RESPONSE VARIATION PHENOMENA IN LONG SPAN BRIDGES CONSIDERING MULTIPLE SUPPORT EXCITATIONS OF DIFFERENT SCENARIO EARTHQUAKES

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1. INTRODUCTION

Increase in engineering demand parameters (EDPs) is observed in long span bridges, under Multiple Support Excitations (MSE) effects. Extended research utilized the synthetic and historical seismic excitations to probe the MSE effects. The past research recognized the significance of employing actual onsite recorded input motions, to limit the uncertainty in seismic assessments. Few researchers utilized onsite recordings and revealed that the response discrepancy is associated to additional mode excitations, specifically to the lateral or antisymmetric modes. However, these studies are limited in number and the phenomena of response variations under diverse scenario earthquakes shall be further clarified. The scenario seismic events are described by three categories of the earthquakes in seismology. The first two categories are referred to the subduction zone type earthquakes with known or unknown source fault information, respectively. On the other hand, last category corresponds to the inland seismic events. Seismic excitations of different categories contain dissimilar seismic characteristics and their influence on the structural response need to be inspected. Nonetheless, relevant seismic data at the target location is often inadequate and a framework is also required to obtain on site realistic MSE related to each earthquake category.

2. FRAMEWORK TO OBTAIN ON SITE SIESMIC EXCITAIONS

2.1 Regional Ground Motion Simulation (RGMS) method

The scarcity of unavailable seismic data at target location is supplemented by Regional Ground Motion Simulation (RGMS) approach (Lu et al. (2021)). This method utilizes the real recorded seismic excitations from data repositories. The ground motion at the target location is generated using the records of the surrounding instrumented stations. The step-by-step procedure is listed in Fig. 1. The process preserves the original characteristics of the ground motion and limits the uncertainty in the structural analysis.

2.2 Spatially Variable Earthquake Ground Motion (SVEGM) models

The spatial variability of ground motions is represented by coherency function (Eq. (1)) which accounts for incoherency effects, wave passage effects and local site effects, respectively.

$$\gamma_{kl}(\omega)=\exp\left[-\left(\frac{\alpha d_{kl}\omega}{v_s}\right)\right].\exp\left(-i\frac{\omega d_{kl}}{v_{app}}\right).\exp\left\{-i\tan^{-1}\frac{\mathrm{Im}[H_k(\omega)H_l(-\omega)]}{\mathrm{Re}[H_k(\omega)H_l(-\omega)]}\right\} \quad (1)$$

Where, α is incoherency coefficient d_{kl} is distance between the support locations k and l, v_s is shear wave velocity, v_{app} is apparent wave velocity and $H_k(\omega)$, $H_l(\omega)$ are transfer functions accounting for local site effects. The details of the process of converting single time history to MSE using SVEGM models can be found in the reference (Konakli et al. (2012)).

To begin with the conversion process, the seismic time history from RGMS model is assumed at engineering foundation of one abutment. First, wave travel effects are incorporated to other supports. Next, the incoherency effects are considered. Lastly, the local site effects are included to obtain the time history at different support locations.

Step-1: Obtain the target spectra using Inverse Distance Weighted (IDW) method (d_i: distances from target site to surrounding stations, $S_i(T_j)$: 5% damped response spectra of records at surrounding stations)

$$S_o(T_j)=\frac{\sum_{i=1}^{n}\frac{1}{d_i}S_i(T_j)}{\sum_{i=1}^{n}\frac{1}{d_i}}$$

Step-2: Select time history of nearest station as a seed ground motion $f(t)$

Step-3: Get ratio of the target spectrum to the response spectrum of seed motion

$$R(T)=\frac{S_o(T)}{S_f(T)}$$

Step-4: Calculate wavelet coefficient of seed ground motion (s: scale p: shift)

$$C(s,p)=\int_{-\infty}^{\infty}f(t)\frac{1}{\sqrt{s}}\psi^*\left(\frac{t-p}{s}\right)dt$$

Mother wavelet:

$$\psi(t)=e^{-\zeta\Omega|t|}\sin(\Omega t)$$

Step-5: Perform inverse CWT

$$f(t)=\frac{1}{K_\psi}\int_0^{\infty}\left(\int_{-\infty}^{\infty}\frac{1}{s^2}R(T)C(s,p)\psi\left(\frac{t-p}{s}\right)dp\right)ds$$

$$K_\psi=\int_0^{\infty}\frac{|\psi(\omega)|^2}{\omega}d\omega<\infty$$

Step-6: Compare response spectrum of reconstructed signal with the target response spectrum, repeat until the desired matching is achieved.

Fig. 1 RGMS based method

3. TARGET BRIDGE AND NUMERICAL MODELING

The target bridge in this study is an 860 m long cable-stayed bridge in Japan. The details on the target bridge and numerical modeling can be found in reference (Waqas et al. (2020)). A validated fish bone finite element model of the target bridge was obtained as shown in Fig. 2. Comparative analysis of MSE and Synchronous Excitation (SE) was executed for three earthquakes of different categories and Peak Ground Acceleration (PGA) i.e. Miyagi (March 11,2011, category 1, PGA:

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2933.2 gal), Kanagawa (July 30, 2015, category 2, PGA:182.9 gal), and Chiba (July 23, 2015, category 3, PGA: 213 gal). In situ ground motions were obtained following the procedure described in section 2.

4. RESULTS AND DISCUSSIONS

Acceleration modal amplitudes at various locations of the target bridge, pertinent to different earthquake categories were compared. Consistent with the previous work, discrepancy in modal amplitudes under SE and MSE was observed and additional mode excitation in case of MSE was confirmed. For instance, the modal acceleration time histories at the tower top location (T1), for category 1 earthquake, are presented in Fig. 3. Modal amplitudes under MSE were found significantly larger than SE analysis for mode 5th, 10th, 17th and 19th. The vulnerability of these vibration modes was further clarified considering the influence from other scenario earthquakes. The Root Mean Square (RMS) of modal amplitude time histories was calculated, for both MSE and SE investigations. Then, the ratios of RMS from comparative analysis were obtained. Fig. 4 shows the surface plot of ratio of RMS, location of interest and mode of vibrations. The analysis results from each category of the earthquake are plotted in the same figure. Three surfaces fairly overlapped and noteworthy projections were observed against previously identified vibration modes, at practically all locations except T2 and A1. T2 and A1 are closed to the support level and smaller modal amplitudes were expected. For more elucidation, the ratios of RMS at the location T1 are shown in Fig. 5. The ratios for the critical modes of vibrations are approximately similar for category 2 and 3 earthquakes but, comparably larger for category 1 earthquake. This difference is believed to be attributed by larger PGA value of this earthquake. A vigilant observation of critical mode shapes, presented in Fig. 6, clarified that lateral or unsymmetrical modes were animatedly vibrated under MSE. Though various scenario earthquakes were employed with dissimilar seismic characteristics however, a recurrent outcome was gained showing the active contribution of these critical mode shapes in response amplification.

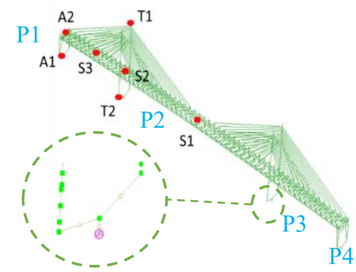

Fig. 2 Numerical model of the target bridge

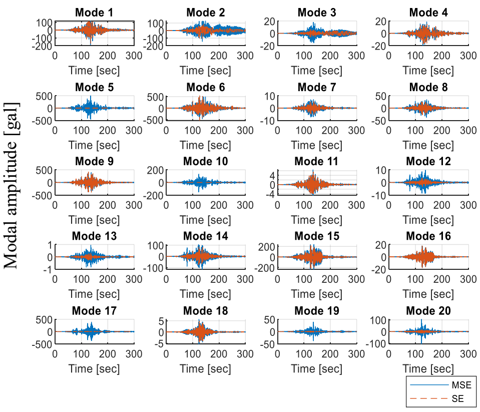

Fig. 3 Time history of acceleration modal amplitudes at T1

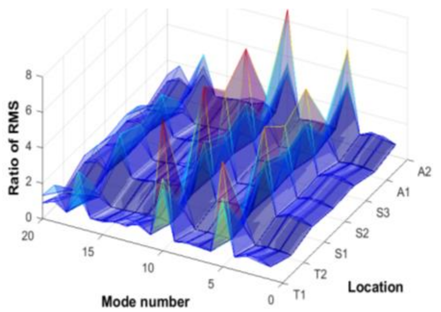

Fig. 4 Ratios of RMS for all three scenario earthquakes

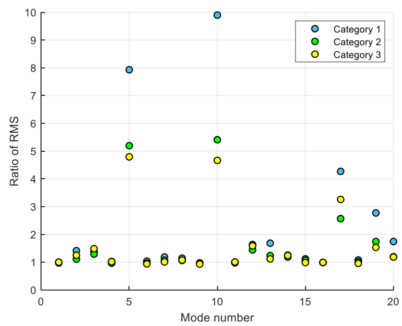

Fig. 5 Comparison of RMS ratios at T1

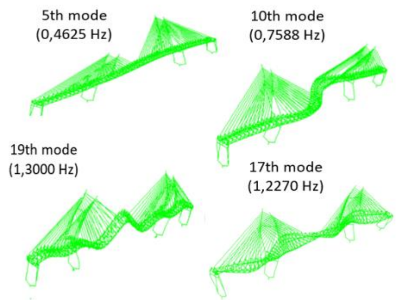

Fig. 6 Mode shapes with larger modal amplitudes under MSE

5. CONCLUSIONS

A cable-stayed bridge was considered to study the MSE effects. A framework was introduced to get real MSE ground motions at site for three scenario earthquakes of each category. The comparative analysis identified the phenomena of dissimilar mode excitation under MSE and vulnerable mode shapes, for all scenarios. It is anticipated that a cable-stayed bridge could experience response variations under MSE, due its inherent vulnerability of unsymmetrical mode excitations, regardless of the category of the earthquake being hit to the base of structure.

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