Available online at www.sciencedirect.com

ScienceDirect

Engineering Structures 30 (2008) 965–975

ENGINEERING STRUCTURES

www.elsevier.com/locate/engstruct

Evaluation of the influence of the column axial load on the behavior of monotonically loaded R/C exterior beam–column joints through numerical simulations

Vladimir Guilherme Haach[a,*], Ana Lúcia Homce De Cresce El Debs[b], Mounir Khalil El Debs[b]

[a] *Department of Civil Engineering, University of Minho, Campus de Azurém – 4800, Guimarães, Portugal*
[b] *Department of Structural Engineering, São Carlos Engineering School, University of São Paulo Av. Trabalhador São Carlense, 400, CEP 13566-590, São Carlos, SP, Brazil*

Received 13 April 2006; received in revised form 4 June 2007; accepted 5 June 2007
Available online 30 July 2007

Abstract

Joints of reinforced concrete are critical regions to study and to manufacture because of their high steel ratio and reduced geometrical dimensions. Column axial load is one of the several variables that influence the behavior of the exterior beam–column joints. This paper investigates the influence of the column axial load on the joint shear strength through numerical simulations. The numerical study is performed through the software ABAQUS®, based on Finite Element Method. A comparison of the numerical and experimental results is presented in order to validate the simulation. The results showed that the column axial load made the joint more stiff but also introduced stresses in the beam longitudinal reinforcement. A more uniform stress distribution in the joint region is obtained when the stirrup ratio is increased. Furthermore, some tension from the top beam longitudinal reinforcement is absorbed by the stirrups located at the upper part of the joint.

Keywords: Beam–column joints; Column axial load; Numerical analysis; Parametrical analysis; Reinforced concrete

1. Introduction

Beam–column joints are critical regions of structures due to the fact that they are located in an area, where, the bond and normal stresses are substantially high. In the past, it was believed that the member with the lowest strength in the connection governed the beam–column joint strength. However, many valuable studies have been performed on this subject, indicating that this is not always true; joints are often the weakest links in a structural system.

Seismic loads are the main focus of the research on beam–column joints because joint failure has been observed in several earthquakes, for example: the Tehuacan, Mexico, earthquake of June 15, 1999, the Izmit, Turkey, earthquake of August 17, 1999, the Athens, Greece, earthquake of September 7, 1999, and the Chi-Chi, Taiwan, earthquake of September 21, 1999 (Pantelides et al. [13]). However, it is important to note that monotonic loads may be also critical in the behavior of the joint.

According to Park and Paulay [14] the essential requirements for the satisfactory performance of a joint in a reinforced concrete structure can be summed up as follows:

(a) A joint should exhibit a service load performance equal to that of the members it joins;
(b) A joint should possess a strength that corresponds to at least the most adverse load combinations that the adjoining members can possibly sustain, several times if necessary;
(c) The strength of the joint should not govern the strength of the structure, and its behavior should not impede the development of the full strength of the adjoining member;
(d) Ease of construction and access for placement and compacting concrete are other prominent issues of joint design.

Many variables such as the bond conditions, column axial load, concrete strength, reinforcement detailing and stirrup ratio influence the beam–column joints behavior. Among them,

* Corresponding author. Tel.: +351 253510200; fax: +351 253510217.
E-mail address: vghaach@civil.uminho.pt (V.G. Haach).

0141-0296/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engstruct.2007.06.005

Notations

f_y	yield strength for reinforcement
ρ_w	ratio of transversal joint reinforcement
ν	normalized column axial load
δ	displacement applied on the beam extremity
ϕ	diameter of bar
f_c	compressive cylinder strength of concrete
f_t	tensile strength of concrete
E	elastic modulus
E_c	elastic modulus of concrete
E_{c1}	secant elastic modulus of concrete
E_s	elastic modulus of steel
F	equivalent force applied on the beam extremity
N	column axial load
e	eccentricity of column axial load
ε_{c1}	strain of concrete in the maximum strength
ε_{cu}	ultimate strain of concrete

column axial load is one that causes many divergence of opinion about its influence on the joint behavior. Early tests on beam–column joints were performed by the Portland Cement Association and the University of Illinois in 1960 (Blume et al. [5]). These experiments clearly demonstrated the benefits of confinement on the hysteretic response of beams, but they failed to simulate the complex behavior of joint region. After them, several researches about beam–column joints have been developed in an attempt to understand their behavior.

Marques and Jirsa [11] investigated the hooked bars anchorages in beam–column joints. Although the level of column axial load analyzed by the authors was very low, they concluded that the influence of column axial load on the behavior of beam–column joints was negligible. In the same way, Bakir and Boduroglu [2–4] made a parametric analysis with experimental database compiled from a large number of tests of exterior joints, proposed a model to predict the failure and concluded that the column axial force has no influence in the value of the joint strength, but it affects the failure mode. Similarly, Parker and Bullman [15] showed that the column axial load affects the behavior of joints only by changing their failure modes. On the other hand, Scott et al. [16] found an enhancement in the ultimate shear capacity in specimens with high axial stresses; however, Hegger et al. [9] showed that in columns, normal stresses higher than 40% of the concrete compressive strength reduce the joint shear strength.

Due to the amount of variables that affect the joint behavior, this subject is still under investigation. Thus, the present paper aims to provide some results and conclusions about the behavior of joints under the influence of column axial loads using numerical simulations.

2. Significance and objectives of the research

Concrete technologies have achieved a great improvement in the last years, and structures became more slender and enterprising. Consequently, some aspects that were not so important in the past have become fundamental. The behavior of exterior R/C beam–column joints is one of the challenges faced by researchers. Several variables influence this part of the structure and the column axial load is only one of them. There are various studies on the behavior of beam–column joints together with many different opinions and unreliable design models. Some authors have studied the influence of column axial loads, but there is limited research on joint with high normal stresses applied to the column.

The present paper focuses on the study of the behavior of exterior beam–column joints under the influence of column axial loads by means of numerical simulations. This simulation intends the extrapolation of the experimental results of monotonic loaded tests performed by Haach [8] through the variation of level and eccentricity of column axial load and stirrup ratio in the joints.

Table 1
Summary of the experimental results obtained by Haach [8]

ν	Failure mode	Failure load (kN)
0.85	Crushing of the diagonal strut	15.2
0.64	Crushing of the diagonal strut	16.0
0.50	Crushing of the diagonal strut	16.9

3. Experimental results

Experimental results of monotonic load tests carried out by Haach [8] were used in order to validate the numerical simulations. The experimental program consisted of tests of three exterior R/C beam–column connections, on a real scale, with the same geometrical and material properties. The column axial load (ν, Eq. (1)) was the only variable investigated in specimens. Table 1 shows a summary of the experimental results.

$$\nu = \frac{N}{A_g * f_c} \quad (1)$$

where A_g is the gross cross-sectional area of the column, f_c is the compressive strength and N is the column axial load.

4. Numerical simulations

Numerical simulation is a very useful tool to study elements that are difficult to investigate by experiments, such as joints with high column axial load. Some variables such as stress distribution in concrete are difficult to measure during the experiments and can easily be evaluated by numerical simulations. Accordingly, a numerical model of joint test by Haach [8] was created using the ABAQUS® software, which uses tools based on Finite Element Method (ABAQUS [1]). Firstly, a comparison is made between the numerical and experimental results in order to validate the model and finally, a parametrical study is carried out.

4.1. Geometrical properties

The geometrical properties (Fig. 1) were kept constant for all analysis except for the study of the joint behavior under the