ANALYSIS OF HPCC PAVEMENTS USING KENPAVE FEA SOFTWARE

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Abstract

A comprehensive research work on High Performance Cement Concrete (HPCC) pavements is being conducted at Bangalore University. As a part of the study static flexural strengths are determined for Conventional Concrete (CC), Silica Fume Concrete (SFC), High Volume Fly Ash Concrete (HVFAC), Fiber Reinforced Concrete (FRC), and Fiber Reinforced High Volume Fly Ash Concrete (FRHVFAC) using third point loading in the laboratory. Laboratory fatigue teats were also carried out on HPCC beam specimens and number of repetitions to failure determined. Using the results fatigue models and stress charts were developed and slab thicknesses of the HPCCs designed. In this paper an attempt is made to analyze the HPCC pavements using a 2-D Finite Element Analysis (FEA) software - KENPAVE. The critical flexural stresses obtained using the FEA software are compared with stresses obtained from the experimental study. The design life of the HPCC pavements is also analyzed using the FEA software. The variation in flexural stresses as obtained from FEA software when compared with actual flexural stresses ranges from 5 to 6 %. Damage analysis using FEA software shows that predicted design life obtained ranges from 1 to 12 % for various HPCCs. The 12 % variation is for Fiber Reinforced HPCCs indicating that the design life of fiber reinforced HPCCs are more.

Keywords: *high performance concrete, flexural stresses, finite element analysis software, damage analysis.*

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1. INTRODUCTION

ACI defines HPC as "Concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing and curing practices". Important governing factors for HPCs are strength, long term durability, serviceability as determined by crack and deflection control, as well as response to long term environmental effects.

A number of Finite Element Analysis (FEA) software is available for analyzing rigid pavements. These software's analyze pavements based on the finite-element method, in which the slab is divided into rectangular finite elements. KENPAVE is a 2D - FEA software developed by Huang [(10)] used in this study. To analyze rigid pavements using KENPAVE FEA software the inputs required are slab geometry, material properties and wheel load. The stresses and deflections of the slab, design life and cracking index are obtained as the outputs.

2. MIX PROPORTIONS AND STRENGTH PROPERTIES OF C CS AND HPCCS

Experimental studies were conducted by Kamalakar [1] on various HPCCs at Bangalore University. The designed mix proportions and strength properties of Conventional Concrete (CC), Silica Fume Concrete (SFC), High Volume Fly Ash Concrete (HVFAC), Fiber Reinforced Concrete (FRC), and Fiber Reinforced High Volume Fly Ash Concrete (FR HVFAC) obtained from the studies on the HPCC mixes are shown in Tables 1, 2 & 3.

Table 1 Proportions of different HPCC mixes

Mix	M1	M2	M3	M4	M5
Water / binder ratio	0.39	0.39	0.39	0.39	0.46
Super-plasticizer, % Rheobuild-816* Conplast ms 432**	0	0.5*	1.25*	1.5*	0.3**
Cement, kg/m^3	405	417	208.5	208.5	372.6
Fly ash /silica fume, kg/m^3	0	0	208.5	208.5	32.4

Steel fibers, %	0	1.25	0	1.25	0
Fine aggregate, kg/m^3	750	565.00	565.02	565.02	814.35
Coarse aggregate fraction –I, kg/m^3	720	786.00	786.00	786.00	676.36
Coarse aggregate fraction –II kg/m3	355	387.00	387.00	387.00	332.64
Water, kg/m^3	150	162.53	162.53	162.53	170.2
Slump, mm	13	14	15	14	20
Density of concrete, Kg/m^3	2500	2540	2350	2400	2550

Where,
M1- Conventional M30 grade Concrete (CC)
M2- Fiber reinforced Conventional M40 grade Concrete (FRC)
M3- High volume fly ash concrete (50 % replacement of cement with fly ash) (HVFAC)
M4- Fiber reinforced High volume fly ash concrete (FRHVFAC)
M5- Silica fume concrete (8% replacement of cement by silica fume) (SFC)

Table 2 Compressive Strength Test Results of Concrete Mixes

Sl. No.	Number of days of curing	M1, MPa	M2, MPa	M3, MPa	M4, MPa	M5, MPa
1	3	21.99	24.52	17.98	19.62	33.77
2	7	34.22	37.88	22.15	24.46	42.07
3	28	48.23	51.42	30.55	33.12	49.48
4	56	-	-	48.82	51.94	-

Table 3 Static Flexural Strength Test Results of Concrete Mixes

Sl. No.	No. of days	M1		M2		M3		M4		M5	
		Load kN	f_{cr} MPa	Load kN	f_{cr} MPa	Load kN	f_{cr} MPa	Load kN	f_{cr} MPa	Load kN	f_{cr} MPa
1	28	11.92	4.76	12.7	5.08	8.12	3.33	9.86	3.94	15.75	5.75
2	56	-	-	-	-	12.32	4.93	13.06	5.22	-	-

f_{cr} is the static flexural strength

3. DETERMINATION OF FLEXURAL STRESSES

Flexural stresses in CC and HPCC mixes, M1 to M5 for single axle loads ranging from 10 to 20 tons and tandem axle loads ranging from 16 to 36 tons for varying k-values and slab thicknesses are evaluated using IRC: 58:2002 [2]. Typical flexural stresses obtained under 36 ton tandem axle load and subgrade soil with k=10 MPa/m are shown in Table 4.

Table 4 Flexural Stresses (MPa) as per IRC:58-2002

Thickness mm	140	160	180	200	220	240	260	280	300	320	340
k = 10 MPa/m and 36 ton tandem axle load											
M1	6.33	5.24	4.41	3.76	3.25	2.83	2.49	2.21	1.97	1.77	1.60
M2	6.37	5.27	4.43	3.78	3.26	2.84	2.50	2.22	1.98	1.78	1.60
M3	6.47	5.34	4.49	3.83	3.30	2.88	2.53	2.24	2.00	1.79	1.62
M4	6.50	5.37	4.51	3.84	3.31	2.89	2.54	2.25	2.01	1.80	1.62
M5	6.56	5.41	4.54	3.87	3.34	2.91	2.56	2.27	2.02	1.81	1.63

4. COMPARISION OF FLEXURAL STRESSES

Flexural stresses obtained using IRC equation under 20 ton single axle load for 200 mm thick slab on sub grade soil with various k-values are compared with stresses obtained using FEA software. The comparisons are shown in Table 5.

Table 5 Stress Comparisons between IRC and FEA Software

Modulus of Sub grade reaction (MPa/m)	KENPAVE (MPa)	IRC:58-2002 (MPa)
k=60	3.85	3.63
k=80	3.61	3.45
k=100	3.44	3.32
k=150	3.33	3.07
k=300	2.87	2.65

It is observed that the flexural stresses determined using FEA software are 5 to 6 % more than flexural stresses determined by IRC equation.

5. DAMAGE ANALYSIS OF DESIGNED HPCC SLABS USING KENPAVE FEA SOFTWARE

The design thicknesses of the HPCC slabs considered in this study are arrived at for the axle load spectrum suggested in IRC: 58:2002.The parameters considered for the design and the thicknesses arrived at are shown in Table 6. All the slabs are designed for a 20 year design period.

Table 6 Parameters for design thickness

Type of Concrete	E, MPa	f_{ck}, MPa	f_{cr}, MPa	Thickness, mm
M1	31000	48	4.92	280
M2	32000	51	5.14	270
M3	35000	49	4.88	270
M4	36000	52	5.19	260
M5	38000	49	6.3	240

Where: E is the modulus of elasticity, fck is the characteristic compressive strength and fcr is the static flexural strength.

Damage analysis is conducted by using KENPAVE FEA software for the HPCC slabs designed. The same parameters considered in Table 6 and loads as per IRC axle load spectrum are considered as the input parameters in the FEA software. The design life and cracking index are determined by running the software. The results obtained are shown in Table 7. It is observed that the design life obtained is almost equal to the design period of 20 years except for fiber reinforced pavements. The design lives of fiber reinforced pavements are found to be 10 to 12% higher than the conventional concrete pavements

Table 7 Cracking Index and Design Life using FEA Software

Type of Concrete	Thickness, mm	E, MPa	$f_{ck,}$ MPa	$f_{cr,}$ MPa	Cracking Index	Design life, Years
M1	280	31000	48	4.92	0.050	19.74
M2	270	32000	51	5.14	0.042	23.46
M3	270	35000	49	4.88	0.052	18.98
M4	260	36000	52	5.19	0.039	25.26
M5	240	38000	49	6.30	0.048	20.66

CONCLUSIONS

The following conclusions are drawn by analyzing the HPCC pavements using KENPAVE FEA software:

- The flexural stresses determined using FEA software for the HPCCs analyzed are 5 to 6 % more than flexural stresses determined by IRC equation.
- The design life obtained by conducting damage analysis using KENPAVE FEA software is almost the same as the design period considered for CC and HPCC pavements without fibre reinforcement.
- The design life obtained for fiber reinforced HPC's slabs are more by 10 to 12% than the design period considered.

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