ABSTRACT

Continuously Reinforced Concrete Pavement, CRCP is a concrete pavement that is reinforced with steel bars in the direction of traffic. CRCP is a durable pavement solution, advancement to plain concrete pavement. Reinforcement is used in CRCP, to tackle the problem of concrete slab cracking, instead of joints used in conventional plain concrete pavement. Joints are the weakest points of failure. On the other hand reinforcement provided in CRCP allows elimination of joints, and improves the strength and life of pavement. Maintenance is virtually eliminated in CRCP. It appears to have been first used in 1921 by the Bureau of Public Roads on the Columbia Pike in Arlington, Virginia. Reports on existing CRCP roads shows that they have surpassed their own design life.

CRCP is the most economical option for highways as its LCC is much lower, by about Rs 5 crore (~0.90 million euros) / Km (4 lane carriage way; 18 m wide) compared to that of flexible pavement as per the study conducted by INSDAG (INS/PUB/035). As per the present prevailing rates the LCC of CRCP is lower by more than Rs. 6 crore (~1.1 million euros) / km (4 lane carriage way; 18 m wide) compared to that of flexible pavement. The savings are mainly due to low maintenance, low vehicle operating cost. LCC of CRCP & JPCP (Jointed Plain Concrete pavement) pavements, considering the rates of Mumbai-Pune Expressway concrete pavement constructed in 1999 as well as present prevailing rates, shows that the CRCP pavement is marginally cheaper by about 3-4% compared to JPCP in addition to the advantage of much desired maintenance free service. CRCP is favourable compared to JPCP because life cycle cost of CRCP is slightly lower than JPCP and also the former offers jointless smooth riding surface.

KEYWORDS

CONTINUOUSLY REINFORCED CEMENT CONCRETE PAVEMENT / LIFE CYCLE COST / FUEL SAVING / VEHICLE OPERATING COST / DUABILITY / BETTER VISIBILITY

1. INTRODUCTION

Transport is a vital infrastructure for rapid economic growth of the country. Speedy transportation of natural resources (such as raw materials), finished goods and perishable materials to all parts of the country including the points of export outlets are basic inputs to economic growth. Recently there has been a major shift in transportation mode from Railways towards the Road sector in India.

Now a days about 60% of freight and 80% of passenger transport is met by Road transport in India. Transport infrastructure has found to be woefully inadequate to accommodate the growing needs of the steep rise of vehicles. Congestion, delays, waste of fuel, accidents and pollution have reached intolerable limits, which demonstrates the need for development of a good road network. Roads do more than mere providing connection between towns and villages. They pave the way for increased commerce, trade and prosperity. It is often said that a country pays for its roads whether it has them or not. It only pays more if it does not have them. Considering the importance of development of National Highways and Expressways for fast movement of goods and passengers, the Government of India has taken up and partly completed mega road development programs like Golden Quadrilateral, North-South and East-west corridor.
Since the investments in road building are very high, proper investigation needs to be made while choosing the type of pavement. One has to carefully exercise the choice, considering various factors such as traffic, environmental conditions, availability of materials, initial cost of construction, serviceability life of pavement, cost of maintenance, road user cost, resistance to overloading and life cycle costs. Fuel saving and vehicle operating costs also play an important role in deciding the pavement type. Out of the total commercial energy 20% is used in transport sector. Road sector is completely dependent on oil, which accounts for 80% of total fuel consumption. Any little amount of fuel saving is a huge benefit to the nation, because major portion of oil is imported.

Vehicle operating costs studies made in several countries including India show that rigid pavements offer fuel savings of 10 to 20% in comparison to flexible pavements. The savings in fuel is about 3 to 4 times of the total cost of pavement itself considering a life span of 30 years, which can be easily achieved without any major rehabilitation work as per the performance studied on reinforced concrete roads built world wide. Hence, any advantage of flexible pavement on account of low initial cost is not significant on life cycle costs.

Also the concrete’s white surface reduces the street lighting cost. Since, concrete road surface has light colour compared to asphalt pavement, the heat generation is lower. Cooler surfaces and air reduce the need for air conditioning, saving energy. Cooler air can also reduce air pollution by slowing the chemical reactions that produce pollution.

Institute for Steel Development and Growth (INSDAG) with its mission to provide and promote the cost effective and efficient designs has carried out a study to establish the techno-economic feasibility of adopting Continuously Reinforced Concrete Pavement for National Highway and Expressway projects in place of conventional flexible bituminous pavements and Jointed Plain Concrete Pavements. Based on this study Life cycle cost of CRCP for highways and expressways is much lower compared to flexible pavement and also marginally cheaper compared to JPCP. CRCP offers greater durability, structural strength, a smoother surface, and better visibility characteristics.

2. HISTORY OF CONCRETE ROADS

In India, concrete roads were built manually in pre-independence period at Hyderabad in 1928, at Chandni Chowk (Delhi) in 1936, and at Marine Drive Bombay in 1939. Cement concrete roads were constructed on Bangalore-Mysore route during 1950-55. Also single lane thin concrete pavements were constructed under sugar cane area scheme near the sugar cane crushing mills in Uttar Pradesh, where the truck movement is very high.

Concrete pavement is most versatile. It is used as sidewalks designed for a life of 5,10,20 and even 50 years, a range that far exceeds what is possible with any other type of pavement material. The commonly used concrete pavements are Jointed Plain Concrete Pavement (JPCP) and Continuously Reinforced Concrete Pavement (CRCP); the later one is being used widely due to virtually maintenance free service life.

2.1 Mumbai -Pune Expressway

Mumbai is the commercial capital of India and is growing significantly in size and population. So also Pune, the cultural capital of Maharashtra is growing into a major industrial and commercial centre. Hence, the importance of Mumbai - Pune road has increased tremendously. Due to the increase in the traffic every year resulting in jams, accidents, increase in travel time, has made it necessary to build a new and independent expressway. Jointed Plain Concrete Pavement was used in this expressway.

Salient Features of Expressway: India's first access controlled expressway having six lane concrete pavement
1. India's first six lane access control expressway
2. Speedy completion of work
3. Use of modern technology & machineries
4. Construction of expressway is done as per international standard
5. For safety of traffic compound wall / fencing is proposed on both side of expressway
6. Underpass / Overpass has been provided for the state highway and other road crossings
7. Ban on two wheelers, three wheelers and tractors vehicles
8. Provision of subways for villagers at every 300 to 500 meters distance.
9. Project is on Build - Operate - Transfer (BOT) basis
10. Government has given guarantee for raising of funds from financial institutions
11. Cranes are provided to lift and remove accident vehicles
12. Provision of petrol pumps / motels/ workshops etc.
13. Provision for 7000 trees plantation on both sides of expressway.
14. Five tunnels of international standards.

Benefits:
1. Reduction in Accidents
2. Savings in travel time
3. Savings in fuel consumption by vehicles
4. Economic development through speedy traffic
5. Reduction in pollution

CRCP has all the good qualities of JPCP in addition to the advantages of

- Jointless smooth concrete riding surface
- Has long term overall value even compared to JPCP – lowest LCC
- Reduces motorist and worker exposure to safety hazards since minimal maintenance and fewer repairs are required
- Is environmentally friendly construction

3. DEFINITION AND CHARACTERISTICS OF CRCP

Continuously reinforced concrete pavement (CRCP) is concrete pavement reinforced with continuous steel bars throughout its length. Its design eliminates the need for transverse joints (other than at bridges and other structures) and keeps cracks tight, resulting in a continuous, smooth-riding surface that is virtually maintenance-free. The whole idea of CRCP is based essentially on the "so-let-it-crack" philosophy rather than the difficult concept of avoiding cracks at any price. The principle in CRCP is to confine random cracking to acceptable spacings and crack widths so that the slab performs the same as if no crack exists, i.e. equal deflection at cracks and the midspan of the slab. In an unreinforced slab, cracks which occur will normally widen and get progressively worse under the effects of traffic and climatic conditions. During the contraction of the concrete fine dirt enters the wide cracks, leading to faulting, spalling and cracking and blow-ups develop, requiring extensive repairs and early surfacing to restore the smooth surface. The amount of reinforcement required to control the cracking is relatively smaller for shorter spans. As the length of the slab increases amount of steel needed also increases. However, the steel is not directly proportional to the slab length, as is usually assumed in the design of conventional jointed reinforced pavement. The steel requirement vs. the amount of steel is a parabolic function with the steel increasing at a progressively decreasing rate as the slab length increases and reaching a maximum at slab length of 180 to 240 meters. Beyond this the steel requirement does not increase.

In CRCP reinforcement steel is an important element and it offers the following functions:

- Holds cracks tight
- Facilitates load transfer across cracks
- Provides stiffness by restraining end movement
The implementation of CRCP will not only benefit the steel and cement industry but the nation will also gain a lot because it reduces the transportation costs drastically and minimizes the accidents on highways.

4. ADVANTAGES OF CRCP PAVEMENTS

CRCP is an asset for heavily traveled high-speed roadways. The excellent service of CRC pavements is reflected in the following significant operational features:

- Joint less concrete pavement, CRCP offers excellent smooth riding surface for the vehicles that maximizes the comfort for the passengers
- CRCP is more durable, which can last 40-50 years without much maintenance problem during the life of the pavement. Concrete actually hardens over time. After its first month in place, concrete continues to slowly gain about 20% strength in first 12 months.
- It needs minimal cost of maintenance and rehabilitation
- It minimizes the detrimental dynamic loads that are applied to the vehicles and pavement
- It offers best visibility. Concrete reflects light, which increases visibility and can save on street lighting costs. During summer riding over flexible pavement causes difficulties due to bitumen sticking to the tyres. Visibility also gets affected due to shining appearance of flexible pavement
- CRCP provides best traction grip there by leading to reduction in accidents – CRC pavements are easily "roughed up" during construction to create a surface that provides superior traction and reduced accidents. Ease in driving with reduced mental tension and overall improvement in quality of driving
- Air and noise environment improve along the thickly populated existing corridor. The noise level would reduce substantially
- Concrete can withstand even the heaviest traffic loads. There's no need to worry about ruts, shoving effects common with asphalt pavements
- Concrete's hard surface makes it easier for rolling wheels. Studies have even shown that this can increase truck fuel efficiency. Savings in fuel to the extent of 20%, may be considered ultimately reducing the vehicle operating cost
- Concrete roads facilitate increased speed and thereby savings in time and money. Almost maintenance free service reduces traffic disturbances and thus reduces man-hour loss to the road users

With the potential to accommodate any level of traffic, under climatic extremes, CRCP has a longer service life than roads made of other materials. This longevity is advantageous to road owners and drivers and can be the long-term answer to revitalizing today's highways and expressways as they reach the end of their service lives.

The following two basic types of concrete pavements and flexible pavement are designed and cost comparisons were made at initial direct cost and LCC basis to assess the economic benefits of CRCP over other pavement types.

1. Jointed un-reinforced or plain concrete pavements (JPCP)
2. Continuously reinforced concrete pavements (CRCP)

The life cycle cost analysis was made considering annual and major maintenance, fuel savings, early completion benefits in addition to initial direct cost consisting of materials, labour, equipment cost and interest during construction.
5. DESIGN ASPECTS

Due to relatively low tensile strength of cement concrete tensile strains are easily generated that are large enough to produce cracking. Cracking of concrete is a result of tensile stresses that are generated by moisture and temperature changes combined with vehicle axial loads that exceed the concrete tensile strength. The volume change stresses in CRCP will be taken care by providing sufficient reinforcement to keep the cracks tightly closed while maintaining adequate pavement thickness to counteract the stresses produced by wheel loads. CRCP allows the concrete to develop very fine transverse cracks that seem to be uncontrolled and random.

The spacings of transverse cracks that occur in CRCP is an important variable that directly affect the behaviour of the pavement. Relatively large distances between cracks result in high steel stresses at the crack and in excessive crack widths. A decrease in crack spacing reduces the steel stresses and crack widths. It is clear that crack spacing is directly related to steel stress and crack width.

Limiting Design Criteria: To determine levels of steel reinforcement for a CRCP, the limits on acceptable levels of crack spacing, crack width, and steel stress are established which minimize distress manifestations occurring in CRCP. The limiting levels are then used to estimate the required level of reinforcement, which will cause the pavement to adequately respond to anticipated environmental and vehicular loading conditions.

Crack Spacing: The limits on crack spacing are based on the possibility of spalling and punchouts. To minimize spalling the maximum spacing between consecutive cracks should be limited to 2.4 m. To minimize the potential of punchouts, the minimum desirable crack spacing is 1.1 m.

Crack Width: The limit on crack width is based on a consideration of spalling and water infiltration. The allowable crack width should not exceed 1.0 mm. The crack width should be reduced as much as possible through the selection of a higher steel percentage or smaller diameter reinforcing bars.

Steel Stress: The limiting stress of 75% of the ultimate tensile strength is recommended. AASHTO Design Nomographs and Equations are available for determining the percentage of longitudinal reinforcement to satisfy the criteria of crack spacing, crack width and steel stress respectively.

The optimum amount of steel reinforcement is selected in CRCP so that crack spacing lies between 1.1 m to 2.4 m, the crack width is less than 1 mm and steel stress does not exceed 75% of the ultimate tensile strength. CRCP allows the use of slightly smaller load transfer coefficient compared to JPCP. The maximum desirable crack spacing is derived from a correlation between crack spacing and incidence of spalling. A maximum crack spacing recommended for crack spacing is derived from consideration of effect of slab length on the formation of punchouts.

Steel Reinforcement: The amount and depth of longitudinal reinforcing steel are the most important aspects of steel reinforcement in CRC Pavements as it affects transverse crack spacing and control the width of the cracks. The longitudinal reinforcement in CRC pavement is used to control the fine transverse cracks that form due to volume changes in the concrete. The function of steel is to hold the random cracks tightly closed to provide structural continuity and to minimize the penetration of potentially damaging surface water and incompressible.

Longitudinal Reinforcing Bars: These are the main reinforcement in CRC pavement. The total area of longitudinal reinforcing bars required usually is stated as a percentage of the cross-sectional area of the pavement. The amount of longitudinal reinforcing bars generally used between 0.5% - 0.7% and it may be more where weather conditions are severe and also the temperature differentials are more. Transverse reinforcements are useful to support the longitudinal steel when the steel is preset prior to concrete placement. Transverse reinforcement may be of lesser grade.
Transverse Reinforcing Bars: The function of these bars is as follows:
To support the longitudinal bars and hold them at the specified spacing. When used for this purpose, the longitudinal bars are tied or clipped to the transverse steel at specified locations

To hold unplanned longitudinal cracks that may occur tightly closed. Causes of unplanned longitudinal cracking include late or shallow longitudinal joint sawing, improper installation of longitudinal joint inserts, and subbase or subgrade irregularities

Terminal Treatments: CRC Pavements can extend to any length till bridge structures or any other pavement obstructs them. The free end of the CRC pavement, unless restrained, can be expected to undergo outward movements of up to and sometimes exceeding 50 mm. Annual movements of up to 25 mm to 50 mm also can be expected. These movements can be either accommodated or restrained for protection of abutting installations.

The most widely used system of accommodation in current application involves the use of a wide-flange beam joint; the most widely used system of restraint involves the use of anchoring lugs.

Drainage: Proper management of both surface and subsurface water to reduce detrimental effects on pavements is essential to long-term good service, regardless of pavement type.

6. DESIGN STANDARD & TYPICAL DESIGN OF JPCP & CRCP

6.1 Design Standard

Indian Road Congress, IRC: 58 deals with design of plain concrete pavement & there is no Indian standard available for design of CRCP. In absence of Indian code, a well accepted AASHTO code and British design manual for roads and bridges has been used for design of thickness and reinforcement requirement of CRCP.

Design traffic influences the thickness requirement. Volume 7, Section 2, Part 3 of HD 26/94 of British code covers the design of various pavements. Thickness based on design traffic can be chosen from Fig. 2.4. Reinforcement can be evaluated as per the note on Fig. 2.4 of the same document. AASHTO design for thickness of pavement and reinforcement are very close to the values arrived as per British standard after making necessary corrections according to the publication of the University Transportation Center for Alabama, Tuscaloosa, Alabama, UTCA Project Number 99247 September 2000, for Concrete Pavement Performance in the Southeastern United States.

6.2 Design Parameters for Typical Design

Brief details of design and cost estimation of a typical 4 Lane (18 m wide) carriageway pavement has been presented below along with cost comparison of CRCP with JPCP and flexible pavement options. INSDAG’s publication “Life Cycle Cost Analysis and Techno-Economic Study for the use of Reinforced Concrete Roads for National Highways and Expressways” covers the detail design calculations for various traffic data.
The following design parameters are considered for design:

- **Design life**: 20 Years for Flexible Pavement  
  30 Years for Rigid Pavements
- **Traffic density**: 5000 Vehicles/day on 4-lane road
- **Concrete grade**: M40
- **Grade of steel**: Fe 415
- **Maximum temperature differential**: 21 °C (This is the maximum value between top and bottom of slab for whole of India as per IRC: 58)

**Difference between mean temperatures of the slab at the time of construction and coldest period**: 30 °C

### 6.3 Design of JPCP and CRCP Based on AASHTO'93

- **Traffic intensity**: 5000 Vehicles/Day
- **Commercial Vehicles**: 0.75 x 5000 = 3750 Vehicles/Day  
  (Assuming 75% of the Traffic Design Traffic for 4 Lane Divided Carriage Way 3750 x 0.50 = 1875 Vehicles/Day
- **Traffic at the end of 3 Year Construction Period**: 1875 x (1+0.075)^3 = 2329
- **Traffic at the end of 30 Year Construction Period**: 2329 x 365 x (1+0.075) / 0.075 = 99,245 Msa
- **Design Traffic**: 99,245 / 4 = 24.81 Msa
- **Design Wheel Load**: 9 t  
  (Corresponding to an axial load of 18 tonne for heavy traffic)

### 6.4 Thickness Design

The thickness of rigid pavement depends on the following parameters:

- Estimation of Cumulative Equivalent Standard Axles (CESA)
- Selection of reliability (Z_R)
- Overall standard deviation (S_o)
- Present serviceability index (P.S.I)
- Serviceability (\Delta P.S.I)
- PCC elastic modulus (E_c)
- PCC modulus of rupture (S_c)
- Load Transfer coefficient (J)
- Selection of drainage coefficient (C_d)
- Effective modulus of subgrade reaction (k)
- Initial serviceability index (p_o)
- Terminal serviceability index (p_t)

The design equation for rigid pavement is given by:

\[
\log W_{18} = Z_R S_o + 7.35 \log(D + 1) - 0.06 + \frac{\log([\Delta P.S.I]/(4.5 - 1.5))]}{1 + 1.624 \times 10^7/(D + 1)^{8.46}} + (4.22 - 0.32 p_t) \log \left[ \frac{S_c C_d (D^{0.75} - 1.132)}{215.63 J [D^{0.75} - 18.42 / (E_c / k)^{0.25}]} \right]
\]

Reliability Z_R 90% factor = 1.282

S_o Considered = 0.29

W_{18} = 38.52 x 10^6

LogW_{18} = 7.39

Assuming thickness of slab D as 300 mm (11.81 inch)

p_o = 4.5; p_t = 2.5; \Delta P.S.I = p_o - p_t; s_c' = 600 psi (4.14 N/mm^2); C_d = 1.0;
J = 3.2 for Plain Concrete Pavement & 2.9 for CRCP;
E = 5x10^6; k = 500

Substituting the above values in the formula given above the thickness assumed is just sufficient i.e. both sides the values are same.

Hence, thickness of the slab of plain jointed concrete pavement is 300 mm (11.81 inch). Using same procedure with j value as 2.9 for Continuously Reinforced Concrete Pavement, reduces the thickness requirement from 300 mm to 285 mm. Therefore 15 mm thickness can be reduced if we adopt CRCP technique considering slightly favourable load transfer coefficient.

It may be noted that as per UTCA project no. 99247 - September 2000, on concrete pavement performance in the South Eastern United States AASHTO’93 designs are closer to actual thickness for JPCP (3% lesser to 5% more on average), but 19% to 22% higher for CRCP on average accordingly for 300 mm thickness of JPCP pavement equivalent CRCP thickness shall be (285x (1-0.19)) = 231 mm, which is very close to design based on British standard and hence it may be concluded that results based on British standard are more appropriate for cost comparison. Accordingly the conclusions are made based on British code results.

6.5 Design of JPCP and CRCP as per British Standard HD26/94 February 1996:

As per British Standard -HD26/94 Volume 7 Section 2 Page 2/6 dated February 1996 (Fig.2.3 Design Thickness for Rigid Pavements) the equivalent design traffic (msa) corresponding to 300 mm PQC thickness of Jointed Concrete Pavement with 500 mm^2/m longitudinal reinforcement (Nominal Steel) shall be 320. Accordingly for 320 million standard axles the PQC thickness in CRCP shall be taken from Fig.2.3 Design Thickness for Continuous Rigid and Rigid Composites shall be 250 mm. Hence, it may be concluded that 300 mm thick JPCP can be replaced with 250 mm thick CRCP a reduction of 50 mm concrete thickness approximately equal to 16.7% is permitted. This looks to be reasonable since many states in USA allows 20% reduction in CRCP thickness compared JPCP.

6.6 Calculation of Reinforcement

\[ P = \frac{1.062[(1 + f_t / 1000)^{1.457} (1 + \alpha_s / \alpha_c)^{0.25} (1 + \phi)^{0.476}]}{(X)^{0.217} (1 + \sigma_w / 1000)^{1.13} (1 + 1000Z)^{0.389}} \]

P is amount of longitudinal steel
\( X \) is the crack spacing in ft
\( f_t \) is the indirect tensile strength in psi
\( \alpha_s / \alpha_c \) is the thermal coefficient ratio
\( \phi \) is the reinforcing bar diameter in inch
\( \sigma_w \) Wheel load stress in psi
\( Z \) is the concrete shrinkage at 28 days

\[ X = \frac{1.32[(1 + f_t / 1000)^{6.70} (1 + \alpha_s / 2\alpha_c)^{1.15} (1 + \phi)^{2.19}]}{(1 + \sigma_w / 1000)^{5.20} (1 + P)^{6.60} (1 + 1000Z)^{1.79}} \]

Given the crack width, CW; the percent of steel can be computed by

\[ P = 0.358[(1 + ft / 1000)^{1.435} (1 + \phi)^{0.484}]/(CW)^{0.220} (1 + \sigma_w / 1000)^{1.079} - 1 \]

Given the steel stress, the percent of steel can be computed by

\[ P = \frac{50.834[(1 + DT_D / 1000)^{0.155} (1 + ft / 1000)^{1.493}]}{(\sigma_s)^{0.365} (1 + \sigma_w / 1000)^{1.146} (1 + 1000Z)^{0.180} - 1} \]

\[ N_{min} = 0.01273P_{min}W_sD/\phi^2 \]
\[ N_{max} = 0.01273P_{max}W_sD/\phi^2 \]
As per AASHTO the limits on crack spacing are based on the possibility of spalling and punchout. To minimize spalling, the maximum spacing between consecutive cracks should be limited to 2.4m. To minimize the potential for punchout, the minimum desirable spacing is 1.1m.

Assuming crack spacing as 1067 mm (3.5 feet) & Crack width as 1 mm
Diameter is 16 mm (≈ 5/8 inch) or bar 5; Grade of steel = Fe 415 (≈ 60000); \(\frac{\alpha_s}{\alpha_c} = 1.32\); Concrete shrinkage at 28 days = 0.0004 inch/inch; Tensile stress due to wheel load = 230 psi (1.59 N/mm²); Concrete tensile strength at 28 days = 550 psi (3.8 N/mm²);
\[
P = 0.358 \left(1 + \frac{550}{1000}\right)^{1.435} \left(1 + \frac{5}{8}\right)^{0.484} \left(\frac{1}{25.4}\right)^{0.226} \left(1 + \frac{230}{1000}\right)^{1.079} - 1 = 0.38\%
\]
Substituting the above values the percentage of steel shall be 0.38%;

Accordingly 0.5% of reinforcement is provided in the concrete slab.

Area of longitudinal steel required = 0.5 x 285 = 14.25 cm²

Therefore longitudinal steel shall be 16 mm diameter TMT steel @ 140 mm c/c & distribution steel - 12 mm @ 600 mm c/c.
Longitudinal steel provided = 1000x2.01/140 = 14.37 cm²
Transverse steel provided = 1000x1.13/600 = 1.89 cm²
Total reinforcement required = 14.37+1.89 = 16.26 cm²
Weight of reinforcement = 16.26 x 0.785 = 12.76 kg
Weight of reinforcement for 18 m wide slab = 18 x 12.76 kg = 230 kg
Weight of reinforcement required for 18 m wide 1 km length slab = 230 tonnes
Add 5% for lapping, cutting allowances etc. = 0.05 x 230 = 11.50 tonne
Total reinforcement required for 1 km length 18 m wide CRCP = 241.50 tonnes

6.7 Quantity of Reinforcement

The design calculations presented above indicate that the longitudinal reinforcement required in CRCP is in the order of 0.5% to 0.6% of cross sectional area of concrete slab. The total reinforcement requirement including transverse reinforcement will be around 0.7%. Longitudinal reinforcement of 16 mm dia. TMT bars @ 125mm to 150mm c/c and transverse reinforcement of 12 mm dia. TMT bar @ 600 mm c/c may be adequate for a typical CRCP designed for 30 years life. The total reinforcement required for 1km length 4-lane carriageway (18 m wide) would be around 250 tonnes.

The design results of different pavement options for a typical design have been reproduced in Table 1.

### Table 1: Comparison of Different Types of Roads for Highways

<table>
<thead>
<tr>
<th>Item</th>
<th>Conventional Bitumen</th>
<th>Plain Concrete Road (JPCP)</th>
<th>RCC Road (CRCP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total pavement thk. (mm)</td>
<td>800</td>
<td>675</td>
<td>625</td>
</tr>
<tr>
<td>Grade of Concrete</td>
<td>M40</td>
<td>M40</td>
<td>M40</td>
</tr>
<tr>
<td>Spacing of contraction joints</td>
<td></td>
<td>4.25 m</td>
<td></td>
</tr>
<tr>
<td>PQC – Thk. mm</td>
<td>---</td>
<td>300</td>
<td>250</td>
</tr>
<tr>
<td>Steel reinforcement</td>
<td>Only at joints- Occasionally thin mesh in top surface</td>
<td>0.69% Long—16 mm @ 130 mm c/c Trans—12 mm @ 600 mm c/c</td>
<td>0.57% Long—16 mm @ 140 mm c/c Trans—12 mm @ 600 mm c/c</td>
</tr>
<tr>
<td>---------------------</td>
<td>------------------------------------------------------</td>
<td>---------------------------------------------------------</td>
<td>-----------------------------------------------------</td>
</tr>
<tr>
<td>Durability</td>
<td>Poor (5-6 yrs)</td>
<td>Long (&gt;30 yrs)</td>
<td>Long (&gt;30 yrs)</td>
</tr>
<tr>
<td>Saving in Fuel</td>
<td>---</td>
<td>10 – 20%</td>
<td>10 – 20%</td>
</tr>
<tr>
<td>Maintenance</td>
<td>High</td>
<td>Less</td>
<td>Very less</td>
</tr>
<tr>
<td>World experience</td>
<td>Poor performance</td>
<td>Good reports</td>
<td>Very good reports. Belgium, USA &amp; many countries successfully used CRCP. In USA 45000 km in USA; All states have started using CRCP.</td>
</tr>
<tr>
<td>Construction</td>
<td>Easy</td>
<td>Special care needed</td>
<td>More special care needed</td>
</tr>
<tr>
<td>Expertise in the country</td>
<td>Very large</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Corrosion Problem</td>
<td>No</td>
<td>Reinforcement at joints needs periodic protection</td>
<td>Joints are practically eliminated. Cracks do not propagate due to reinforcement. No corrosion problem.</td>
</tr>
</tbody>
</table>

7. LIFE CYCLE COST ANALYSIS

Life Cycle Cost Analysis (LCC) of pavement includes not only present and future maintenance and rehabilitation costs, but also related costs such as vehicle operation, vehicle maintenance, delays and interest during construction and loss of revenue through road closure and long construction period etc.

The following main costs are calculated for all the 4 options mentioned above:

Initial Direct Cost: The initial direct cost consists of materials, labour for constructing the road including design cost and interest on capital during the construction period.

Maintenance: Maintenance costs for a concrete pavement are negligible. Nominal regular maintenance cost of Rs. 5000/ per km has been considered apart from joint sealing cost. The concrete roads can stand more than 40 years without any major repair and hence there will not be any major repair in 30 years life considered. Joint sealing at every five years has been considered in case of JPCP. Flexible Pavement suffers deformations, rutting and weathering. Major maintenance will be required after every 5 years apart from regular maintenance. Hence the maintenance cost of road after 5, 10 & 15 years from the commissioning has been worked out.

Fuel Saving: The concrete roads, which are rigid pavements, save fuel of loaded trucks plying upon them. Heavier the trucks, more is the saving. This fact was first documented in USA, by the Federal Highway Administration (FHWA) after trials carried out by them in 1982 while comparing the fuel consumption by load carriers on different types of pavements. A saving of upto 20% fuel was obtained on concrete roads by FHWA. Similar experiments were carried out in India first in 1992 and again in March 1997. The trials carried under the supervision of Central Road Research Institute, CRRRI, New Delhi and the results confirm the findings of FHWA. The fuel cost, about 21% is one of the major components of vehicle operating cost (VOC) and any reduction in fuel consumption contributes larger savings in overall VOC of trucks and other vehicles.

Construction Period: Any reduction in construction period facilitates the fast all-round development of that area and also helps to reduce interest during construction, generate revenue from toll
charges and fuel savings etc. Fast track construction is possible in case of rigid pavement. This helps to save interest burden during construction and to generate revenue from toll charge etc.

8. COST COMPARISON

Both initial direct cost and life cycle cost of all the three options namely plain concrete, continuously reinforced concrete and flexible pavement were calculated based on the assumption that escalation/ inflation rate will remain constant at 7% per annum and annual interest rate at 8% for the 30 years period of LCC analysis, though Planning Commission has given this projection for the next 5 years. Unit rates considered for estimation of pavement cost has been shown in Table 2. Summary of cost items for the various rigid pavement & flexible pavement options (Cost of 1km length road of 18m wide-4lanes) were indicated in Table 3.

<table>
<thead>
<tr>
<th>SL</th>
<th>Material</th>
<th>Units</th>
<th>Rate (Rs.)</th>
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<tbody>
<tr>
<td>1</td>
<td>Pavement Quality Concrete (PQC)</td>
<td>Cum</td>
<td>4000</td>
</tr>
<tr>
<td>2</td>
<td>Reinforcement Steel – Basic cost</td>
<td>Tonne</td>
<td>21000</td>
</tr>
<tr>
<td>3</td>
<td>Extra for corrosion resistant property</td>
<td>Tonne</td>
<td>800</td>
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<tr>
<td>4</td>
<td>Reinforcement cost in RCC</td>
<td>Tonne</td>
<td>28893</td>
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<tr>
<td>5</td>
<td>Dry lean concrete (with &amp; without fly ash)</td>
<td>Cum</td>
<td>2400</td>
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<tr>
<td>6</td>
<td>Drainage layer (DL)</td>
<td>Cum</td>
<td>1000</td>
</tr>
<tr>
<td>7</td>
<td>Granular sub base (GSB)</td>
<td>Cum</td>
<td>850</td>
</tr>
<tr>
<td>8</td>
<td>Wet mix macadam (WMM)</td>
<td>Cum</td>
<td>1400</td>
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<tr>
<td>9</td>
<td>Water bound macadam (WBM)</td>
<td>Cum</td>
<td>900</td>
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<tr>
<td>10</td>
<td>Dense bituminous macadam (DBM)</td>
<td>Cum</td>
<td>4000</td>
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<tr>
<td>11</td>
<td>Bituminous concrete (BC)</td>
<td>Cum</td>
<td>4500</td>
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<tr>
<td>12</td>
<td>Premier granular layer</td>
<td>Sq.m</td>
<td>16</td>
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<td>13</td>
<td>Track coat on primed granular layer</td>
<td>Sq.m</td>
<td>10.00</td>
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<tr>
<td>14</td>
<td>Track coat on bituminous layer</td>
<td>Sq.m</td>
<td>5.00</td>
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<table>
<thead>
<tr>
<th>Item of Cost</th>
<th>Flexible</th>
<th>JPCP</th>
<th>CRCP</th>
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<tbody>
<tr>
<td>Material &amp; Labour</td>
<td>281.03</td>
<td>355.27</td>
<td>373.61</td>
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<tr>
<td>Interest during Construction</td>
<td>23.08</td>
<td>14.21</td>
<td>14.94</td>
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<tr>
<td>Initial Direct Cost</td>
<td>304.11</td>
<td>369.48</td>
<td>388.56</td>
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<td>Extra in Direct Initial Cost over Flexible</td>
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<td>65.37</td>
<td>84.44</td>
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<td>Percentage of initial direct cost</td>
<td>100%</td>
<td>121%</td>
<td>128%</td>
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<tr>
<td>Extra in VOC over Flexible</td>
<td>605.78</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>Maintenance Cost</td>
<td>126.15</td>
<td>32.50</td>
<td>1.30</td>
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<tr>
<td>Revenue due to early Completion</td>
<td>--</td>
<td>33.39</td>
<td>33.39</td>
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<tr>
<td>Total Life Cycle Cost</td>
<td>1036.05</td>
<td>368.59</td>
<td>356.47</td>
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<tr>
<td>Saving in LCC w.r.t. Flexible</td>
<td>667.45</td>
<td>679.58</td>
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<tr>
<td>Percentage of total LCC cost</td>
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<td>64%</td>
<td>66%</td>
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<tr>
<td>LCC Without considering fuel saving</td>
<td>430.27</td>
<td>355.27</td>
<td>373.61</td>
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</tbody>
</table>
9. CONCLUSIONS

- Continuously Reinforced Concrete Pavement, CRCP is the most desirable rigid pavement considering its lowest LCC Cost. As per the present prevailing rates, CRCP is most economical option for highways as its LCC is much lower, by about Rs 6 crore (~1.1 million euros) / Km (4 lane carriage way; 18 m wide) compared to that of flexible pavement and compared to plain concrete, its LCC is lower by Rs 12.12 lac (~22440 euros). However, the same may vary depending on actual rates prevailing at the time and location of actual commissioning of work.
- These savings will be much higher for 6 and 8 lane carriageway
- CRCP saves fuel & money: The major part of the benefit (about 80%) in respect of rigid pavement over flexible is on account of well-established fuel saving and substantial saving in vehicle operating cost comprising reduced consumption of fuel, lubricants and vehicle maintenance cost.
- Excellence Qualities: CRCP provides all the attributes a roadway designer seeks: Strength, Durability, Smoothness, Traction, Very Low Maintenance, Long Life and Low Life Cycle Costs. Further, it offers much better riding quality, less dislocations to traffic movement.
- Thermo mechanically treated, TMT bars are desirable for CRC Pavement. Corrosion resistant TMT bars may be used in corrosion prone areas.

ACKNOWLEDGEMENTS

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