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Effect of URM infills on inelastic floor response of RC frame buildings

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ABSTRACT

The effect of unreinforced masonry infills on the floor acceleration response of inelastically responding mid-rise RC frame buildings is studied using incremental dynamic analyses. Two structural building configurations, uniformly infilled, and with open ground storey are analyzed by using the FEMA P695 far-field ground-motion suite. It is observed that the effect of structural nonlinearity is much more pronounced in case of infilled RC frame buildings than bare RC frame buildings. Sequential failure of infills results in a significant elongation of period of vibration resulting in the shifting of peaks in floor spectrum towards longer periods. Modified floor spectral amplification functions are presented for both uniformly infilled and open ground storey RC frame buildings. The proposed spectral amplification functions are validated using nonlinear analysis of typical buildings for recorded as well as spectrum-compatible ground-motions and can be used to estimate the floor response spectra directly from the code-based or site-specific design spectra.

1. Introduction

The assessment of floor acceleration demands is a crucial task in the framework of performance-based seismic design of non-structural components (NSCs). To this day, a significant number of attempts have been made to study the floor acceleration demands in RC bare frame buildings [1–8]. The crucial parameters affecting floor accelerations have already been identified including the frequency content of the ground motion [9–12], the dynamic characteristics of the supporting structure (the “building structure” throughout this article is referred as the “supporting structure”), the level of nonlinearity (inelasticity) of the supporting structure [12–27], and both the period and damping of the NSC [2–6,9,12,21]. Amplification of Peak Floor Acceleration (PFA) along the height of the building has been identified to be governed by the dynamic characteristics (i.e. frequency and mode shape) of the supporting structure [4,5,9,11,18]. Some recent studies focused on irregular supporting structures [25] and the development of probabilistic models [26,27] for prediction of the floor accelerations.

Major findings of earlier studies on RC bare frame buildings include that the amplification of the PFA along the height of the building reduces with increasing period of vibration as well as with increasing inelasticity of the supporting structure [8,9,11,12]. The floor response spectra (FRS) show peaks corresponding to the different modes of vibration [1–6,9,12,18]. These peaks reduce with increasing inelasticity of the supporting structure [1,12,13]. It has also been shown that the floor spectra are amplified ground-motion spectra [9,10,12] and the spectral amplification factors (defined as the ratio of the spectral ordinate at a given floor level to the spectral ordinate at ground level) corresponding to the different modes of vibration follow the respective elastic mode shapes along the height of the supporting structure [12,21,25]. This observation was reasonably valid even in case of inelastically responding supporting structures [12].

Infills are generally treated as NSC and therefore generally ignored in the seismic design of buildings. It is well accepted that the presence of infills completely alters the dynamic behaviour of the buildings, as they interact with the adjoining frame especially in the in-plane direction. On the other hand, for out-of-plane action, the infills themselves are considered as decoupled secondary systems subjected to the floor response as the input motion. Therefore, the estimation of floor response of URM infilled RC frame buildings is not only crucial for the safety of NSCs, but also for ensuring the safety of URM infills in out-of-plane action.

Contrary to RC bare frame buildings, very limited studies [18,28,29] have been conducted so far focusing on the effect of presence of Unreinforced Masonry (URM) infill walls on the floor acceleration demands. It was shown that the modelling of infills (even if weak and distributed uniformly along the height) can significantly affect both PFA and FRS [18]. Perrone and Filiatrault [28] highlighted

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the inability of the current models available in literature to predict the FRS of RC frame buildings with masonry infills subjected to frequent earthquakes. Blasi et al. [29] showed that the variation of the elastic modulus of the infill panels can significantly influence the dynamic response of the structures, and hence can modify the distribution of the PFA along the height of the supporting structure.

In general, buildings are designed to respond with different degrees of inelasticity under earthquakes of different intensities. Therefore, the floor response can be estimated accurately only by considering the effect of inelasticity of the building, especially in the framework of performance-based design, in which the buildings are designed for different levels of ductility demand. However, current seismic design codes [30–32] do not consider the effect of inelasticity of the supporting structure and the level of shaking imparted to the NSCs. Therefore, the present study attempts to include the effects of inelasticity of the supporting structure on the floor response of RC frame structures, both uniformly infilled (UI) with URM walls and with open ground storeys (OGS; also known as "pilotis frames" and "buildings on stilts"). Buildings of the latter structural typology, although not considered to be desirable for good seismic performance, are prevalent in India and many other parts of the world [33–36]. For the present study, a total of 1232 nonlinear dynamic analyses are conducted using a suite of 22 far-field ground-motion records that are applied on four different building models (i.e. two uniformly infilled models and two models with open ground storeys) having different dynamic characteristics in the two orthogonal directions. Further, to study the effect of inelastic behaviour of the supporting structure on floor response, seven different levels of inelasticity (ductility demands) are considered. The spectral amplification functions, which were developed for RC bare frame buildings in an earlier study [12], are modified to predict the floor acceleration demands for NSCs mounted on UI and OGS buildings. The developed spectral amplification functions take into account the ground-motion characteristics (acceleration response spectrum of the free-field ground-motion), dynamic characteristics (periods and mode shapes) and level of inelasticity of the supporting structure, as well as the frequency tuning between the NSC and the supporting structure. The developed spectral amplification functions are validated through nonlinear time-history analyses using both recorded and spectrum-compatible time histories.

2. Numerical study

For the present study, RC frame buildings with plan shape and elevations as shown in Fig. 1 are considered. The building plan was chosen from earlier studies [11,12] based on a field survey to consider the variety of characteristics (e.g. typical storey height, bay width) of the building stock in the National Capital Region (NCR) of India [37]. The heights of these buildings are considered as 4 and 8 storeys, representing two examples of the mid-rise building stock typical for the NCR of India. The storey height is taken as 3.3 m, consistent with the field observations. The thickness of URM infill walls is considered as 230 mm and 110 mm for exterior and interior walls, respectively. The compressive strength of infill walls masonry is assumed to be 4.1 MPa considering the fair quality of masonry, also consistent with typical average compressive strength values for solid clay brick masonry in Northern India [38,39]. A total of four building models are investigated with two different heights (i.e. 4 and 8 storeys) and two different configurations consisting of UI and OGS buildings.

The buildings are modelled in the building analysis and design software ETABS [40,41]. Beams and columns are defined using 3D frame elements and slabs are considered as rigid diaphragms. The cracked section properties of beams and columns are derived following ASCE 41 [42]. Dead and live loads on the buildings are assigned according to IS 875 Part 1 [43] and IS 875 Part 2 [44], respectively. In order to model the URM infill walls, the eccentric strut model of ASCE 41 [45] with some modifications as per Burton and Deierlein [46] is used. The initial (uncracked) stiffness of the masonry infill wall is considered as twice of the stiffness obtained from the equivalent strut width model of ASCE 41, as recommended by Burton and Deierlein [46] based on experimental investigations on URM infill walls. All the buildings are designed as Special Moment Resisting Frames (SMRF), following the most recent Indian Standards IS 1893 [47] and IS 13920 [48].

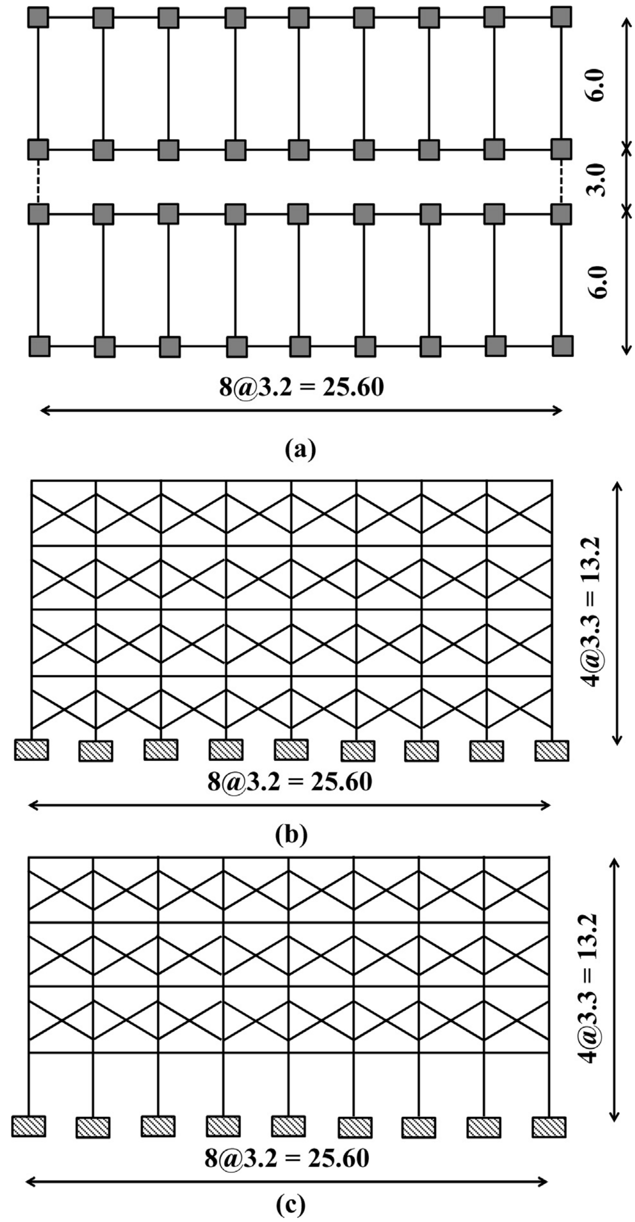

Fig. 1. (a) Generic plan; (b) schematic elevation in longitudinal direction, for a 4 storey UI RC frame building; and (c) schematic elevation in longitudinal direction, for a 4 storey OGS RC frame building. Elevations in the transverse direction are not shown here for brevity. (The dashed lines in the floor plan represent the floor slab boundaries, which are assumed to be rigid in plane. The inclined lines in elevations represent the infills. All dimensions are in meter.)

The buildings are designed for seismic actions corresponding to Indian seismic zone IV (Effective Peak Ground Acceleration = 0.24 g), and assumed to be situated on soil type I (hard soil/rock). The design response spectrum corresponding to Maximum Considered Earthquake (MCE) hazard as per the Indian Standard IS 1893 [47] is shown in Fig. 2. All the considered building models are designed conforming to the strong-column weak-beam (SCWB) design criteria with a SCWB ratio of 1.40 [48]. P-delta effects are also considered both in the