Challenges Encountered in Column Tests Under Eccentric Axial Load and Proposed Solutions

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***Abstract* – The difficulties encountered in experimental research cause loss of time and money. For this reason, both the sample production process and the experimental setup design are extremely important. In this study, the difficulties encountered in column tests under uniaxial bending and the solution of the problem are presented. For the solution, the structure of the end regions of the columns and the design of the support plates of the experimental setup are revised and the expected column buckling behavior is obtained. The unreinforced concrete cover in the end zones of the columns breaks suddenly due to bending effect as a result of eccentric axial compressive loading and the expected collapse behavior in the middle zone does not occur. In order to solve the problem, firstly, modifications were made to increase the support stiffness in the experimental setup. Then, in order to provide sufficient improvement, the 25 mm concrete cover formed during production at the ends of the columns was cut. In fact, column longitudinal reinforcements should be welded directly to the metal plates to be formed in the end cross-section of the column during fabrication without mitring. Thus, in this way, no concrete cover is left in the end regions of the column, preserving its slenderness without reducing the effective length of the column, and preventing fracture from occurring at the end region.**

***Keywords* - Column test, uniaxial bending, experimental difficulties, longitudinal reinforcements, test setup.**

I. Introduction

IN order for civil engineers to overcome the difficulties in their experimental work, comprehensive approaches including detailed planning, correct equipment selection, data collection and analysis, and safety measures are required. Furthermore, environmental variability and weather conditions, cost overheads and time constraints affect the feasibility and process of experiments. Scaling in the laboratory should also not lead to behavioral differences. Many research topics have either remained in the background due to experimental difficulties or have been concluded only by means of numerical models.

There are challenging stages in a study in terms of design, fabrication, and experimental set-up. In the aforementioned research, slab irregularity was investigated by creating slab openings at different ratios on a one-storey ½ scale structure with two openings in both directions. For this purpose, an axial compressive load of 10% of the bearing capacity was applied to nine columns in the structure and the performance of the structure under horizontal load was analyzed. Under laboratory conditions, an axial compressive force of 200 kN from a single hydraulic jack was distributed to the columns of the structure in the calculated ratio using a steel test rig [1]. Another study states that it is very difficult to perform short column tests and that the aspect ratio should be very low to capture the behavior. It is reported that this situation, which causes an increase in the lateral load level, leads to the production of faulty columns and in most studies these columns are treated as control specimens [2]. In another study it was noted that the deflection results of the second-floor slab were not considered. The reason was that the measurement range was completely different than expected [3]. It is noted that steel-reinforced natural rubber bearings, which are widely used in bridges, have rarely been investigated in previous experiments due to the complexity and experimental difficulties [4]. Similarly, it has been suggested that the analysis of cylindrical shells with different boundary conditions has rarely been investigated in the literature due to experimental difficulties [5]. To overcome such experimental difficulties, finite element analysis has been used to determine the mechanical properties of isotropic short fibre SRPP composites with varying strand lengths [6]. Concrete toughness is better determined by uniaxial tensile testing. However, due to the experimental challenges associated with these tests, several code developers have suggested flexural tests (with three- or four-point loading) as an alternative [7]. Different standards are used in different countries around the world for the design and testing of prestressed concrete railway sleepers. (TS) EN 13230-2 is one of the most widely used prestressed concrete railway sleeper standards in the world and is actively applied by some 73 members of the International Union of Railways (UIC). Several sleeper tests are mentioned in this standard. The most important are the "positive moment capacity of the rail seat" and the "negative moment capacity of the center" tests. These tests are designed to determine several different parameters. The most important of these parameters are the "first elastic (re-closing) crack initiation loads" (Frr for rail seat positive moment tests and Fcr for center negative moment tests). The detection of these cracks in prestressed concrete sleepers can often be misleading because these cracks remain at the micro level due to the effect of prestressing compression. Therefore, the standard test procedure in EN 13230-2 is often not satisfactory and results in much higher Frr loads than the actual values. Therefore, the authors of the cited studies [8-10] used "acetone spray" to overcome the test result deviations. During testing, a fine mist of acetone spray is applied to the prestressed concrete sleepers under load and this chemical, which evaporates rapidly from undamaged surfaces, is used to detect cracks. Once a crack has started, some of the chemical can penetrate into the crack and, due to its slower evaporation in these areas, can assist in the rapid detection of cracks, even at the micron level. As a result, the Frr load values are more accurate, and the results show less variation and high repeatability.

II. MATERIAL AND METHOD

The problems that cause experimental difficulties arise from both the reinforced concrete column and the experimental setup. In order to solve the problem, the experimental setup was first revised and when it was not sufficient, it was necessary to make changes on the reinforced concrete column specimens.

Reinforced concrete columns have been designed with a cross-section of 200 x 200 mm and a height of 1500 mm. A reinforced concrete column with a compressive strength of 45 MPa has an approximate axial load-bearing capacity exceeding 2000 kN. Therefore, considering laboratory capabilities, the maximum dimensions for column sections that can be produced have been set at 200 mm (Fig.1).

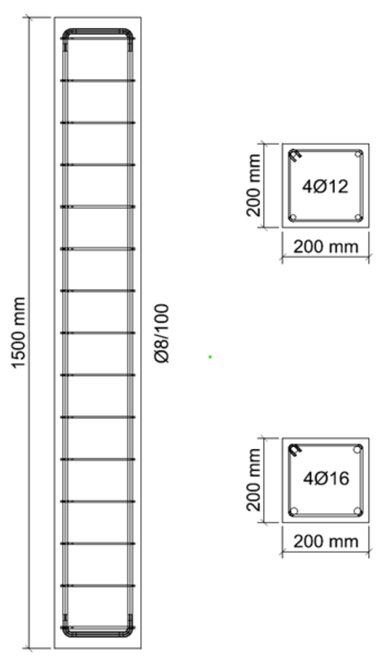

Figure 1: Column reinforcement and geometric properties

The longitudinal reinforcement ratio of the column is approximately 0.01 (4Ø12) and 0.02 (4Ø16). In columns, the axial load is expected to be carried more by the concrete section rather than the reinforcement. Therefore, longitudinal reinforcement diameters have been determined according to the most commonly preferred minimum reinforcement spacing in practice. To prevent sudden and brittle collapse in columns, shear reinforcement has been placed along the section at a constant interval (Ø8/100). This arrangement aims to induce column failure through uniaxial bending under the axial compressive effect in experimental conditions.

The plates on the upper and lower heads where the columns are supported have been designed to accommodate eccentric axial loading. They also act as pinned support, allowing the column to experience uniaxial bending. The column is placed into a 220 x 220 mm and 50 mm deep socket and secured using plates in Figure 2.

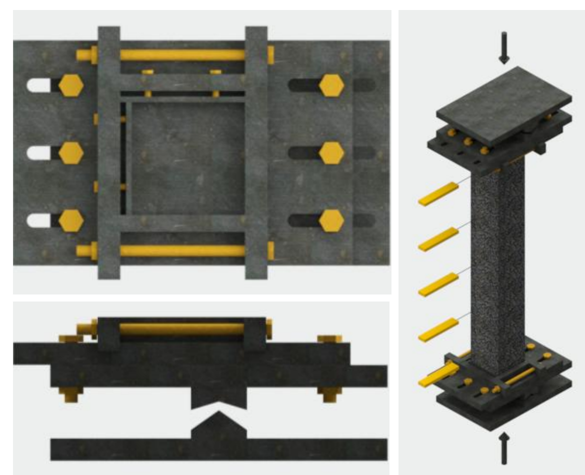

Figure 2: Column lower and upper supports

The column support plates are 40 mm thick and the upper and lower supports consist of 3 plates each. Plate dimensions are 400 x 600 mm. The first two plates provide rotation with male and female adapters. The second and third plates have large oval hole bolt connections to provide eccentricity. Eccentric connection is made with 6 M24 bolts. After the column was placed, 10 mm thick removable plates were placed on the column surface and fixed to the support by tightening with M12 bolts from the outside (Figure 2).

After the reinforced concrete columns were placed in the steel loading setup, displacement readings were taken with a total station between load controlled increments of 30 kN. During the experiments, 63 mm eccentric axial pressure loading was applied to the columns. For horizontal displacement readings, 5 potentiometric rulers were also used along the column height. Two LVDTs were used to read the shortening and elongation on the compression and tension faces, and one LVDT was used to control the deflections outside the bending plane. Finally, one LVDT was installed to measure the shortening of the column length (Figure 3).

Figure 3: Taking measurements from the experimental setup

During load-controlled loading, collapse occurred when the load suddenly dropped after reaching a specific level. Therefore, since fracture occurred with the transition to the plastic stage, the experiments were terminated without the need for a displacement-controlled loading as in beams.

III. EXPERIMENTAL CHALLANGES

During the experiments, instead of the anticipated failure occurring within the column body, damage in the support region led to premature termination of the experiments before reaching the column's load-carrying capacity, and the desired column collapse behavior could not be achieved. The desired failure mode was eventually achieved after a series of experiments. For this purpose, various improvements were implemented after each experiment, and the issue was resolved after a total of 5 experiments.

Table 1: The failure loads of the column specimens.

Sample Name	Longitudinal Reinforcement	M_{max} (kNm)	F_{max} (kN)
Test1	4Ø12	52	713
Test 2	4Ø12	37	508
Test 3	4Ø16	40	570
Test 4	4Ø16	44	592
Test 5	4Ø12	46	615

The upper and lower support plates, where the ends of the reinforced concrete column are connected, have rotational freedom. This allows the column body to bend (in a C-shape) due to eccentric axial loading, resulting in the expected form of failure. In the first test, the column fractured from the lower support region. The fractured part consists of plain concrete where the longitudinal reinforcement mitred, and where only concrete cover was left at the column end zones. As the axial load increased during the experiment, the concrete on the compression side of the column was crushed in the support regions. Subsequently, due to the moment effect and the absence of longitudinal reinforcements at the column ends, the concrete cover in the end zone ruptured, leading to the end of the experiment (Figure 4).

Figure 4. End of Test1

After the investigation, it was concluded that the problem could potentially be resolved by cutting the average 25 mm thick concrete cover that had detached from the bottom column end. However, due to the initial lack of equipment for cutting, alternative solutions were explored. As a second approach, experiments were conducted by placing the column freely between the support plates in the test setup, without compressing the column ends. This approach aimed to prevent stress concentrations at the column ends by allowing the column to rotate on the plate surfaces, in addition to the rotational freedom provided by the support plates (Figure 5).

Figure 5. End of Test2

The issue of longitudinally reinforcing bars being mitred at the column end and concrete cover being placed perpendicular to the column cross-section revealed a production planning error. To address this, a third solution was implemented: the slot depth in the support plates where the column is placed was increased to 100 mm in the bending direction. This modification was intended to allow the tensile effect resulting from the bending moment to be effectively resisted by the longitudinal reinforcements situated at levels higher than the lower end. Similar to the previous experiment, the column end was left free on the support plates without compression (Figure 6).

Figure 6. End of Test3

The increase in the slot depth in the support plates of the experimental setup has shifted the point of failure slightly higher. However, it was still unable to prevent the rupture of the concrete cover at the bottom end of the column. As a fourth solution, it was decided to confine the column within the slot using plates in a direction perpendicular to the bending plane, with a height of 100 mm. Despite the decrease in column slenderness due to the confinement of the column ends within a 100 mm deep slot instead of the previous 50 mm, it was assumed that this arrangement would allow for more effective performance of the longitudinal reinforcements along the column length (Figure 7).

Figure 7. End of Test4

Finally, the only remaining option was to proceed with the initial plan of cutting the concrete cover at the column ends. For this purpose, the process of purchasing and procuring the necessary machinery has begun. After obtaining the machine, the columns were cut by 25 mm from both ends, reducing the column length to 1450 mm (Figure 8). This allowed the longitudinal reinforcements to extend up to the top and bottom cross-sectional faces of the column.

Figure 8. Concrete cutting

As a result of both the improvements made in the steel plates on which the column ends were supported and the cutting of the reinforced concrete column ends, the experiment was successful. Although the column slenderness decreased slightly, the fracture occurred in the center of the column due to bending. The column reached its full load carrying capacity and more accurate data were obtained for the evaluations to be made (Figure 9).

Longitudinal reinforcements that will meet the bending moment effect occurring in the end regions of the column should extend to these regions without mitring. Additionally, the slot depth in the bottom and top loading plates, where the column is supported in the experimental setup, should be increased to limit the bending effect in the end regions. Mitred longitudinal reinforcements in the column end zones and leaving 25 mm concrete cover causes the problem.

Figure 9. End of Test5

IV. SOLUTION PROPOSALS

After a series of experiments, a solution was found. However, in order to avoid this difficult and troublesome process again, two important issues should be taken into consideration in the tests of axial pressure loaded columns under uniaxial bending effect. Firstly, longitudinal reinforcements should be welded by extending up to the sheet plates to be formed at the ends of the column. No concrete cover should be left at the ends of the column in the direction perpendicular to the cross-sectional area. Secondly, attention should be paid to the steel test apparatus on which the upper and lower ends of the column are supported. In this setup, the depth of the slot in which the column will be placed and fixed in the bending plane should be at least 100 mm. If these two aspects are taken into consideration, the expected collapse behavior would occur as intended, with the column body bending and fracturing.

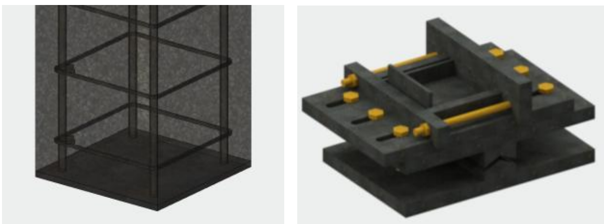

Figure 10. Improvements

V. CONCLUSION

In order to simulate the structural behavior in a laboratory environment and establish the support conditions for the test specimen, various steel testing setups are designed. However, if the produced specimens and designed equipment fail to fulfill their intended functions, it can lead to increased costs, wasted time, and efforts going in vain. Therefore, in order to avoid encountering problems that are difficult to rectify, meticulous planning is crucial during the initial stages.

In some cases, unforeseen issues might arise despite thorough planning. To mitigate such situations, the experience and knowledge gained from previous endeavors are of paramount importance. This information helps in preventing and addressing unexpected challenges, ensuring a smoother execution of the testing process and achieving accurate and reliable results.

In eccentric axial load tests on columns, slenderness is a crucial factor. Firstly, the columns designed should not be short but instead, they should be slender and flexible. In a two-hinged testing setup, the columns are expected to buckle and fail at their midsection due to the combined axial force and bending moment. At the points where the column connects to the steel setup for load transfer, maximum rigidity should be ensured. For this purpose, a robust reinforced concrete design should be implemented at the column ends, and the connection between the column and the steel setup should have sufficient depth to facilitate a reliable transfer of forces.

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REFERENCES

[1] Özbayrak, A., & Altun, F., (2018). Experimental Difficulties and Solution Proposals in a Three-Dimensional Reinforced Concrete Frame. 13th International Congress on Advances in Civil Engineering (pp.56). İzmir, Turkey.

[2] Dirikgil, T., Altun, F., & Düğenci, O., (2018). Experimental Investigation of Performance of Externally Collared Reinforced Concrete Short Columns. The 2018 Structures Congress_Structures18, Incheon, South Korea

[3] Pacheco, J., De Brito, J., Ferreira, J., & Soares, D. (2015). Flexural load tests of full-scale recycled aggregates concrete structures. Construction and Building Materials, 101, 65-71.

[4] Maghsoudi-Barmi, A., Khaloo, A., & Moeini, M. E. (2021, August). Experimental investigation of unbonded ordinary steel reinforced elastomeric bearings as an isolation system in bridges. In Structures (Vol. 32, pp. 604-616). Elsevier.

[5] Temami, O., Ayoub, A., Hamadi, D., & Bennoui, I. (2019). Effect of boundary conditions on the behavior of stiffened and un-stiffened cylindrical shells. International Journal of Steel Structures, 19, 867-878.

[6] Goutianos, S., Cabrera, N. O., Alcock, B., Reynolds, N., & Peijs, T. (2020). Self-Reinforced polypropylene composites based on discontinuous tapes-an experimental and numerical study of the influence of tape length. Applied Composite Materials, 27(6), 767-793.

[7] Carpinteri, A., Aledda, L., & Accornero, F. Ductile-to-brittle transition in fiber-reinforced materials: Effects of dimensional scale and fiber volume ratio.

[8] Çeçen, F., Aktaş, B., (2021). Incremental LUR tests of new LCR concrete railway sleepers. *Engineering Failure Analysis,* Cilt: 130 (105793). doi: https://doi.org/10.1016/j.engfailanal.2021.105793

[9] Çeçen, F., Aktaş, B., Öztürk, H., Öztürk, İ. Ş., Navdar, M. B., (2022). Comparison of new LCR and ordinary prestressed concrete railway sleepers with LUR tests. *Construction and Building Materials,* Cilt: 321. Doi: https://doi.org/10.1016/j.conbuildmat.2022.126414

[10] Çeçen, F., Aktaş, B., Özbayrak, A., (2023). Decarbonization of the concrete railway sleeper production: bringing the low-dosage pozzolanic cement usage in the sleeper production via novel laminated CFRPU reinforcement technique. *Materials Today Sustainability*, Cilt: 23, ID: 100455. doi: https://doi.org/10.1016/j.mtsust.2023.100455