Behavior of Slender Reinforced High Performance Concrete Columns under Biaxial Loading

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ABSTRACT
Columns are structural elements used primarily to support compressive loads. The short column is one in which the ultimate load at a given eccentricity is governed only by the strength of the materials and the dimensions of cross section. Slender concrete columns are economically appealing in tall buildings design; the rentable space over the many floors can be increased by a substantial margin through reduction of the column sections. The slenderness of a column may result in the ultimate load being reduced by lateral deflections of the column caused by bending. Reinforced concrete columns are generally subjected to eccentric compression as a result 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. The analysis of slender reinforced concrete columns is complicated because the buckling analysis must take account of the non-linear properties of the materials and also construction imperfections. Exact analysis methods are generally complicated and unsuitable for everyday design. Over the last few decades, the development in material technology, especially with the availability of super plasticizers, led to the production of High Performance Concrete. With the robust growth of construction with HPC, the design of slender concrete columns is now a subject of considerable relevance. One application of HPC has been in the columns of high-rise buildings. Buckling has become more of a problem in recent years since the use of high-strength materials requires less material for load support-structures and components have become generally more slender and buckle-prone.

Key words
Reinforced concrete column, slenderness ratio, high performance concrete column, bi- axial loading and P-M Interaction diagram.

Introduction

Columns are structural elements used primarily to support compressive loads. The short column is one in which the ultimate load at a given eccentricity is governed only by the strength of the materials and the dimensions of cross section. A slender column is one in which the ultimate load is governed not only by the strength of the materials and the dimensions of the cross section but also by the slenderness, which produces additional bending moment due to lateral deformations. For eccentrically loaded short columns, the column behavior will follow the linear path until intersect the interaction diagram. For eccentrically loaded slender columns, the column will follow a non-linear path until intersects the interaction diagram. This means that, due to non-linear effects the actual moment on the column is greater than the linear moment. [1]

Slender concrete columns are economically appealing in tall buildings design; the rentable space over the many floors can be increased by a substantial margin through reduction of the column sections. The slenderness of a column may result in the ultimate load being reduced by lateral deflections of the column caused by bending. Reinforced concrete columns are generally subjected to eccentric compression as a result 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. The analysis of slender reinforced concrete columns is complicated because the buckling analysis must take account of the non-linear properties of the materials and also construction imperfections. Exact analysis methods are generally complicated and unsuitable for everyday design. [2]

Over the last few decades, the development in material technology, especially with the availability of super plasticizers, led to the production of High Performance Concrete [3]. With the robust growth of construction with HPC, the design of slender concrete columns is now a subject of considerable relevance. One application of HPC has been in the columns of high-rise buildings. Buckling has become more of a problem in recent years since the use of high-strength materials requires less material for load support-structures and components have become generally more slender and buckle-prone. As a result, the slenderness limits based on normal strength concrete (NSC) have to be reassessed to make use of the merits of HPC. Attempts have been made to modify the theory of analysis of slender columns by introducing effects of inelastic behavior and large deformations.

There are two important limits for the slenderness ratio, which are the upper limit for the short column and maximum slenderness limit. The upper slenderness limit is the limit that when the column exceeded is considered a long column. On the other hand, the maximum slenderness limit is stipulated to avoid carrying out second order analysis of the column, which is burdensome and more complicated [1].

The technology of High Performance Concrete (HPC) has greatly improved over the last decade. Globally, there is an increased usage of higher strength concrete with compressive strength of 60 - 120 MPa. The high compressive strength of HPC is advantageous in compressed members such as columns, which can be made more slender and, consequently, make economic benefits possible. When the concrete strength of the long columns was increased, the maximum load carrying capacity becomes greater, inducing more ductile behavior in the post-peak region. Due to increased strength of concrete it is necessary to introduce new limits for the slenderness of the columns. Codes of practice recommend various design methods for slender columns based on capacity reduction factors, additional design moments, or moment magnification, to account for effects of buckling. There design methods are approximate and largely empirical in nature. Therefore, it is necessary to investigate the theoretical behavior of long columns in order to establish certain rules for the design. The proposed research includes the experimental work on HPC slender columns with biaxial loading and analytical modeling to compare with work in the literature and codes

Literature review

Literature review focuses on various aspects such as deflection of column under various loading, buckling analysis of column, and design procedure for high strength braced reinforced concrete column under the action of uniaxial and biaxial loading, Estimating the strength of a slender reinforced concrete column under biaxial bending and axial load. The review of literature on Behavior of Slender The Reinforced High Performance Concrete Columns under Biaxial Loading is presented in this paper.

Code Provisions (ACI 318-11 and IS 456-2000).

If a column is slender, engineers must consider either an elastic second order analysis or they may analyze the column by the moment magnification procedure contained within the Building Code Requirements for Structural Concrete (ACI 318-11). In contrast, engineers would evaluate a non-slender or short column using an elastic first order analysis. The provisions in the moment magnification procedure allow for a column to be designed using a conventional first order analysis provided that the moments calculated by the analysis are increased to account for second order effects. Considerable inconsistencies can exist between the results obtained from an elastic second order analysis and the moment magnification procedure. These inconsistencies cause confusion amongst practitioners and result in wide variations in their use and/or interpretation. Simply put, moments estimated by the moment magnification procedure may be upwards of five times larger than those estimated by a second order analysis. As a result, engineers often discount the moment magnification procedure in favor of the more manageable results obtained from an elastic second order analysis. The main source of these inconsistencies can be attributed to the approximation of a column's flexural stiffness, EI. The two methods use different base values for stiffness, and then each apply different reduction factors to the stiffness values. Indian Code of practice for reinforced concrete IS 456-2000, has also not considered the second order effects of the biaxial bending. P-M interaction diagrams are available for uni-axial loading on columns, however, no P-M diagram are available for biaxial bending of columns. Some time the additional moment due to buckling and eccentricity may be higher than the actual moment due to applied

L. Pallaras, J. L. Bo.net, P. F. Miguel, M. A. Fernandez (2008).

In this work high strength concrete columns subjected to compression and biaxial bending forces were studied. Authors have tested 56 pinned columns of rectangular cross-section (200 ×100 mm) of reinforced concrete of 1, 2 and 3 m length. The Slenderness ratios were varied from 10, 20 and 30 and were adopted by increasing the length. They maintained the strength of the concrete constant throughout their research work, it was 103MPa. The parameters of the work include eccentricity, skew angle and slenderness of the test specimen. The experimental programs of this work include testing of columns in uni-axial bending and biaxial bending. They conclude that, the less slender column and those loaded with high relative eccentricities present failure due to ultimate load of the cross section and on the other hand the more slender column with small eccentricities tends to fail due to instability. The column with intermediate eccentricity and slenderness cases tends to present both instability and ultimate strength of the cross section. The authors present a procedure to identify the failure of concrete column subjected to axial compression force and moment.

N.Khalil, A.R.Cusens, and M.D.Parker (2001).

The study includes testing of 19 full-scale pinned reinforced concrete columns with slenderness ratios between 18 and 63 in short term and long term eccentric loading. The experimental study indicates the fact that instability is the primary failure criteria for slender columns and experience relatively low compressive strains. They have concluded that in all column instability occurred as the primary mode of collapse before the ultimate material capacity of the section was reached. The onset of instability was indicated by a drop in load. A load of 60% of short term capacity sustained for 90 days causes a reduction of 10 to 40% in the load carrying capacity of the slender column and under sustained load of 60% of the short term capacity, the mid height deflection is four times the value on initial loading thus reflecting the magnitude of secondary moments attainable in the slender column.

A. N. Beal, and N. Khalil (2000). This research paper provides the experimental analysis to develop Beal's graphical method of buckling the analysis confirms that Beal's method is accurate and effective; the method provides a powerful analytical tool, allowing fast determination of the column capacity for a wide range of slenderness and loading conditions. It is used here to investigate the behavior of normal- and high-strength concrete columns under both axial and eccentric loads and with a variety of slenderness ratios and reinforcement proportions. The results of this accurate analysis are used as a benchmark for the assessment of code of practice design rules.

The computer programs developed to generate graphs for eccentricity against curvature for different capacity ratios and eleven reinforced concrete columns with slenderness ratios between 18 and 63 were tested under short-term load and eight similar columns tested under sustained load

They concluded that Analysis of the theoretical behavior of columns under long-term loading shows that the existing recommendations of BS 8110 are seriously inadequate. It is proposed that recommendations for slender column design are revised and based on either modified additional moments, or else on an alternative approach based on column capacity reduction factors. In either case, caution is needed where a lightly reinforced high-strength column is subjected to applied moments.

Hamdy Mohy El-Din Afefy, Salah El-Din Fahmy Taher, and Salah El-Din E. El-Metwally (2009).

In this paper the authors have presented a design procedure for braced high-strength reinforced concrete columns under the action of uni-axial and biaxial loading. The first phase represents the design procedure of such columns under the action of uniaxial bending, while the second phase shows the implementation of the design procedure on the columns under biaxial bending. The design procedure given in this is limited to braced buildings, showed its application in the case of the availability of ready-made strength interaction diagrams for high-strength concretes. It also shows its efficiency in verifying the column design under different loading conditions. It can be used to design most complicated columns having different boundary conditions with different curvature modes.

H. P. Hong (2001).

The author proposed new approach for estimating the strength of a slender reinforced concrete column under biaxial bending and axial load. The model considers the nonlinear stress-strain relations of concrete and reinforcing steel, and can be used for slender reinforced concrete column with arbitrary cross section. The nonlinearly constrained optimization problem is used to find the strength of slender reinforced concrete column. The method adopted is used to predict the slender column strength. The author has compared the theoretical and experimental results. A simple theoretical method is presented for estimating the strength of slender reinforced concrete columns under axial load and biaxial bending. The method considers the nonlinear stress-strain curves of concrete and reinforcing steel, and uses a nonlinearly constrained optimization algorithm to find the strength of slender reinforced concrete columns. It can be used to deal with column cross sections of arbitrary shape. The predicted strength obtained by using the proposed method compares well to the limited test data.

J. A. Rodriguez-Gutierrez and J. Dario Aristizabal-Ochoa (2001).

An analytical model that determines the inelastic structural response, ultimate strength, and failure mode of reinforced concrete, partially prestressed concrete, and prestressed concrete slender columns of any cross section under biaxial bending and axial load is presented. The effects of rotational and lateral restraints at the ends are included, but the effects of shear deformations and torsional moments along the member are neglected. The proposed method uses (1) a nonlinear stress-strain relationship for the concrete; (2) a multilinear elastic-plastic relationship for the conventional reinforcement; (3) a modified Ramberg-Osgood function for the prestressed steel; (4) Gauss's integral method for equilibrium at the sectional level to generate the moment-axial load-curvature characteristics along the member; and (5) the finite-element method to evaluate the transverse deflections and second-order moments (*P*-d and *P*-D effects) along the member. The proposed method can be utilized (1) to study the effects of creep, confinement, and tension-stiffening in the concrete and relaxation in the prestressed steel on the behavior, strength, ductility, and failure mode of slender concrete columns; and (2) to analyze prismatic and non prismatic slender concrete columns of an arbitrary cross section under different end supports and bracing conditions. The biaxial bending behavior, strength, ductility, and failure mode of slender concrete columns can be obtained using a minicomputer, and as expected, they depend on (1) bracing and support conditions; (2) cross section and reinforcement layout along its span; (3) the stress-strain characteristics of the concrete and different reinforcements; and (4) the type and intensity of the applied loads. Three numerical examples are presented in detail to verify and show the effectiveness of the proposed method.

Christina Claeson and Kent Gylltoft (2000).

A test series examining the structural behavior of six slender reinforced concrete columns subjected to short-term and sustained loading is presented. The columns had cross sections 200 x 200 mm and were 4 m long. Concrete strengths used were 35 and 92 MPa with a load eccentricity of 20 mm. Key parameters such as concrete strength, concrete and steel strains, cracking, mid height deflection, and loading rate were studied. The high-strength concrete (HSC) columns subjected to short-term loading displayed less ductility and more sudden failures than the normal strength concrete (NSC) columns. Furthermore, the tests conducted indicated that the structural behavior of the HSC is favorable under sustained loading, i.e., the HSC column exhibited fewer tendencies to creep and could sustain the axial load without much increase in deformation for a longer period of time. An analysis based on a simplified stability analysis, using a stress-strain relation for concrete that includes creep, aging, and the confining effect of the stirrups was carried out. The model was shown to simulate the load-deflection curves satisfactorily for all of the concrete columns.

Christopher Richard Urmson (2010).

The purpose of this research is to develop a model for the full compressive behavior of longitudinal steel including the effects of bar buckling. A computational algorithm is developed whereby experimental data can be rigorously modeled. An analytical model is developed from rational mechanics for modeling the complete compressive stress-strain behavior of steel including local buckling effects. The global buckling phenomenon is then investigated in which trends are established using a rigorous computational analysis, and a limit analysis is used to derive simplified design and analysis equations. The derived buckling models are incorporated into well established sectional analysis routines to predict full member behavior, and the application of these routines is demonstrated via an incremental dynamic analysis of a ten-storey reinforced concrete building.

O.Germain and B. Espion (2005).

Author has reviewed all published result concerned with testing of slender high strength concrete column under eccentric loading, the result of testing up to failure for 12 large, slender, high strength reinforced concrete columns are reported. The main parameters of this series were the column slenderness and the load eccentricity. Loading was controlled by the transverse deflection of the column, which permitted the smooth capture of the post peak behavior. The structural behavior of the column is modeled by the comile Euro-international du Beton, finite difference method and the CEB column model method. Discussion of the result shows the necessity of taking into account the influence of the accidental eccentricity in the analysis of the behavior of the slender column with small eccentricity of the load, both methods are adequate to predict the carrying capacity of slender high strength concrete column, but finite difference method appear more reliable than the column model method to model the post peak behavior.

Literature Summery

The technology of High Performance Concrete (HPC) has greatly improved over the last decade. Globally, there is an increased usage of higher strength concrete with compressive strength of 60 - 120 MPa. The high compressive strength of HPC is advantageous in compressed members such as columns, which can be made more slender and, consequently, make economic benefits possible. When the concrete strength of the long columns was increased, the maximum load carrying capacity becomes greater, inducing more ductile behavior in the post-peak region. Due to increased strength of concrete it is necessary to introduce new limits for the slenderness of the columns. Codes of practice recommend various design methods for slender columns based on capacity reduction factors, additional design moments, or moment magnification, to account for effects of buckling. There design methods are approximate and largely empirical in nature. Therefore, it is necessary to investigate the theoretical behavior of long columns in order to establish certain rules for the design.

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