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Experimental Studies of Sustainable Cement Concrete Pavement

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Abstract: *The difference in the construction cost of concrete and bituminous roads has narrowed down considerably on account of sudden rise of cost of bitumen. Now a day's cement concrete Roads are more preferred than bituminous roads in urban cities in India. Concrete roads are potential users of Cement. The behavior of concrete, whether fresh or hardened, depends basically on the behavior of its components and the relationship between them, therefore, obtaining a concrete with certain properties depends fundamentally on the concrete mix design.*

Keywords: *Fly ash, HVFAC, Sustainability, LCA, PQC, DLC, Mix Design*

I. Introduction

A large amount of theoretical and experimental research programs were carried out by many universities and research institution in various countries. As a result, a great deal of useful information has been disseminated, and fruitful results have been put into practice. Yet, there is a need for developing a comprehensive understanding about the detailed contribution of Aggregates sizes, shape, gradation, towards minimizing the Cement Content. Different Codial Provisions for Concrete Mix Design, use of chemical & mineral admixture, for Pavement concrete. As per guidelines laid by new government all new Highway Projects supported by NHAI of India will use Cement Concrete.

The entire 28 KM stretch for Satara-Kolhapur section of NH4 has been constructed with 40%age Fly-ash as replacement of Cementitious material for PQC & DLC, duration May 2002 to February 2005. As per IRC: SP: 84-2014 provides guidelines for design & construction the proposed alternative conforms to any one of the international standards, code of practice, specifications, guidelines etc.

a) IRC revised codes or new codes or amendments to existing codes
b) American Association of State Highway and Transportation Officials (AASHTO)
c) American Society for Testing of Materials (ASTM)
d) Euro Codes
e) National Standards of any of the following countries: United States of America (USA), Canada, United Kingdom (UK), France, Germany, Sweden, Denmark, Norway, Netherlands, Spain, Australia, New Zealand, Japan and South Africa.

General

Roads are the arteries and the veins of a nation. They not only foster the economic growth of a nation but unite and uniform the whole nation. Roads are essential ingredients for rapid growth of an economy and a vital input to economic development, trade and social integration, which rely on the conveyance of both people and goods. Both the urban and the rural markets benefits with two traffic and have the upward spiral effect on the life style of the nation. India is most recent examples of the effect of roads on the economic development of the country. With two decades of conscious efforts to built roads to connect the entire country, the face of the whole nation is changed. The overall effect is the creation of more and more opportunities with the construction of the roads and with it there is overall buoyancy in the country. [17, 20]

II. Literature Review And Need Of The Study

Due to growing interest in sustainable development engineers and architects are motivated more than ever before to choose materials that are more sustainable. Engineers and architects have choices of the material and products they use to design projects – when it comes to a building frame the choice is typically between concrete, steel and wood; for paving applications the choice is generally between concrete and asphalt. Material choice depends on several factors including first cost, life cycle cost and performance for a specific application. However this is not as straight forward as selecting an energy star rated appliance or a vehicle providing high gas mileage.

Life Cycle Assessment (LCA) seems to offer a solution. LCA considers materials over the course of their entire life cycle including material extraction, manufacturing, construction, operations, and finally reuse/recycling. LCA takes into account a full range of environmental impact indicators—including embodied

energy, air and water pollution (including greenhouse gases), and potable water consumption, solid waste and recycled content. Recent focus on climate change and the impact of greenhouse gas emissions on our environment has caused many to focus on CO_2 emissions as the most critical environmental impact indicator. Recent research at the Massachusetts Institute of Technology (MIT) explores advances key areas relevant to the field of pavement LCA: methodology, benchmarking and impact reduction.

Designing and proportioning of ingredients in a concrete mix requires sound technical skill which should further incorporate all possible variation in properties of the ingredients. Bureau of Indian standard in this direction released IS: 10262 1982 which was further revised in the year 2009. IRC: 44-1976 "Tentative Guidelines for Cement Concrete Mix Design for Pavement" was prepared by Cement Road Surfacing Committee. The Revision of IRC:44 1976 was taken up by the Rigid Pavement Committee (H-3) and the revised draft as prepared by document incorporating the comments of the HSS Committee was approved for printing in the year 2008. The objective of the study was to check whether the new guidelines ensure better and economical concrete mixes.

Here study was carried to prepare M40 Mix Design as per Indian Standards Old & New Guidelines i.e. I.S:10262- 1982 & I.S:10262-2009 and also with Indian Road Congress Old & New Mix Design Guide lines i.e. IRC: 44-1976 & I.R.C:44-2008, here study was done to ensure whether the new & old guidelines of both Indian Standards & Indian Road Congress will give better and economical concrete mixes. Previously no comparisons has been done between IRC old & new code, whereas no study was carried out to check & ensure better & economical concrete mixes with Indian Standard & Indian Road Congress Mix Design guidelines. In addition to this study effect of proper size and grading of aggregates to be used in concrete and prepare job mix formula. To Work out proper dosage& brand of super plastizer to be used in the Design mix.

Many investigations are performed to evaluate the long-term performance of concrete pavements made high volumes fly ash (FA), the theory and construction practice with concrete mixtures containing more than 50% fly ash by mass of the cementitious material. There has been quite a few research studies carried out for the laboratory investigations of high performance concrete mix to study the suitability on basis of various laboratory tests. [21-23]. In the present study the Verification of engineering properties of M40 Concrete produced generally meant to be used for Rigid Pavement with significant less cement content. Parametric study of Engineering properties like Workability Test, Density of Concrete, Flexural strength, Equivalent Cube Strength has been carried out here.

An equally important goal at this point is to determine fairly M40 Concrete is prepared on Basis of IRC: 44-2008, Design Guide lines as provided in IRC: 15-2011 "Standard Specification and code of practice for construction of Concrete Roads" is followed Gradation of aggregates as provided in table: 3 of IRC: 15 is followed. After preparing the final Mix fiber dosage at the rate of 125 gm per 50 kg of Cementious Material is used. A Trial Patch of @ 1.0 mt X 3.0 mt of 300 mm thickness done, its site evaluation of strength is done by cutting 3 nos of cores and working out is compressive strength. Thus, the research work is extended to obtain a sustainable Green M40 Pavement Quality Concrete to be used in Highway Construction.

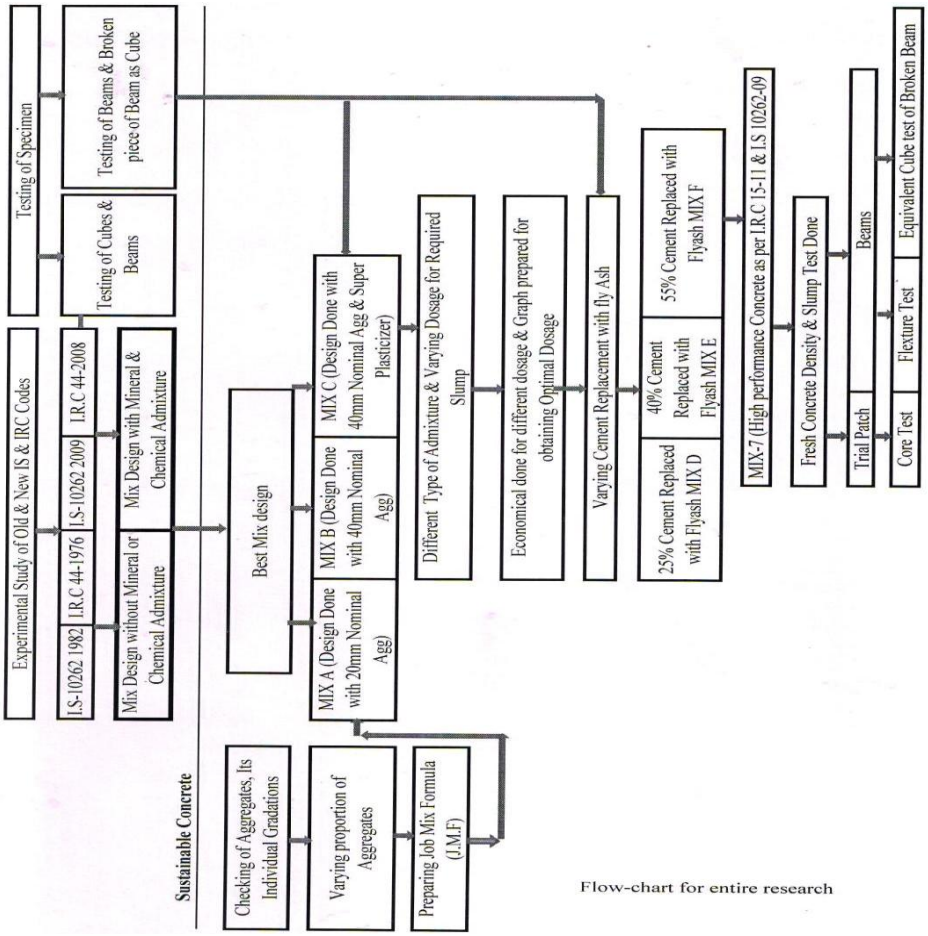
Research Objectives

To accomplish the purpose of the study, the main objectives can be identified as follows and viewed as flowchart in **Figure 1.**

1. Experimental study of Old & New code used for Concrete Mix Design, Further deciding the codal provision to be used to decide the Water to Cementitious ratio.
2. To decide the proper dosage of super plastizer to be used in the Design mix.
3. To find out the proper size and grading of aggregates to be used in concrete.
4. To carry out Mix Design for Flexural Strength and verify its equivalent Cube strength as per I.S 516-2004.
5. To minimizes the Cement Content in the Design Mix.
6. To further reduce the cement content in the mix by using Fly Ash as a replacement for Cement.

a) 25 %age Cement replaced by fly ash
b) 40 %age Cement replaced by fly ash
c) 55 %age Cement replaced by fly ash

7. To prepare M40 Mix Design in accordance to codial provision of IRC-44 2008 & follow Design Guidelines as per IRC1—15 2011.



III. Experimental Study Of Old & New Code Used For Concrete Mix Design

Concrete Mix Design

Concrete mix design is defined as the appropriate selection and proportioning of constituents to produce a concrete with pre-defined characteristics in the fresh and hardened states. In general, concrete mixes are designed in order to achieve a defined workability, strength and durability. The mix design methods being used in different countries are mostly based on empirical relationships, charts and graphs developed from extensive experimental investigations. Most of them follow the same basic principles and only minor variations exist in different mix design methods in the process of selecting the mix proportions.

3.1 Illustrative Examples

Four illustrative examples two of each of M40 concrete mix proportion is given in Column 2 & 3. The Column 2 is an example of Mix proportion of M40 concrete, the mix is prepared on Design principle of IS 10262 1982 old edition. Column 3 represents proportion of M40 concrete based on Design Principle of IS 10262 2009 First revision. Both this concrete is to be used for Pavement Quality Concrete (PQC) in road work. Remaining Two illustrative example of concrete mix proportioning for conventional concrete pavement (PQC) is given in Column 4 & 5. The Column 4 is an example of Mix proportion of M40 grade of concrete, the mix is prepared on Design principle of IRC 44 1976 first revision. Column 5 represents proportion of M40 concrete based on Design Principle of IRC 44 2008 second revision.

Table 3.1 Ingredients of Concrete Raw Material as per Previous & Revised I.S & I.R.C Codes for Mix Design

Ingredients	**Trial-1 with I.S 10262-1982**	**Trial-2 with IRC:44-1976**	**Trial-3 with I.S 10262-2009**	**Trial-4 with IRC:44-2008**
Grade Of Concrete	M40	M40	M40	M40
Characteristics Compressive Strength in N/mm^2	49.24	47.06	48.25	48.25
Characteristics Tensile Strength in N/mm^2	4.427	4.427	4.427	4.427
Cement	428.57	406.98	330.00	347.37
Water	165.00	175.00	132.00	132.00

Fine Aggregate	Narmada	430.19	313.67	270.32	254.90
	Tapi	430.19	313.67	270.32	254.90
	20mm	696.38	627.26	774.38	746.00
	10mm	696.38	627.26	774.38	746.00
Chemical Admixture		Nil	Nil	6.60	6.950
Water-Cement ratio		0.385	0.430	0.400	0.380
Date of Casting		27/05/2012	2/6/2012	13/06/2012	18/06/2012
Ingredients		**Trial-1 with I.S 10262-1982**	**Trial-2 with IRC:44-1976**	**Trial-3 with I.S 10262-2009**	**Trial-4 with IRC:44-2008**
Observed slump in mm after 15 minutes from addition of water		10	30	25	25
Concrete looks		Harsh	Cohesive	Cohesive	Cohesive
Density Of cube		2.635	2.588	2.654	2.654
Results	3'Days Compressive Strength	28	27.852	26.815	29.926
	7'Days Compressive Strength	35	28.552	28.145	30.963
	28'Days Compressive Strength	56.185	48.18	46.519	47.125
	7'Days Flexural Strength	4.326	4.978	5.393	4.504
	28'Flexural Strength	6.136	4.8	6.104	6.051
Aggregates to Cement Ratio		5.257	4.625	6.332	5.763

Discussion

Here comparison of Ingredients obtained for Different Guidelines for Mix Design Codes of Previous & Revised I.S & I.R.C is tabulated its workability in terms of slump is worked out along with compressive strength of cubes. The Mix as per I.S 10262 1982 guidelines is Harsh comparative to other Mix obtained from other Mix Design Guidelines, its Compressive & Flexural Strength is the most in all of the four Design. The Mix Obtained with new codes of I.S & I.R.C guidelines is cohesive.

IV. Experimental Program

The following test program was planned in order to evaluate the material proportions as required in the design of pavements and to investigate the structural strength (Flexural Strength) of high strength high performance concrete pavements using different proportion of fly ash as cement replacement.

4.1 Experimental Investigation to prepare Mix A, Mix B

Design of concrete mix of **M-40 grade** and evaluation of flexural strength, equivalent cube strength for determining its Compressive Strength.

4.1.1 Materials

Concrete mix of M40 has been developed .The characteristics of the various materials used in the present investigation i.e. cement, fly ash, coarse aggregate, fine aggregate, water & super plasticizer are as follows

Cement: Ordinary Portland cement, Grade-53, confirming to IS: 12269-1967 was used throughout the investigation.

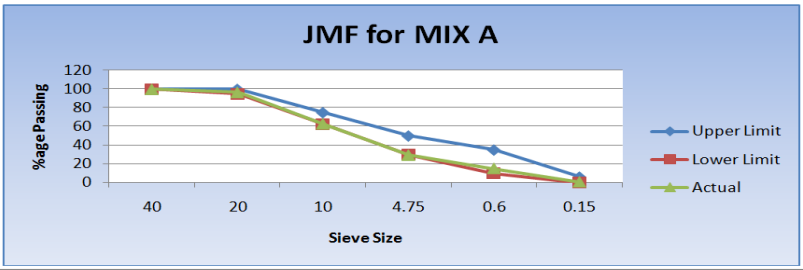
Water: Water used for mixing and curing should be free from injurious and deleterious materials. Throughout the investigation, potable tap water was used.

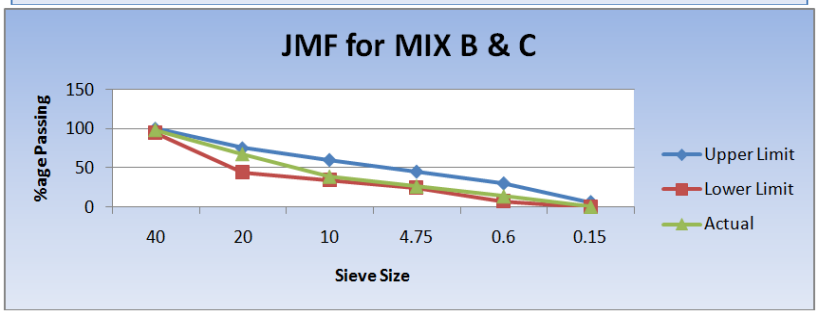
Coarse Aggregate: Locally available crushed stone coarse aggregate of maximum size 40 mm used along with 20mm &10mm confirming to IS: 383:1970 was used. The fineness modulus of coarse aggregate in the study is 6.7.

Fine Aggregate: Fine aggregate, locally available confirming to IS: 383-1970 is used. Two source of River sand one Tapi & one Narmada is used. The proportion of both the sand has been decided on Job Mix Formula for All-in-Aggregate confirming to IS: 383-1970. The fineness modulus in the study used is 2.89.

Two different mixtures **Mix A & Mix B** are developed for this Investigation work one by using Nominal aggregates of 20mm and in Second mixture Nominal Size of aggregates considers is 40mm instead of regular 20mm size.

Individual gradation of Fine & Coarse aggregates were done so as to established ideal proportion of aggregates so that value of all in aggregates comes in the centre of envelope.





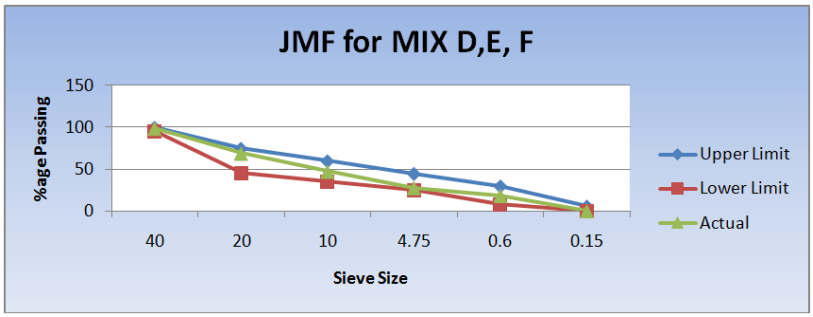


Table 4.1 Design of Mix Proportion for M40 for Designed flexural strength

Ingredients in Kg		**Mix-A**	**Mix-B**
Cement		489.47	434.21
Fly Ash			
Water		186.00	165.00
Fine Aggregate	Narmada	235.94	243.31
	Tapi	235.94	243.31
Coarse Aggregate	40mm	0.00	569.67
	20mm	552.41	569.67
	10mm	828.62	284.84
Chemical Admixture		0.00	0.00
Water-Cement ratio		0.38	0.38
Slump in mm after 1 hour of addition of water		30	28
Mix-A	Design done on Nominal Aggregates sizes of 20mm		
Mix-B	Design done on Nominal Aggregates sizes of 40mm		

The test specimen for, flexural strength and equivalent cube strength were prepared and tested according to IS: 516-2004. Using the above specified material, concrete of grade M40 being developed. To measure the flexural strength 150mm×150mm×700mm beam for flexural strength. The broken piece of Beam has been used for measuring the Equivalent Cube Strength.

Discussion

As Concrete Road Flexural failure is predominant for that reason flexural Strength is considered for defining the target mean strength for Mix design Calculation. The transition zone between aggregate and hydrated cement paste (HCP) is the weakest link in the concrete. Due to the presence of high water cementations material ratio in the transition zone compared to other portion of the concrete, it contains large size and numbers of capillary voids as well as micro-cracks created during the manufacture and hardening of concrete. The performance of concrete is adversely affected by the increase in the size and/or number of micro-cracks in the transition zone. The size and number of micro-cracks are influenced by Aggregate size and grading. A well graded coarse & fine aggregates mixtures helps to reduces micro-cracks increasing the strength & durability.

Mix-A W/C ratio is 0.38 for water content of 186 litres Cement Content Comes out to be 489.47 kg/Cum. In Mix-B 40mm aggregates are used so water content comes out to be 165 litres instead of 186 litres due to which cement content decrease from 489.47 to 434.21 kg/cum.

4.2 To fix the dosage of super plastizer for using it in Design Mix & Prepare Mix C

Different brand of admixtures i.e. Super-plasticizer are available in market. In these experiment investigations admixtures for slump retention is used In this experimental program brand like Forsac, Fairmate, Sika & Lovely Chemicals are used to verify the required dosage to obtained the design slump of 30mm + 5mm, This slump is required @ retention time of 1 hours.

Very first the dosage of admixture was established on trial for 30± 5mm slump. Dosage of admixture of 0.5%, 1.0%, 1.2%, 1.5% and 2.0% were used. This value was plotted on graph to obtain the optimum dosage required to get 30± 5mm slump. **Mix C** is Developed with adding 1%age of admixture of N-170.

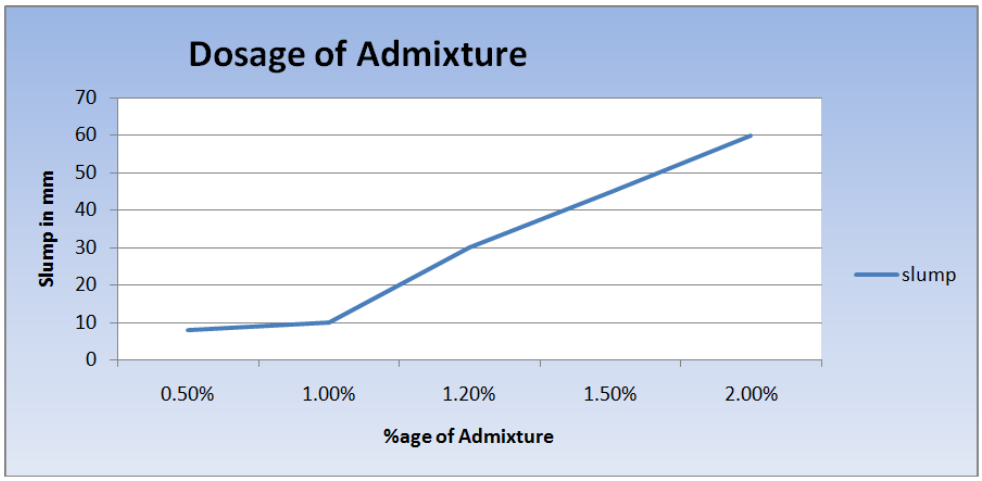


Table 4.2 Design of Mix Proportion for M40 for Designed flexural strength

Ingredients in KG		**Mix-B**	**Mix-C =Mix B-1.2**
Cement		434.21	390.79
Fly Ash			
Water		165.00	148.50
Fine Aggregate	Narmada	243.31	250.11
	Tapi	243.31	250.11
Coarse Aggregate	40mm	569.67	585.58
	20mm	569.67	585.58
	10mm	284.84	292.79
Chemical Admixture		0.00	4.69
Water-Cement ratio		0.38	0.38
Slump in mm after 1 hour of addition of water		28	32
Mix-B	Design done on Nominal Aggregates sizes of 40mm		
Mix-C =Mix B-1.2	Design done on Nominal Aggregates sizes of 40mm with different Super Plasticizer Dosage		

Discussion

Out of the three admixtures brand used, Super Plasticizer: Lovely N-170 which is modified Naphthalene Formaldehyde sulphonate type is better & economical. It is dark brown in colour and specific gravity is around 1.16 to 1.20. It complies with IS: 9103, ASTMC 494 Type F and BS: 5075 part 3. The control of water content is most essential which is obtained by adding a super-plasticizing admixture. As Super plasticizer is used water content further reduced to 148.50 litres without changing the workability. The cement content reduces to 390.79 kg/cum

4.3 M40 Trial Mix With Chemical as well as Mineral Admixtures Mix D, Mix E, Mix F.

Three different mixtures are developed for this work out of High-Volume Fly Ash concrete. The experiment of Trial mixes was carried out on three proportion of Fly ash replacement. Each mixture was batched and mixed in mixer machine. Test Specimen was prepared to measure properties of each mixture, in accordance with ASTM C 31. Each Mixture was tested for fresh and hardened concrete properties.

Table 4.3 Mix Proportion for Trial for M40 with fly-ash for flexure strength

Ingredients		Mix-D	Mix-E	Mix-F
Cement		322.40	251.31	171.95
Fly Ash		107.47	167.54	210.16
%age of Fly Ash		25%	40%	55%
Water		148.50	148.50	132.00
Fine Aggregate	Narmada	342.15	337.8	350.79
	Tapi	146.63	144.77	150.34
Coarse Aggregate	40mm	572.2	564.93	586.65
	20mm	357.62	353.08	366.66
	10mm	518.15	494.31	513.32
Chemical Admixture		5.16	5.16	4.59
Water-Cement ratio		0.46	0.58	0.77
Slump in mm after 1 hour of addition of water		32	30	35
Mix-D	Design done on Nominal Aggregates sizes of 40mm with 25% Fly Ash Replacement			
Mix-E	Design done on Nominal Aggregates sizes of 40mm with 40% Fly Ash Replacement			
Mix-F	Design done on Nominal Aggregates sizes of 40mm with 55% Fly Ash Replacement			

4.4 Details of Hardened Properties of Test Specimen

The following table gives the value of Test results carried out in house laboratory

Table No 4.4 Details of Flexure Strength of 150mm X 150mm X 700mm size Beam & Equivalent Cube Strength of Broken Beam

Sr. No.	Mix Details	Density Kg/Cum	Beam's Flexural Strength		Equivalent Cube Strength	
			7 days strength in N/mm^2	28 days strength in N/mm^2	7 days Beam strength in N/mm^2	28 days Beam strength in N/mm^2
1	Mix-A	2580	4.267	5.689	31.11	42.67
2	Mix-A	2519	5.333	6.4	32.89	48.89
3	Mix-A	2486	4.627	5.689	28.89	53.33
4	Mix-B	2604	3.2	5.867	32	42.67
5	Mix-B	2616	4.27	6.578	32.89	53.33
6	Mix-B	2604	3.91	6.044	35.56	51.11
7	Mix-C	2779	4.089	6.044	32.44	44.44
8	Mix-C	2633	6.222	6.756	31.11	51.11
9	Mix-C	2673	5.511	6.222	31.56	54.22
Sr. No.	Mix Details	Density Kg/Cum	Beam's Flexural Strength		Equivalent Cube Strength	
			7 days strength in N/mm2	28 days strength in N/mm2	7 days Beam strength in N/mm2	28 days Beam strength in N/mm2
10	Mix-D	2575	3.90	6.044	32.13	42.67
11	Mix-D	2519	4.27	6.578	32.89	48.89
12	Mix-D	2590	3.80	5.867	29.79	47.37
13	Mix-E	2580	3.85	6.044	32.89	48.77
14	Mix-E	2550	3.90	6.222	31.15	52.34
15	Mix-E	2604	4.29	6.587	34.54	50.12
16	Mix-F	2525	3.55	6.400	33.45	44.44
17	Mix-F	2585	3.95	6.044	32.15	49.15
18	Mix-F	2595	3.95	6.222	32.58	48.32

Discussion: The Flexural strength test data are given in Table 4.4 As expected, the Flexural strength increased with age. The rate of increase depended upon the level of cement replacement, type of fly ash, and age. In general concrete strength decreased with increasing fly ash concentration at th For Mix-A with 20mm Nominal aggregates, with no admixture cement content is 489.47 kg keeping same W/C ratio of 0.38 the Target Flexural strength of 5MPa is achieved with required slump of 30mm. The equivalent Cube Strength obtained is 48.29 N/mm2. From Mix A to Mix F the Cement Content is decreased first by replacing maximum aggregate from 20mm to 40mm then by adding Chemical and Mineral Admixture. The Cement content of Mix F with 40mm Nominal aggregates, with 1.2% admixture, cement content is 171.95 kg & Fly ash 210.16 Kg (55%age replacement) with same W/C ratio of 0.38 the 28 Day's Flexural Strength is 6.222 N/mm2 & Equivalent Cube strength is 47.30 N/mm2 against required e very early ages.
Flexural strength of 4.91 N/mm2 with achieved slump of 35 mm.

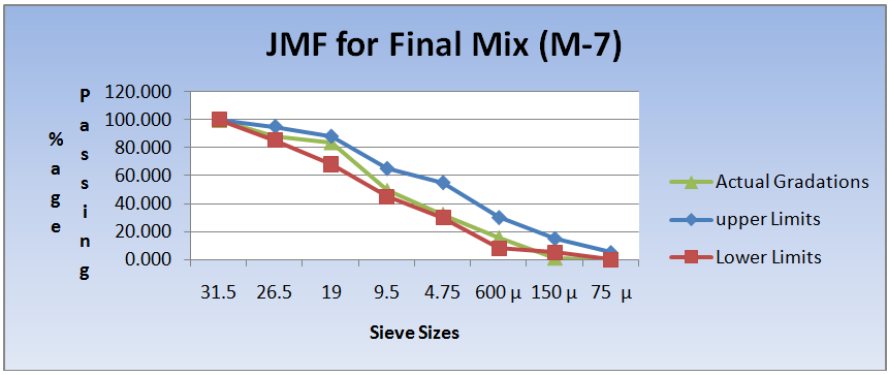
4.5 Preparation of High Performance Concrete for Pavement Quality Concrete (PQC) to be used in Highway Pavements.

M40 Concrete is prepared on Basis of IRC: 44-2008, Design Guide lines as provided in IRC: 15-2011 "Standard Specification and code of practice for construction of Concrete Roads" is followed Gradation of aggregates as provided in table: 3 of IRC: 15 is followed. Super plasticizer can be added up-to 2%, but here

1.2%age is added. After preparing the final Mix fiber dosage at the rate of 125 gm per 50 kg of Cementious Material is used. A Trial Patch of @ 1.0 mt X 3.0 mt of 300 mm thickness done, its site evaluation of strength is done by cutting 3 nos of cores and working out is compressive strength.

4.5 Mix Proportion for Trial for M40 with fly-ash for flexure strength

Ingredients in KG		**Trial-1**	**For Beam set 1**
Cement		171.95	30.467
Fly Ash		210.16	37.237
Water		132.00	23.389
Fine Aggregate	Narmada	349.39	61.908
	Tapi	149.74	26.532
Coarse Aggregate	40mm	584.31	103.533
	20mm	365.20	64.708
	10mm	518.15	91.809
Chemical Admixture		4.59	0.812
Water-Cement ratio		0.77	0.77
Slump in mm after 1 hour of addition of water		38.00	



V. Summary & Conclusion

Conclusion from Experimental study of Old & New code used for Concrete Mix Design, & Deciding Admixture Type & Dosage quantity. As per table 3.1 all four mixes can be used, but the Mix with Highest aggregates cement ratio must be used which will be more economical.

The 30mm $\pm$ 5mm slump is worked out for One hour retention time, Out of the three admixtures brand used, Super Plasticizer: Lovely N-170 which is modified Naphthalene Formaldehyde sulphonate type is better & economical. The dosage of admixture is fixed at 1.2% by weight of Cementitious material used.

Conclusion from Trial Mix of Mix-A, Mix-B, Mix-C, Mix-D, Mix-E, Mix-F

Mix-A is having Cement content of 489 kg were as Mix F is having Cement content of 172 Kg. The indirect saving in Carbon Emission of Mix-F is greatest out of all the six Design mixes. For Mix-F with 40mm nominal Aggregates and with 55 %age Cement replacement by Fly ash the 28's Day Flexural Strength is 6.222 N/mm^2 against requirement of 4.91 N/mm^2 , The equivalent cube strength comes out to be 47.303 N/mm^2 with slump achieved of 35mm after one hour retention time.

Conclusion from Trial Mix of Mix-7 and Results from trial patch.

The trail mix can be readily used for in field placement of concrete road pavement work for constructing the trail length. As per MORTH the trial length shall be constructed at least one month in advance of the proposed start of concrete paving work. Ingredient of Mix-7 can be readily used for laying. The demonstration for material, for plant, equipment and method of construction that are proposed for concrete.

As per Guidelines of IRC:SP:84-2014 any alternative material, technology/method, that is not covered in the Indian or International standards but the use of which has been permitted on similar projects, as the project Highway such as NH-4 from Satara - kolhapur, Kagal section completed in the year 2005, its continued successful performance of materials for at-least 5 years which is a supportive for its critical performance can be a very good support for design of sustainable green Pavement concrete.

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