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Influence of column shear failure on pushover based assessment of masonry infilled reinforced concrete framed structures: A case study

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ABSTRACT

Structural frames, constructed either of steel or reinforced concrete (RC), are often infilled with masonry panels. However, during the analysis of the structural frames, it has become common practice to disregard the existence of infills because of the complexity in modeling. This omission should not be allowed because the two contributions (of infills and of frames) complement each other in providing a so different structural system. The use of different modeling assumptions significantly affects the capacity as well as the inelastic demand and safety assessment. In specific, the adoption of equivalent diagonal pin-jointed struts leaves open the problem of the evaluation of the additional shear on columns and consequently of the choice of a proper eccentricity for the diagonal struts. In this context, this paper presents the results of a real case study. The seismic performance of the RC structure of a school is evaluated by using concentric equivalent struts for modeling infills and the level of the additional shear on the columns is fixed as a rate of the axial force on them in agreement to a strong correlation obtained after a numerical experimentation. Hence, the applicability of the correlation mentioned before is shown and the form in which the results can be provided is presented. The characteristics of the new approach, first time applied to a real case, are highlighted by a comparison between the performance obtainable with different modeling detail levels of the infills. Through the paper, it is proved that the simplified evaluation of the additional shear demand produced by infills just for the base columns is sufficient to warn that a simplified model disregarding infills or based on the use of concentric struts for the infills may considerably overestimate the structural capacity. Further, by the study of a real case, the paper provides an overview of the models developed by the authors to obtain the capacity of reinforced concrete framed structure for the practical applications.

1. Introduction

Building frames are usually infilled with masonry walls as a natural consequence of the necessity of separating the internal spaces from the external environment. Although masonry infills are not designed as structural elements per se, their interaction with the RC frames significantly influences the structural behavior of a building in terms of stiffness, strength and overall ductility. During an earthquake, infill walls may increase or not the lateral earthquake load resistance significantly, may undergo a premature damage, developing diagonal tension and compression failures or out-of-plane failures. The degree of lateral load resistance depends on the amount of masonry infill walls used and their direction and position within the structure. Negative effects are often associated with irregularities in the distribution of infills in plan and elevation. This stiffness asymmetry may cause torsion which magnifies the lateral displacement response of the structure while the abrupt change in stiffness in elevation may cause "soft story" mechanisms (Fig. 1). Besides these mechanisms, which involve the overall structural response, the infill – frame interaction occurs also locally. Infills, because of their high stiffness, attract a large amount of lateral force, that is transferred to the surrounding frames in the proximity of the ends of RC beams and columns as an additional shear force. The further shear demand may be not supported by these regions if adequate shear reinforcement is not present, and may have as a consequence a brittle failure localized in most of the cases in joints or the ends of columns (Fig. 2). Due to the design and methodological complexity of masonry infilled RC framed structures, the numerical analysis for their structural assessment is necessary.

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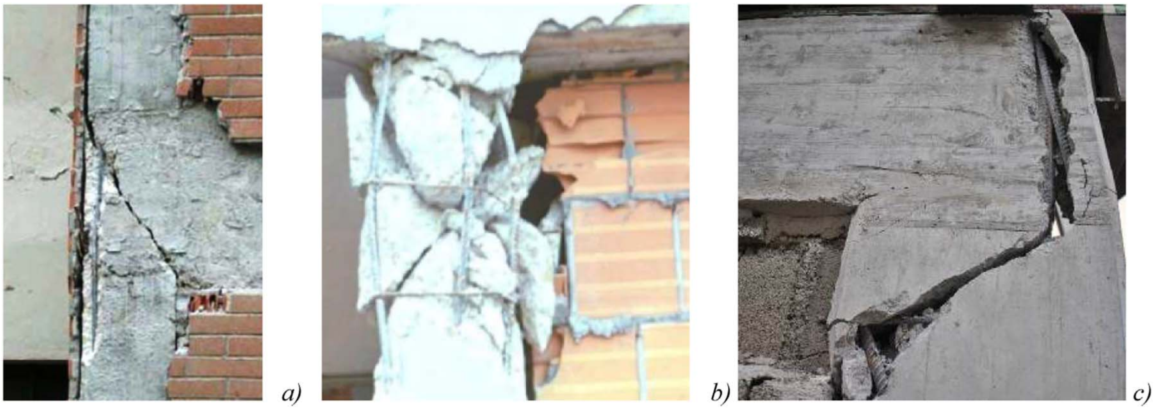

Fig. 1. Effect of geometrical irregularities in distribution of infills: *a)* Adapazari-Turkey (1999); *b)* L'Aquila-Italy (2009).

Over the last three decades, different computational modeling strategies have been developed aiming to address different levels of complexity. Among the modeling strategies, the most common one is that of the macro-modeling approach, which consists of the replacement of the infill by an equivalent pinned strut made of the same material and having the same thickness as the infill panel. The macro-modeling approach is mainly used for the assessment of the stiffening and strengthening effects in non-linear static or dynamic analyses [1,27,34,35,41,42,44,45]. In this approach, the selection of a constitutive law for the strut able to represent accurately the mechanical behavior of the masonry wall is essential. Available models for the definition of a force – displacement curve for the strut are based on preliminary hypotheses about the modality of failure of the infill – frame system [3,40,48]. In addition, for the assessment of the seismic response of the masonry infilled RC framed structures, several experimental studies (e.g. [29,21]; Cavaleri, Fossetti & Papia M, 2005; [28]; Cavaleri, Di Trapani, Macaluso, Papia, & Colajanni, 2014; [6,25,32,33,37]) have been undertaken and simplified modeling rules have been identified in order to predict the hysteretic behavior of the structure. A radically different approach makes use of FE micro-models to simulate the mechanical behavior of both infills and RC frames (e.g. [38,43,2,31,30]). In this case, infills are modeled generally by 2-D finite elements. maintaining the geometry as it is. The surrounding frame is modeled by beam elements and ad hoc finite elements are used for the interface frame-infill able to simulate the detachment occurring between frame and infill during the application of a lateral load. This choice surely represents the most accurate solution, being the closest to the actual physical system under investigation. However, any analysis with this level of refinement requires a large computational effort. Focusing the attention on macro-modeling approach it constitutes an attractive solution, despite the fact that a conspicuous number of uncertainties affect the identification of the equivalent geometrical and mechanical properties be attributed to the struts. Recent studies (e.g. [20,46]) demonstrate that the resulting structural response (mainly determined by means of static pushover analyses) may be sensitive to the imprecise or incorrect identification of some key parameters such as equivalent strut width or panel strength. The major difficulties regarding the identification of governing parameters are mainly related to:

- uncertainty in the identification of mechanical characteristics of existing masonry due to the variability of materials, differences in arrangements techniques and aging;
- uncertainty in the identification of actual ultimate strength capacity of the masonry wall panel including the influence of vertical loads, panel – frame effective contact lengths and possible failure mechanisms;
- variability of equivalent properties depending on the aspect ratio of the frame and on infill – frame strength and stiffness ratios;
- contact issues between the infill and the frame which control the transfer of shear force.

Further uncertainties arise when concentric braced macro-models are adopted, configuring the impossibility to predict the additional shear demand at the ends of RC beams and columns due to the local interaction with infills. To circumvent this limit, multiple strut macro-models have been developed (e.g. [13]; Chrysostomou et al., [11,22]). According to these models, the additional shear demand is determined as result of a non-concentric disposition of two or more equivalent struts. However, the calibration of an adequate nonlinear constitutive law, which is needed for each strut, determines new unknowns. An alternative solution has been proposed by Cavaleri L, & Di Trapani

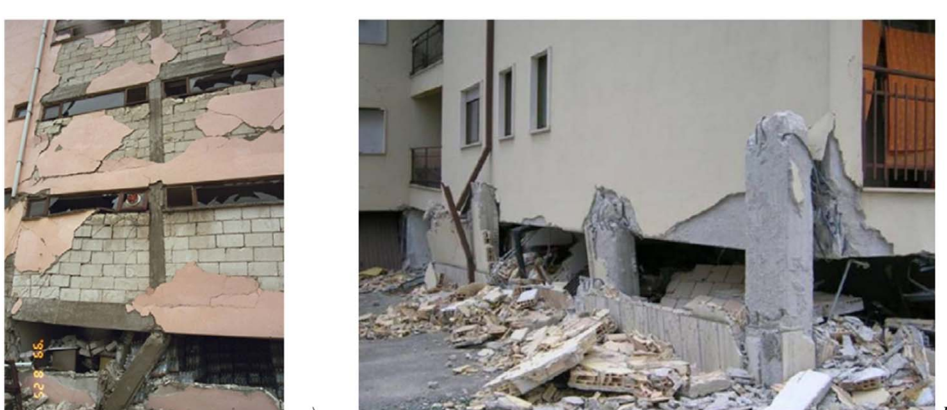

Fig. 2. Local failures of RC frames due to the interaction with infills: *a)* Failure of a joint; *b)* Failure of a column end; *c)* Failure of column and joint.

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