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Structural Behavior of High Strength High Performance Concrete Pavement under Heavy Loads

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***Abstract* - Three high performance semi full scale concrete pavements of size 1800 mm x 1800 mm having varying thicknesses were cast over compacted subgrade. Loads were applied at critical locations corner, edge and centre. It had been found that strains and deflections were quite low at substantial high loads. The load carrying capacities of the pavement at each location were sufficiently high. Due to high modulus of elasticity of concrete and load dispersion characteristics over larger area, the pavement could be laid over the weaker soil also. Thinner pavement of high performance concrete having longer design life and lower maintenance could be constructed as compared to normal concrete for the same load. This leads to greater saving in natural aggregate.**

I. INTRODUCTION

Cement concrete roads have made a come-back in India after a gap of many years. Delhi-Mathura road, the Mumbai-Pune Expressway and Indore Bypass have been constructed with cement concrete. With the construction of these projects and realizing the advantages of cement concrete roads, we are mentally ready to adopt the rigid pavements. More projects are under implementation. By now, approximately in all rigid pavement projects, the concrete grades of M30 or M40 had been used on a sub-base of dry-lean concrete. The design pavements thicknesses range from 30 to 35cm and even more. With the invention of plasticizer and super plasticizer, it has now been possible to produce the concrete of much higher strength. Today, concrete of more than 100 MPa designed strength are being used in bridges construction. The interest in high strength high performance concrete has grown over the last decades of the 20th century. High strength high performance is being frequently used in high rise buildings and bridges deck. High strength high performance concrete could be used in highway rigid pavements. By the use of HSHPC, it will not only reduce the design thickness of pavements but could also design the pavements for longer design period due to higher durability and impermeability. Which will result in lower life cycle cost and economical compared to flexible pavements. In present investigations, the HSHPC concrete of grade M60 with fly ash has been used.

II. OBJECTIVES OF THE STUDY

The study was conducted with the following objectives -

(i) To assess the suitability of high performance concrete for laying highway pavements over prepared subgrade. For this, strength characteristic parameters of concrete like as compressive strength, flexural strength and modulus of elasticity had been tested. Plate load test was conducted on prepared subgrade.

(ii) To study the strains and deflections behavior of high performance concrete pavement with loads.

(iii) To assess the maximum load carrying capacity of pavement at different locations like as central, edge and corner position at flexural strength.

(iv) To study the crack patterns under different critical loading positions.

(v) To carry out economic analysis of pavement.

III. REVIEW OF LITERATURE

With the understanding of the potential advantages of high strength high performance concrete (HSHPC) due to its ease of placement and consolidation, long term mechanical properties, higher toughness, higher abrasion resistance, higher volume stability, extended life in severe environment, its use is increasing day by day. High strength high performance concrete (HSHPC) is being used, generally, in all kind of civil engineering structures like as in Tall Buildings, Bridges, Tunnels and Highways etc. Due to the above advantages, the interest is continuously increasing in use of HSHPC in highway pavements. With the use of HSHPC in pavement, pavement could be designed for longer design life and lower maintenance cost that will result in low life - cycle cost.

High-strength high-performance concrete have been used for rehabilitation of Bridge decks. In Washington, twelve bridges decks were rehabilitated with latex modified concrete. But the results were not satisfactory. In Virginia, the bridge decks were rehabilitated with silica fume (7% to 10%) concrete. The results showed that silica fume concrete can be used as an alternative to LMC.

In Oregon, the bridges decks were rehabilitated using micro silica modified concrete [Miller, 1991]. The overlay met two design objectives of their three after one year in service. They were adding strength to the deck and providing a smooth and durable wearing surface. Because of cracks, they could not retard the intrusion of chlorides to the underlying deck. Sprinke et. al., studied the polymer concrete overlay. He suggested polymer concrete constructed with epoxy, methacrylate and polyster styrene binders and graded silica and basalt aggregate can provide skid resistance and protection against chloride intrusion for 1 to 20 years.

High-performance concrete can be employed as thin overlays of concrete by 100 mm over old flexible pavement. This is called white-topping. This technique is being adopted by U.S.A. and some North-West European countries. This technique was also in use earlier decades of twenty century..

In Norway, to overcome the increased wear resistance of steel studded tires, high strength concrete has been used in highway pavements. 18 cm thick pavement was laid by using 90 MPa concrete in 1989. After 4 year of service pavement performed as per expectation to meet the wear resistance of HSC. But some longitudinal cracks have been observed, near to the some of joints. This problem is probably due to insufficient thickness of pavement and also due to fatigue. In Sweden and Norway, there are many cases of using high strength concrete for highway pavements to improve the abrasion resistance .

IV. WHY CALLING HSHPC

As per Indian Standard, the concrete having strength 60 MPa or more, are known as high strength concrete. Various researchers found that by using the fly ash in concrete, there are number of benefits like as higher ultimate strength, improved workability, reduced bleeding, reduced heat of hydration, reduced permeability, increased resistance to sulphate attack, lower cost, reduced shrinkage and high durability. In development of mix 11% fly ash by weight of cement had been used.

VI. EXPERIMENTAL PROGRAMME

Locally available coarse and fine aggregate having fineness modulus 6.7 and 2.89 respectively had been used in the development of M60 grade concrete for laying the concrete pavements. Trial mix having mix proportion 1:1·1:1·9 was adopted with water cementitious ratio 0·29. Fly ash was used approximately 11% and 1.6% high range water reducer Sikament N-170 was used by weight of cement. It is modified naphthalene formaldehyde sulphonate type. It is dark in brown and specific gravity is around 1.16 to 1.20. It complies with IS: 9103, ASTMC 494 Type-F and BS: 5075 Part-3, IS: 6925. Ordinary Portland cement, grade-43, confirming to IS: 8112-1989 was used throughout the investigations.

The cubes of size 150 mm x 150 mm x 150 mm, beams of size 100 mm x 100 mm x 50 mm and cylinders of size 150 mm diameter and 300 mm height were cast for determination of compressive strength, flexural strength and modulus of elasticity as per IS-16-1959.

Plate of size 750 mm was used in Plate Load Test for finding out modulus of subgrade reaction.

Using the mix developed in the lab of M60 grade, the three concrete pavement slab of size 1800 mm x 1800 mm of varying thicknesses 160 mm, 200 mm and 240 mm were cast.

V. TESTING OF PAVEMENTS

All concrete pavements slabs were tested for corner, edge and central loading conditions. Plate of size 300 mm was used in testing of concrete pavements. Before carrying out tests for different positions, the pavement surface was cleaned and white washed. Studs were pasted with araldite. Arrangement for testing was made. The dial gauges and studs were numbered for each position of testing. The surface was leveled by spreading fine sand and 300 mm diameter plate was seated over it. Initially a seating load of 5 KN was applied for 2 minutes to ensure proper seating. A proving ring and hydraulic jack of capacity 50 tonnes was used. The initial strains and deflections were recorded. The load was applied in increment and retained for 40 to 60 seconds. The readings of deflections and strains were recorded for incremental loading. The loading was applied up to the capacity of loading frame i e. 23 tonnes.

VII. RESULTS

The strength parameters of soil and concrete are shown in Table 1 and Table 2.

Table 1: Characteristics of Roorkee Soil

Sl. No	Type of soil	K. value of subgrade (KN/mm^3)	CBR (%)	OMC (%)	Dry unit weight (g/cm^3)
1	Sandy soil, A-3 as per U.P.S.R.A. soil classification	0.0463	6	11	1.92

Table 2: Characteristics of High Strength High Performance Concrete

Sl. No.	Average compressive strength (N/mm^2)		Flexural strength (N/mm^2)		Modulus of elasticity (N/mm^2)	Slump (mm)
1	7-days	28-days	7-days	28-days	28-days	
	42.47	63.5	4.82	6.4	$4.17x 10^4$	30

The results of observed deflections with loads for different thicknesses of pavements are shown in following Tables.

Table 3: Deflections at Different Loading at Different Positions for 160 mm Thick Pavement

Sl. No.	Loads in KN	Deflections at corner (mm)	Deflections at edge (mm)
1	50	4.33	3.47
2	100	8.25	5.53
3	130	11.45	
4	150		7.65
5	200		9.23
6	210		10.06

Table 4: Deflections at Different Loading at Different Positions for 200 mm Thick Pavement

Sl. No.	Loads in KN	Deflections at Corner (mm)	Deflections at Edge (mm)	Deflections at Centre (mm)
1	50	3.22	2.27	1.9
2	100	6.63	4.43	2.92
3.	150	11.33	7.03	3.73
4.	200	14.53	9.17	4.43
5.	230	18.53	10.73	4.78

Table 5: Deflections at Different Loading at Different Positions for 240 mm Thick Pavement

Sl. No.	Loads in KN	Deflections at Corner (mm)	Deflections at Edge (mm)	Deflections at Centre (mm)
1	50	2.85	2.03	0.7
2	100	4.81	3.63	1.28
3.	150	7.51	5.65	1.87
4.	200	12.35	6.97	2.38

The results of observed longitudinal strains with loads for different thicknesses of pavements are shown in following Tables.

Table 6: Longitudinal Strains at Different Loading for Different Position for 160 mm Thick Pavement

Sl. No.	Loads in KN	Strain in micron (μ) at corner	Strain in micron (μ) at edge
1	50	142.6	120.3
2	100	287.4	255.14
3	130	320.3	-
4	150	-	331.14
5	200	-	398.09
6	210	-	418.0

Note 1-Central position could not be tested due to failure of slab at edge position

Table 7: Longitudinal Strains at Different Loading for Different Position for 200 mm Thick Pavement

Sl. No.	Loads in KN	Strain in micron (μ) at corner	Strain in micron (μ) at edge	Strain in micron (μ) at centre
1	50	98.5	85.74	62.45
2	100	195.25	165.56	117.3
3	150	292.5	235.93	167.4
4	200	360.6	307.45	255.6
5	210	375.2	-	-
6	230	-	312.8	275.3

Table 8: Longitudinal Strains at Different Loading for Different Position for 240 mm Thick Pavement

Sl. No.	Loads in KN	Strain in micron (μ) at corner	Strain in micron (μ) at edge	Strain in micron (μ) at centre
1	50	70.25	55.1	45.3
2	100	135.4	101.85	85.25
3	150	193.30	138.99	120.9
4	200	240.3	176.98	162.7
5	230	-	207.36	182.5

The experimentally maximum loads carried by the pavements are shown in the following Table.

Table 9: Experimentally maximum loads carried by the pavements

Sl. No.	Pavement thickness in mm	Positions	Experimentally applied maximum load in KN
1	160	Centre Edge Corner	- 220 130*
2.	200	Centre Edge Corner	230* 230* 210*
3.	240	Centre Edge Corner	230* 230* 200*

Note 2 * Pavement slab did not fail upto the capacity of loading frame.

A. Crack Patterns:

The HSHPC pavements of size 1800 mm x 1800 mm with different thicknesses had been tested for edge, corner and central position. Only 160 mm thick pavement failed under edge loading condition. Rest of the pavements did not show any kind of failure at any position i.e. central, corner and edge position. For 160 mm thick pavement at edge position, the pattern of the crack was straight line passing through under the testing plate. The crack width was 1.86 mm under the loaded condition. There was sudden failure from bottom to top. Prior failure, there was no visible crack from sides. The pavement failed at 220 KN load at edge position.

B. Economic Analysis

Economic analysis of HSHPC pavements were carried out as per P.W.D., SOR (Schedule of Rate) year 2013, and compared with two lane single carriage way highway flexible pavement, designed for 360 commercial vehicles per day having CBR value 6% and traffic 5 msa. It had been found that life cycle construction / maintenance cost for HSHPC pavements are low as compared to flexible pavement.

Table 10: Life Cycle Construction / Maintenance Cost for HSHPC Pavements and Flexible Pavements

Sl. No.	Pavement type	Initial construc-tion cost in lakhs	Life Cycle construction / Maintenance cost in lakhs	Percent Higher initial construction cost of rigid pavement	Percent Lower Life Cycle construction / Maintenance
1.	Flexible	110	236.14	-	-
2.	Rigid				
	160 mm	136.78	154.21	24.3	34.8
	200 mm	155.57	173.0	41.4	26.7
	240 mm	174.36	191.79	58.5	18.78

VIII. DISCUSSIONS

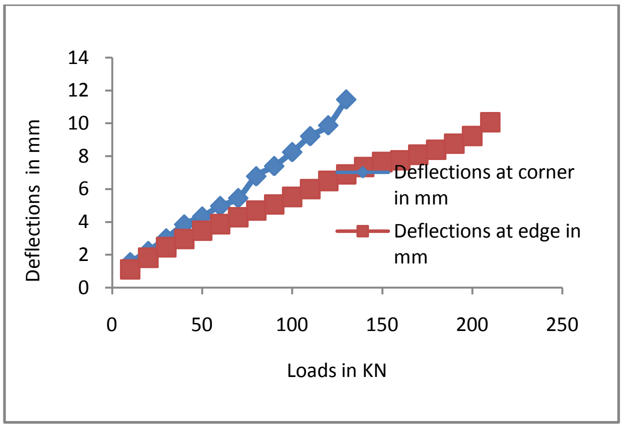

Fig1: Variation of Deflections with Varying Loads for Different Positions For 160 mm Thick Pavement

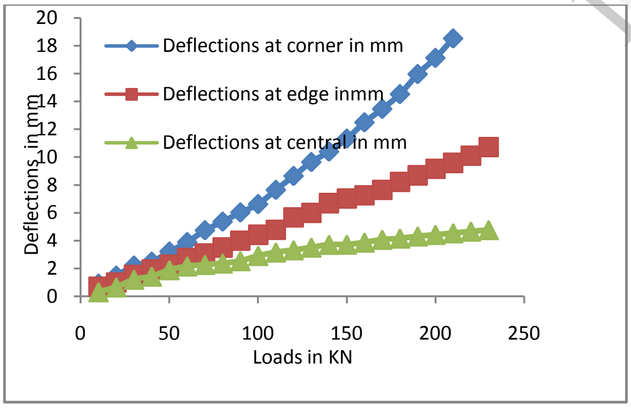

Fig. 2: Variation of Deflections with Varying Loads for Different Positions For 200 mm Thick Pavement

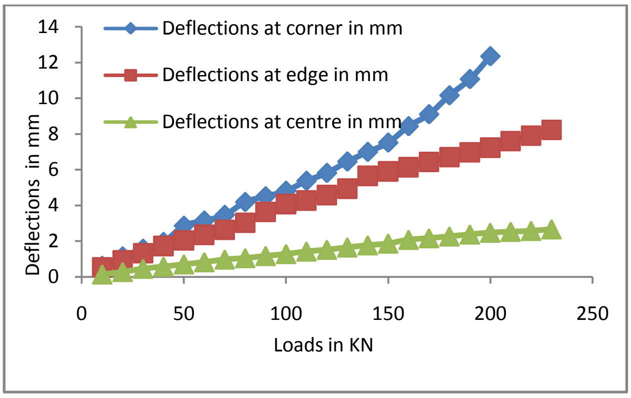

Fig. 3: Variation of Deflections with Varying Loads for Different Positions For 240 mm Thick Pavement

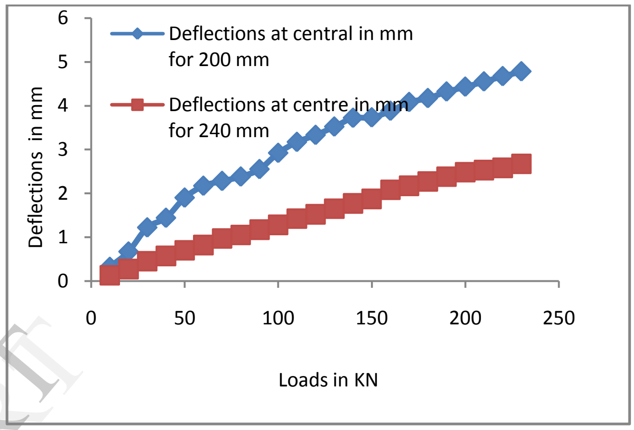

Fig. 4: Variation of Deflections with Varying Loads for Different Thicknesses of Pavement at Central Position

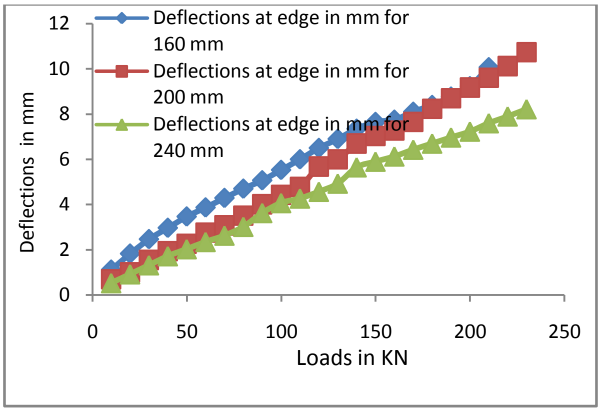

Fig. 5: Variation of Deflections with Varying Loads for Different Thicknesses of Pavement at Edge Position

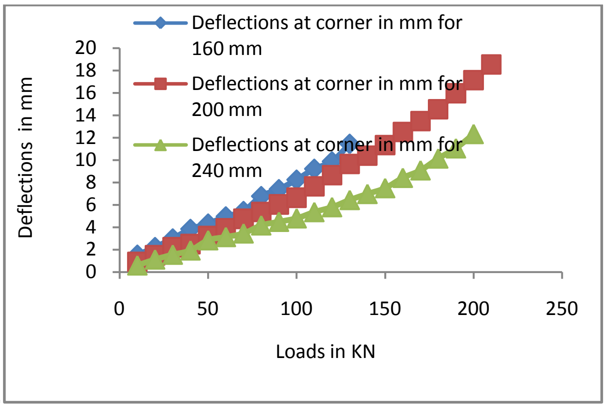

Fig. 6: Variation of Deflections with Varying Loads for Different Thicknesses of Pavement at Corner Position

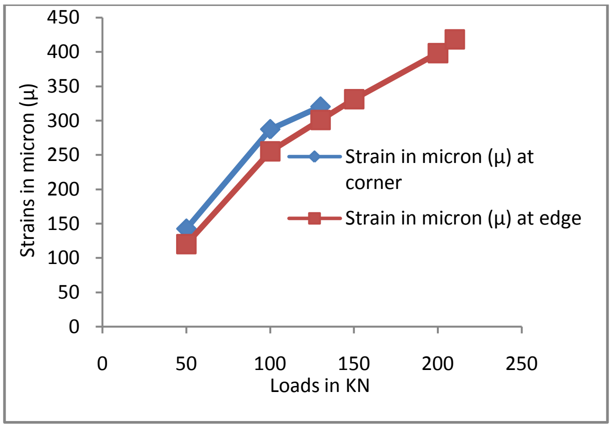

Fig. 7: Variation of Strains with Varying Loads for Different Positions For 160 mm Thick Pavement

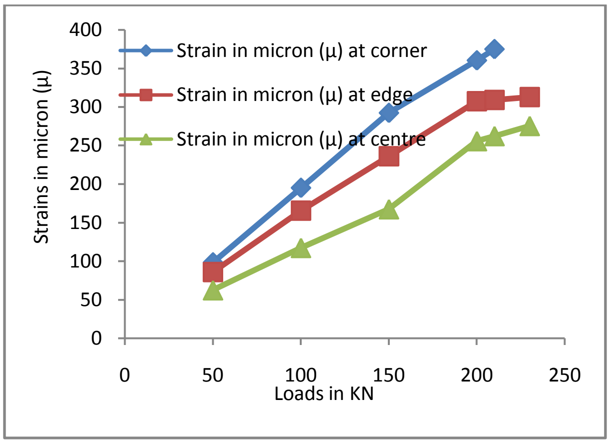

Fig. 8: Variation of Strains with Varying Loads for Different Positions For 200 mm Thick Pavement

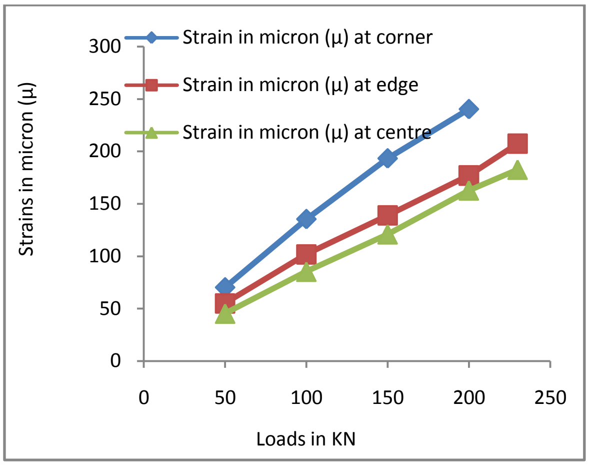

Fig. 9: Variation of Strains with Varying Loads for Different Positions For 240 mm Thick Pavement

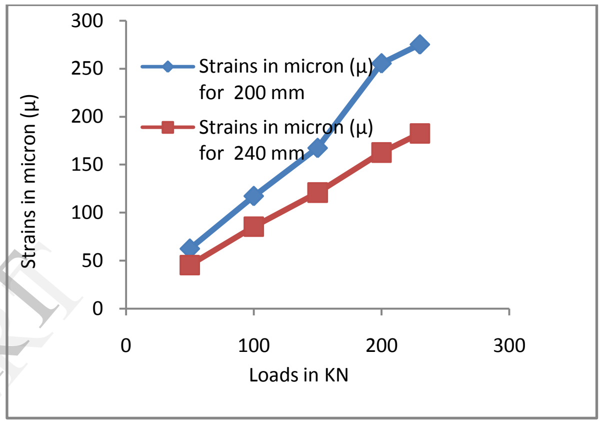

Fig. 10: Variation of Strains with Varying Loads for Different Thicknesses of Pavement at Central Position

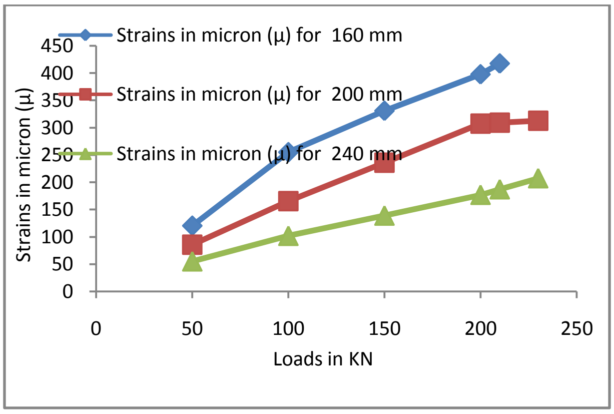

Fig. 11: Variation of Deflections with Varying Loads for Different Thicknesses of Pavement at Edge Position

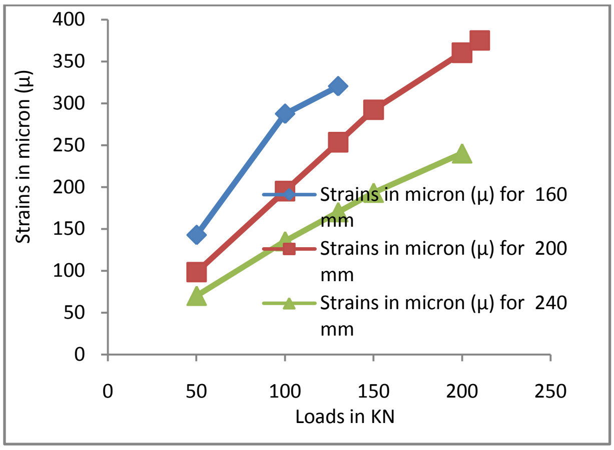

Fig. 12: Variation of Strains with Varying Loads for Different Thicknesses of Pavement at Corner Position

The 28 days compressive and flexural strength of the mix was found to be 63.5 MPa and 6.4 MPa respectively. The modulus of elasticity of the mix was found to be 4.17x 10^4 MPa. The poison's ratio of concrete 0.2 had been used in analysis.

The modulus of subgrade reaction over which pavements were cast was found 0.0463 N/mm3and CBR value 6%. The modulus of elasticity, 20.96 N/mm2 and poison's ratio 0.305 of soil were used in calculation.

For 160 mm thick pavement, for each position as the loads are increased, the deflections also increase. At corner, the maximum observed deflection is 11.46 mm at 130 KN load and at edge the maximum observed deflection is 10.07 mm at 210 KN load. This may be due to the higher flexural rigidity at edge position compared to the corner position. The variations are shown in Figure 1.

For 200 mm thick pavement, for each position the deflections keep on increase with increase in load. For the same load, deflection is highest at corner position and lowest at central position. This is may be due to the maximum flexural rigidity at central position and lowest at corner position. The maximum deflections observed were 18.53 mm at corner for 210 KN load and 10.73 mm at edge and 4.78 mm at central position for load 230 KN. The variations are shown in Figure 2.

The same trend of deflection with load was observed for 240 mm thick pavements. The maximum deflection was 12.35 mm for 200 KN load at corner position, 8.22 mm at edge and 2.67 mm at central position for 230 KN. The variations are shown in Figure 3.

It can also be noticed that for the same load, the deflections are continuously decreasing with increasing thickness for each position. This is may be due to increase in flexural rigidity with increase in thickness. It is evident from Figures 4,5&6.

From the above discussions, it is clear that deflections are quite low at higher load as the limiting deflection is 21.5 mm.

The strains were measured in both directions i.e. longitudinal and transverse direction. The strains in transverse directions are generally very low. That is why, strains in transverse directions had not been considered.

For 160 mm thick pavement, the strain is highest for corner position. Strains were measured 320.3 μ at 130 KN load for corner position and 418.0 μ for edge position at 210 KN. For the same load, the strain was higher for corner position than the edge position. The variations are shown in Figure 7.

For 200 mm thick pavement, the strains are highest for corner position and lowest for central position. This may be due to highest flexural rigidity near central position and lowest at corner position. Strains were measured 315.2 μ at 210 KN load for corner position, 312.8 μ at 230 KN load for edge position, and 275.3 μ at 230 KN for central position. The variations are shown in Figure 8.

The same trend of strains with load were observed in 240 mm thick pavement. The strains measured were 240.3 μ at 200 KN load for corner position, 207.36 μ at 230 KN load for edge position and 182.5 μ at 230 KN for central position. The variations are shown in Figure 9.
It can also be observed that for the same load, the strains continuously decrease with increase in thickness for each position. This is may be due to the increase in flexural rigidity with increase in thickness of pavement. It is manifest from Figures 10, 11 &12.
The crack pattern is straight line passing through under testing plate across the width. The failure is sudden.

Experimentally the load carrying capacities of pavements are exceptionally high for each positions and increase with increase in thickness.
The initial construction costs of concrete pavements are higher over flexible pavements by 24.3%, 41.4% and 58.5% for 160, 200 and 240 mm thick pavements respectively. But the life cycle construction / maintenance costs of concrete pavement over flexible pavements are lower by 34.8%, 26.7% and 18.78% for 160, 200 and 240 mm pavements respectively.

IX. CONCLUSIONS

From the above discussions following conclusions may be drawn:

1. The compressive strength of high strength high performance is 63.5 MPa and flexural strength is 6.4 N/mm^2.The modulus of elasticity is 4.13×10^4 and workability is 30 mm. All these parameters are as per requirement of laying of HSHPC pavement.
2. The super plasticizer 1.6% and flyash 11% by wt. of cement had been used.
3. The modulus of subgrade reaction is 0.0463 N/mm^2. The soil is sandy A-3 type as per U.S.P.R.A and CBR is 6%.
4. The observed deflections are quite small for all thicknesses of pavement as the limiting deflection is 21.5 mm. The HSHPC pavement showed low deflection laid on subgrade having modulus of subgrade reaction 0.0463 N/mm^2.This demonstrate that HSHPC pavement could be laid over weaker soil due to its greater load dispersion characteristics being higher modulus of elasticity 'E'.
5. At failure load i.e. 220 KN of 160 mm thick pavement at edge position, the strain observed was 418 µ. The 200 mm and 240 mm thick pavement at 230 KN load, the strains observed were 312.8 µ & 207.36 µ .which shows that 200 mm and 240 mm thick pavement could carry more load.
6. With increase in thickness, the strains and deflections keep on reduce for each locations due to increase in flexural rigidity. The deflections and strains are maximum at corner position and lowest at central position being highest flexural rigidity at central position and lowest at corner position.
7. The crack pattern is straight line and failure is sudden which is the characteristic of high strength concrete.
8. Experimentally the 160 mm thick pavement failed at 220 KN load at edge position and 200 mm and 240 mm did not fail up to 230 KN load. This shows that load carrying capacity of HSHPC pavements are very high. Hence HSHPC pavement could be used as heavy duty pavement.
9. Life cycle cost / maintenance are low as compared to flexible pavements. This shows that HSHPC pavements are economical.

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