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Temperature Analysis of Admixed Concrete Pavements

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ABSTRACT: Roads are necessary for connecting two different places. They help us to provide door-to-door service of goods and other valuable benefits. They must withstand millions of tonnes of business throughout their serviceable lives. This study is based on Rigid Pavement which fails due to two reasons. They are Fatigue stresses and Temperature stresses. Slag is widely used in concrete, either as a separate cementitious mix or as part of a blended cement mix. Admixture works synergistically with Portland cement to increase strength, reduce permeability and improve many properties. Therefore, many portions are called single and composite sections, as advanced in the experiment. Two different layers of the concrete mixture are placed on constructing composite sections. Fly Ash, Silica Fume, Ground Granulated Blast Furnace Slag (GGBS), Polypropylene Fibers, Iron Slag and Copper Slag are the types of additives used in this experiment. The additives used are partially replaced place of fine aggregates in concrete. Based on the current study, the composite sections possess greater strength than single admixture and conventional concrete sections. In the current study, temperature analysis can be carried out by observing temperature variations in slabs made utilizing prototype moulds for several section types. The temperature on the top of the slab will be higher than the bottom during the day and lower than the bottom during the night. IRC 58-2015 provides options for dealing with this type of stress. The IRC-recommended temperature varies from state to state. However, because of variations in atmospheric temperature from one area to another, the temperature fluctuates, which could substantially impact pavement design thickness. In this study, different temperature differential values for different slab sections are obtained, and (CFD) cumulative fatigue damage is calculated using these temperature differentials per IRC 58-2015.

KEYWORDS: Temperature Differential; Pavement Quality Concrete, Warping Stress, Rigid Pavement, Concrete.

I. INTRODUCTION

The transportation of people and goods through roads is referred to as road transport. A road is a path between two sites that has been paved or renovated to permit travel by carriages with and without motors. Compared to other forms of transportation like trains and aeroplanes, road transportation requires far less investment. Road construction, maintenance, and operation costs are lower than those of railroads.

Building a road has a comparatively low upfront cost. Pavements can also be subdivided. The two types of pavements are rigid pavements and flexible pavements. Each has its benefits and drawbacks. Although rigid pavement requires a larger initial investment than flexible pavement, the maintenance cost of flexible pavement is higher.

Rigid pavements are those that have exceptional flexural strength or rigidity. The stresses in the rigid pavement are not transferred from grain to grain to the lower layers. Rigid pavements are made of Portland cement concrete, which can be plain, reinforced, or pre-stressed. The plain cement concrete slabs are expected to withstand higher flexural strength. The rigid pavement has a slab action and can transmit wheel load stresses over a larger area below. Tensile stresses are developed due to the bending of the slab under wheel load temperature variations in the rigid pavement slab as tensile strength. Providing a good sub-base course layer beneath the cement concrete slab increases pavement life significantly, making the workout more cost-effective in the long run. The elastic theory is typically used to design rigid pavements and analyze stress.

Rigid pavements collapse under two different circumstances. First, that is caused by fatigue stresses, and the second that is caused by temperature stresses. In hot weather, concrete slab tends to expand. When joints are not designed properly, it prevents expansion of concrete slab and therefore results in the development of excessive stress. This stress cause formation of warping cracks on the concrete slab near the joint edge. This type of crack can be prevented by providing proper reinforcement at the longitudinal and transverse joints.

The addition of admixtures such iron slag, copper slag, silica fume, fly ash, polypropylene fibres, and GGBS in differing proportions to conventional concrete allows for additional analysis of pavements.

It is also possible to study pavements by creating single or composite sections, where a composite section is one that contains a variety of materials or compositions.

II. LITERATURE REVIEW

Many publications and journal papers were discovered, among which numerous options for partial replacements of cement were investigated, using admixtures such as Fly Ash, Silica Fume, Polypropylene Fibres, Iron Slag, Copper Slag, and GGBS. Several studies on Temperature Differential on Rigid Pavements were also discovered, with a few papers highlighting work that was related to the current study. Some of the studies are as follows:

According to (Gotur et al., 2018), replacing iron slag by 10% to 30% with river sand resulted in a significant increase in compressive and flexural strength, as well as an almost identical result for split-tensile strength. According to the findings, it is recommended that approximately 40% of the iron slag be replaced. According to (Singh and Siddique, 2016), the compressive strength of concrete increases as the proportion of iron slag in the mix increases. The gain in strength at the start of the study was greater than the gain in strength at the end. Iron slag replaces thirty percent of the fine aggregate.

(Al-Jabri et al., 2009) discovered that copper slag has a significant effect on the properties of concrete when sand is replaced with concrete in his experiments. When copper slag is gradually replaced at around 5%, the mix's workability improves significantly. The proportions ranging from 80% to 100% had the lowest compressive strength. A 40% replacement reduced surface water absorption while increasing absorption rate. In his subsequent study on the partial replacement of copper slag, (Kumar, 2013) discovered that increasing the copper slag increased bleeding and harshness. The addition of copper slag reduced the drying shrinkage of the concrete. One disadvantage of copper slag is that it separates cement from concrete. Finally, 40% copper slag is recommended as a fine aggregate replacement.

Fly ash is widely available in today's world. Fly ash can be used as an admixture because it is readily available and inexpensive. (Kumar, Tike, and Nanda, 2007), (Amit et al., 2015), and (Uma Magesvari and Sundararajan, 2017). A few studies have been conducted in which fly ash was used as a fine aggregate replacement. All of the fly-ash-concrete mixtures with 0.40 w-cm ratios had lower compressive and flexural strengths than the control mixture at 7 and 28 days. The strengths decreased as the amount of fly ash increased. Maximum strength was achieved at 60% and 40% replacement, respectively. The introduction of 30% fly ash increases the compressive and flexural strengths of concrete.

Silica Fume is generated from ferrosilicon alloys and is known for its highly reactive mineral nature, which aids in the development of better engineering properties in concrete. (Dhananjay and Vindhya, 2015), (Liu et al., 2018), and (Chung, 2002) are some of the authors. Numerous studies on silica fume and concrete have been conducted, with the addition of silica fume resulting in lower warping stresses and lower temperature stresses. Furthermore, silica fume admixed concrete performed better during the freeze-thaw cycle demonstration. Additionally, when silica fume is replaced, concrete properties improve overall. A silica fume replacement rate of 12-15% is recommended.

Polypropylene fibers have been used in concrete for many years, and their use in improving crack propagation and positively affecting many properties is always encouraged. There are numerous findings on the addition of fibers to concrete mixtures. According to (Blazy and Blazy, 2021), (Alhozaimy, Soroushian, and Mirza, 1996), and (Milind V. Mohod, 2015), adding polypropylene fibers to the concrete mix reduces the workability of the concrete and reduces shrinkage cracks. Another observation is that the bleeding and segregation of cement have been greatly improved. Furthermore, the compressive strength increased by only up to 0.5 percent more addition resulting in strength degradation. Polypropylene is used at a rate of 0.5-1 %.

Ground Granulated Blast Furnace Slag is primarily used in cement because it is readily available and less expensive than cement. In their studies, (El-Hassan and Kianmehr, 2018), (Gopal and Reddy, 2017), and (Tadi and Rao, 2021) discovered that the compressive, split tensile, and flexural strength of concrete have been greatly improved by up to 40% replacement of concrete and beyond that, it is almost the same as a conventional mix. However, in some cases, 30% replacement produced the best results.

There have been several studies, investigations, and journals on temperature differential in rigid pavements but there have been only a few studies on the admixed rigid pavement. Here are some of the studies on Temperature Differential in Rigid Pavements. (Kumar and Ravindraraaj, 2018), (Sathish, Kumar and Sridhar, 2017). The temperature differential observed is very less, it is almost half of what is specified in the Indian Road Congress for tested rigid pavement of thickness 300mm and it is also less for thickness lesser than 300mm. Another thing observed is that the temperature differential should be region-specific not state specific. Similarly, upon conduction of finite element simulation, it is

discovered that curling of pavement occurs in both upward and downward movement when there is a greater temperature differential. Overall, the temperature difference is greater in conventional concrete pavements than in the pavements which are admixed.

III. METHODOLOGY

1. Materials

1. Fly Ash

Fly ash is a by-product of the combustion of pulverised coal in power plants. Fly ash chemically reacts with calcium hydroxide, a by-product of the chemical reaction between cement and water, to form additional cementitious products that improve many desirable properties of concrete. The nearby Bellary Thermal Power Station, KPC Ltd, provided the fly ash in Kudithini village, Karnataka.

2. Silica Fume

Silica fume is produced as a by-product of the production of silicon metal or ferrosilicon alloys. Concrete containing silica fume can be extremely strong and long-lasting. It was shipped from Kolkata, India, by Chatterjee and Co.

3. Polypropylene Fibres

Polypropylene (PP) fibers are a type of synthetic fiber that has properties that make it an excellent addition to construction materials, particularly when concrete is required. When compared to plain concrete, fiber reinforced concrete is much more durable due to increased tensile strength and is less likely to crack.

4. Ground Granulated Blast Furnace Slag (GGBS)

Ground Granulated Blast Furnace Slag (GGBS) is a by-product of iron blast furnaces. Iron and the remaining materials from a slag that floats on top of the iron are extracted from the iron ore. In conjunction with ordinary Portland cement and/or other pozzolanic materials, GGBS is used to create long-lasting concrete structures.

5. Copper Slag

Copper slag is the by-product of matte smelting and refining copper. Copper slag is used in concrete, which benefits the environment as well as all businesses involved.

6. Iron Slag

Concrete strength can be increased by partially replacing fine aggregate with iron slag. Because sand is more expensive, discarded iron slag is used as a substitute. Slag waste is less expensive and increases the strength of concrete by 30-40%. Pollutants are reduced by iron slag. Slags can be used as the main component of fine aggregates due to their improved pozzolanic properties.

7. Cement

The cement used in the experiments is Ordinary Portland Cement (OPC). Ordinary Portland Cement of Grade 53 (Birla Super OPC) in accordance with IS:8112-1989 is used. The cement is dry powdery, with high-quality chemical compositions and physical properties. Many tests were performed on cement, including specific gravity, consistency tests, setting time tests, compressive strengths, and so on.

Table 1. Basic Test Results on Cement.

Test	Method	Results	Specification According to IS: 12269-1987
Normal Consistency	IS: 4031-1988	29%	25-35%
Initial Setting		29 min.	Max 30min.
Final Setting		600 min.	Max 600min.
Pan		7.5%	Less than 10%
Total Weight		3.12	3.15

8. Aggregates

The term 'aggregate' refers to any particulate material. Gravel, crushed stone, sand, slag, recycled concrete, and geosynthetic aggregates are all part of it. Aggregate can be natural, synthetic, or recycled. The majority of the concrete mix is made up of aggregates. They give concrete compressive strength and bulk. Aggregates in any concrete mix are chosen for their durability, strength, workability, and ability to accept finishes. Aggregates for a good concrete mix must be clean, hard, and strong particles free of absorbed chemicals or coatings of clay and other fine materials that could cause concrete deterioration. Aggregates are classified as either 'coarse' or 'fine'. 'Coarse aggregates are particles larger than 4.75mm in size. The standard diameter range is between 9.5mm and 37.5mm.

M-sand, which is sourced from a nearby quarry, is used for fine aggregates and the coarse aggregates also have been obtained from the same. The most common aggregate size used in construction is 20mm. In mass concrete, a larger size, 40mm, is more common.

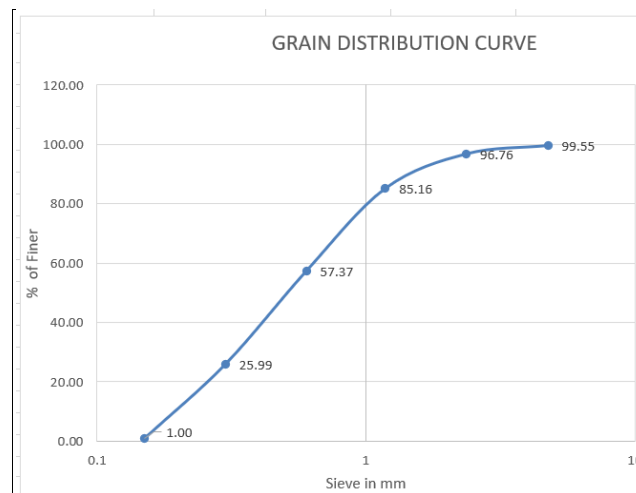
Table 2. Particle Size Analysis.

IS Sieve Size (mm)	Particle Size	Weight Retained (gm.)	Cumulative Weight Retained	Cumulative % Retained	% of Finer
4.75	4.75	2	2	0.45	99.55
2.36	2.36	14	16	3.24	96.76
1.18	1.18	58	74	14.84	85.16
0.6	0.6	139	213	42.63	57.37
0.3	0.3	157	370	74.01	25.99
0.15	0.15	125	495	99.00	1.00
Pan	-	5	500	100.00	0.00
Total Weight		500		233.65	

9. Water

Water is an essential component of concrete because it participates in the chemical reaction with cement. Because it contributes to the strength of the cement gel, the quantity and quality of water must be carefully considered.

Fig. 1. Grain Size Distribution



Specific gravity of the fine aggregates used for the study is 2.62. Water absorption of the fine aggregates used for the study is 0.90%. Fineness Modulus of the fine aggregates is 2.336 from the Graph shown below.

10. Superplasticizers

Superplasticizers (SP) are additives used in the production of high strength concrete. They are also known as high range water reducers. Plasticizers are chemical compounds that enable the production of concrete with up to 15% less water content.

Table 3. Results on Tests on Coarse Aggregates

IS Sieve Size (mm)	Particle Size	Weight Retained (gm.)	Cumulative Weight Retained	% of Finer
Toughness	Aggregate Impact Value	IS: 2386 (Part-4)	16.85%	Max. 30%
Hardness	Los Angeles Abrasion Test		23.5%	Max. 35%
Crushing Strength	Crushing Value Test		20.2%	Max. 30%
Particle Shape	Combined Flakiness and Elongation Index	IS:2386 (Part-1)	18.33%	Max. 35%
Porosity	Water Absorption	IS:2386 (Part-3)	0.2%	Max. 2%
Strength/Quality	Specific Gravity		2.65	2.5 - 3.2

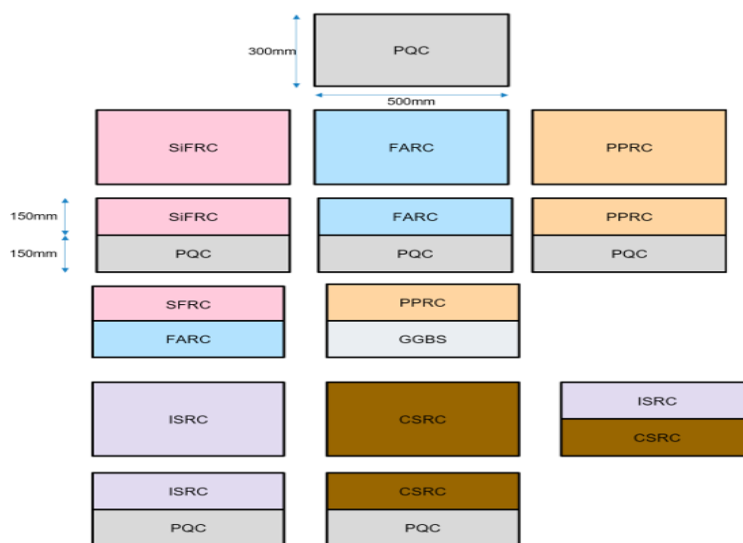
1. Method

In this study, the preferred characteristic strength of 40 N/mm² at 28 days was used. The IS:456 method was used to design the mix. This experiment produced a total of fourteen prototype moulds, eight of which were composite moulds. A composite mould is made up of two distinct layers in which the various layers of concrete are placed. The first layer of concrete is laid, followed by the second layer after 30 minutes of initial setting time. The prototype mould measures 500mm X 500mm X 300mm and is made of steel. The concrete is hand mixed and then placed in the manner shown below. The thermocouples are then installed after the concrete is placed in the mould.

Thermocouples are used to measure temperature by inserting one end into the mould and measuring the other end with a digital thermometer. The thermometer is placed in three layers, one on top, one in the middle, and one on the bottom. Following that, the prototype moulds are cured for 28 days, and temperature variations in the Top, Middle, and Bottom layers are recorded for 7 days continuously, with one-hour readings recorded for each. The temperature variation is then analyzed for CFD values.

Different Pavement Sections considered are Pavement Quality Concrete (PQC), Silica Fume Reinforced Concrete (SFRC), Fly Ash Reinforced Concrete (FRC), Polypropylene Fiber Reinforced Concrete (PPRC), ISRC (Iron Slag Reinforced Concrete), CSRC (Copper Slag Reinforced Concrete), SFRC+PQC, FARC+PQC, PPRC+PQC, PPRC+GGBS, SFRC+FARC, ISRC+PQC, CSRC+PQC, ISRC+CSRC.

Fig. 2. Different Pavement Sections Considered



3.3 Mix Design

The following are the exact mix proportions for M40 grade concrete, Fly Ash, Silica Fume, GGBS, Iron Slag, and Copper Slag. In these, Fly Ash is replaced by about 30%, Silica Fume by 30%, and 0.25 percent polypropylene fibre is added to the concrete mixture. GGBS is also replaced by 40%. Following that, approximately 30% of the concrete mixture is replaced with iron slag and copper slag.

Table 4. Mix Proportion of M40 grade PQC

Materials	Quantity (kg/m ³)
Cement	392
Iron Slag/ Copper Slag	200
Water	149
Fine Aggregates	465
Coarse Aggregates	1194
Chemical Admixture	1.96
Water Cement Ratio	0.38

Table 5. Mix Proportion of Iron Slag and Copper Slag

Materials	Quantity (kg/m ³)
Cement	372.5
Water	149
Fine Aggregates	754
Coarse Aggregates	1135
Chemical Admixture	1.96
Water Cement Ratio	0.4

Table 6. Mix Proportion of Fly Ash Table 7. Mix Proportion of Silica Fume

Materials	Quantity (kg/m ³)
Cement	310
Fly Ash	123
Water	149
Fine Aggregates	721
Coarse Aggregates	1079
Chemical Admixture	1.96
Water Cement Ratio	0.4
Materials	Quantity (kg/m ³)
Cement	360
Silica Fume	50
Water	149
Fine Aggregates	665
Coarse Aggregates	1195
Chemical Admixture	1.96
Water Cement Ratio	0.36

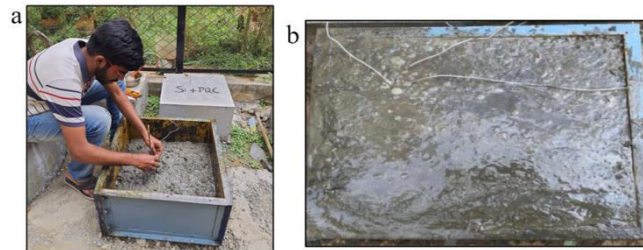
Table 8. Mix Proportion of GGBS

Materials	Quantity (kg/m ³)
Cement	250
GGBS	163.9
Water	149
Fine Aggregates	648
Coarse Aggregates	1197
Chemical Admixture	1.96
Water Cement Ratio	0.36

Fig. 3. (a) Mixing of Concrete; (b) Addition of Admixtures



Fig. 4. (a) Placement of Thermocouples; (b) Finished Slab Mould



IV. RESULTS AND DISCUSSIONS

After the temperatures are noted down, Cumulative Fatigue Damage (CFD) is determined as per IRC-58:2015 for single and composite sections. The CFD values are calculated by considering both with shoulder and without shoulder conditions. The Tables 4 and 5 showing Maximum positive day time and night time temperature differential of Different composite sections of Cement concrete slabs during Summer season (From day 1 to 7).

Table. 8. Max. Positive Day Time Temperature Differential

Slabs	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
PQC	15	14	14	12	15	16	11
SF	12	11	10	12	11	10	10
SF+PQC	10	11	9	10	11	10	11
FA	12	11	12	14	13	14	12
FA+PQC	13	12	11	13	12	13	12
PP	13	11	12	13	11	12	13
PP+PQC	12	11	11	12	10	12	11
PP+GGBS	11	11	9	10	11	10	11
SF+FA	11	11	10	11	11	10	11
IS	9	10	11	9	9	10	10
IS+PQC	6	7	6	7	7	6	7
CS	9	8	9	9	8	9	9
CS+PQC	7	8	8	7	7	8	7
IS+CS	6	7	6	7	7	6	7

Table 9. Max. Positive Night Time Temperature Differential

Slabs	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
PQC	-11	-12	-11	-10	-12	-10	-12
SF	-10	-9	-8	-10	-10	-9	-9
SF+PQC	-8	-9	-8	-8	-9	-9	-10
FA	-10	-10	-10	-12	-12	-12	-10
FA+PQC	-12	-10	-9	-11	-10	-11	-10
PP	-11	-10	-10	-11	-10	-11	-11
PP+PQC	-10	-9	-9	-10	-8	-10	-9
PP+GGBS	-10	-9	-8	-8	-9	-8	-9
SF+FA	-9	-9	-8	-9	-9	-8	-9
IS	-8	-8	-9	-8	-8	-8	-9
IS+PQC	-6	-7	-7	-7	-7	-6	-6
CS	-7	7	-7	-8	-7	-7	-7
CS+PQC	-6	-6	-6	-6	-5	-6	-5
IS+CS	-4	-5	-5	-5	-6	-5	-6

Fig. 6 is showing the Variation of maximum positive temperature differential of single and composite sections of cement concrete slabs during Summer season (From day 1 to 7) and followed by Fig. 7 and Fig. 8 showing CFD values with and without Shoulder bars.

Fig. 6. Variation of Maximum Day Time Temperature Differential

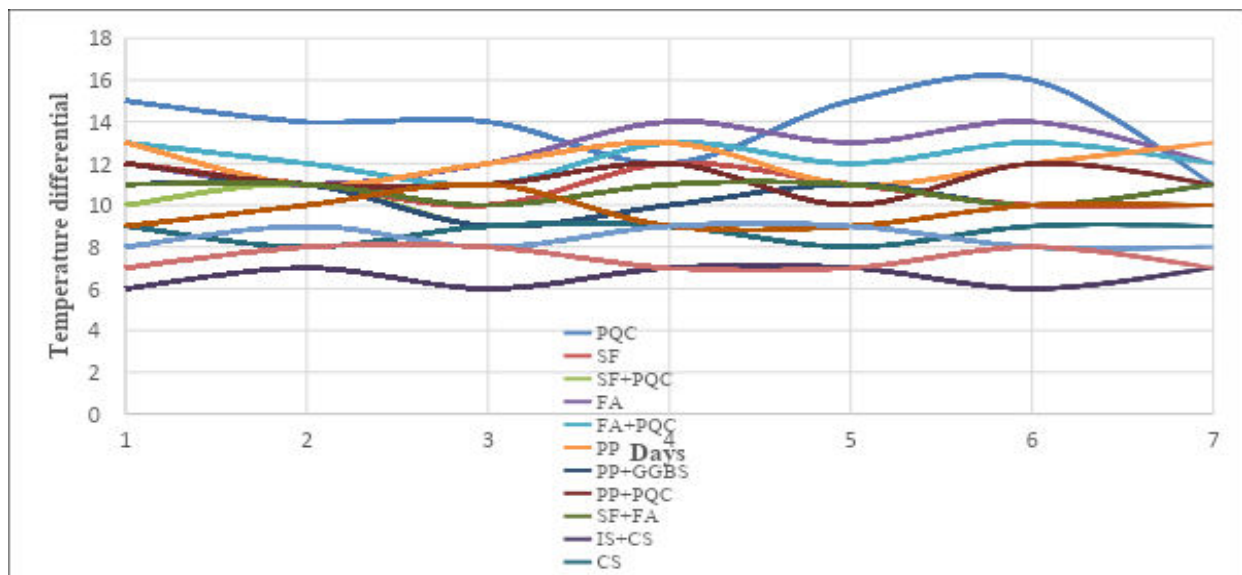


Table. 10. Cumulative Fatigue Damages of Single and Composite Sections without Shoulder Bars

Slabs	CFD for Bottom-Up Cracking Case			CFD for Top-Down Cracking Case				Sum of BUC and TDC CFD	Remarks
	Due to Rear Single Axles	Due to Tandem Axles	Total CFD	Due to Rear Single Axles	Due to Tandem Axles	Due to Tridem Axles	Total CFD		
PQC	8.426	0.179	8.606	1.583	2.164	0.263	4.009	12.615	Unsafe
SF	1.529	0.000	1.529	0.093	0.204	0.007	0.304	1.833	Unsafe
SF+PQC	0.866	0.000	0.866	0.026	0.079	0.002	0.107	0.973	Safe
FA	3.910	0.016	3.926	0.497	0.804	0.065	1.366	5.292	Unsafe
FA+PQC	2.514	0.000	2.514	0.236	0.433	0.026	0.695	3.209	Unsafe
PP	2.514	0.000	2.514	0.236	0.433	0.026	0.695	3.209	Unsafe
PP+PQC	1.529	0.000	1.529	0.093	0.204	0.007	0.304	1.833	Unsafe
PP+GGBS	0.866	0.000	0.866	0.026	0.079	0.002	0.107	0.973	Safe
SF+FA	0.866	0.000	0.866	0.026	0.079	0.002	0.107	0.973	Safe
IS	0.866	0.000	0.866	0.026	0.079	0.002	0.107	0.973	Safe
IS+PQC	0.205	0.000	0.205	0.000	0.000	0.000	0.000	0.205	Safe
CS	0.205	0.000	0.205	0.000	0.000	0.000	0.000	0.205	Safe
CS+PQC	0.073	0.000	0.073	0.000	0.000	0.000	0.000	0.073	Safe
IS+CS	0.022	0.000	0.022	0.000	0.000	0.000	0.000	0.022	Safe

Fig. 7. Graph of CFD values without Shoulder

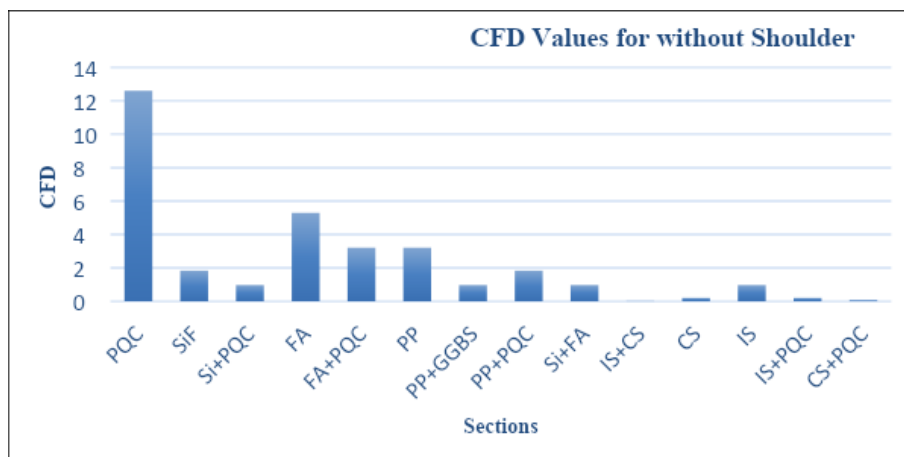
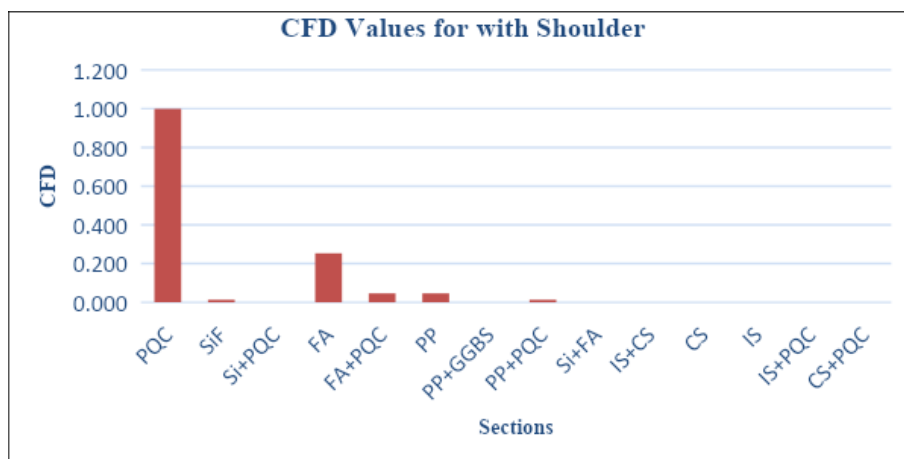


Table. 11. Cumulative Fatigue Damages of Single and Composite Sections with Shoulder Bars

Slabs	CFD for Bottom-Up Cracking Case			CFD for Top-Down Cracking Case				Sum of BUC and TDC CFD	Remarks
	Due to Rear Single Axles	Due to Tandem Axles	Total CFD	Due to Rear Single Axles	Due to Tandem Axles	Due to Tridem Axles	Total CFD		
PQC	0.607	0.000	0.607	0.134	0.246	0.015	0.395	1.000	Safe
SF	0.013	0.000	0.013	0.000	0.000	0.000	0.000	0.013	Safe
SF+PQC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	Safe
FA	0.137	0.000	0.137	0.090	0.026	0.000	0.116	0.253	Safe
FA+PQC	0.046	0.000	0.046	0.000	0.000	0.000	0.000	0.046	Safe
PP	0.046	0.000	0.046	0.000	0.000	0.000	0.000	0.046	Safe
PP+PQC	0.013	0.000	0.013	0.000	0.000	0.000	0.000	0.013	Safe
PP+GGBS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	Safe
SF+FA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	Safe
IS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	Safe
IS+PQC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	Safe
CS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	Safe
CS+PQC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	Safe
IS+CS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	Safe

Fig. 8. Graph of CFD values with Shoulder



V. CONCLUSION

- In single and composite concrete sections, the maximum temperature differential value is lower than PQC.
- Due to the greatest temperature difference compared to other parts, the composite section of IS+CS has a low stress value.
- The warping stress in the IS+CS section decreases as the temperature differential in the IS+CS section decreases. The stresses at BUC and TDC for all single and composite sections of slab with shoulder are less than one, indicating the structure is safe, according to IRC: 58-2015 cumulative fatigue damage analysis.

- According to IRC:58-2015, all single and composite slab sections without shoulders, with the exception of SF, FA, PP, PP+PQC, and FA+PQC, have stresses at BUC and TDC that are less than one, suggesting that the structure is secure.
- Compared to all other single and composite sections, the IS+CS slab composite section has a lower CFD value. Composite sections would be preferable for future traffic since they are practical.
- Because of the decreased overall stresses in the pavements, the pavement thicknesses will be lower than those of CC pavements. Bituminous overlays are less expensive to create initially and to maintain than concrete overlays. Over time, however, concrete overlays are more economical.

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