Construction of a Cement Concrete Pavement in a Hilly Terrain in India

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Abstract

The National Highway No 48 is an important artery connecting the capital city of Bangalore and the coastal city of Mangalore in the state of Karnataka in India.Over 5000 heavily loaded commercial vehicles per day with single and tandem axle loads as high as 200 kN and 400 kN respectively form bulk of the traffic. The highway alignment passes throughan eco-sensitive area with topography having steep longitudinalgradients up to 6%, and temperaturesfrom 16°Cto 36°C. The road has 152curvesin a length of 26 km with a large number of acute angled curves on gradients. The existing Asphalt Concrete pavement needed continuous maintenance due to heavy rain. It was decided to rehabilitate it with a jointed cement concrete pavement overlaid on a subbase of Roller Compacted Concrete (RCC) of10 MPa strength. The Paper gives highlights of design and construction of Dowel Jointed Cement Concrete Pavement having an8.50-meter wide carriageway constructed in two halves because of space constraints. Intercepting water by means of nonwoven geotextile and open graded aggregate due to the artesian condition owing to high water table was an important feature of the project.

Introduction

The capital city of Bangalore, an IT hub of India known as Indian Silicon Valley, is connected to coastal port cityof Mangalore by the National Highway No.48. The distance separating the two cities is 348 km and the region has an annual rainfall ranging from 5500 mm to 6000 mm.The existing road is made up of asphalt concrete and granular bases. 26km of the road passing through a hilly terrain known as Ghat area from km 237 to km 263 is a reserve forest formingan eco-sensitive zone. Quarrying of stone from hills in this forest is prohibited by law.All coarse and fine aggregates had to be transported from distant quarries about 250 km away. About 5000 heavy commercial vehicles plied daily on the road. The asphalt concrete surfacing did not last even one year due to heavy rain and frequentbraking action of heavy trucks. The deteriorated condition is shown in Figure 1. Sometimes the road also got blocked due to landslides. During rainy season Artesian conditions developdue to high water table and the subgrade is eroded due to oozing of water at many places. No amount of patch work helped smooth plying of traffic. About 6 years ago cement concrete pavement was over laid on 13 number of . sharp curves using semi-mechanized methods. This was overlaid with 25 mm thick mastic asphalt which also got eroded in five years. This rigid pavement on the curves during 6 years of service life performed very well. This has encouraged the decision to pave the balance of about 26 km of road with cement concrete. It was decided to adopt a jointed cement concrete pavement(JCCP)designed as per the guidelines of IRC:58-2011[1.] The design thickness was found to be 300 mm. The

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pavement is 8.5 m wide laid in two halves of width 4.25m each, due to space limitation, with contraction joints at every 4.5 m.

Figure 1 Condition of highway during Rainy season before laying rigid pavement

Pavement Design

Axle load survey was carried out and projected repetitions of different axle loads were computed over a design life of 30 years. Flexural stresses due to single and tandem axle loads due to simultaneous action of axle loads and temperature gradients were computed as per the regression equations of IRC:58:2011 and cumulative fatigue damage analysis was carried out to examine the safety of the pavement. Single axle loads were as heavy as 200 kN. A thickness of 300mm was selected considering that retexturing and grinding for removing faulting may have to be done every ten years to restore the skid resistance and smoothness of the pavement surface. Dowel bar of diameter 32mm 500mm long was provided at 200mm spacing and the tie bars of dimeter 8mm and length 480mm had a spacing of 220mm. The grade of pavement concrete was considered as M40[2]. 90 day flexural strength of 4.95 MPa was considered for cumulative damage fatigue analysis. Since the rainfall is very heavy in the area, 150mm thick roller compacted concrete[3](RCC) subbase of 10 MPa strength at seven days was selected to obtain a strong support which does not erode due to moisture and traffic.Since no debonding treatment was proposed due to steep gradients,transverse grooves in RCC to a depth of 50mm co-terminous with those of the pavement slab were proposed to avoid random cracks in the pavement.

Topography of the project Site

Ground contours the ghat area falls under hilly terrain. The curves are sharp and gradientsare as high as 6%.. The vertical fall in a km varies from 10m to 60 m i.e. from 1% to 6%. The hilly area is prone to land slide.

Artesian Condition

Due to high rainfall zone spread over a period of about 5 months in monsoon season raises the water table substantially. This creates artesian condition and the seepage line cuts across the carriageway at different points resulting in water oozing at many places across the pavement as shown in Figure 2.

Figure 2 View of Artesian conditions

Interception of water from Artesian condition

Nonwoven geo-fabric of 200 GSM (Figure 3) was provided over the subgrade across the full width of the road to act as aseparation layer to prevent ingress of subgrade soil into the open graded aggregate drainage layer.It will prevent the migration of fine soil particles into the drainage layer so that it is not choked. Transverse furrows were provided in the subgrade at 25m interval to intercept water flowing in the longitudinal direction along the sustained gradient to prevent damage to pavementsas shown in Figure 4.

Figure 3Laying of nowovenGeofabric over the subgrade

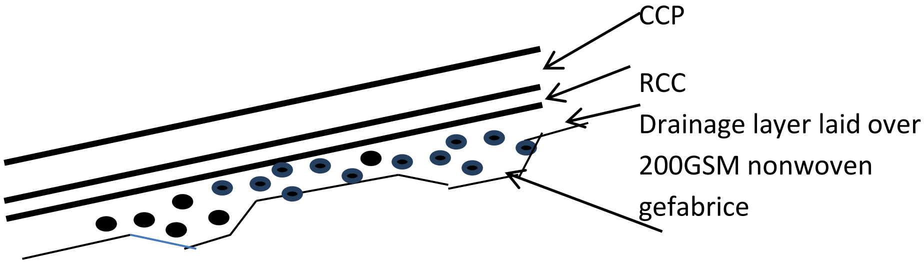

Figure 4 Transverse furrows at 25m intervals to intercept water along longitudinal slope

Other unique features of the project road:

It has following unique features.

1. There are series of curves including single curve, compound curve and reverse curve. The radius varies from 200m to as low as 16 m.There are summit curvesand valley curves also.

2. There are steep gradients, as steep as 6%, and mostly on curves. This attribute makes the construction operation very sensitive requiring special attention. The extreme precision was needed to make the paver negotiate such curves and gradients. The stakes of guide wire of sensors of the paver were installed as close as at two metres intervals instead of usual five metres interval (Figure 5) .

Figure 5Photo Showing Stakes of Guide Wire Installed at Closer intervals

3. Another difficult task was to match the levels of existing concrete pavement on the curvesat both ends with new pavement. The dowel bars were inserted in the existing pavement by drilling holes(Figure 6) and grouting the holes with epoxy resin in the annular space. The level as checked with 3-m long straight edge so that the level of existing and new pavements matched to ensure good ride quality. The newly built sections have fully merged with the existing pavement to provide a smooth ride.

Figure 6. Dowel Bar insertionin the Existing pavement and new pavement
to ensure Smooth ride quality

4. **Matching levels at 4 minor bridges:** There are 4 no. existing minor bridges. Holes of 40 mm dia were drilled in the deck slab at both ends and 32 mm diadowel bars were grouted by injecting epoxy resin in the annular space. Procedure described as above was followed and level of deck slab and newly cast panels was matched. Similarly there are two no of skew bridges. The same method was followed to pave on both sides of the bridge. Some acute angled panels were provided with 12 mm diameter reinforcement bars in two directions @ 150 mm c/c placed at 60 mm below the top to avoid cracking near the top for preventing ingress of water.
5. **Paving in Narrow ROW**: Due to high hill on Right Hand Side(RHS) and Ravine on Left Hand Side(LHS), the roadway width was as low as 10-12m. Since the pavement width was 8.5m,one side was paved with Slip Form paverand the remaining half had to be paved with semi-mechanical means. The tie bars were fixed by drilling holes in recently built pavement and epoxy grouting the ties(Figure 7). The matching of level of two halves was ensured during the construction.

Figure 7Fixing of Tie Bar with Epoxy Grouting

6. **Paving over drain**: A reinforced cement concrete drain was constructed on the hill sideto drain away the water. At a few locations such as chainage245.500 to 245.550,247.150 to 247.250,248.050 to 248.250,248.050 to 248.640 and 249.000 to 249.100, the side walls of the drain were designed to withstand the traffic load and the cover of drain was made up of reinforced cement concrete to bear the weight of traffic.
7. **Paving during rains:** The paving was a game of hide and seek with rains. The construction was done both in day and night as and when the rain had stopped.The Concreting was done by erecting movable tents to protect freshly laid pavements from unexpected rains.In two hoursof rain free interval, a minimum length of 50m could be laid by the paver..

8. **Bonding of RCC with cement concrete pavement(CCP) :**Another important feature is that RCC and CCPare bonded with the help of cement slurry to prevent slipping of the pavement along the steep longitudinal gradient. This will ensure monolithic behavior. The joints are provided in boththe layers and they are co-terminus..

9. **Mix design:** the mix design for RCC and cement concrete for pavement was done in-house by Engineers of Public works Department in its departmental laboratory using IRC:44[2]. The minimum design strengths of RCCis10 MPA at 7 days and that of cement concrete was 40 MPa at 28 days. Minimum 28 day flexural strength was 4.50 MPa. The cement contents for the two mixes were 165kg and 424.32 kg respectively. For the cement concrete a slump of 25±10mm at a water cement ratio of 0.37 could be obtained by adding water reducer. At the concrete production site, on random checking the slump was 38 mm while at the paving site, the slump was found to be 18mm.

10. **Sealing the joints:**The initialsaw cut for the transverse joints was made in the concrete pavement within 18 hours of casting and a thin coco-nut rope was inserted as temporary baker rod. The joints were then temporarily sealed with bitumen so as not to allow the joints to be filled with debris during the construction. Regular widening and joint sealing are proposed after the cessation of monsoon in mid-October

11. **Trial length:** The initial trials were made both for RCC and cement concrete pavements to work out all the logistics. Cores were taken from the trial lengths and they were found to be homogeneous and they possessed the necessary strengths. The slump valus also were within limits.Figure 8 shows laying of trial section.

Trail Length of RCC and CC pavement

Figure 8 Trial of laying of cement concrete

Sequential construction:

Subgrade: The existing sub grade was made up true to the profile where needed. It was properly watered and compacted with soil compactor. It was ensured that there are no soft spots in the subgrade. The designed superelevation and cross fall was provided in the subgrade itself.200gsm non-woven geo-fabric was provided just above the sub grade i.e. at the interface of sub grade and drainage layer. This acts as a filter cum separation layer and prevents the transgression of fine particles from sub grade into the drainage layer.

Sub surface drain with Perforated pipe: - The subsurface drain with perforated pipe was provided to drain off the water to the nearest culvertwherever the level does not permit for easy drainage of water along the side drain. The above drain has been provided for a total length of 1034 m.

Transverse furrow drain: The transverse furrows (Figure 5) were provided for the subgrade width with trapezoidal cross section of top width:300mm, bottom width:200mm and Depth:150mm at every 25m across the centerline of the road for full length of road. Excavation for furrow in subgrade is shown in Figure 9.

Figure 9 excavation of transverse furrow for drainage

Granular drainage layer: After spreadingnonwoven geo-fabric of 200 GSM over the subgrade, a 150 mm thick open graded drainage layer (DL)of granular materialmeeting the grading requirement of Table 1 was laid over the geo-fabric. The open graded DL is unstable for laying RCC. Hence after spreading and levelling with a grader, bitumen emulsionwas sprayed at the rate of 2.5 kg/sqm and 10mm aggregates were further applied androlled with the vibratory road rollers to obtain a stable platform for laying of roller compacted concrete.. The DL was compacted to 97% modifiedProtector’s density.

Table 1 Gradation of Granular Drainage Layer

Description of sample collected	IS Sieve size mm	Requirement of %age passing as per MORT&H specifications	Percentage by weight passing the IS sieve	
			Laboratory evaluated value	
The representation samples of the crushed stones of sizes 45 mm and D/s, 22.4 mm and D/s , 11.20 mm and d/s and fine aggregates are collected and mixed in different trial proportions and tested for its suitability for GSB Grading-IV material as per table 400-2 of MORT&H specifications	53	100	100	MDD = 2.41 gm/cc OMC = 5% P.I non plastic material Aggregates impact value = 11.86 Water absorption of coarse aggregates = 0.77 CBR = 57.9
	26.5	50-80	65.00	
	4.75	15-35	24.72	
	0.075	<5	2.69	

Roller Compacted Concrete(RCC): The RCC, also known as DLC[5](Dry Lean Concrete) was designed in house. The mix was prepared in a Batch mix plant and transported to paving site in tipping trucks, duly covered to prevent loss of moisture from the mix.

Figure 10 Showing the Laying of RCC at Km:246.720

This was laid with paver and compacted with vibratory road roller (Figure 10). Any deficiency was rectified in green concrete itself. The density was taken by sand replacement method. The RCC was water cured for 7 days. Cores were extracted to see the homogeneity. The DLC was laid in two haves due to space constraint; otherwise the construction traffic would have used the freshly laid DLC which was not desirable. After laying, the DLC surface was roughened with steel wire brushes to make the surface rough to ensure bonding with concrete. 7 days design cube strength of RCC varied from 10 to 13MPa. Figure 10 shows laying of RCC.Saw cut grooves of width 3 to 5 mm and depth 40-50 mm were made in RCC and filled with crumb rubber modified bitumen so that the cement slurry applied before laying of cement concrete does not bond the joints..

Cement Concrete Pavement(CCP) : Before the start of laying of CCP with Slip Form paver,cement slurry was sprayed on RCC surface in a length of 20 meter (Figure 11). This is essential to bond the CCP with RCC. The timing of spray is of great importance. It should not be more than 10 m advance of paver so that the slurry does not dry up. In that case will act not as a bonding agent but as a separation layer.

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Figure 11Applying Slurry Before laying of PQC

CCP was laid in half width i.e. 4.25 meter wide in one go. This paver is custom made. The manufacturing company was shown the site much before the paving started and therefore it could manufacture the paver of adequate dimension. The concrete was produced in **0.50 / 1.00C**um capacity batching plant. The temperature was lower than 30^{c}. The mix was carried to site in tipping trucks. The concrete was laid in front of paver. The average paving speed was 0.6 m / minute. The slump of each tipper was measured at loading site. The slump of concrete was also measured at paving site. At paving site it was around 20 mm and at production plant it was from

45 mm to 35 mm varying according to distance from paving site. The paving was done on ascending grade so as to prevent slipping down green concrete. At sharp curves the side forms of the SF paver cut the fresh pavement on inner side of curve. It was re-built by using shuttering planks. Wherever there was danger of edge slumping the shuttering planks were used for about one hour of paving. The auto-float behind the paver was adjusted to iron out all the surface irregularities .Any honeycombed spot was rectified by masons sitting on the work bridge. A burlap was tied to paver frame to soak bleeded water. The paver was equipped with automatic dowel bar inserter and tie bar inserter. Where ever tie bars could not be inserted automatically, the same were installed by drilling oversize holes and epoxy resin grouting.

Weather condition: The paving started on **12/4/2015** and was completed on 1**4/7/2015** in a length of 11.77 km. The road had to be opened to traffic without widening and sealing the transverse and longitudinal joint. This is planned be done in October -Nov 2015.The temperature in Shiridighat during intense summer never crossed 36°c. The relative humidity was never less than 20%. Wind velocity sometimes was more than 40 km/h. The paving activity was a game of hide and seek with rains. Whenever the rains permitted paving was done without caring whether it was day or night. Even minimum possible length 50 meter was also paved. A big water proof tent (Figure 12) was kept ready so that paving could be done even during drizzling so as to save the concrete from rain. Rain gauge was installed at site and maximum rainfall achieved was 195.10mm on 26-06-2015

Figure 12Temperary water proof Tent to C**CP**

Curing: The curing and texturing machine worked as soon as time was appropriate. Soon after transverse tining, curing compound was sprayed. After two hours or so of texturing a mist spray of water was applied so as to prevent rapid loss of surface water due to evaporation (Figure 13). Then pavement was covered with mobile tents for 3 hours, if paving was done during day. For night paving this covering was not required. After removing the mobile tents the surface was covered with wet paddy straw. This was kept wet for 21 days.

Figure 13Mist Spray of water to prevent drying

Provision of anchor beam: The anchor beam as shown in the Figure 14 was provided near bridges as shown in the sketch. The CCP was taken over the culverts but it butted against the deck slab of the bridge. It was provided with expansion joint on both sides of deck slab. Steel reinforcement at a depth of 60 mm from top was provided in all acute angled panels and valley curve of low radius.

Figure 14 Photo of anchor beams constructed at site

Quality Control: Cube compressive and flexural strength tests were done to judge the quality of work. The tests met the minimum strength requirement and the coefficients of variations were less than five percent for the cube tests and seven percent for the flexure test. Thus the quality control was reasonably good in spite of adverse site conditions. Alignment and position of dowel bars were checked by removing green concrete in one meter (half meter each side of dowel bars) and then restoring the concrete. Core were taken only when there was doubt of achieving designated strength as per norms set out in MORTH[5] Specifications.

Conclusion

The existing asphalt concrete roads in a hilly terrain with heavy rainfall needed continuous attention. It was decided to adopt cement concrete pavement (CCP) to avoid repeated reconstruction. The construction of CCP in a difficult hilly terrain with restricted space for construction was a challenge. Artesian condition due to high water table, steep gradient, limited land width and heavy rainfall caused immense difficulty. It was possible to address all the problems with innovative design and construction

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