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An Innovative No-Fines Concrete Pavement Model

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Abstract:*In spite of having low Compressive and flexural strength, No-fines concrete has properties capable of being used as rigid pavement for low traffic volume roads. Along with the mix proportions and water content to have sufficient bond between the aggregate particles, it is critical to determine what happens to the water once it penetrates the pavement surface. In this paper, an innovative model that can transport water percolated into the pavement has been suggested in this direction. Different combinations of Cement, water and Course aggregate with different maximum size and gradation were adopted for trial mixes to arrive at M20 grade concrete.M20 grade concrete is achieved with a w/c ratio of 0.45, Course aggregate of nominal size 20 mm and with a cement to Course aggregate ratio of 1:4. Its density and flexural strength were observed to be 21 kN/m^{3}and 35 kg/cm^{2}respectively.A pavement slab suitable for low traffic volume roads is designed as per IRC SP62: 2004 which allows storage of water upto 125 lit./m^{3}of concrete pavement giving time for infiltration thereby reducing the runoff and recharging the ground water or sufficient time for transport of it. A perforated pipe can be provided at center of the pavement above sub-base such that it collects the water stored in concrete and drains it to the required treatment plant or a recharge pit. This however needs further investigation and trials before practical implementation.*

Keywords:*No-fines concrete, trial mix design, pavement, low traffic volume roads, runoff.*

I. Introduction

One of the major disadvantages of normal concrete is its high density. No-fines concrete also known as porous concrete, pervious concrete, zero slump concrete etc. which is partially a solution to high density of concrete is made without fine aggregate in conventional concrete.

No-fines concrete had its origin in Europe in 19th century where it was considered for a variety of applications such as load bearing walls, prefabricated panels and paving. In U.K in 1852, two houses were constructed using gravel and concrete. Cost efficiency seems to have been the primary reason for its earliest usage due to the limited amount of cement used. It was not until 1923 when no fines concrete resurfaced as a viable construction material. This time it was limited to the construction of two story homes in areas such as Scotland, Liverpool, London, and Manchester. The use of no fines concrete in Europe increased steadily especially in post-World War II era. It continued to gain popularity and its applications spread across Venezuela, West Africa, Australia, Russia and Middle East as it consumed less cement. Since the U.S did not suffer the same type of material shortages as Europe after World War II, no-fines concrete did not have a significant presence in U.S until 1970's. Its use began not as a cheaper substitute for conventional concrete, although that was an advantage, but for its permeability characteristics. However in U.S, with increase in land use, runoff increased which in turn led to flooding. This had a negative impact on environment, causing erosion and degradation in quality of water. No-fines concrete began in the states of Florida, Utah and New Mexico but have rapidly spread throughout the U.S to such states such as California, Illinois, Oklahoma and Wisconsin. The use of no fines concrete as a substitute for conventional concrete pavement has grown into a multi-functional tool in construction industry (Ghafoori. 1995).Considerable research has been conducted on environmentally sustainable development. This has led to the use of no-fines concrete in place of conventional concrete and asphalt surfaces. No-fines concrete dramatically reduces environmental degradation and the negative effects associated with urban sprawl. No-fines concrete has been used as an effective method for treating and reducing negative environmental impacts. The big three pollutants in urban runoff are sediment (dirt and debris), heavy metals (from the brake linings of cars), and hydrocarbons. One source of hydrocarbons is the oil that drips onto pavements from vehicles. Studies have shown that 90 to 95 percent of the hydrocarbons in urban runoff are from the binder and sealer used for asphalt pavements. Pervious concrete is becoming one of the most viable solutions. No fines concrete does not allow polluting water sheds and ecosystems. It helps to prevent run off.No-fines concrete pavements are a form of rigid pavement but differ substantially due to materials used during construction. The no fines concrete pavement consists of a concrete slab over a clean aggregate sub base, a filter fabric and a permeable sub grade. The sub grade material is important, as it is required to be permeable to allow the water in the sub base to penetrate the soil. The sub grade material has to contain a set of favorable properties relating to permeability, support and moisture content while the sub base requires a homogeneous materials with set of properties. The permeability of sub grade is important as it dictates the effectiveness of no fines concrete pavement. Prior to the place of no fines concrete pavement the sub grade has to be tested for rate of permeability with a suitable sub grade permeability test. The minimum percolation rate acceptable for no fines concrete pavement is 2.5 mm per hour. The organic material in sub grade is required to be scarified to a minimum depth of 75 mm. This material requires a proof roll to identify any weak or wet areas that may cause premature pavement failures. Fill materials may be incorporated if it is clean and free from deleterious materials as specified by geo technical study. The sub grade is required to be in moist condition before the construction of pavement sub base. The moist content should be within 3% of optimum moisture content as determined by a compaction test. The entire area of the pavement requires the placement of a non-woven geo textile filter fabric. This has two purposes- firstly to separate the sub grade from sub base material and secondly to stop the solids from rising upwards into the pavement and reducing its water holding capabilities. The sub base is made up of a clean aggregate that is retained on a 37 mm sieve and passes through a 50 mm sieve. It must not contain any fines as this will affect the performance of pavement. A washed river bed rock or crushed stone would be most appropriate material. Compaction on the sub base will occur with the use of a plate or roller compacter to provide a smooth uniform working surface. Any irregularities in the sub grade will be smoothened during this phase of construction.

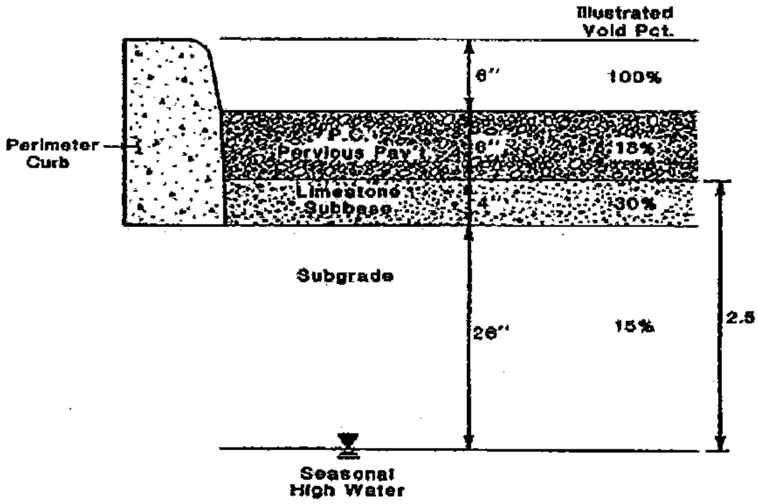

Figure 1 Cross section of No-Fines Concrete Pavement

II. Review of Literature

Krishna Raju et al (1975) focused on the optimum water content for no-fines concrete. It was determined that for the particular aggregate cement ratio there is a narrow range for optimum water-cement ratio. (Malhotra 1976) determined that the initial use of no-fines concrete was in the United Kingdom in 1852 with the construction of two residential houses and a sea groyne. It was a further 70 years before any further recorded use of no-fines concrete occurred when it was reintroduced into the United Kingdom in 1923 from Holland. The use of no-fines concrete became more important after the conclusion of World War II with the associated material shortages. He found that the density of no-fines concrete is generally about 70 percent of conventional concrete when made with similar constituents. The density of no-fines concrete using conventional aggregates varies from 1602 to 1922 kg/m^3. A clinker aggregate was trailed and the no-fines concrete produced a density of 961 kg/m^3. Adequate vibration is imperative for strength of conventional concrete. The use of no-fines concrete is different and is a self-packing product therefore the use of mechanical vibrators and ramming is not recommended with no-fines concrete. A light rodding should be adequate and used to ensure that the concrete reaches all sections of the formwork. This is not a problem with conventional concrete since it has greater flow ability than no-fines concrete. The light rodding ensures that the concrete has penetrated all the areas impeded by reinforcing steel. Malhotra (1976) stresses that in situations where normal conditions are not achieved during placement and curing, the formwork should not be removed after 24 hours as with conventional concrete. No-fines concrete has very low cohesiveness and formwork should remain until the cement paste has hardened sufficiently to hold the aggregate particles together. However, this is more of a consideration in low temperature conditions and when used in non-pavement applications where the concrete is not sufficiently supported by the ground or other means and noted that the depth of penetration in no-fines concrete by this method under conditions of high humidity and no air movement is generally no greater than two or three times the largest aggregate diameter. The penetration of moisture was higher in no-fines concrete made from conventional aggregates than clinker aggregate. Meininger (1988) investigated the effect on the properties of no-fines concrete with the addition of sand. He found that when a small amount of sand was added to the mixture, the Compressive strength of the concrete increased from 10.3 MPa to 17.2 MPa. Development of this material in pavement applications did not take off until the late 1970's, where it was first used as a wearing course for a parking lot. The first no-fines concrete pavement design was patented as a 'porous pavement' and a following no-fines pavement design was called a 'pervious pavement. He found that poor curing techniques allowed the cement paste to dry too rapidly and did not allow the hydration process to finish. It could be seen by the roughness of the pavement surface that no compaction was undertaken. All these factors affected one particular parking lot studied and started raveling one year after construction. Another pavement was constructed and it was made sure that sufficient compaction was provided to ensure the top aggregate was correctly seated and covered with plastic to establish proper curing conditions.

Ghafoori et al. (1995) undertook a considerable amount of laboratory investigation to determine the effectiveness of no-fines concrete as a paving material. The curing types were investigated to determine if there was any difference between wet and sealed curing. There appeared to be only a negligible difference in strength between the different curing methods. It was clear from the test results that the strength development of no-fines concrete was not dependent upon the curing conditions. The indirect tensile test conducted by him found that the sample tests varied between 1.22 and 2.83 MPa. The greater tensile strength was achieved with a lower aggregate-cement ratio. He explained the more favorable properties obtained by the lower aggregate-cement ratio by an improved mechanical interlocking behavior between the aggregate particles. Ghafoori et al. (1995) produced no-fines concrete with a Compressive strength in excess of 20 MPa when using an aggregate-cement ratio of 4:1. The demand for no-fines concrete for pavement applications continued to increase and an institute called 'Portland Cement Pervious Institute' was formed in 1991 to continue the research. Ghafoori et al. (1995) documents the development of permeable base materials capable of storing a greater volume of water until it dissipates into the surrounding soil. Raveling can occur in no-fines concrete pavements when there is a deficiency in the curing process or improper compaction and seating of the top aggregate particles. Ghafoori et al., (1995) Opined that After World War II, porous concrete became wide spread for applications such as cast-in-place load-bearing walls of single and multistory houses and, in some instances in high-rise buildings, prefabricated panels, and stem-cured blocks. Abadjieva et al., (2000) determined that the Compressive strength of no-fines concrete increases with age at a similar rate to conventional concrete. The no-fines concrete specimens tested had aggregate-cement ratios varying from 6:1 to 10:1. The 28 day Compressive strength obtained by these mixes ranged from 1.1 and 8.2 MPa, with the aggregate-cement ratio of 6:1 being the strongest. He concluded that the most plausible explanation for the reduced strength was caused by the increased porosity of the concrete samples. This strength is sufficient for structural load bearing walls and associated applications. He investigated the influence of the aggregate-cement ratio on the tensile and flexural strength of no-fines concrete. This study only assessed aggregate-cement ratios ranging from 6:1 to 10:1. The highest strengths were obtained with an aggregate-cement ratio of 7:1 and the strength decreased with an increasing aggregate-cement ratio. He found that the tensile and flexural strengths of no-fines concrete were considerably lower than those obtained from conventional concrete. (Tennis et al. 2004) determined that Pervious concrete can be used to reduce storm water runoff, reduce contaminants in waterways, and renew groundwater supplies. With high levels of permeability, pervious concrete can effectively capture the "first flush" of rainfall (that part of the runoff with a higher contaminant concentration) and allow it to percolate into the ground where it is filtered and "treated" through soil chemistry and biology.Pervious concrete contains little or no fine aggregate (sand) and carefully controlled amounts of water and cementitious materials. The paste coats and binds the aggregate particles together to create a system of highly permeable, interconnected voids that promote the rapid drainage of water. Typically, between 15 and 25 percent voids are achieved in the hardened concrete, and flow rates for water through the pervious concrete are generally in the range of 81 to 730 L/min/m^2. Also applications include walls for two-story houses, load-bearing walls for high-rise buildings (up to 10 stories) and infill panels for high-rise buildings (Tennis et al. 2004).

(Wanielista et al. 2007) stated that the initial use of porous concrete was in the United Kingdom in 1852 with the construction of two residential houses and a sea groin. Cost efficiency seems to have been the primary reason for its earliest usage due to the limited amount of cement used. It was not until 1923 when porous concrete re surfaced as a viable construction material. This time it was limited to the construction of 2-story homes in areas such as Scotland, Liverpool, London and Manchester. Use of porous concrete in Europe increased steadily, especially in the World War II era. Since porous concrete use less cement than conventional concrete and cement was scare at that time. It seemed that porous concrete was the best material for that period. Porous concrete continued to gain popularity and its use spread to areas such as Venezuela, West Africa, Australia, Russia and the Middle East.Darshan S. Shah et al. (2013) opined that Pervious concrete is a relatively new concept for rural road pavement, with increase into the problems in rural areas related to the low ground water level, agricultural problem. By capturing rainwater and allowing it to seep into the ground. This pavement technology creates more efficient land use by eliminating the need for retention ponds, swell, and other costly storm water management devices.Patil et al. opined that our cities are being covered with building and the air-proof concrete road more and more. In addition, the environment of city is far from natural. Because of the lack of water permeability and air permeability of the common concrete pavement, the rainwater is not filtered underground. Without constant supply of water to the soil, plants are difficult to grow normally. In addition, it is difficult for soil to exchange heat and moisture with air; therefore, the temperature and humidity of the Earth's surface in large cities cannot be adjusted. The research on pervious pavement materials has begun in developed countries such as the US and Japan since 1980s. Pervious concrete pavement has been used for over 30 years in England and the United States. Pervious concrete is also widely used in Europe and Japan for roadway applications as a surface course to improve skid resistance and reduce traffic noise. However, the strength of the material is relatively low because of its porosity. The compressive strength of the material can only reach about 20 – 30 MPa. Such materials cannot be used as pavement due to low strength. The pervious concrete can only be applied to squares, footpaths, parking lots, and paths in parks. Using selected aggregates, fine mineral, admixtures, organic intensifiers and by adjusting the concrete mix proportion, strength and abrasion resistance can improve the pervious concrete greatly.

Although no-fines concrete is a versatile material able to be used in many situations there are times when its use is not a viable choice. No-fines concrete pavements have a rough-textured, honeycomb like surface, which lacks the high bonding strength on the wearing course. Moderate amounts of raveling are normal with little or no problems but this becomes a major issue on highly trafficked roadways. This problem is being investigated with the top 12 mm being ground away so the exposed aggregate have stronger bonds with the surrounding material. Pavement design is of critical importance, as the substructure of the pavement is required to hold water until it permeates into the soil without failing. This requires the use of storm water management principles to determine what happens to the water once it penetrates the surface and pavement design principles to design a pavement structure that is capable of withstanding the internal pressures caused by the water in the pavement.

III. Objective and Scope

In recent times many studies have been carried out on no fines concrete. The objective of the present study is to check the performance of no fines concrete on various sizes of aggregates. Concrete is the most important material for construction purposes and cement is the most expensive ingredient in it. The name of no fines concrete itself explains that the fine aggregate has been omitted in this kind of concrete. Due to the absence of fine aggregate in no fines concrete, there is a high percentage of void space which results in high permeability. The unit weight, drying shrinkage and hydrostatic pressure for no fines concrete is less compared to conventional concrete. Due to the less cement content in no fines concrete, the cost of the overall project reduces. No fines concrete also helps in the reduction of urban heat island effect due to its light color.In this project cubes of 150 mmxl50 mm x 150 mm size are caste with three categories of SET A, SET B, SET C coarse aggregates. The cubes are tested and their corresponding Compressive strengths and densities are noted.

The objective of trying various ratios and their combinations is to arrive at a mix for M20 grade concrete and design a pavement with the mix.The scope of the present work is to carry out a detailed analysis of the following sub systems for the prescribed conditions-

1. Cement: concrete mix by volume is taken as 1:4, 1:6, 1:8, 1:10, and 1:12.
2. Ordinary Portland cement of 53 grade
3. Aggregates of sizes SET A, SET B, SET C are taken
    SETA (20mm nominal size aggregates)
    SET B (20mm passing and 10mm retained aggregates)
    SET C (10mm passing and 4.75mm retained aggregates)
4. Water/cement ratios are limited to 0.4,0.45and 0.5.
5. 108 cubes of size 150mm are cast with different w/c ratio and different aggregate size.
6. Testing of specimens at the ages of 7, 14, 28 days.
7. Determining the flexural strength of M20 grade mix.

IV. Methodology

The methodology adopted and material characterization and design mix is carried out is presented in the form of flow chart and parameters studied. Also the sequential activities involved in this study are presented in graphical form. Details of experimental study in materials are presented in the sub sequent headings.

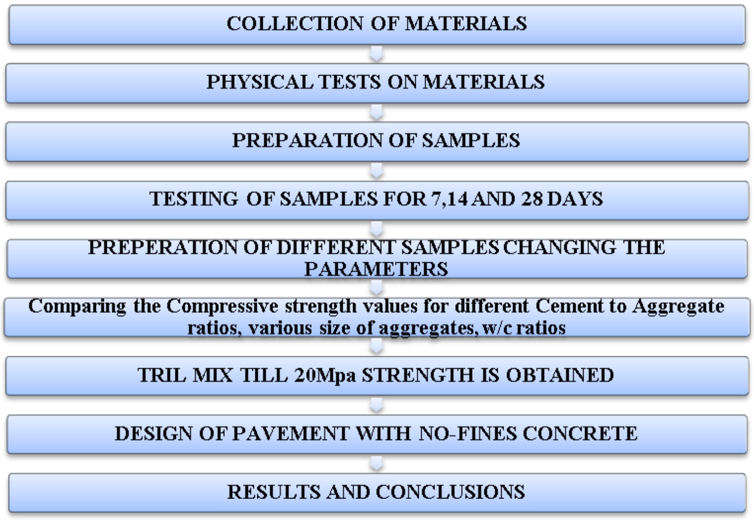

Figure 2 Methodology

V. Experimental Program

1. Materials for Experimental Program

According to the code IS: 1277-1983 the cement: concrete mix a by volume is taken as 1:8 and the optimum w / c ratios are taken as 0.4, 0.45, and 0.5 respectively. Aggregates of sizes 20mm regained, 20 mm passing 10 mm retained and 10 mm passing and 4.75 mm retained are taken and designated as SETA, SET B and SET C. The approximate quantities of materials required for concrete mix in the present study are 240 kg. of Cement and 1800 kg of Coarse Aggregates. Ordinary Portland Ultra Tech cement of 53grade was used for this work. The coarse aggregate has been brought from durga stone crusher, Gandhi Gundam, Andandapuram mandal, Visakhapatnam District.Laboratory tests have been conducted on cement, coarse aggregates at the Concrete Technology and Highway Engineering laboratory.

Properties of ingredients

Standard consistency of cement		=	35%	(IS 4031 PART 4: 1988)
Initial setting time of cement		=	55 min	(IS 4031 PART 5: 1988)
Specific gravity of cement		=	2.41	(IS 4031 PART 11: 1988)
Fineness of cement		=	4.33	(IS 4031 PART 1: 1996)
Soundness of cement		=	3 mm	(IS 4031 Part 3: 1996)
Specific gravity of coarse aggregate		=	2.7	(IS 2386 PART 3: 1963)
Aggregate crushing test		=	16.9 %	(IS 9377: 1979)
Aggregate impact value		=	1516 %	(IS 9377: 1979)
Los Angeles abrasion test	SET A	=	28.98%	(IS 1007: 1982)
	SETB	=	25.52 %	
	SETC	=	23.22%	
Flakiness index	SETA `	=	15%	(IS 2386 PART 1: 1963)
	SETB	=	11%	
	SETC	=	5%	
Elongation Index	SETA	=	15%	(IS 2386 PART 1: 1963)
	SETB	=	11%	
	SETC	=	5%	

The limits for flakiness and Elongation indices were further compared with those studied in Markandeya (2014) and it was observed that the course aggregate is acceptable for making concrete.

2. Experimental Program, Results and Discussion

The following graph represents the average compressive strength of cement: aggregate ratio 1:8 with 0.4, 0.45, and 0.5 water-cement ratios for SETA,SETB and SETC.

The results are consolidated and average values of the three samples are calculated to obtain the design for M20 grade no fines concrete.

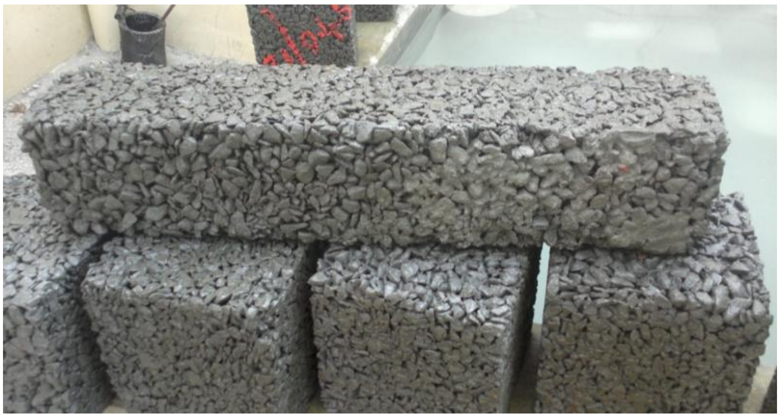

Figure 3No-fines concrete cubes and prisms ready for testing

Cement to Course Aggregate	**Type of Course aggregate**	**Water/ Cement Ratio**	**Compacting factor**	**Average Density of specimen (kg/m^3)**	**Average Compressive strength (N/mm^2)**
1:8	SET A	0.4	0.93	2172.837	8.27
		0.45	0.92	2143.21	8.94
		0.5	0.92	2021.73	7.3
	SET B	0.4	0.88	2083.95	7.4
		0.45	0.87	2162.96	8.9
		0.5	0.86	2034.56	6.4
	SET C	0.4	0.90	2004.93	6.1
		0.45	0.89	2039.14	6.6
		0.5	0.91	2123.44	6.0
1:10	SET A	0.4	0.95	1955.50	5.4
		0.45	0.94	1886.37	4.6
		0.5	0.93	1802.4	4.7
	SET B	0.4	0.88	1876.47	4.3
		0.45	0.88	2054.27	5.1
		0.5	0.96	1965.37	4.4
	SET C	0.4	0.91	1807.37	4.1
		0.45	0.92	1955.50	4.4
		0.5	0.92	1846.87	4.6
1:12	SET A	0.4	0.95	1649.4	2.62
		0.45	0.95	1817.28	3.36
		0.5	0.94	1758	3.69
	SET B	0.4	0.94	1797.53	2.87
		0.45	0.94	1995.05	3.85
		0.5	0.93	2024.6	3.71
	SET C	0.4	0.82	1807.40	2.96
		0.45	0.92	1896.29	3.58
		0.5	0.93	1985.18	3.62

Table 1 Experimental results

Figure 4 represents the average compressive strength of cement: aggregate ratio 1:8 with 0.4,0.45and 0.5water-cement ratios for SETA, SETB and SETC.

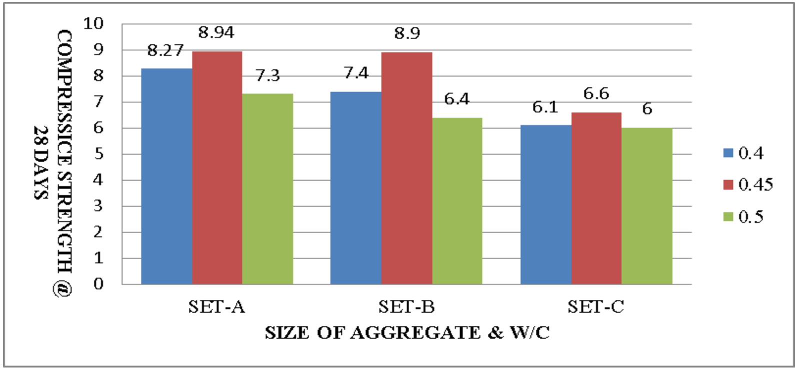

Figure 4Average compressive strength of 1:8 C: A ratio at 28 days

Figure 5 represents the average compressive strength of cement: aggregate ratio 1:10 with 0.4,0.45,and 0.5 water-cement ratios for SETA, SETB and SETC.

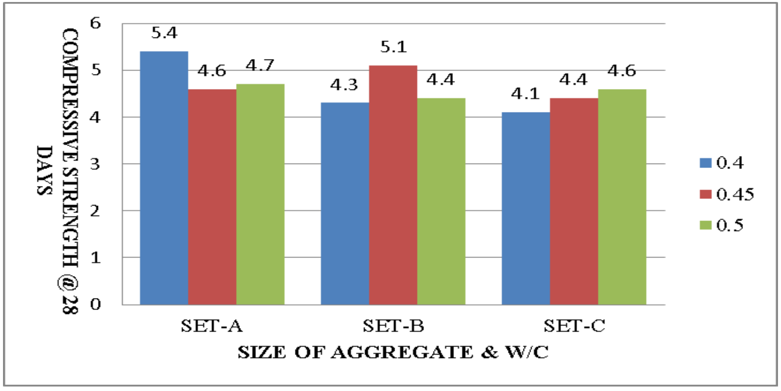

Figure 5 Average compressive strength of 1:10 C: A ratio at 28 days

Figure 6 represents the average compressive strength of cement: aggregate ratio 1:12 with 0.4,0.45,0.5 water-cement ratios for SETA,SETB and SETC.

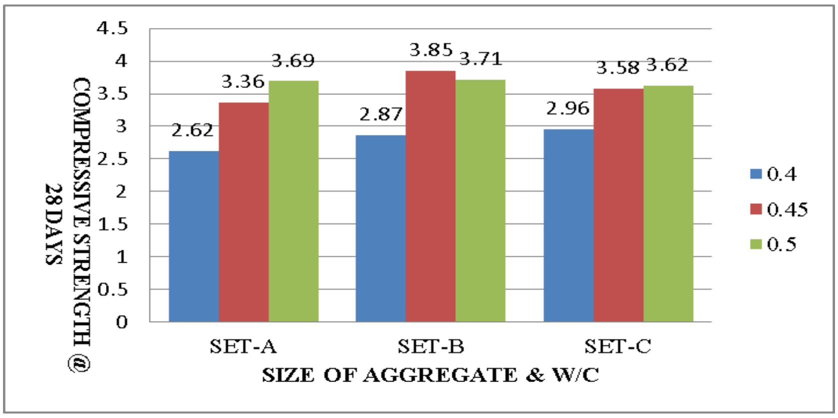

Figure 6 Average compressive strength of 1:12 C: A ratio at 28 days

From the above results, it can be observed that, for SETA aggregate with 0.45 w/c ratio and with cement to course aggregate ratio of 1:8, the maximum Compressive strength is arrived. Keeping these variables constant and varying only cement to course aggregate ratio to 1:6 and 1:4 the following results are achieved.

Cement to Course aggregate	**Water/Cement Ratio**	**Average Density of specimen (kg/m^3)**	**Average Compressive strength (N/mm^2)**
1:6	0.45	2081.88	14.39
1:4	0.45	2106.54	21.31

Table 2 Details of Experimental results on C: A ratios of 1:6 and 1:4

The following graph represents the compressive strength of SETA aggregates with 0.45 water-cement ratio and cement: aggregate ratio of 1:6 and 1:4 at 28 days.

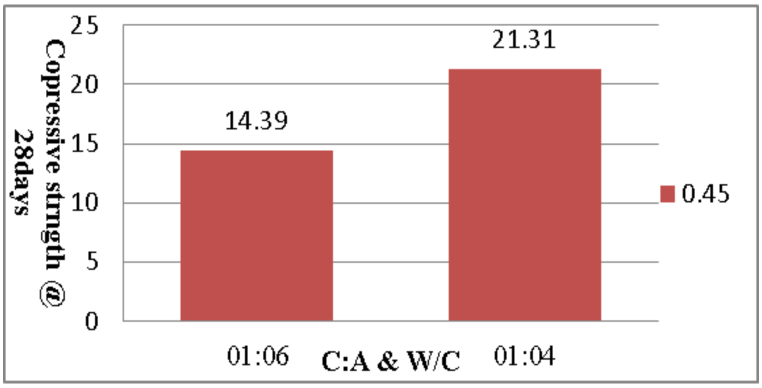

Figure 7Compressive strength of SETA aggregates at 28 days

Hence M20 grade concrete can be achieved with a w/c ratio of 0.45, Course aggregate of nominal size 20 mm and with a cement to Course aggregate ratio of 1:4. Its density was observed to be 21kN/m^3.
The flexural strength of this mix was determined by 2 point loading flexural tension test at 28 days and was observed to be 35 kg/cm^2.

VI. Pavement Design

1. Design of slab thickness

Pavement slab is designed as per IRC SP62: 2004. The flexural strength is directly taken from the beam flexural test. This design method is suitable for low volume roads or rural roads. The no-fines concrete pavement is to be designed for rural roads, arterial roads and even pedestrian paths. The total traffic is 300 commercial vehicles per day at the end of the construction period; the storm water is stored there by reducing the runoff.

Flexural strength of cement concrete = 32.29 kg/cm^2
Grade of no-fines concrete achieved = M20 @ 28 days
Elastic modulus of concrete = 2.2×10^5 kg/ cm^2
Poisson's ratio = 0.15
Modulus of subgrade reaction = 5.04kg/cm^3
Coefficient of thermal expansion of concrete = $10\times10^{-6}/^0$C
Tyre pressure = 7.5 kg/cm^2
Rate of traffic increase = 0.05
Spacing of contrction joints = 4.5 m
Width of slab = 3.5 m
Design life = 20 years
Present traffic = 300 cvpd.

Design

Present traffic= A = 300cvpd, Design life = n = 20 yrs., r = 0.05
Cumulative repetition in 20 yrs.

$$N = A * \left[\frac{(1+r)^n-1}{r}\right]*365 = 3,620,721 \text{ commercial vehicles}$$

Design traffic = 25% of the total repetitions of commercial vehicle = 905,180

Strength parameters of no-fines concrete

Grade of concrete =M20 @ 28days
Elastic modulus of concrete Es = $5000(20)^{0.5}$ = 22360 MPa
Flexural strength of no-fines concrete obtained = 35.2kg/cm^2
Flexural strength of no-fines concrete = $0.7\sqrt{f_{ck}} = 0.7*\sqrt{21.31} = 32.3$ kg/cm^2
Assume, Trail thickness of 30 cm
Edge load stresses

Radius of relative stiffness, $l = \sqrt[4]{\frac{Eh^3}{12(1-\mu^2)k}} = \sqrt[4]{\left[\frac{228012*30^3}{12*5.04*(1-0.15^2)}\right]} = 101.01$ cm

Assume, load contact area is circular ,

$$a = \sqrt{\left(\frac{5200}{7.5*\pi}\right)} = 14.85 \text{ cm}$$

$$b = \sqrt{1.6a^2} + \sqrt{h^2} - 0.675h = 15.14 \text{ cm}$$

Load stresses at the edge region

$$\sigma_{edge} = 0.529\frac{P}{h^2}(1+0.54\mu)\left[4log\left(\frac{l}{b}\right) + logb - 0.4048\right] = 13.43 \text{ kg/cm}^2$$

Maximum warping stress at the edge
Length of slab, L =375cm
Bradbury's coefficient, L / l = 375 / 101.01 =3.71

L / l	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
C	0.000	0.040	0.175	0.440	0.720	0.920	1.030	1.077	1.080

Table 3 Bradbury's coefficient

Edge warping stresses
Radbury'scoefficient , C = 0.36 (by interpolation from Table 3)
Young's modulus, E = 228012kg/cm^2
Coefficient of thermal expansion, α =10*10^{-6} / ℃
Temperature, t = 21^0 (for Andhra Pradesh region)
Edge warping stress = $\sigma_{edge} = \frac{E\alpha tC}{2}$ = 8.6 kg/cm^2
Maximum limit of total load stress at edge due to warping stress = 13.43+8.6=22.03kg/cm^2
This is less than the flexural strength of the obtained no-fines concrete i.e., 32.29kg/cm^2. So the pavement thickness of 31cm is safe .
Assume, wheel load, P = 5200kg
Stress at corner $\sigma_{corner} = \frac{3P}{h^2}\left[1-\left(\frac{a\sqrt{2}}{l}\right)^{1.2}\right]$ = 14.70kg/cm^2

At corner, wheel load stress is less than that of flexural strength. Hence, the designed thickness of slab, 31cm is safe and a sub-base layer of 75-100cm thickness can be provided.

2. Pavement model

M20 grade of pervious concrete with 12 -15% voids and a flexural strength of about 3.5Mpa can be used for the construction of rigid pavement for low volume traffic roads (up to 300cvph with mini trucks and buses).

The porous concrete allows storage of water up to 125liters per cubic meter of concrete pavement giving time for infiltration thereby reducing the runoff and recharging the ground water.

If there is a possibility of settlement of sub-base and sub-grade a geo-membrane can be provide below the previous concrete pavement to prevent percolation and a perforated pipe can be provided at center of the pavement. The pipe is so arranged in gradient that it collects the water stored in concrete and drains it to the required treatment plant or a recharge pit. The Figure 8 below shows the cross-section and longitudinal section of the pipe and isometric view of the pavement.

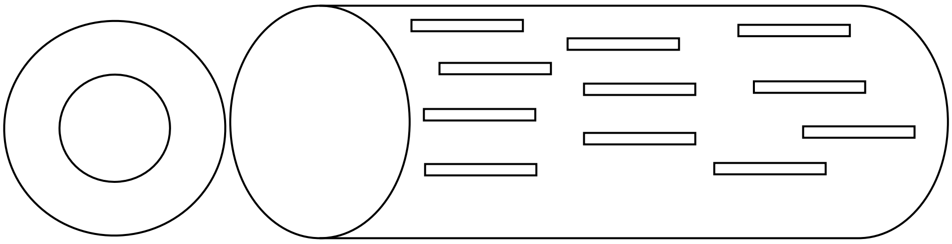

Figure 8(a) Cross section **Figure 8(b) Longitudinal Section**

This pavement material can be used as a pedestrian pathway very safely.In developed countries it is observed that 30% of the land used is covered with pavements and pedestrian pathways. If this area was covered with pervious concrete, it would have greatly contributed to the ground water recharge. However it is nearly impossible for them now to replace all those now with pervious concrete pavements.India, being a developing country has many rural roads to be constructed. If this technology is used for rural roads and pedestrian pathways it would go a long way in contributing to environmental sustainability. An innovative pavement model has been presented in this chapter which can collect all the rain water falling on the pavement which can later be transported to a required place. This however needs further investigation and trials before practical implementation.

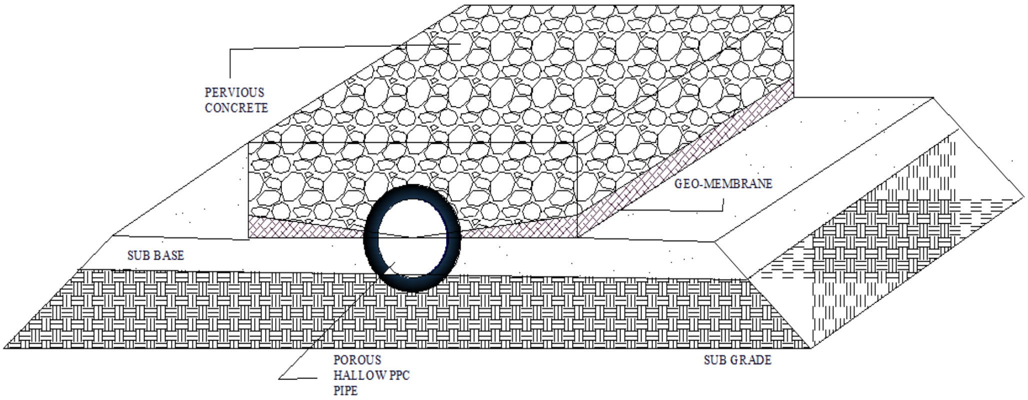

Figure 9 Model of pervious concrete pavement

VII. Conclusions

Based on the study conducted within the scope of the research, the following specific and general concluiosn can be drawn.

1. M20 grade no fines concrete with a density of about 21 kN/m^3 can be obtained bythe following mix proportions.

Cement : Course aggregate 1 : 4

Course aggregate	20 mm nominal size aggregate
Water to cement ratio	0.45
Water	Potable water

2. Assuming a uniform distribution of material and density of normal concrete to be 24 kN/m^3, it can be observed that there is a reduction of12.5% in the density of no-fines concrete. Hence there would also be an increase in the water absorption of this concrete by 12.5 %.
3. Determination of the water absorption of the no-fines concrete by conventional method was very difficult as water was not being retained. Hence, it has to be determined by finding immersed weight of the Concrete in water.
4. The physical properties of the individual components and the no-fines concrete as a whole are extremely important and should be explored further. The rheology of the concrete and the individual materials determine properties like the strength, void ratio, durability and the chemical properties. All these properties need to be known and assessed to make the most appropriate choice for a particular application.
5. The mix proportions for no-fines concrete depends predominantly on the final application. In building applications, the aggregate-cement ratio used is leaner, usually ranging from 6:1 to 10:1 where strengths ranging from 5 MPa to 15 MPa are obtained. This leaner mix ensures that the void ratio is high and prevents capillary transport of water. However, in pavement applications the concrete strength is more critical and aggregate-cement mixes as low as 4:1 has to be used. This lower ratio ensures an adequate amount of bonding between the aggregate and cement to withstand the higher loads.
6. Flexural strength of pervious concrete ranges between 1.5and 3.5 MPa.
7. The general range for water-cement ratio is between 0.38 and 0.52 (Neville 1997). From our study it was observed that 0.45 w/c ratio is ideal for No fines concrete.
8. The void content is dependent upon the aggregate-cement ratio and thus varies greatly. The air content of no-fines concrete ranges from 13 to 28 % for aggregate-cement ratios between 4:1 and 10:1.
9. Approximately, 125 liters can be retained by 1 cubic meter of no-fines concrete.
10. An innovative pavement model has been presented in this project which can collect all the rain water falling on the pavement which can later be transported to a required place. This however needs further investigation and trials before practical implementation.

No-fines concrete has properties capable of being used in road pavement applications. In spite of having low Compressive strength, it still has favorable properties that can be utilized in road pavement applications. The mix proportions and water content are critical when obtaining a sufficient bond between the aggregate particles.

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