A Prioritization Scheme for Seismic Intervention in School Buildings. The case of Thessaloniki, Greece

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ABSTRACT
Seismic risk assessment of critical buildings stock, like the school buildings, pdrovides the authorities and the community with the necessary information for decision- making regarding the mitigation of the adverse effects of a catastrophic earthquake on the built environment and the population. Especially in the case of school buildings, the requirements for a reliable seismic vulnerability and risk assessment are particularly high. Seismic risk assessment involves many uncertainties, as it depends on several steps, starting from the identification of the exposure of the elements at risk (school buildings, student population, employees etc.), the evaluation of site-specific seismic hazard, concluding to the calculation of the expected damages and losses for each seismic scenario. As a general remark, most of the existing methodologies allowing the assessment of seismic risk cannot be easily applied, as they require highly specialized users together with a significant amount of data not always available or accessible. Therefore, there is a need to develop an integrated and relatively simple easy-to-use methodology, which should be specially adapted to school buildings. To this end, the present work outlines the essentials of a unified methodology for assessing the vulnerability and seismic risk of schools, adapted to the Greek data, which will be suitable for use by both non-specialized and experienced users. The proposed approach is suitable for the development of a realistic mitigation and prioritization scheme of retrofitting and structural strengthening actions for the different school building typologies.

Keywords: natural hazards, vulnerability assessment, risk, hazard, exposure model

1. INTRODUCTION
School buildings, which house a vulnerable population, are often hit by catastrophic earthquakes and the losses in many cases are significant. Protecting school buildings from earthquakes should be a priority in all countries. In the last decades, thousands of students lost their lives when the buildings of the school units in which they attended collapsed (e.g. Armenia earthquake in 1988, Venezuela earthquake in 1997, China earthquake in 2008). In Greece, despite the low damage and fatality rate related the seismic response of the school building stock, it is necessary to develop a coherent approach to evaluate the seismic vulnerability of the schools using state-of-the-art techniques. The seismic vulnerability of a school depends on many factors such as construction year, construction characteristics and details including materials and the quality of construction, geometry of the building, the connections of the structural elements, foundation system, quality of maintenance etc. Significant subsequent modifications (e.g. addition of floors), as well as any past damages or material degradation with time, for example due to corrosion and aging effects, can increase the seismic vulnerability of school buildings. Most schools in large cities such as Athens and Thessaloniki were built in between 1960s and 1980s with no/low code seismic regulations and therefore with low safety factors. Thus, even a moderate earthquake can cause significant losses in the school building stock. Consequently, hierarchical identification of the most vulnerable schools in order to proceed to their retrofitting and strengthening is certainly an urgent priority. To this end, the present work proposes a prioritization scheme for seismic intervention in school buildings in Greece, which is based on a seismic risk assessment methodology of school buildings using the open-source earthquake

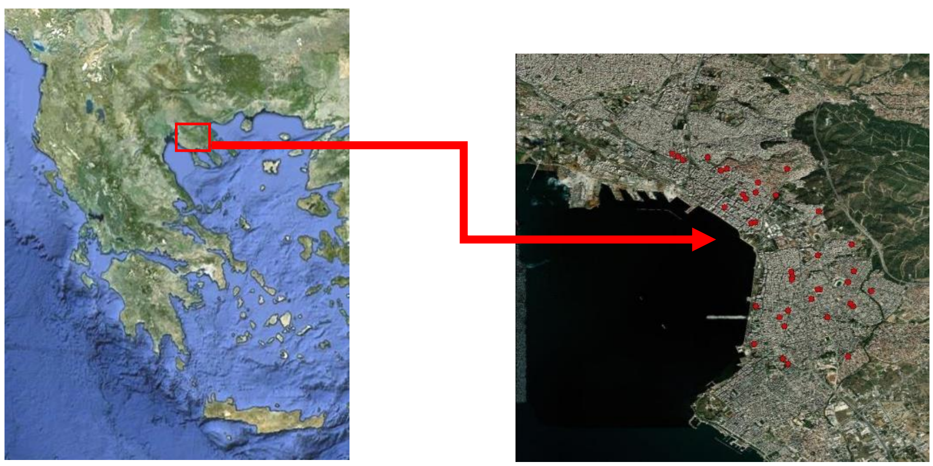
hazard and risk software OpenQuake Engine (Pagani et al., 2014). The methodology is applied in the schools of Thessaloniki municipality.

2. DESCRIPTION OF THE METHODOLOGY AND APPLICATION IN THE SCHOOLS OF THESSALONIKI MUNICIPALITY, GREECE

The proposed methodology for the prioritization for seismic intervention in school buildings in large scale (here in city scale), consists of the following steps:

Step 1: Mapping and classification of the school buildings.

The primary step of the methodological chain is to develop an appropriate exposure model of the school buildings at risk. For this purpose, one can may use the general inventory of buildings of ELSTAT, which include for all buildings in Greece detailed data concerning the construction material, the number of floors, existence of pilotis, construction period etc. These data openly available are used to classify the schools, using adequate taxonomy scheme, in appropriate typologies based on their geometric and dynamic characteristics. Figure 1b shows the location of the 62 studied school building (132 structural independent components). Their classification according to the GEM Building Taxonomy (Brzev et al., 2013) is shown in Figure 2.



(a) (b)

Figure 1. (a) Study area on the map of Greece, (b) Mapping of the studied school buildings (in red)

Step 2: Seismic hazard model.

For the application at the school buildings of Thessaloniki municipality we performed an Event-Based Probabilistic Seismic Hazard Analysis in OpenQuake, using the ESHM13 seismic hazard logic tree (Woessner et al., 2015). Figure 3 shows the resulting spatial distribution of peak ground acceleration PGA across the city of Thessaloniki for a mean return period of 475 years using the $V_{s,30}$ model from the microzonation study of Thessaloniki (Anastasiadis et al., 2001).

Step 3: Assessment of seismic damages

The first step of the risk assessment, i.e. estimation of losses, consist of the selection of appropriate fragility curves according to the building typologies defined in Step 1. For that we adopted herein the fragility model proposed by Martins and Silva (2020). Then, combining the results of the exposure (step 1), the hazard (step 2) and the selected fragility models (step 3), we estimated the expected seismic damages to the school buildings (Figure 4a) for a return period of 475 years. According to this analysis, the main conclusion is that on average the school buildings in the municipality of Thessaloniki will exhibit slight damages independently of their typology. The higher damages are estimated, as expected, for the masonry buildings (MUR+CL99).

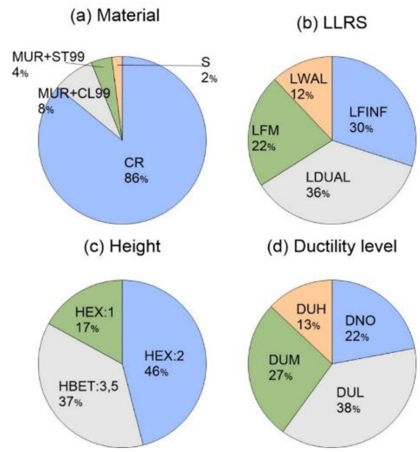


Figure 2. Classification of the studied school buildings based on (a) Material, (b) Lateral Load-Resisting System (LLRS), (c) Height and (d) Ductility level according to the GEM Building Taxonomy (Brzev et al., 2013). (CR: CONCRETE, MUR+CL99: CLAY BRICK UNREINFORCED MASONRY; LFINF – INFILLED FRAME, LDUAL – DUAL FRAME-WALL, LFM– MOMENT FRAME, LWAL– WALL; DUH – HIGH DUCTILITY, DUM – MEDIUM DUCTILITY, DUL – LOW DUCTILITY, DNO– NO DUCTILITY; HEX:1– ONE-STOREY BUILDING, HEX:2 – TWO STOREY BUILDING, HBET:3,5 – THREE TO FIVE-STOREY BUILDING)

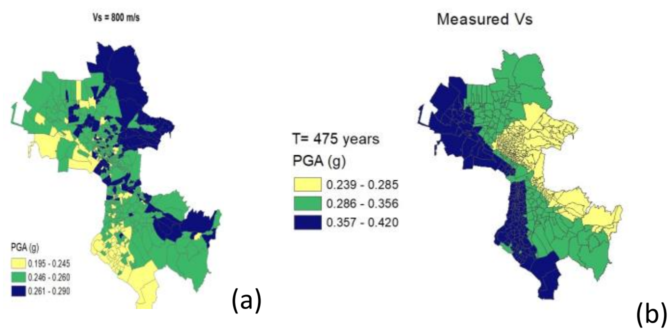


Figure 3. Spatial distribution of peak ground acceleration PGA in the city of Thessaloniki for a mean return period equal to 475 years a) for rock site conditions, considering $V_{s,30}$=800 m/s and (b) using the $V_{s,30}$ model from the microzonation study of Thessaloniki (Anastasiadis et al., 2001).

In order to evaluate the reliability and usefulness of this proposed approach it has been decided to compare the results with a more simplified methodology applying a rapid visual screening (RVS) procedure quite familiar to engineers for a first order vulnerability assessment. For that, we adopted herein the method proposed by FEMAR-154 (2015), which is also adopted by the Organization for Earthquake Planning and Protection (OASP) in Greece. A relevant tool for this purpose has been developed recently in the framework of an ongoing project entitled SAFESCHOOLS (https://sites.google.com/view/safeschools-project). The RVS procedures use a methodology based on a Data Collection Form, completed on site by the person conducting the survey; it is based on visual screening of the building. Based on the data collected during the survey, a score is calculated that provides an indication of the expected seismic vulnerability of the building irrespectively the seismic hazard. In this study, in order to see the differences of the two procedures in terms of the estimated vulnerability, we applied the RVS procedure proposed in 2014 by the Ministry of Environment (FEK 405/B'/20-2-2014, §40), which classifies the school buildings in three categories, i.e. red, yellow and green for the high, medium and low prioritization for seismic intervention, respectively (Figure 4b).

The main conclusion of the comparison is that the simple RVS procedure (visual screening), which is certainly associated with important uncertainties, results in higher vulnerability and hence damages' estimations for almost all school building typologies, compared to the herein proposed methodology. Consequently, any mitigation strategy based on the results of RSV might give a misleading picture of the actual needs for retrofitting.

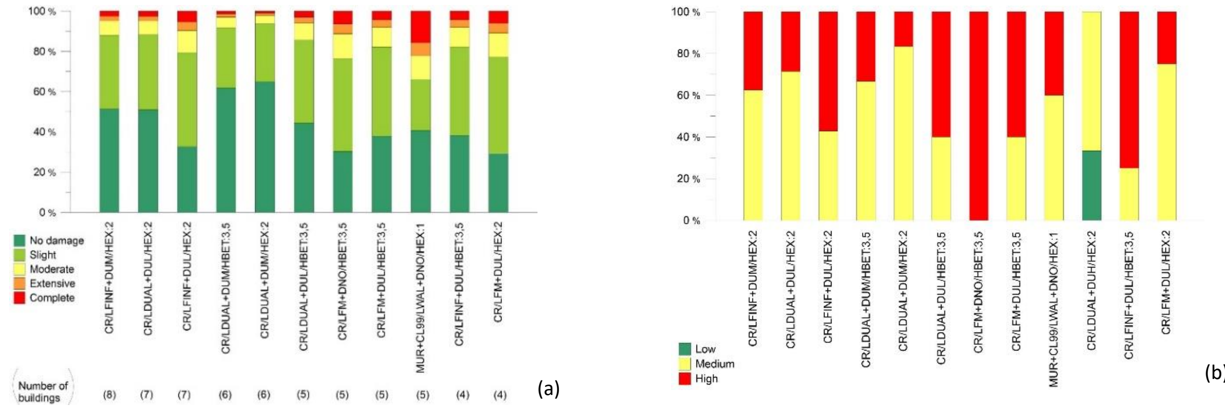


Figure 4. (a) Summary of the estimated level of damages (low, medium, high) according to the different school building typologies. (b) Application of the RVS procedure to the 62 school buildings in Thessaloniki municipality and classification of their vulnerability level. (CR: CONCRETE, MUR+CL99: CLAY BRICK UNREINFORCED MASONRY; LFINF – INFILLED FRAME, LDUAL – DUAL FRAME-WALL, LFM– MOMENT FRAME, LWAL– WALL; DUH – HIGH DUCTILITY, DUM – MEDIUM DUCTILITY, DUL – LOW DUCTILITY, DNO– NO DUCTILITY; HEX:1– ONE-STOREY BUILDING, HEX:2 – TWO STOREY BUILDING, HBET:3,5 – THREE TO FIVE-STOREY BUILDING)

3. CONCLUSIONS

We present a methodology for the assessment of seismic vulnerability of school buildings which might lead to a more accurate and realistic prioritization scheme and strategy for retrofitting and strengthening needs. The methodology is applied to 64 school buildings located in the municipality of Thessaloniki. For the seismic hazard we perform an event- based seismic hazard analysis. For the vulnerability model, we apply the fragility curves by Martins and Silva (2020). Estimated damages are compared to the resulting vulnerability from a RVS procedure for the same school buildings. The herein proposed methodology proved to give more realistic results in order to make a prioritization strategy for strengthening and retrofitting actions for school buildings.

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