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SEISMIC HAZARD ASSESSMENT OF SCHOOL BUILDINGS IN PENINSULAR MALAYSIA

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Abstract

Peninsular Malaysia is located on the southern edge of the Eurasian Plate. However, it is close to a seismically active plate boundary, the interplate boundary between the Indo-Australian and Eurasian Plates. Occasionally, tremors can be felt throughout the region even when active faults are located several hundred kilometers away. Lessons learnt from past events, active earthquakes located far from the existing building can cause potential damage. Thus, fragility curves become an essential tool to estimate probability of building damage caused by seismic ground motions. In this study, the response of low-rise and mid-rise RC school buildings located in various soil conditions within Peninsular Malaysia under earthquake excitation was investigated by performing dynamic response spectrum analysis. These buildings were analysed using DIANA 9.3 structural analysis program and subjected to a range of low to high seismic ground motions to determine the performance damage state of each type of building. All structural elements were modeled using solid brick finite-element. Correspondingly, the fragility curves were developed using the log-normal distribution for structural response. The effects of various soil conditions on the response of the buildings were also investigated. The results indicated that the effect of soil parameters had a significant effect on the outcome of the fragility curves. However, the risk of these existing school buildings at a location in the northern part of Peninsular Malaysia showed the highest probability of exceeding each damage state. On the contrary, the risk of the existing school buildings at a location in the central part of Peninsular Malaysia was the lowest.

Keywords: *Interaction, fragility curves, soil-structure*

1 Introduction

Peninsular Malaysia is located in a low seismicity region of Southeast Asia, where seismic sources are located more than 700 km away (Azlan et al, 2001). Consequently, tremors can be felt in most western parts of Peninsular Malaysia due to seismically active plate boundaries. Although earthquakes have never caused any catastrophic structural failures, cracking have been observed on several buildings in Kuala Lumpur as a result of the 8.7 Mw earthquakes near Bengkulu on 12th and 13th of September 2007. These incidents were reported in local newspaper. In order to be prepared for such natural disasters, it becomes essential to reasonably estimate, predict and mitigate the risk associated with distant earthquakes.

Recently, fragility curves have become an essential tool to estimate probability of building damage caused by seismic ground motions. These curves can be classified into four groups, namely empirical, judgmental, analytical and hybrid. The classification depends on the damage data used in their generation which are derived mainly from observed post-earthquake survey, expert opinion, analytical simulation or combination of these, respectively (Kwon and Rossetto, 2006). According to the Malaysian Meteorological Department only limited numbers of strong motions have been recorded. Therefore, the curves are derived based on an-

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alytical simulation. Postearthquake survey are not appropriate for this study because the damage data from post earthquake is only limited to the Andaman Tsunami, 2004. In addition, these curves are extremely useful in vulnerability assessment, postearthquake evaluation and retrofit prioritization from potential earthquakes (Jeong and Elnashai, 2007). These curves are also important in preventing loss of life, occupancy and economy that many occur as a result of future earthquakes.

The scope of this study is to carry out seismic risk assessment for typical two and four storey RC school buildings subjected to long distance earthquakes. A case study of a typical structural configuration and mechanical characteristics is presented. The influence of the number of stories in the building and typical soil conditions on the fragility curves is then investigated. In the last part of this study, the fragility curves are verified through comparison of analysis results with those derived in HAZUS 99 technical manual.

The objectives of this study are to:

1. develop analytical seismic fragility curves for two and four storey RC school buildings,
2. study the impacts of the number of stories in the building and soil conditions on the fragility curves, and
3. compare the analysis results with those derived in HAZUS technical manual.

2 Methodology

Fragility curves express the probability of reaching or exceeding a damage state at a specified ground motion level. The conditional probabilities are shown in Eq. 1 (Singhal and Kiremidjian, 1996).

$$P_{ik} = P\left[D \geq d_i \mid Y = y_k\right] \tag{1}$$

where P_{ik} = Probability of reaching or exceeding damage state d i given that ground motion is y_k, D = Damage random variable defined on damage state vector $D = \{d_0, d_1, \ldots, d_n\}$, Y = Ground motion random variable.

Several analytical methods have been proposed to estimate building responses subjected to earthquake loading. For example static pushover analysis, incremental dynamic analysis, yields the capacity and collapse mechanism (Borzi et al, 2008; Rossetto and Elnashai, 2005); Vamvatsikos and Cornell, 2002). However, there are two approaches for developing the fragility curves either based on the assumption that the structural response follows the log-normal distribution or using reliability analysis method for calculating the probability of exceeding the damage state for a variety of seismic intensity levels (Ellingwood, 2001; Lagaros et al, 2009). In the present study, the fragility curves are developed from the seismic response data obtained from an elastic spectral analysis following the log-normal distribution. Full scale three dimensional finite element models were established using DIANA version 9.3 Structural Analysis Program.

2.1 Modelling of structural elements

In the present study, the finite element models are established using solid elements and have been implemented using DIANA 9.3. These models consist of both solid and bar elements representing the concrete and reinforcement respectively. In these models, all elements such as beam, column, pile caps, friction piles and soil mass are modeled using 8-node brick element. The distributions of reinforcement bars within the sections are embedded completely inside a structural element. Moreover, the connectivity of the elements is formed between faces of three dimensional elements as presented in Figure 1. With respect to the shape and connectivity, these elements can be used directly in structural analysis.

2.2 Modelling of soil-structure interaction

Several models have been proposed to model the soil-structure interaction (Lee et al, 1995 and Santu et al, 1995). In the present study, the finite element modelling of soils is the same for structural elements but joint elements are proposed in that particular context to model the soil-structure interaction as presented in Fig-

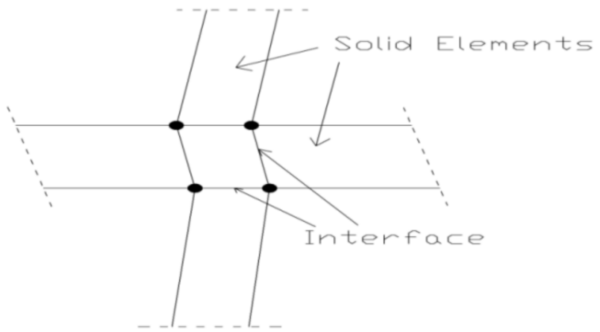

Figure 1: Modeling of structural elements: beams, columns, concrete foundations, floors and soil mass

ure 2. In this situation, the behavior of soil-structure interaction is defined independently and this situation allows relative movement of the structure with respect to the soil.

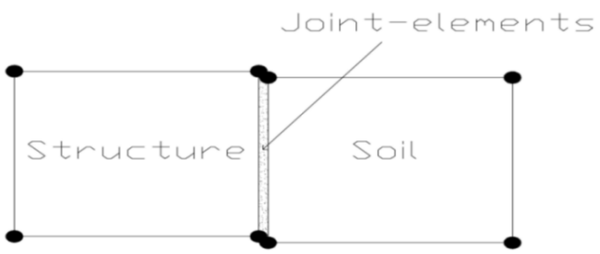

Figure 2: Soil structure system

2.3 Modeling of base excitation

A base excitation is proposed at the base of the structure with a horizontal acceleration equals to 1m/s^2. Therefore, the frequencies and the corresponding load amplification factor are assigned to the base excitation load for various earthquake spectral acceleration diagrams as presented in Figure 3.

2.4 Limit states

The building response is measured in terms of the maximum interstory drift angle (Song and Ellingwood, 1999). This measurement is consistent with FEMA 356. Thus, damage states (DS) defined in FEMA 356 are used since this study focuses on the generation of fragility curves for two and four storey buildings and also for the

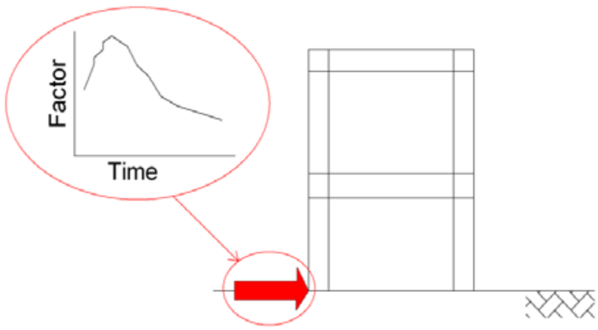

Figure 3: Base excitation

selected sites. Moreover, the use of these damage states for fragility curve generation has also been presented by other researchers (Hueste and Bai, 2007; Park et al, 2009). Structural performance and damage states defined in FEMA 356 are tabulated in Table 1.

3 Case study

In the present study, two and four storey RC school building built during the 9th Malaysia Plan was selected for seismic risk assessment. These buildings are not designed for seismic resistance, but representative of as-built structures in the region of study which is located in a low seismicity region of Southeast Asia. Moreover, the structural configuration is typical of buildings designed for education purpose, thus appropriate for the purpose of this study.

3.1 Structural configuration

A case study of typical structural configuration is presented. The structural system of the sample buildings consists of RC frames in two directions and original floor plan has been simplified, where all secondary beams are removed. As seen from the Figure 4, the layout is symmetrical in the plan for simplicity. The structure consists of fourteen frames with constant interstorey heights of 3.6 m and the typical floor area of 304.2 m^2 (7.8 m $\times$ 39 m). The total building height for two and four storey is 7.2 m and 14.4 m, respectively. Concrete slabs are at each storey levels with 13 cm thickness. Moreover, the strength of concrete and yield strength of steel are selected as 25 MPa and 460 MPa, re-

Table 1: Structural performance levels for Reinforced Concrete Frames (FEMA 356)

Damage levels	Collapse Prevention S-5 Severe	Life Safety S-3 Moderate	Immediate occupancy S-1 light
Overall damage descriptions	Extensive cracking and hinge formation in ductile elements. Limited cracking and/or splice failure in some nonductile columns. Severe damage in short columns.	Extensive damage to beams. Spalling of cover and shear cracking (<1/8″ width) for ductile columns. Minor spalling in nonductile columns. Joint cracks <1/8″ wide.	Minor hairline cracking. Limited yielding possible at a few locations. No crushing (strains below 0.003)
DS	4%	2%	1%

spectively. These material strengths are consistent with the local design information. Geometric and mechanical properties for the building are presented in Figure 5.

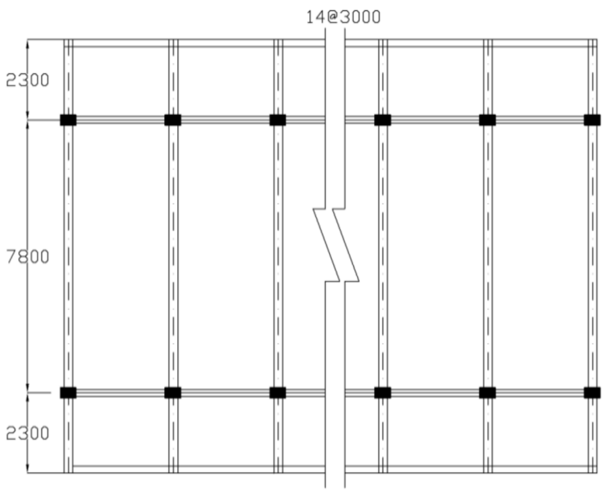

Figure 4: Floor plan of the sample buildings

3.2 Long distance earthquakes

Earthquake ground motions are random in nature and difficult to predict accurately. Therefore, a large number of records of earthquakes representing various ground motion parameters are needed in order to increase the reliability of damage estimation. In Peninsular Malaysia, strong motion instruments have been installed only after the Andaman Tsunami in 2004. Therefore, a set of representative simulated ground motions were proposed due to insufficient amount of earthquake records. In the present study, one hundred and fifty local spectrums were randomly selected from the available records. The properties of the selected ground motions are presented in Table 2. It can be seen that the records are highly clustered in the low ground motions severity range. For each local spectrum, eight ground motions were generated. These ground motions are scaled in the range from 0.025g to 0.2g with an interval of 0.025g. For evaluating building response, these ground motions are scaled to the same Sa and can be used directly without modification for bias effect (Song and Ellingwood, 1999). The selected ground motions are presented in Figure 8. It can be seen that duration of 40 second can be considered as the most significant part for all ground motions and consequently used for this study. Epicenter distances of these ground motions are in the range of 400-800 km. This is because most of the earthquakes are mainly from the island of Sumatra, Indonesia. Response spectrums for the selected ground motion are presented in Figure 9.

3.3 Impact of the number of stories in the building on the fragility curves

Figure 10 shows the impact of the number of stories in the building on the fragility curves. As apparent for Soil Profile 1, the fragility curves for two-storey building show lower probabilities of exceeding each damage state as compared to the fragility curves of four-storey building. Similar observation for Soil Profile 2, where the probabilities of two-storey building

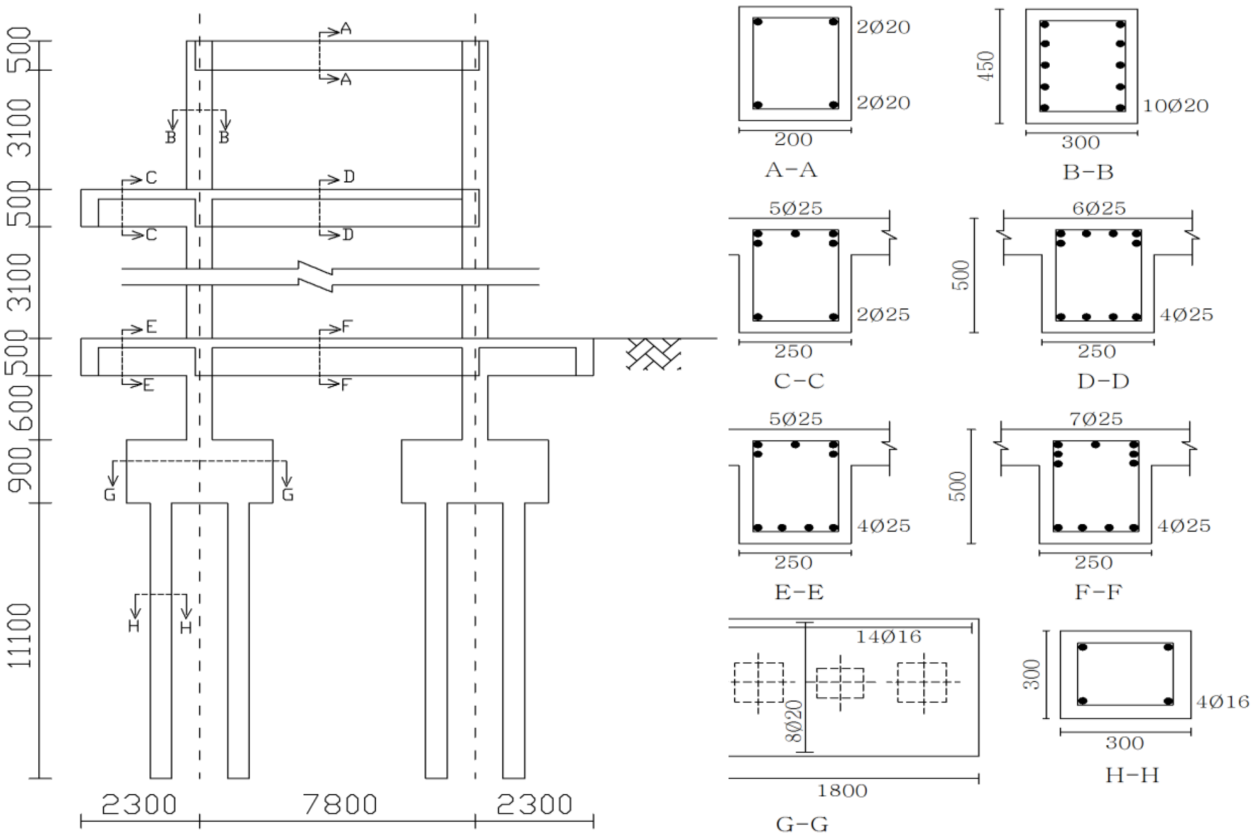

Figure 5: Geometric and mechanical properties for the building

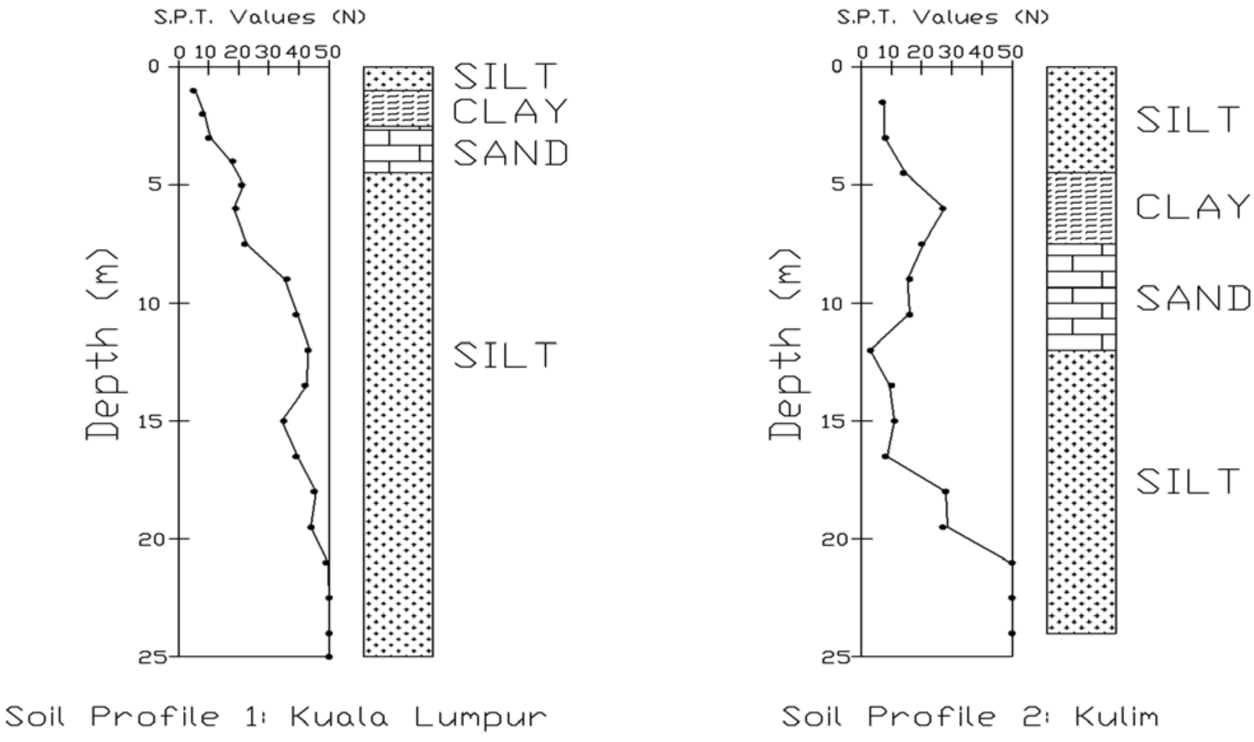

Figure 6: Summary of borehole logs for the selected site

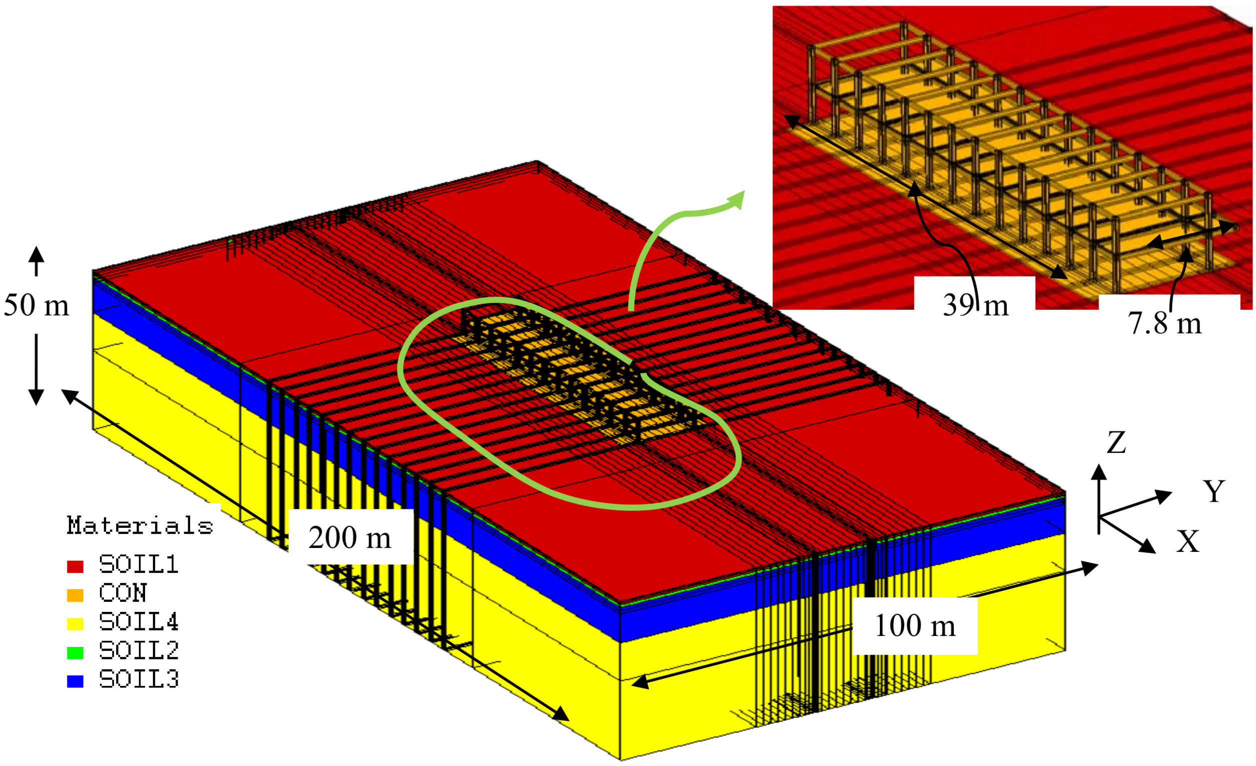

Figure 7: Idealized full soil-structure system for Soil Profile 1

Table 2: Properties for the selected ground motions

Events	Date	Time (UT)	Epicenter Latitude	Epicenter Longitude	Magnitude (Richter scale)	A max (cm/s^2)
Kuala Lumpur						
Mindanao Earthquake	05/02/2005	12:23:20	5.2 N	123.5 E	7.2	0.117
Sumatra Earthquake	03/04/2005	03:10:56	1.9 N	97.5 E	6.1	0.227
Sumatra Earthquake	28/04/2005	14:07:34	2 N	96.6 E	6.0	0.081
Sumatra Earthquake	14/05/2005	05:05:20	0.4 N	98.3 E	6.7	0.483
Sumatra Earthquake	17/12/2006	21:39:15	0.6 N	9.8 E	5.6	0.993
Kulim						
Sumatra Earthquake	26/12/2004	00:58:59	3.1 N	95.5 E	9.0	-1.918
Andaman Earthquake	24/07/2005	15:42:07	7.5 N	92.1 E	7.0	-0.129
Sumatra Earthquake	16/05/2006	15:28:27	0.2 N	97.1 E	6.6	-0.164
Sumatra Earthquake	06/05/2007	05:49:00	0.6 S	100.4 E	5.8	0.150
Sumatra Earthquake	24/07/2007	14:51:00	2.1 N	97.7 E	5.8	0.053

(a)Kuala Lumpur (b) Kulim

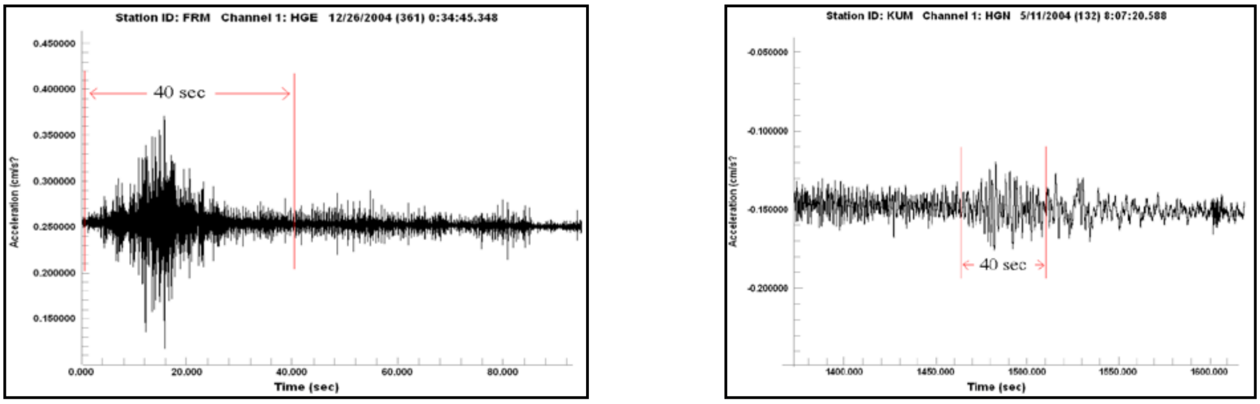

Figure 8: Selected ground motion

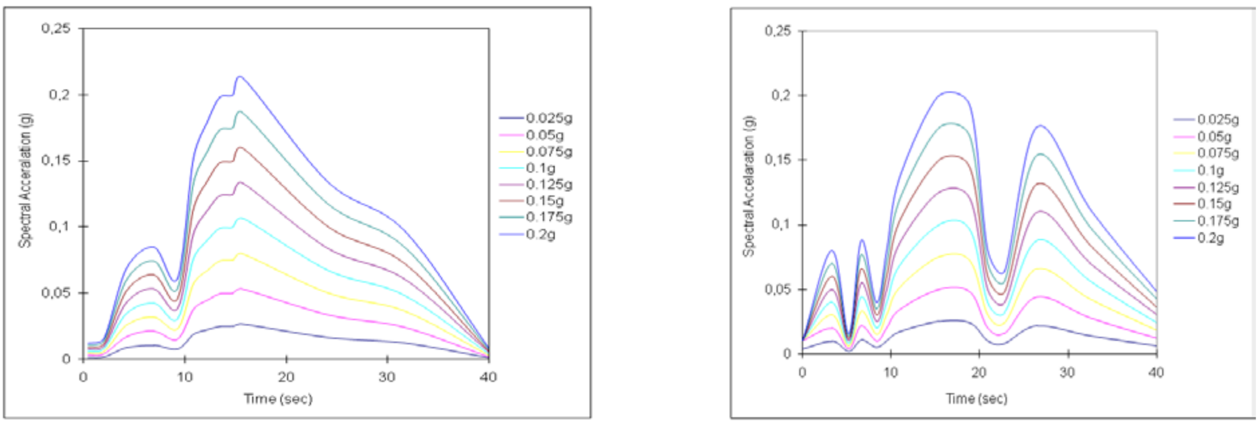

Figure 9: Response spectrum

exceeding each damage state are lower than four-storey building, while the probabilities values appeared to be close for damage state of immediate occupancy. On the contrary, the probabilities of exceeding a damage state for Soil Profile 1 decreases more gradually from immediate occupancy to the collapse damage state. It can be stated that, however, the fragility curves are affected by the number of stories in the buildings. This observation was also presented by Kircil and Polat (2006).

3.4 Fragility curves comparisons and verification

Figure 11 shows comparison between the developed fragility curves and HAZUS fragility curves for two and four storey building. Soil Profile 1 shows better seismic resistance than Soil Profile 2 where the probabilities of Soil Profile 1 exceeding a certain damage state is less than Soil Profile 2. This is expected, since the soil condition for Soil Profile 1 is stiffer than the Soil Profile 2. Therefore, the fragility curves are also affected by soil conditions. Moreover, the fragility curves developed for Soil Profile 1 and Soil Profile 2 in this study are compared with HAZUS fragility curves for verification purpose as presented in Figure 11. It can be seen that, the fragility curves developed in this study give higher probabilities of exceeding each damage state as compare to the HAZUS fragility curves. This discrepancy is caused by several factors namely the idealization of the building configuration and soil conditions adopted in this study.

4 Conclusions

The results of this study indicate that the fragility curves are affected by both the number of stories in the building and soil conditions. However, it should be noted that a poor comparison was found between the developed fragility curves and with HAZUS fragility curves based on the proposed approach. The developed fragility curves show higher probabilities of exceeding each damage state as compared to those derived in HAZUS technical manual and thus provide an upper bound estimate for hazard assessment.

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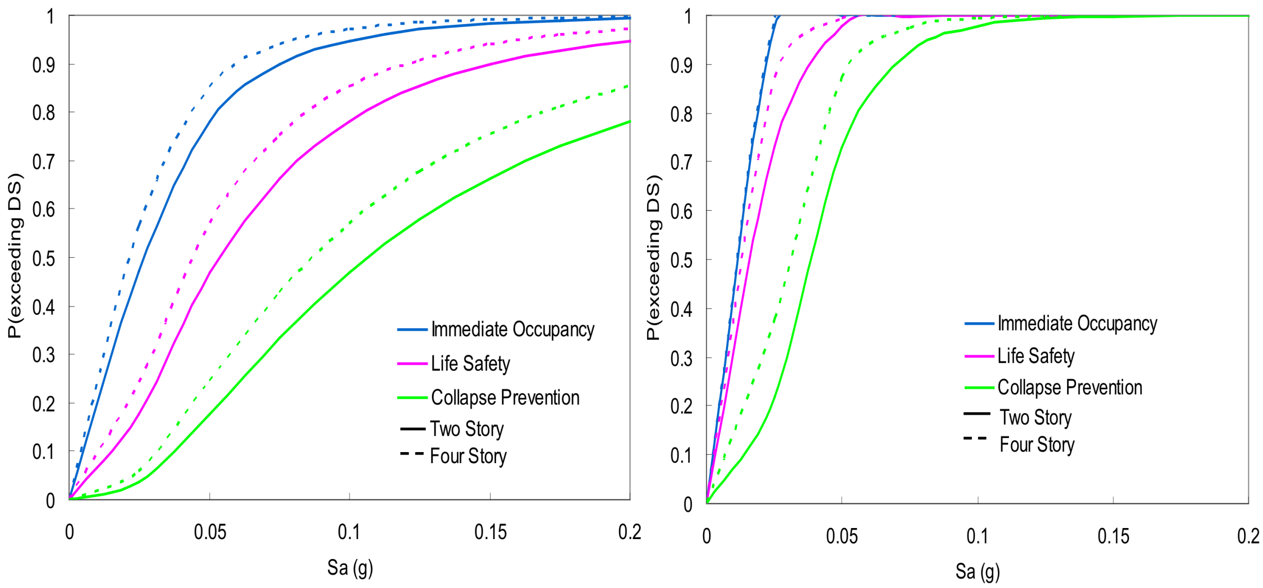
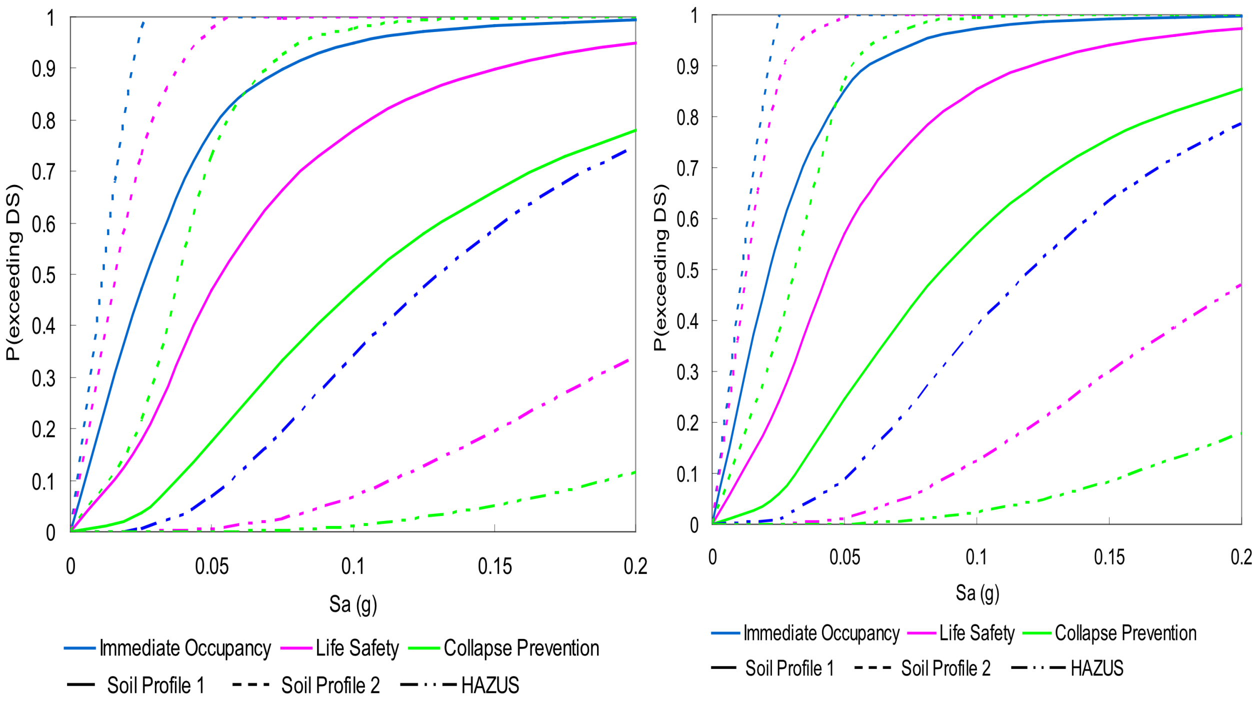


(a) Soil Profile 1 (b) Soil Profile 2

Figure 10: Fragility curves for Soil Profile 1 and Soil Profile 2



(a) Two storey building (b) Four storey building

Figure 11: Comparison between the developed fragility curves and HAZUS fragility curves for both two and four storey building

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