Paraseismic Strengthening of Concrete Columns by Composite Confinement

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Summary

The assessment of an important chemical plant highlighted a lack of resistance and deformation capacity of about 80 reinforced concrete columns in the case of an earthquake. In this situation, the owner commissioned the UAS Fribourg to propose technical measures to increase the resistance of the columns and to verify the efficiency of the strengthening by means of an experimental study. This paper describes the comparative tests carried out on different strengthening measures by using composite confinement. After comparing the advantages and inconveniences of the measures, it presents the technical solution chosen for the seismic strengthening of the columns.

Keywords: RC columns; confinement; seismic strengthening; aramid material; prestressed strips; full scale tests.

1. Introduction

Lonza Ltd, a company active in the fields of chemistry and biotechnologies, has an important production site, which includes the Niazol building D29 (Fig. 1) in Visp, Switzerland. This 6 storey building, which has a reinforced concrete structure, was built in the 1970's in accordance with the Swiss codes of 1962. At that time, the codes took less in account the seismic activity than current codes. At the ground level, the building rests on reinforced concrete columns and walls. As the walls are rather lightly reinforced, in the case of an earthquake the RC columns must resist the vertical and horizontal forces in their entirety (Fig. 2). This type of structural layout, known as Soft Storey, constitutes a very unfavorable case of paraseismic design.

Fig. 1: Niazol D29 Building.

Fig. 2: Ground floor columns.

An assessment carried out by a design office specialized in seismic actions drew attention to the lack of resistance and deformation capacity of the columns. This lack was mainly due to the insufficiency of the stirrups, with regard to their arrangement and form, especially in the fitted zones at the extremities of the columns. In this situation, Lonza Ltd commissioned the University of Applied Sciences of Fribourg to propose, on the one hand, technical measures to increase the resistance and the deformation capacity of the concrete columns and, on the other hand, to verify the efficiency of this measures by means of an experimental study.

2. Experimental studies

The concrete columns on the ground level of the Niazol D29 building are fixed to the foundation slab and the ground floor slab at their extremities. Their total length is 5.30 m with a 650 x 450 mm cross section. For the experimental studies, we selected 2.65 m high half-columns, built into a foundation block at the base, thus forming a cantilevered structural system. Owing to the complexity of the phenomena and in order to avoid uncertainties in scaling, the tests were carried out at full scale.

It was decided to produce six test specimens in the form of columns on foundation blocks (Fig. 3). The first of these specimens, column P0, is considered as a reference and does not contain any strengthening. Columns P1 through P4 are strengthened by different types of confinement using bonded sheets or prestressed strips of aramid (Fig. 4 and 5). Column P5 is reserved in preparation for subsequent application of the definitively chosen reinforcement.

Fig. 3: Test specimen.

Fig. 4: Strengthening of columns P3 and P4.

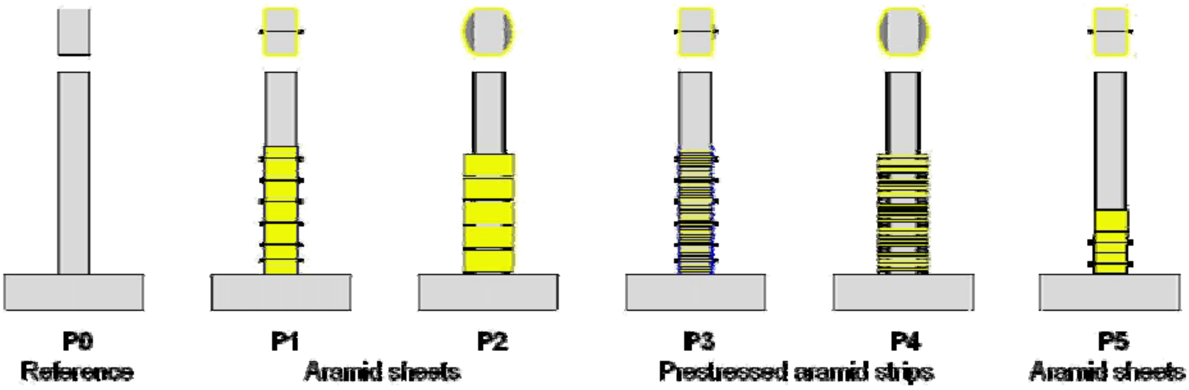

Fig. 5: Paraseismic strengthening.

In order to reproduce seismic strains, the columns underwent static-cyclic load tests with simultaneous vertical and horizontal strains. These tests were carried out on a specially designed test set-up in the Structures Laboratory of UAS Fribourg (Fig. 6). The test specimens are restrained by steel box girders anchored to strong floor by means of prestressed rods. Horizontal and vertical forces are applied by means of a strong steel frame consisting of vertical columns, horizontal beams, and cross-bracing (Fig. 7). The test device permits simultaneous application of 2'000 kN vertical loads and ± 500 kN horizontal forces, with ± 300 mm displacements.

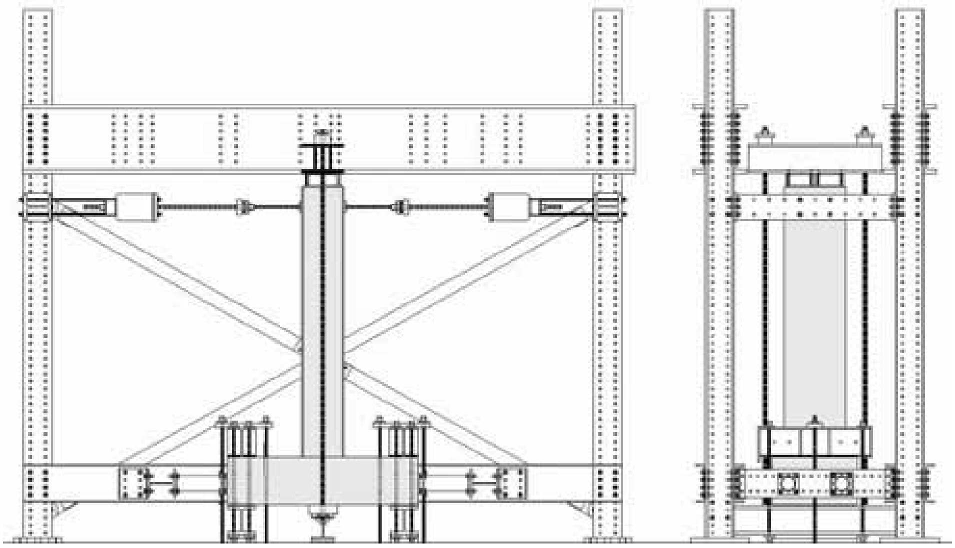

Fig. 6: Testing device during static-cyclic load tests.

The loading procedure is identical for all test columns. In the first phase, a centered 1'300 kN vertical load is applied on the top of the column by two flat jacks. In the second phase, the horizontal actuators, positioned at a height of 2.65 m, apply load in a cyclic manner. The test is conducted in strain increments of 10 mm and 20 mm. Each cycle is repeated twice. The rupture is determined after a drop of 20% of the horizontal force. During the load tests, the horizontal and vertical forces and deformations are measured, as well as the rotations of the foundation block, the crack openings, and the strains in the confinement.

Fig. 7: Test set-up with specimen P2.

Test results

The load tests performed on specimens P0 through P4 permitted detailed observation of each column's behaviour under static-cyclic loads and, in particular, the relation between horizontal forces and deformations (Fig. 8). The reference column withstood ± 105 mm deformations, insufficient to meet the required ± 120 mm of the theoretical analysis (Fig. 9). Furthermore, the application of this deformation caused concrete spalling and buckling of the longitudinal reinforcement in the confined section. The insufficient number of stirrups with hooks non compliant with paraseismic design could not prevent the buckling of the longitudinal reinforcement, thus causing premature failure of that section (Fig. 10). A reinforcement of that zone proves itself, therefore, to be indispensable for guaranteeing paraseismic resistance and required deformation capacity of the column.

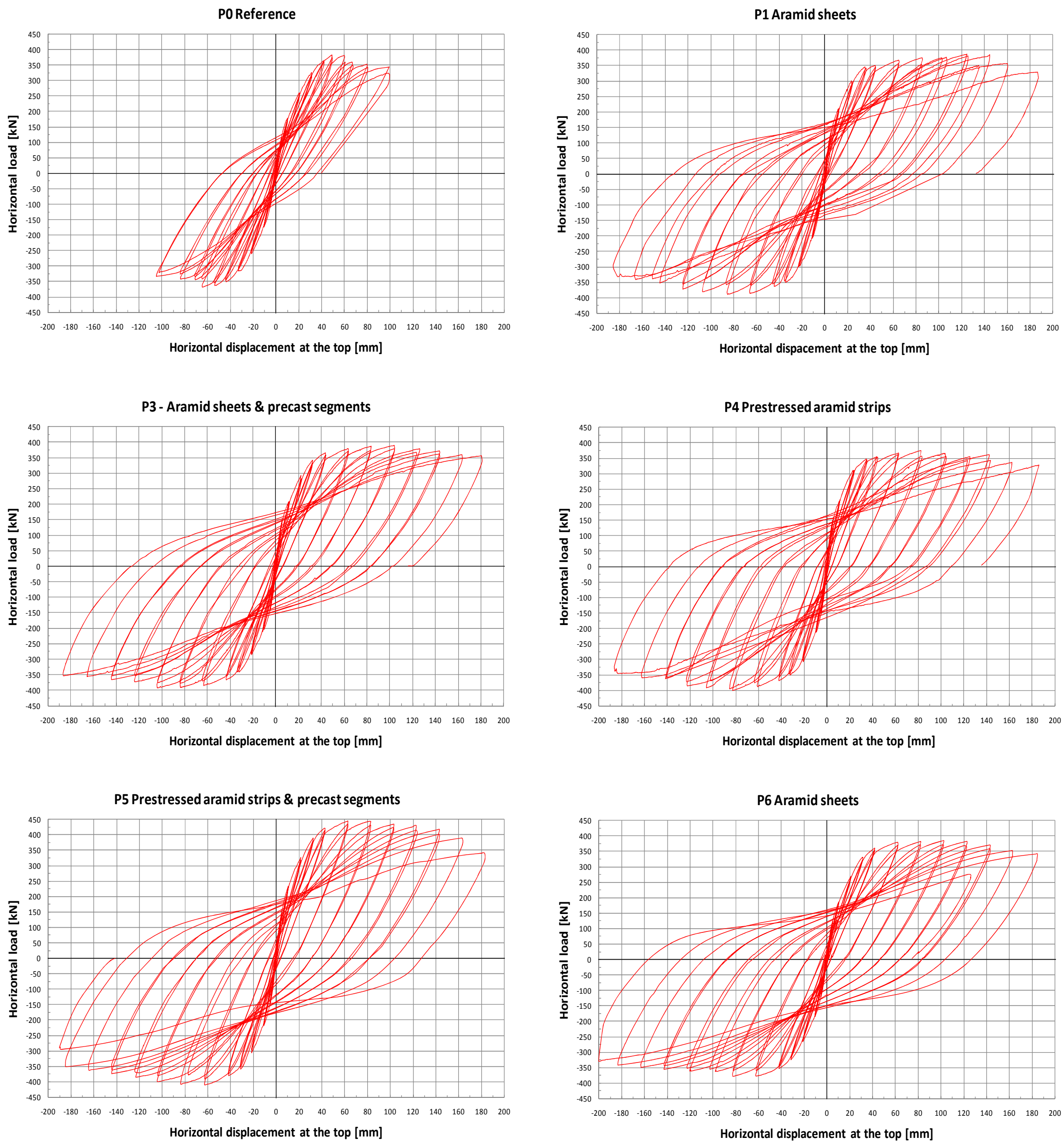

Fig. 8: Horizontal forces and deformations of the specimens.

Fig. 9: Deformation at ruin of columns P0 & P1

The four strengthening solutions enabled forces between 390 and 445 kN and horizontal displacements between ± 180 and 190 mm to be attained, which is considerable, while also guaranteeing adequate stability of the plastic hinge. They have been shown, however, to have certain disadvantages. Confinement using lateral steel plates requires numerous drillholes, with the risk of damaging existing reinforcement. Strengthening with added precast segments of fibre reinforced concrete gives excellent stability to the embedment, thanks to improved confinement efficiency. But the presence of operating equipment near the columns makes the setting-up of the segments difficult. The solutions with prestressed aramid strips create an over-rigidity of the confined section, which could cause premature brittle failure owing to the increased shear action.

Fig. 10: Confined section of column P0 with buckling of rebars

3. Proposed solution for strengthening

After analysis of the test results and the observations on the first five columns, we tried to determine the optimal solution for strengthening. First, we abandoned the idea of using the precast segments of fibre reinforced concrete, due to their bulk and implementation complications. Secondly, we rejected solutions using prestressed aramid strips. The stressing procedure is, effectively, complex and requires specialized employees, which makes its application very expensive.

Our considerations were directed towards confinement using aramid sheets anchored by steel plates. In fact, test results for column P1 demonstrated a very satisfactory general behaviour with horizontal displacements of ± 185 mm, easily fulfilling the requirements formulated in the expert's report. We proposed, therefore, a simpler strengthening solution, which appeared nonetheless sufficient. This solution involves confinement using aramid material over a reduced height of 900 mm. The height of the lateral steel plates is reduced to 500 mm and requires no more than two anchor rods (Fig. 11).

After discussion with the owner of the building and the representatives of the design offices, this solution was selected and applied to the reserve column P5. The static-cyclic load tests showed very good results. The behavior of the confined section was excellent and the displacements at the top of the column were ± 200 mm, with a horizontal force of ± 385 kN. The global ductility factor reached a value of 5.0, which is superior to the 3.0 factor required within the framework of capacity dimensioning. Lastly, energy dissipation was tripled, from 48,000 to 149,000 joules, when compared with the reference column (Fig. 12).

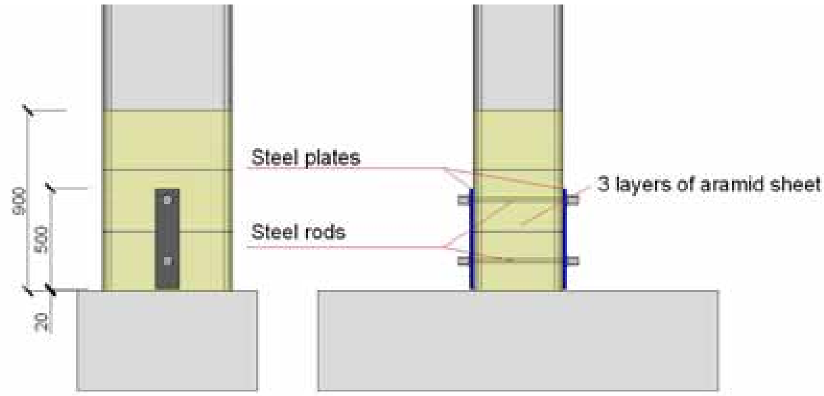

Fig. 11: Proposed strengthening solution.

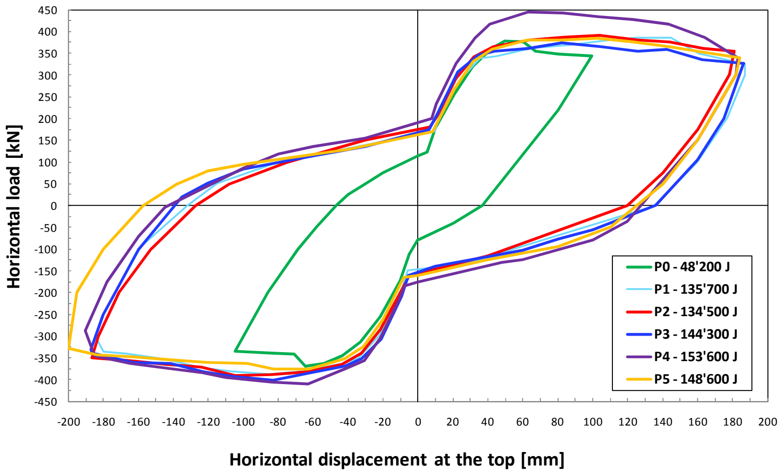

Fig. 12: Energy dissipation of the columns.

4. Conclusions

The experimental studies and, particularly, the static-cyclic load tests performed in University of Applied Sciences, Fribourg permitted the elaboration of a technical solution for the paraseismic strengthening of the concrete columns of the Niazol D29 building. They demonstrated that strengthening of the columns was indispensable, but that this strengthening could be simplified, in comparison to the initially recommended solutions.

The tests also showed the necessity to take into account certain detailing aspects during the execution of the strengthening. Thanks to the tenacity of the aramid material, the confinement remains operational at very high deformations.

In conclusion, we contend that good collaboration between the owner of a building, the design offices, and the test laboratory permitted important savings regarding the strengthening of the columns. This collaboration also allowed us to carry out a very interesting study that provides new scientific knowledge for the paraseismic rehabilitation of existing structures.

5. Acknowledgements

The authors would like to thanks all of the participants in this project for their successful cooperation: the owner of the buildings, Lonza Ltd; the design office, KBM Civil Engineers Inc ; the expert for seismic aspects, Résonance Consulting Engineers Inc ; the production of test specimens, Element Inc ; the strengthening of columns, S&P Clever Reinforcement Company Inc.

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