COMPDYN 2015
5th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, V. Papadopoulos, V. Plevris (eds.)
Crete Island, Greece, 25–27 May 2015

SIGNIFICANCE OF EARTHQUAKE INCIDENCE ON RESPONSE OF PLAN-IRREGULAR INFILLED R/C BUILDINGS

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Keywords: plan-irregular structures, infilled frames, earthquake incidence response, graphic dynamic torsional trends, Incremental Dynamic Analysis.

Abstract. *Masonry infilled R/C buildings present a number of complexities inherent to in-plan eccentricities and asymmetric layout of infills. Their dynamic earthquake response cannot generally be characterized in terms of principal directions of deflection as for plan-regular structures. The response is then complicated by nonlinear frame-infill interaction, which makes the resulting collapse mechanism particularly sensitive to local shear failures. A three-dimensional nonlinear model is developed incorporating frame elements, eccentric infill struts, and shear-prone short columns. Results from nonlinear Response History Analyses (RHA) changing the earthquake incidence are analyzed starting from Graphic-Dynamic modal torsional trends and directional inelastic response envelopes. Directional Incremental Dynamic Analyses (IDA) and Uncoupled Modal Response History Analyses (UMRHA) over a range of hazard levels (OP, DL, SD, NC) highlight the polarization of the elastic and inelastic modal response.*

1 INTRODUCTION

This paper investigates the estimation of the nonlinear seismic response of plan irregular buildings under unidirectional earthquakes with changing angle of attack based on Graphic Dynamics and nonlinear Response History Analyses (RHA). The elastic modal torsional trends computed from Graphic Dynamics, [1] - [7], are used as a basis to highlight the inelastic contribution to the overall response and the relevant polarization with the earthquake angle. In performance-based earthquake engineering, the identification of synthetic structural and modal parameters in the linear range is critical for the choice of optimal spectrum-based intensity measures, [8]. The importance of earthquake directionality has been addressed by several researchers, in particular [9] and [10] showed that the response of uniformly plan-asymmetric multi-story buildings can be expressed in terms of a multi-story system and a rigid-diaphragm single-story torsional system. The work of [11] introduced the CQC3 rule for maximum directional response computation under concurrent seismic components and for determination of the critical response angle. More recently [12] pointed out the importance of seismic incidence in the context of performance-based assessment of plan-asymmetric buildings through nonlinear RHA.

The objective of this work is to investigate the directional nonlinear response of a plan-asymmetric building based on the in-plan torsional trends and the effect of the modal contributions in terms of polarization of the inelastic response. Incremental Dynamic Analyses (IDA) are performed on a nonlinear model of an irregular one-story R/C building with masonry infills in two consecutive open sides. The model includes nonlinear frame behavior, eccentric hysteretic infill struts and nonlinear shear in short columns. The graphical modal torsional trends and the elastic response predictors based on the 8-shaped modal influence circles, are used to further investigate the nonlinear response through Uncoupled Modal Response History Analysis (UMRHA), [13], [14].

2 DIRECTIONAL NONLINEAR RESPONSE HISTORY ANALYSES

The case study structure is a two-ways plan-asymmetric building with eccentric infills in the left and bottom frames, used also in [7]. Previous studies have pointed out the influence of the infills-induced shear failure of the columns, resulting in increased strength and stiffness at low hazard levels, and triggering shear-dominated story mechanisms [15], [16], while the response of the bare frames is characterized by increased flexibility due to bond slip effects [17], [18]. These additional mechanisms and components result in increased plan irregularity both in terms of stiffness and strength. The structure modal periods computed with the initial elastic frame and infill properties are $T_1 = 0.21$s, $T_2 = 0.14$s, and $T_3 = 0.09$s.

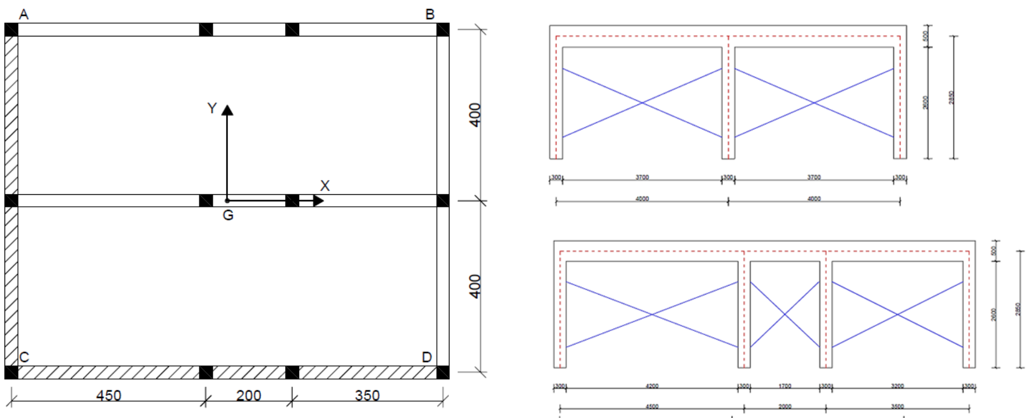

Figure 1: (a) Plan layout of two-ways asymmetric single story building structure with eccentric infills, (b) R/C frames with eccentric infill struts and shear-prone short columns.

Figure 2 shows the results of RHA at the Operational (OP), Damage Limitation (DL), Significant Damage (SD) and Near Collapse (NC) limt states, obtained with the actual nonlinear model and with the elastic model based on initial elements stiffness. It is evident how the maximum directional nonlinear response is polarized along the direction of the elastic modal torsional trends, indicated by the internal 8-shaped figures. Plan-irregular infills induce a change of polarization and of the critical angle with respect to the geometric axes of the bare frame, particularly at lower hazard levels.

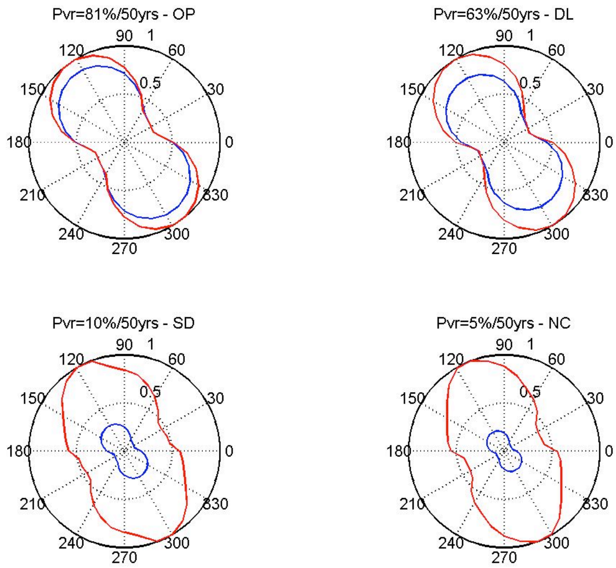

Figure 2: Directional RHA response at the center of mass with linear (blue line) and nonlinear (red line) structure models at OP, DL, SD and NC limit states.

3 DIRECTIONAL MODAL RESPONSE DECOMPOSITION

Modern seismic codes prescribe the use of complete NL RHA to simulate the earthquake response of structures subjected to damage or equipped with protection devices. In fact the robustness of NL RHA allows accounting for the nonlinear coupling of the modal response, which in some cases has been observed also experimentally [19]. It has been shown that in some cases the nonlinear modal coupling may be neglected, [14], and the results of NL RHA may be approximated by the so-called Uncoupled Modal Response History Analysis (UMRHA). In Figures 3,4 and 5 we show the results of directional UMRHA carried out using the modal forces obtained from the initial stiffness elastic analysis.

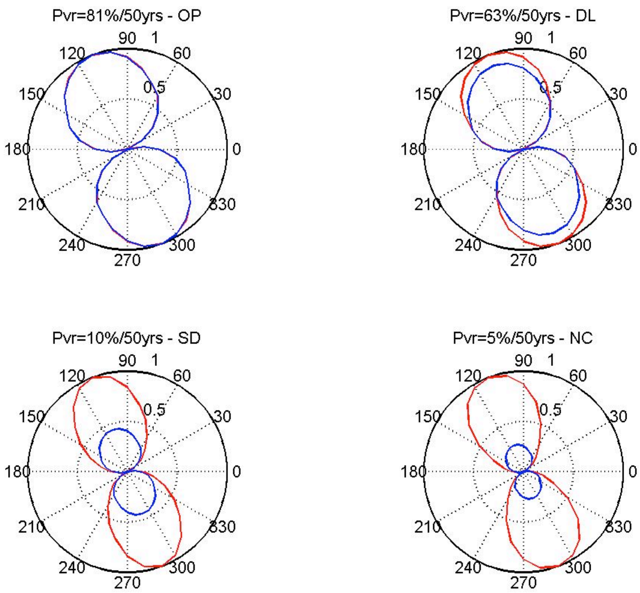

Figure 3: Directional Mode 1 RHA response at the center of mass with linear (blue line) and nonlinear (red line) structure models at OP, DL, SD and NC limit states.

It is evident how the directional response obtained with the elastic model and at the lower hazard level match well and are well described by the 8-shaped circle directional envelopes.

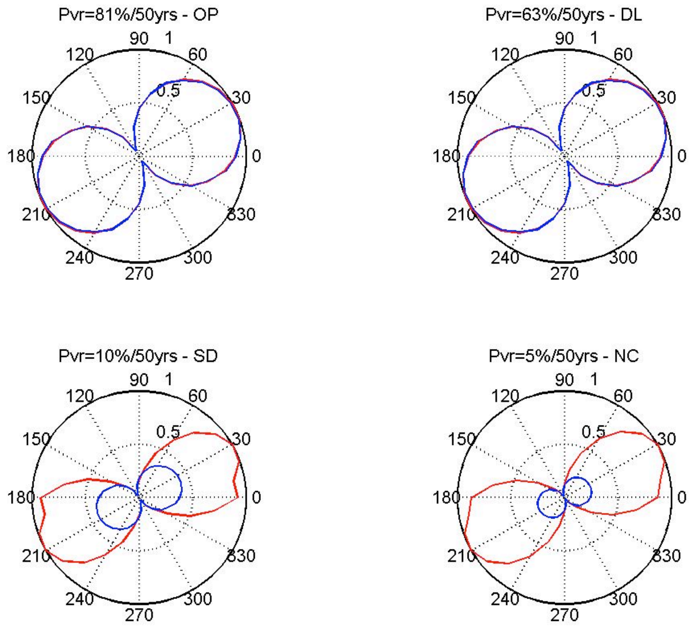

Figure 4: Directional Mode 2 RHA response at the center of mass with linear (blue line) and nonlinear (red line) structure models at OP, DL, SD and NC limit states.

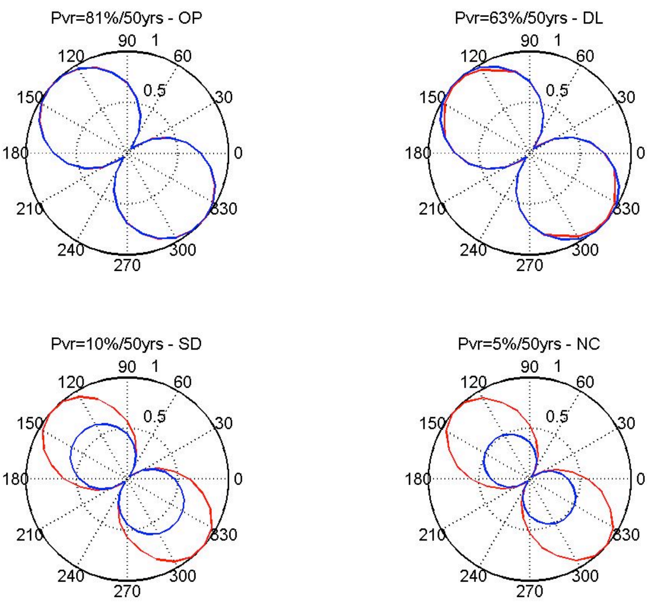

Figure 5: Directional Mode 3 RHA response at the center of mass with linear (blue line) and nonlinear (red line) structure models at OP, DL, SD and NC limit states.

At the higher hazard levels the system nonlinearities cause the response to deviate from the elastic prediction. The inelastic response is maximum along the critical directions of each modes, and is zero along the mode-orthogonal directions. The comparison of Figure 6 indicate a generally good agreement between the RHA and the total UMRHA summed over all modes, and therefore a weak influence of nonlinear modal coupling on maximum response envelopes along most of the incidence angles.

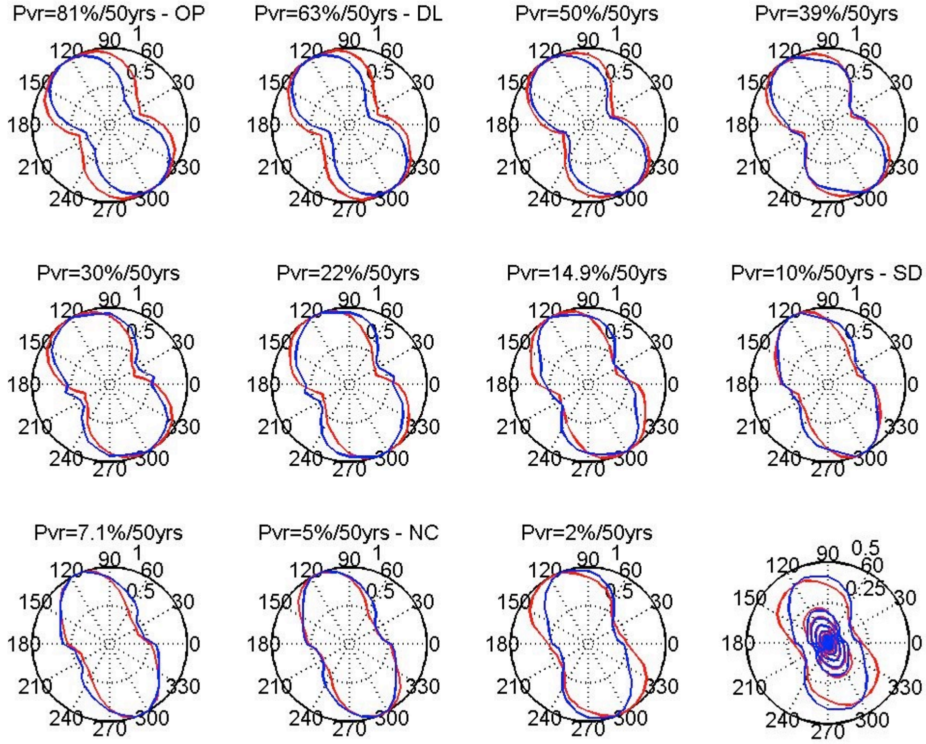

Figure 6: Directional Incremental Dynamic Analyses (IDA) response at the center of mass at 81% through 2%PoE/50yrs hazard levels with coupled RHA (blue line) and uncoupled UMRHA (red line).

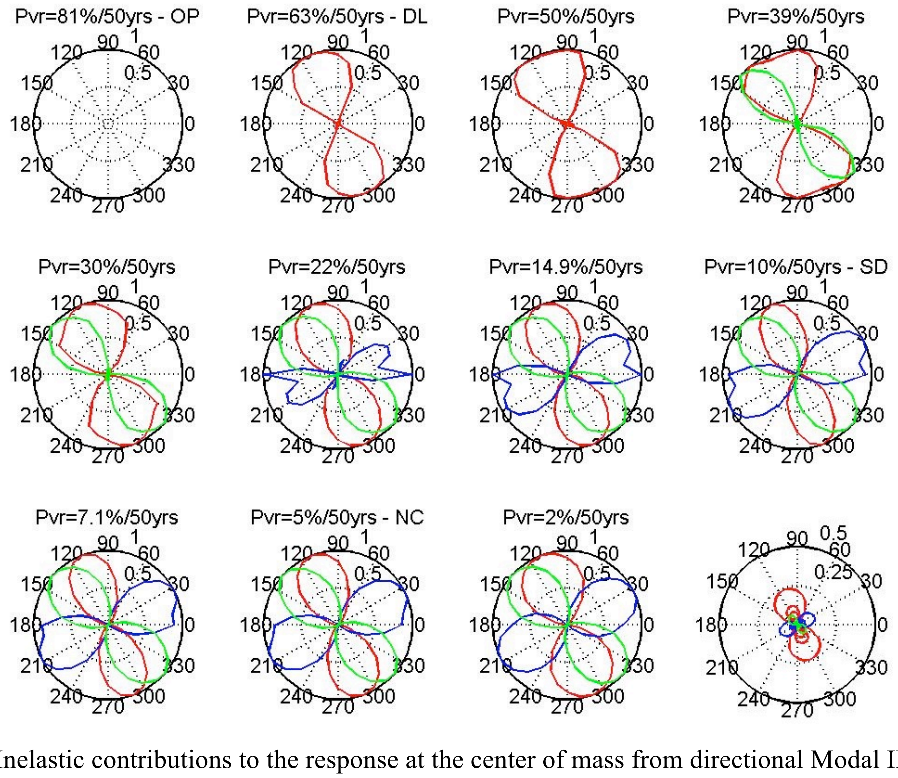

Figure 7: Inelastic contributions to the response at the center of mass from directional Modal IDA at 81% through 2%PoE/50yrs hazard levels based on Mode 1 (red line) Mode 2 (blue line) and Mode 3 (green line).

Finally Figure 7 shows the radial plots of the inelastic contribution of the response obtained from each modal RHA at the different hazard levels. The inelastic contributions are obtained as the difference between the total response of the RHA and the response from the elastic analysis.

4 CONCLUSIONS

This paper investigated the graphic directional response envelope prediction for torsionally coupled systems subjected to unidirectional earthquake with rotating angle of attack. Numerical nonlinear analyses were performed on an example of two-ways asymmetric R/C single story building with irregular infills layout. Results show that: plan-irregular placement of infills can induce a change of polarization and of the critical angle with respect to the geometric axes, particularly at lower hazard levels. Graphic dynamic in-plan torsional trends and modal pivots can be used to predict the direction of polarization of the overall response and the critical angle. The Modal decomposition of the response through UMRHA and comparison of response with RHA indicate a weak influence of nonlinear modal coupling on response envelopes, and highlight the directions of polarization of the inelastic component of the response.

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