Seismic Fragility Analysis of Water Pumping Stations

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ABSTRACT

Reinforced concrete low-rise water pumping stations are one of the most common structural types in Taiwan. The fragility curves for water pumping stations based on analytical models are scarce in the field of earthquake engineering. This study performs seismic fragility analysis of reinforced concrete low-rise water pumping stations. Fragility curves are developed for a two-story reinforced concrete low-rise water pumping station designed to represent a typical essential facility in a metropolitan area. The analytical fragility curves developed are based on damage states of HAZUS.

Keywords: Reinforced concrete low-rise water pumping station; fragility curve; earthquake.

1. Introduction

Reinforced concrete low-rise water pumping stations are one of the most common structural types in Taiwan. However, most existing water pumping stations have been designed on the basis of low-level seismic resistance. Moreover, past earthquake reconnaissance reports in the 1999 Chi-Chi earthquake have suggested that low-rise structures are highly susceptible to damage from earthquakes [1].

A number of seismic assessments in fragility analysis have been developed for earthquake risk estimation. In HAZUS-MH, the building fragility can be implemented for the assessment of seismic performance and risk of various classes of buildings such as steel moment frame, braced frame, and light frame structures [2]. The damage states in the fragility curves include slight, moderate, extensive and complete structural damage states.

The scope of this research is to develop the seismic fragility curves of water pumping stations. The nonlinear static pushover analysis is performed to achieve this seismic fragility curves.

2. Analytical modeling

A typical two-story RC water pumping station, with a height of 3.8 m for each floor, is used to develop the fragility curves as shown in Figure 1.This station was constructed in 1987 based on the 1982 seismic design code and designed with a moment resisting frame. However, compression strength of masonry during pushover analysis provided a lateral resistance is properly incorporated to reflect the contribution from masonry walls. The ductility of bare frames significantly reduces with increasing masonry walls.

This water pumping station was designed with f_c'=210kgf/cm^2 concrete. The mean values of the compression strength of concrete from cored specimens are reported as f_c'=89 kgf/cm^2 spreaded over two stories. The strength of the reinforcing steel was assumed as f_y = 2800 kgf/cm^2.

Analytical models for the water pumping station are carried out with a nonlinear pushover procedure proposed by NCREE [3]. The physical plastic hinge includes the flexural bending plastic hinges and shear hinges. Flexural plastic hinges may develop both at the ends of the columns and beams. The shear plastic hinges are assigned to the half length of columns as depicted in Figure 2. The reductions of the cracked sections are 35% and 70% of the gross sections for columns and beams with rectangular sections, respectively. The floor slabs are assumed as a rigid diaphragm. Prior to perform a nonlinear pushover procedure, gravity loads are composed of the dead load plus 0.5 times the live load imposed in the vertical direction. The force profile is using the first-mode in the pushover analysis. This is adequate to a two-story water pumping station, which higher mode contributions are negligible.

The capacity curves of water pumping stations with bare frames based on design are presented in Figure 3. The gradually incremental pushover lateral forces are imposed along the transverse and longitudinal directions respectively. The capacity of bare frames is nearly identical in two opposite directions. The base shear capacities in the transverse direction are less than 5.18% as those in the longitudinal direction. In addition, infilled frames are significant and lead to increase lateral resistance as shown in Figure 5. The lateral resistance strength increases with incorporating masonry wall, but the ductility of infilled frames are less than 27.7% as those in the bare frames. This general trend also reveals in relations of roof displacements and PGA as illustrated in Figures 4 and 6.

3. Fragility Curves of Water Pumping Stations

The seismic fragility or probability of exceeding a limit state given ground-motion intensity is assessed for the damage states in HAZUS [4]. The methodology predicts a structural damage state in terms of one of four ranges of damage: Slight, Moderate, Extensive, and Complete. General building stock in HAZUS represents typical buildings of a given model building type designed to either High-Code, Moderate-Code, or Low-Code seismic standards, or not seismically designed (referred to as Pre-Code buildings). The Pre-Code seismic standards are adopted in the water pumping stations of this research.

The interstory drifts at threshold of damage in HAZUS for the low-rise reinforced concrete frames are 0.004(Slight), 0.0064(Moderate), 0.016(Extensive), and 0.04(Complete), and those of the low-rise reinforced concrete frames with unreinforced masonry infill walls are 0.0024(Slight), 0.0048(Moderate), 0.012(Extensive), and 0.028(Complete).

The total variability of each structural damage state, β_{Sds} , is modeled by the combination of following three contributors to damage variability, uncertainty in the damage-state threshold of the structural system β_{Sds} = 0.4 for all structural damage states and building types, variability in capacity (response) properties of the model building type/seismic design level of interest $\beta_{C(Au)}$= 0.25 for Code buildings, $\beta_{C(Au)}$= 0.30 for Pre-Code buildings, and variability in response due to the spatial variability of ground motion [4]. Each of these three contributors to damage state variability is assumed to be lognormally distributed random variables. Capacity and demand are dependent parameters and a convolution process is used to derive combined capacity/demand variability of each structural damage state.

Figures 7 and 8 illustrate the fragility of water pumping stations with bare frames and infilled frames, respectively, using PGA as an intensity measure and defining slight, moderate, extensive, and complete damage states. Water pumping stations with infilled frames have higher fragility than the bare frame ones. This finding is consistent with those structural inventory specified in HAZUS.

Comparison of Fragility curves between bare frames and infilled frames in slight damage states is depicted in Figure 9. For a PGA of 0.24 g in the design basis earthquakes(DBS), these water pumping stations have in general more than a 3% and 10% probability of exceeding the slight limit state, for bare frames and infilled frames, respectively. For a PGA of 0.32 g in the maximum considered earthquakes(MCE), these water pumping stations increase their fragility more than a 6% and 15% probability of exceeding the slight limit state, for bare frames and infilled frames, respectively. However, when the limit state increased to the complete limit state, the probability of complete damage is less than 5% for both bare and infilled frames in DBE and MCE, as shown in figure 10.

Comparison of Fragility curves between Taiwan and HAZUS in bare frames and infilled frames is illustrated in Figures 11 and 12, respectively. The water pumping stations based on Pre-Code design are more fragile the ones specified in HAZUS. Therefore, the fragility curves of water pumping stations using HAZUS may lead to unconservative in risk estimation. The fragility developed in this research can implement to improve seismic risk assessment of water pumping stations.

4. Concluding Remarks

This study performs seismic fragility analysis of reinforced concrete low-rise water pumping stations. Fragility curves are developed for a two-story reinforced concrete low-rise water pumping station designed to represent a typical essential facility in a metropolitan area. The analytical fragility curves developed are based on damage states of HAZUS.

The fragility of water pumping stations is achieved with a nonlinear pushover analysis in bare frames and infilled frames. The water pumping stations with bare frames have less vulnerable than the ones with infilled frames. The fragility curves of water pumping stations using HAZUS may lead to unconservative in risk estimation. The fragility developed in this research can implement to improve seismic risk assessment of water pumping stations.

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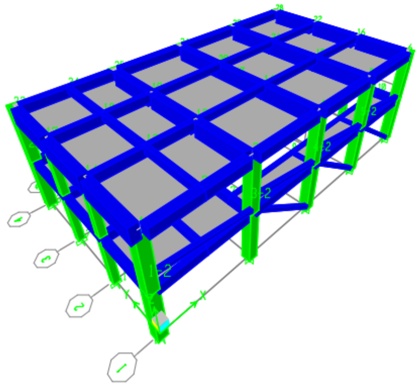
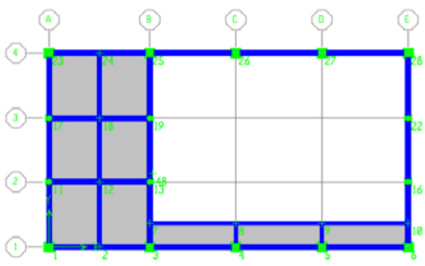
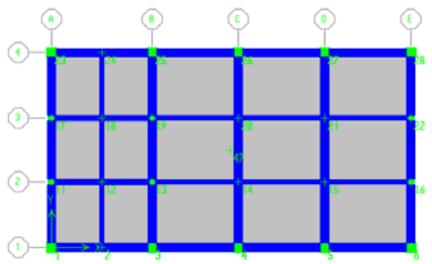


3-D view





First floor Second floor

Figure 1 Schematic representation of the two-story water pumping station.

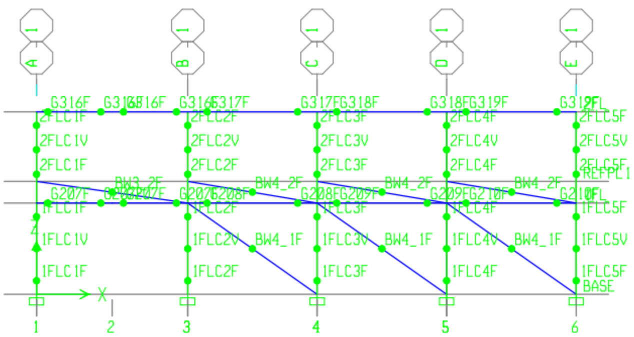


Figure 2 Typical assigned plastic hinges.

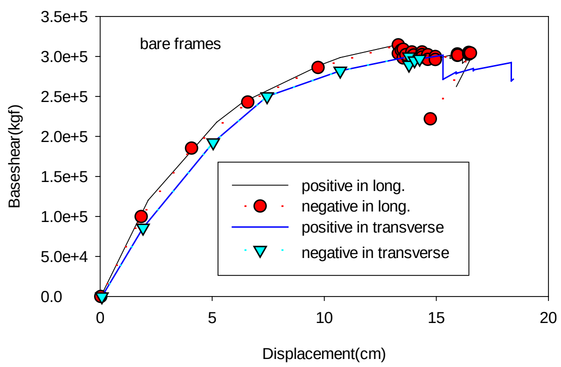


Figure 3 Capacity curves of bare frames

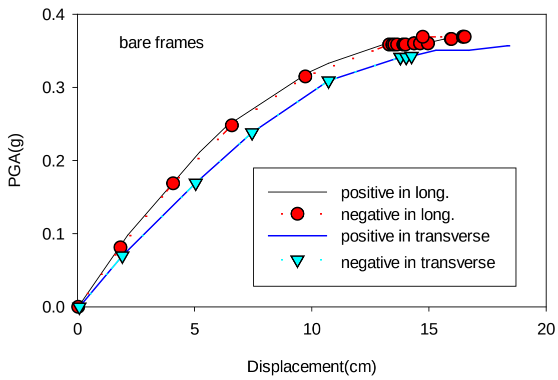


Figure 4 Relations of roof displacements and PGA in bare frames

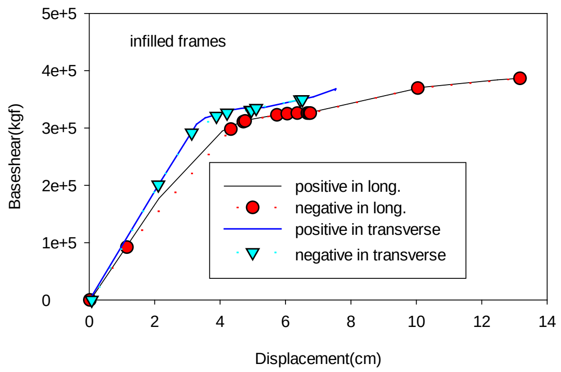


Figure 5 Capacity curves of infilled frames

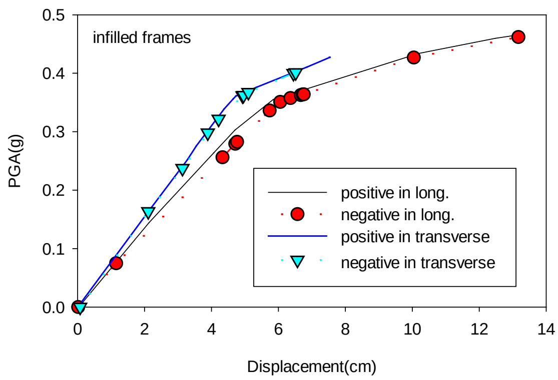


Figure 6 Relations of roof displacements and PGA in infilled frames

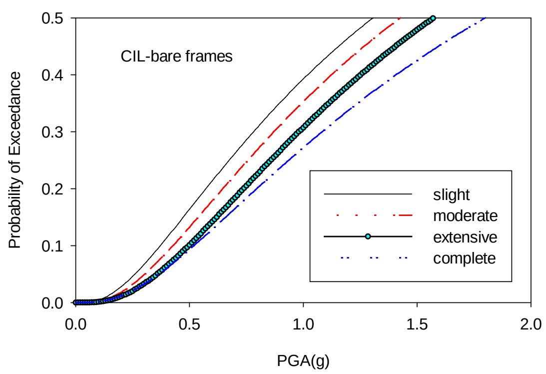


Figure 7 Fragility curves of bare frames with various damage states

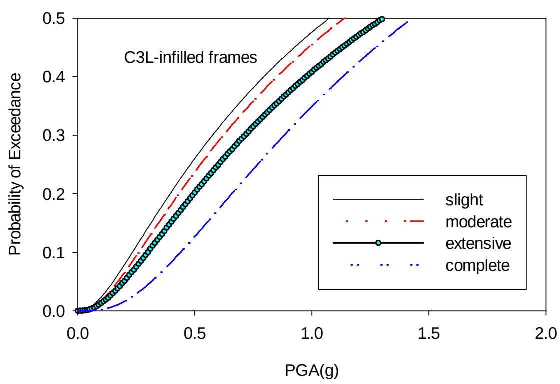


Figure 8 Fragility curves of infilled frames with various damage states

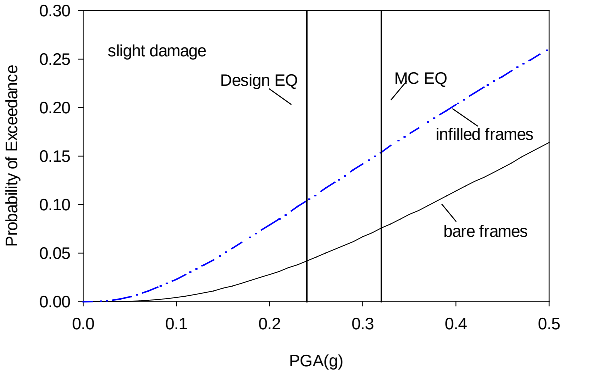


Figure 9 Comparison of Fragility curves between bare frames and infilled frames in slight damage states

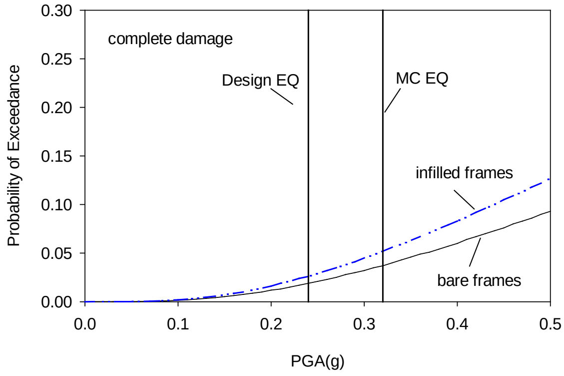


Figure 10 Comparison of Fragility curves between bare frames and infilled frames in slight damage states

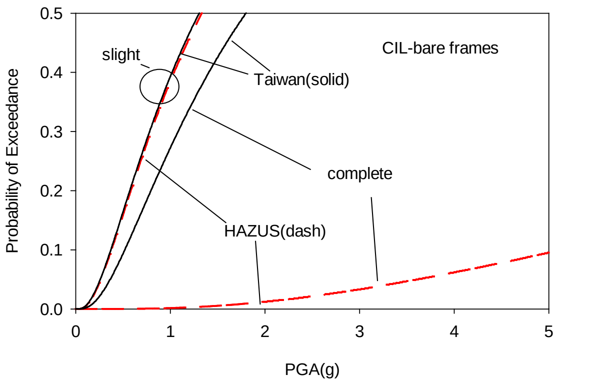


Figure 11 Comparison of Fragility curves between Taiwan and HAZUS in bare frames

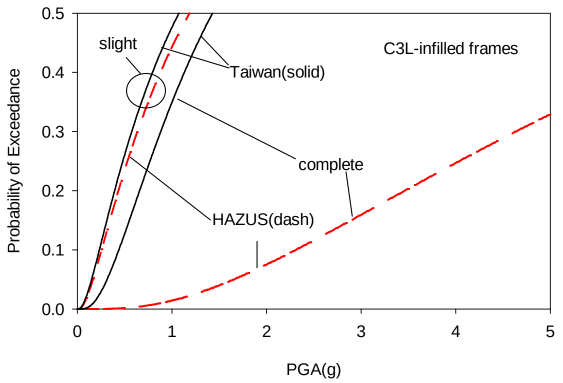


Figure 12 Comparison of Fragility curves between Taiwan and HAZUS in infilled frames