Engineering Structures 31 (2009) 487–497

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

The influence of the weak axis on the behavior of high strength RC slender columns subjected to biaxial bending

Luis Pallarés *, José L. Bonet Senach, Pedro F. Miguel Sosa, Miguel Á. Fernández Prada

Departamento de Ingeniería de la Construcción, Universidad Politécnica de Valencia, Camino de Vera s/n, 46002 Valencia, Spain

ARTICLE INFO

Article history:
Received 15 December 2007
Received in revised form
13 June 2008
Accepted 3 October 2008
Available online 11 November 2008

Keywords:
Biaxial bending
High strength concrete
Weak axis
Slender columns

ABSTRACT

This paper focuses on the behavior of high strength reinforced concrete columns subjected to biaxial bending. Experimental research with 56 high strength columns was carried out to achieve this purpose. The analyzed parameters were: the slenderness, the eccentricity, and the skew angle of the applied load.

The coupling of the second order effects in each main direction of bending was analyzed. It has been observed that the behavior of the column was strongly influenced by the flexibility of the weak axis. However, the proposed simplified approaches in ACI-318(05) and EC-2 (2004) do not take it into account.

The experimental results have been compared with a numerical simulation and with simplified approaches based on moment magnification factors such as that proposed by ACI-318(05) and by EC-2 (2004). Numerical simulation provided good agreement with displacement-load results and failure loads from the tests. In general, the simplified approaches are conservative in the case of the smaller eccentricities and result unsafe in the case of larger eccentricities.

1. Introduction

In recent years, the use of high strength concrete is increasing due to it taking less space and saves material in large piers for bridges or columns in the high-rise buildings. However, a stronger value for concrete strength allows designers to reduce the cross section size keeping the same ultimate strength of the section, and consequently the slenderness is increased.

Usually, these 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.

In the literature the number of tests for high strength concrete subjected to this type of forces is scarce. The cross section of the columns found in the literature was commonly square shape and the values of geometric slenderness (L/h) were low or medium. For instance, Hsu et al. [9] tested 9 columns ($L/h = 16$) and Sarker et al. [15] tested 12 columns ($L/h = 8.6$).

The behavior of slender columns depends on the shape of the cross section among other parameters. When the cross section is rectangular the flexibility of the column is different in each bending direction. In this way, as Furlong [8] pointed out, the second order effects in columns subjected to biaxial bending were strongly affected by the weak axis flexibility, producing a coupling effect between both bending direction. This effect is called as *influence of weak axis* in this paper.

However, most authors found in the literature analyzed (for example, Drysdale and Huggins [6], Tsao and Hsu [16]) the behavior of square cross sections in pin-end columns subjected to biaxial bending. Only Mavichak and Furlong [12] with 9 columns (slenderness of weak axis equals to 14.9) and Kim and Lee [10] with 10 columns (slenderness of weak axis equals to 13) analyzed the behavior of rectangular cross sections in pin-end columns subjected to biaxial bending and manufactured with normal strength concrete. Both authors [10,12] analyzed the accuracy of proposed approach by ACI-318 regarding to the moment magnification. They concluded that this approach resulted in it being conservative for large values of axial compression force and was unsafe for the smaller ones.

Whether the columns are subjected to biaxial bending, both ACI-318 (05) [1] and EC-2 [7] magnify independently the first order moment in each direction. The cross section design of the column is carried out from this magnified moment. However, these approaches may provide non-conservative results within rectangular columns subjected to biaxial bending (Bonet [2]).

This non-conservative situation due to these approaches does not take into account the influence of weak axis on the behavior of the column.

2. Research significance

To analyze the influence of the weak axis on the behavior of the columns is the main objective of the present paper.

Provisions given by ACI-318(05) [1] and EC-2 [7] do not come up the influence of weak axis when the columns are subjected to

* Corresponding author. Tel.: +34 963877561; fax: +34 963877569.
E-mail address: luipalru@cst.upv.es (L. Pallarés).

0141-0296/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engstruct.2008.10.001

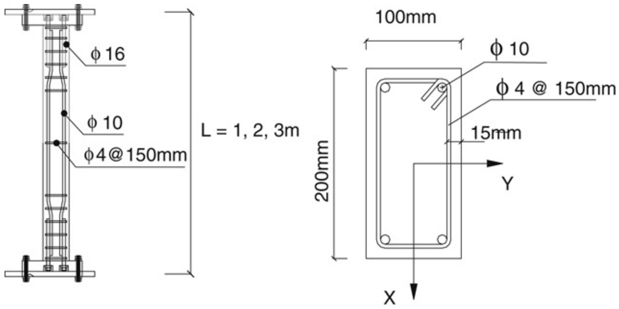


Fig. 1. Details of the specimens.

biaxial bending forces. This effect may decrease the failure load resisted by the column.

3. Experimental research

Since the slenderness considered in the literature was lower than 16, a series of 56 tests with 10, 20, and 30 slenderness ratios was carried out. Value 2 for the ratio h/b of the cross section was designed in order to analyze the influence of the weak axis on the behavior of the column.

3.1. Test setup

Test dimensions for 56 specimens are shown in the Fig. 1. Detailed specifications of the experimental research can be found in Pallarés [13].

The analyzed parameters are: the geometric slenderness ($\lambda = L/b$) where L is the column length, and b is the smaller dimension of the cross section (equals to 100 mm); the eccentricity of the load at the ends of the columns (e), and the skew angle of the load (β_{end}) as can be seen in the Fig. 2.

$$\beta_{\text{end}} = a\tan\left(\frac{e_y \cdot h}{e_x \cdot b}\right) \tag{1}$$

$$e = \sqrt{e_x^2 + e_y^2} \tag{2}$$

where: e_y eccentricity in the Y-axis direction
e_x eccentricity in the X-axis direction
h larger dimension of the cross section equals 200 mm.

Load eccentricities were located elliptically over the cross section of the specimen. Then, the eccentricity (e) was defined from the non-dimensional parameter (ζ):

$$e = \zeta\sqrt{\frac{h^2 + \alpha^2 \cdot b^2}{1 + \alpha^2}} \tag{3}$$

where: α is the ratio between relative eccentricities of the load

$$\alpha = \frac{e_y \cdot h}{e_x \cdot b}. \tag{4}$$

Four non-dimensional eccentricities (ζ) for each skew angle (β_{end}) were taken into account: 0.1, 0.2, 0.4, and 0.8.

Three values of slenderness (λ) were considered in this study: 10, 20, and 30.

Finally, the values for the skew angle (β_{end}) were: 0, 26.56°, 45°, 63.43°, and 90° which belonged to ratios (α) of 0, 0.5, 1, 2, and h.

Details of the specimen configuration (Fig. 1) can be found in Pallarés [13].

In the Table 1, the results of 56 tests are presented. The terminology used to name each test is shown in the expression 5:

$$\lambda x\_\alpha n\_\zeta N \tag{5}$$

where: λx "x" points out the slenderness of the specimen
αn "n" is the ratio between relative eccentricities (from 0 to ∞)
ζN "N" is the non-dimensional eccentricity.

The material properties, the instrumentation and the setup of the test can be seen in Pallarés [13,14].

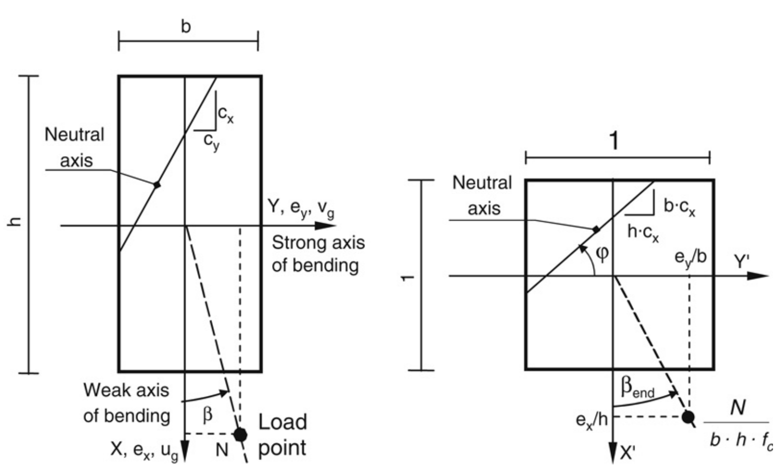
4. Numerical analysis

A finite element model proposed by Bonet [2] was used to analyze the behavior of the column subjected to axial compression and biaxial bending forces. The numerical simulation assumed next hypothesis:

- Plane cross-section remains plane after deformation.
- Perfect bond between steel rebars and concrete.
- Shrinkage and creep are neglected.
- Monotonic load.

The numerical model included the following basic features:

- One-dimensional finite element with thirteen degrees of freedom (Marí [11]). The element had three nodes and each end node had six degrees of freedom (three rotations and three displacements), meanwhile the central node had only one degree of freedom: the axial displacement. As Chan [3] showed, the central degree of freedom is needed to determine correctly the flexure stiffness of the column due to the change of the neutral axis along the column that is caused by cracking.



(a) Real section. (b) Non-dimensional section.

Fig. 2. Skew angle of the load and neutral axis.