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USING CEMENT TREATED BASE AND SUB-BASE IN FLEXIBLE PAVEMENTS AT EXTREME HIGH ALTITUDE AREAS: A CASE STUDY

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ABSTRACT

This case study is based on the road construction activity, being undertaken by Border Road Organization in High Altitude Area in Eastern Ladakh in India. The road is being constructed along an altitude ranging from 12000 feet up to 18200 feet above Mean Sea Level (MSL), and the construction activity is restricted to only 4-5 months in a year, due to extreme winters during balance of the year. At higher reaches, lack of good quality aggregate material meant their haulage from long distances which was costly, time consuming and energy intensive. Considering the peculiarity of the terrain and challenges imposed by extreme weather and climatic conditions and in order to expedite the road construction to offset the limited working season in a year, few stretches on this road were identified for undertaking technological initiate. Thus, there was a need to adopt alternate road construction techniques which can improve the characteristics of available soil-aggregates and provide an economical, strong and durable load bearing and distributing surface thereby improving pavement performance while reducing construction time. Therefore, in-situ soil stabilization was undertaken to construct cementitious sub-base (CTSB) and cementitious base (CTB) course layers while constructing flexible pavement.

The concept, mechanism and requirement of executing CTSB/CTB are studied and the construction methodology to execute the work has been discussed. The mechanical properties and characteristics of the materials are tested in laboratory and based on several iterations, most economical yet adequate job mix design for a particular thickness for both CTSB/CTB layers with specified quantity of admixture and cement at OMC and desired density during compaction offering desired E-values were derived. Post construction performance evaluation was done wherein cores were tested for strength and durability parameters. FWD testing was done to obtain critical stresses, strains and deflections using Elastic Analysis Module (EAM) and results were compared with the stresses, strains and deflections obtained for design parameters using IIT-PAVE. Back calculations were performed to ascertain the remaining pavement life based on the FWD tested and reported strains for the BC layer, the sub grade and stresses under CTB layer.

KEYWORDS: *Admixture, Cement Treated Base (CTB), Cement Treated Sub-base (CTSB), Flexible Pavement, Performance Analysis*

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INTRODUCTION: BACKGROUND

Countries all over the world are developing rapidly and infrastructure development plays a vital role in the economic growth of any country. Transportation is the main constituent of infrastructure sector and road transport is presently developing at fastest pace among all other known means of transportation. To cater to the increasing needs of a growing economy like India and its ever increasing demand for improved and faster transport services, it is required to expand, develop and improve its existing road network.

India shares 15106.7 Km of land boundary with its neighboring countries, and there is an increasing demand to provide last mile connectivity up to the border areas both from socio-economic as well as military and strategic point of view. Hence, the requirement of good quality construction material is huge. On many occasion good quality construction material may not be available locally thus requiring its haulage over long distances thereby affecting cost economics of the road project and burdening the limited energy resources.

High altitude areas in Eastern Ladakh in India has extremes of climatic conditions, complex and challenging terrain and topography, extremely low population density and lacks even basic infrastructural facilities. These massive mountains with altitudes in excess of 11000 feet also forms our borders with our neighboring countries and in order to facilitate sustained deployment of our armed forces over these harsh, inhospitable and remote locations, an all-weather road network is extremely essential. Design and construction of an effective road network in extreme high altitude areas in Ladakh region pose more difficulties than elsewhere in the country.

PROBLEM STATEMENT

This case study is based on the road construction activities being undertaken by Border Roads Organization along a road in Eastern Ladakh in India. This road is being constructed along an altitude ranging from 12000 feet up to 18200 feet above Mean Sea Level (MSL). The road alignment is challenged by the complex geology of mountainous terrain coupled with instability of slopes, rock-falls, large number of re- entrants, glacial deposits and paleos that have been formed due to deposition of the downwash material which comes down as a result of melting of heavily glaciated mass/ Glaciated Lake Outburst Flow (GLOF). Other challenges encountered include extremely low surface temperatures during major part of the year with peak winter temperatures touching minus 50 °C, lack of adequate oxygen which has adverse impact on the performance efficiency of men and machinery employed on construction activities, fractured rock strata which tends to wither during winter months when the seeped water from the melting snow refreezes and expands, low friction coefficients due to snow covered pavement surface, frozen soil conditions (Permafrost) at higher altitudes and freeze-thaw conditions at slightly lower altitudes. Again, strong UV radiation adversely affects the bituminous pavement surfaces.

Road construction activity is restricted to only 4-5 months in a year due to extreme winters during balance of the year. At higher reaches, lack of good quality aggregate material corresponds to haulage of material from long distances which were costly, time consuming and energy intensive. Considering the peculiarity of the terrain and challenges imposed by extreme weather and climatic conditions and in order to expedite the road construction activity to fully utilize the limited working season in a year, few stretches on this road were identified for undertaking technological initiate. Thus, there was a need to adopt an alternate road construction methodology which can improve the characteristics of available soil-aggregates and provide an economical, strong and durable load bearing and distributing surface thereby improving pavement performance while reducing construction time. Therefore, road stretches were identified for undertaking in-situ soil stabilization in providing cementitious sub-base and cementitious base course layers while constructing flexible pavement.

Engineering design of a pavement is based on an assumption that each layer in the pavement has a minimum specified structural quality to support and distribute the superimposed loads. However, available construction material does not always meet these requirements and may require improvements to their engineering properties.

A road stretch between chain-age Km 204 to Km 216 on a strategically and militarily important road along an altitude of 16500 feet to 18000 feet in Eastern Ladakh was identified for in-situ soil stabilization and providing a crust composition comprising of CTSB, CTB, Stress Absorbing Membrane Interlayer (SAMI) of elastomeric modified binder followed by a wearing course of Bituminous concrete. A test of the physical properties and characteristics of the virgin soil samples collected from the selected road stretch was done followed by development of design mix for a particular thickness for both CTSB and CTB layers specifying the quantity of admixture and cement at optimum moisture content (OMC) and desired density during compaction offering desired E-values. Validation tests were done to confirm if the finished pavement is meeting the desired design values and the earlier laboratory results. Cores were extracted and tests performed to ascertain the strength and durability parameters as per IS: 4332 (Part V) Method 2 [1] for both wetting and drying and freezing and thawing cycles. FWD tests were performed as per IRC 115:2014 [2]. Finally, analysis of the critical stresses and strains obtained for design values as per IIT-PAVE were compared with Elastic Analysis Module (EAM) to check the safety of the prepared CTSB/CTB layers.

TESTS PERFORMED AND RESULTS

The road stretch identified was between chain-age Km 204 to Km 216, a stretch of 12 Km linear length at an altitude ranging from 16500 feet to 18000 feet above MSL. The road specifications were planned for snow bound area (SBA), wherein formation width is 7.45 m wide and carriageway width is 5.5m. Considering design parameters as; soil CBR 12 percent, traffic intensity of 5 MSA and for design life of 15 years, crust composition and crust thickness for the proposed road stretch was derived using IIT-PAVE. Proposed crust composition is as depicted in Figure 1.

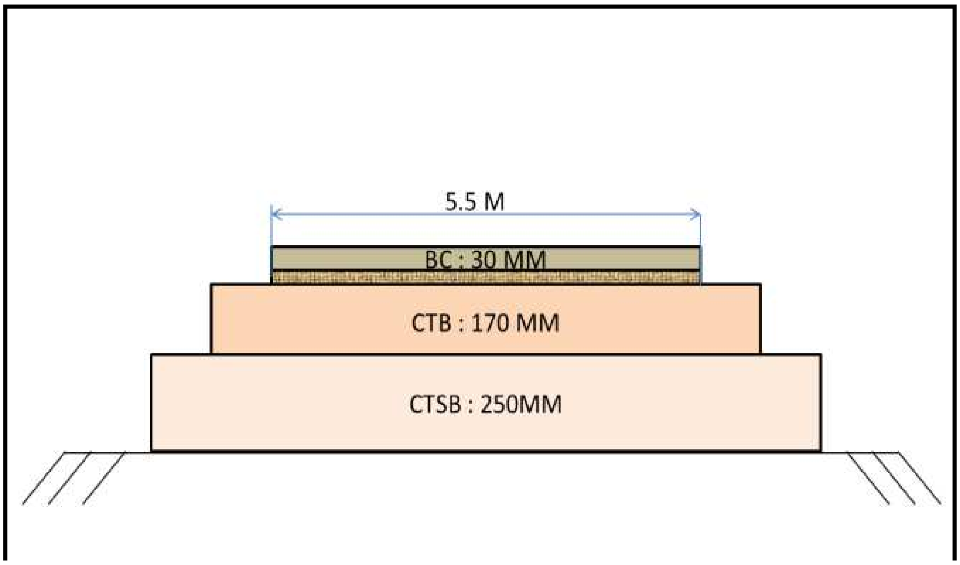

Figure 1: Design Crust Composition for Stretch between Chain-age Km 204 - Km 216.

Soil stabilization process are soil and site specific and needs to be developed for different soil types based on the effectiveness of a given stabilizer/admixture to improve the physio-chemical properties of the selected soil. As per (NCHRP 144) [3], the preliminary selection of the appropriate additives for the soil type should consider the following:-

- Soil consistency and gradation.
- Soil mineralogy and composition.
- Desired engineering properties.
- Purpose of treatment.
- Mechanism of stabilization.
- Environmental conditions and engineering economics.

Soil samples were collected from the proposed stretch and tests were carried out on “Virgin soil”. The test results are listed in Table 1.

Table 1: Physical Properties of “Virgin Soil” Samples

S No	Chain-age (Km)	Sieve Analysis (% Passing by Wt)		Atterberg Limits			Proctor Test		CBR	
		4.75 mm	0.075 mm	LL (%)	PL	PI	MDD (gm/cc)	OMC (%)	Un-soaked (%)	Soaked (%)
1	210-211	52.2	14.6	18.1	NP	-	2.19	8.5	32.5	12.6
2	211-212	48.7	11.9	19.6	NP	-	2.18	8.1	31.0	12.3
3	212-213	53.1	12.4	18.6	NP	-	2.21	8.6	32.6	13.7
4	213-214	50.7	14.4	17.7	NP	-	2.20	8.2	31.1	13.1
5	214-215	55.4	14.3	18.1	NP	-	2.21	8.6	32.8	13.6
6	215-216	57.1	18.3	20.1	NP	-	2.21	8.7	32.7	13.8
7	216-217	42.9	19.4	18.2	NP	-	2.18	7.9	31.1	11.0
8	217-218	52.4	18.7	18.4	NP	-	2.20	8.3	32.7	13.6
9	218-219	55.5	14.1	18.1	NP	-	2.21	8.2	32.4	13.9
10	219-220	50.3	14.8	17.5	NP	-	2.11	8.9	32.2	12.6
11	220-221	47.7	15.2	17.8	NP	-	2.18	8.1	31.0	11.6
12	221-222	52.2	13.1	18.7	NP	-	2.20	8.5	32.2	12.4

Job mix design for CTSB layer of proposed design thickness 250 mm for target elastic modulus, E-value minimum 3000 MPa and for CTB layer of proposed design thickness of 170mm for target elastic modulus, E-value minimum 5000 MPa as per (IRC: 37-2018) [4] was derived using test moulds of size 100 mm (diameter) X 200 mm (height) after 7 days curing prepared by varying admixture and OPC Grade 43 ratios to achieve targeted result values. Test results for iterations done to derive job mix design for 250 mm thick CTSB layer, target E-value minimum 3000 MPa in 7 days curing are as listed in Table 2. Thus, recommended job mix design for 250 mm CTSB layer is 1.40 Kg/m^2 admixture and 30 Kg/m^2 OPC Grade 43 at a moisture content of 3-4 percent over optimum moisture content (OMC) compacted at modified proctor density within 1 hour homogenization.

Table 2: Job Mix Design for 250 mm Thick CTSB Layer

S No	Admixture (Kg/m²)	OPC 43 (Kg/m²)	Crushing Load (KN)	Crushing Load (Kgs)	Area (cm²)	Crushing Strength (Kg/cm²)	Correction Factor (MPa)	E- Value (MPa)
Set-1								
1	0.0	20.0	3.85	392.58	78.5	5.001	0.6253	625.31
2	1.1	20.0	5.15	525.15	78.50	6.690	0.8365	836.45
3	1.2	20.0	6.00	611.82	78.5	7.794	0.9745	974.51
4	1.3	20.0	6.10	622.02	78.5	7.924	0.9907	990.75
5	1.4	20.0	6.25	637.31	78.5	8.119	1.0151	1015.11
6	1.5	20.0	6.40	652.61	78.5	8.313	1.0395	1039.47
Set-2								
1	0.0	25.0	4.6	469.06	78.5	5.975	0.7471	747.12
2	1.1	25.0	5.45	555.74	78.5	7.079	0.8852	885.18
3	1.2	25.0	6.35	647.51	78.5	8.249	1.0314	1031.35
4	1.3	25.0	6.70	683.20	78.5	8.703	1.0882	1088.20
5	1.4	25.0	6.95	708.69	78.5	9.028	1.1288	1128.80
6	1.5	25.0	7.25	739.28	78.5	9.418	1.1775	1177.53
Set-3								
1	0.0	30.0	6.35	647.51	78.5	8.249	1.0314	1031.35
2	1.1	30.0	7.95	810.66	78.5	10.327	1.2912	1291.22
3	1.2	30.0	14.55	1483.66	78.5	18.900	2.3632	2363.18
4	1.3	30.0	16.75	1708.00	78.5	21.758	2.7205	2720.50
5	1.4	30.0	18.65	1901.74	78.5	24.226	3.0291	3029.09
6	1.5	30.0	18.90	1927.23	78.5	24.551	3.0697	3069.70
Set-4								
1	0.0	35.0	7.80	795.37	78.5	10.132	1.2669	1266.86
2	1.1	35.0	8.25	841.25	78.5	10.717	1.3399	1339.95
3	1.2	35.0	14.9	1519.35	78.5	19.355	2.4200	2420.03
4	1.3	35.0	17.1	1743.69	78.5	22.213	2.7773	2777.34
5	1.4	35.0	18.80	1917.04	78.5	24.421	3.0535	3053.45
6	1.5	35.0	19.05	1942.53	78.5	24.746	3.0941	3094.06

Test results for iterations done to derive job mix design for 170 mm thick CTB layer, target E-value minimum 5000 MPa in 7 days curing are as listed in Table 3. Thus, recommended job mix design for 170 mm CTB layer is 1.40 Kg/m^2 admixture and 30 Kg/m^2 OPC Grade 43 at a moisture content of 3-4 percent over optimum moisture content (OMC) compacted at modified proctor density within 1 hour homogenization. Approximate quantity of cement, admixture and water for a CTSB/CTB mix is determined based on the mix design process of each. While deriving the mix design, unconfined compressive strength (UCS) of CTSB/CTB is specified to meet the requirements of pavement structure [5, 6]. Subsequently, the trial and error process is performed with varying cement and admixture contents in a series of CTSB/CTB mix prepared until achieving required UCS value at a specific cement and admixture content. The CTSB material should have a 7 day UCS of 1.5 to 3.0 MPa while E-value of 600 MPa may be considered ideal for analysis of pavement. The laboratory based E-value for CTSB is in the range of 2000-4000 MPa. Since the sub-base acts as a platform for the heavy construction traffic, low strength cemented sub-base is expected to crack during the construction and hence design value of 600 MPa is recommended for the stress analysis. The CTB material shall have a minimum UCS of 4.5 to 7.0 MPa in 7 days while E-value of 5000 MPa may be considered for analysis of pavement (IRC:SP:89 Part II- 2018) [7].

Verification of the finalized job mx design for both CTSB and CTB layers is done by preparing three moulds each of size 100 mm (diameter) X 200 mm (height) with recommended mix design and 7 days soaked/un-soaked unconfined compressive strength (UCS) conforming to IS: 4332 (Part V) was determined to further derive Elastic modulus (E-value) as per IRC: SP: 89 (Part II) - 2018. Test results for both CTSB and CTB proposed mix design are given at Table 4 and 5.

Table 3: Job Mix Design for 170 mm Thick CTB Layer

S No	Admixture (Kg/m²)	OPC 43 (Kg/m²)	Crushing Load (KN)	Crushing Load (Kgs)	Area (cm²)	Crushing Strength (Kg/cm²)	Correction Factor (Mpa)	E-Value (Mpa)
Set-1								
1	0.0	20.0	9.30	948.32	78.5	12.081	1.5105	1699.30
2	1.1	20.0	15.20	1549.94	78.50	19.745	2.4688	2777.34
3	1.2	20.0	18.9	1927.23	78.5	24.551	3.0697	3453.41
4	1.3	20.0	19.2	1957.82	78.5	24.940	3.1184	3508.22
5	1.4	20.0	21.15	2156.67	78.5	27.473	3.4351	3864.53
6	1.5	20.0	21.55	2197.45	78.5	27.993	3.5001	3937.62
Set-2								
1	0.0	25.0	12.6	1284.82	78.5	16.367	2.0465	2302.27
2	1.1	25.0	15.5	1580.54	78.5	20.134	2.5175	2832.16
3	1.2	25.0	19.4	1978.22	78.5	25.200	3.1509	3544.77
4	1.3	25.0	22.85	2330.01	78.5	29.682	3.7112	4175.15
5	1.4	25.0	24.85	2533.95	78.5	32.280	4.0361	4540.59
6	1.5	25.0	25.6	2610.43	78.5	33.254	4.1579	4677.63
Set-3								
1	0.0	30.0	13.9	1417.38	78.5	18.056	2.2576	2539.81
2	1.1	30.0	16.45	1677.41	78.5	21.368	2.6718	3005.74
3	1.2	30.0	23.25	2370.80	78.5	30.201	3.7762	4248.24
4	1.3	30.0	26.6	2712.40	78.5	34.553	4.3203	4860.35
5	1.4	30.0	28.65	2921.44	78.5	37.216	4.6533	5234.93
6	1.5	30.0	29.4	2997.92	78.5	38.190	4.7751	5371.97
Set-4								
1	0.0	35.0	15.8	1611.13	78.5	20.524	2.5662	2886.98
2	1.1	35.0	16.75	1708.00	78.5	21.758	2.7205	3060.56
3	1.2	35.0	23.8	2426.89	78.5	30.916	3.8655	4348.74
4	1.3	35.0	26.85	2737.89	78.5	34.878	4.3609	4906.03
5	1.4	35.0	28.7	2926.54	78.5	37.281	4.6614	5244.06
6	1.5	35.0	29.55	3013.21	78.5	38.385	4.7994	5399.38

Table 4: Verification of Finalized Mix Design for 7 Days Soaked/Un-soaked Moulds for 250 mm Thick CTSB Layer

S No	Admixture (Kg/m²)	OPC 43 (Kg/m²)	Crushing Load (KN)	Crushing Load (Kgs)	Area (cm²)	Crushing Strength (Kg/cm²)	Correction Factor (Mpa)	E- Value (Mpa)
Un-soaked Mould Samples								
1	1.4	30.0	18.9	1927.23	78.5	24.55074	3.0697	3069.70
2	1.4	30.0	18.8	1917.04	78.5	24.42084	3.0535	3053.45
3	1.4	30.0	18.6	1896.64	78.5	24.16104	3.0210	3020.97
Soaked Mould Samples								
1	1.4	30.0	18.6	1896.64	78.5	24.16104	3.0210	3020.97
2	1.4	30.0	18.5	1886.45	78.5	24.03115	3.0047	3004.73
3	1.4	30.0	18.6	1896.64	78.5	24.16104	3.0210	3020.97

Table 5: Verification of Finalized Mix Design for 7 Days Soaked/Un-soaked Moulds for 170 mm Thick CTB Layer

S No	Admixture (Kg/m²)	OPC 43 (Kg/m²)	Crushing Load (KN)	Crushing Load (Kgs)	Area (cm²)	Crushing Strength (Kg/cm²)	Correction Factor (Mpa)	E- Value (Mpa)
Un-soaked Mould Samples								
1	1.4	30.0	29.4	2997.92	78.5	38.19004	4.7751	5371.97
2	1.4	30.0	29.7	3028.51	78.5	38.57973	4.8238	5426.78
3	1.4	30.0	29.5	3008.12	78.5	38.31994	4.7913	5390.24
Soaked Mould Samples								
1	1.4	30.0	29.2	2977.52	78.5	37.93024	4.7426	5335.42
2	1.4	30.0	29.4	2997.92	78.5	38.19004	4.7751	5371.97
3	1.4	30.0	29.1	2967.33	78.5	37.80034	4.7264	5317.15

In order to ensure that the admixture does not contain toxic/heavy metals which due to leachability should not adversely affect the soils, plants and ground water, test for presence of heavy metal and leachability on admixture was done as per IRC:SP:89 (Part II) guidelines. Test for heavy metals was performed on the pure admixture and pure soil sample for identifying the presence of heavy metal concentration using WD: XRF spectrometer (Model- Buker, Tiger S-8) capable of detecting presence of heavy metals from solid and liquid samples from 1 ppm to 100 percent concentration and results are listed in Table 6. The results exhibits presence of heavy metals in ppm as detected for pure admixture and for pure soil samples. The compared values show that presence of the listed elements in admixture is far less than their presence in pure soil sample. Hence, this admixture is safe for usage in CTSB and CTB layers.

Table 6: Results for Presence of Heavy Metal in Admixture and Virgin Soil Samples

S No	Heavy Metal	Admixture	Virgin Soil Sample
1	Lead (Pb)	11	306
2	Arsenic (Ar)	0	198
3	Chromium (Cr)	28	73
4	Nickle (Ni)	30	66
5	Zinc (Zn)	80	88
6	Cobalt (Co)	2	6
7	Mercury (Mg)	Not Observed	Not Observed
8	Thorium (Th)	2	41
9	Uranium (U)	1	6
10	Copper (Cu)	6	385
11	Iron (Fe)	1.39%	7.89%

Test for leachability was performed, whereby sample moulds of the soil treated with admixture and cement (as per job mix design) were prepared and immersed in distilled water for a period of 7 days and then water sample drawn after 7 days is tested using WD: XRF Spectrometer (Model- Buker, Tiger S-8) capable of detecting presence of heavy metals from solid and liquid samples from 1 ppm to 100 percent concentration and its results are listed in Table 7.

Table 7: Leachability Test Results

S No	Heavy Metal	Sample Mould (CTB)	Sample Mould (CTSB)
1	Lead (Pb)	-	-
2	Arsenic (Ar)	-	-
3	Chromium (Cr)	-	-
4	Nickle (Ni)	-	-
5	Zinc (Zn)	-	-
6	Cobalt (Co)	-	-
7	Mercury (Mg)	-	-
8	Thorium (Th)	-	-
9	Uranium (U)	-	-
10	Copper (Cu)	76	77
11	Iron (Fe)	65	72

CONSTRUCTION METHOD

The design of flexible pavement is based on the principle that for a traffic load, the intensity of load diminishes as the load is transmitted downwards from the surface by virtue of spreading over an increasingly larger area through successive layers of granular material. The sub-base course acts as a secondary load spreading layer in flexible pavement and also as a drainage layer. To ensure its efficacy as a good drainage layer, the amount of fines must be limited. A high quality sub-base material is therefore essential at places where loading or climatic conditions are severe. When pavements are constructed over moist frost susceptible soil in hilly areas, granular sub-base would have to act as a retardant for frost action in addition to acting as a drainage layer. The base course is the main load bearing layer in flexible pavement system and is primarily constructed as a structural component. Road bases are expected to conform to specified material gradation and provide high mechanical stability. Undertaking flexible pavement construction by incorporating CTSB/CTB layers provides additional strength and support without increasing the overall thickness of the pavement. Providing a stiffer base would reduce the deflection due to heavy traffic loads and extend pavement life. Although theoretically, a thin but strong base can carry the same load as a thick but weaker base however, the thin yet strong base should be avoided because it can become brittle and fracture resulting in potential reflection cracks in the pavement surface. (George et al.) [8].

Soft and yielding subgrade was corrected and made stable before dumping of soil/aggregates for processing of CTSB begins. Any unsuitable soil/aggregate or material was removed and replaced with acceptable material. Dumping and placing of aggregate for CTSB was done as per grading IV of Table 400-1 of MORTH specifications [9] and as per Table 400-4 for CTB layer. Spreading and levelling is done using a Motor-grader and initial rolling is done to planned lines and grades. The surface of the soil/aggregate to be processed into CTSB/CTB shall be at an elevation so that when mixed with admixture, cement and water and compacted to required density, the final elevation will be as marked in the plan. A rectangular frame with equally spaced grids/enclosures was fabricated to cover the entire width of the proposed CTSB/CTB layer, wherein desired quantity (as per job mix design) of admixture and OPC Grade 43 could be uniformly applied. Cement and admixture were applied or mixed when the air temperature was well above 40°F (4°C). Moisture in the soil/aggregate at the time of cement application shall not exceed the quantity that will permit a uniform and intimate mixture of the soil/aggregate and cement during mixing operations. It shall be within 2 percent of the OMC for the CTSB/CTB mixture at the start of compaction. The operation of cement and admixture application, mixing, spreading, compacting and finishing was kept continuous and completed within two hours from the start of mixing.

Self-propelled prime-movers capable of delivering power through “Infinite Variable Transmission System” with dedicated rear mounted pulverizing and homogenizing machines were used over the uniformly spread measured quantity of admixture and cement and continued until a uniform mixture is produced. The mixture was pulverized such that 100 percent passes the 75 mm sieve, at least 95 percent passes the 50 mm sieve and at least 55 percent passes the 4.75 mm sieve. Mixing continued until the product turned uniform in colour, met gradation requirements and remained at the required moisture content throughout. The entire operation of admixture and cement spreading, water application and mixing resulted in a uniform mixture for the full design depth and width. Consistency of the mix was checked by digging trenches or series of holes at regular intervals for the full depth of treatment and inspecting the colour of the exposed mixture. Uniform colour and texture from top to bottom indicates a satisfactory mix; a streaked appearance indicates insufficient mixing.

Figure 2: Construction Sequence for Laying CTSB/CTB : (a) Dumping of Soil/Aggregate for Processing of CTSB/CTB, (b) & (c) Spreading of Admixture-Cement as per Job Mix Design, (d) Pulverization, Homogenization and Compaction under Progress, (e) Finished CTB layer after 7 Days Curing,(f) FWD Testing for Performance Evaluation.

CTSB/CTB layers are then uniformly compacted with compaction starting immediately upon mixing/ spreading of material, using vibratory steel-wheel rollers to a minimum of 98 percent of maximum dry density (MDD), based on a moving average of five consecutive tests with no individual test below 96 percent. Compaction and finishing was done in such a manner so as to produce a dense surface free of compaction planes, cracks, ridges or loose material. All finishing operations were completed within 4 hours from start of mixing. The newly finished CTSB/CTB surfaces were kept moist for a 7 day period to permit the cement-admixture to hydrate. Sufficient protection from freezing was provided to the CTSB/CTB layer for at least 7 days after its construction. Completed stretch of CTSB/CTB can be immediately opened to movement of construction equipment or low-speed traffic provided moist-curing operations are not impaired and provided the CTSB/CTB layer is sufficiently stable to withstand permanent deformation. Cemented layers, normally develop transverse and longitudinal cracks due to shrinkage and thermal stresses during hydration and during its service life. Studies have shown that incorporating a stress absorbing membrane interface (SAMI) can effectively solve the problem of reflective cracks in bituminous overlays and also extends the service life of the composite pavement. In addition, it can reduce the cost of repair and maintenance for pavements, thus decreasing its life-cycle costs. (Ogundipe et al. 2013) [10].The surface of CTB was made rough and free from dust and loose material before applying prime coat. The binder used was elastomeric modified binder complying with the requirements for areas of sub-zero temperatures as given in Table-2 of IRC: SP: 53- 2010 [11]. The binder was heated to a temperature of 160-170°C and sprayed uniformly over the prepared surface at the rate of 12 Kg/10 Sqm. Immediately after application of binder, clean, dry aggregates satisfying the physical requirements as given in Table 500-8 of MORTH (5th Edition) were sprayed uniformly by means of a mechanical spreader as specified in IRC: SP -34 [12] so as to cover the coated surface completely with a single layer of aggregates. Immediately after the application of chips, rolling is undertaken and continued until the chips are filially embedded over the bituminous coat and forms a uniform closed surface.

PERFORMANCE EVALUATION OF CTSB/CTB LAYERS

Post completion of work, testing was done to validate whether the finished surface are actually meeting the designed values. Cores were extracted from the 28 days cured paved layers for both CTSB and CTB. Minimum six cores per Km stretch for each layer were collected and tests performed to ascertain the strength and durability parameters as per IS: 4332 (Part V) Method 2 for both wetting and drying and freezing and thawing cycles. Wetting and Drying affects the strength and modulus values of cement stabilized materials. The modulus and strength values reduce as the number of wet-dry cycles increases (Paige-Green 1998, Zaman et al. 1999, Khoury and Zaman 2007, Ling et al.2008, Scullion et al. 2008) [13-17]. However, after a certain number of cycles, the strength and modulus reach their minimum values. Freeze-Thaw also affects the performance of cement stabilized layers. Research has found that freeze-thaw cycles significantly reduce the resilient modulus, flexural modulus, modulus of rupture (MOR) and UCS values (Khoury. 2005) [18]. It is suggested by research that after a certain number of freeze-thaw cycles, the reduction in the strength and modulus is not pronounced because freezing and thawing increases the pore size, thereby reducing the damaging effects of later freeze-thaw cycles (Esmer et al. 1969) [19].

Strength Parameters: CTSB

The test results of the cores tested exhibit average density = 1973-2000 Kg/m^3 and average E- value = 1215-1275 MPa for soaked and un-soaked tests.

Strength Parameters: CTB

The test results of the cores tested exhibit average density = 2210-2258 Kg/m^3 and average E-value = 10108-10608 MPa for the soaked and un-soaked tests.

Durability Parameters: CTSB

The test results of the cores tested exhibit average material loss after twelve durability cycles = 9.13 percent for wet-dry cycles and 8.20 percent for the freeze-thaw cycles. In any of the twelve durability cycles the material loss is less than 14 percent.

Durability Parameters: CTB

The test results of the cores tested exhibit average material loss after twelve durability cycles = 7.16 percent for wet-dry cycles and 6.16 percent for the freeze-thaw cycles. In any of the twelve durability cycles the material loss is less than 14 percent.

FWD Analysis and Results

Falling Weight Deflectometer (FWD) is an impulse loading device, in which a transient impulse load is applied to the pavement surface and deflection shape of pavement surface is measured by a series of geophones located at different radial distances from load plate which provides a more complete characterization of the structural condition of the pavement layers. The area of pavement deflection under and near the load application is collectively known as the "Deflection Basin". Using FWD deflection data, characterization of the existing pavement layers in terms of their layer moduli using back calculation procedure with the help of mechanistic structural model can be done. FWD deflections were measured in millimeter (mm) at standard configuration of geophones placed radially at 0mm (D1), 300mm (D2), 900mm (D3), 1200mm (D4), 1500mm (D5) and 1800mm (D6) respectively starting from the center of the loading plate.

FWD gives a very quick and accurate means of assessing the residual life of the pavement and is equally effective for composite pavement design. FWD based testing is an important part of any pavement evaluation plan. The FWD deflection measurements were done to measure the design assumptions such as the compressive strength and the recommended material stiffness of the CTSB/CTB have actually been achieved during stabilization. Results from FWD testing are also being utilized to check if the assumptions made during the pavement design were met or not thus, ensuring that the finished pavement would achieve the required design service life. FWD testing is done as per IRC 115: 2014. The critical readings obtained for the pavement stretch using FWD are as per Table 8. Layer-wise stresses and strains obtained for critical FWD readings with Elastic Analysis Module (EAM) are listed as Table 9.

Table 8: FWD Test Results (Critical Values)

S No	Height of Drop (mm)	Pressure (KPa)	Load (KN)	Air Temp (°C)	Surface Temp (°C)	D1 (µm)	D2 (µm)	D3 (µm)	D4 (µm)	D5 (µm)	D6 (µm)
1	45.21	916.68	64.8	23.02	18.82	229.1	153.54	86.22	57.68	35.69	33.97
2	45.09	909.77	64.31	23.47	18.77	230.22	156.06	87.42	54.11	24.11	34.18
3	45.67	913.36	64.56	23.87	18.74	232.01	157.13	85.67	59.08	31.53	34.63

Table 9: Layer-Wise Stresses and Strains Using EAM (Critical Values)

Pavement Structure Details			
Layer Description	**E (MPa)**	**Poisson's Ratio**	**Layer Thickness (m)**
BC	3277.98	0.35	0.03
CTB	10381.2	0.25	0.17
CTSB	1239.93	0.25	0.25
Subgrade	144.36	0.35	-

Symmetric Axis							
Layer Description	**σx**	**σy**	**σz**	**Ex**	**εy**	**εz**	**δz**
BC (Top)	-212.44	-293.79	5.04	-33.98	-67.48	55.59	-0.179
BC (Bottom)	-194.87	-226.83	-14.61	-33.67	-46.83	40.57	-0.18
CTB (Top)	-498.22	-600.4	-17.76	-33.11	-45.41	24.75	-0.181
CTB (Bottom)	298.02	528.99	-97.17	18.31	46.12	-29.28	-0.18
CTSB (Top)	8.14	36.09	-96.26	18.69	46.87	-86.55	-0.179
CTSB (Bottom)	86.42	96.04	-22.91	54.96	64.65	-55.27	-0.164
Subgrade	0.56	1.6	-22.81	55.27	65.05	-163.23	-0.164

Table 9: Contd.,

Tyre Centre								
Layer Description	**σx**	**σy**	**σz**	**εx**	**εy**	**εz**	**δz**	**δx**
BC (Top)	-704.78	-753.85	-800	-50.29	-70.5	-84.88	-0.185	-0.006
BC (Bottom)	-594.04	-625.16	-776.08	-31.61	-44.42	-106.58	-0.182	-0.005
CTB (Top)	-712.97	-816.15	-776.08	-30.41	-42.84	-37.62	-0.182	-0.005
CTB (Bottom)	422.9	544.99	-109.41	30.25	44.95	-33.85	-0.176	0.004
CTSB (Top)	19.92	34.7	-107.73	30.79	45.69	-97.89	-0.176	0.004
CTSB (Bottom)	78.07	90.37	-21.6	49.1	61.5	-51.38	-0.161	0.008
Subgrade	0.11	1.44	-21.5	49.38	61.87	-152.72	-0.161	0.008

The critical stresses, strains and deflections as obtained from IIT-PAVE were compared with those obtained by Elastic Analysis Module (EAM) in conformity with IRC:115- 2014, and results derived are as per Table 10.

Table 10: Comparison of Critical Stresses, Strains and Deflections as Derived from IIT-PAVE (Designed) and Elastic Analysis Module (Achieved)

Stains								
S No	**Layer**	**IIT-PAVE**	**EAM**	**IIT-PAVE**	**EAM**	**IIT-PAVE**	**EAM**	**Remarks**
		epZ(μ)	**εz(μ)**	**epT(μ)**	**εy(μ)**	**epR(μ)**	**εx(μ)**	
1	BC	-150.6	-106.58	-112.3	-46.83	-83.42	-33.67	EAM<IIT-PAVE : Safe
2	CTB	-164.3	-37.62	76.31	46.12	51.21	30.25	EAM<IIT-PAVE : Safe
3	Subgrade	-245.8	-163.23	98.73	65.05	83.5	55.27	EAM<IIT-PAVE : Safe

Stresses								
S No	**Layer**	**IIT-PAVE**	**EAM**	**IIT-PAVE**	**EAM**	**IIT-PAVE**	**EAM**	**Remarks**
		σZ(kPa)	**σZ(kPa)**	**σT(kPa)**	**σT(kPa)**	**σR(kPa)**	**σR(kPa)**	
1	BC	-789.3	-800	-796	-753.85	-746.7	-704.78	EAM<IIT-PAVE : Higher stresses in 30 mm BC Layer.
2	CTB	-87.87	-109.41	442.1	544.99	344.6	422.9	
3	Subgrade	-19.44	-22.81	1.49	1.6	0.56	0.56	

Deflections				
S No	**Layer**	**IIT-PAVE**	**EAM**	**Remarks**
		DispZ	**δz(mm)**	
1	BC	0.2734	-0.185	EAM<IIT-PAVE : Safe
2	CTB	0.2626	-0.182	EAM<IIT-PAVE : Safe
3	Subgrade	0.2376	-0.164	EAM<IIT-PAVE : Safe

It can be seen that the deflections and stains as per EAM < IIT-PAVE. However, due to lesser thickness of BC layer, stresses in the BC layer are higher resulting in transfer of stresses in the under-lying layers. Although, 10 mm thick SAMI layer is also present between the BC and CTB layer however, it does not act as a structural layer. It is therefore recommended to over-lay BC layer after every five years (resurfacing). Overall the EAM strains of the pavement are within permissible limits of allowable strains as per provisions of relevant codes. The remaining life for the BC, CTB layers and the sub grade vertical strains are within the permissible limits considering the design msa. The back calculations to ascertain the remaining pavement life based on the FWD tested and reported strains for the BC layer and the sub grade and stresses under the CTB layer in conformity with IRC:115- 2014 were derived and found to be safe against the design life as per IRC:37-2018. The results derived are as follows:

- Subgrade: 507.08 msa >> 5.0 msa.
- BC Layer: 2189.60 msa >> 5.0 msa.
- CTB Layer: 182.89 msa >> 5.0 msa.

CONCLUSIONS

On the basis of work that has been carried out in this study and the results obtained, it is observed that the remaining life of the Bituminous Concrete (BC) layer, Cement Treated Base (CTB) and the Sub grade vertical strains are within the permissible limits and much higher than the designed 5.0 msa. Since this stretch was constructed only one year ago and has still to under-go several freeze-thaw and wet-dry cycles besides the anticipated traffic growth, the reported values will tend to reduce over a period of time.

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