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Analysis of Rigid Pavement Joints under Different Shoulder Types

Abhishek[1], Abhishek Pandit[2], Dr. Hemant Sood[3]
[1, 2, 3]Civil Engineering, NITTTR Chandigarh

Abstract: ***From the past few years, the building and maintenance of high-quality roadways is vital. And nowadays, ministry of road transport and highways is shifting more on rigid pavements because of its good characteristics. The cost factor is the primary concern in every project. With the right design, even a slight reduction in the thickness of the concrete slab can save the project cost. As a result, an attempt was undertaken to build a two-lane, two-way National highway with variable concrete grades. The analysis has been carried out with variable slab thickness, different shoulder types and variable panel size of slab in which the cost has been optimized.***
Keywords: Rigid pavement, Design of joints, Different shoulder types in rigid pavement, Cost optimization in rigid pavement, Analysis of rigid pavement, IRC: 58-2015.

I. INTRODUCTION

Over the centuries, the roads and pavements have evolved to be able to meet the needs of humans to move themselves and the products they produce. The pavements have developed in recent decades, as studies have introduced new materials in their construction (e.g., Asphalt), new standard sizing and new requirements for the surface characteristics. The surface characteristics, namely the critical contact surface with vehicle tires, is able to deliver higher quality, speed and travel comfort without compromising the integrity of mobile vehicles and their passengers. A pavement is a man-made surface on natural ground that people, vehicles, or animals can use to cross. A pavement's principal purpose is to transfer loads to the sub-base and underlying soil. It is the durable paving of a road, airstrip, or other comparable area in civil engineering

The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favourable light reflecting characteristics, and low noise pollution. The ultimate aim is to ensure that the transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed bearing capacity of the sub- grade. Two types of pavements are generally recognized as serving this purpose, namely flexible pavements and rigid pavements. This gives an overview of pavement types, layers and their functions, cost analysis. In India transportation system mainly is governed by Indian road congress.

A. Requirements of a Pavement

An ideal pavement should meet the following requirements:

1) Strong enough structurally to withstand all types of forces exerted on it
2) A sufficient coefficient of friction to prevent vehicle sliding.
3) Smooth surface to provide comfort to road users even at high speed.
4) Sufficient thickness to distribute the wheel load stresses to a safe value on the sub-grade soil
5) Produces the least amount of noise from moving cars
6) Has a dust-proof surface to ensure that traffic safety is not compromised by reduced visibility
7) Long design life with low maintenance costs
8) Impervious surface to protect sub-grade soil.

B. Type of Pavements

Flexible and rigid pavements are the two types of pavements that can be classed based on their structural performance. Wheel loads are transferred via the granular structure of flexible pavements through grain-to-grain contact of the aggregate. Because of its lower flexural strength, the flexible pavement works like a flexible sheet (e.g., bituminous road). In rigid pavements, on the other hand, the flexural strength of the pavement transfers wheel stresses to the sub-grade soil, and the pavement acts like a rigid plate (e.g., cement concrete roads).

C. Flexible Pavement

Flexible pavements will transmit wheel load stresses to the lower layers by grain-to-grain transfer through the points of contact in the granular structure.

The wheel load acting on the pavement will be distributed to a wider area, and the stress decreases with the depth. Taking advantage of this stress distribution characteristic, flexible pavements normally have many layers. Hence, the design of flexible pavement uses the concept of layered system.

Based on this, flexible pavement may be constructed in a number of layers and the top layer has to be of best quality to sustain maximum compressive stress, in addition to wear and tear. The lower layers will experience lesser magnitude of stress and low-quality material can be used.

D. Rigid Pavement

Rigid pavements have enough flexural strength to disperse the wheel load strains over a larger region. Rigid pavements are laid directly on the prepared sub-grade or on a single layer of granular or stabilised material, as opposed to flexible pavement. This layer can be referred to as the base or sub-base course because there is only one layer of material between the concrete and the sub-grade. The slab action distributes force in rigid pavement, and the pavement behaves like an elastic plate sitting on a viscous medium. Rigid pavements are made of Portland cement concrete (PCC).

Due to wheel load and temperature variations, the slab bends, causing tensile and flexural stress. Finite element analysis was used to investigate the stress condition of stiff pavement. The cement concrete pavement slab can function as both a wearing surface and a solid base course. As a result, the rigid pavement structure is commonly made up of a cement concrete slab with a granular base or subbase course beneath it.

Rigid concrete pavements are built of Portland cement concrete and may or may not have a base course between the pavement and the subgrade.

The concrete, excluding the base, is generally referred to as the pavement. Because of its stiffness and high modulus of elasticity, the concrete pavement distributes the applied load over a relatively large surface of soil; hence, the slab provides the majority of the structural capacity.

E. Types of joints in Rigid Pavement

1) Longitudinal joints are joints in the direction of paving and are provided in al l street and highway pavement built in lanes over about 15 f t wide. They are also used in some airfield pavement hut may he omitted in thicker pavements by some engineers.
2) Contraction joints are transverse joint s used to relieve longitudinal stresses due to contraction as the concrete cools and lose s moisture. Contraction joint s also relieve longitudinal stresses due to loads and curling or warping and control the location of transverse cracking if properly spaced. Some engineers refer to these as cracker joints, plane of weakness joints, or dummy grooves. They all relieve contraction stresses in the concrete
3) Expansion joints are usually transverse joint s used to relieve expansion stresses in the concrete by providing room for expansion. An expansion joint is filled with a nonextruding, compressible material. The filler must have sufficient strength partial y to resist horizontal slab movement but to permit such movement before crushing or buckling stresses developed in the concrete
4) Construction joints are transverse header joint s put i n at the end of each day's run or longitudinal joint s between lanes of multiple lane pavement. The purpose of such joint is to divide large pavement areas into convenient size s for paving. Longitudinal construction joints are usually provided with deformed tie bars or tie bolts to prevent horizontal movement and keyways or tongue and grooves built into slab edges to provide load transfer between lanes.

II. DESIGN ANALYSIS

IRC 58 gives the guidelines for design of plain jointed cement concrete pavements. These codal recommendations are relevant for roads having a day-to-day commercial traffic with vehicles with weight more than 3 tones. The different recommendation for design of rigid pavements as per IRC: 58-2002 and IRC: 58-2015.

Since user cost comparison is part of the total investment cost analysis, and the results of this study are taken into consideration in planning and decision making, the study of user cost estimation on rigid pavements is important.

Table 1
Tied concrete shoulders + transverse joints having dowels with diameter of bar is 38mm (constant) and slab thickness is variable and grade of concrete =45

Slab Thickness (mm)	Radius of relative stiffness (mm)	Permissible Bearing stress in concrete (Mpa)	Bearing stress in dowel bar (Mpa)	Remark	Amount in INR per KM
280	754.77	30.04724409	27.45	SAFE	24498025
290	774.89	30.04724409	26.44	SAFE	25107550
300	794.85	30.04724409	25.55	SAFE	25717075
310	814.64	30.04724409	24.77	SAFE	26326600
320	834.27	30.04724409	24.07	SAFE	26936125
330	853.75	30.04724409	23.44	SAFE	27545650
340	873.08	30.04724409	22.88	SAFE	28155175
350	892.27	30.04724409	22.36	SAFE	28764700

Inferences

- It can be inferred that the dowel bar spacing and diameter assumed are safe for all the slab thickness.
- Permissible bearing stress in concrete is increased by 15% with increase f_{ck}40 to f_{ck}45
- There is almost 10% increment in total cost by increasing the f_{ck}40 to f_{ck}45.

Table 2
Tied concrete shoulders + transverse joints having dowels with diameter of bar is 36mm (constant) and slab thickness is variable and grade of concrete =45

Slab Thickness (mm)	Radius of relative stiffness (mm)	Permissible Bearing stress in concrete (Mpa)	Bearing stress in dowel bar (Mpa)	Remark	Amount in INR per KM
280	754.77	30.99212598	30.39	SAFE	24370406
290	774.89	30.99212598	29.27	SAFE	24979931
300	794.85	30.99212598	28.29	SAFE	25589456
310	814.64	30.99212598	27.42	SAFE	26198981
320	834.27	30.99212598	26.64	SAFE	26808506
330	853.75	30.99212598	25.95	SAFE	27418031
340	873.08	30.99212598	25.33	SAFE	28027556
350	892.27	30.99212598	24.76	SAFE	28637081

Inferences

- It can be inferred that the dowel bar spacing and diameter assumed are safe for all the slab thickness.
- There is a negligible change in total cost by changing the diameter of bar in same f_{ck}.
- Stresses in dowel decreases with increase in slab thickness.
- No change in total cost within same f_{ck}.

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In Non tied concrete shoulder having dowels, the condition is safe only when the value of f_{ck} and diameter of bar is 50 and 38mm respectively in 340mm and 350mm of slab thickness within our assumed values and remaining cases are unsafe so only one table is formed below.

Table 3
Total cost for different slab thickness having two-lane rigid pavement *when grade of concrete=50*

Slab Thickness (mm)	Radius of relative stiffness (mm)	Permissible Bearing stress in concrete (Mpa)	Bearing stress in dowel bar (Mpa)	Remark	Amount in INR Per KM
280	754.77	33.38582677	39.22	UNSAFE	--
290	774.89	33.38582677	37.77	UNSAFE	--
300	794.85	33.38582677	36.50	UNSAFE	--
310	814.64	33.38582677	35.38	UNSAFE	--
320	834.27	33.38582677	34.38	UNSAFE	--
330	853.75	33.38582677	33.49	UNSAFE	--
340	873.08	33.38582677	32.68	SAFE	18230066
350	892.27	33.38582677	31.95	SAFE	18705716

Inferences

- It can be inferred that the dowel bar spacing and diameter assumed are safe for greater than 340mm of slab thickness.
- But there is 65% in cost reduction within same parameters as we are not providing tied shoulders in rigid pavement.
- But this condition only satisfies when the characteristics compressive strength of concrete would be high.

Table 4
Details of tie bar for longitudinal joints of two-lane when
diameter of bar=12mm

Slab thickness mm	Tie Bar Details						Grand amount for deformed bars in INR/KM
	Max. Spacing, mm		Minimum length, mm		No. of tie bar , mm		
	Plain	Deformed	Plain	Deformed	Plain	Deformed	
280	400.51	640.82	578.57	637.80	11	7	22356673
290	386.70	618.72	578.57	637.80	12	7	22916016
300	373.81	598.10	578.57	637.80	12	8	23475359
310	361.75	578.80	578.57	637.80	12	8	24034702
320	350.45	560.71	578.57	637.80	13	8	24594045
330	339.83	543.72	578.57	637.80	13	8	25153389
340	329.83	527.73	578.57	637.80	14	9	25712732
350	320.41	512.65	578.57	637.80	14	9	26272075

Inferences

- Maximum spacing is decreasing with increase in the slab thickness in both plain ad deformed bars.
- Maximum spacing and minimum length are increasing with increase in diameter of tie bar.
- There is approx. 2.5% increment in total cost for each case with uniformly increase in slab thickness.
- There is negligible change in total cost when we increase the diameter of tie bar.

III. CONCLUSION AND FUTURE SCOPE

A. Conclusion

The conclusions of the study are as follows:

1) It can be concluded that the bearing stresses in concrete are increasing only with increase in grade of concrete.
2) There is no change in stresses in dowels with any variation in grade of concrete.
3) The Bearing stresses in dowel increases with decreasing the diameter of dowel bar.
4) It can also be concluded that there is approximate 10% increment in total cost with increasing the grade of concrete.
5) It can be concluded that the permissible bearing stresses in concrete are increased by 15% with increase in the grade of concrete.
6) Bearing stresses in dowels are decreasing with increment in the slab thickness.
7) There is negligible change in total cost with variation of diameter of dowel bar.
8) It can be concluded that the total cost rises 2.5% with increasing in slab thickness uniformly by 10mm
9) It can also be concluded that there is 65% in the reduction of total cost by avoiding the tied shoulder in pavement.
10) It can be concluded that the maximum spacing in tie bars is decreasing with increment in the slab thickness by 10mm
11) It can also be concluded that the maximum spacing and minimum length are increasing with increase in diameter of tie bar.
12) It can be concluded that the maximum spacing in deformed tie bars is 60% more than the plain tie bars.
13) Number of tie bars are decreasing as we increase the diameter of tie bar.
14) Maximum spacing is slightly reducing as we increase the lane width in the design of tie bar.
15) It can also be concluded that there is negligible change in total cost by changing the panel size of pavement by 0.25m
16) It can also be concluded that the cost would be reduced up to 70% when there is no provision of tied concrete shoulder on sides of rigid pavement but this condition will only be applicable when the design of dowel bar in transverse joints would be safe.

B. Future Scope

1) The theoretical data presented can be verified on field research.
2) The study on the type of shoulders in rigid pavement on different slab thicknesses can be analyzed by different CBR values.
3) Variation of pavement thickness with spacing of dowels and tie bars along with joints load transfer efficiency.
4) Various economic aspects like with decrease in thickness of slab, vary the dimensions of bars in joint, shoulder types, etc. can decrease in the costing of project which can also be done on future study.

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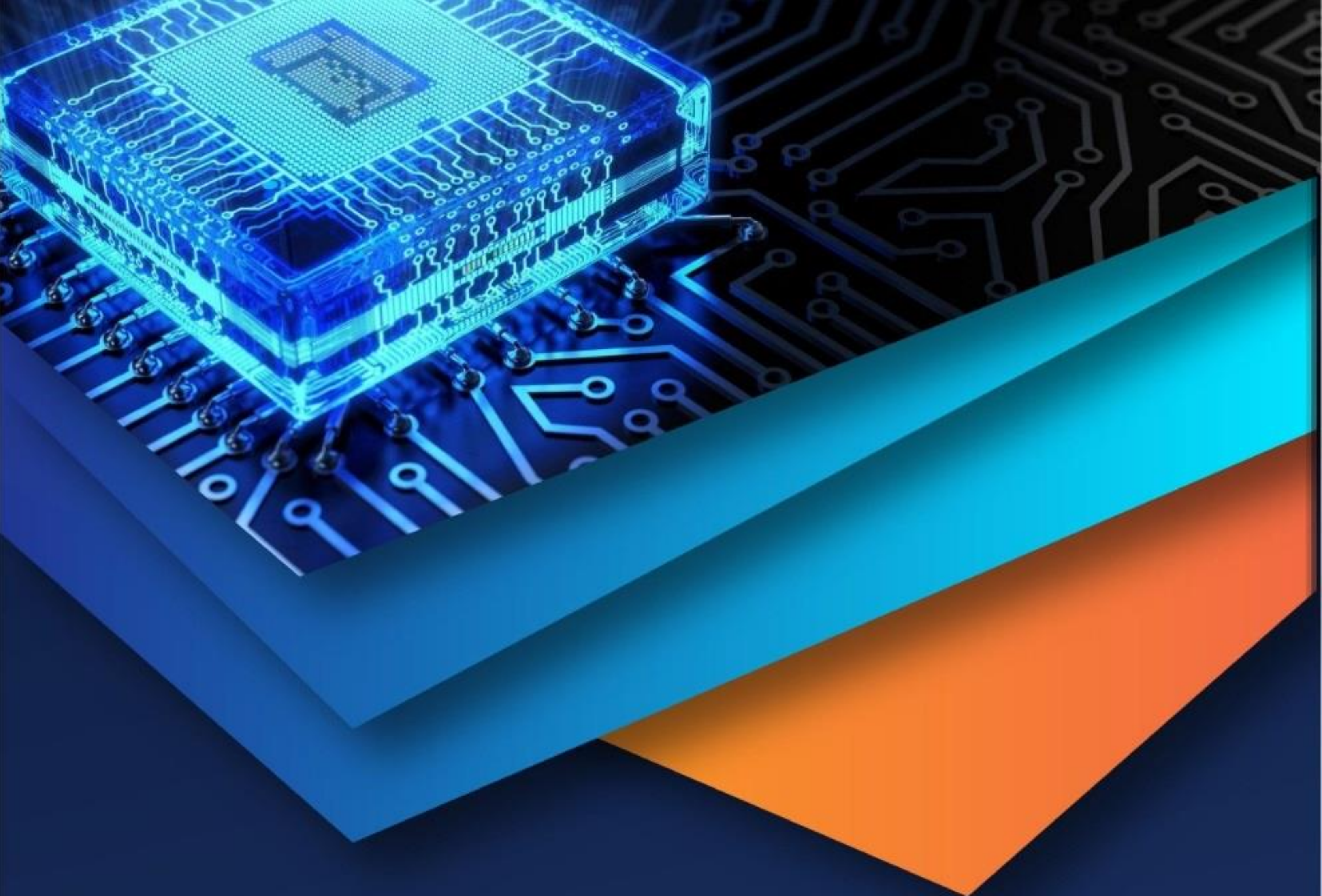

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