Response prediction of an RC building using analytical model updated with seismic response observation data
Part 1 Basic concept of updating of analytical model and response prediction

Keyword:
Seismic response observation　Updating of analytical model
Response prediction　Kalman filtering
Characteristic point　Performance modification factors

正会員　〇前田 匡樹*1　易 卓然*2
同　大野 歩美*3　Jonathan Monical*4
同　鈴木 裕介*5　関 松太郎*6

1. Introduction

Previous studies have employed structural health monitoring systems to estimate the degree of damage of a reinforced concrete structure [1-2]. In this study, the effectiveness of the proposed method is further validated through a series of simulations conducted on a 4-degree of freedom (4DOF) lump mass model by investigating the effects of input ground motions and difference between original and real performance curve.

Part 1 presents the research objective and proposed methodology. Pushover and vibration analyses are utilized to represent the simulation and experiment outcomes, respectively, referred to as original and real behavior in this paper. As depicted in **Fig. 1**, the analytical approach consists of two parts: ① updating performance curve and damping behavior by comparing the real and original behavior under low-intensity (observed) earthquake inputs; and ② response prediction using capacity spectrum method (CSM) for high-intensity (future) earthquake inputs. The viability of the proposed approach is verified by comparing predicted responses with and without updating.

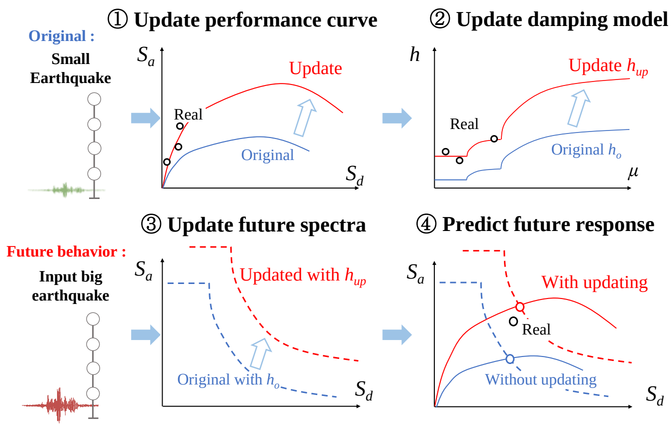

Fig.1 Overview of structural health monitoring system

2. Reduction of MDOF to SDOF system

The results of pushover analysis and time-history analysis are first converted to the response of an equivalent single degree of freedom (SDOF) system separately, further obtaining spectral displacement (S_d) and acceleration (S_a) [3]. Eqs. 1-2 are utilized to transform pushover results to the original performance curve, and Eqs. 3-4 are utilized to transform results from time-history analysis.

$$S_d = (\sum_{i=1}^{4} m_i d_i^2) / \sum_{i=1}^{4} m_i d_i \quad (1)$$

$$S_a = (Q_b \sum_{i=1}^{4} m_i d_i^2) / \sum_{i=1}^{4} (m_i d_i)^2 \quad (2)$$

where m_i and d_i are the mass and displacement of floor i. Q_b is the base shear force.

$$S_d(t) = [\sum_{i=1}^{4} m_i \beta\mu_i d_i(t)] / \sum_{i=1}^{4} m_i \beta\mu_i \quad (3)$$

$$S_a(t) = [\sum_{i=1}^{4} P_i(t) S_d(t) \beta\mu_i] / \sum_{i=1}^{4} [m_i S_d(t) \beta\mu_i] \quad (4)$$

where $\beta\mu_i$ represents the first mode participation factor. $P_i(t)$ is the external force for floor i in time t. The real behavior data are maximum values of calculated $S_d(t)$ and $S_a(t)$.

3. Updating performance curve
3.1 Obtain characteristic points

Because the real performance curve is expressed as several line segments connecting points of the peak response reached in each run, it may include some deviation. Therefore, the real behavior is smoothed by the Kalman filtering method using the real performance curve as the input measurement data and the original performance curve as the simulated input data, as illustrated in **Fig. 2**.

After smoothing, the lateral stiffness and rate of change of lateral stiffness are calculated using the slope of the smoothed performance curve. The tangential stiffness K of a structure may change rapidly as damage such as cracking and yielding occurs. Hence, the local maximum points of the rate of change of stiffness are identified as "characteristic points" of the real performance curve. The characteristic points of the original performance curve are obtained from initial cracking, yielding, flexural mechanism and ultimate points obtained from the pushover analysis.

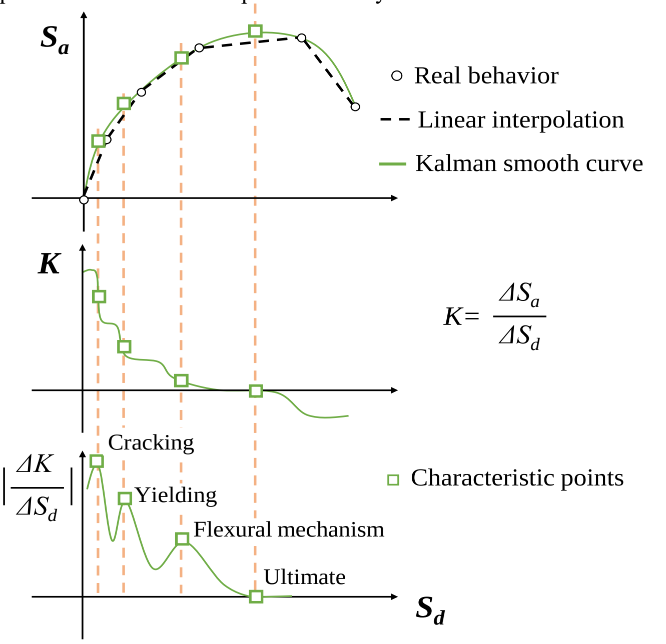

Fig.2 Identification of characteristic points

3.2 Updating future performance curve

After identifying the characteristic points, the original performance curve is updated such that characteristic points of both real behavior

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MAEDA Masaki, YI Zhuoran, OONO Ayumi, MONICAL Jonathan, SUZUKI Yusuke, SEKI Matsutaro

and original performance curves match, as shown in **Fig. 3**. The original performance curve is updated by fitting each real characteristic point with the corresponding original characteristic point using a series of modification factors α_i and β_i for S_a and S_d.

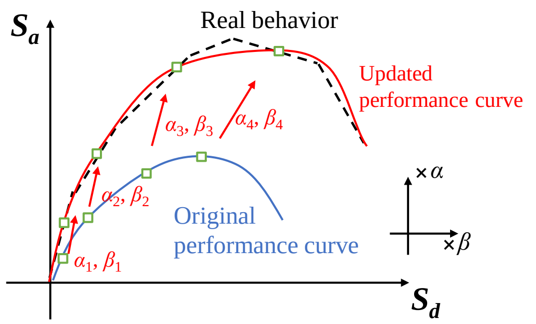
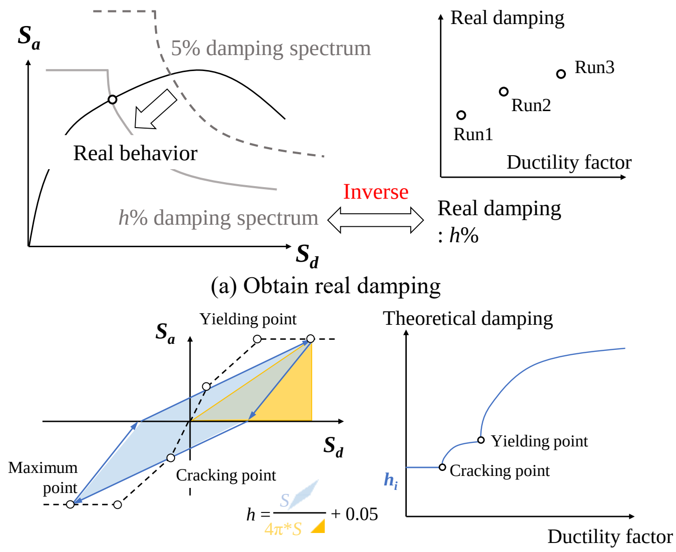


Fig.3 Prediction of performance curve

4. Damping calculation and prediction

The CSM is used to predict the future response in a high-intensity earthquake. Because yielding is likely to occur, the damping behavior should be clarified. Two kinds of damping may be obtained according to the real behavior and original performance curve: ①. Real damping can be obtained from the inverse calculation of spectra method as **Fig. 4(a)** shown; ②. Applying the Takeda model, original damping can be obtained from the theoretical calculation considering the original cracking and yielding point, as shown in **Fig. 4(b)**.



(a) Obtain real damping

(b) Obtain original damping

Fig. 4 Calculation of damping behavior

The original damping model is updated using Kalman and amplification methods to produce more accurate estimates of damping before and after yielding. **Fig. 5** shows the basic principle of updating damping. For damping before cracking, updated damping is constant and is equal to the maximum real damping. After cracking and before yielding, the Kalman method is used to update the original damping using an amplification factor calculated using the known real damping. Damping is predicted in the nonlinear range of response by updating the theoretical damping model using the same amplification factor calculated in the linear range of response.

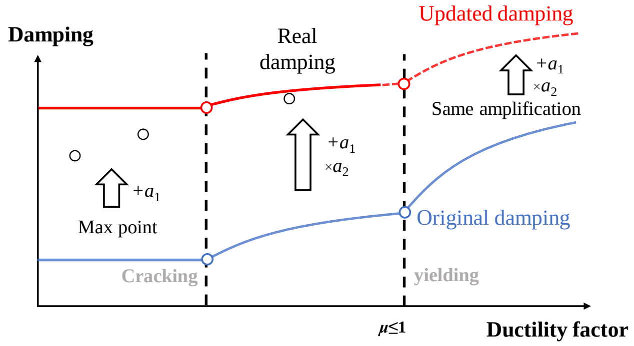


Fig.5 Prediction of damping

5. Future response prediction and error evaluation

The future response is estimated using the CSM, as shown in **Fig. 6**. There are two kinds of prediction corresponding to the conditions with or without updating.

Considering the S_d prediction of run n, the error E_{rn} is defined as

$$E_{rn} = \left|(d_{pr} - d_{re})/d_{re}\right| \tag{5}$$

where d_{pr} and d_{re} are the predicted and real S_d. Considering a set of predicted runs from n_1 to n_2, the average error E_a is defined in Eq.6 to evaluate the accuracy of the proposed method.

$$E_a = \sum_{n=n_1}^{n_2} E_{rn}/(n_2 - n_1) \tag{6}$$

Based on input parameters such as type of ground motion or differences in base shear strength, the average error E_a for the case with updating and without updating will be compared, further verifying the workability of the proposed updating method.

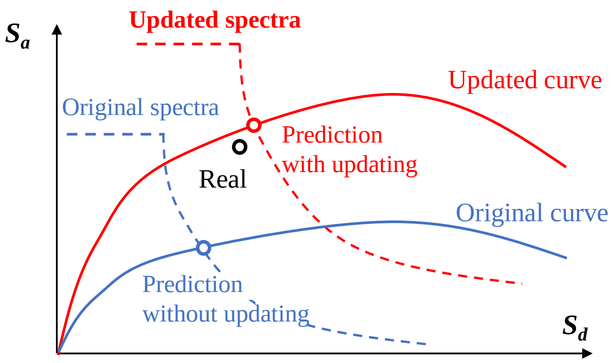


Fig.6 Prediction of future response using CSM

6. References

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1* 東北大学大学院工学研究科　教授・博士（工学）
2* 東北大学大学院工学研究科 博士課程後期
3* 東北大学大学院工学研究科 博士課程前期
4* 東北大学大学院工学研究科　研究員・博士（工学）
5* 大阪公立大学大学院工学研究科　准教授・博士（工学）
6* 建築研究所 特別客員研究員・工学博士

1* Professor, Graduate School of Eng., Tohoku Univ., Dr. Eng.
2* Ph.D. student, Graduate School of Eng., Tohoku Univ.
3* Master student, Graduate School of Eng., Tohoku Univ.
4* Research Fellow, Graduate School of Eng., Tohoku Univ., Dr. Eng.
5* Associate Professor, Graduate School of Eng., Osaka Metropolitan Univ., Dr. Eng.
6* Visiting Research Fellow, Building Research Institute, Dr. Eng.