997), CGRA 1965).

The testing programme was initiated after the start of the 2002 monsoon season – June to July. The existing carriageway was broken up into a number of sections based on project chainages. In these sections several of the Supervisory Engineering and Contractor staff members walked the site to obtain a visual assessment. Subsequently, a BB deflection survey was carried out on the existing pavement structure. In most cases, the characteristic BB deflections (taken as the average deflection plus two standard deviations) were determined to be in the order of 2mm or less. A number of stretches that were initially considered for reconstruction were then changed to CIPR construction based on this data and general site observations.

Upon completion of the CIPR process, another set of BB deflection readings were undertaken to assess the effects of the CIPR process on the pavement structure strength. A direct comparison of the limited number of before and after BB deflection readings implies that the CIPR process quite beneficially strengthens the ECW. The results of the comparison are shown on Figure 9. There is scatter among the results but not significantly different that one would expect for other geotechnical-oriented situations (*e.g.*, prediction of settlement of compressible clay deposits). It is observed that the average improvement was in the order of 30%. Similar trends were determined in the variability of the standard deviation within the test sections.

The deflections have also shown that the required thickness of added bituminous layers for the corresponding deflections is within those values anticipated in the design of bituminous pavement structure (210mm DBM/BC). The CIPR test results verified the bituminous concrete design thickness.

Deflection comparisons were also made in a number of limited cases of other layers. In particular, the new carriageway was designed to consist of 500mm subgrade (minimum CBR 6%), 150mm GSB drainage layer, 180mm GSB, 250mm WMM and 210 DBM/BC. Benkelman Beam deflections determined on two sections at the top of the WMM (with a subgrade having a minimum CBR 10%) were in the range of 1.7 to 2mm – this is similar as the measured CIPR deflection results. This verified, indirectly, that the CIPR approach provides a bitumen-modified base equivalent or better than the design WMM.

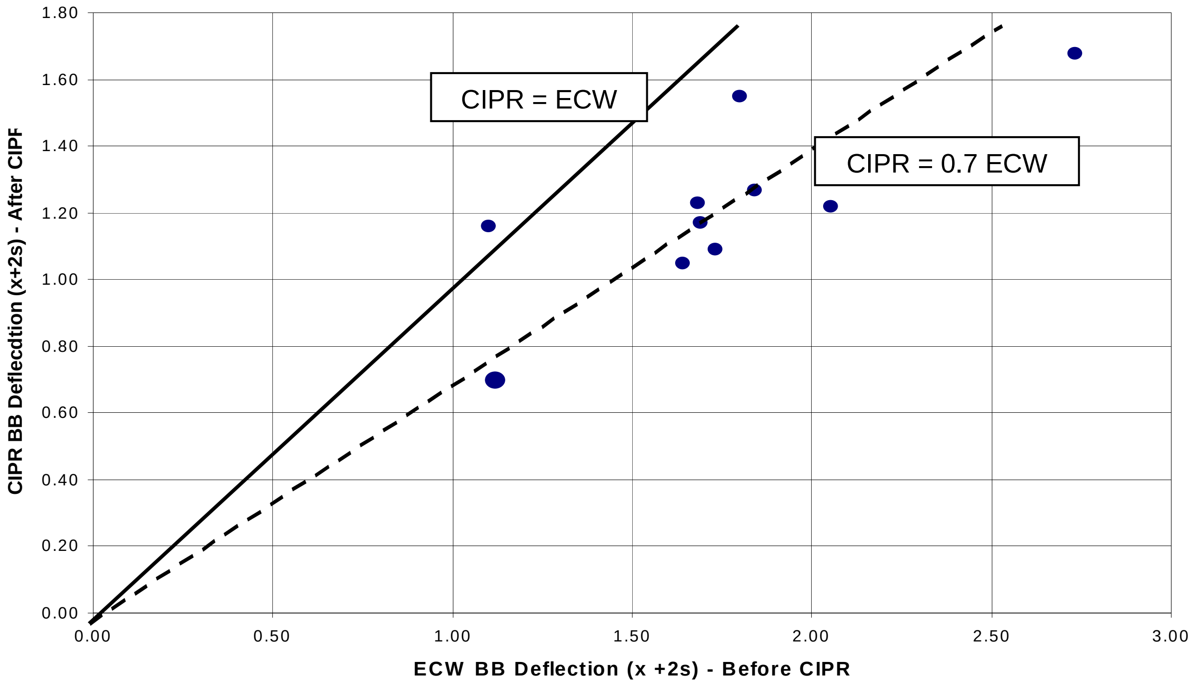


Fig. 9 Comparison of ECW and CIPR Benkelman Beam Deflections

RECOMMENDATIONS FOR FUTURE USE AND SPECIFICATIONS

Based on the authors' experiences in road construction, several comments are deemed worthy of putting forth with respect to highway design and construction projects. These points are general and are directed to both new pavement or to strengthening/rehabilitation of existing pavement structures.

In those roads where the existing structure shall be incorporated into the new works, such as in strengthening/rehabilitation, assessments of the existing road condition and the treatments to be done are best made in detail during the design phase. The assessments should include a detailed programme of pavement structure determination, evaluation of underlying foundation, existing strength reserve, evaluation of existing pavement materials with respect to resilient modulus, and detailed condition survey of existing road. A number of techniques would be used for such evaluations with the primary focus on *in situ* assessments. However, such assessments cannot be done in vacuum with other design aspects going on concurrently such as improvement of horizontal and vertical profiles. In strengthening/rehabilitation works, the vertical profile adjustments have a large influence on the most appropriate method of strengthening or rehabilitation.

Construction is the time to build the design – to get on with the work in a fashion that schedules are met and the work progresses in a satisfactory fashion. The contractors have planned their work with regard to scheduling, equipment and manpower in order to achieve their goal of completing a quality job with maximum financial gain. The supervising engineers are employed full time tending to the minutia of details that always need to be addressed. Staffing is usually insufficient for detailed assessments and design modifications.

Typical specifications usually address only material grading and field compaction. It is our opinion that these alone are insufficient to adequately ensure the quality construction. The design and subsequent specifications should address in a clear and succinct fashion the Constructors' needs for identifying (a) what is to be done where, (b) the basis of assessments (such as Benkelman Beam characteristic deflection maximums) and (c) provide the simple but effective tools by which the Constructors can verify and confirm the Engineer's design requirements.

Such tools, simple in operation, are necessary for both new and strengthening stretches – methods that can be employed in the field to verify project minimum requirements. Such field verification would not result in the redesign of the pavement structure unless the design norms are not met. In these cases, the performance evaluation would identify areas where thicker pavement sections are needed. To this end, and due to its simplicity of use, a most suitable tool that should be provided to the Constructors is the Benkelman Beam apparatus. In any event, it is our opinion that performance verification in contract specifications is paramount.

There is a need for more research to establish design criteria with respect to mix properties such as minimum ITS value or resilient modulus, minimum curing time and effect of curing. We have found that the field compaction, atmosphere cured ITS values as given herein are achievable. These could be considered, at this time, for minimums to be adopted as interim requirements in future construction with the caveat that modifications may arise from results of future research and continued observations in real construction projects.

CONCLUSIONS AND OBSERVATIONS

1. Milling and Cold In-Place Recycling of existing bitumen concrete pavements can provide an attractive option for improving and strengthening an existing pavement structure especially where the recycled mix will be used as a bitumen-stabilized base course.
2. CIPR has a uniquely bright future to rehabilitate State and Distrcit secondary roads where the road vertical profile is not changed to any appreciable degree and where there may be financial limitations to total reconstruction and realignment.
3. Properly selected equipment and a rational mix design result in a nearly homogeneous mix with good compactive quality. Double drum rollers (10t) typically utilized for bituminous concrete works have been found suitable for compaction of CIPR.
4. After placement, the recycled thickness is greater than the original with increased thickness in the order of 10 to 15% on average.

5. The limited data to date (on approximately 5.5km of the existing carriageway) suggests that Benkelman Beam deflections after CIPR are in the order of 30% smaller on the same stretch of highway during the same climatic conditions when compared to readings obtained immediately prior to CIPR. As well, the standard deviation has also been improved by the CIPR process when compared to pre-CIPR deflection surveys (see Figure 9).
6. Benkelman Beam deflections of CIPR give similar deflections to those found for a new pavement structure's WMM course (overlying GSB, DL and sandy subgrade with CBR>10). More data, however, is necessary to confirm this to a satisfactory degree of confidence.
7. Assessments of existing pavements for strengthening need to be done, in detail, during the design phase of work. Delineations for the application of various alternatives for pavement construction should be carried out at that time.
8. Specifications should provide the Constructors (contractor and supervising engineers) the tools and means with which to verify the adequacy of design.

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