# SIMPLIFIED FRAGILITY EVALUATION METHOD OF SOIL-STRUCTURE INTERACTION FOR TYPICAL RC BRIDGE PIERS

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## 1. INTRODUCTION

RC bridge piers are being used in large numbers as part of elevated high-speed rails and highways. Fragility analysis allows taking into consideration of the uncertainty of the structure's materials characteristics due to initial variability and progressive material degradation and accounting for the uncertainty in the soil conditions and in the loadings. The effect of the Soil-Structure Interaction (SSI) is significant for bridge piers structures and a number of studies have addressed the effect of foundation support flexibility, see Barbarosa et al. (2014). The swinging of the pier on foundations could further increase the displacements of the top of the pier and of the deck. The safety limit ratio $C_{SSI}$ defined in Eq. 1 has been proposed to quantify the ratio between the column deformation, considering the top-bottom column displacement $D_f$, height H and rotation $\theta_f$ versus the maximum allowable member rotation $\theta_y$, computed as specified in JSCE (2002).

$$C_{SSI}= (D_f / H + \theta_f) / \theta_y \tag{1}$$

Current study focuses on the investigation of the effect of SSI of RC bridge piers through fragility analysis, with consideration of the uncertainty of the ground and constitutive materials parameters. The Simplified Fragility Evaluation Method (SimFrEM) is being described and is applied for the purpose of speeding-up of the fragility curves computation.

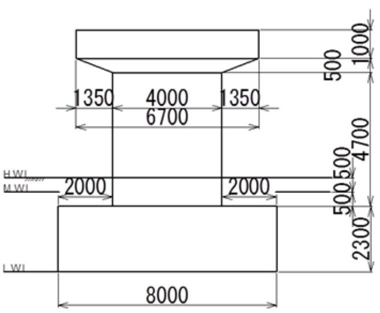
## 2. BRIDGE MODEL AND PARAMETERS UNCERTAINTY

A typical RC bridge pier designed by the Japanese standards, similar to the RC pier proposed in JSCE (2002) was selected for the modeling, and a simplified FEM model based on the lumped mass model idealization and beam elements has been implemented, with translation and rotation ground springs accounting for the modeling of SSI. The RC pier dimensional characteristics are shown in Fig. 1. Variability of concrete, steel and soil material's characteristics are taken into analysis as follows under the assumption of normal distribution of the physical values, assumed constitutive material parameters and corresponding variability are summarized in Table 1. The concrete modulus of elasticity $E_c$ and tensile strength $f_t$ are assumed to be correlated with the material strength $f'_c$ variability as described in the Eq. (2) and (3), see Yoshida et al. (2003). The foundation ground material variability is considered by the $V_s$ parameter, reflected in analysis by the corresponding properties of the ground springs of the equivalent FEM model, see Motegi et al. (2007).

For the fragility analysis, a number of scaled L2 earthquake accelerograms as described in JSCE (2007) have been used for the assessment of the RC pier response at incremental levels of the input motion between 200 and 800 gal. The pier response is being summarized in Fig. 2 for the effect of the material variability and the effect of the SSI.

Table.1 Constitutive material characteristics of the RC pier

| Structural Material | Material Parameter | Mean Val. $\mu$ | Standard Deviation $\sigma$ |
|---|---|---|---|
| Concrete 24.0[N/mm2] | fc [N/mm2] | 32.0[N/mm2] | 1.215 |
| | ft [N/mm2] | $ft = 0.23 * f'c^{2/3}$ (2) | |
| | Ec [KN/mm2] | $Ec = 8.39*f'c^{1/3}$ (3) | |
| Steel SD390 | fs [N/mm2] | $\gamma_S$*390.0[N/mm$^2$] | 17.78 ($\gamma_S$=1.0) |
| | Es[KN/mm2] | 195.0[KN/mm$^2$] | |
| Soil N50 | Vs[m/s] | 300m/s (hard) | 31.06 |



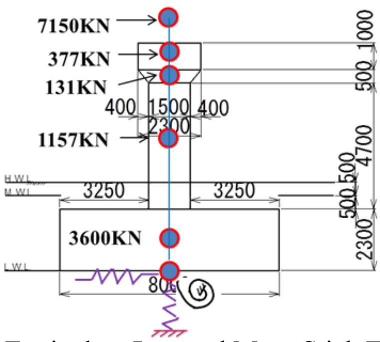




Fig.1 RC Pier Dimensional Characteristics and the Equivalent Lumped Mass-Stick FEM Model

## 3. SIMPLIFIED FRAGILITY EVALUATION METHOD

For typical fragility analysis, the Monte-Carlo (MC) simulation of the material parameters uncertainty is applied with material characteristics as listed in Table.1. The failure state limit criterion is flexural failure (ultimate displacement and ultimate rotation angle of pier column due to flexural moment combined with axial loading), with verification of the share failure condition, assuming no torsional failure occurs. The corresponding demand versus capacity ratio including the variability of soil and concrete material and SSI effect are plotted in Fig. 2, with safety limit ratio $C_{SSI}$ as defined in Eq. 1, considering the translation term.

Keywords: Fragility Evaluation Method, RC Pier, SSI
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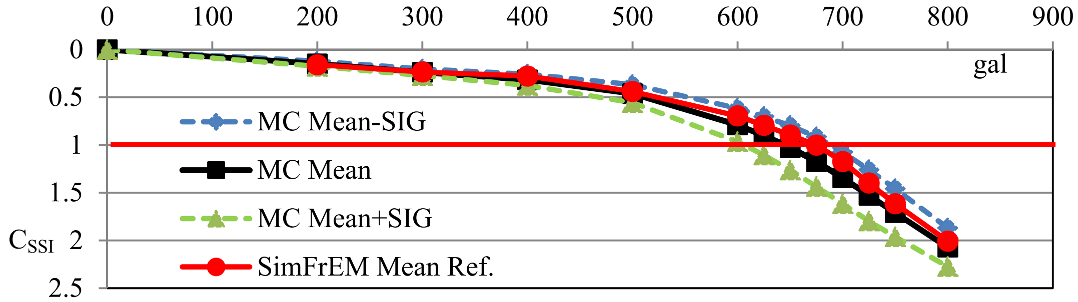


Fig.2 MC Method RC Pier's Demand vs. Capacity Ratio Considering SSI and Concrete Variability

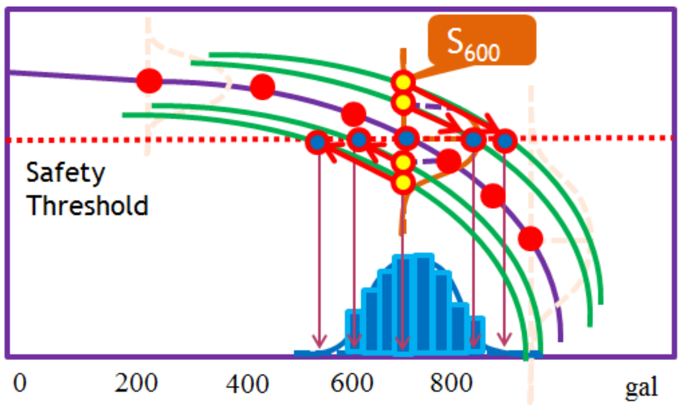


Fig.3 Flow of Direct Estimation of Safety Threshold Crossing by Simplified Fragility Evaluation Method

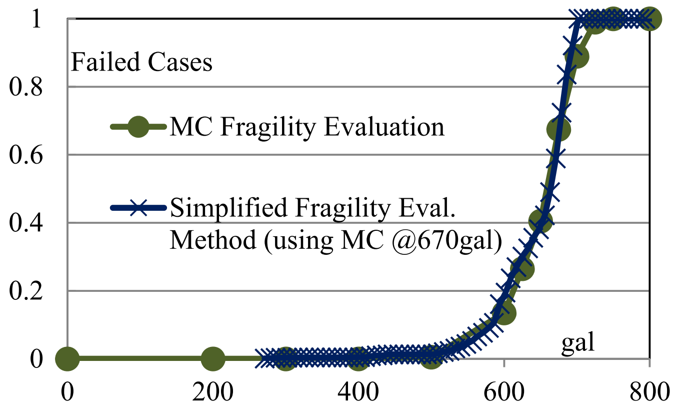


Fig.4 RC Pier Fragility Curves by MC and SimFrEM Considering SSI and Concrete Variability

Computation of fragility curves by MC method is requiring a very large number of simulations, when the number of loading cases and parameters accounted in simulation increases, and is summarized in Fig. 2. Therefore, the Simplified Fragility Evaluation Method (SimFrEM) is being proposed herein to speed-up the evaluation of the fragility curves. The mean curve is being determined for modeling of the non-linear demand-capacity response of the structure using the mean value of the parameters, as the mean value could be determined with ease. In addition, SimFrEM method requires only a single complete set of MC simulations computed at a given loading level, and is extrapolating the response of the structure to determine additional point on the load-response diagrams by interpolation, without requiring the computing of the MC simulations at each loading level, as shown in Fig. 3. For this purpose, the non-linear response analysis of the structure was carried out using the mean parameters values and by computing demand by capacity ratio of the pier $C_{SSI}$ for each input level. The linear behavior is assumed on each sub-interval between the points determined on the mean demand-response curve and linear interpolation is used for determining the accelerations corresponding to the crossings of threshold safety level (blue circles in Fig.3), by shifting demand/response curves parallel to the mean curve.

Proposed method determines directly the earthquake input level exceeding a certain safety threshold using a single complete set of MC simulations and the mean curve, reducing significantly the number of the numerical analysis cases needed to determine simplified fragility curves. Integrated values when Safety Threshold is exceeded as determined by SimFrEM are shown in Fig. 4 and are compared to fragility curve determined by typical MC. The SimFrEM method could give a faster, direct and simplified evaluation of structural fragility.

## 4. CONCLUSIONS

For highways and viaducts RC bridge piers the foundation soil parameters effect is significant, and could increase the superstructure displacements, potentially increasing the earthquake effects. The fragility analysis of the bridge pier including spread foundations SSI effect was performed, with focus on modeling of RC and soil parameters variability.

* Comparison of the structural materials and soil characteristics variability effect is being performed by Monte Carlo multi-parametric simulation and FEM analysis. Modeling of the soil-structure interaction and soil parameters variability is shown to be significant for more accurate modeling of structural response but increases modeling complexity.
* Proposed Simplified Fragility Evaluation Method could provide a faster way to determine the earthquake level where response exceeds certain safety threshold, helping reduce number of FEM cases required for fragility evaluation.

## REFERENCES


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