

## **“Comparative Study Of Performance And Properties Of Reactive Powder Concrete Over High Performance Concrete And Conventional Concrete”.**

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**Abstract:** Reactive Powder Concrete is an ultra high strength and high ductility cementitious composite with advanced mechanical and physical properties. It is a special concrete where the microstructure is optimized by precise gradation of all particles in the mix to yield maximum density. This new material demonstrates greatly improved strength and durability characteristics compared with traditional or even high performance concrete. The improved properties of RPC are obtained by improving homogeneity of the concrete by eliminating large aggregates, increasing compactness of the mix by optimizing packing density of fine particles, and using fine steel fibers to provide ductility. In this paper the benefits of the RPC over the HPC and Conventional concrete and reduction in the cost of RPC by replacing the Micro Silica and Cement with fly ash and its effect on durability of RPC as well. An attempt has been made in the present experimental study to determine the Effect of dosage of Admixture and water cement ratio on workability, compressive strength and flexural strength of high performance concrete. In the absence of standard mix design procedure, on the basis of data obtained from previous experimental study, specific mix proportions has been evaluated and total 4 number of mix proportion were decided 9 specimen for compression and 1 no for mix proportion were decided 3 specimen for flexural each proportion were casted and tested under the action of uni-axial compression and flexure. 51 specimens were tested using a compression testing machine, flexural testing machine and workability is determined by slump cone test.

**Keywords:** RPC, Compression, Flexural, Workability, Admixture, Steel fiber

### **I. INTRODUCTION**

Concrete is one of the necessary elements for structural work in the modern construction. In the decade, buildings around the world have become higher and so the structural strength demand for concrete is increased as they require high strength concrete. Concrete is widely used construction material dominating the construction industry worldwide. Portland cement important ingredient in modern concrete was first used in 1824 by Joseph Aspdin in England. Today world production of concrete exceeds 1 billion tonnes per annum. High strength concrete is an important member of the concrete family. The concrete that was once known as high-strength concrete in the late 1970s is now referred to as high-performance concrete because it has been found to be much more than simply stronger; it displays enhanced performance in such areas as durability and abrasion resistance. Reactive Powder Concrete (RPC), which is an Ultra High Performance Concrete (UHPC), represents one of the most recent technological leaps witnessed by the construction industry. Reactive powder concrete (RPC) have been marketed as high performance concretes in various countries. This new family of materials has compressive strengths of (170 MPa to 230 MPa) and flexural strengths of (30 MPa to 50 MPa). There is a growing use of RPC owing to the outstanding mechanical properties and durability. Since the intrinsic strength of concrete is its ability to resist compressive loads, reinforced concrete members are designed to take advantage of this intrinsic strength. Therefore, the knowledge of the behaviour of concrete in compression is very important. Therefore, the behaviour of RPC under compression, flexural, tensile is of considerable interest in the design of RPC members and prediction of their structural behaviour. Compressive strengths of RPC ranges from 200 to 800 MPa. There is a growing use of RPC owing to the outstanding mechanical properties and durability. RPC structural elements can resist chemical attack, impact loading from vehicles and vessels, and sudden kinetic loading due to earthquakes. Ultra high performance is the most important characteristic of RPC. Reactive Powder Concrete (RPC), which is an Ultra High Performance Concrete (UHPC), represents one of the most recent technological leaps witnessed by the construction industry. Among already built outstanding structures, RPC structures lie at the forefront in terms of innovation, aesthetics and structural efficiency.

Beginning with Richard and Cheyrezy(1995), Jörg Jungwirth(2002), Chang.et.al(2009) and Malik.et.al.(2010),Neven Ukarainczyk(2014) many researchers have investigated the various aspects of RPC. However, proper selection of materials, their proportioning and process of production influence the rheological properties and mechanical performances of RPC. Since the intrinsic strength of concrete is its ability to resist compressive loads, reinforced concrete members are designed to take advantage of this intrinsic strength. Therefore, the knowledge of the behavior of concrete in compression is very important. RPC is a recent development in concrete technology. Therefore, the behavior of RPC under compression is of considerable interest in the design of RPC members and prediction of their structural behavior. However, only a few studies have been undertaken on the rheological and strength properties of RPC. Current study aims at comparing the benefits of the RPC over the HPC and reduction in the cost of RPC by replacing the Micro silica with fly ash and subsequent effect on durability of RPC as well.

#### **A. Historical Background of RPC**

RPC is advanced cement based material, which originally developed in the early 1990s by Bouygues laboratory in France. RPC possess ultra-high static and dynamic strength, high fracture capacity, low shrinkage and excellent durability under severe condition. The microstructure of RPC is optimized by precise gradation of all particles in the mix to yield maximum compactness. With these merits, RPC has a great potential prospect in the protective shelter of military engineering and nuclear waste treatment, which has received significant concerns from experts across the word. However, the high cost, complex fabrication technique and high energy demand of RPC severely limit its commercial development and application in the practical engineering. It is well known that the major components of RPC commonly used across the world include Portland cement, ultra-fine quartz powder, micro silica (accounting for 25% or greater weight of the total binders) and small sized steel fibers. Obviously, these expensive raw materials are responsible for the high production cost.

#### **B. Scope Of Project Work**

1. RPC with micro silica encourage pozzolonic reactions are activated by temperature for curing of 90<sup>0</sup>C for two days while decreasing the size of pores and made to withstand upto 524Mpa compressive strength use of silica fume.
2. To types of shapes thickness are considered to reduce high frequency oscillations effect and achieve constant rate over certain deformation range.
3. To reduce thickness of structures such as slab, beams and girders, etc.
4. Achievement of ductility and homogeneity in structure.
5. It is most beneficial for purpose of impact resistant structures, nuclear structures, skyscrapers, corrosion proof structures, pavements, barrier to nuclear radiation.
6. It is also preferable for sewers, culverts and pressure pipe structures.
7. It is most important of cost reduction.
8. It is most beneficial for purpose of impact resistance structures, such as structures in coastal region such as pavements, ports and harbor.
9. To reduces thickness of structures such as pavements upon bridges, flyovers, Culverts, causeway etc.

### **II. MATERIALS USED AND THEIR PROPERTIES**

In this paper, ingredients used in preparing RPC mixtures are different from conventional concrete. The materials include Cement, Fly Ash, Micro Silica (MS), Quartz Sand (QS), Sea Sand, steel fibers, Admixture and Water. Details of each constituent are as follows. Table 1 and table 2 shows the properties of Super Plasticizer and Silica fume.

#### **A. Cement**

The Birla Super A1 53 grade ordinary Portland cement was used during the experiments which conforms to IS:12269-1987. The specific gravity 3.14; the initial and final setting times are 120 min and 255 min.

#### **B. Micro Silica**

The silica fume was used in this experiments conforms to ASTM C 1240 and IS 15388:2003. The specific gravity 2.63; Moisture content 0.058%; Pack density 0.76 gm/cm<sup>3</sup>. The silica fume is extremely fine

particle size of 0.5µm-1µm, which exists in white color powder form. Silica has been procured from National mineral LTD. Pimpri, Pune

### C. Quartz Sand

The specific gravity 2.6 and it is in White colour sand form and has particles size ranging from 200µm-500µm was procured from Sakalchand PVT. Ltd. Pune

### D.Sea Sand

The ideal Sea sand for the experimental studies are intermittent sand filters receiving domestic wastewater is coarse sand with ineffective size between 0.3 mm and 0.5 mm (Crites and Tchobanoglous, 1998; Ohio State University,1999);Was procured from DeeJay Enterprises, Bebedohal, Punawale.

### E. Admixture

Master Glenium sky 8233formely B-233 which is poly-carboxylic ether based hyper super plasticizer procured from BASF India Ltd construction chemicals-Secundarabad.

### F. Steel fibers

Crimped fibers are used in this study which have diameter of 0.4mm, length of 13 mm and aspect ratio of 32.5 and procured from steel fibers reinforcement redefined proceeded by Vinayaka Shot PVT. Ltd. Indore Madhya Pradesh, India

Table 1 Properties of Silica fume

Sr No.	Properties	Specification Limits
1	Appearance	White free flowing powder
2	Sp. Gravity	2.20g/m <sup>3</sup>
3	Colour	White
4	Pack density	0.76gm/cc
5	Specific surface	20 m <sup>2</sup> /g
6	Particle Size	20 µ m
7	Bulk density	1.25g/cm <sup>3</sup>
8	SiO <sub>2</sub>	99.89%

Table 2 Properties of Admixture  
Properties Glenium Sky B-8233

Sr. No.	Properties	Specification Limits
1.	Specific Gravity	1.09
2.	Aspect	Light brown liquid
3.	PH	> 6
4.	Chloride ion content	<0.2%
5.	Type	Poly Carboxylic ether
6.	Solid content	>30%

## III. EXPERIMENTAL PROGRAMME

### A. Mix proportion

The mix design of RPC based on the reference mixes available in the literature and various trail and errors had done at the laboratory. It is identified that Micro Silica /Cement ratio,Fly Ash/Cement ratio and Quartz powder/Cement ratio 0.1,0.25 and 0.73 respectively (Richard and Cherzy, 1995; Ductal et al, 1995; Dill

and Santhanm, 2004; Graybel, 2007; Prabhat Ranjan et al, 2013). The optimal dosage of Steel fibre ratio is 11.33% by volume or about 216.8 kg/m<sup>3</sup>.

**Table 3. shown RPC mixes used in this present study;**  
**Trial three For Steel Fibre 11 % (100mm block) and for W/C = 0.3 MS/C=0.1, QS/C=0.73, Sea.S/C=1.71**

Sr. No.	Item	Without steel fibre	Steel fibre 15.22%	Steel fibre 11.0%	Steel fibre 11.33%
1	Portland Cement	400	400	400	400
2	Fly ash	100	100	100	100
3	Sea Sand	685	685	685	685
4	Quartz Sand	292	292	292	292
5	Micro Silica	40	40	40	40
6	Admixture	5.5	5.0	5.0	5.0
7	Steel Fibre	-	300	216.83	223.5
8	Total Water	160	160	160	160
	Total	1682.5Kg	1982.5 Kg	1898.83Kg	1905.5Kg

### B. Mixing sequence

Since RPC is composed of very fine constituents the conventional mixing is not appropriate, so the mixing method can't be the same. The following sequence in mixing RPC is based on the previous studies and our own trails at laboratory.

- A pan mixer of 100 kg capacity was used to mix RPC, having RPM of 300
- Mixing all dry powders includes cement ,fly ash, micro silica, quartz sand and sea sand for about 5min
- Addition of half the volume of water containing of admixture, mixing it for about 3 min
- Addition of remaining water and admixture; mixing is continued for until uniform mixture was achieved which has flow able self compacting consistency.
- Finally steel fibers were added when the flow able consistency was achieved.



**Fig 1. Shows Flow ability of the RPC**

**C. Specimen preparation and curing**

For each mix of concrete, 4 sets of samples were cast, each set contain 3 cubes (100mmX100mmX100mm) ,1 set of (150mmX150mmX150mm)and one 4 sets of samples were cast, each set contain 3 cubes (100mmX100mmX100mm),3 beam of size (150mm X 150 mm X 750 mm ),demoulded after 24 hours then they were allowed for normal water curing for seven day. Then after which they were allowed with atmospheric temperature and then kept in water till the date of testing. Similarly second set, third and fourth set of samples were taken out from the water after which they allowed to attain.

**D. Testing**

Cubes of size 100 mmX100mm X100mm and 150mmX150mmX150mm were tested to compute compressive strength and beam of size 150 mmX150mmX750mm were tested to compute flexural strength of concrete. Both specimens were tested under the Compression testing machine of 2000 KN capacity. Average of 3cubes compressive strength and 3 beam of flexural strength are tabulated.

Table 4: Trial First for without Steel Fiber(For 100mm block) and for MS/C=0.1, QS/C=0.73, Sea.S/C=1.71

Days	Specimen	W/C ratio	FA/C ratio	Admixture (ml)	Load	Compressive Strength (MPa)	Average (MPa)	Standard Deviation
3	A1	0.3	0.25	5.5	264	26.41		
	A2	0.3	0.25	5.5	280	28.01	26.7	2.38
	A3	0.3	0.25	5.5	257	25.68		
7	A4	0.3	0.25	5.5	316	31.55		
	A5	0.3	0.25	5.5	356	35.64	33.6833	4.10
	A6	0.3	0.25	5.5	339	33.86		
28	A7	0.3	0.25	5.5	538	53.76		
	A8	0.3	0.25	5.5	518	51.82	52.1767	2.88
	A9	0.3	0.25	5.5	510	50.95		

Table 5: Trial Second For Steel Fiber 15.22%(100mm block)and for MS/C=0.1, QS/C=0.73, Sea.S/C=1.71

Days	Specimen	W/C ratio	FA/C ratio	Admixture	Load	Compressive Strength (MPa)	Average (MPa)	Standard Deviation
3	B1	0.3	0.25	5	314.6	31.46		
	B2	0.3	0.25	5	338.8	33.88	31.07	6.05
	B3	0.3	0.25	5	278.7	27.87		
7	B4	0.3	0.25	5	366.6	36.6		
	B5	0.3	0.25	5	382.9	38.29	36.9667	2.37
	B6	0.3	0.25	5	360.1	36.01		
28	B7	0.3	0.25	5	732	73.2		
	B8	0.3	0.25	5	717.9	71.79	73.22	2.88
	B9	0.3	0.25	5	746.7	74.67		

Table 6: Trial Second for Steel Fibre 15.22%(150 mm block)and for MS/C=0.1, QS/C=0.73, Sea.S/C=1.71

Days	Specimen	W/C ratio	FA/C ratio	Admixture	Load	Compressive Strength (MPa)	Average (MPa)	Standard Deviation
3	C1	0.3	0.25	16.87	477.6	31.84		
	C2	0.3	0.25	16.87	488.4	32.56	31.5333	2.42
	C3	0.3	0.25	16.87	453	30.2		
7	C4	0.3	0.25	16.87	538.4	35.89		
	C5	0.3	0.25	16.87	547.3	36.48	36.7733	2.12
	C6	0.3	0.25	16.87	569.3	37.95		
28	C7	0.3	0.25	16.87	1085	72.32		
	C8	0.3	0.25	16.87	1096	73.04	72.11	2.10
	C9	0.3	0.25	16.87	1047	70.97		

Table 7: Trial three For Steel Fibre 11 % (100mm block)and for MS/C=0.1, QS/C=0.73, Sea.S/C=1.71

Days	Specimen	W/C ratio	FA/C ratio	Admixture	Load	Compressive Strength (MPa)	Average (MPa)	Standard Deviation
3	D1	0.3	0.25	5	359.4	35.94		
	D2	0.3	0.25	5	381.8	38.18	36.8633	2.34
	D3	0.3	0.25	5	364.7	36.47		
7	D4	0.3	0.25	5	587.5	58.75		
	D5	0.3	0.25	5	600.2	60.02	58.8867	2.14
	D6	0.3	0.25	5	578.9	57.89		
28	D7	0.3	0.25	5	1006	100.64		
	D8	0.3	0.25	5	1028	102.81	101.103	3.06
	D9	0.3	0.25	5	998.6	99.86		

Table 8: Trial Three and First for beam (750 x 150 x 150mm)and for MS/C=0.1, QS/C=0.73, Sea.S/C=1.71

Days	Specimen	W/C ratio	FA/C ratio	Admixture (ml)	Load	Compressive Strength (MPa)	Average (MPa)	Standard Deviation
3	F1	0.3	0.25	84.35	6174	5.48		-0.29
	F2	0.3	0.25	84.35	5771.3	5.13	5.19	0.06
	F3	0.3	0.25	84.35	5602.5	4.98		0.21

Table 9: Trial Forth For 100mm blocks with Steel Fiber 11.33% and for MS/C=0.1, QS/C=0.73, Sea.S/C=1.71

Days	Specimen	W/C ratio	FA/C ratio	Admixture	Load	Compressive Strength (MPa)	Average (MPa)	Standard Deviation
3	E1	0.3	0.25	5	381.4	38.14		
	E2	0.3	0.25	5	377.4	37.74	37.57	1.34



	E3	0.3	0.25	5	368.3	36.83		
7	E4	0.3	0.25	5	602.8	60.28		
	E5	0.3	0.25	5	596.8	59.68	60.33	1.35
	E6	0.3	0.25	5	610.3	61.03		
28	E7	0.3	0.25	5	1029	102.89		
	E8	0.3	0.25	5	1020	101.96	102.427	0.93
	E9	0.3	0.25	5	1024	102.43		

**Closure:** The results are obtained in satisfactory manner barring readings of some specimens. The analysis of the same is presented in result & discussion.

#### IV. RESULTS AND DISCUSSION

The results tabulated in the chapter of Experimental Results are analyzed by sorting the tables according to water cement ratio.

##### A. Production process

By physical observation during concrete mixing, a long time is required for RPC mixes to ensure that self flow able self-compacting consistency. The total mixing time is 15 min; the long time mixing is necessary for dispersing micro silica, quartz sand, sea sand and steel fibers in well manner.

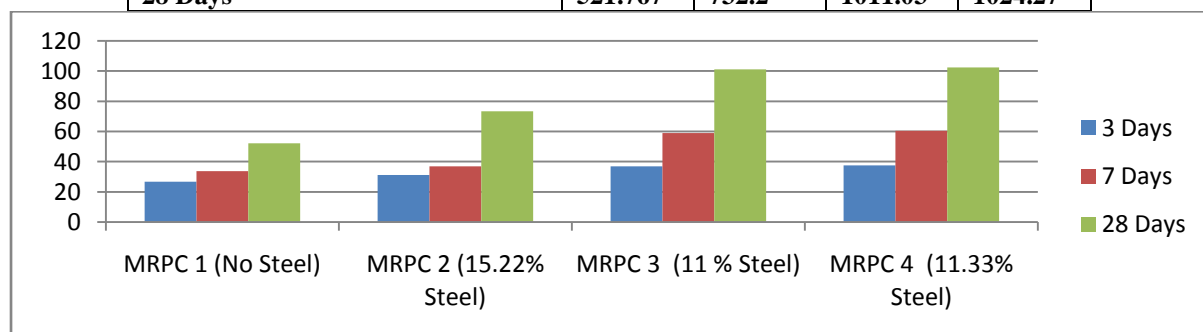
##### B. Mechanical properties

The test results of compressive strength, and split tensile strength and theoretical modulus of elasticity for corresponding mixes are tabulated.

Compressive strength test results are shown in table 10 and fig no 2. The compressive strength results shows that there is good positive effective of optimize steel fiber content up to 11.33% by weight of concrete. The main reason for the increase in compressive strength is due to the physical effect of crimped steel fiber that allows denser packing within the cement particle and quartz powder also acts as pozzalanic materials as well as sea sand as siliceous material at higher temperature and improves the micro structure which leads to increase in compressive strength.

**Table 10: Compressive strength results load in KN**

Mix ID	Trail 1	Trail 2	Trail 3	Trail 4
3 Days	267	310.7	368.633	375.7
7 Days	336.833	369.667	588.867	603.3
28 Days	521.767	732.2	1011.03	1024.27



**Fig2: Variation of Compressive Strengths for different proportions**

By the observation of the graphical representation we observed steel fiber is the most important material parameter to be optimized for cost saving and achieving high strength

Flexural strength results are shown in table 11 and It was recorded that maximum flexural strength is 5.48 MPa for Trail-3 mix with 7 days normal curing. From the results it can be observed that flexural strength of concrete increased in line with compressive strength.

Table 11: flexural strength results load in KN

Mix ID	Trail 3
3 Days	6174
7 Days	5774.3
28 Days	5602.5

### C. Analysis of strength of RPC

In the experimental program carried out the effect of w/c ratio ,dosage of admixture, fly A/c ratio and % of steel fiber optimization was taken initially as 0.3( w/c ratio),5ml (admixture), 0.25 (fly A/c ratio),11.33%(% of steel fiber) respectively. for this slump or no slump was observed also the specimen for compression and flexural testing could be prepared properly.

By the trials we have achieved high strength with material optimization such as for 1m<sup>3</sup>.

- Cement (400Kg)
- Steel fiber (11.33%)
- Admixture (5ml)
- Fly Ash (100 kg)
- Micro silica (40 kg)
- Quartz sand (292 kg)
- Sea sand (685 kg)
- 

### D. Variation of cost for different concrete

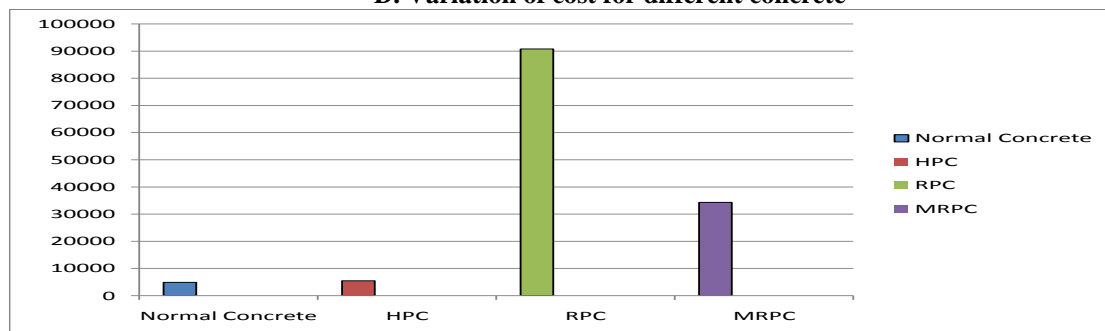


Figure 3: Variation of cost for different concrete

### E. Variation of Compressive Strengths for different concrete

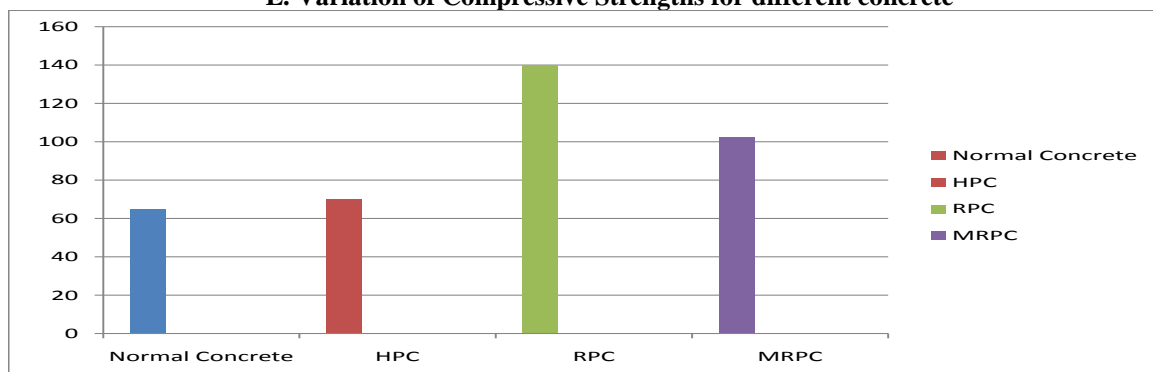


Figure 4: Variation of Compressive Strengths for different concrete



#### **D. Density of RPC specimens**

The density of all specimens is varied between 23.3 - 26.0 KN/m<sup>3</sup>

#### **F. Effect of Steel Fiber Quartz powder on compressive strength**

Hydrated cement alone can't help to evaluate the compressive strength of RPC but other parameters contribute marginally such as steel fiber, quartz sand and sea sand types. Here quartz sand and sea sand act as effective filler material at normal water curing and also it's act as a pozzolanic and silicious material at higher temperature. From the observations of following graphs, the optimization of steel fibre produce the better results of normal water curing. The results show that maximum compressive 102.427 MPa is attained at steel fibre of 11.33% by weight of concrete under the normal curing condition. This is possible due to optimize steel content and increased proportion of fine fillers that enhance the packing density, pore fill in action and long chains of C-H-S gel.

#### **G. Rate Analysis Costing factor of Original RPC and Modified RPC**

In this parameter we have saved the cost of RPC for M40 grade with 61% (Rs34345.5 /-) Over original RPC as 100% (Rs.90785/-) per cu.m. with achieving near about the strength of original strength 200 Mpa..

### **V. CONCLUSIONS**

In this paper the investigations of effect of increase of quartz powder and thermal curing on UHSC are presented.

The following conclusions can be summarized from the study.

**A. Compressive & Flexural Strength:** With the replacement of fly ash with cement it increases its compressive & flexural strength, reducing water cement ratio.

**B. Serviceability:** With the increase sea sand and quartz sand with the help of micro silica, enhances the serviceability of concrete. Increase due to higher percentage of silica's matter (sea sand contains 96-98% silica stated in chemical properties in chapter no. 5).

**C. Mechanical Properties** Optimized percentage of steel fiber utilized in RPC has immense potential in construction due to superior mechanical and durability properties than conventional high performance concrete

**D. Microstructure:** RPC has an ultra dense microstructure giving advantages, waterproofing and durability characteristics.

**E. Homogeneity:** Enhancement in homogeneity elimination of coarse aggregates utilizing of pozzolanic properties of micro silica's and sea sand by its potential compressive & flexural strength.

**G. RPC provides improved seismic performance** by reducing inertia loads with the higher members allowing larger deflections and providing higher energy absorption

**H. Workability:** The development of RPC is based on the application of some basic principles to achieve enhanced homogeneity, very good workability, high compaction and improved microstructure

### **VI .NOMENCLATURE**

HPC- High Performance Concrete

RPC-Reactive Powder Concrete

MRPC-Modified Reactive Powder Concrete

MC-Micro Silica

QS-Quartz Sand

LCRPC-Low Cement Reactive Powder Concrete

Cu.M-Cubic Meter

Mpa-Mega Pascle

KN-Kilo Newton

Et al.- Etc. and all

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