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Examining codes and practices for reducing pavement quality concrete thickness

By an analyst

This paper addresses the point raised by some engineers that our concrete pavements thickness are over designed. Those arguing in favor of reduced thickness, cite data from abroad and point out that such high thickness as 300 mm or so being prescribed in various tenders are not used in developed countries, especially in European countries. Their expectation is that if pavement quality concrete thickness reduces, the cost of road construction would also reduce resulting in more contracts for concrete roads.

This analyst studied the current design codes and consulted references for understanding various practices to find out whether there is indeed any scope for reducing PQC thickness. The reduction is possible only if certain basic changes are introduced in design calculations, construction practices and discipline in loading of commercial vehicles such as trucks and trailers. The author however cautions that any relaxation in design practice must be accompanied by a concomitant responsibility, because poor construction practices by petty contractors could affect concrete road performance. The author proposes an innovative tendering that includes design, construction and performance guarantees as contractors' responsibility, rather than constructing to a given design.

As road construction gains momentum, engineers in construction companies in India are seeking avenues for economy and are questioning the basis for designing concrete roads, which some say leads to a higher pavement thickness. They would like to see an increased share of cement concrete roads in our road construction projects. However, a higher first cost of concrete roads over bituminous alternative blocks the latter's large-scale construction. To explore the options of cost reduction, construction companies would like to understand whether the pavement thickness prescribed in Indian tenders could be reduced. Those advocating reduced thickness feel that design safety margin practiced in India is high. To buttress their point, they cite examples of lower pavement thickness in foreign countries, particularly in European countries

With this in view, this paper discusses the guidelines for design of concrete roads following IRC: 58-2002 with respect to axle loads, temperature differential data for day night temperatures, modulus of sub-grade reaction, combination of stresses due to load and temperature. Assumptions about wheel loads for design purposes and methods of estimating flexural strength of concrete are also discussed. The effect of modern equipment for concrete manufacture and aging of concrete are also considered for discussions. Owing to the limited purpose of this paper, procedure and design of concrete road have been excluded from this discussion. Readers can find the design procedure in IRC: 58-2002.

Guideline for design of concrete roads:

IRC: 58 -2002 prescribes current methodology for PQC thickness design. According to this, axle load is one of important inputs to the design calculation. The code specifies vehicle axle load limits as 10.2, 19 and 24 tons for single axles, tandem axles and tridem axles respectively.

The loads applied by single as well as tandem axles cause maximum flexible stresses when the tyre imprint touches the longitudinal edge of the pavement. Therefore, edge load stresses are important for design purpose. However, an interesting situation develops when comparing tandem axle and single axle; tandem axles carry twice the load of single axles, but they cause flexural stresses that are about 20% lower than that of the single axles load because of superposition of negative bending moment due to one dual wheel load over the other. This means that if the vehicle population with single axles reduces, pavement thickness could be reduced. If more vehicles with tandem and tridem operate, stress due to load would be lower in pavements and so would pavement thickness. With so many varieties of modern vehicles now available in India, a suitable axel load survey is needed to estimate the share of various types of axles and their damaging power.

Temperature differential data for day night temperatures

Temperature related stresses in pavements are the second most important stresses in designing the concrete roads. The difference in day and night temperatures (diurnal) gives rise to warping of slab due to temperature differential between the top and bottom. The temperature gradient across pavement of about 250 mm thick is not constant and measurements indicate that the difference between the top and mid -depth is almost twice of that between the mid depth and the bottom of the slab when the surface temperature is highest. As a result, the bending process sets up internal stresses and these tend to increase the restrained warping stress at the top of the slab and decrease it at the bottom.

IRC: 58-2002 suggests that data on temperature differential at the pavement construction site be used for computation of thermal warping. In prescribing design methodology, the specification assumes that designers would collect the necessary data. Only when such a data cannot be organized, the temperature differential data suggested by CCRI is to be used. The CRRI's own data for the recommended temperature differentials for different parts of the country was generated more than 25 years ago.

In the light of the need to review pavement thickness design, perhaps it is time to revalidate the data with modern temperature probes and techniques for greater accuracy. Needless to say that a higher value of temperature differential would tend to overestimate the pavement thickness.

The guideline for road design proceeds further to suggest that stresses may be computed assuming linear temperature variation across the depth using Bradbury's approach. However, studies in India and abroad indicate that the temperature gradients in concrete pavements are non-linear and the warping stresses given by Bradbury's formula may overestimate the stress. This factor also contributes to increasing the PQC thickness.

Further, in India, it is safe to suggest that temperature gradient is highest only during summer months in the afternoons and the volume of traffic of commercial vehicles is low during this period of the day. Therefore, chances of occurrence of combination of load and temperature related stresses acting on the pavement at such times may be well below computed stress levels. Further, the IRC: 58-2002 says that the total of thermal warping and wheel load stresses is generally lower than the simple algebraic addition. In the design calculation, therefore, the cumulative effect of this results in over designing the PQC thickness.

Modulus of Sub-grade Reaction

The modulus of sub-grade reaction k gives strength of soil sub-grade on which the road is to be constructed. This measurement is carried out by plate bearing tests and deflection of the foundation soil is found out by applying load on a plate of 75cm. IS : 9214-1974 gives details in this regard. The concrete pavements design uses deflection of 1.25 mm to find out k from the pressure

Table 1. k values from the California Bearing Ratio (CBR) test [1]

Soaked CBR, %	2	3	4	5	7	10	15	20	50	100
k-value, $kg/cm^2/cm$	2.1	2.8	3.5	4.2	4.8	5.5	6.2	6.9	14.0	22.2

sustained at this deflection. Table 1. gives an estimate of k values from the California Bearing Ratio (CBR) test

If owing to the requirement of the design guideline, sub base is laid over sub-grade, the effective k values increase. This increase is more with cement treated granular layers than with untreated granular layers and is influenced by the thickness of the granular sub base layer as well. IRC: 58-2002 provides details in this regard.

The author has used a software to calculate minimum pavement thickness required for a range of modulus of sub-grade reaction value -k. Although the sub grade k values increase from 8 $kg/cm^2/cm$ to 40 $kg/cm^2/cm$ and the pavement thickness increases (from 230 mm to 295 mm), the rise takes a sinusoidal path. In ranges of 6-10 and 20-30 k values, the sensitivity of change in pavement thickness is higher than in other ranges. It is therefore necessary that in these ranges k value is correctly used to avoid any design error.

This in turn makes it imperative that CBR value of the soil sub-grade be measured following the relevant specification and guidelines. In most road contracts, contractors are not involved in these measurements. The tenderer specifies and the contractor constructs. To avoid over design, the system may have to be modified to permit contractors' involvement.

Wheel load

Wheel load of the commercial vehicles is half of the axle load. For the axle load of 10.2 tons, which is the permissible axle load in India for single axles, therefore the wheel load is 5.1 tons. However, stresses due to single axles are higher compared to tandem and tridem axles. Therefore, the pavement designs should be based on the wheel loads of single axles. However, in place of using the 5.1 tons as the wheel loads, designers use higher values for wheel loads. In fact, a Load Safety Factor (LSF) is applied to the selected design wheel load. This is done to account for the over loading resorted by the truck operators to maximize their profits.

Designers should find out the extent of overloading for their stretch of the proposed road and the traffic rules' enforcement authorities need to counsel erring truckers against overloading. The extent of overloading can be determined and included in the fatigue analysis. Application of LSF then may not be necessary. If a reasonable wheel load value is used, the designed pavement thickness would be lower than what is obtained by assuming the higher loading using LSF.

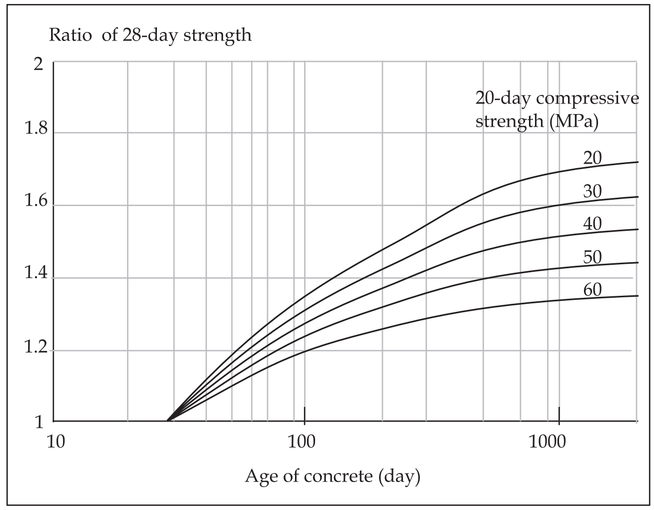

Figure 1. Relationship between age and compressive strength for pavement quality concrete [2]

Advantage of concrete shoulders

When concrete shoulders are provided, the edge stress on the main carriageway is lower than that without concrete shoulders. This can be taken advantage of by reducing the edge stress. Portland Cement Association (PCA) provides details in this regard.

Formula for estimation of flexural strength of concrete:

Flexural Strength of concrete is used for designing the concrete roads. A higher flexural strength would mean thinner pavement design. Although flexural strength can be measured using prism casts of concrete, for want of elaborate arrangement at site, generally, compressive strength of concrete is measured using concrete cubes and then flexural strength is calculated using formulas.

The IRC:58-2002 illustrates flexural strength calculation using formula as per IS 456-2000 which is

$$f_{cr} = 0.7\sqrt{f_{ck}}$$

where,
f_{cr} = flextural strength (modulus of rupture) N/mm^2
f_{ck} = characteristic cube compressive strength, N/mm^2

Table 2. Effect of age on compressive strength and the modulus of rupture of concrete made with gravel and crushed rock aggregates [3]

Age of concrete	F_e	M_R		F_e	M_R		F_e	M_R		F_e	M_R		F_e	M_R		F_e	M_R	
		CR	G		CR	G		CR	G		CR	G		CR	G		CR	G
28 days	10.0	1.80	1.74	20.0	2.93	2.55	30.0	3.89	3.18	40.0	4.76	3.73	50.0	5.51	4.21	60.0	6.32	4.66
40 days	11.0	1.93	1.84	22.1	3.14	2.69	32.9	4.15	3.35	43.5	5.05	3.90	53.8	5.86	4.39	63.6	6.59	4.81
3 months	13.3	2.20	2.03	26.5	3.57	2.97	38.4	4.63	3.64	50.4	5.59	4.23	61.8	6.46	4.73	71.1	7.12	5.11
6 months	14.7	2.36	2.15	29.4	3.84	3.15	42.5	4.97	3.85	55.0	5.95	4.44	65.8	6.75	4.90	75.6	7.43	5.29
1 year	15.9	2.50	2.24	31.8	4.06	3.28	45.8	5.23	4.01	58.6	6.22	4.60	69.0	6.97	5.03	78.3	7.62	5.39
2 years	16.6	2.57	2.30	33.3	4.19	3.37	48.0	5.41	4.12	61.0	6.39	4.70	71.3	7.14	5.12	79.5	7.70	5.44
3 years	17.0	2.62	2.33	34.0	4.25	3.41	48.6	5.46	4.15	61.6	6.44	4.73	72.0	7.19	5.15	79.8	7.67	5.45
4 years	17.2	2.64	2.35	34.4	4.28	3.43	48.7	5.47	4.15	61.8	6.46	4.73	72.3	7.21	5.16	80.1	7.74	5.46
5 years	17.3	2.65	2.35	34.5	4.29	3.44	48.9	5.48	4.16	62.0	6.47	4.74	72.3	7.21	5.16	80.1	7.74	5.46

F_e = Compressive strength; M_R = Modulus of rupture; CR = crushed rock; G = gravel. (all units N/mm^2)

However, the IRC: 15-2001 gives the following formula

$$F_r = \frac{F_c - 2.58}{7.63}$$

where
F_r = Flexural strength, N/mm^2
F_c = the compressive strength, N/mm^2.

A lower flexural strength is obtained using the IRC: 58-2002 formula. The variation in flexural strength between formulae could be as much as 10%. A higher flexural strength means reduced design pavement thickness. This is yet another example to over estimate the thickness of the concrete pavement.

Strength improvement with aging of concrete

Strength of concrete keeps on increasing with time and 90-day strength would be about 10% higher than the 28-day strength. Effect of age on compressive strength and modulus of rupture presented in Figure 1 and Table 2 respectively. They show the long-term variation of strengths with time for PQC. The data presented covers a period of 5 years.

According to IRC: 58-2002, concrete roads are designed for a period of 30 years. However, design calculations, use 28-day flexural strengths. Those interesting in exploring reduced pavement thickness options question the rationale behind using 28 day strength because road projects are seldom opened to traffic in 28 days. For 90-day strengths, a gain of 10% in modulus of rupture is possible. Using 90-day strength would reduce the design thickness of PQC.

Concrete mix design and requirement of minimum cement content

With the advent of the state-of-the-art equipment for batching, mixing, placing and curing concrete in the country, construction companies are now in a position to follow a strict regime for quality control and deliver consistent quality concrete required for pavement construction. The site mixed concrete still being used on some sites does not offer this level of quality assurance. Therefore, newer plants need not have a large safety margin in the mix design.

IRC: 58-2002 suggests 4.5 MPa flexural strength for pavement design. However, by resorting to concrete mix design and under certain conditions, it is possible to achieve higher strength concrete than is required by the design. Use of admixtures both mineral and chemical increase concrete strength without increasing the cement content. Although such a mix could result in concrete with higher flexural strength, the current practice of tendering do not allow contractors to take advantage of this improvement to reduce PQC thickness. Data in Table 3 is from Mumbai Pune Expressway project. The average value of the 28-day compressive strength ranged from 43.98 MPa (Section B) to as high as 72.17 MPa (Section D) and the 28-day flexural strength ranged between 4.88 (Section C) to 6.90 MPa (Section D). But

Table 3. Average compressive and flexural strengths of PQC and standard deviations in the different sections [4]

	Section A	Section B		Section C		Section D			
	Mix I	Mix I	Mix II	Mix I	Mix II	Mix I	Mix II	Mix III	Mix IV
Compressive strength, MPa									
7-day	35.26	34.32	35.67	40.25	38.39	49.08	48.58	42.93	39.31
28-day	46.04	43.98	45.29	51.13	49.55	72.17	64.24	62.24	60.23
90-day	52.84	51.79	52.41	57.32	59.04	N.A.	N.A.	73.65	N.A.
Flexural strength, MPa									
7-day	4.17	4.22	4.39	4.03	3.81	5.38	4.81	4.71	4.43
28-day	5.24	5.16	5.67	4.89	4.88	6.90	6.53	6.38	6.30
90-day	6.54	6.12	6.64	5.77	5.67	7.66	7.42	6.97	N.A.
Standard deviation, MPa									
7-day	2.96	1.50	1.46	2.67	0.75	3.90	3.02	3.37	1.18
28-day	3.26	1.63	2.30	1.66	0.72	3.93	1.92	2.42	1.23
90-day	3.03	1.92	1.16	1.90	2.00	N.A.	N.A.	1.62	N.A.

the contractor could not take advantage of this flexural strength.

From the above it clear that there are several parameters in the design steps that give margins to pavement designers in estimating pavement thickness and are surely conservative in nature. To remedy this situation, however contractors would have to prepare themselves to undertake detailed measurements and carefully select design parameters. Introducing tenders with design and construction in the contractor's scope of work could help achieve this objective. Of course, contractors would have to support their design and construction with performance guarantees.

Conclusion

Of late, there is a demand for examining the details of concrete pavement design with a view to reducing pavement thickness. A design check has been made with respect to some important parameters and it has been found that there are several parameters that have the potential to lead a designer to a higher PQC thickness. However, one of the ways to remedy this situation would be to include design in pavement contractors scope of work, along with construction. The contractors would have to support their design and construction with a performance guarantee. This is necessary to avoid poor construction practices and unsatisfactory performance from concrete roads.

References

1. ______*Guidelines for the design of plain jointed rigid pavements for highways*, Table 2, IRC 58-2002, The Indian Roads Congress, New Delhi.
2. Croney, David and Croney, Paul, *Design and Performance of Road Pavements*, McGraw Hill, New York, Figure 14.1, p. 224.
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4. Momin, S.S., Bongirwar, P.L. and Kulkarni, V.R., Rigid Pavement Construction Technology for Mumbai-Pune Expressway, *Journal of The Indian Roads Congress*, September 2005, Vol. 66-2, pp. 213-243.