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Transportation Research Procedia 17 (2016) 359 – 368

Transportation Research Procedia

www.elsevier.com/locate/procedia

11th Transportation Planning and Implementation Methodologies for Developing Countries, TPMDC 2014, 10-12 December 2014, Mumbai, India

Rehabilitation by in-situ cold recycling technique using reclaimed asphalt pavement material and foam bitumen at vadodara halol road project (SH 87) – a case study

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Abstract

Cold Recycling Technology (CRT) of worn out bituminous pavement is a relatively new technology which has important application in the road surface treatment and paving towards green highway. Due to economic and environmental constraints like reduction in construction cost, preservation of aggregate and binder, etc, more attention is turning towards recycling of bituminous surface as an alternative to conventional pavement rehabilitation. The objective of this paper is to analyze flexible pavement with insitu cold recycling technique using Reclaimed Asphalt Pavement Material (RAP) and Foam Bitumen. As a case study, pilot project consisting of segregated stretches having major distresses and totaling 10 km length were selected on Vadodara Halol Road Project (SH 87) where cold recycling technique using reclaimed material and foam bitumen was used as a part of rehabilitation of flexible pavement instead of conventional overlay in order to achieve economy and executing within limited time period. Various field as well as laboratory tests are conducted and representative cores were extracted to investigate the pavement characteristics. The results of tests conducted on the cold recycling surface are very encouraging and adopted CRT is found to be economically viable also.

Peer-review under responsibility of the Department of Civil Engineering, Indian Institute of Technology Bombay

Keywords: Insitu Cold Recycling Technique; Reclaimed Material; Foamed Bitumen; Indirect Tensile Strength; Economic Evaluation.

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Peer-review under responsibility of the Department of Civil Engineering, Indian Institute of Technology Bombay
doi:10.1016/j.trpro.2016.11.126

1. Introduction

According to Kamran et al [4] road transportation system is one of the key components in social and economic development of a country and it takes a considerable amount of national budget. Construction materials preservation, environment friendly construction, speedy and cost effective rehabilitation alternatives are the requirements of current age. M. Amaranatha et al [2] described that conservation of energy and materials is important practices for achieving sustainability in road construction. Major road infrastructure activities currently under taken by different agencies in India for the last one decade have shown greater impact on energy consumption and depletion of aggregates. There is a problem with non-availability of good quality aggregates in some states of the country and aggregate being very expensive because of large lead distances. It is also to be noted that thicknesses of existing pavements are increasing due to addition of periodic overlays. The rise of road levels causes serious drainage problems in the urban areas.

Even well designed road pavements reach a phase where the general condition demands rehabilitation for their structural and functional quality. The rehabilitation could be undertaken through an overlay consisting of one or more bituminous layer or through reutilization of existing pavement materials eventually with an improvement of their characteristics defined as pavement recycling.

Defined in handbook of Wirtgen cold recycling technology [5] pavement recycling is one of the technique by which one can address the scarcity of the natural material. In pavement recycling we use the aggregates obtained by cutting and milling of the existing pavement and by doing this we not only conserve the virgin aggregates but also address drainage problem and save millions of rupees. In situ cold recycling technique is environmental friendly, utilizes fewer amount of fuel as well faster in construction. Use of Reclaimed Asphalt Pavement (RAP), obtained from milling of existing distressed bituminous surfacing in pavement construction and rehabilitation works is being routinely used in developed countries for conserving natural resources.

The objective of this paper is to analyze flexible pavement with insitu cold recycling technique using RAP / reclaimed material and foam bitumen. As a case study, pilot project consisting of segregated stretches having major distresses and totaling 10 km length were selected on Vadodara Halol Road Project (SH 87) where cold recycling Technique using reclaimed material and foam bitumen was used as a part of rehabilitation of flexible pavement. Vadodara Halol Road Project was commissioned in year 2000. The project road is four lane divided carriageway. Over a period, due to conventional overlay the thickness of bituminous layer increased excessively. Even after regular maintenance and rehabilitation, various distresses like segregation, severe cracking like alligator cracking, longitudinal cracking, etc undulation and rutting at segregated locations on the pavement were observed. Beyond a point distresses in the lower bituminous layers could not be curtailed as they surfaced after plying of traffic. Also the profile correction had reached its limits because of kerb height. Various field as well as laboratory tests were conducted and representative cores were also extracted on existing bituminous pavement to investigate the pavement characteristics and collecting data for design.

On the basis of results and considering design period of 10 years and 28 msa, conventional overlay was designed as per IRC 81:1997. In order to achieve economy and executing within limited time period, option of Insitu cold recycling technique was also considered.

Foam bitumen mix using RAP, virgin aggregate and bitumen proportioned was produced as per Cold Recycled mix design was produced. A 180mm thick foam bitumen RAP mix layer was prepared and over it 40mm thick bituminous concrete layer was laid. Laboratory investigation like Indirect Tensile Strength (ITS) on specimen of recycled mix and field investigation like Benkleman Beam Deflection (BBD) and Roughness Survey by 5th Wheel Bump Integrator was conducted. Laboratory and field test were conducted on rehabilitated surface before and after one monsoon season. Due to lack of availability of standards on foam bitumen in India, BSG guideline (TG-2, 2009) is adopted for mix design. At present the pavement surface seems to be intact without any visible distress. The results of tests conducted on the new surface have so far been very encouraging.

2. Literature review

Insitu cold recycling is being considered to be an efficient and effective method in the developed countries for rehabilitating asphalt roads showing non-structural aging and cracking of the pavement layer.

In rehabilitation of pavement using foam bitumen, the bitumen is heated in a chamber and cold water is injected into the hot bitumen resulting in the spontaneous formation of foam with huge expansion of bitumen. The foam bitumen is added to the Reclaimed Asphalt Pavement (RAP) and virgin aggregates. As per TG-2 [6] foamed bitumen is a hot bituminous binder which has been temporarily converted from a liquid state to a foam state by the addition of a small percentage of water and pressurized air. This is mainly a physical rather than a chemical process. Foamed bitumen is characterized by Expansion Ratio (ER) and Half-life time (τ½). The expansion ratio is defined as the maximum volume over its original volume (before foaming) and half-life time is defined as the time it takes (in seconds) for foam to become a half of its maximum volume. The optimum foaming water content is determined by the amount to obtain the maximum expansion ratio and the longest half-life time of foamed bitumen. The expansion of the bitumen and the half-life time are dependent mainly on: the type and temperature of base bitumen, the working pressure of bitumen, water and air, the quantity of foamant water added and temperature of the mixing chamber or vessel into which the foamed bitumen is sprayed.

This cold recycling technique can be used to treat both marginal and recycled materials and applied as base and sub-base layers in pavements.

The advantages of cold recycling with foam bitumen highlighted by Kamran et al [4] and handbook of Wirtgen cold recycling technology [5] are hereafter.

- Increase in strength over granular pavement material due to improved cohesion and moisture resistance.
- Quick construction method comparing with other hot mix technology
- Lower cost than reconstruction by utilizing RAP material.
- Bitumen stabilized material are not temperature sensitive.
- As only bitumen is required to be heated and not aggregate or RAP material, this technology is environmental friendly.
- Also due to less fuel consumption there is appreciate cost saving.

2.1. Mix design outline.

Defined by handbook of Wirtgen cold recycling technology [5] mix design procedure involves several steps and one or more levels depending on magnitude of design traffic. The mix design procedure starts with testing of materials to be stabilized and then commencing mix design Level 1 that provides an indication of application rate of bitumen and active filler required to achieve an indicated class of Bitumen Stabilized Materials (BSM). Thereafter depending on requirement of design traffic additional series Level 2 & 3 are adopted to refine application rate and gain confidence in performance potential of treated material. In this paper Level 1 mix design procedure is adopted.

2.2. BSM classification.

Described in handbook of Wirtgen cold recycling technology [5] BSM are classified in three classes depending on quality of parent material and design traffic. The three classes of BSM are BSM1, BSM2 and BSM3. In this paper Material Specification requirement for BSM1 is adopted. BSM1 material has high shear strength and is used as a base layer for design traffic.

Table 1: Material indicators for bitumen stabilized material – I with foamed bitumen

Test or Indicator	Material	Used For BSM-1	Codal Provision
Material passing 0.075 mm	CS or RAP	0 - 10	TG-2
Field Density	All	> 98%	IS:2720 (Part-8 & 28)
Plasticity Index	CS or RAP	< 4	IS:2720 (Part 5)
ITS (Dry) kpa	100 mm dia Marshall Mould	> 225	TG-2
ITS (Soaked) kpa		> 100	TG-2
ITS (Dry) kpa	150 mm dia Marshall Mould	> 175	TG-2
ITS (Soaked) kpa		> 150	TG-2

Note: CS – Crushed stone, RAP – Reclaimed Asphalt Pavement Material

2.3. Gradation

The grading of material requires careful considerations. The grading requirement for BSM-Foam for BSM-1 classification as per TG-2 [6] is adopted in this paper.

Table 2: Gradation for BSM-foam

I S Sieve (mm)		50	37.5	26.5	19	13.2	9.5	6.3	4.75	2.36	1.18	0.6	0.425	0.3	0.15	0.075
Percent Passing	Ideal	100	87 to 100	77 to 100	66 to 99	67 To 87	49 to 74	40 To 62	35 To 56	25 to 42	18 to 33	14 to 28	12 to 26	10 to 24	7 to 17	4 to 10
	Less Suitable	---	---	100	99 to 100	87 to 100	74 to 100	62 to 100	56 to 95	42 to 78	33 to 65	28 to 54	26 to 50	24 to 43	17 to 30	10 to 20

Foam bitumen requires sufficient fines particles to be present in the material to facilitate the dispersion of the bitumen. Where the material is deficient in fines, a poor mix will result. For this reason minimum requirement specified is 5% by mass for fines passing 0.075mm sieve. The general grading requirements for BSMs are indicated in terms of zones of most suitable aggregate composition in Figure 1.

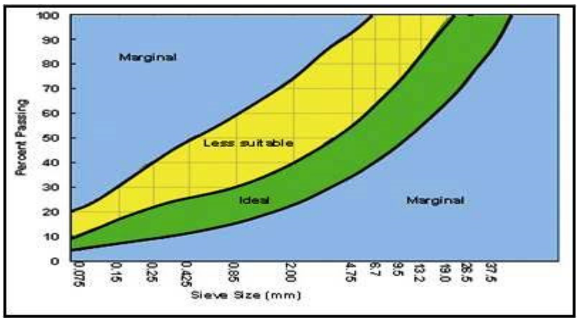

Fig.1. Grading requirement in terms of zones

2.4. Active filler

According to handbook of Wirtgen cold recycling technology [5] filler shall consist of finely divided mineral matter such as Portland cement, hydrated lime or rock dust as approved by Engineer. The filler shall be graded within limits indicated in Table 500-9 of MORT&H specification and shall be free from organic impurities. In this paper for cold mix blend 1% OPC was adopted.

Table 3: Application rate for cement or hydrated lime as filler

Plasticity index: < 10	Plasticity index: 10 - 16	Plasticity index: > 16
Add 1% Ordinary Portland cement	Add 1% Hydrated Lime	Pre Heat with 2% Hydrated Lime

2.5. Foaming properties

Foamed bitumen is a mixture of air, water and bitumen and the proportion of 98% bitumen, 1% water & 1% foaming agent (compressed air) was adopted for preparing foam bitumen in this paper. The minimum foaming properties that is acceptable for effective stabilization as per TG-2 [6] is as per table below.

Table 4: Foam characteristics limits (minimum value)

Aggregate Temperature	10^0 C to 25^0 C	Greater Than 25^0 C
Expansion Ratio, ER (Times)	10	8
Half Life, ½ (Secs)	6	6

If these requirement does not meet than the bitumen should be rejected as unsuitable for foaming.

2.6. Indirect Tensile Strength Test (ITS)

Defined in TG-2 [6] the ITS test is used as an indirect measure of the tensile strength and flexibility of the BSM to reflect the flexural characteristics of the material. It is the most economical method for investigating the effectiveness of the bitumen. The ITS test is used to test the specimen under different moisture condition like dry, soaked and equilibrium moisture content. The ITS is determined by measuring the ultimate load to failure of a specimen that is subjected to a constant deformation rate of 50.8 mm/minute on its diametric axis.

Indirect Tensile Strength (ITS) = (2 x P) / (π x h x d) x 10000 where,
P = Maximum applied load, H = Average height of specimen, D = diameter of specimen

Place the specimen under water at 25^0C for 24 hours. Remove the specimen from water, surface dry and repeat the procedure to determine the ITS of soaked specimen. The tensile strength ratio is the relationship between the soaked and unsoaked ITS for a specific batch of specimen, expressed as a percentage using equation:

Tensile Strength Ratio (TSR) = (Soaked ITS / Unsoaked ITS) x 100

The TSR is useful to identify problem materials. Where a material has a TSR less than 50%, and the ITS_{dry} exceeds 400 kPa, the material is likely to contain clays and the bitumen is ineffective.

2.7. Determination of optimum binder content

The 100 mm dia Marshall Specimen are tested for indirect tensile strength under dry and soaked conditions. The results of the dry and soaked ITS test are plotted against respective bitumen content that was added. The added bitumen content that best meets the desired properties is regarded as optimum binder content.

3. Existing pavement investigation

The segregated locations were selected along the project road and were considered for rehabilitation by In situ cold recycling.

Table 5: Selected stretches for rehabilitation

Left Carriageway	From	9.000	17.000	22.000	23.000	24.000	25.000	30.000
	To	10.000	18.000	23.000	24.000	25.000	26.000	31.000
Right Carriageway	From	20.000	21.000	25.000	26.000	29.000	30.000	35.000
	To	21.000	22.000	26.000	27.000	30.000	31.000	36.000

The pavement investigation on selected stretches on existing pavement was carried out for rehabilitation. The activities like Pavement Condition Survey, Roughness survey, BBD test and existing pavement bituminous layer Tk were conducted under pavement investigation.

3.1. Pavement condition survey

The pavement condition was carried out prior to commencement of BBD test. The pavement condition survey was conducted by visual observations and collecting details regarding the distresses that have crop up on existing pavement. On conducting pavement condition survey it is observed that various distress exists in varying percentage on entire road project. The distress that were observed are alligator cracks, reflection cracks, stripping, ravelling, pot hole, undulations, etc. At very few locations minor rutting or settlement were observed. This indicates that the existing pavement is structurally sound from base. The photos of the distresses observed at selected stretches are presented below.

Km 9+400 LCW Km 22+200 LCW Km 30+200 LCW Km 20+100 RCW Km 26+900 RCW Km 35+600 RCW

Fig.2. Photographs of few stretches with distresses

3.2. Roughness survey

The pavement roughness is defined as the irregularities in the pavement surface that affect the ride ability of a vehicle and thus causes discomfort to road users. The roughness survey on selected stretches was carried out by using 5th Wheel Bump Integrator (Automatic Road Unevenness Recorder) towed by Scorpio Gateway utility vehicle. The vehicle attached with 5th Wheel Bump Indicator was moved along the wheel paths at an averagely speed of 30 Km/hr over the slow lane & fast lane of both left carriageway & right carriageway of project road. The roughness data was measured at every 100m interval. The roughness value in mm/Km for fast lane & slow lane of right carriageway & left carriageway is presented in table below.

Table 6: Roughness value in mm/Km on existing pavement at selected stretches

Chainage (in Km)		Left carriageway		Chainage (in Km)		Right carriageway	
From	To	Slow Lane	Fast Lane	From	To	Slow Lane	Fast Lane
9.000	10.000	2600	2524	20.000	21.000	2800	2724
17.000	18.000	2712	2590	21.000	22.000	2682	2576
22.000	23.000	2740	2616	25.000	26.000	3000	2890
23.000	24.000	2500	2432	26.000	27.000	2620	2534
24.000	25.000	2262	2220	29.000	30.000	2600	2564
25.000	26.000	2590	2470	30.000	31.000	2858	2766
30.000	31.000	2602	2520	35.000	36.000	2690	2614

3.3. *Benkelman Beam Deflection (BBD) test*

BBD test was undertaken on carriageway to determine the residual strength of the existing pavement. The test was carried in accordance with IRC: 81-1997 "Guidelines for Strengthening of Flexible Road Pavement using Benkelman Beam Deflection Technique". The readings taken during the test are used for arriving characteristic deflection. The pavement temperature and subsoil moisture correction factor was also considered. The achieved characteristic deflection is presented in table below.

Table 7: Characteristic deflection in mm on existing pavement at selected stretches

Left hand side carriageway			Right hand side carriageway		
Chainage (in Km)		Characteristic deflection (in mm)	Chainage (in Km)		Characteristic deflection (in mm)
From	To		From	To	
9.000	10.000	1.48	20.000	21.000	1.36
17.000	18.000	1.65	21.000	22.000	1.53
22.000	23.000	1.14	25.000	26.000	1.42
23.000	24.000	1.60	26.000	27.000	1.67
24.000	25.000	1.28	29.000	30.000	1.39
25.000	26.000	1.59	30.000	31.000	1.39
30.000	31.000	1.46	35.000	36.000	1.18

3.4. Existing pavement bituminous layer thickness

Due to overlay and patchwork the bituminous layer thickness has been increased excessively resulting in kerb height reaching the limit. In order to verify the same, cores were extracted at different locations of selected stretches and the thickness of bituminous layer is provided in table below.

Table 8: Existing pavement bituminous layer Tk in mm at Selected Stretches

Left Hand Side Carriageway	Location	9+500	22+550	23+500	24+700	25+650	30+400
	BT Tk in mm	220	230	210	180	220	230
Right Hand Side Carriageway	Location	20+300	25+500	26+300	29+500	30+000	35+600
	BT Tk in mm	200	210	200	280	220	210

4. Proposal for rehabilitation

On the basis of pavement investigation collaborating roughness survey and BBD test results, proposal for rehabilitation by conventional overlay and cold recycling was evaluated and compared. On the basis of traffic data collected and analysed, the rehabilitation was designed considering design period of 10 years and 28 msa.

4.1. Conventional overlay

The overlay bituminous thickness is derived based on characteristic deflection and projected msa as per design chart given in IRC: 81-1997. The overlay thickness in terms of Bituminous Macadam (BM) layer established as per design chart is accordingly converted into DBM (Dense Bituminous Macadam) & BC (Bituminous Concrete). The proposed bituminous overlay for strengthening the existing pavement is presented in table below.

Table 9: Proposed bituminous overlay as per conventional method

Left carriageway					Right carriageway				
Chainage (in Km)		Character -istic deflectio	BM in mm	Overlay proposal	Chainage (in Km)		Characteri -stic deflection	BM in mm	Overlay proposal
From	To				From	To			
9.000	10.000	1.48	151.57	40mm BC + 70mm DBM	20.000	21.000	1.36	137.75	40mm BC + 60mm DBM
17.000	18.000	1.65	166.79	40mm BC + 80mm DBM	21.000	22.000	1.53	156.52	40mm BC + 70mm DBM
22.000	23.000	1.14	103.03	40mm BC + 50mm DBM	25.000	26.000	1.42	145.03	40mm BC + 65mm DBM
23.000	24.000	1.60	162.76	40mm BC + 75mm DBM	26.000	27.000	1.67	168.31	40mm BC + 80mm DBM
24.000	25.000	1.28	126.71	40mm BC + 50mm DBM	29.000	30.000	1.39	141.49	40mm BC + 60mm DBM
25.000	26.000	1.59	161.91	40mm BC + 75mm DBM	30.000	31.000	1.39	141.49	40mm BC + 60mm DBM
30.000	31.000	1.46	149.47	40mm BC + 65mm DBM	35.000	36.000	1.18	110.43	40mm BC + 50mm DBM

4.2. Cold recycling

It was observed that the bituminous layer thickness of existing pavement at selected stretches that were distressed excessively was averagely 220 mm. It was decided to replace 220mm thickness of bituminous layer of existing pavement by 180 mm of cold insitu recycle layer + 40 mm fresh bituminous concrete layer as wearing course. After conducting number of trial with varying blending proportions of RAP, 20mm virgin aggregate & Cement, the blending as shown below falls within the specified limits and was adopted.

Table 10: Cold mix material blending

IS sieve (mm)		45	37.5	26.5	19	13.2	4.75	2.36	0.600	0.300	0.150	0.075
% Passing	RAP	100	100	100	90.5	82.34	44.36	33.87	21.45	16.65	11.25	5.7
	20 mm	100	100	100	71.93	27.11	2.07	0.15	0.04	0.02	0.01	0.01
	Cement	100	100	100	100	100	100	100	100	100	100	98
Blending (RAP 91%+ 20mm 8% + OPC 1%)		100.00	100.00	100.00	89.11	78.10	41.53	31.83	20.52	16.15	11.24	6.17
Mid limit		100.00	93.50	88.50	82.50	77.00	45.50	33.50	21.00	17.00	12.00	7.00
Lower limit		100	87	77	66	67	35	25	14	10	7	4
Upper limit		100	100	100	99	87	56	42	28	24	17	10

On finalizing the cold mix with blending proportion of 91% RAP, 8% 20mm virgin aggregate & 1% Ordinary Portland Cement (OPC), the modified proctor test was conducted as per IS: 2720 Part 8 to determine Maximum Dry Density (MDD) in gm/cc and Optimum Moisture Content (OMC) in percentage. On achieving MDD and OMC, foamed bitumen mix samples were prepared by mixing blended mix with foam bitumen. VG 10 bitumen was used for preparing foam bitumen with proportion of 98% bitumen, 1% water & 1% foaming agent (Compressed Air). The foam bitumen properties were verified prior to cold mix preparation. Total 18 numbers of foam bitumen mix samples were prepared with 6 samples for each percentage of 1.8%, 2% and 2.2% of foam bitumen. The Foam bitumen mix sample of 100 mm dia was prepared adopting Marshall Method. Out of 18 foam bitumen mix samples prepared, 9 samples were tested for ITS dry condition and remaining 9 samples for ITS wet condition. The Indirect Tensile Strength (ITS) Test is conducted as per ASTM: D 6931 – 12 to determine Optimum Bitumen Content (OBC) to be adopted. The obtained results for foam bitumen as well modified proctor and Indirect Tensile Strength (ITS) on cold recycle mix are presented below.

Table 11: Test results for Reclaimed Asphalt Pavement (RAP) material and virgin 20mm aggregate

Reclaimed Asphalt Pavement Material (RAP)		Virgin 20mm Aggregate	
Parameters	Results	Parameters	Results
Unit weight (gm/cc)	2.20	Bulk specific gravity (Oven dry)	2.826
Optimum moisture content (%)	5.00	Bulk specific gravity (SSD)	2.847
California bearing ratio (%)	24.20	Water absorption (%)	0.72
Aggregate impact value (%)	12.10	Aggregate impact value (%)	10.20
Aggregate abrasion value (%)	13.20	Aggregate abrasion value (%)	12.30

Table 12: Test results for foamed bitumen for aggregate temperature of 26.4^0 C.

Parameters	Results
Expansion Ratio, ER (Times)	24
Half Life, ½ (Secs)	11

Table 13: Test results for modified proctor & ITS

Maximum dry density (g/cc)	2.42	Optimum moisture content (%)	6
Summary for Indirect Tensile Strength Test (ITS)			
Bitumen content (%)	Average ITS_{Dry} (kPa)	Average ITS_{Wet} (kPa)	Tensile Strength Ratio (TSR) (%)
1.8	367.90	313.80	85
2.0	331.11	269.15	81
2.2	284.64	218.80	77

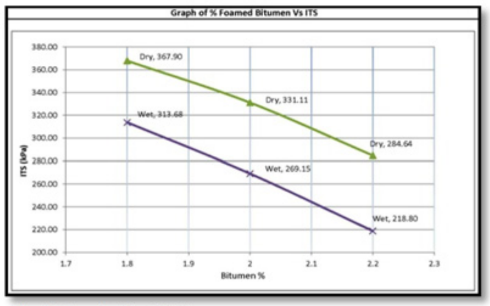

Fig.3. Graph for OBC

From the above results of ITS and TSR as well graph plotted for ITS_{dry} and ITS_{wet} against % foam bitumen, it was observed that the achieved results satisfies the required criteria for all three percentage of foam bitumen. Even though results were satisfying at 1.8% foam bitumen, but looking to percentage of finer material it was decided to adopt 2% foam bitumen for cold recycle mix to be on a safer side.

5. Construction methodology adopted

It was decided to replace 220 mm thick existing bituminous pavement by 180 mm of in situ cold recycled layer and 40 mm bituminous concrete layer as wearing course. The cold recycle mix consist of 91% RAP material + 8% virgin 20 mm aggregate + 1% OPC + 2% foam bitumen. The top 66 mm of existing bituminous pavement was milled and discarded to compensate 40 mm thick fresh BC layer and 26 mm thickness to accommodate additional 8% virgin aggregate. After milling 66 mm of existing bituminous pavement, 20 mm virgin aggregate and 1% OPC in proportion was spread on the milled surface. The remaining 154 mm thick existing bituminous pavement along with layer of 20 mm virgin aggregate and OPC was pulverized with 2% foam bitumen at in situ by WR 2400. The recycled cold mix was then compacted using heavy compactor to achieve required density. Finally 40 mm BC wearing course was laid on top of cold recycled surface.

Fig.4. Photograph of Cold Recycle Construction in Progress

6. Investigation on rehabilitated (cold recycled) stretch

After cold recycling at selected stretches and allowing drying for one day, field density test was conducted to verify the compaction. Moreover few representative cold recycle cores were extracted for ITS testing. Also BBD testing and roughness survey were conducted on the selected stretches. As planned, the set of testing were conducted on selected stretches before monsoon season and also after monsoon season.

Table 14: Test results for field density & % compaction achieved

Location	22+550 LCW	23+500 LCW	25+650 LCW	30+400 LCW	20+300 RCW	25+500 RCW	30+000 RCW	35+600 RCW
FDD (g/cc)	2.38	2.38	2.40	2.40	2.39	2.40	2.39	2.40
% Compaction Achieved	98.2	98.5	99.0	99.1	98.7	99.2	98.6	99.3

Table 15: ITS & TSR results on cold recycled core specimen after cold recycling.

Location	9+600 LCW	17+300 LCW	24+300 LCW	30+500 LCW	21+700 RCW	26+400 RCW	29+600 RCW	30+600 RCW
Average ITS_{Dry} (kPa)	341.51	337.12	335.25	338.12	339.12	333.65	335.28	336.19
Average ITS_{Wet} (kPa)	278.89	270.54	271.23	273.21	274.61	269.17	270.69	271.52
Tensile Strength Ratio (%)	82	80	81	81	81	81	81	81

Table 16: Roughness value in mm/Km on cold recycled surface at selected stretches

Chainage (in Km)		Left carriageway				Chainage (in Km)		Right carriageway			
		Before Monsoon		After Monsoon				Before Monsoon		After Monsoon	
From	To	Slow Lane	Fast Lane	Slow Lane	Fast Lane	From	To	Slow Lane	Fast Lane	Slow Lane	Fast Lane
9.000	10.000	1990	1944	2010	1976	20.000	21.000	2005	1965	2020	1972
17.000	18.000	1978	1928	2000	1948	21.000	22.000	1902	1872	1900	1878
22.000	23.000	1970	1932	1998	1952	25.000	26.000	1865	1887	1958	1906
23.000	24.000	2080	2024	2110	2070	26.000	27.000	2020	1970	2050	1976
24.000	25.000	1956	1900	2000	1928	29.000	30.000	2000	1952	2090	2064
25.000	26.000	1900	1876	1940	1900	30.000	31.000	1942	1900	1980	1958
30.000	31.000	2050	2002	2090	2042	35.000	36.000	1834	1780	1840	1806

Table 17: Characteristic deflection in mm on cold recycled surface at selected stretches

Left carriageway				Right carriageway			
Chainage (in Km)		Characteristic deflection (in mm)		Chainage (in Km)		Characteristic deflection (in mm)	
From	To	Before Monsoon	After Monsoon	From	To	Before Monsoon	After Monsoon
9.000	10.000	1.19	1.21	20.000	21.000	1.06	1.08
17.000	18.000	1.33	1.34	21.000	22.000	1.21	1.24
22.000	23.000	0.99	1.01	25.000	26.000	1.14	1.15
23.000	24.000	1.21	1.24	26.000	27.000	1.27	1.30
24.000	25.000	1.08	1.11	29.000	30.000	1.11	1.12
25.000	26.000	1.15	1.18	30.000	31.000	1.05	1.09
30.000	31.000	1.08	1.10	35.000	36.000	0.98	0.99

7. Conclusion

Based on achieved test results of cold recycled with foam bitumen, following conclusions can be drawn:

- On analyzing the roughness survey and deflection value between existing bituminous surface and cold recycled surface, it was observed that there was significant improvement.
- Moreover roughness survey and deflection value on cold recycled surface before and after monsoon season remains almost near.
- The Indirect Tensile Strength (ITS) & Tensile Strength Ratio (TSR) for cold recycle mix during mix design and for cold recycle core specimen after cold recycling, both satisfies the required criteria.
- The field density & % compaction of cold recycled surface is found satisfactory.
- From the laboratory as well field evaluation of recycled pavement using foam bitumen, it appears that CRT is promising alternative for rehabilitation of in service pavement.
- Looking to construction cost and the present performance of CRT we expect of saving around 15% in 10 years of cycle cost.

8. References

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