An Experimental Study on Cost Optimization of Cold-in-Place Recycling Technique

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Abstract: India has a road network of over 5,603,293 kilometers (3,481,725 mi) as on 31 March 2016, the second largest road network in the world.
To match with the growing industrialization and development of the country, Government has made ambitious plans to expand network of national highways across the length and width of the country at a rapid pace.
Road transport is one of the major components in economic and social development of a country. There is a growing interest in sustainability in the area of pavement construction that maximizes the utilization of existing pavement materials in maintenance, reconstruction and rehabilitation activities.
Recycling of pavement is the process in which the existing pavement material are reclaimed re-used after processing for either (a) resurfacing, or (b) repaving, or (c) reconstruction of pavement depend upon the condition of the existing pavement and the treatment that the pavement requires.
The emphasis on sustainability has led to establishing a new terminology in pavement design and construction among which “Sustainable pavements” has emerged. A sustainable pavement has been defined as those pavements that are safe, efficient, environmentally friendly meeting the needs of present-day users without compromising the needs of future generations. In the CIR process, the existing asphalt surface is not heated prior to milling, and the reclaimed material is not shipped to a plant for processing, but processed in-place.
It is clear that the CIR technology addresses the above definition and criteria of sustainability by (1) optimizing the use of natural resources, (2) reducing energy consumption, (3) reducing greenhouse gas emissions, (4) limiting pollution, (5) improving health, and risk prevention, (6) ensuring a high level of user comfort and safety, and (7) less requirement of expensive virgin bitumen.
Cold in-place recycling (CIPR) is a continuous multi-step process in which the existing asphalt pavement is recycled using specialized equipment that cold mills the asphaltic pavement and blends asphalt emulsion and aggregate (if necessary) with the reclaimed material.

I. INTRODUCTION

A. General
Cold In-Place Recycling (CIPR) is an asphalt pavement rehabilitation technique that processes the existing in-situ pavement materials, by cold-milling the pavement and supplementing the milled material with asphalt emulsion and aggregate (if necessary). All work is completed on site and the transportation of materials, except for the additives being used, is normally not required. In the cold mix in-place recycling process, existing in-place materials are mixed with recycling agents and/or new or reclaimed materials without the application of heat.
The method can be used to eliminate a variety of distresses such as rutting, cracks, and irregularities while maintaining the original profile and with a minimum traffic disruption. The depth of processing is typically 3 to 4 inches. The process is sometimes referred to as partial depth recycling because the base and or some of the bituminous materials are left intact. Once cured, all CIPR projects are overlaid with a wearing course.
While CIPR is presently employed as a maintenance option on asphalt pavements in New York State, its use tends to be limited to select regions of the state and to specific pavement types. Decisions on whether to employ CIPR are in most cases determined by the Regional Maintenance Engineer. As a result, the decision making process is in great part based on the Engineer’s preference and experience with CIPR.
B. Importance And Relevance

Cold in-place recycling is an eco-friendly paving process for any road structure in irreparable condition. Recycling and reusing the existing pavement layer does away with the need for—and therefore the costs of purchasing and transporting fresh aggregate. During cold in-place recycling, two to five inches of the current road surface are pulverized to a specific aggregate size; mixed with a rejuvenating asphalt emulsion; and then reused, then and there. Overall labor costs are reduced. Because no heat is applied to the asphalt, cold in-place recycling reduces the noxious fumes and pollution associated with many other processes—what is safe for the environment is also safer for the road construction workers.

1) The Need: The Development of Vehicle transport facility, causing increase numbers of vehicle user and road users as well as increase load on pavement. A Major part of Indian Highway/Roads has severely deteriorated and required immediately improve the pavement surfaces. CIR with foamed bitumen uses 100% of reclaimed material by converting distressed layers into new stabilized materials. When major surface rehabilitation is required, conventional approaches mean extensive planning, traffic delays, fleets of equipment and numerous trips to and from the construction site.

2) The Applications: Ideal for urban, residential, state & county route applications.
   a) Roads marred by potholes, wheel ruts, cracks & major structural problems.
   b) Ideal for returning built-up bridge underpasses to safe clearances; also reduces dangerous dead-load materials on bridges.

II. LITERATURE REVIEW

Cold In-place Recycling (CIR) is defined as a rehabilitation technique in which the existing pavement materials are reused in place. The materials are mixed in-place without the application of heat. The reclaimed asphalt pavement (RAP) material is obtained by milling, planing, or crushing the existing pavement. Virgin aggregate or recycling agent or both are added to the RAP material which is then laid and compacted. The use of cold in-place recycling can restore old pavement to the desired profile, eliminate existing wheel ruts, restore the crown and cross slope, and eliminate pothole, irregularities and rough areas. It can also eliminate transverse, reflective, and longitudinal cracks. Some of the major reasons for the increased use of cold in-place recycling are the increased scarcity of materials, particularly gravel and crushed rock, the method's high production rate and potential of cost savings, minimum traffic disruption, ability to retain original profile, reduction of environmental concerns, and a growing concern for depleting petroleum reserves.

1) Charles T. Jahren (1998): A research project was undertaken to evaluate the performance of cold in-place recycled (CIR) asphalt projects in the state of Iowa. A sample of eighteen roads was selected. Then performance was evaluated in two ways: pavement condition indices (PCI) were calculated and over-all ratings were given on ride and appearance. A regression analysis was extrapolated predict the future service life of CIR roads. The results were that CIR roads within the state of Iowa with less than 2000 annual average daily traffic (AADT) have an average predicted service life of fifteen to twenty-six years. Overall, CIR roads in Iowa are per-forming well.

2) California State (USA): The use of foamed asphalt in CIR applications has been limited in the United States; however, it has lately started gaining momentum due to the many benefits that this technology possesses compared to using traditional stabilization products. As mentioned previously, CIR is limited to recycling 2-4 inches of the existing asphalt concrete. Whereas foamed asphalt was not widely used in CIR, foamed asphalt has been used on a number of full depth reclamation (FDR) projects throughout the state where all the existing asphalt concrete and a portion of the base layer are recycled.

III. ANALYSIS OF EXISTING CONDITION

A. Investigation

The following types of investigation on the existing pavement are required:

For the investigations and the research was taken from Swaroopganj-Pindwara section of National Highway NH-27in the state of Rajasthan India. The existing pavement along the project is flexible. The project road has four lanes with paved shoulder and 2 carriageways.

The general procedure for the evaluation and strengthening design of in-service pavements follows the guidelines of IRC: 37-2012 – “Guidelines for the Design of Flexible Pavements” and IRC: 115-2014- “Structural Evaluation and Strengthening of Flexible Road Pavements Using Falling Weight Deflectometer (FWD) Technique”.

The Rehabilitation of the section aims to:-
1) Improve the riding quality of existing pavement.
2) Improve the pavement parameters to accommodate heavy traffic loading.
3) Improve the safety for road users.
4) Rationalized the existing material from the existing pavement, using CIR technique.
5) Sub-grade characteristics and strength: investigation of required sub-grade and sub-soil characteristics and strength for road and embankment design and sub soil investigation.

a) Pavement Condition: Characteristics of Technical condition road section pavement
The analysis was performed for the section of the existing highway.
A network Survey Vehicle is a high-performance survey equipment that allows the collection of roads geometrical data (such as slope, cross slope and radius of curvature), roads surface pavement distresses (such as cracking, IRI, rutting, raveling) road assets inventory data, and roads images (frontal and pavement). NSVs have been developed to obtain all such information in one single pass along each lane of the highway.
The images of the pavement captured are used to identify sample units. Multiple sample units are marked along the road and each sample unit are recorded with road distresses based on the surface type i.e., Asphalt, PCC and etc.

Figure 1

The PCI, Rutting and IRI rating for the roads will finally be done based on the required standards about road condition applicable to each particular project.

Figure 2
b) **Pavement Composition And History:** The investigations were carried out along the existing road using trial pits and the following investigation and tests were conducted in those pits:

i) Pavement Composition, layer thicknesses

ii) In-situ Dynamic Cone Penetration Tests to determine the field CBR of expose base and sub-grade.

iii) In-situ Field Density and Moisture Content test at sub-grade top.

iv) Collection and preservation of samples of all materials for further testing at the laboratory.

The locations of test pits investigated for this highway stretch (Swaroopganj-Pindwara) with their co-ordinates are provided in the next table.

| S.No. | Chainage  | Direction | Test Pit No. | Coordinates   |
|-------|-----------|-----------|--------------|---------------|
| 1     | 677+000   | LHS       | 1            | 291309.00     |
|       |           |           |              | 2730907.00    |
| 2     | 679+200   | RHS       | 2            | 293054.00     |
|       |           |           |              | 2732488.00    |
| 3     | 682+000   | LHS       | 3            | 294956.00     |
|       |           |           |              | 2734165.00    |
| 4     | 684+500   | RHS       | 4            | 296862.00     |
|       |           |           |              | 2735443.00    |
| 5     | 687+150   | LHS       | 5            | 298314.00     |
|       |           |           |              | 2737445.00    |
| 6     | 689+500   | RHS       | 6            | 299627.00     |
|       |           |           |              | 2739488.00    |
| 7     | 692+100   | LHS       | 7            | 300821.00     |
|       |           |           |              | 2741896.00    |
| 8     | 694+500   | RHS       | 8            | 303161.00     |
|       |           |           |              | 2741268.00    |
| 9     | 697+000   | LHS       | 9            | 305154.00     |
|       |           |           |              | 2739850.00    |
| 10    | 699+700   | RHS       | 10           | 306108.00     |
|       |           |           |              | 2737857.00    |
| 11    | 702+050   | LHS       | 11           | 306921.00     |
|       |           |           |              | 2735247.00    |

The results obtained in site for DCP test are given in the next table.

| Layer               | Average CBR Value (%) | 65 Percentile CBR Value (%) |
|---------------------|-----------------------|-----------------------------|
| Exposed Base        | 36                    | 38                          |
| Subgrade Base       | 38                    | 41                          |

The details of crust composition is presented in the following table:

| S.No. | Layer Material | Average Thickness (mm) | 60 Percentile Thickness (mm) |
|-------|----------------|------------------------|-----------------------------|
| 1     | Bituminous Layer | 160                    | 180                         |
|       | WBM/WMM (Base)  | 250                    | 255                         |
|       | GSB (Sub-base)  | 240                    | 250                         |
|       | TOTAL CRUST     | 650                    | 685                         |
c) **Structural Evaluation**: The deflection of a pavement is the vertical deviation suffered by this pavement when it supports a standard load. The deflection itself is not a value that can define the structural capacity of a pavement. It depends on:

1. Intensity of the applied load
2. Surface on which it is applied
3. Thickness of every layer
4. Elastic module of each of the layers
5. Cohesion degree among layers
6. Resistance characteristics of support layers
7. Discontinuity presence near the load
8. Temperature of pavement
9. Moisture

The higher the bearing capacity, the lower the deviation (deflection) the pavement will suffer.

Falling Weight Deflectometer (FWD) is the most common and used vehicle for knowing the support capacity of pavements.

![Typical method of site data collection using FWD](image)

**Figure 3**

x) Prepare the FWD unit for deflection testing

 xi) Bring the FWD to a stopped position at the beginning of the test section, centered on the outside wheel path (or specific position), and take a measurement by applying load using following sequence:

 xii) One settling drop to ensure proper contact. Three drops with an applied load of 40 KN ± 10% (or Specified Load).

Structural Condition of pavement has been evaluated using Falling Weight Deflectometer (FWD) and subsequent analysis was carried out to ascertain the relative performance of the pavement for entire Project Stretch, in the context of evaluating its residual life, overlay and other maintenance requirements.

Normalization of data obtained from the average of three readings at each location is done taking into account the temperature and seasonal correction factors. The results are provided at below table.

| Side | Average Deflection (mm/100) | Characteristic Deflection (mm/100) |
|------|----------------------------|----------------------------------|
| LHS  | 24                         | 40                               |
| RHS  | 25                         | 41                               |

Moduli of each layer have been calculated using KGPBACK for each test point. The calculated modulus values for each layer are presented in the table, for LHS and RHS of the Project Stretch. The Elastic Modulus of Bituminous/Granular/Subgrade Layers is shown in the table below:
Table 5

| Chainages | Bituminous Layer LHS | Bituminous Layer RHS | Granular Layer LHS | Granular Layer RHS | Subgrade LHS | Subgrade RHS |
|-----------|---------------------|---------------------|-------------------|-------------------|-------------|-------------|
| 677.500   | 814                 | 4562                | 156               | 132               | 120         | 120         |
| 684.500   | 878                 | 1782                | 158               | 132               | 120         | 120         |
| 689.500   | 2451                | 2820                | 146               | 146               | 120         | 120         |
| 694.500   | 3503                | 889                 | 124               | 150               | 120         | 76          |
| 699.500   | 1028                | 519                 | 131               | 159               | 120         | 117         |

Table 6

| Chainage | Liquid Limit (LL) % | Plastic Limit (PL) % | Plasticity Index (PI) % | FSI [IS:2720-Pt-40] % | Max. Dry density (gm/cc) | OMC (%) | Soaked CBR at 3 energy level | Unsoaked CBR at 3 energy level |
|----------|---------------------|----------------------|------------------------|------------------------|--------------------------|---------|----------------------------|-------------------------------|
| 677+000 to 797+000 | 38.00                  | 21.00                | 15.00             | 18.00             | 2.20 | 13.00 | 36.00 | 45.00 |
| Maximum  | 23.00                | 14.00                | 5.00                 | 8.00               | 1.84 | 6.00 | 9.00  | 13.00 |
| Minimum  | 27.79                | 19.43                | 9.50                 | 11.53              | 2.06 | 8.52 | 19.88 | 29.96 |
| Average  | 24.08                | 18.96                | 5.68                 | 10.26              | 2.20 | 6.57 | 36.15 | 2.78  |

Table 7

| Chainage | Liquid Limit (LL) % | Plastic Limit (PL) % | Plasticity Index (PI) % | Max. Dry density (gm/cc) | OMC (%) | CBR Value at 98 % dry density (Soaked) % | Specific Gravity |
|----------|---------------------|----------------------|------------------------|--------------------------|---------|------------------------------------------|------------------|
| 677+000 to 797+000 | 25.00                  | 20.00                | 6.00                 | 2.24 | 7.00 | 40.00 | 2.83  |
| Maximum  | 22.00                | 18.00                | 4.00                 | 2.16 | 6.00 | 33.00 | 2.73  |
| Minimum  | 24.08                | 18.96                | 5.68                 | 2.20 | 6.57 | 36.15 | 2.78  |
| Average  | 24.54                | 19.33                | 5.44                 | 2.24 | 5.72 | 2.78 | 20.46 |

Table 8

| Chainage | Liquid Limit (LL) % | Plastic Limit (PL) % | Plasticity Index (PI) % | Max. Dry density (gm/cc) | OMC (%) | Specific Gravity | Impact (%) |
|----------|---------------------|----------------------|------------------------|--------------------------|---------|-----------------|------------|
| 677+000 to 797+000 | 25.00                  | 20.00                | 6.00                 | 2.27 | 6.00 | 2.82 | 25.00  |
| Maximum  | 23.00                | 19.00                | 4.00                 | 2.20 | 5.00 | 2.71 | 16.00 |
| Minimum  | 24.54                | 19.33                | 5.44                 | 2.24 | 5.72 | 2.78 | 20.46 |
| Average  | 24.54                | 19.33                | 5.44                 | 2.24 | 5.72 | 2.78 | 20.46 |

d) Existing Pavement Material Properties: To identify the system of structural layer, test pit and core cut were made in the pavement and the subgrade was evaluated to the depth of 1.5 m below the existing road level.

The summary of laboratory test results is given in table. The detailed laboratory test results are given in tabular form in Annexure Labs Investigation.

### B. Granular Sub Base

The test results of GSB are generally Sandy Gravels. OMC value is in the range of 6.0% to 7.0% and that of MDD is in the range of 2.16gm/cc to 2.24 gm/cc. CBR value is in the range of 33.0% to 40.0%. Specific gravity value is in the range of 2.73% to 2.83%. The laboratory test results are given in table. The detailed laboratory test results are given in tabular form in Annexure Labs Investigation.

### C. Wet Mix Macadam

The WMM sample is generally Silty Gravels of low plasticity. Plasticity Value is found to be in the range of 4 to 6. The laboratory test results are given in table. The detailed laboratory test results are given in tabular form in Annexure Labs Investigation.
D. **Bituminous Mixes**

Two types of mixes compose basically the bituminous layers of the highway:

1) **Bituminous Concrete (BC):** BC is a Dense Graded Bituminous Mix used as Wearing Course for flexible pavements.

2) **Dense Bituminous Macadam (DBM):** DBM is a close Graded Bituminous mix of lower bitumen content and used as a binder course for all pavements.

Average sieve analysis results of material derived from the existing pavement and subgrade are illustrated in fig.....

**Figure 4**

| Sieve | BC | % Passing | % passing as per MORTH | DBM | % Passing | % passing as per MORTH |
|-------|----|-----------|------------------------|-----|-----------|------------------------|
| 27    |    | 100       | 100                    | 38  | 100       | 100                    |
| 19    |    | 99        | 90-100                 | 27  | 100       | 90-100                 |
| 13    |    | 80        | 59-79                  | 19  | 96        | 71-95                  |
| 10    |    | 68        | 52-72                  | 13  | 79        | 56-80                  |
| 5     |    | 51        | 35-55                  | 5   | 43        | 38-54                  |
| 2     |    | 37        | 28-44                  | 2   | 32        | 28-42                  |
| 1     |    | 28        | 20-34                  | 0   | 11        | 7-21                   |
| 1     |    | 22        | 15-27                  |     | 5         | 2-8                    |
| 0     |    | 16        | 10-20                  |     |           |                        |
| 0     |    | 11        | 5-13                   |     |           |                        |
| 0     |    | 6         | 2-8                    |     |           |                        |
different axle load repetitions into equivalent standard axle load repetitions. The equations for computing equivalency factors for single, tandem and tridem axles given below have been used for converting VDF are calculated in accordance with the guidelines provided in IRC: 37.

Traffic loading on the highway can be determined and standardized by using Equivalent Standard Axle Load (ESAL) factors like the Vehicle Damage Factor (VDF).

The equations for computing equivalency factors for single, tandem and tridem axles given below have been used for converting different axle load repetitions into equivalent standard axle load repetitions.

\[ \text{Single axle with single wheel on either side, } E_SA = \left( \frac{\text{axle load in kN}}{65} \right)^4 \]

\[ \text{Single axle with dual wheels on either side, } E_SA = \left( \frac{\text{axle load in kN}}{80} \right)^4 \]

\[ \text{Tandem axle with dual wheels on either side, } E_SA = \left( \frac{\text{axle load in kN}}{148} \right)^4 \]

\[ \text{Tridem axle with dual wheels on either side, } E_SA = \left( \frac{\text{axle load in kN}}{224} \right)^4 \]

Summation of all ESA gives the total damaging effect for that location. By knowing the number of vehicles weighed and number of axles weighed and total damaging effect, VDF and Axle Equivalency were computed.

\[ \text{VDF} = \frac{\text{Total ESA}}{\text{No. of vehicles weighed}} \]

\[ \text{Axle Equivalency} = \frac{\text{Total ESA}}{\text{No. of axles weighed}} \]

Based on the spectrum of axle loads and analysis of axle load data at surveyed location the resulting VDFs are as given in Error! Reference source not found..

### Table 10

| Sieve | % Passing | % passing as per MORTH | Sieve | % Passing | % passing as per MORTH |
|-------|-----------|------------------------|-------|-----------|------------------------|
| 53    | 96        | 80-100                 | 53    | 97        | 95-100                 |
| 45    | 74        | 55-90                  | 45    | 67        | 60-80                  |
| 22    | 33        | 20-40                  | 22    | 19        | 15-30                  |
| 11    | 13        | 10-15                  | 11    | 11        | 8-22                   |
| 5     | 33        | 25-55                  | 5     | 36        | 25-40                  |
| 2     | 33        | 20-40                  | 2     | 19        | 15-30                  |
| 1     | 13        | 10-15                  | 1     | 11        | 8-22                   |
| 0     | 3         | 5-10                   | 0     | 2         | 0-5                    |

The above table gradation shows that existing pavement gradation is as per specification and limits given in MORTH clause 400 and 500 for Granular base and Bituminous.

### E. Traffic Conditions

In the road pavement design, multiple loading and unloading is represented by the number of axle loads. Traffic volume analysis has been carried out to assess the volume of traffic, its composition, hourly variation in traffic over 24 hours, and the daily variation in the traffic over 7 days at the project locations.

The traffic loading on the highway can be determined and standardized by using Equivalent Standard Axle Load (ESAL) factors like the Vehicle Damage Factor (VDF).

VDF are calculated in accordance with the guidelines provided in IRC: 37.

The equations for computing equivalency factors for single, tandem and tridem axles given below have been used for converting different axle load repetitions into equivalent standard axle load repetitions.

### Table 11

| Type of Vehicle | Calculated VDF | Calculated VDF LHS | Calculated VDF RHS |
|-----------------|----------------|--------------------|--------------------|
| LCV             | 0.98           | 0.67               |                    |
| 2 Axle truck    | 4.61           | 7.11               |                    |
| 3 Axle truck    | 5.65           | 6.78               |                    |
| MAV             | 9.23           | 10.46              |                    |
| BUS             | 1.00           |                    |                    |
The design traffic is considered in terms of the cumulative number of standard axles in both directions of the carriageway during the design life of the road. This can be computed using the following equation:

\[ N = \frac{989 \times [(1 + r)^n - 1]}{r} \times A \times D \times F \]

where \( N \) is the cumulative number of standard axles to be catered for the design in terms of Million Standards Axle (MSA), \( A \) is the initial traffic in terms of the number of commercial vehicles per day, \( D \) is the lane distribution factors, \( F \) is the vehicle damage factor, \( n \) is the design life in years, and \( r \) is the annual growth rate of commercial vehicles. The traffic in the year of completion is estimated using the following formula: \( A = P (1 + r)^x \) where \( P \) is the number of commercial vehicles as per last count, and \( x \) is the number of years between the last count and the year of completion between the last count and the year of completion of the project.

Section wise design traffic in average MSA based on VDF parameters has been worked out and summarized in table below:

| Section                  | Traffic in year (i.e. 2018) | 10 years (i.e. 2028) | 20 years (i.e. 2038) | 30 years (i.e. 2048) |
|--------------------------|------------------------------|----------------------|----------------------|----------------------|
| I: Swaroopganj - Pindwara| 6.0                          | 83.3                 | 176.8                | 302.6                |

F. Remaining Life Analysis

The structural condition of the pavement has been assessed by its Remaining Life which in this case is estimated from the critical strains computed for the present condition of the pavement.

Any method used to estimate the remaining life of a pavement will have its limitations and the results cannot automatically be accepted. It is, hence, very important that the estimations be compared with other indicators of the structural condition such as surface distress data, test pit inspection, coring data, etc., to check whether all these data give similar indications.

The layer moduli of in-service pavement back calculated from FWD deflection data are used to analyze the pavement for critical strains which are indicators of pavement performance in terms of rutting and fatigue cracking failure. This criterion follows IRC: 115-2014 and IRC: 37-2012 and facilitates the estimation of the remaining life of the pavement and the subsequent design of overlays.

1) Fatigue In Bituminous Layer

Following IRC: 115-2014, it is used the fatigue model for 90% reliability as below

\[ N_f = 0.711 \times 10^{-4} \times \left( \frac{1}{E_t} \right)^{3.89} \times \left( \frac{1}{M_r} \right)^{0.854}, \text{ For 90% Reliability} \]

Where:
\( N_f \) = fatigue life in number of standard axles.
\( E_t \) = Maximum Tensile strain at the bottom of the bituminous layer.
\( M_r \) = Resilient Modulus of the bituminous layer.

2) Rutting In Pavement

Following IRC: 115-2014, it is used the rutting model for 90% reliability as below

\[ N = 1.41 \times 10^{-8} x^3 (1 - 0.001x)^4.5887 \]

Where:
\( N \) = Number of cumulative standard axles.
\( E_v \) = Vertical strain in the subgrade.

Using the moduli values previously calculated, the remaining life of the pavement is estimated by using IIT PAVE. Remaining Life in (Fatigue and Rutting) of Pavement section wise LHS Carriageway are presented below in table.
### Table 13

| Section | Length | Chainage | Pavement | 15th Percentile | Before overlay |
|---------|--------|----------|----------|-----------------|---------------|
|         | From   | To       | BT       | GR             |               |
| Sec - 01 | 2.50   | 677  | 680  | 220  | 520 | 1400 | 135 | 120 | 37 | 2201 |
| Sec - 02 | 5.00   | 680  | 685  | 180  | 450 | 814  | 135 | 120 | 37 | 301  |
| Sec - 03 | 5.00   | 685  | 690  | 200  | 490 | 878  | 158 | 120 | 13 | 742  |
| Sec - 04A| 3.10   | 690  | 693  | 140  | 480 | 2451 | 146 | 120 | 11 | 487  |
| Sec - 04B| 1.90   | 693  | 695  | 140  | 480 | 2451 | 146 | 120 | 11 | 487  |
| Sec - 05 | 5.00   | 695  | 700  | 130  | 470 | 3503 | 124 | 120 | 12 | 473  |

Remaining Life (Fatigue and Rutting) of Pavement. LHS

### Table 14

| Section | Length | Chainage | Pavement | 15th Percentile | Before overlay |
|---------|--------|----------|----------|-----------------|---------------|
|         | From   | To       | BT       | GR             |               |
| Sec - 01 | 5.00   | 677  | 682  | 170  | 560 | 1802 | 132 | 120 | 14 | 1387 |
| Sec - 02 | 5.00   | 682  | 687  | 185  | 550 | 4562 | 174 | 120 | 138 | 6020 |
| Sec - 03 | 6.00   | 687  | 693  | 180  | 480 | 1782 | 132 | 120 | 17 | 1070 |
| Sec - 04 | 4.00   | 693  | 697  | 145  | 470 | 2820 | 138 | 120 | 15 | 581  |
| Sec - 05 | 5.00   | 697  | 702  | 145  | 475 | 1879 | 155 | 120 | 9  | 391  |

Remaining Life (Fatigue and Rutting) of Pavement. RHS

Both tables presented above show back calculation of each layer system with corrected values and remaining life of pavement.

### G. Overlay Requirements Of Existing Pavement

The flexible pavements are designed as a three layered system consisting of typical component layers, namely sub-grade, sub-base & base course (granular) and binder & surface course (bituminous).

The Proposed overlay requirements are obtained from the calculated Remaining Rutting life and Fatigue Life of the pavement, based on elastic modulus of bituminous layer as determine by back calculations. IITPAVE is used to calculate the strain values (vertical/horizontal) based on elastic modulus of all pavement layers, and assists to evaluate the remaining life of pavement in accordance to the thickness of overlay design in structural and functional requirement.

### Table 15

| Ch. | Length | Section Details | Design Traffic (MSA) | After overlay | Overlay Thickness (mm) | Overlay Thickness Adopted (mm) | Remarks |
|-----|--------|-----------------|----------------------|--------------|------------------------|-------------------------------|---------|
|     |        | From           | To                   | Fatigue Life | Rutting Life           | BC | DBM |                   |
| Sec 02 | 5.0   | 679+500        | 684+500              | 45           | 68.0                   | 2,764.0 | 90 | 40 | 50 | Structural Overlay |
| Sec 05 | 5.0   | 697+000        | 702+000              | 35           | 92.0                   | 3,961.0 | 90 | 40 | 50 | Structural Overlay |

Overlay thickness of LHS/RHS

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IV. DESIGN OF THE RECONSTRUCTION/STRENGTHENING/REHABILITATION OF THE ROAD SECTION USING THE COLD-IN PLACE RECYCLING TECHNIQUE WITH FOAMED BITUMEN

In order to demonstrate particle application of the waste material to the construction of base and subbase of the road segment under traffic loading of 35 MSA to 45 MSA for different carriageways, the thickness of particular layers was designed individually using mechanistic method.

Economic and environmental benefits of the CIR with Foamed Bitumen were estimated by comparison with the alternative typical solution provided in the IRC.

Option-I- the road pavement structure based on new raw material (Figure 13)

Option-II- the road pavement structure with the cold recycled material (with foamed bitumen and bitumen emulsion) (Figure 14)
The type and a layer system pavement structure

### Option - I

| Layer Type          | Proposal as per overlay requirement | Existing crust |
|---------------------|-------------------------------------|----------------|
|                     | \( \mu \) Possion Ratio | \( \text{Thick. (mm)} \) | \( E \) (Mpa) | \( \mu \) Possion Ratio | \( \text{Thick. (mm)} \) | \( E \) (Mpa) |
| Wearing course      | BC | 0.35 | 40 | 1700 | - | - | - |
| Binder Course       | DBM | 0.35 | 50 | 1700 | - | - | - |
| Existing Bitumen Course | BC+DBM | 0.50 | 180 | 814 | 0.5 | 180 | 814 |
| Base Course         | WMM+GSB | 0.35 | 450 | 135 | 0.35 | 450 | 135 |
| Subgrade            | Sand | 0.35 | - | 120 | 0.35 | - | 120 |
| The total thickness of the pavement structure: | | | | | | | 720 |

**Fatigue life calculation**

| Fatigue life (Nf) | Rutting life (Nr) |
|-------------------|-------------------|
| 45.72             | 1702.72           |
| 6.33              | 310.26            |

### Option - II

| Layer Type          | Proposal as per CIR+FB | Existing crust |
|---------------------|------------------------|----------------|
|                     | \( \mu \) Possion Ratio | \( \text{Thick. (mm)} \) | \( E \) (Mpa) | \( \mu \) Possion Ratio | \( \text{Thick. (mm)} \) | \( E \) (Mpa) |
| Wearing course      | BC | 0.35 | 40 | 1700 | - | - | - |
| Binder Course + CIR | DBM | 0.35 | 125 | 1700 | - | - | - |
| Existing Bitumen Course | BC+DBM | 0.50 | 105 | 814 | 0.5 | 180 | 814 |
| Base Course         | WMM+GSB | 0.35 | 450 | 135 | 0.35 | 450 | 135 |
| Subgrade            | Sand | 0.35 | - | 120 | 0.35 | - | 120 |
| The total thickness of the pavement structure: | | | | | | | 720 |

**Fatigue life calculation**

| Fatigue life (Nf) | Rutting life (Nr) |
|-------------------|-------------------|
| 53.20             | 1702.72           |
| 6.33              | 310.26            |

### V. CONCLUSION

Cold in place recycling with foamed bitumen allows to converting existing distressed material of existing pavement into full –depth value of bituminous surface, bringing economic and ecological benefits. The re-use of the existing material should be evaluated a priority. Even we can use 100% of existing surface can be reproduced when cold in place recycling technique is applied.

The structure analyzed with the surface course of 125 mm recycled with CIR technique, the thickness of similar to that in typical solution, showed the highest fatigue life and the highest resistance to the structural deformation. This was the result of a significant improvement of pavement parameter layer made with foamed bitumen in CIR mixtures. Increased fatigue life of the designed pavement may translate into longer period between repairs and lower maintenance cost.

The application of CIR-foamed bitumen creates the possibility to reduce the thickness of structural overlay layers for designing of long terms.

The design of strengthening and rehabilitation of the existing pavement using with Cold-in-place recycling is riskier, due to limited access in the upper layer of pavement. But using with the New Technology allows the extracting the full depth reclaims with control depth. Nevertheless, cold-in-place recycling has more advantageous then the strengthening such as reducing the haulage cost, lowering harmful emission, noise and reducing energy consumption.
VI. RECOMMENDATION

This paper provides the preliminary results of the influence of Cold in place recycling in comparison with Strengthening with DBM+BC in the existing pavement. Implementing of Cold in place recycling as pavement rehabilitation makes it possible to involve high strength in pavement. By using this technology around 100% of RAP can be utilized without undesirable effects within surface courses.

Investigations present that the test on mixtures are less brittle and durable than the normal mixtures requirement. It is recommended to evaluate mechanical properties of RAP mixtures in accordance with Super-pave criteria. Mixtures should be prepared by means of a gyratory compactor and evaluated for volumetric analysis. Supplementary performance based experiments should be conducted. For RAP mixture tests, rutting and fatigue performance evaluation are recommended. It is also recommended that the comparative evaluation of normal overlay process with DBM+BC and CIR+FB be studied. The results of a comparative study may provide information on whether CIR+FB, which will be a supportive conclusion when one determines whether the strength of CIR in comparison with the normal mix design is higher in fatigue life in mix design.