

**Research Project on**  
**Investigation the Dynamic Response of Acceleration-sensitive Non-structural**  
**Components Integrated on Irregular Reinforced Concrete Structures**

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*Software used:* MIDAS Gen, ABAQUS, REXEL, SIMQKE and SeismoMatch.

## **Background**

The term of non-structural components (NSCs) represents to the secondary systems (S-systems) that integrated on a structure and which are not considered as the main structural elements of the principal vertical load-bearing structure, but are affected by the seismic actions of the primary structure (P-structure) under the effect of earthquakes.

Seismic design of NSCs is quite essential for important structures and lifeline systems. In earlier years, engineers were emphasised on the design of the main elements of the supporting frames rather than the secondary elements. After the most of earthquake events, it was recognised that damage to the S-systems integrated on the P-structures could have a considerable effect on the life of the occupants and the function of some parts of the main structures. Therefore, based on the losses suffered after the damage to the S-systems during the seismic loading, seismic design provisions of NSCs were included in the main codes provisions, and a large number of studies has been carried out over that last four decades to investigate their seismic behaviour.

Review of literature on the research that studied the response of NSCs has revealed that the number of studies on NSC attached to regular P-structures has largely exceeded the number of studies on NSC attached to P-structures with significant torsional effects. In the majority of the studies regards NSCs attached to systems with torsional modes, the NSCs were mounted over either a linear P-structure with eccentricity in one direction or an inelastic single-bay irregular building with eccentricity in both directions.

Multi-storey structures with complicated geometries have become widespread due to novel materials, advanced construction techniques and modern architectural requirements. In such structures with plan and/or vertical irregularities, significant torsional effects induced by moderate and strong

earthquakes are usually responsible for the damage to the structure and non-structural components (NSCs).

To evaluate the seismic behaviour of the NSCs attached to the P-structures having different cases of plan and/or mass distribution along the height of complicated reinforced concrete (RC) structures, the effect of torsion and the structural ductility of the P-structures were investigated. However, the structural layouts and composite materials used in present-day P-structures are too complicated for an analytical solution to be available and research studies addressing the seismic response of NSCs attached to such P-structures are scarce. One possible solution to bridge the knowledge gap in this area is to use advanced numerical methods such as finite element (FE) analysis. The FE package MIDAS Gen ver. 3.1 is adopted in the nonlinear analyses of the primary-secondary systems.

The NSCs considered in the investigation are lightweight acceleration-sensitive mechanical, electrical or medical equipment such as those found in industrial, commercial or healthcare buildings respectively. Normally, only the fundamental modes of such NSCs are of importance therefore they can be modelled as vertical cantilevers fixed at their bases with lumped masses on their free ends.

## **Research Aim and Objectives:**

### ***Aim***

The ultimate intention of the current research is to investigate the dynamic response of the lightweight acceleration-sensitive non-structural components attached to the floors of different cases of irregular multi-storey RC buildings using 3D FE dynamic analyses.

### ***Objectives***

To achieve the aim of the research, the following research objectives have to be met:

- (1) to evaluate the effect of different design provisions of the P-structures on the seismic response of the NSCs having different natural frequency values;
- (2) to evaluate and quantify the dependence of behaviours of the acceleration-sensitive NSCs on the properties of multi-storey RC structures such as their fundamental periods, seismic capacities and types of the ground that assumed to be constructed, as well as the properties of the NSCs such as their damping ratio and natural frequencies, location along the height of the building and their location on the floors, i.e., the flexible sides and centres of rigidities of the irregular RC buildings;
- (3) to investigate the influence of different values of eccentricity ratios of the P-structure on the acceleration responses of the attached NSCs;
- (4) to investigate the seismic performances of the acceleration-sensitive NSCs due to the effect of vertical mass irregularity, besides any irregularity in the plan of multi-storey RC structures designed according to the modern code provisions. Expressions that can be used to calculate the percentage of the increase in the accelerations of the NSCs due to the increase in the total masses of the floors along the height of the building can be proposed;
- (5) to propose a relation between the amplification in the accelerations of the NSCs and the top floors' rotations of the P-structures;
- (6) to compare the predictions of the non-linear dynamic FE analyses with those of the EC8 (2004) seismic design provisions for the NSCs;

(7) to extend the current EC8 (2004) design expression for the NSCs to include the structural ductility, seismic capacity and the torsional effects. Furthermore, the accuracy of the proposed expression is to be validated.

It is necessary to achieve the aim and objectives listed above to obtain a solid knowledge basis and to understand the real global seismic behaviour of the NSCs mounted on irregular multi-storey RC buildings with significant torsional effect under bi-directional base motions. Therefore, this research will lead to further understanding and development of the current design codes.

In the study by Aldeka et al. (2014), a validation of the FE code, MIDAS Gen Ver. 3.1 (2012), was made for the dynamic analysis of irregular RC frame structures with significant torsional behaviour. Furthermore, verification of modelling the NSCs using FE approach was also implemented by adopting both of the modal and time-history analyses.

## Findings

In general, for a given case of the P-structure, the numerical results suggested that there was a strong correlation between the torsional amplification factors of NSCs and the top floors' rotations of the P-structures.

- As would be expected for near-resonance behaviour, a sharp increase in the dynamic response of the NSCs occurred when their vibration periods matched the vibration periods of the P-structures.
- For a given P-structure, the NSCs accelerations varied approximately linearly with base excitation up to the PGA value corresponding to the elastic seismic capacity of the P-structure. At higher PGA values, the relationship between NSCs accelerations and PGA was non-linear.
- The NSCs attached to the flexible sides of the P-structures had accelerations that were on average 42% higher than the accelerations of the NSCs attached to the centres of rigidity.
- The maximum values of the component amplification factor, defined as  $PCA_{xy}/PGA$ , occurred at the PGA values corresponding to the elastic seismic capacities of the P-structures.
- The increase in the torsional behaviour of the P-structures resulted in a corresponding increase in the accelerations of the NSCs attached at the flexible sides of the studied P-structures.
- Comparison between the FE results and the recommendation of EC8 suggests that when the fundamental periods and heights of the NSCs match those of the P-structures, EC8 underestimates the dynamic responses of the NSCs mounted on the flexible sides of irregular RC P-structures with a mean predicted-to-numerical ratio in range between 0.42 and 0.72. The perceived cause of this discrepancy is that EC8 does not take into account the amplification in the dynamic response of the NSCs caused by the torsional behaviour of the RC P-structures.

In the following, the numerical results of several selected cases of NSCs attached to centres of rigidities and/or the flexible sides of the P-structures were compared with the recommendation of the EC8 (2004).

### I. NSCs attached the floors of the first group of the buildings

This group of buildings consists of three irregular RC P-structures with heights equal to 15, 30 and 45 m. Their plan is shown in Fig. 1.

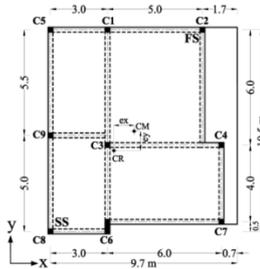


Fig. 1 Plan of group 1

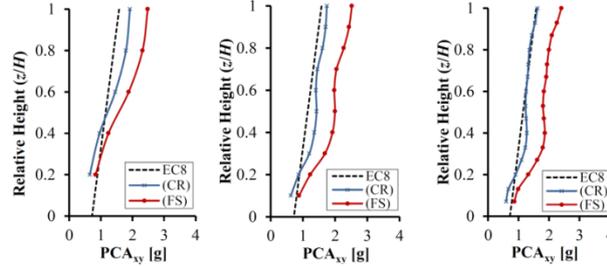


Fig. 2 Comparison between the FE results and EC8 for NSCs attached to P-structures having heights equal to: (a) 15, (b) 30 and (c) 45 m.

### II. NSCs attached the floors of the second group of the buildings

This group of buildings consists of four RC 3-story P-structures with eccentricity ratios  $Re$  equal to 0.0, 0.143, 0.205 and 0.372. Their plan is shown in Fig. 3.

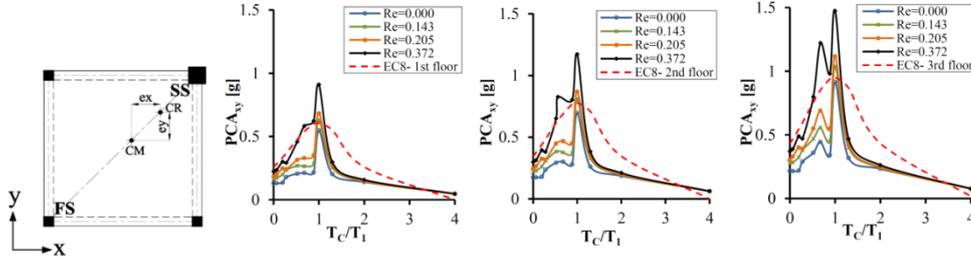


Fig. 3 Plan of group 2

Fig. 4 Comparison between the FE results and EC8 for NSCs attached to P-structures at: (a) first, (b) second and (c) top floors.

### III. NSCs attached the top floors of the third group of the buildings

This group of buildings consists of 31 cases of P-structures having different cases of vertical mass irregularities. Their plan is shown in Fig. 5.

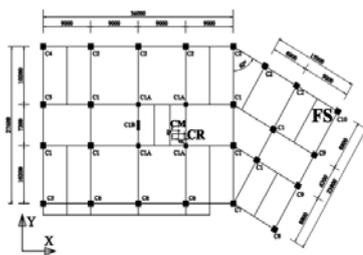


Fig. 5 Plan of group 3

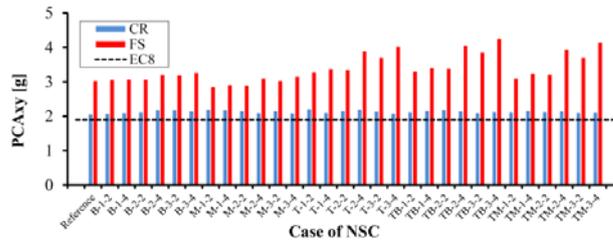


Fig. 6 Comparison between the FE results and EC8 for NSCs attached to P-structures having different cases of vertical mass irregularities.

## Researcher's Publications

- Aldeka, A. B.** (2010), "Tendons Arrangement Effects on Reinforced Concrete Frames", *Tikrit Journal of Engineering Science*, 17, 22-30.
- Mahmood, M. N. and **Ayad, B. B.** (2010), "Embedded formulation of prestressed tendon in 3D-brick element", *Journal of Al-Rafidain Engineering*, 18(6), 1-14.
- Aldeka, A.**, Chan, A. and Dirar, S. (2012), "Finite element modelling of non-structural components mounted on a torsionally multi-storey building", *Proceedings of the 20<sup>th</sup> UK Conference of the Association for Computational Mechanics in Engineering (ACME2012)*, Manchester, United Kingdom, March.
- Aldeka, A.**, Chan, A. and Dirar, S. (2013a), "Finite element modelling of non-structural components mounted on irregular RC buildings", *Proceedings of the International Conference on Computational Mechanics (CM13)*, Durham, United Kingdom, March.
- Aldeka, A.**, Chan, A. and Dirar, S. (2013b), "Effects of torsion on the behaviour of non-structural components mounted on irregular reinforced concrete multi-storey buildings", *Proceedings of the 4<sup>th</sup> ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering*, Kos Island, Greece, June.
- Aldeka, A.**, Chan, A. and Dirar, S. (2014), "Response of non-structural components mounted on irregular RC buildings: comparison between FE and EC8 predictions", *Earthquakes and Structures*, 6(4), 351-373.