EFFECT OF LATERAL REINFORCEMENT IN COLUMNS
EFEKT PŘÍČNÉHO VYZTUŽENÍ VE SLOUPECH

J. Němeček, P. Padevět, Z. Bittnar [1]

This paper deals with the behavior of eccentrically compressed reinforced concrete columns. Not only the load-carrying capacity, but mainly post-peak behavior (i.e. ductility), size and shape of the damage zone is studied. The investigation is focused on these parameters with respect to the different lateral reinforcement in a column. The question of sufficient ductility in the framework of the overall structural collapse is discussed.

Keywords:
reinforced concrete structures; ductility; softening; post-peak behavior; lateral reinforcement

1 Introduction

Nowadays, the main parameter checked during the design process of a reinforced concrete structure is the load-carrying capacity of the structure (i.e. the maximum load, which the structure is able to carry). This parameter is evaluated for critical cross sections, where the maximum stresses occur, generally in the elastic state. Secondly, the design is focused on deformations and long term behavior of the structure. Besides these very important parameters, it is also necessary to study the ductility of the structure, i.e. the rotational capacity at the limit load and event after this limit, in case of overloading of the structure. The ductility plays a significant role in cases of some limit or accidental situations and significantly influences the final failure mode of the structure.

In case of low ductility (typically: highly reinforced cross sections with low rotational capacity) the collapse of the structure is sudden, whereas the carried load drops down fast with only small displacement increment. The failure is followed by a low dissipation of the energy and the collapse is quick and dangerous. Against it, the energy dissipated in structures with sufficient ductility is higher. After reaching the maximum load forces transmitted in the cross section are gradually decreasing with an increasing deformation.

From the above follows that the ductility of the specimen must be evaluated only from the post-peak behavior, i.e. from the region, which is out of the scope of the common design practice. The content of this paper involves the study of the behavior of eccentrically loaded reinforced concrete columns from both limit (peak) and post-peak points of view.

2 Motivation for our research

Our aim was concerned at the reinforced concrete column due to the fact that it is a typical representant of the structural element. Columns are typical load bearing elements, which are multiply used in the

[1] Ing. J. Němeček, Ph.D.; Ing. P. Padevět, Ph.D.; Prof. Ing. Z. Bittnar, DrSc.
Czech Technical University in Prague, Faculty of Civil Engineering, Department of Structural Mechanics, Thákurova 7, 166 29 Praha 6, Czech Republic. e-mail: jn@cml.fsv.cvut.cz

structure and where the design is driven by the ultimate limit state (peak). According to design rules contained in codes (national codes or Eurocodes) only the longitudinal reinforcement is checked. Lateral reinforcement is designed according to constructional rules based on the size of the column and the reinforcement. The behavior of concrete, which belongs to the group of so called quasi-brittle materials, is influenced by the stress state to which it is exposed. The response can then change from brittle behavior (in case of absence of lateral confinement) to perfectly ductile (in case of hydrostatic stress state). It is clear, that the behavior is influenced by the size of the column but also by the reinforcement. The creation of the confinement is determined by the amount of lateral reinforcement (stirrups), which is directly responsible for the creation of triaxial stress state in the structure.

To remind the above, one may postulate, that even the lateral reinforcement is not directly designed (according to codes), it is responsible for the confinement, which is connected with the ductility or brittleness of the specimen, respectively.

From the overall structural point of view, it is also necessary to take into account the fact, that after reaching the maximum load, the cross section is no longer able to sustain higher load. But for ductile structures, this additional load can be redistributed to the surrounding cross sections, while the initial cross section softens (due to ductility). This aspect guaranties, that the sudden collapse is restricted in contrast to the non-ductile structures, where the brittle collapse can occur.

3 Experimental investigation

For the effect of lateral reinforcement on the studied parameters (load carrying capacity, ductility) three series of reinforced concrete columns were investigated. All columns had square cross section with the dimensions 150x150 and the length 1150mm.The reinforcement was made from 4 ribbed rebars ϕ 12mm placed to the corners and stirrups from smooth steel ϕ 6mm. Material parameters are summarized in Tab. 1.

Concrete	compressive strength	$f_{c,av}$	30 MPa
Concrete	Yong's modulus	E	35300 MPa
Longitudinal reinforcement	yield limit	f_y	561 MPa
Stirrups	yield limit	f_y	314 MPa

Table 1: Average values of material parameters.

The lateral reinforcement was created in three versions. The distance between stirrups in the middle part of the column was changed from 5cm (series N5) to 10cm (N10) and 15cm (N15). Each series contained 5 specimens. Specimens were loaded in eccentric compression with small eccentricity (10% of cross sectional depth) in order to keep the failure cased not by yielding of steel but by a compression failure of concrete, which is typical for RC columns. Overall axial load, lateral displacement at the midheight and strains at compressed and tension sides were registered. The type and size of the damage zone was also studied.

The experiment was performed on a very stiff loading machine equipped with fast mechanical and electronic facilities. It was possible to measure also post-peak behavior, i.e. softening of the specimen. The overall view on the specimen in the machine before and after test can be seen in Fig. 1.

4 Results

It was found, that after reaching the peak load, the behavior of the column does not contain the yield plateau but the softening regime, i.e. an increasing deformation is followed by a load reduction, occur. The speed of this reduction is influenced by a stirrups' density (by ductility in fact). Furthermore, it was found that the distance between stirrups in the range 5-15cm practically does not influences the value of load carrying capacity (see Fig. 2). The distance between stirrups influences the ductility in

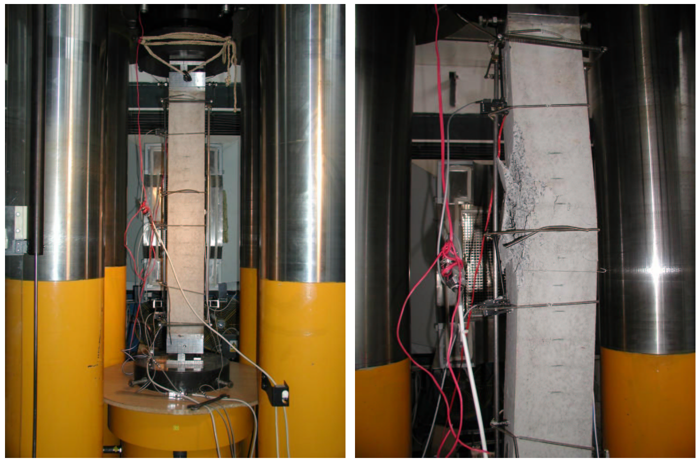

Figure 1: Overall view on experimental setup and specimen after collapse.

such a way, that with increasing distance between them the ductility decreases and vice versa. This can be seen again in Fig. 2, where the different descending slope of the softening branch is depicted.

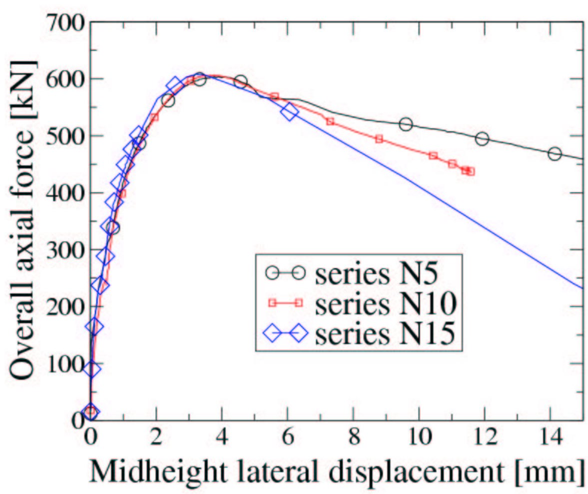

Figure 2: Graph of midheight lateral displacement vs. overall axial force in column.

Typical shape of the damage zone can be found in Fig. 3. Failure is characterized by a wedge of cracked concrete and buckled reinforcement which was observed always between the stirrups. The size of the damage zone was approximately the same for all series.

5 Conclusions

Form the above investigation of reinforced concrete columns loaded in eccentric compression we can conclude, that the type of the failure is always similar. Concrete is compressed and crushed in the midspan forming a wedge-shaped failure zone. The failure is followed by a buckling of longitudinal reinforcement between the stirrups. The influence of the stirrups' density on the load carrying capacity is negligible. Important influence was encountered in the post-peak regime, where the columns with denser stirrups had higher ductility.

Practical influence of this finding is evident. Columns with higher amount of lateral reinforcement have high ductility and consequently higher safety against collapse. After reaching of the peak load

Figure 3: Detail of the damage zone in midheight (front and side views).

the column is no longer able to carry higher load and the column softens. But the softening is as slower as the ductility is higher. The ductility allows the redistribution of the load into surrounding places and does not lead to the brittle type of collapse. The use of denser stirrups' leads to safer design form the point of view of the overall capacity and type of collapse.

Acknowledgments

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