RESPONSE AMPLIFICATION DUE TO ANTI-SYMMETRIC MODES EXCITATION IN A CABLE-STAYED BRIDGE UNDER MULTIPLE SUPPORT EXCITATIONS

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1. BACKGROUND

Extended structures such as long-span bridges are subjected to Multiple Support Excitation (MSE) in contrast to the simplified design Synchronous Excitation (SE). Under MSE, bridge supports experience spatially variable ground excitations due to wave time lag, coherency loss and local site-amplification effects, resulting in dissimilar structural response. Modern seismic design codes are rather deficient to tackle this issue and additional research is indispensable. Extensive research has been carried out to investigate the MSE effects on bridges which has disclosed the response enlargement effects and increase in engineering demand parameters (EDPs). In the previous research, it is pointed out that the response amplification is linked to those modes (specifically the anti-symmetric ones) that usually are not excited by SE [1]. However, synthetic or spatially interpolated input motions were utilized and, bridges with simpler structural geometry and relatively shorter span lengths were considered [1][2]. Investigation of MSE effects on long-span bridges with real seismic records is also desirable for the development of a robust design framework to reliably estimate the EDPs.

2. TARGET BRIDGE AND RESPONSE MEASUREMENT

Target bridge is a three-span continuous cable-stayed bridge of 860 m length. The main girder is double-deck truss structure containing box section at the upper cord. Bridge towers are H-shaped rigid frame structures with a height of 172m. Bridge girder is hanged with towers by tower links which act like a pendulum and seismic isolation device to provide movements in both longitudinal and transverse directions. The bridge monitoring system consists of 85 different accelerometers having sampling frequency of 100 Hz. The sensors are mounted along the girder, on towers and piers, and in the ground and foundation levels. Fig. 1 shows the typical recorded input excitations to the target bridge from 2011 Great East Japan Earthquake. Overall, asynchronous motions were observed and spatial variation of recorded input excitations is quantified by means of arias intensities, I using Eq. (1).

$$I = \frac{\pi}{2g}\int_0^{to}[\,a(t)\,]^2 dt \tag{1}$$

Where, $\boldsymbol{a}$ is acceleration and $\boldsymbol{t_o}$ is total time duration. Fig. 2 shows the distribution of arias intensities. Observed MSE were found with time lag, coherency losses and diverse arias intensities which could influence the structural response and have potential to inflict detrimental effects.

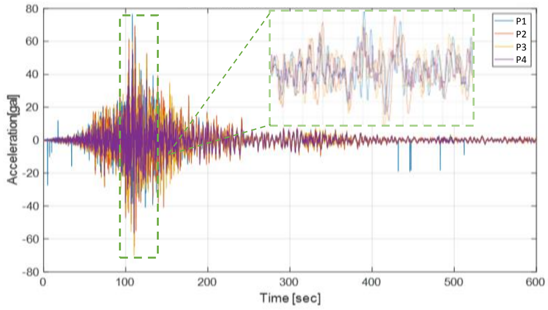

Fig. 1 Typical recorded input excitations at foundation level of piers, in longitudinal direction

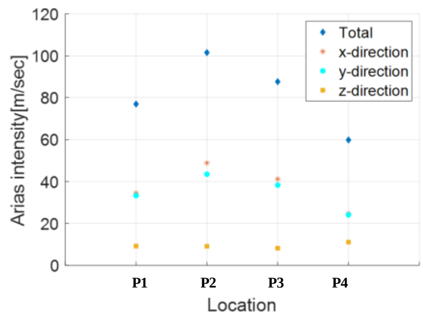

Fig. 2 Arias intensities at foundation level of piers

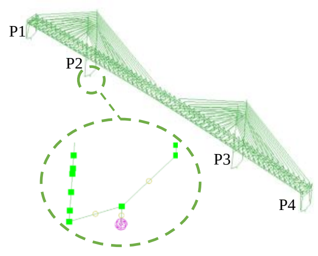

Fig. 3 Numerical model of target bridge

3. NUMERICAL MODELING

A fish bone finite element model of the target bridge comprising of beam elements and lumped masses, is constructed. Cables were modeled by tension-only truss members and deformation of the base structure is realized by SR springs. Fig.3 displays the numerical model of target bridge. Modal dynamic analysis approach using Large Mass Method (LMM) is applied for MSE and SE analyses. On-site recorded ground motions are employed for MSE analysis and a single uniform

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input excitation, matching with mean acceleration response spectra of all recorded motions, is applied as SE for rational comparison. This selected SE could induce average modal forces almost analogous to MSE [2]. Time domain and frequency domain response of MSE and SE analyses are compared at the bridge tower and girder. Next, Shear Force (SF) and moments (M) at pier ends were examined and the effects of MSE are evaluated by impact ratio, $\boldsymbol{\rho}$ (ratio of maximum absolute response from MSE and SE) using Eq. (2).

$$\rho = \frac{(Absolute\ maximum\ response\ )_{\mathbf{MSE}}}{(Absolute\ maximum\ response\ )_{\mathbf{SE}}} \tag{2}$$

4. RESULTS AND DISCUSSIONS

Bridge response at various locations is examined and discrepancies in response were observed through the comparative analysis. For instance, Fig 4 illustrates the mid span response of the girder in lateral direction exhibiting response amplification at several instances under MSE. Fourier amplitudes of mid span response is further explored to clarify the mechanism. Fig. 5 show that the amplitude of MSE response exceeds the SE response at various frequencies which contributes to the response amplification. This amplification in frequency ranges of 0.41 to 0.65 Hz and 1.43 to 1.8 Hz correspond to the lateral anti-symmetric modes whereas, it is associated with the longitudinal anti-symmetric modes in frequency range of 1.18 to 1.28 Hz. Some higher symmetric modes are also excited in MSE after the frequency of 1.8 Hz.

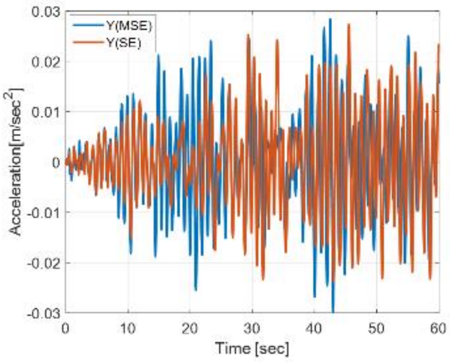

Fig. 4 Mid span response of the girder

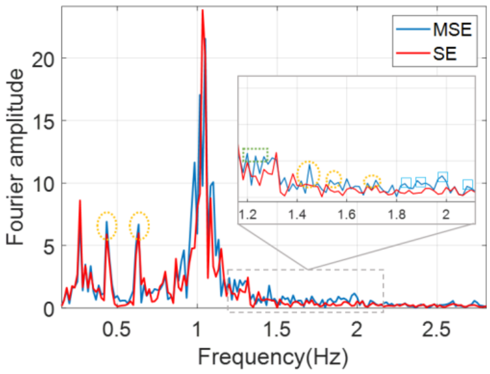

Fig. 5 Fourier amplitudes at mid span

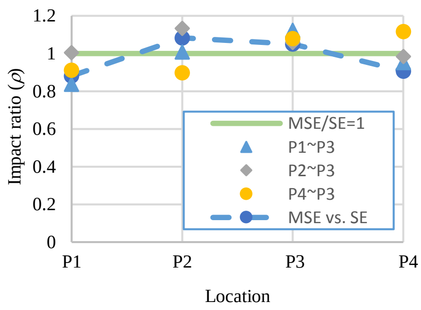

Fig. 6 Pier end moment impact ratio

Next, impact ratios for pier end moments and shears are estimated as shown in Fig. 6 and Fig. 7, respectively. The values of impact ratios for intermediate piers are found greater than unity showing detrimental effects of MSE. Further, input excitations at each pier locations were replaced with one used for SE analysis (P3 excitations) to perform the sensitivity analysis. For example, case P1~P3 describes the analysis case where input excitations of pier 1 are replaced with those at pier 3 and so on. Altering input motions in MSE analysis showed the sensitivity of impact ratios to the input excitations. Like, replacing P4 input excitations with P3 (P4~P3 case) increased the MSE effects both on pier 4 and pier 3, compared to the previous direct MSE vs. SE analysis. And, $\boldsymbol{\rho}$ values greater than unity for edge piers were obtained suggesting that the detrimental MSE effects are not only limited to the intermediate piers but also could extend to the edge piers as well.

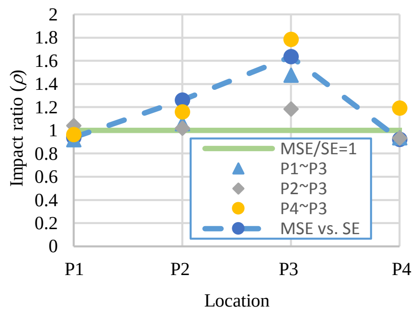

Fig. 7 Pier end shear impact ratios

5. CONCLUSIONS

A cable-stayed bridge was analyzed with actual earthquake records to investigate the effects of MSE. Arias intensities of recorded input excitations elaborated the variability of input excitations. Comparison of MSE and SE analyses disclosed the increase in engineering demands under MSE and clarified the contribution of anti-symmetric modes as well as some higher symmetric modes to induce the response amplifications. Estimates of impact factors indicated the detrimental effects of MSE on intermediate piers. Moreover, sensitivity analysis revealed the influence of MSE on edge piers too. Additional work is necessary to aid the current seismic design codes for MSE records selection and estimation of engineering demand parameters with limited uncertainties and enhanced confidence.

REFERENCES

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