VARIATIONS DUE TO TEMPERATURE ON MODULUS OF RUPTURE OF CONCRETE AND PAVEMENT THICKNESS

[1] Sara Jabeen, [2]Paramjeet Singh
[1]M.Tech Scholar, 2Assistant Professor at GEC Panipat
[1]Civil Engineering Department
1Kurukshetra University,Haryana,India

Abstract : Modulus of rupture is the measure of the tensile strength of an unreinforced slab or concrete beam to resist failure. In order to know the quality of concrete work done, Modulus of rupture is very useful in determining the same. Usually Flexible pavements are preferred as compared to Rigid pavements due to its low initial cost. But in rainy season flexible pavements get detoriated and its maintenance becomes costly. The basic aim is to see the variation of modulus of rupture of concrete in rigid pavements at different temperatures. Modulus of rupture of concrete is determined by the use of a simple beam with third-point loading. This test method is used to determine the modulus of rupture of specimens prepared and duly cured in accordance with ASTM standards also used in India. Results are calculated and reported as the modulus of rupture. The strength determined will vary where there are differences in specimen size, preparation, moisture condition, curing, or where the beam has been molded or sawed to size.

Index Terms-**Modulus of rupture, Rigid pavement, pavement thickness.**

I. INTRODUCTION

Pavement is the core component of the site that provides transportation routes and parking facilities crucial to everyday life. The road pavement is the actual surface on which the vehicles will travel. Its purpose is twofold, to provide friction for the vehicles and to transfer normal stresses to the underlying soils. The United States has the largest network of roadways of any country with 6,430,366 kilometers (3,995,644 mi) (2005). The Republic of India has the second largest road system in the world with 3,383,344 kilometers (2,102,312 mi) (2002). People's Republic of China is third with 1,870,661 kilometers (1,162,375 mi) of roadway (2004). When looking only at expressways the National Trunk Highway System (NTHS) in People's Republic of China has a total length of 45,000 kilometers (28,000 mi) at the end of 2006, and 60,300 km at the end of 2008, second only to the United States with 90,000 kilometers (56,000 mi) in 2005.

II. METHODOLOGY

Our basic aim is to see the variation in modulus of rupture of concrete used in rigid pavements (plain concrete) at different temperatures. As far as this area of research is concerned, no substantial work has been accomplished so far. Thus our work is an initiative in this direction.

III. MATERIALS USED

1. Cement
2. Coarse Aggregates
3. Fine Aggregates
4. Water

IV. STEPS INVOLVED

1. Reconnaissance of the sub-grade and temperature of the area on which the highway pavement is to be constructed.

2. Procurement of raw material used in the construction of pavement for making standard concrete prisms used in testing.
3. Casting and curing of the test specimens.
4. Maintaining specimens at various degrees of temperatures to simulate the actual ground conditions.
5. Testing the specimens for modulus of rupture.

V. DESIGN METHOD FOR CONCRETE MIX

IS 456-2000 has designated the concrete mixes into a number of grades as M10, M15, M20, M25, M30, M35 and M40. In this designation the letter M refers to the mix and the number to the specified 28 day cube strength of mix in N/mm^2. The mixes of grades M10, M15, M20 and M25 correspond approximately to the mix proportions (1:3:6), (1:2:4), (1:1.5:3) and (1:1:2) respectively. These mixes of fixed cement-aggregate ratio which ensures adequate strength are termed nominal mixes. These offer simplicity and under normal circumstances, have a margin of strength above that specified. However, due to the variability of mix ingredients the nominal concrete for a given workability varies widely in strength.

We used a nominal mix of M-20 (1:1.5:3) for the concrete mix design. We used cement of grade-43 along with equal proportions of 10 and 20 mm aggregate size. Fine aggregate used was of grade I.

Cube compressive strength for 150mm x 150mm x 150mm sample prisms of the nominal mix used gave an average 28 days strength value of 25 N/sq.mm.

Table1. Characteristic Cube Compressive Strength of Concrete Used

Sample No.	Failure Load (kN)	Compressive Strength (N/sq.mm)	Average Compressive Strength (N/sq.mm)
1.	561	24.93	25.03
2.	562	24.97	
3.	565	25.11	

VI. FLEXURAL TESTING

1. Standard Method of Test for Modulus of rupture of Concrete (Using Simple Beam with Third-Point Loading)

This test method covers determination of the modulus of rupture of concrete by the use of a simple beam with third-point loading.

2. Significance and use

This test method is used to determine the modulus of rupture of specimens prepared and duly cured in accordance with ASTM standards also used in India. Results are calculated and reported as the modulus of rupture. The strength determined will vary where there are differences in specimen size, preparation, moisture condition, curing, or where the beam has been moulded or sawed to size.

3. Apparatus:

Steel prism moulds of 100mm x 100mm x 500mm are used. The testing machine may be any reliable type of sufficient capacity for the tests and capable of applying load at 1.8 kN per minute. The bed of the testing machine shall be provided with two steel rollers 38mm in dia, on which the specimen is to be supported and these rollers shall be so mounted that the distance from centre to centre is 400mm. The load shall be applied through two similar rollers mounted at third points of the supporting span that is spaced at 133mm centre to centre. The load shall be divided equally between the two loading rollers and all rollers shall be mounted in such a manner that the load is applied axially without subjecting the specimen to any torsion or restraints. One suitable arrangement which complies with these requirements is indicated below.

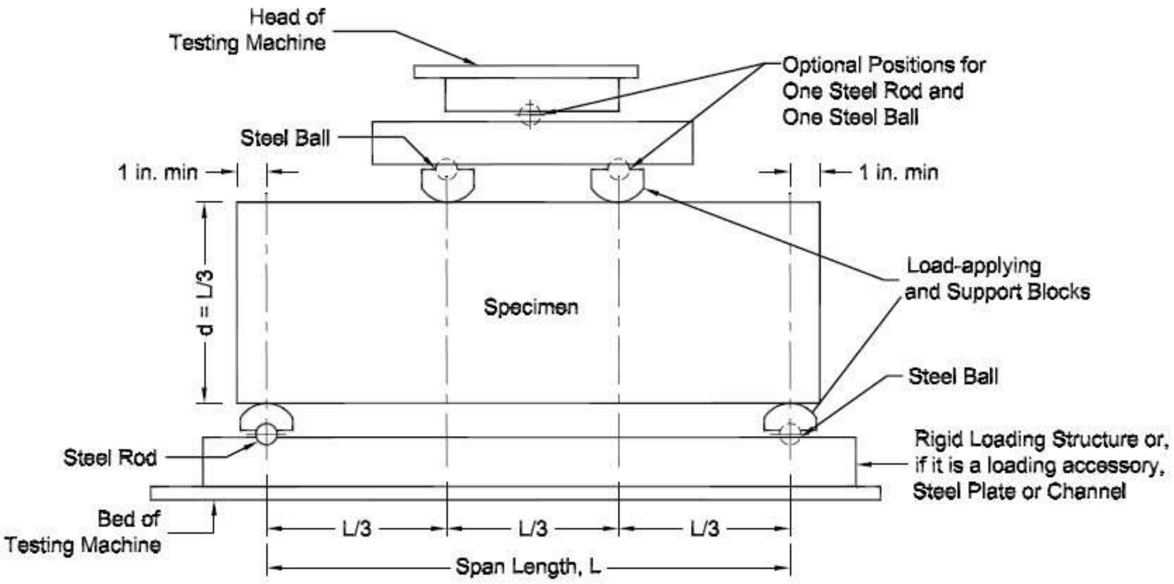

Fig 1 Diagrammatic View of Apparatus for Flexure Test of Concrete by Third-Point Method

4. Procedure of the test:

Using mix proportion as 1:1.5:3, W/C ratio as 0.45 and each prism of size 100mm x 100mm x 500mm; we took cement 2.2 kg, fine aggregate 3.3 kg, and coarse aggregate of 6.6 kg.

Curing of samples was done for 28 days and then they were maintained at specified temperatures for at least 24 hrs followed by immediate testing. Specimen was placed in the Universal testing machine (UTM), in such a manner that load is applied along two lines spaced 133mm apart. The axis of the specimen was carefully aligned with the axis of loading device. The load was applied without shock at a rate of 1.8 kN per min. The load was increased till the specimen failed and the failure loads were noted. The distance between the line of fracture and the nearer support measured on the central line of the tensile side of the specimen was noted.

MR = $p.a/b.d^2$

where,

p = max load in N applied to the specimen

a = distance between the line of fracture and the nearer support, measured on the central line of the tensile side of the specimen in mm.

b = measured width in mm of the specimen

d = measured depth in mm of the specimen at the point of failure

Table 2 Modulus of rupture Results at Various Temperatures

Temperature (0’C)	Sample no.	Failure load (kN)	a (mm)	MR (N/sq.mm)	Avg MR (N/sq.mm)
0	1	1.73	153	3.45	3.510
	2	1.75	162	3.57	
5	1	1.90	152	3.83	3.805
	2	1.80	160	3.78	
10	1	1.70	199	4.83	3.875

	2	1.68	160	3.52	
15	1	1.68	180	3.86	3.875
	2	1.68	182	3.89	
20	1	1.74	171	3.84	3.975
	2	1.73	188	4.11	
25	1	1.61	152	3.25	3.180
	2	1.70	133	3.11	

VII. RESULT ANALYSIS AND DESIGN

The highest value of modulus of rupture was observed at 20’ C. There is an increase in the modulus of rupture from 0’C upto 20’C and then a drop in the value. The variation is about 13% from 0’C to 20’C. Also there is an anomalous drop on moving from 20’C to 25’C.

1. Design steps involved:

The slab depth (D) is required to determine the number of ESALs to design for before the pavement is ever designed. The iterative design process usually proceeds as follows:

1. Determine and gather rigid pavement design inputs.
2. Determine and gather rigid pavement ESAL equation inputs.
3. Assume a slab depth (D).
4. Determine the equivalency factor for each load type by solving the ESAL equation using the assumed slab depth (D) for each load type.
5. Estimate the traffic count for each load type for the entire design life of the pavement and multiply it by the calculated ESAL to obtain the total number of ESALs expected over the design life of the pavement.
6. Insert the assumed slab depth (D) into the design equation and calculate the total number of ESALs that the pavement will support over its design life.
7. Compare the ESAL values in #5 and #6. If they are reasonably close (say within 5 percent) use the assumed slab depth (D). If they are not reasonably close, assume a different slab depth (D), go to step #4 and repeat the process.

TABLE3. STRESS RATIO AND ALLOWABLE REPITITIONS IN CEMENT CONCRETE

STRESS RATIO	ALLOWABLE REPITITIONS	STRESS RATIO	ALLOWABLE REPITITIONS
0.45	6.279*10^7	0.53	2.29*10^5
0.46	1.4335*10^7	0.54	1.66*10^5
0.47	5.2*10^6	0.55	1.24*10^5
0.48	2.4*10^6	0.56	9.41*10^4
0.49	1.287*10^6	0.57	7.12*10^4
0.50	7.62*10^5	0.58	5.4*10^4
0.51	4.85*10^5	0.59	4.08*10^4
0.52	3.26*10^5	0.60	3.09*10^4

Design of a concrete pavement for a two lane two way national highway in Kashmir region.

The total traffic is assumed at 1500 cvpd at the end of construction period. The various design parameters are:

Modulus of sub grade reaction of dry lean concrete (DLC) sub base (assumed)

= k = 8kg/sq.cm

Elastic Modulus of concrete = 300000 kg/sq. cm

Poisson’s ratio= 0.15

Coefficient of thermal expansion of concrete= 10×10^5

Tyre pressure= 7 kg/ cm^2

Growth rate = .075

Width of slab panel= 3.5m

Table4. Calculation of axle loads from IRC: 58-2002

Single axles		**Tandem axles**	
Axle load class (tonnes)	**Percentage of axle load**	**Axle load class (tonnes)**	**Percentage of axle load**
15-17	.6	30-34	.3
13-15	1.5	26-30	.8
11-13	15.6	22-26	1.9
9-11	22	18-22	1.6
7-9	23	14-18	.7
<9	30	<14	2
	92.7		7.3

Cumulative repetition in 20 yrs= 1500×365[(1.075)*20 – 1]/0.075= 23709313.03 commercial vehicles

Design traffic=50% of total repetitions= 11854657

MR=3.51 kg/cm^2 and k=8 kg/cm^2

Take trial thickness as 32cm

Table5. Calculation of fatigue life consumed for 32cm thick Pavement

Axle load	**Stress from charts**	**Stress ratio**	**Expected repetition**	**Fatigue life from table 6 of IRC58**	**Fatigue life consumed**
Single axle					
16	18	.52	71127	3.26×100000	.22
14	16	.45	177820	6.3×10000000	.003
12	13.5	.38	1849326	infinite	0.00
Tandem axles					
32	16	.45	35564	6.3×10000000	.0005
28	13.5	.38	94837	infinity	0.000

Cumulative fatigue life consumed = 0.2235

The design is safe since cumulative fatigue life consumed is <1

VIII. CHECKS:

1. **Check for temperature stresses**

Edge warping stress = C.E.α_t/2 = 13.03 kg/sq.cm

Assume spacing of contraction joints, L = 450 cm

Breadth of panel, B = 350 cm

Radius of relative stiffness, $l = \sqrt[4]{\dfrac{Eh^3}{12(1-\mu^2)k}}$ =101.2 cm

L/l = 450/101.2 = 4.44

C = .55

Temperature differential for Kashmir region = 15.8 ‘C

Total of temperature warping stress and highest axle load stress = 15.8+18 = 33.8 kg/sq.cm which is less than 35.1 kg/sq.cm, the modulus of rupture. So the pavement thickness of 32cm is safe under the combined action of wheel load and temperature.

2. Check for corner stress

Corner stress is not critical in a dowelled pavement. The corner stress can be calculated from the following formula.

$$\sigma_c = \frac{3P}{h^2}\left[1-\left(\frac{a\sqrt{2}}{l}\right)^{1.2}\right]$$

σ_c = 14.55 < 35.1 kg/sq.cm

$$a = \sqrt{\frac{0.8521\times P_d}{q\pi}+\frac{S_d}{\pi}\left(\frac{P_d}{0.5227q}\right)}^{1/2}$$

a = 25.57 cm

Therefore design is safe for the assumed thickness of 32 cm.

Assuming a standard panel size of width 350 cm and length of panel = 450 cm

And taking cost per cum of concrete as Rs. 5500.

Table6. Table showing the variation of cost of panel with temperature changes.

Temperature (‘C)	Modulus of rupture (kg/sq.cm)	Design Thickness (cm)	Cumulative Fatigue Value	Warping Stresses (kg/sq.cm)	Warping Stress + Axle Load Stress	Corner Stresses	Vol. Of Concrete for Panel (cu.m)	Cost of Panel (Rs.)
0	35.10	32	0.2235	13.03	33.80	14.55	5.04	27720
5	38.05	31	0.153	14.077	33.077	15.39	4.882	26850
10	38.75	30	0.138	14.980	32.98	15.57	4.725	25990
15	38.75	30	0.138	14.980	32.98	15.57	4.725	25990
20	39.75	29	0.131	15.070	32.69	15.83	4.567	25120
25	31.8	33	0.247	12.740	30.94	14.24	5.197	28590

If we take the modulus of rupture as got from the cube compressive strength of 0.7$\sqrt{f_{ck}}$, the modulus of rupture value would be 35 kg/sq.cm. As can be seen from the table above we would require a pavement thickness of 32 cm. But from the successive values of modulus of rupture at higher temperatures, we see that pavement thickness required decreases and subsequently it results in a decrease in the overall cost of the panel.

As the number of pavement panels increases, so do the savings in terms of cost.

IX. CONCLUSION

We find that as modulus of rupture increases with the increase in temperature from 0’C to 20’C, the pavement design thickness also decreases. Thus economical sections are valid for higher temperatures like 20’C. An exception was found in case of 25’C whose thickness comes out to be maximum. This result can be discarded, and further tests can be conducted to verify the result.

Instead of directly using the modulus of rupture obtained from the cube compressive strength values, if modulus of rupture values are directly obtained from testing, we can construct more slender pavements, thereby offsetting costs.

Also in certain cases, like at 25’C we find that modulus of rupture values are less than those obtained from cube compressive strength. Thereby, at higher temperatures, it is desirable to test for independent modulus of ruptures rather than go by obtaining the same from cube compressive strengths.

X. REFRENCES

1. Guidelines for the design of Plain Jointed rigid Pavements for Highways- IRC:58-2002.
2. Material Testing Laboratory Manual. Kukreja, Kishore, Chawla.
3. Design of Pavements. Yoder.
4. Highway Engineering. S.K. Khanna.
5. American Society for Testing Material (ASTM) Guidelines.
6. Washington State Department of Transportation (WSDOT), Guidelines for Pavement Design.
7. National Programme on Technology Enhanced Learning (NPTEL). IIT’s.
8. State of the Art and Practice in Rigid Pavement Design. Kathleen T. Hall, Consultant and Chair, Committee on Rigid Pavement Design.
9. National Concrete Pavement Technology Centre, Iowa State University.
10. Rigid Pavement Stress Analysis, Dr. Christos Drakos. University of Florida.
11. Concrete in Practice. National Ready Mixed Concrete Association.
12. Time to Rein in the Flexural Test, Orrin Riley, ACI Concrete International, August, 1994. Farmington Hills, MI. Compression vs. Modulus of rupture for Quality Control Of Pavements, Steve Kosmatka, CTT PL 854, 1985, Portland Cement Association, Skokie,IL

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