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Efficiency and Economic Analysis of No-Fines Concrete as Construction Material in Parking Lots

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Abstract: *Use of No-fines concrete as a building material is comparatively a new innovation. To determine the aptness of this type of concrete for constructing the pavement of a parking lot is the aim of this study. The thickness of the pavement made of no-fines concrete was decided on the basis of the engineering properties of the special concrete mixtures prepared in the laboratory, and various traffic conditions and sub-grade characteristics. The constant cement-aggregate ratio of 1: 5 was maintained for the development of the pervious concrete mixtures. The gradation of coarse aggregates used for this study comprised of 20-16mm, 16-13.2mm and 13.2-9.5mm and water-cement ratio was changed from 0.45 to 0.35. The compressive strength of the no-fines concrete mixtures after 28 days of curing was found to be in the range of 9-20 M Pa. The compressive strength of 18.22 M Pa was maximum and as such was used to design the safe thickness of the pavement of no-fines parking lot. The required thickness of the pavement was 400 mm. Further, the cost of the no-fines parking lot was estimated as Rs. 1,34,107 per 100 m^2 and was compared with the cost of the parking lot made of interlocking concrete blocks which was computed as Rs. 86,192 per 100 m^2. The difference was due to expensive materials and increased pavement thickness used to design the no-fines parking lot. However, in long term, the former is considered to be more cost effective due to its increased porosity and other numerous advantages.*

Keywords*: No-fines concrete, compressive strength, trial mix design, pavement thickness determination, cost analysis*

1. Introduction

No- fines concrete, as the name suggests, has very little or no content of fine aggregates and has an adequate amount of cementitious paste to coat the coarse aggregates while maintaining the interconnectivity of the voids. The amount of water should be apt to give a coating of cement paste on all the aggregates. Otherwise, the aggregates may get loose inside the concrete if the water is too less or segregation of cement from the concrete may take place if the water content is too high. Thus, no-fines concrete is basically a pervious building material with relatively large interconnected voids formed by mixing cement, water and single-sized coarse aggregates in an appropriate proportion.

Ever-increasing urbanization has resulted in escalation of the impervious land cover which further intensifies various environmental problems. The widening of the impervious land makes the infiltration of water through the soil difficult and the resulting increased runoff often causes flooding. Due to this, hydrology of a developing area gets severely impacted. Consequently, instability in the stream banks, increase in erosion of channel bed, reduction in recharge of groundwater, excessive silting and otherwise degradation in water quality can be expected.

This paper suggest a solution to all the above mentioned problems i.e. the utilization of no-fines concrete pavement for parking lots, footpaths, shoulders, cycle-tracks and other low-volume roads such as residential streets. Basically, the permeable pavements functions as a detention device which may temporarily detain the rainfall in the voids of no-fines concrete pavement (Ghafoori and Dutta [1]). It then allows the water to percolate through the slab and consequently boost the supply of ground-water. Also, this type of pavement can help in reducing the requirement of drains for storm management. Furthermore, it may also eradicate the problem of on-site standing water. Due to this, improvement in coefficient of friction and skid resistance can be experienced because of the resulting drier surface of the pavement. Large number of voids in the pavement may also reduce the frost damage. Moreover, reduction in tire pressure and pumping action can be expected in case of pervious pavements because of evaporation of water from the sub-base through large pores of the pavement. In addition to this, due to the light colour of the no-fines concrete pavement, it require less site lighting for safe night-time illumination levels on the parking lots. Also, the voids in the porous concrete used for constructing a parking lot around trees can actually help the environment by not cutting off the air and moisture to the roots below.

2. Historical Background

The application of no-fines concrete is not new to the world. Francis [2] mentioned its earliest application which was in 1852 for the construction of two houses and a seagryone 61m long and 2.15m high in the

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United Kingdom. Malhotra [3] find out that in 1923, the use of no-fines concrete was again introduced in the United Kingdom by Holland which resulted in the building of over 50 two-storey houses; and this count increased to over 900 houses made of this material by the 1940's. Maynard [4] quoted that pervious concrete was also utilized in Europe for constructing parking areas, roof pavements and some minor roads in Switzerland and England. In the United States, the use of this special concrete as a surface paving material for parking lots has been reported by Monahan [5] in New Mexico, Florida, and Utah whereas states like Oklahoma, California, Wisconsin and Illinois made its use as a permeable base course and to construct edge drains (Mathis[6]).

Ghafoori and Dutta [7] cited that a large proportion of these construction ventures took place in Florida because of the three factors. Firstly, due to its topographical features, Florida repeatedly experiences heavy thunderstorms that cause flash floods and quick pooling of water. The rapid excess runoff can be diminished by the use of no-fines concrete. Secondly, as per the state regulations, the storm water needs to be utilized for recharging the ground-water system which can be efficiently achieved by the use of no-fines concrete. Lastly, with the diminution in the requirement of storm sewers and storage facilities, the cost-effectiveness of using no-fines concrete over conventional concrete was impressively enhanced.

3. Objectives

The intention of the research presented is to execute the efficiency and economic analysis of no-fines concrete as a construction material in the parking lot.
To achieve the above said objective, various trial mixes were prepared by combining water, cement and coarse aggregates in different proportions. Out of the various mixes, a trial mix with the desired compressive strength was used to calculate an optimum thickness of the no-fines concrete pavement slab for a parking lot. To perform the economic analysis, the cost of the parking lot pavement made of no-fines concrete was studied and compared with that of the interlocking concrete paver blocks.

4. Experimental Programme

Figure 1 is the flowchart which depicts the methodology undertaken during the course of this investigation to achieve the above said objective.

4.1. Physical Characteristics of Materials Used

Coarse aggregates- The presence of coarse aggregates reduces the drying shrinkage and other dimensional changes occurring on account of movement of moisture. To achieve the desired objective of high porosity, it is obvious to use the single-sized coarse aggregate, otherwise voids will get reduced. Therefore, gradation of coarse aggregates used for this study includes 20-16mm, 16-13.2mm and 13.2-9.5mm. Aggregates confirmed the requirements of IS 383: 1970. The sieve analysis and other physical properties of coarse aggregates were determined as per their respective IS codes and are given in Table 1 and 2.

Cement- Binani's Portland Pozzolana Cement was used throughout this investigation. The physical properties of cement used have been determined as per their respective IS codes and the same are presented in Table 3.

Figure 1*: *Methodology

Table 1: *Gradation of Coarse Aggregates*

I.S. Sieve Size (mm)	% retained	% cumulative retained	% passing
20	1.6	1.6	98.9
16	21.9	23.5	78.1
13.2	29.4	52.9	70.6
9.5	39.65	92.55	60.35
Pan	7.45	100	-

Table 2: *Physical Properties of Coarse Aggregates*

Bulk Density (kg/m^3)		Specific Gravity
Rodded State	**Loose State**	
1580	1370	2.67

Table 3: *Physical Properties of Cement*

Consistency	**36%**
Initial Setting Time (min)	**162**
Specific Gravity	**3.131**
28 days Compressive Strength (N/mm^2)	**34.163**

4.2. Mix Design

The discovery of the ratio of single-sized coarse aggregates, cement and water possessing the most favorable properties is said to be the most appropriate mix design. For this study, nine trial mixes were designed using the estimated proportions. The mixes were prepared with the help of previous literature. Table 4 gives the mix proportions used for no-fines trial mixes.

Table 4: *Mix Proportion for No-Fines Trial Mixes*

Size of Aggregates	Cement-Aggregate Ratio	Water-Cement Ratio
	1 : 5	0.35
20-16 mm	1 : 5	0.40
	1 : 5	0.45
	1 : 5	0.35
16-13.2 mm	1 : 5	0.40
	1 : 5	0.45
	1 : 5	0.35
13.2-9.5 mm	1 : 5	0.40
	1 : 5	0.45

The no-fines concrete is designed on the basis of the strength required at a particular age. The relations between the w/c ratio and strength and between the a/c ratio and strength are given in Fig. 2. It is evident from Table 4 that the cement-aggregate ratio used to conduct this investigation was 1:5. This was done to make an attempt to obtain a mix design having compressive strength beyond 150 kg/cm^2**.**

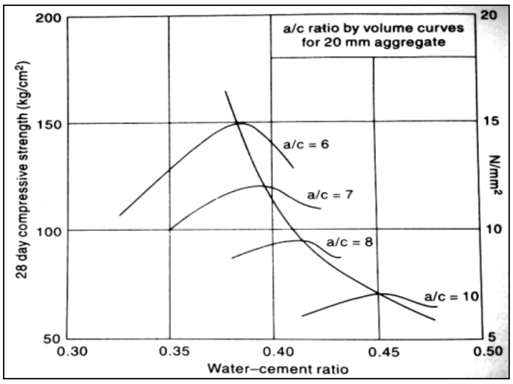

Figure 2: *Compressive Strength, w/c ratio, and a/c ratio for no-fines concrete*

4.3 Testing

Eight specimens for each trial mix were casted in moulds and left in place for 24 hours to allow ample bonding among the aggregates. After this, the specimens were demoulded and placed in the curing tank till the time of testing. The most appropriate mixture was selected out of all the trial mixes for the analysis. Fig. 3-5 shows the sample of each trial mix prepared. These samples can be differentiated with the help of visually distinguishing the size of aggregates used.

Four concrete cubes of each trial mix were tested for determining the water absorption values and the other four cubes in saturated surface-dried condition were tested for the 28 days compressive strength. Average of four specimens of each trial mix gave the result. The observations made after testing are tabulated in Table 5.

Figure 3: *Samples of no-fines concrete cube having varying size of aggregates (w/c ratio= 0.35; cement-aggregate ratio=1:5)*

Figure 4: *Samples of no-fines concrete cube having varying size of aggregates (w/c ratio= 0.40; cement-aggregate ratio=1:5)*

Figure 5: *Samples of no-fines concrete cube having varying size of aggregates (w/c ratio= 0.45; cement-aggregate ratio=1:5)*

Mix with the combination of aggregate-cement ratio 5:1 and water-cement ratio 0.40 along with 16-13.2 mm as the size of aggregate gave the maximum compressive strength of 18.22 N/mm^2 out of all the specimens.

Table 5: *Water Absorption & Compressive Strength of Trial Mixes of No-Fines Concrete*

Size of Aggregates	Cement-Aggregate Ratio	Water-Cement Ratio	Water Absorption (%)	28-days compressive strength (N/mm^2)
	1 : 5	0.35	3.42	16.3
20-16 mm	1 : 5	0.40	3.57	13.92
	1 : 5	0.45	3.77	11.11
	1 : 5	0.35	3.62	14.81
16-13.2 mm	1 : 5	0.40	3.68	18.22
	1 : 5	0.45	4.26	16.74
	1 : 5	0.35	4.24	9.63
13.2-9.5 mm	1 : 5	0.40	4.25	16.89
	1 : 5	0.45	4.32	17.03

The percent of water absorption of interlocking concrete paver blocks was also estimated as per ASTM C642-13. For this, the four interlocking paver blocks 80 mm thick were taken and each was weighed in saturated as well as in oven-dried condition. The difference in the two weights gave the amount of water absorbed by that block. 3.06% was the percent of water absorbed.

4.4 Design Of No-Fines Concrete Pavement Slab

This study used the Westergaard's theory mentioned in IRC: 58-2002 for designing the optimum thickness for the pavement slab made of no-fines concrete for a parking lot.

As per the code IS 12727: 1989, flexural strength of no-fines concrete pavement is given as 0.23 f_c, where f_c is the strength of cube at 28th day

Therefore, flexural strength= 0.23 X 18.22

= 4.1906 N/mm^2 = 42.73kg/cm^2

The values for the other parameters considered for the designing of no-fines concrete pavement slab are as follows:

Poisson's ratio, μ = 0.2

Elastic modulus of concrete, E = 1.5 X 10^5 kg/cm^2

Coefficient of thermal expansion, e = 10 X 10^{-6} /ºC

Contact pressure, p = 7.5 kg/cm^2

Design wheel load, P = 5100 kg (LMV)

Modulus of subgrade reaction, K = 7.6 kg/cm^3

Spacing of contraction joint = 3.5 m

Width of slab = 3.5 m

For Haryana, temperature differential in slab, t=15.8 ºC

Radius of load, $a=\sqrt{(P/p\Pi)}=\sqrt{(5100/7.5\Pi)}$ =14.71cm

Using hit and trial method, various values were supposed for the pavement thickness out of which the following value gave the desired result.

Trial pavement thickness, h = 40 cm

$$l=\left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{1/4} \quad (1)$$

$$l = \left[\frac{1.5 \text{ X } 10^5 \text{ X } 40^3}{12 \text{ X } 7.6(1-0.2^2)}\right]^{1/4} = 102.32\text{cm};\ a/h = 0.36 < 1.724$$

$$b=\sqrt{1.6a^2 + h^2}-0.675h \quad (2)$$

$$b = \sqrt{1.6(14.71)^2 + 40^2} - 0.675(40) = 17.11$$

$$l/b=5.98 \quad (3)$$

$$S_e=\frac{0.572P}{h^2}\left[4\log_{10}\left(\frac{l}{b}\right) + 0.359\right] \quad (4)$$

$$S_e=\frac{0.572 \text{ X } 5100}{40^2}\left[4\log_{10}(5.98) + 0.359\right]= 6.31 \text{ kg/cm}^2$$

$$St_{(e)}=\frac{C_x Eet}{2} \text{ or } \frac{C_y Eet}{2} \text{ (whichever is higher)} \quad (5)$$

Since L_x = 3.5m = L_y

And $\frac{L_x}{l} = \frac{350}{102.32} = 3.42$

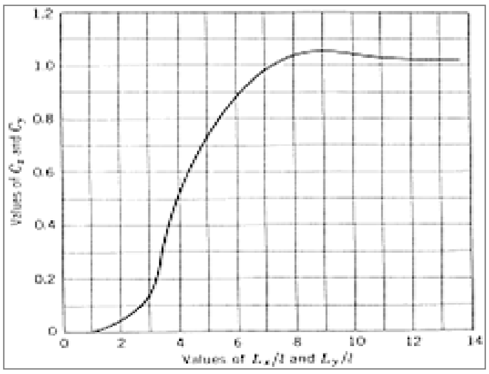

Figure 6: *Warping Stress Coefficient (By Bradbury)*

Therefore, using Bradbury graph, C_x = 0.3

$$St_{(e)} = \frac{C_x Eet}{2} = \frac{0.3 \text{ X } 1.5 \text{ X } 10^5 \text{ X } 10 \text{ X } 10^{-5} \text{ X } 15.8}{2}$$

= 35.55 kg/cm^2

Total stresses = 6.31 + 35.55

= 41.86 kg/cm^2 < 42.73 kg/cm^2

Also,

Factor of Safety= (Flexural strength/total flexural stress)

= 42.73/41.86 = 1.02

Therefore, pavement thickness of 400 mm was safe.

5. Cost Analysis

Figure 7. *Cross-section view of no-fines concrete pavement slab*

Figure 7 and 8 shows the cross- section view of the no-fines concrete pavement and interlocking concrete block pavement considered for their cost analysis respectively.

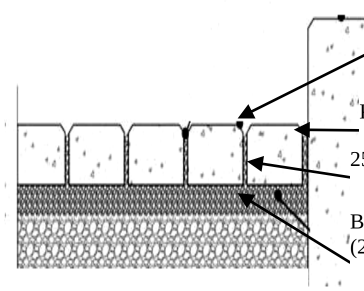

Figure 8 *Cross-section view of ICBP slab*

The cost of 100 m^2 of no-fines concrete pavement of a parking lot was analyzed and is given in Table 6.

In case of ICBP pavement, an area of 10 m X 10 m was considered for a parking lot surrounded by kerb blocks at the periphery of the area from the four sides leaving 3.5 m from two of its sides for the entry and exit of vehicles. Table 7 gives the cost analyzed for ICBP pavement for a parking lot.

Table 6. *Cost Analysis of No-Fines Concrete Pavement*

Layer of Pavement	Item	Required Quantity	Rate	Amount
Base Course (200 mm thick)	Cement	2218.05 kg	Rs. 5.6/ kg	Rs. 12421.08
	Sand	6.153 cu. M	Rs. 1165.38/ cu. m	Rs. 6522.61
	Aggregate (40 mm)	12.307 cu. M	Rs. 1236/ cu. m	Rs. 13046.29
	Labour	(100 m^2 X 0.2m)	Rs. 215.29/ cu. m	Rs. 4305.80
Surface course (40 cm thick)	Cement	9619.27 kg	Rs. 5.6/ kg	Rs. 53867.90
	Aggregate (20 mm)	33.33 cu. M	Rs. 1236/ cu. m	Rs. 35332.15
	Labour	(100 m^2 X 0.4m)	Rs. 215.29/ cu. m	Rs. 8611.60
Total				**Rs. 1,34,107.43**

6. Conclusions

- The experimental results have indicated that the strength attained by no-fines concrete was lower than that of the conventional concrete, but appears to be sufficiently enough for a parking lot where compressive stress demand is not very high.
- The compressive strength of concrete varied with the water-cement ratio and the size of the aggregate particles used.
- Westergaard's analysis was used to design the safe thickness of the pavement which was computed as 40 cm.
- Minimum percent of water absorbed by no-fines concrete was observed to be 3.42% and that was for the trial mix having aggregates of size 20-16 mm and water-cement ratio of 0.35. However, the value went up to 4.32% for a different trial mix.
- Through experimental investigations, it was found that the interlocking concrete paver block have water absorption value of 3.06%. This shows that the no-fines concrete is more advantageous as compared to the interlocking paver blocks for areas receiving heavy rainfall. This is because of the higher percentage of water absorption of no-fines concrete mixes.

Table 7. *Cost Analysis of Interlocking Concrete Block Pavement*

Layer of Pavement	Item	Required Quantity	Rate	Amount
Kerb	Kerb blocks	109 blocks	Rs. 100/block	Rs. 10900
	Labour	33 m	Rs. 90/m	Rs. 2970
Base course* (150 mm thick)	Cement	1586.39 kg	Rs. 5.6/ kg	Rs. 8883.78
	Sand	4.4 cu. M	Rs. 1165.38/ cu. m	Rs. 4664.31
	Aggregate (40 mm)	8.8 cu. M	Rs. 1236/ cu. m	Rs. 9328.62
	Labour	(95.36 m^2 X 0.15 m)	Rs. 215.29/ cu. m	Rs. 3079.51
Filler* (25 mm thick)	Yamuna Sand	2.384 cu. M	Rs. 883.39/ cu. m	Rs.1684.80
	Labour	(95.36 m^2 X 0.025 m)	Rs. 215.29/ cu. m	Rs. 513.25
Surface course*	Paver Blocks	3736 blocks	Rs. 11/ block	Rs. 41096
	Labour	95.36 m^2	Rs. 33.29/ m^2	Rs. 3079.17
Total				**Rs. 86,199.44**

- A detailed cost analysis was carried out which showed that the initial costs of no-fines concrete pavements were higher than those for interlocking concrete block pavements. The two factors were responsible for this. Firstly, the materials used in pervious concrete were slightly more expensive. Secondl
- y, the increased thickness of the slab of no-fines concrete pavement compared to that of the interlocking concrete block pavements. However, in the long term, considering the advantages of no-fines concrete pavements over the interlocking concrete block pavements, the former is more economical for areas where run-off management is considered to be a difficult task.

7. Scope For Further Study

The present study was limited to the cement-aggregate ratio of 1: 5 but further studies may vary this value to get the desired compressive strength of the no-fines concrete. Through the results of those studies, different trial mixes of concrete may be used to optimize and determine the more suitable and economical mix of concrete. Moreover, the compressive strength of conventional concrete is directly proportional to the water-cement ratio but the same was not observed in this study. It might be probably because of other factors affecting the strength of concrete. Any remarks can be made regarding this after further investigations.

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