Quantification of Seismic Capacity Absorbing Inelastic Energy of Steel Structure

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1. Introduction

A building structure in non-nuclear industry is designed by a commercial building code. Sometimes the building may be required to be seismically requalified so as to take advantage of some function of system housed in the structure for back up of safety function of the major safety-related system [1]. A seismic margin over the original design can be shown by quantifying ductility capability inherent to the structure. This study derives seismic fragility curve for ductility capacity of the structure in terms of peak ground acceleration.

2. Methods and Results

2.1 Steel Structure to be studied

The building to be studied consists of a steel super structure and a reinforced concrete substructure. It contains the electrical power distribution equipment on the upper floors and compressors, cooling units, heat exchangers and pumps on a lower level. The building has horizontal dimensions of 97.6 m x 65.1 m. Its foundation consists of a reinforced concrete raft extending over the entire area of the building. The raft is surrounded by retaining walls up to elevation 100 m, and by a safety-related building foundation. The vertical lateral force resisting braced frames are located at seven column lines. The building was designed to perform normally under all normal operating loads and under the earthquake loads based on non-nuclear commercial building code assuming seismic zone 2. For nuclear safety, the building should not cause damage to the adjacent safety-related building under the postulated earthquake greater than 0.2g.

2.2 Median System Ductility

The predominant natural frequencies of the building structure are 0.95Hz and 2.5Hz. When a steel structure goes into fragility condition, structural damping ratio gets close to about 10% [2]. Thus earthquake ground motion to be input is a 10% damped median ground response spectra anchored to 0.2g from NUREG/CR-0098 [2]. The knuckle frequency is 2.05 Hz of the spectrum as shown in Fig. 1. The most critical failure mode has been judged to be a yielding of clip angle of the diagonal bracing member. Note that the entire structural system is in elastic even if the clip angle yields.

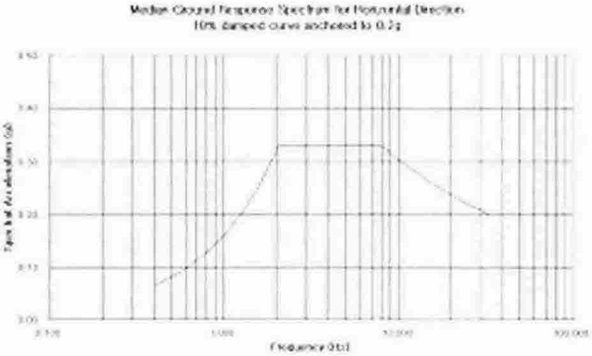

Figure 1. 10% damped Ground Response Spectrum

The deflection curves along the height of the building are shown in Fig. 2 together with maximum deformation curves based on story drift criteria of 0.5% and 0.7%, respectively. The lower bound story drift is estimated to be 0.5%. The elastic deflection curve was obtained when the structure is subject to 0.2g ground motion.

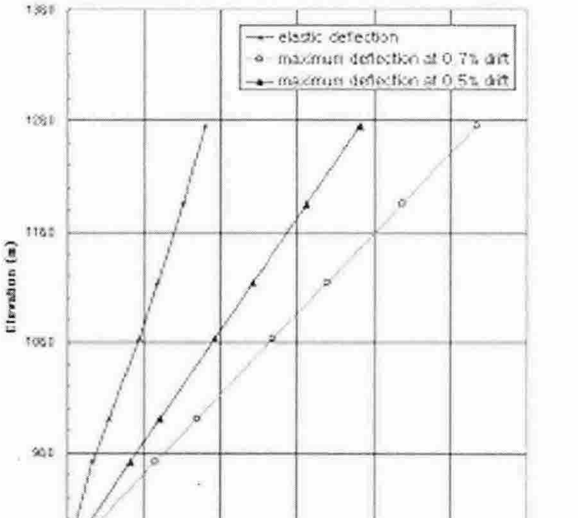

Figure 2. Lateral Deflection Curves

The median system ductility can be evaluated using mass weighted story drift approach. The median and lower bound system ductility is 2.94 and 2.10, respectively.

2.3 Seismic Fragility Parameters

The seismic fragility is defined based on double log-normal model and all the inputs are median centered [3].

An entire seismic fragility curve can be generated by three key parameters; median, and randomness and uncertainty associated with the median, which is a median of the medians.

For quantifying the inelastic energy absorption capacity factor, effective Riddell-Newmark method and effective Frequency/Damping method have been applied [4]. The inelastic energy absorption factor by using effective Riddell-Newmark method is 1.95 as a median, and the effective Frequency/Damping method resulted in 2.14. Finally, the average value of the two factors is 2.05, which represents a median inelastic energy absorption factor. All these results are evaluated based on median story drift criterion of 0.7%. The randomness and uncertainty can be evaluated by consideration of 0.5% story drift criterion as a lower bound. The randomness and uncertainty is 0.09 and 0.19, respectively. A conditional failure probability, f' with a confidence level of Q for a given peak ground acceleration, a' are formulated as shown below [3];

$$f' = \Phi\left[\frac{\ln(\frac{a'}{\tilde{\tilde{A}}}) + \beta_U \Phi^{-1}(Q)}{\beta_R}\right]$$

where,

Φ : standardized normal distribution function

Q : confidence level (95%, 50%, or 5%)

$\tilde{\tilde{A}}$: (double) median peak ground acceleration capacity

β_R : randomness associated with median

β_U : uncertainty associated with median

The median confidence of low probability of failure of the structure has been evaluated to be 0.35g in terms of peak ground acceleration. The HCLPF capacity of the structure evaluated to be 0.26g. The entire fragility curves are shown in Fig. 3.

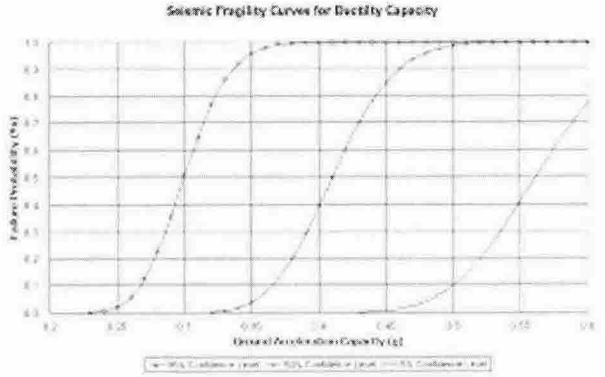

Figure 3. Seismic Fragility Curves

3. Conclusion

Even non-seismically qualified building structure shows good seismic performance by developing its own ductility. The seismic capacity of 0.26g is an acceleration capacity higher than commonly expected in a commercial graded building and this gives an additional margin of safety. This seismic margin backs up reliability of the safety function of nuclear graded safety-related system, which should be seismically qualified. Note the seismic margin comes from consideration of ductile characteristics only of the structure. Thus there is expected to be much more margin in the other variables and finally realistic seismic margin earthquake would be greater than 0.26g.

In addition, the methods to obtain inelastic energy absorption factor were developed depending on definition of strength factors of safety. The methods used in this study come from a definition based upon a factor of safety for strength that corresponds to an ultimate capacity of the controlling element. Therefore, what approach be applied to obtain inelastic energy absorption factor of a structural system should be decided by taking account for what failure mode controls a structural damage of the system.

REFERENCES

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