Engineering Structures 31 (2009) 2554–2567

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

The response of a 344 m long bridge to non-uniform earthquake ground motions

J. Wang [a], A.J. Carr [b], N. Cooke [b,*], P.J. Moss [b]

[a] Sawrey Consulting Engineers Ltd, Wellington, New Zealand

[b] Department of Civil Engineering, University of Canterbury, Christchurch, New Zealand

ARTICLE INFO

Article history:
Received 30 March 2007
Received in revised form
18 May 2009
Accepted 19 May 2009
Available online 7 July 2009

Keywords:
Seismic response
Long bridges
Ground motions
Dispersion
Spatial variation
Expansion gaps
Pier hinging
Pier drifts

ABSTRACT

This paper investigates the influence of wave velocity and the dispersion of waves associated with variations in seismic ground motions, on the inelastic responses of four 344 m long bridges. The bridges were 9 span continuous prestressed concrete box girders supported on sliding bearings, which eventually permitted movement in the longitudinal direction of the bridges, with shear keys that prevented transverse movement. The sub-structure consisted of reinforced concrete circular piers with cross-heads and rigid beams at the abutments. Earthquake motions were applied in the transverse direction for two bridges and for two others, with two expansion joints, the motions were applied longitudinally. The analyses of the latter were carried out to examine expansion gap movements and all analyses were carried out to produce time-history responses of pier drift, pier shear forces and pier curvature demands. The reinforcement in the piers was modelled so that either one base hinge can form or one base hinge with a hinge at the top of the pier. Pier heights varied between 5 m and 11 m or, for one bridge, were of constant height of 11 m. The non-uniform earthquake inputs at supports were generated by using the conditional simulation method with a natural earthquake record specified at one abutment. The response to wave velocities from 100 to 2000 m/s and infinity were studied both without dispersion and with various degrees of dispersion. The El Centro 1940 N–S and Sylmar Northridge 1994 N–S were used as the transverse earthquakes and the E–W components were used longitudinally. The results of these analyses show that non-uniform earthquake ground motions significantly influence the response of long bridges both with and without expansion joints. The responses change significantly with travelling wave velocity and the degree of dispersion and these can be more critical than for uniform inputs. Significant dispersion can generate rotational inertia of the deck and, with the torsional stiffness of the deck, can lead to the formation of top and bottom pier hinges and significantly larger shear forces compared to the normal cantilever design of these types of bridge piers.

© 2009 Elsevier Ltd. All rights reserved.

1. Introduction

The fact that spatial variation of earthquake ground motions affects the response of extended structures was recognised a number of decades ago, e.g. Bayrak [1]. However, the spatial variability was attributed only to the "wave passage effect", where it is assumed that the bridge response is solely due to the difference in arrival time at each support of an unmodified ground motion. With the installation of the strong motion arrays and the analyses of the recorded data, especially from SMART-1 array, see Abrahamson et al. [2], it was realised that the earthquake waves not only propagate on the ground surface but also change in shape due to reflections, refractions and superposition of waves in the soil. Saxena et al. [3] have reported on the effect of spatial variation of earthquake ground motions on the non-linear dynamic response of two bridges, TY0H and the Santa Clara Bridge. They studied the response of the bridges supported on the same local soil conditions and then different ones at each support. They found that the soil differences were more significant than the wave passage effect, except for low velocities applied to the long Santa Clara Bridge. They quote responses for wave velocities of 1000 m/s although work had been done on 300 m/s. Dumanoglu and Soyluk [4], Soyluk [5] and Lin et al. [6] investigated the effect of spatially varying ground motions including the effect of wave passage, the incoherence of the support motions, and site response. The structures studied were long span cable stayed bridges analysed in the frequency domain to determine their linear, elastic behaviour. The continuous, multi-span bridges considered in this paper were expected to behave in a non-linear, inelastic manner (i.e. with some plastic hinging) and consequently, a different approach was necessary involving dynamic analysis in the time domain.

The responses of bridges subjected to non-uniform inputs consist of a dynamic component, induced by the inertial forces, and a pseudo-static component resulting from the differential

* Corresponding author. Tel.: +64 3 366 7001; fax: +64 3 364 2758.
E-mail address: nigel.cooke@canterbury.ac.nz (N. Cooke).

0141-0296/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engstruct.2009.05.022

displacements between the adjacent supports. This paper shows that the response of long continuous bridges is dominated by the pseudo-static component when the travelling wave velocity is small and the dynamic component becomes more dominant as the travelling wave velocity increases. In addition, it clearly shows the importance of providing sufficient pier shear reinforcement when a bridge is subjected to large relative inter-pier base displacements associated with dispersion. Bridge 1 was designed for plastic hinging at the top and bottom of the piers after it was realised that shear forces in Bridge 2, designed on the normal cantilever basis, had been subjected to shear forces considerably in excess of those associated with normal practice. Bridge 1 pier design resulted in greater control of shear forces and minimised the risk of disastrous shear failure. Two expansion joints were inserted into each of the decks of Bridges 3 and 4 and the results indicate that the expansion joint movements associated with dispersion can be much larger than for the wave passage only and therefore require larger joint restraints and larger seating than provided for the wave-passage effect. All four bridges were modelled with expansion joints at the abutments and that movements were unrestricted by an abutment structure. The exception is that Bridge 2 was fixed in the longitudinal direction at one end. Soil-structure interaction was not considered in any of these analyses. Only the horizontal components of the earthquake records were used, rather than including vertical components, as these provide the greatest transverse and longitudinal pier response, and give an indication of expansion joint displacements that lead to possible unseating, two objectives of this research.

The bridge modelled by the authors consisted of a 9 span continuous pre-stressed concrete box girder supported on longitudinally sliding bearings and transverse shear keys on single reinforced concrete piers with a cross-head. Analyses were carried out to produce time-history responses of pier drift, pier shear forces and pier curvature demands. The response parameters investigated in this research were the maximum pier drifts, where 'drift' is defined as the deflection of the top of a pier relative to the base, the drift ratio i.e. the ratio of the drift to pier height expressed as a percentage, the maximum pier shear forces, and the maximum section curvature ratios of the piers, i.e. the ratio of the curvature demand at the base of a pier divided by the section yield curvature.

The reinforcement in the piers was modelled in two ways. First, because of the possibility of large rotational and torsional inertias of the deck associated with large dispersion of the earthquake ground wave as it moves along the bridge, confinement reinforcement is provided at the top of the pier as well as the bottom (Bridge 1) so that plastic hinges can form with double curvature in the pier. Secondly, the piers were designed in the normal manner, i.e. the pier is assumed to act as a cantilever, with confinement reinforcement provided so that a plastic hinge can form at the base only and the remainder of the pier behaves elastically with shear reinforcement provided on this basis (Bridges 2, 3 and 4). The first situation is associated with shear forces that are double the second case so more shear reinforcement would have to be provided than is normal. Pier heights varied between 5 m and 11 m. The El Centro 1940 N–S and the 1994 Sylmar Northridge earthquake acceleration records were applied in the transverse direction.

Two further analyses were carried out on Bridges 3 and 4, those with two expansion joints inserted in the deck, and in these cases the earthquakes were applied in the longitudinal direction so that longitudinal expansion joint movement could be studied as well as the longitudinal pier response. Bridge 4 model had variable height piers and Bridge 3 had constant 11m high piers. The E–W acceleration records of El Centro 1940 and Sylmar Northridge 1994 were used for these analyses.

Collapse of bridges with expansion joints by girder unseating have been observed in many earthquakes, e.g. the San Fernando and Northridge earthquakes to name but two, so the maximum relative longitudinal displacement of the bridge deck across the expansion joints and the maximum relative longitudinal displacement between the girder end and the top of the abutment are investigated here. For these bridges, relative joint displacements consist of (Wang [7–9]) a dynamic component due to the inertia effects arising from the difference between the vibrations of the two adjacent frames separated by the expansion joint, and a pseudo-static component caused by the time delay between the vibrations of the separated frames. The dynamic component is affected by the stiffness and the yield strengths of the frames, the frictional restraint of sliding, the impact on closing the joints, and the characteristics of restrainers connecting the frames as described by Priestley et al. [10]. The pseudo-static component is dominated by the fact that the separated frames vibrate out of phase with each other.

In summary, the objectives of the study were to investigate the effect of non-uniform earthquake ground motions on a long bridge taking into account the influence of the travelling wave acting on its own, and the effect of dispersion of the travelling wave. Two slightly different structures were analysed under transverse earthquake ground motions and two different structures each incorporating two expansion joints were analysed under longitudinal ground motions.

2. The analytical method

Recent work has concentrated on the development of fragility curves for assessing the vulnerability of bridges e.g. by Mander [11] and the use of a Monte Carlo simulation for production of the fragility curves, for example, by Kim and Shinozuka [12], but this approach cannot be used to find out the effect on bridge response to a wave travelling along a bridge modified with time and distance from a starting point, i.e. with dispersion of the earthquake ground wave. However, some assessment of the damage state from the ductility demands on the bridges analysed by the authors can be made using Table 1, from Sang-Hoon Kim and Feng [13], based on Dutta and Mander [14].

A simple method of generating the non-uniform input motions, taking these effects on the recorded time-histories into account, has been developed by Wang [7,9] and is summarised in Appendix A. This is based on two assumptions; first that the spatial correlation function depends only on the predominant frequency of the earthquake motion and second that there is no correlation in the time domain between the acceleration elements in the same record. With the aid of these two assumptions, the modified Kriging method proposed by Hoshiya [15,16] and Hoshiya and Ishii [17] was used to simulate ground motions in the time domain and a wave dispersion factor 'd' was developed to take into account the variability of the motions. The smaller the value of 'd', the more dispersion takes place; the larger the value of 'd' the more uniform is the motion. The factor 'd' scales the accelerations associated with the ground motion but the acceleration response spectra of the earthquake does not change.

The spatial variability of the earthquake motion is generally obtained from the time domain analyses of the recorded data, and is usually described by a function that decays exponentially with separation distance and frequency as described by Hoshiya and Ishii [17], Janowski and Wilde [18], Der Kiureghian and Neuenhofer [19], Luco and Wong [20], Vanmarcke [21] and Zerva and Shinozuka [22]. The autocorrelation function $R_{ij}\xi_{ij}$ adopted by the authors is that of Janowski and Wilde [18] (see also Appendix A), based on that by Zerva and Shinozuka [22], has the negative exponential form:-

$$R_{ij}(\xi_{ij}) = \sigma^2 \exp\left(-\frac{\omega_d \left|\xi_{ij}\right|}{2\pi v d}\right) \quad (1)$$

Download English Version:

https://daneshyari.com/en/article/268841

Download Persian Version:

https://daneshyari.com/article/268841

Daneshyari.com