# Sustainable Frames for Seismic Resistance to Captive Column Defects

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## Summary

Reinforced concrete constructions with partial masonry infill face serious earthquake shear damages in columns due to captive-column effect. An experimental program is carried out with one-third scale, two-bay two-story laboratory models having partial infill in the bottom story. Glass-fibre reinforced polymer sheets are wrapped around the columns at critical points for adequate ductility. Two frames namely, a control specimen and a retrofitted specimen are tested under quasi-static cyclic load to failure. The control specimen showed a brittle shear failure in the bottom story columns due to the induced captive-column effect while the retrofitted specimen showed a more ductile failure without any brittle damages. Results demonstrated the behavior with respect to strength and stiffness characteristics. The aim is, therefore to contribute for developing a sustainable structure to overcome the seismic failure due to captive-column defects.

**Keywords:** Reinforced concrete; partial infill; retrofitting; GFRP sheets; captive columns.

## 1. Introduction

During past earthquakes, a good number of reinforced concrete framed buildings suffered more damage because of column shear failure due to captive-column conditions. The need for providing openings to the walls of a building in order to provide natural lighting and ventilation leads to partial lateral confinement along the height of the column by rigid elements such as internal partitions, facades etc. The captive-column effect is caused by the non-intended modification to the original structural configuration of the column that restricts the ability to deform laterally by confining it with non-structural building components like partial brick masonry infill.

Various codes of construction have laid down general recommendation/provisions for construction of such buildings with partial infill. But many of the existing buildings are found to have inadequate strength because they were designed and built when modern seismic requirements did not exist. Strengthening of existing reinforced concrete framed buildings for improving seismic resistance is a challenging engineering problem. In recent years, external Fibre Reinforced Polymer (FRP) wraps are used for increasing the performance of reinforced concrete structural elements. The purpose of this research is to experimentally identify the captive-column effect due to partial brick masonry infill under lateral loads and to provide a retrofit solution using GFRP.

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## 2. Experimental Program

The two test frames manufactured and tested under lateral loads were two-bay two-storied and non-ductile. These test frames were detailed and constructed purposely with some deficiencies commonly observed in buildings such as insufficient confinement of concrete at column and beam ends and no confinement at beam-column joints. Partial brick masonry was provided in the bottom story and the top story was completely filled with the infill. High strength glass fibre mat crossly knitted in two directions were used for retrofitting. The specimen was cast in the laboratory in a horizontal position and cured. At the end of 28 days, the frame was erected and the infill wall was constructed after retrofitting. The specimens were tested after the curing of infill. The proposed retrofit scheme consists of upgrading the capacity of columns and joints by confining them with a single layer of GFRP wrap.

The frames were tested as vertical cantilevers under a cyclic loading program. Lateral cyclic loading was applied at first story and roof levels in line with the beams using hydraulic jacks of capacity 500 kN actuated by a hydraulic pump. The loading was increased, resulting in 5 kN base shear in successive cycles until the ultimate load carrying capacity of the specimen is reached. At maximum load level of each cycle, cracks were marked on the test specimens. The test was terminated when severe damage in the specimens is noticed.

## 3. Discussions

The partial brick masonry infilled frames are designated as M1 and M2 in which M1 was the control specimen tested to identify the captive-column behavior and M2 retrofitted with GFRP wrap. Unlike the ductile flexural failure anticipated from a normal frame, the test frame M1 experienced a brittle shear failure in the concrete followed by inelastic deformation of the reinforcement. The specimen failed due to captive-column effect with the formation of flexural hinges and diagonal shear cracks in the portion of ground story columns above the partial infill. The retrofitted frame M2 exhibited a mode of failure that could be described as similar to a frame completely infilled with low strength masonry. The GFRP wrap increased the shear strength with adequate confinement to overcome the lateral deformation of captive columns. The partial masonry infill failed first and the entire column swayed laterally without any critical shear cracks.

## 4. Conclusions

In this experimental study, two-bay two-storied structures were investigated under in-plane lateral loads using partially infilled reinforced concrete frames with and without retrofitting. Based on the work, the following conclusions were drawn:

- The partial-infilled reinforced concrete frame failed with flexural hinges and diagonal shear cracks at the portion of columns adjacent to the gap of infill in the bottom story indicating a distinct captive-column effect.
- The retrofitted frame with GFRP wrap exhibited an enhanced performance with adequate confinement. This increased shear strength helped in overcoming the captive-column condition but is limited by the bond between concrete and GFRP interface.

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