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Review

An equivalent frame model for seismic analysis of masonry and reinforced concrete buildings

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Abstract

In this paper a novel equivalent planar-frame model with openings is presented. The model deals with seismic analysis using the Push-over method for masonry and reinforced concrete buildings. Each wall with opening can be decomposed into parallel structural walls made of an assemblage of piers and a portion of spandrels. As formulated, the structural model undergoes inelastic flexural as well as inelastic shear deformations. The mathematical model is based on the smeared cracks and distributed plasticity approach. Both zero moment location shifting in piers and spandrels can be evaluated. The constitutive laws are modeled as bilinear curves in flexure and in shear. A biaxial interaction rule for both axial force–bending moment and axial force–shear force are considered. The model can support any shape of failure criteria. An event-to-event strategy is used to solve the nonlinear problem. Two applications are used to show the ability of the model to study both reinforced concrete and unreinforced masonry structures. Relevant findings are compared to analytical results from experimental, simplified models and finite element models such as Drain3DX and ETABS finite element package.

Keywords: Seismic evaluation; Unreinforced masonry; Reinforced concrete; Structural wall; Equivalent frame

Contents

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1. Introduction

Earthquakes are considered to be the major cause of structural failure of buildings in Europe. Despite their rarity and moderate intensity, earthquakes in the interior of northwest and central Europe have the potential to cause extensive damage and associated financial losses, due to the vulnerability of the local building stock. The mitigation of earthquake hazard involves the collaboration of many specialists with different tasks. One of these topics is structural engineering providing and advancing the knowledge for earthquake resistant construction. However, a problem arises for existing buildings analysis. In this context, in the few last decades, technical advances have been made in seismic engineering and particularly in the seismic vulnerability assessment of existing buildings. The vulnerability assessment focuses on the study of the extent of damage for different earthquake scenarios.

In almost all countries, the majority of the building stock is classified as existing buildings. This is why extensive assessment of such structures is motivated since they have been generally designed to resist gravity loads. Nevertheless, the seismic vulnerability of existing buildings designed against wind loads, is found to be very low.

This paper makes a contribution to the seismic vulnerability assessment of existing buildings through the development of a simplified analytical model. The need for such models is always motivated by first, the large amount of structures that should be analyzed in a very short time and second, the search for optimal solutions for structural retrofitting.

For vulnerability assessment purposes, the analysis of a large number of existing buildings requires relatively simple approaches that are capable of representing their essential characteristics. The models should be able to evaluate the ultimate strength, maximum displacements and the failure modes. Different models are developed based on analytical and finite element approaches [1]. The analytical models are found to be very simple to use and require lesser amount of data. However they are very limited, particularly for large building analysis in terms of structural behavior (coupling effect, distribution of the nonlinearity, modes of failures prediction). The performed analysis show that they are conservative and are not able to represent all features of such buildings [2]. On the other side, finite element approach is a powerful tool for seismic analysis but it is time consuming and requires a large amount of data. Moreover, refined models based on either discrete or continuum approaches suffer from the strong mesh-dependency and require numerous parameters that may not be directly extractable from structural analysis. Hence, these models are very sensitive to the parameter calibration that affects closely the reliability of the results and the analysis stability (lack of convergence, flip-flop occurrence, sudden load falling, and so on). With such methods it is not possible to treat a stock of buildings. Thus, these methods are cumbersome due to the high analytical skills required for their numerical implementation and they are restricted only to practitioners with a high level of knowledge.

A widely used model for structural analysis is the linear (beam-column element) finite element or the equivalent frame models. Despite of some limitations in the equivalent frame model, it is very attractive in comparison to complex finite element models [1,3–5]. Moreover, they have shown satisfactory results particularly for RC structures. In this context, the proposed model is based on beam-column element and distributed of nonlinearity approaches. It is adapted to analytical methods without use of finite element method.

In this paper, the developed model deals with the seismic vulnerability assessment of existing multistoried buildings.

2. A model for structural walls with openings

2.1. Description and hypotheses of the structural model

The mathematical model can represent solid walls, frame structural elements (made in beams and columns), coupled walls and perforated walls (or framed walls) [6]. The model can represent different openings. However, the vertical axis should lie through all vertical piers elements as well as for the horizontal axes that should lies through all spandrels.

The structural model consists of an assemblage of vertical plane walls with openings that form a single perforated wall. Each structural wall is made of pier elements with or without rigid offsets and a portion of spandrels such that there are two kinds of individual walls: exterior walls and interior walls (Fig. 1). The length of these parts of spandrels is equal to the zero moment length, and can be updated at each step depending on the bending moments at the spandrel ends.

In the equivalent frame models that are based on finite element method, nonlinear flexural springs (lumped plasticity) are inserted into the model at the ends of the piers and/or spandrel elements. These elements are defined in terms

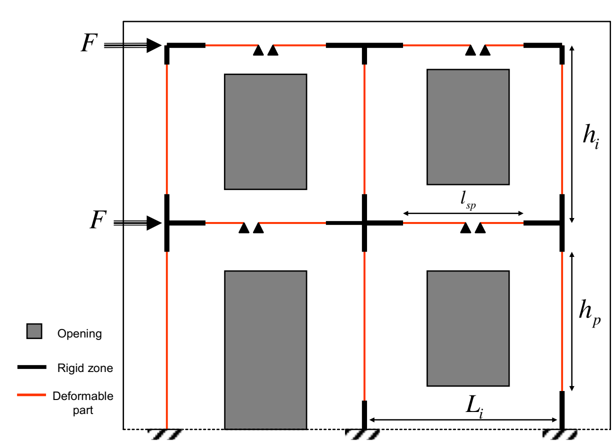

Fig. 1. A schematic representation of equivalent frame model for planar walls with openings.