TRANSIENT RESPONSES OF GIRDER BRIDGES WITH POUNDINGS UNDER NEAR-FAULT VERTICAL EARTHQUAKES

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Summary By the expansion of transient wave functions in a series of eigenfunctions, the transient responses of a two-span bridge with elastic poundings under near-fault vertical earthquakes is solved. The numerical example shows that the present method can simulate reasonably the pounding phenomenon between girder and pier. The pounding force, bridge responses and the waves induced by poundings can be calculated.

INTRODUCTION

The pounding phenomenon [1-2] of bridges during earthquakes is of great interest in science and engineering. The pounding under horizontal earthquake excitation between superstructure segments or segments and abutments are usually investigated by the multiple-degree-of-freedom lumped mass model [3-4]. The pounding phenomenon of bridges excited by vertical earthquake is less studied because the vertical earthquake excitation is usually considered to be less important, but the records of near-fault earthquakes showed the large vertical ground motions and serious bridge damages [5-7]. Hence, in the present paper, the transient responses of girder bridges with possible poundings under near-fault vertical earthquake are solved by the expansion of transient wave functions in a series of eigenfunctions.

MECHANICAL MODEL

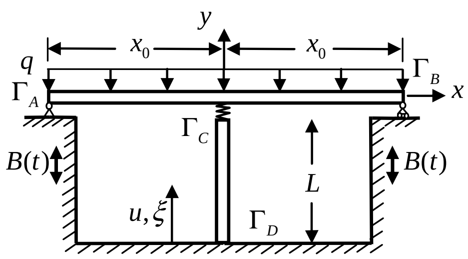

Fig. 1 Model of two-span continuous bridge

The two span continuous beam bridges with elastomeric bearings are investigated in this paper. The mechanical model as shown in Fig. 1 consists of a Bernoulli-Euler beam, a St. Venant rod and a spring modelled the elastic bearing with the stiffness *k*. The beam has the area of cross-section *A*, Young's modulus *E*, area moment of inertia *I* and mass density ρ.The rod has the area of cross-section A_r, Young's modulus E_r and mass density ρ_r. The gravity of the bridge applies upon the beam with a linear loading *q*. The vertical ground motions *B*(*t*) is excited by near-fault vertical earthquakes.

SOLUTION

The equations of motion of the beam and the rod are, respectively,

$$\rho A\ddot{y} - \nabla\cdot\nabla\cdot M_b = q, \quad \rho_r \ddot{u} - \nabla\cdot\sigma_r = 0 \tag{1}$$

The boundary conditions are

$$y = B(t) \text{ and } M_b = 0, \text{ on } \Gamma_A \text{ and } \Gamma_B \quad u = B(t), \text{ on } \Gamma_D \tag{2}$$

The initial displacement distribution and initial velocity distribution are

$$y(x,0) = [q(-5x_0^4 + 6x^2x_0^2 - x^4) - 2F_s(2x_0^3 - x^3 - 3x^2x_0)]/24EI, \quad u(\xi,0) = F_s\xi/E_rA_r, \quad \dot{y}(x,0)=0, \quad \dot{u}(\xi,0)=0 \tag{3}$$

The pounding condition of the beam and the rod is

$$u - y = -E_rA_ru'(L,t)/k, \text{ on } \Gamma_C \tag{4}$$

Where $y(x,t)$ the beam deflection, $u(\xi,t)$ the longitudinal displacement of the rod.

By the use of the expansion of transient wave functions in a series of Eigenfunctions [8], the transient responses of the bridge are solved. The solution is divided into two parts. The first part is the quasi-static solution and the second part is the dynamic solution.

$$\mathbf{u}(\mathbf{x},t) = [y(x,t), u(\xi,t)]^T, \quad \mathbf{u}(\mathbf{x},t) = \mathbf{u}_s(\mathbf{x},t) + \mathbf{u}_d(\mathbf{x},t) \quad t\in[0,\infty], \quad \mathbf{u}_d(\mathbf{x},t) = \sum q_n(t)\,\boldsymbol{\varphi}_n(\mathbf{x}) \tag{5}$$

Where $\boldsymbol{\varphi}_n(\mathbf{x}) = [\varphi_{bn1}, \varphi_{bn2}, \varphi_{rn}]^T$ are the wave mode functions of beam and rod. The wave modes are governed by the eigenvalue problem. Their orthogonality relations are

$$\int_{-x_0}^{0} \rho\varphi_{b1i}\varphi_{b1j}A dx + \int_0^{x_0} \rho\varphi_{b2i}\varphi_{b2j}A dx + \int_0^L \rho_r\varphi_{ri}\varphi_{rj}A_r d\xi = \delta_{ij} \tag{6}$$

Use the orthogonal condition and Laplace transforms, the time functions $q_n(t)$ are solved as the followings:

$$q_n(t^*) = q_n(0)\cos(\omega_n t^*) + \dot{q}_n(0)\sin(\omega_n t^*)/\omega_n + \int_0^{t^*} \ddot{Q}_n(t_{2k}+\tau)\sin(\omega_n\cdot(t^*-\tau))\mathrm{d}\tau \Big/ \omega_n \tag{7}$$

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Where $t^* = t - t_{2k}$ is the time variable of the k times pounding phase and t_{2k} is the initial time of the k times pounding phase. $q_n(0)$ and $\dot{q}_n(0)$ are determined by the initial displacement and velocity distributions, which are the remaining distributions at the moment of the ending of the previous phase. In this paper, the remaining response distributions of the previous separation phase can be considered, so the continuous calculation from separation phase to pounding phase is done. The pounding force is the internal pressure along the axis of the rod at the rod end is

$$P(t) = \iint_{\Gamma_c} \sigma_r dA \tag{8}$$

NUMERICAL RESULTS AND DISCUSSION

An example is showed in this Section. The girder has E = 34.5 GPa, ρ = 2600 kg/m^3, A = 6.4 m^2, I = 3.51 m^4, x_0 = 38 m and $q = 2.5\times10^5$ N/m. The pier has E_r=31.7 GPa, ρ_r = 2600 kg/m^3, A_r = 3.0772 m^2 and L = 5.2 m. The earthquake cycle T = 0.3 s and the acceleration of vertical earthquake a = 3.4 m/s^2.The main ground motions $B(t) = -0.00776 \sin(20.93t)$. Fig. 2 shows the girder and pier don't separate when the stiffness of linear elastic spring $k = 2.0\times10^8$ N/m, but when $k = 2.0\times10^9$ N/m, there are six poundings in two seconds. The first separation in t_1=0.52298s, the first pounding in t_2=0.57307s, the maximum pounding force is 25.2MN taken placed in first pounding. Fig. 3 shows the time history of girder middle deflection and pier top displacement in different stiffness of spring. The separation phase can be clearly appeared. Fig.4 and Fig.5 show, respectively, the propagations of the transient waves of shear force start from the vertical earthquake excitation and the first pounding. It is demonstrates clearly that the present method can depict the propagations of the pounding-induced transient waves.

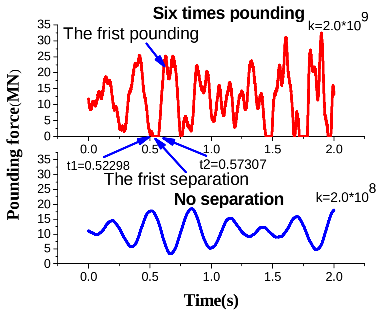

Fig. 2 Time history of multiple-pounding force

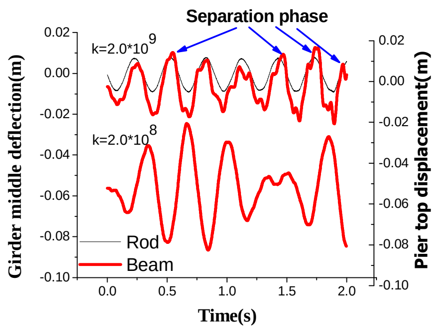

Fig.3 Time history of girder middle deflection and pier top displacement

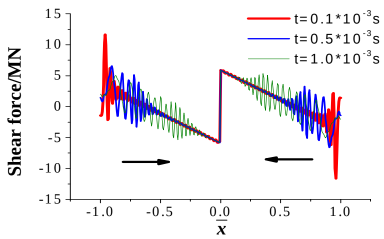

Fig.4 Beam shear force wave propagation

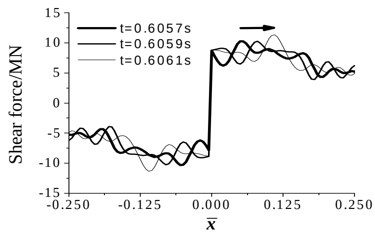

Fig.5 Beam shear force wave propagation induced by the first impact

CONCLUSIONS

The present investigations show that the expansion of transient wave functions in a series of eigenfunctions can be applied to the pounding problems in bridges under near-fault vertical earthquakes, and obtain transient responses of the bridge and the pounding wave propagations.

References

[1] Earthquake Engineering Research Institute (EERI).: Northridge earthquake reconnaissance report [R].Oakland, CA, Rep, No.95-03, 1995.

[2] Earthquake Engineering Research Institute (EERI).: 1999 Chi-Chi, Taiwan earthquake reconnaissance report[R].Oakland, CA, Rep, No.01-04, 2001.

[3] Pantelides C P., Ma X.: Linear and nonlinear pounding of structural systems [J]. *Computers and Structures*. 66: 79–92, 1998.

[4] Jankowski R., Wilde K., Fujino Y.: Pounding of superstructure segments in isolated elevated bridge during earthquakes [J]. *Earthquakes Engineering and Structural Dynamics*. 27: 487-502, 1998.

[5] Papazoglou A J., Elnashai A S.: Analytical and fileld evidence of the damaging effect of vertical earthquake ground motion [J]. *Earthquake Engineering and Structural Dynamics*. 25: 1109-1137, 1996.

[6] Sashi K. Kunnath., Emrah Erduran., Y.H. Chai., and Mark Yashinsky.: Effect of near-fault vertical ground motions on seismic response of highway overcrossings [J]. *Journal of Bridge Engineering*. 13:282-290, 2008.

[7] Shinji Tanimuraa., Takashi Satob., Tsutomu Umedaa., Koji Mimuraa.: A note on dynamic fracture of the bridge bearing due to the great Hanshin－Awaji earthquake [J]. *International Journal of Impact Engineering*, 27: 153-160, 2002.

[8] Yin X C., Qin Y., Zou H.: Transient responses of repeated impact of a beam against a stop [J]. *International Journal of Solids and Structures*. 44: 7323-7339, 2007.