The System Development of Bridge Seismic Risk Analysis

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1. Introduction & System Flow

This paper presents the system development of seismic risk analysis applied to bridge piers with the consideration of the different levels of earthquakes. The employed theory is a probability-based method with considering the seismic risk, structural fragility and economic loss formulated by H. Yoshikawa[1), 2)]. The aim of our work is to provide designers a convenient tool to quickly evaluate possible seismic loss. Fig.1 shows a general flow-chart of the system and Fig.2 shows a concept graph of the whole calculation procedure of the employed theory.

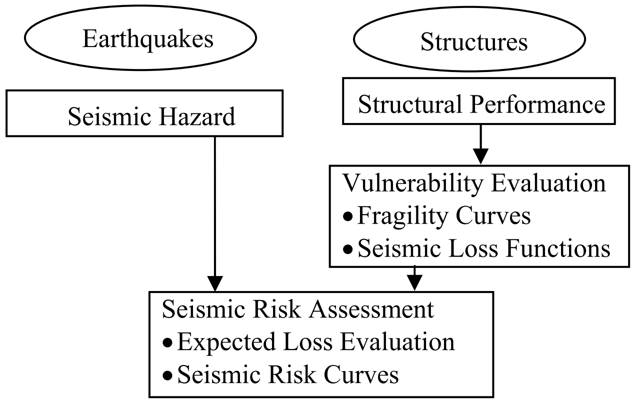

Fig. 1　Flow diagram for seismic risk assessment

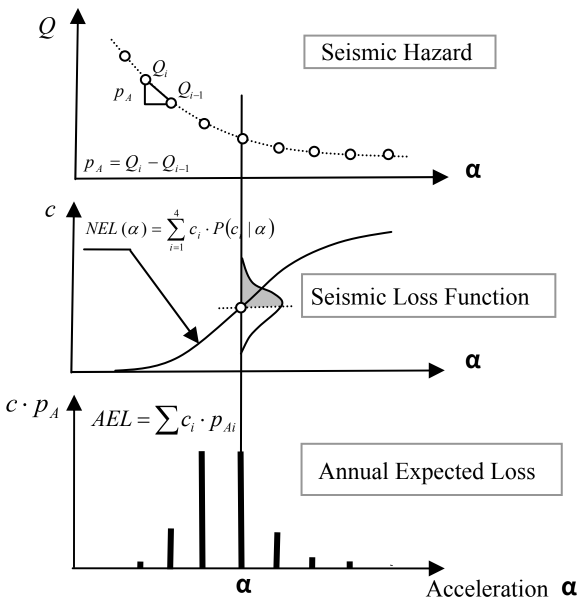

Fig.2 Schematic graphs of calculation procedure

2. The Employed Theory & Formulas

2.1 Seismic Hazard & Elastic Acceleration Response

The seismic hazard $[p_A(\alpha)]$ is computed from other tools. The Kanda formula is used for elastic acceleration of structures from the rock base acceleration (α) as the following.

$$\alpha_{resp} = 19.44\alpha^{0.6523} \quad \text{----------------------------- (1)}$$

2.2 Nonlinear Seismic Responses of Structures and Damage Level (DL) Definition

The nonlinear earthquake responses of bridge piers are calculated by the reduction factor based on the input P-δ curve. The different reduction factor such as the equal energy principle (2) can be selected to obtain the plastic displacements from the input maximum acceleration. Fig.3 shows an input P-δ curve and the DL definition.

$$\delta_{resp.} = \frac{1}{2}\left(R^2+1\right)\delta_Y \quad \text{---------------------------- (2)}$$

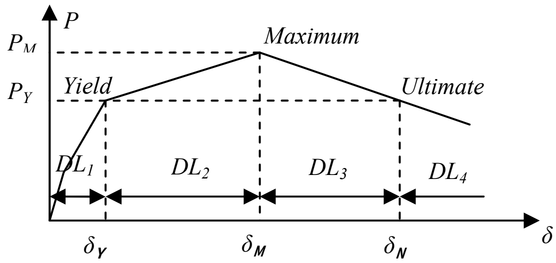

Fig.3　P-δ curve and DL definition

2.3 Probability Model of Responses and Damages

The probability model of damages (δ_i, i∈[Y, M, N]) and response (δ_{resp}) is assumed as lognormal distribution and thus the condition occurrence probability of δ_{resp} exceeding over δ_i can be expressed[1)] as below.

$$F_i(\delta_{resp}) = \int_0^{\delta_{resp}} \frac{1}{\sqrt{2\pi}\varsigma_x z}\exp\left[-\frac{1}{2}\left(\frac{\ln z - \ln\delta_i}{\varsigma_x}\right)^2\right]dz \quad \text{-------- (3)}$$

In which

$\varsigma_x^2 = \ln\left[\left(1+v_i^2\right)\left(1+v_R^2\right)\right]$;

v_i=cov. of δ_i; v_R=cov. of δ_{resp}.

The each DL occurrence probability for a certain level earthquake response $\delta_{resp}(\alpha)$ is expressed as follows and

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shown in Fig. 4.

$$P(c_i \mid \alpha) = F_{i-1}(\alpha) - F_i(\alpha) \quad i=1,\ldots,4 \quad \text{---------- (4)}$$

And

$$\sum_{i=1}^{4} P(c_i \mid \alpha) = 1;\ F_0(\alpha) = 1;\ F_4(\alpha) = 0; \quad i = 1,2,3 \rightarrow \mathrm{Y, M, N}$$

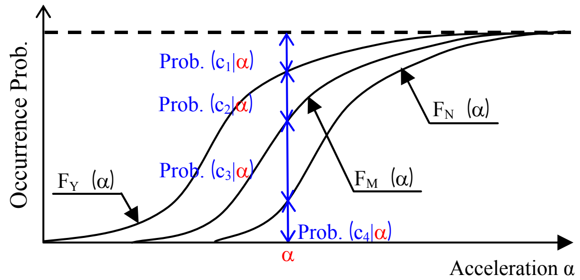

Fig. 4 Occurrence probability of each DL

2.4 Loss Model of 0-1 Index

Damage event tree is used to establish the relationship between the damage Occur. Prob. P(c_i|α) and loss c_i as below.

$$DL_i \rightarrow c_i \rightarrow P(c_i|\alpha), \quad i=1,\ldots,4 \quad \text{---------- (5)}$$

Further the probability model of c normalized by c_{max} is assumed as the β Distribution. It has form

$$f(c \mid \alpha) = \frac{c^{q-1}(1-c)^{r-1}}{B(q,r)},\ c \in [0,1] \quad \text{---------- (6)}$$

In which,

B(q, r) : the β Function;

$$q = \frac{c_m(c_m - c_m^2 - \sigma_c^2)}{\sigma_c^2};\ r = \frac{(1-c_m)(c_m - c_m^2 - \sigma_c^2)}{\sigma_c^2};$$

$$c_m = \sum_{i=1}^{4} c_i \cdot P(c_i \mid \alpha);\ \ \sigma_c^2 = \sum_{i=1}^{4} (c_i - c_m)^2 \cdot P(c_i \mid \alpha).$$

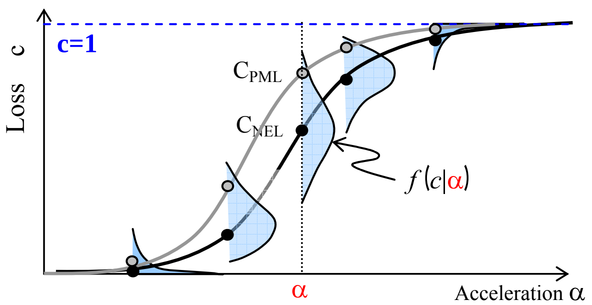

Fig. 5 Loss Functions

2.5 Seismic Risk Analysis

Two Loss Indices, Probable Maximum Loss (PML) and Normal Expected Loss (NEL), are calculated as below.

$$C_{PML} = R^{-1}(0.1) \quad \text{--------------------- (7)}$$

$$C_{NEL} = c_m \quad \text{--------------------- (8)}$$

In which, $R(C_{PML}) = \int_{C_{PML}}^{1} f(c \mid \alpha)\, dc$

Annual Expected Loss (AEL) can be expressed in the formula as below.

$$AEL = \int_0^{\infty} p_A(\alpha) \sum_{i=1}^{4} \{c_i \cdot P(c_i \mid \alpha)\}\, d\alpha \quad \text{------- (9)}$$

3. System Outline: Input & Output

Based on the above theory, the system of the bridge seismic risk in the name of *FrameRisk*[3)] was developed. The input and output are shown in Table 1. Fig.6 shows typical result curves; the left is Seismic Loss Functions and the right is Seismic Event Curves.

Table 1 Input/Output of the *FrameRisk*[3)] System

Input items
• Seismic Hazard • P-δ Curve(Crack, Yield, Maximum, Ultimate) • Definition of Damage Level and Economic Loss
Output items
• P.D.F and C.D.F for each damage level • Seismic Loss Function(NEL, PML) • Seismic Event Curve & AEL Values • P.D.F of β Distribution • Report Export

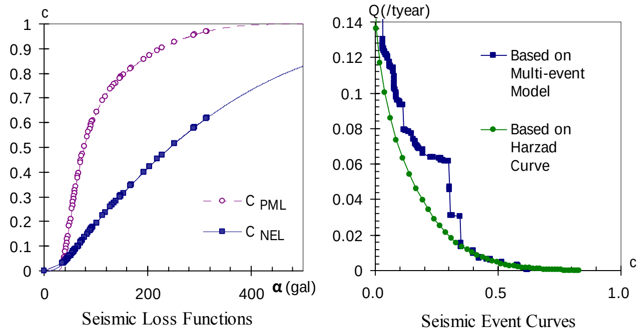

Fig. 6 Examples of system output

4. Concluding Remarks

The developed system of seismic risk analysis for bridges has the following features;

- Provide an integrating tool for Bridge Seismic Risk Analysis on Windows platform,
- Make the seismic risk analysis of actual structures easier and quicker,
- Help to improve and advance the theory & formulas in the system.

References

1) Yoshikawa, H. et al., Seismic Risk Assessment and Expected Damage Evaluation of Railway Viaduct, 10th International Conference on Applications of Statistics and Probability in Civil Engineering/ICAP10, 2007.7

2) Yoshikawa, H., Seismic Design and Risk Analysis of Reinforced Concrete Structures, Published by Maruzen, 2008.2(In Japanese)

3) http://www.forum8.co.jp/product/uc1/ijikanri/framerisk.htm