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COMPARATIVE NON-STRUCTURAL VULNERABILITY ASSESSMENT METHODS FOR HISTORICAL RESIDENTIAL MASONRY BUILDINGS

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Abstract

The determination of seismic risk is the foundation for risk mitigation decision-making, is a key step in risk management. Large corporations and other enterprises (e.g., local governments) analyze their 'portfolio' of properties, to determine how to best allocate limited funds for structural strengthening of buildings, or other risk reduction measures such as emergency planning. When assessing the seismic vulnerability of buildings, it is essential to first establish the project objectives, before subsequently choosing the most appropriate strategy and tools necessary for building assessment and fulfillment of these objectives. It is also extremely important to understand the difference between the detailed approaches used for individual building assessment and those methods most efficient for larger-scale analysis, pursued for city center assessment. While the latter results can be used as a general measure of seismic risk for different types of buildings, the actual seismic risk for any individual building may vary considerably and will depend upon its exact configuration and condition. In this study, some historical masonry buildings located in Alsace France, are considered and the dynamic characteristics of these structures were estimated by the analysis of seismic noise recordings by sensors installed at each floor of the buildings under study. The estimated dynamic properties for small-amplitude vibrations of these historical structures were used to derive fragility curves through vulnerability models with different complexity and accuracy levels. These fragility curves have been calculated using incremental dynamic analysis for the seismic demands generally imposed upon linear and slightly nonlinear models of single and multiple degrees of freedom, which is the case for the effects of induced seismicity. Considering the latter case of induced seismicity, the vulnerability assessment requires the expected damage to refer to non-structural components. The conclusions through comparison of the results of this study in terms of refinement of the verified structural models will prove useful for both local end-users and industrial stakeholders, with a clear perspective for a better understanding of the risk related to induced and triggered seismicity and its sound management.

Keywords: Instructions, ECCOMAS Thematic Conference, Structural Dynamics, Earthquake Engineering, Proceedings.

1 INTRODUCTION

The determination of seismic risk is the foundation for risk mitigation decision-making, a key step in risk management. Large corporations and other enterprises (e.g., local governments) analyze their 'portfolio' of properties to best allocate limited funds for structural strengthening of buildings or other risk reduction measures such as emergency planning. When assessing the seismic vulnerability of buildings, it is essential to first establish the project objectives before choosing the most appropriate strategy and tools necessary for building the assessment and fulfilment of these objectives. It is also extremely important to understand the difference between the detailed approaches used for individual building assessment and those methods most efficient for larger-scale analysis, pursued for city center assessment. While the latter results can be used as a general measure of seismic risk for different types of buildings, the actual seismic risk for any individual building may vary considerably and will depend upon its exact configuration and condition.

In this study, some historical masonry buildings located in Alsace France are considered, and the dynamic characteristics of these structures were estimated by the analysis of seismic noise recordings by sensors installed at each floor of the buildings under study [1].

In the considered test site, the analysis of the collected exposure information indicates that traditional or historical masonry structures occur in large numbers near in the mostly rural areas close to the geothermal platforms in Alsace region in France [2]. Two general classes of structures, namely unreinforced masonry (URM) and timber-framed masonry (TFM) buildings, have been considered, and the simple performance assessment models ([3], [4]) have been adopted in order to carry out a preliminary vulnerability assessment for these classes of structures. The objective is to rapidly identify buildings and their non-structural components that are at greater risk in the event of an induced earthquake, and to model their non-structural fragility.

The vulnerability modelling focused on buildings constructed of masonry, which may be more susceptible to the range of ground motion expected in the event of induced seismicity in the area. The measurements have been carried out using the MPwise (Multi-Parameter Wireless Sensing System) smart device [5], which has been designed to carry out rapid measurement activities by exploiting the computing and advanced networking capacities embedded in individual units. Based on environmental, seismic noise measurements, the fundamental frequency of vibration of the inspected buildings has been estimated and used to calibrate the respective fragility curves.

In collaboration with GFZ and ES-Géothermie a three-day acquisition campaign was organized, which involved installing four sets of sensors in private houses located in villages located around the Soultz and Rittershoffen geothermal sites. The fundamental period of these structures was verified by analyzing the ambient noise measured using the MPwise sensors [5], with one sensor installed outside of the buildings, and the three others installed on each floor of the houses (basement, ground floor and first floor). The sensors were installed to record the ambient noise and to draw a vulnerability mode that allows the issuing of damage forecasts (Table 1, [1]). Finally, the main geometry required as input for the simplified vulnerability models was taken through field inspection of these buildings.

No	Building Type	Building Latitude	Building Longitude	Fundamental ESDOF Model Period (s)	Fundamental Frequency Sensor (Hz)
1	URM	48.964946	7.881095	0.17	5.5
2	URM	48.902075	7.874917	0.37	2.7
3	URM	48.905270	7.950266	0.11	9
4	TFM	48.914307	7.882233	0.15	6.7
5	URM	48.932865	7.874377	0.32	3.1

Table 1: Real URM and TFM buildings located near the geothermal platforms in Alsace region in France [1].

2 INCREMENTAL DYNAMIC ANALYSIS OF EQUIVALENT SINGLE DEGREE OF FREEDOM SYSTEM

The estimated dynamic properties for small-amplitude vibrations of these historical structures were used to derive simplified vulnerability models. While steel or concrete frames are mostly lumped systems with stiff diaphragms, URM buildings have distributed mass and stiffness commonly in combination with flexible diaphragms. This fact obstructs the adoption of the established methodologies to URM buildings. Specifically, the latter buildings' fundamental mode shape involves a low percentage of the total mass of the building below the 75% limit required for the good performance of ESDOF-based methods. In order to solve this issue, the simplified procedure of Vamvatsikos et al. (2015) [6] was adopted. In their procedure, the dynamic URM building response is represented. Global response indices are transformed to local deformation measures in closed-form seismic assessment solution both for demand and supply in the critical structural locations. The solution involves the definition of the fundamental vibration mode, approximated by 3D shape function consistent with the building's boundary conditions. Strength and deformation indices are adopted for the evaluation of the acceptance criteria. Typical local failures are estimated through a local shape of deformation while the model captures the global dynamic characteristics. The adopted method allows the automation of the necessary calculations through closed-form expressions.

In the case of TFM the walls are reinforced with timber elements, both horizontal and vertical, but also X-type diagonal braces. It is evident historically, since the Bronze Age that the timber reinforcement into masonry walls is strongly related to seismic resistance in earthquake-prone areas. In TFM walls, there is also recent experimental and numerical evidence [7] that the diagonal braces' contribution is vital for walls' lateral behaviour in the nonlinear range due to early detachment of the masonry infill from the surrounding timber frame in the event of an earthquake. It is also observed that the diagonals in tension detach from the surrounding frame for very low horizontal displacement. Therefore, it is suggested [7] that the diagonals should contribute to the lateral behaviour only in compression and moreover, the infill masonry walls of the timber frame should not be considered in the analytical model. Based on these considerations, a macro-model was proposed ([7], [8]) where its input can be easily determined since it involves only the key geometric characteristics of the timber panels and the timber strength. The latter model facilitates the seismic assessment of TFM walls resulting in a valuable tool for simplified seismic vulnerability and risk analyses [9]. Based on the resulting pushover curves produced by pushover analysis [10] of the TFM walls' macro-model, a shape-function is defined for the derivation of the ESDOF properties which is similar to the methodology already described for URM buildings [6].

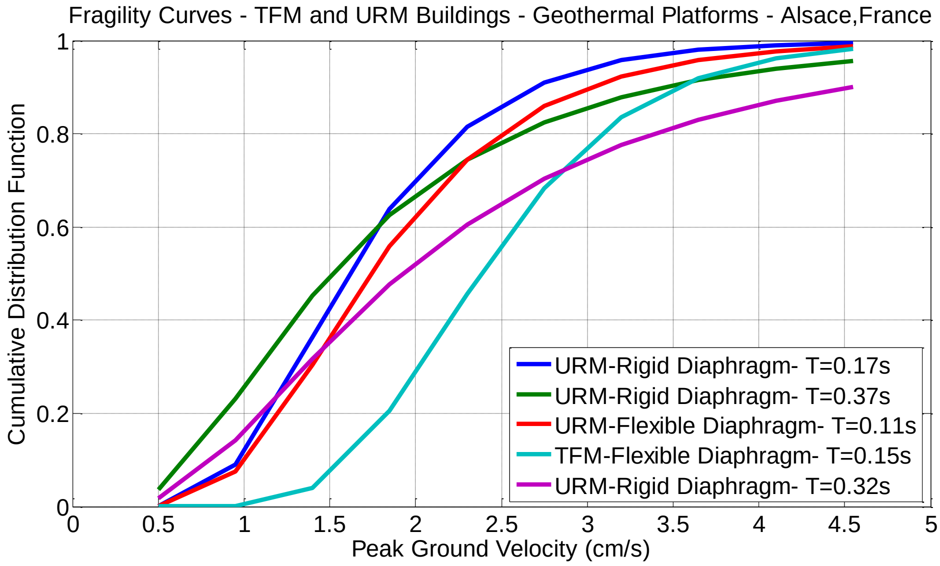

Figure 1: Proposed analytical fragility curves for first damage state (pre-yielding damage state –DS1-0.1% drift limit for non-structural damage) for Unreinforced Masonry Buildings (URM) and Timber-Framed Masonry Buildings (TFM). The buildings are located near the geothermal platforms in Alsace France and are loaded in the weak/short plan view direction of shaking. The fundamental period of these structures was verified with ambient noise measurements through applied sensors [1].

Considering these real TFM and URM building cases in Alsace France (Table 1) the corresponding fragility curves are derived in terms of Peak Ground Acceleration (PGA) with the aid of structural analysis for a gradually increasing intensity (incremental dynamic analysis - IDA) [11]. The latter analysis of ESDOF of the building cases under study was performed with the MATLAB [12] toolbox FEDEAS Lab [13]. The PGA values of the recordings used in the IDA analysis with the corresponding PGV values follow the rule that for very flexible structures (very high fundamental periods), the relative velocity response spectrum of the used record tends to the peak ground velocity (PGV). The induced ground motions obtained from the PEER database were employed and applied in the transverse/short/weak building plan direction ([14]). As already mentioned, the fundamental periods of these structures were verified with ambient noise vibration measurements using sensors [5] located at each floor of the buildings under study (Table 1). Moreover, the main geometry required as input for the simplified vulnerability models was taken through field inspection of these buildings. The results are shown in Fig. 1. It can be seen that the fragilities for URM buildings have more or less the same range of probability of damage while the more earthquake-resistant TFM building is less fragile for low and medium intensities.

3 INCREMENTAL DYNAMIC ANALYSIS OF THREE-DIMENSIONAL MODEL

The above fragility curves (Fig.1) have been calculated using incremental dynamic analysis for the seismic demands generally imposed upon linear and slightly nonlinear models of single and multiple degrees of freedom, which is the case for the effects of induced seismicity. If considering the latter case of induced seismicity, the vulnerability assessment requires the expected damage to refer to non-structural components. In this section, a comparison is provided of the results of this study in terms of refinement of the verified structural model for the No.1 building in Table 1 that will prove helpful for both local end-users and industrial stakeholders, with a clear perspective for a better understanding of the risk related to induced and triggered seismicity and its sound management.

3.1 Structural modelling process

In this work, the production of analytical fragility curves for URM buildings is demonstrated on a box-shaped unreinforced masonry structure, presented in Figure 2. Namely, this building comprises the town hall of Keffenach (URM building No.1 of Table 1) in the Alsace region. As can be observed from Figure 2, the building has two storeys and one basement, which serves as parking. In the same Figure, the respective views of the structural model are presented.

The structural model was designed using thick-shell elements for modelling the walls, thin-shell elements for the concrete floor slab, while straight rectangular frames were used for roof members. As regards material properties and the structure's dimensions, they can be found in the previous work of (Megalooikonomou, 2020) [3], where ESDOF analysis was performed. The ESDOF model of the URM building did not include an analytical roof model but only its height. However, it was found that the roof's bearing structure affected the period of the eigenmodes. Thus, for the analytical Multiple Degrees Of Freedom (MDOF) model (Fig. 2), the roof was designed to resemble the actual building and obtain the fundamental period corresponding to 0.17 s (Table 1) obtained from the installed sensors.

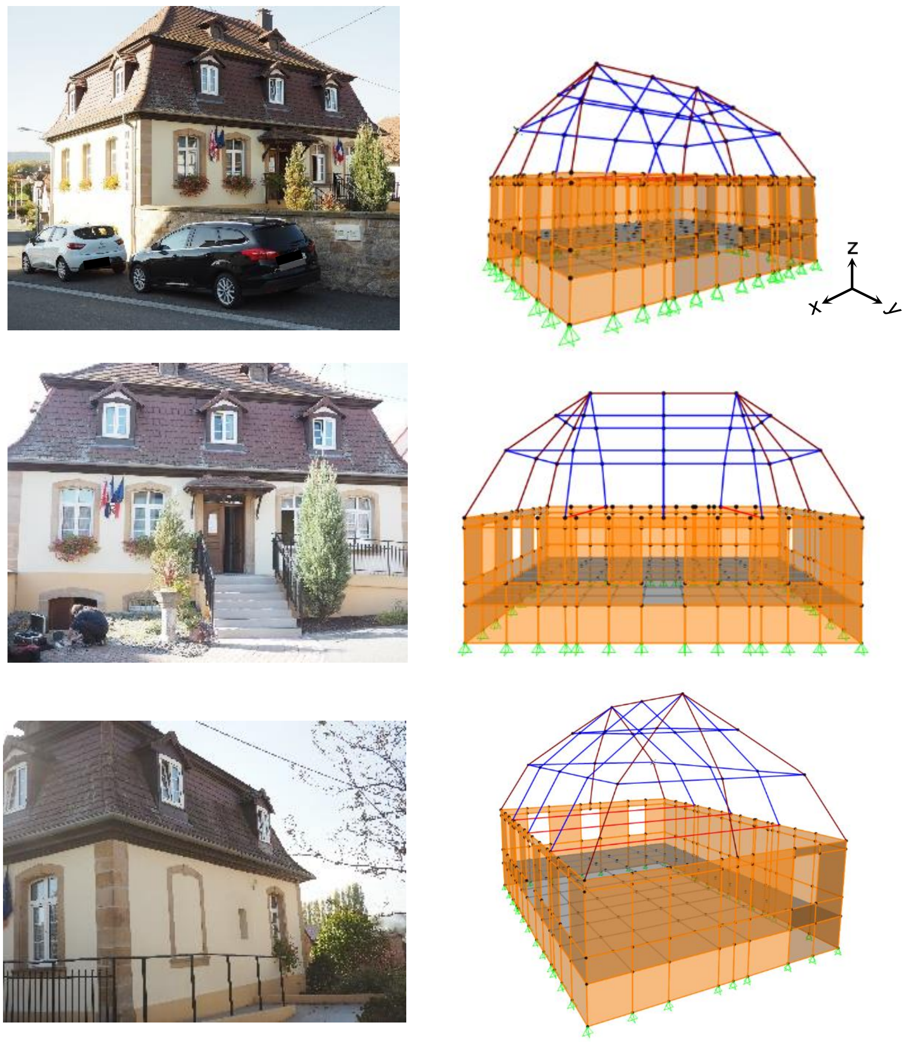

Figure 2: URM building's actual views and the generated model's respective views

3.2 Time history analysis

Producing the analytical fragility curves of the MDOF model requires a number of actual ground motion recordings, which after scaling, are used in time history analysis. In this work, ground motion data of 20 earthquakes were used; more information can be found in Megalooikonomou et al. (2018) [1]. The ground motion data was incrementally scaled based on their Peak Ground Acceleration (PGA) to obtain different levels of gravity acceleration. Ten levels of gravity acceleration were used for scaling that ranged from 0.1g (9.81 m/s^2) to 1g (with increments of 0.1g). As regards the application of the scaled ground motions, 100% of the force was applied in the primary direction (y of Figure 2), while 30% of the earthquake load was applied on the secondary (direction x Figure 2).

After performing all 200 (20 earthquakes x 10 scaled ground motion data) time history analysis, the earthquake that produced the largest displacements was selected. This earthquake was recorded at the Luther Middle School station in 2011, had a magnitude of 5.68 at an epicentre distance of 54km, and generated a peak ground motion of 2.70E-02 g. Figure 3 (a) depicts the scaled ground motion of the earthquake rendering the largest displacements. Moreover, the same Figure presents the time-dependent displacements for the node where the maximum displacement was observed for the primary direction of application (Figure 4 b) and the secondary direction of application (Figure 4 c) .

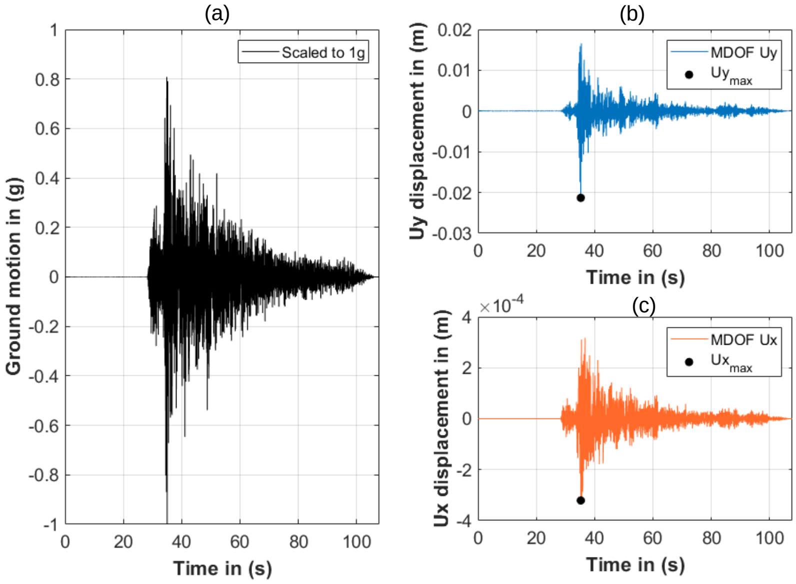

Figure 3: (a) Ground motion of earthquake producing maximum displacements; (b) node displacement for main direction (y of Figure 2) and (c) node displacement for secondary direction (x of Figure 2).

3.3 Analysis results

The results of the time history analysis of the 20 earthquakes and the considered scale factors for the MDOF and ESDOF models were used to fit log-normal distributions for each model. Figure 4 (a) presents the frequency of the maximum drift's natural logarithm for the MDOF and ESDOF and the fitted normal distribution probability density functions. The fits were used to estimate the fragility curves for the different Peak Ground Velocity levels depicted in Figure 4 (b).

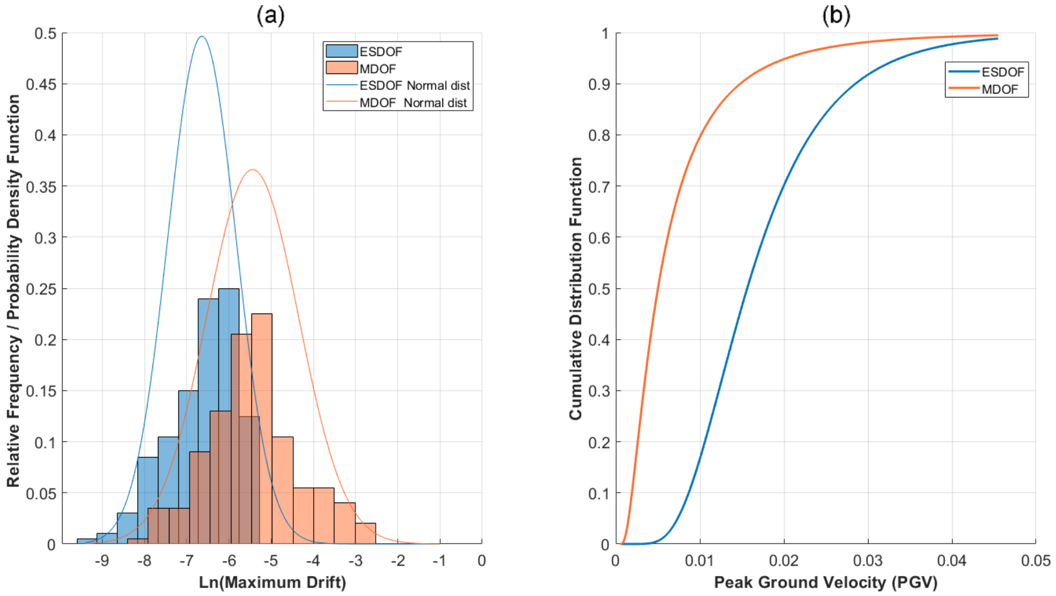

Figure 4: Analysis results for ESDOF and MDOF: (a) Relative frequency and probability density function of the natural logarithm of the maximum drift at height 3.81m and (b) Fragility curves.

4 CONCLUSIONS

- Papers should be submitted online.
- Papers should be written following the format of the Word macros for submission that can be found at the conference website.
- Papers must be translated to Portable Document Format (PDF) before submission through the Conference website.
- Deadline for the submission of papers posted at the website must be respected.
- The organizers do not commit themselves to include in the Proceedings any paper received later than the above-mentioned deadline.
- At least one of the authors should register and pay his/her registration fee before the full-length paper submission deadline for their paper to be included in the final program of the Conference.

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