



Behaviour of reinforced concrete column under different loading - A review

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Abstract: High Performance Concrete (HPC) has improved a lot in the last 10 years. It has higher compressive strength, greater stiffness, and smaller section sizes. These features affect how structures are designed is often used in columns of buildings and bridges where high strength is needed. Columns are usually designed for straight (concentric) loads. But in real life, loads are often off-centre (eccentric). HPC columns with different shapes were tested under different loading conditions. The strength of the concrete ranged from 40 MPa to 124 MPa. The columns were tested with slowly increasing concentric loads. Researchers studied how HPC columns with rectangular ties behaved under these loads. They looked at different properties and how these affected the strength of the columns. Some HPC columns were also tested under low axial loads and reversed inelastic displacements. These columns showed a small amount of ductility.

Keywords–High Performance Concrete, Axial loading, biaxial bending, column,

1.0 INTRODUCTION

High Performance Concrete (HPC) has improved a lot in the last 10 years. It has higher compressive strength and greater stiffness. It also allows smaller column sizes, which saves space. These features help structural designers a lot. HPC is used in parts of buildings and bridges that carry heavy loads, like columns. Using HPC in columns can reduce their size and give more usable floor space. HPC has a higher elastic modulus than Normal Strength Concrete (NSC). This means buildings made with HPC can be stiffer than those made with NSC, even if the size is the same. Most design codes like ACI, IS 456, and AASHTO are still based on tests done with NSC. In India, IS 456:2000 limits concrete strength to 55 MPa unless more tests are done. These limits are not because HPC cannot perform well. They are there because not enough research was available when the standards were made. In general, reinforced concrete columns are subjected to bending moments at the ends due to their location in the structures, the shape of the cross section, the geometric imperfections or horizontal loads as wind or seismic forces. Depending on the type of force and restraints at the ends, columns are subjected to axial forces acting with equal or unequal eccentricities at the ends. Most researchers found in the bibliography focus on the study of the slender columns subjected to compression and uniaxial bending with equal eccentricities at the ends. Reinforced concrete columns are generally subjected to eccentric compression because of their location in the structure, their cross-section, or the type of forces they bear. Many columns are subjected to this kind of loads, for example the corner columns of a building or the piles of a bridge. Most authors have studied the behaviour of high strength concrete subjected to uniaxial bending,

2.0 FUTURE SCOPE

More research must be done to get full benefits of HSC. it is important to study the concrete column with maximum possible grade of concrete (i.e. beyond M100) with varying percentage steel, variable transverse steel, different yield strength of longitudinal reinforcement.

3.0 METHODOLOGY

3.1 General

In this chapter, the procedure or methods are discussed briefly to complete investigate of the behaviour of member. This chapter includes different steps due to which the research work meets to its objectives i.e. the material used and its properties, methods used for designing and execution of specimen and testing equipment.

3.2 Ingredients of High-Performance Concrete

- 1) Cement
- 2) Coarse aggregate
- 3) Fine aggregate
- 4) Mineral admixtures (supplementary cementitious materials)
- 5) Chemical admixtures (plasticizers, super plasticizers, retarders etc.)

3.3 Selection of Material

To get or to achieve design compressive strength of particular concrete proportion is very difficult, hence proper selection of material is more necessary to select the ingredients of high strength and performance-based concrete very carefully. Performance and quality of materials become critical at some points due to increase in target strength. For making of the required compressive strength of concrete with performance of concrete and expected workability, number of chemical admixture and mineral are used along with regular concrete ingredient, so there no simple rule to make choice of materials.

3.3.1 Cement - While making of HPC the first choice to be made of binder or cement even when more than one supplementary binding material are to be used in HPC. This is due to performance of cement under rheology and strength point of view becomes a critical issue because the target strength increases. Experience shows that the difference in the composition of cement makes large difference after water to cementitious material ratio is decreases to value by 0.35 to 0.3, while utilizing it in forming of HPC.

3.3.2 Coarse aggregate - It has been observed that, while target compression capacity increases the aggregate act like most strength less connection, it is because the failure initiated started under high stress. So careful selection of aggregate is important in case of formation HPC. While making HPC our primary consideration is to reduce the water requirements, so that it is necessary to have close control on quality of aggregate and maximum size of aggregate. It must be necessary to use only well graded coarse aggregates. In HPC crushed hard and dense rocks like granite, syenite, diorite have been used.

3.3.3 Fine Aggregate- Sand properties can differ across a wide range. Little researches had been made for enhancing properties of fine aggregate for application of it in the practice. Normally, fine aggregate used for production of HPC have particle size distribution up to the restrictive value that are given ACI code for normal concrete. The use sand having fineness modulus 2.7 to 3.0 for making of HPC. The usage of coarser particle of sand result in easy shearing of cement paste formed during formation of mix.

3.3.4 Mineral Admixtures- HPC may be produced by utilizing Portland cement unaccompanied as binder. Some replacement of binder by single binding material or by more binding material, when the cementitious material available at competitive rates in market then the use of such material might become beneficial according to economic point along with rheological and in some cases strength point of view.

3.3.4.1 Micro silica - (Silica Fume) Silica fume is another substitute of cementitious material. It is the by-product produced during production of silicon metal and ferrosilicon alloy, other silicon alloy. from Structural thoughts of understanding, silica fume contains vitreous quantity of silica, from physical thought, silica fume particles look like sphere-shaped shape and having diameter less than 0.1µm to about 1 or 2µm. which is averagely hundred times less than cement particle.

3.3.4.2 Fly Ash - Fly ash are little size particles gathered by dust collecting system of coal burning plants. It has various phase composition and chemical composition as fly ash are entirely associated to the category and quantity of dirt that present in coal burnt in plant. When we consider physical property of fly ash, it can be more varying from each other. The shape of the fly ash particles appears as spherical. the grain sizes of particles are nearly equal to grain size distribution of Portland cement. Whereas in some cases angular particles are also observed in fly ash.

3.3.5 Chemical Admixtures - Chemical admixtures are added in concrete to achieve number of objectives, for example improving consistency and controlling the setting time. During making of High-performance concrete, the desired workability is to be achieved with reducing water content is very important, it is normally achieved by using superplasticizers. It is very important to select good and efficient superplasticizer, is very critical to select such superplasticizer while making of High performance of concrete. Because the behavior of superplasticizer with brand is not same with the cement.

3.4 Mix Proportioning

The process which is used to calculate accurate contribution of each material that used in making of concrete mix with required properties at minimum possible amount. The mix proportioning process is not easy even with normal concrete. because this process includes, skills that helps in selecting the material quantity which has conflicting requirements. Hence it is necessary to test earlier suitable proportion of ingredients are arrived.

Preparing the High-performance concrete is complicated process comparing to preparation of ordinary concrete. The reason behind this complication is, number of issues requires to adjust are more (up to three additional elements). Most critical point always is matching a binding ingredient with superplasticizer in such manner, both can make a proper concrete mix even if the water present in mixture is very less and it must be remained fluid for long enough for purpose of convenient or easy placing of mixture. Following are the steps that followed during the process of mix proportioning.

1. First, selecting the material, the priority given to use of locally available materials.
2. Second, defining the proportion of constituents of concrete has probability to specify the specification.
3. Tentative frame must be optimized by theoretical or empirical methods.
4. The cement and different admixture must be investigated

.5. Mix Design Method

The method proposed by author basically related to the calculation of configuration of non-air entrained concrete. for mix deign of air of air entrained concrete this method can be utilized for HPC but the reduction in strength due to occurrence of the air bubble system is taken into consideration. This method is very simple, the method is same as ACI 211-1 Standard Practice for determining proportion for Normal Strength Concrete, Heavyweight Concrete and Mass Concrete. this method based on absolute volume method and are combination of mathematical calculation and empirical results. The water present in chemical admixture is counted as water which is to be used for formation of concrete.

Following are the steps followed in this method of mix design.

1. Selection of water binder ratio
2. Selection of water content for mix
3. Selecting dosage of superplasticizer
4. Selection of coarse aggregate content
5. The entrapped air

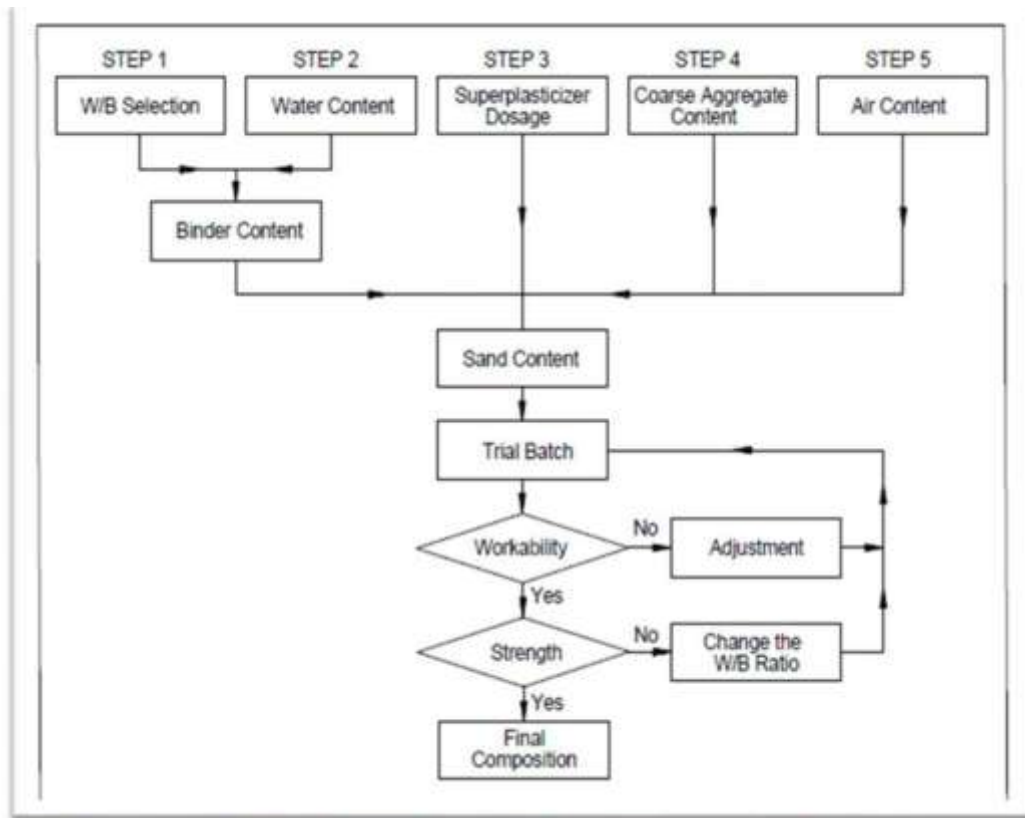


Figure 3.1: Figure Showing the Proposed Method for Mix Design.

4.0 Experiments

4.1 Testing of Concrete Cube and Cylinder

Compressive strength is property of concrete that not only proves advantageous to HPC but also advantageous to normal concrete. Compressive strength is very important and useful property of concrete which also related to other properties like durability, elastic modulus, and imperviousness. Compression tests are conducted on the cubelike and cylinder-shaped specimen. The concrete cube specimens with dimension equal to 150mm x 150mm x 150mm was tested. Cylindrical specimen having size 150mm in diameter and 300mm tested. Concrete blocks and cylinders were removed from curing container after 28 days of curing period. These cubical and cylindrical specimens then tested under CTM having capacity of 3000KN. Loads crushing the concrete were recorded and average compression capacity is calculated. When normal concrete is tested under compressive load and is observed by naked eye, it is observed that the failure occurred also within the mortar or it is along the boundary between concrete mortar and coarse aggregate elements. In normal concrete these two zones contribute as weakest link. However, in some cases failure plane is passes through the aggregate particles, it is because of weaker aggregate present in concrete.

4.2 Testing of Column Specimens

In previous literature it has been seen that, the research regarding the high strength slender column is not much, and it also observed that there is lack of research in high strength concrete column under uniaxial and biaxial loading. Hence to reinforce this area, the objectives of the present research is to observe the performance of slender RC column under uniaxial and biaxial loading experimentally and comparing it with numerically calculated values. This experimental work begins with, studying the behavior of slender column and to observe the available codes for calculation of ultimate load and moment. For this purpose, the variables are determined that are, slenderness ratio (35), compressive strength of concrete (M60, M100) and varying eccentricities for loading (10% and 20% of sectional dimension of column). Experimentally, it is starts with casting of cubes for 60 and 100 N/mm² and casting of total eight column four of 60 N/mm² with different eccentricities under uniaxial and biaxial loading. And same with 100 N/mm².

4.3 Instrumentation and testing

To remove any surface unevenness present on column specimen surfaces, top and bottom surfaces of column specimen were grinded by the grinding machine. while care is taken for excessive grinding and is avoided. Uniform cover is kept uniform to the longitudinal reinforcement at the ends. Sheet was put on both ends of column to get the parallelism of top and bottom end surfaces of column specimen in addition to grinding. Putting sheets on column surfaces also done to uniform distribution of load on the specimen.

4.4 Testing Procedure

The displacement of the concrete specimen was noted with the help of two Linear Variable Displacement Transducer's (LVDT's) and dial gauges, one was attached by the means of steel clamp on opposite sides to continuously record the displacement when column is subjected to the loading. The other LVDT is attached on bottom plates of CTM, that used to measure the post peak displacements. The displacement was manually noted from the displacement indicator. The testing assembly that used in present work is as shown in figure 6.12. The column specimen was subjected to loading by means of hydraulic jack of loading frame. Initially an approximately 20% of total ultimate estimated load was applied and the readings of LVDT's were recorded to ensure eccentric

loading. When the readings of the LVDT's were equal on both faces, this ensure that the load is applied at an eccentricity from center of column specimen and the testing is continued. If it is not, then the load applied on column was removed and the additional minor packing was provided to the column. While testing of column specimen, the load when cracking occurs at surface of column, first peak load, maximum load, second peak load and related displacement were observed. The displacement value was recorded from the LVDT's till they are separate from the concrete. The data is obtained by data acquisition system. The data extracted were used to plot the moment interaction curve and load verses displacement. The data that obtained from experimental work may be compared with the data that available in research. The results obtained are confirmed and conclusions may be made which can give more insight on the behaviour of long columns under biaxial loading.

5.0 RESULTS AND DISCUSSION

5.1 General

While testing of column specimen it is noticed that at the starting, all column performed in similar way up to when the removal of concrete column cover is not happened. Mostly the stress-strain relationship was observed linear. Normally, HSC column appears steeper. The strain at point when the concrete cover spalling observed were not more than strain of related strength of long columns as shown in following table.

5.2 Experimental strength of rectangular long columns:

Table No. 5. Mixture Design for Target Cube Strength M60 To M12

Description	Grade of Concrete			
	60	80	100	120
Water Content (lit/m ³)	151.56	143.15	119.6	124.57
Cement (kg/m ³)	365.71	361.67	440	547.82
Fly Ash (kg/m ³)	91.43	103.33	68.75	31.30
Silica Fume (kg/m ³)	-	51.67	41.25	46.96
Fine Aggregate (kg/m ³)	794.14	780.38	824.22	750.89
Coarse Aggregate (kg/m ³)	1027.95	1027.95	1027.95	1027.95
Superplasticizer (%)	0.4	1.0	1.0	1.2
Concrete Cube Compressive Strength after 28 Days (N/mm ²)	63.13	78.02	107.23	119.77
Concrete Cylinder Compressive Strength after 28 Days (N/mm ²)	57.76	-	101.68	89.82

Table No. 5.2 Biaxial Load Carried by Column Specimens

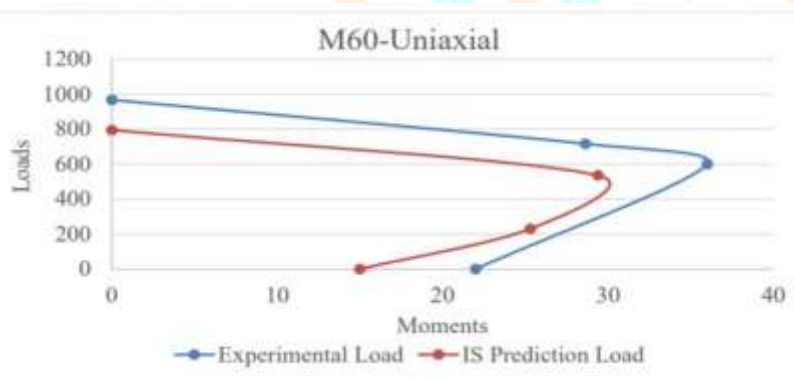
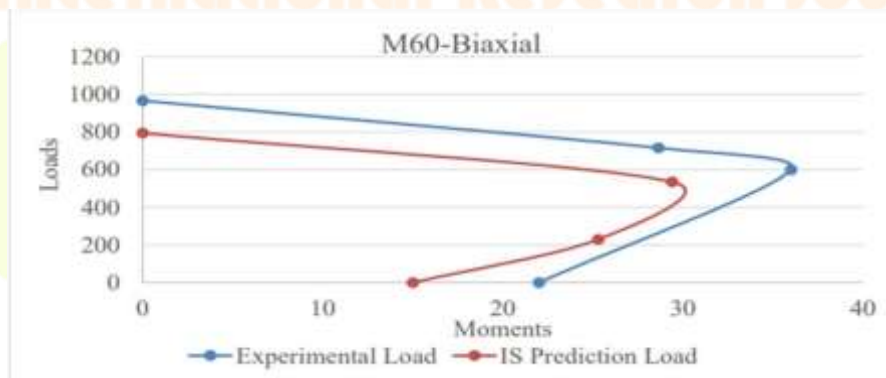
Column Designation	Eccentricity		f_{cu} in MPa	M Test in KN-m	P Test KN
	e in %	e in mm $\sqrt{e_x^2 + e_y^2}$			
I35B10(60)	10%	25	64	17.93	717
I35B20(60)	20%	50	67	32.50	650
II35B10(100)	10%	25	95	25.15	1006
II35B20(100)	20%	50	99	45.55	911

Table No. 5.3 Comparison Between Results of Column Under Uniaxial and Biaxial loading

Grade of Concrete	Eccentricity In %	Concrete Strength (N/mm ²)	Uniaxial Loading (KN)	Biaxial Loading (KN)
M60	10	64	744	717
M60	20	67	716	650
M100	10	95	1044	1006
M100	20	99	1003	911

5.3 Moment -Interaction Curve

“Graphical representation, that summaries ultimate bending capacity of a particular RC column that having dissimilar sizes and longitudinal steel area” is termed as moment interaction curve. The interaction curve is over all graphical presentation of design strength of column which subjected to eccentric loading. The analysis and design of column that subjected to combination of loading is not easy whenever the principles of statics are to be used. The neutral axis having some inclination from both the axis, hence to determine the position of neutral axis the lengthy calculation is needed. It is also needed to calculate strains, concrete compression area and internal forces and their point of action. So that it is important to have a practical solution to calculate the strength of column under uniaxial and biaxial loading. The biaxial bending strength of a biaxially loaded column can be presented by a moment interaction curve.

**Fig. No. 5.1 Interaction Curve for M60 Concrete Under Uniaxial Loading****Fig. No. 5.2 Interaction Curve for M60 Concrete Column Under Biaxial Loading**

The above interaction curve shows the moment is more for slender column subjected to loading at the eccentricity of 20% as compare to 10% eccentricity for M60 grade concrete. the column interaction curve graphical representation of the combined that is bending and axial load which causes the failure of column. X- Axis represents the bending moment that acts on column. Y- Axis represents the Biaxial force that acting on column. The curve is used for knowing the maximum magnitude of loads and eccentricity of load acting of column that can be handle safely.

6.0 CONCLUSION

The conclusions from the study are as follows.

1. For M60 and M100 grade concrete, maximum compressive strength of 67 N/mm² and 99 N/mm² had after substituting of cementitious material by Fly Ash and Silica Fume. The compression failure occurs due to crushing of coarse aggregate not because of weak bond in concrete ingredients.

2. The normal behaviour of RC columns follows the path as, development of surface cracks, starting of cover spalling, separation of concrete cover, yielding of longitudinal reinforcement, yielding of lateral reinforcement and at the end crushing of concrete core of column.
3. The moment interaction diagram shows that the moment is more at midspan of column for M100 grade concrete column with 20% eccentricity.
4. IS 456-2000 is too conservative to determining the ultimate load and ultimate moment of high strength concrete column, need to modify for HPC columns.
5. The experimental results were compared with the ACI code and IS code, the loads predicted by ACI are nearly resemble to experimental results. Whereas the loads predicted by is code are not near to the experimental loads, that indicates lack of provision in is code for high strength concrete.

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