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Seismic Design Load for Highway Bridges

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ABSTRACT

The effects of local soil condition and characteristics of input ground motions are major concerns in seismic resistant design of bridges. This paper presents the results of a study on seismic design load for a highway bridge, taking into consideration the effects of different soil profiles and depths. The soil effects and the dynamic response of the bridge are quantified by response spectra analyses. The calculated seismic design loads are compared with the code values as specified in the OHBDC (1991)

INTRODUCTION

The dynamic behaviour and performance of highway bridges under seismic loads are subjects of major concern to bridge engineers in seismic active areas. This is particularly more so in view of the extensive damage suffered by many highway bridges in recent earthquakes. Consequently, there is a strong need to examine the safety of many existing bridge structures and to reconsider the adequacy of the seismic design load specified in current highway bridge design codes.

The dynamic response of highway bridges under earthquake loads can be significantly affected by local soil conditions. The seismic design loads depend not just on the intensity and characteristics of the input bedrock ground motions, and the properties of the bridge structures, but also on the local soil amplification effects on the surface ground motions. Studies and experiences from recent major earthquakes have shown that the amplification effect is strongly influenced by the type and depth of the soil in the soil profile at the site. Bridges built on soft clay are particularly susceptible to earthquake damage. One of the lessons form the 1989 Loma Prieta earthquake is that the damaged bridge locations are strongly correlated with the presence of soft soil at the sites (Mitchell et al. 1991).

In the current edition of the highway bridge design code OHBDC(1991), the seismic design load is determined by means of the response coefficient C, which is a function of the fundamental period of the bridge superstructure, the zonal velocity ratio v, and the depth of the alluvium fill at the site. The amplification effects related to the soil type, which may significantly influence the site response, are not considered.

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The objective of the present study is to determine and quantify the influence of different soil profiles on the seismic design loads for highway bridges, and to compare the calculated load values with the OHBDC(1991) seismic load requirements. The response spectra at the ground surface level are first generated for different soil profiles using the computer program FLUSH. The soil amplification effect and the dynamic response of the considered highway bridge are then determined by response spectrum analysis techniques using the computer program NEABS-II (Imbsen and Penzien 1986). It is assumed in the present study typical short to medium span bridges are not heavy structures, so that the soil-structure interaction effect can be safely neglected without any seismic energy feedback from the bridge to the soil.

SEISMIC GROUND MOTIONS

In this study, it is assumed that the highway bridge considered is located in eastern Canada. Consequently the earthquake records selected are representives of seismic events in the region with high frequency content or high a/v ratio (Basham et al. 1985). All the selected ground motions are scaled to an intensity level expected at Ottawa of a peak ground horizontal acceleration (PHA) of 0.2g and peak ground horizontal velocity (PHV) of 0.10 m/s.

Because earthquakes are random processes in the nature, a group ground motion records from recent significant earthquakes in Canada and United States, with a relevant range of variation in characteristics are selected as input motions in the present study. Description of the selected records are listed in Table 1. The time history of the ground motion accelergrams are shown in Figure 1.

SOIL MODELS

In the study, three different depths for the soil profile are considered: 15m, 25m, and 45m. Soil stiffness is an important parameter which can significantly affect the shaking at the ground surface as the bedrock motions propagate upwards through the soil deposit . Therefore, for each soil deposit depth, three different sets of soil properties, representing soft, firm, and stiff soils, are considered. Shear modulus value of 58, 120, and 168 MPa are chosen as representive stiffness for soft, loose and stiff soil.

Free field seismic excitations on the ground level due to shear waves propagating upwards from the bedrock are determined using the computer program FLUSH (Lysmer et al. 1975). The nonlinear behaviour of the soil layer is considered in the analysis by an equivalent linear model, which continually updates the dynamic properties of shear modulus and damping ratio with respect to the effective shear strain amplitudes as the shaking progresses. A 5% damping ratio is assumed for the bridge structure in the analysis.

BRIDGE MODEL

The bridge considered in this study is a two span slab on girder bridge, as shown in Figures 2 (a) and (b). This type of bridge is very common for highway crossing. The bridge deck considered is a composite concrete slab on steel girder with a total length of 80.6 m. The deck superstructure is continuous with no intermediate expansion joint. It is supported by hinge bearings on a single column pier at the mid-span of the deck, and roller bearings on the two abutments.

The bridge is modelled by three-dimensional finite elements. The rollers at the abutments are free to move in the x-direction, and to rotate about the y-axis. The finite element model for the bridge is shown in Figure 2 (c).

NUMERICAL RESULTS

The soil effects are quantified by means of the soil amplification factor. For each consideration of the soil deposit profile and input ground motion considered, the ratio of the response spectrum of the free field motion on the ground surface to the corresponding spectrum due to the input motion at the bedrock level is defined as the site amplification factor (SAF). This factor provides an indication on the significance of the soil effects at the site. The analysis results indicate that soil deposit can greatly amplify the ground motions on the surface felt by the bridge superstructure. Figure 3 shows the variation of the soil amplification factor as function of the variation period of the bridge structure for all the cases. For the case of soil depth of 15m, the bridge dynamic response is significantly amplified between the period 0.1 to 1.0 second, whereas for the soil depth of 25m, the high amplification range is between 0.2 to 1.5 second, and for the soil depth of 45m between period 0.3 to 1.5 second. The peak SAF can be as high as 8 because of resonance of the bridge with the underlaying vibrating soil. At long period the average SAF is only about 1.5 to 3.

The dynamic response of the slab-on-girder bridge is evaluated for each soil cases. The maximum envelop and the mean of the surface response spectra are used as input in the bridge analysis. The natural period of the bridge is determined to be 0.6 second. The seismic design lateral force at the base of the pier is obtained by CQC modal combination procedures using the 30 lowest vibration modes. The calculated seismic design base shear of each soil case is compared with the design code value specified in the OHBDC (1991). The ratio of the maximum base shear, V, to the directional weight of the bridge, W_d, is compared with the seismic response coefficient C in the code. The results are shown in Table 2. The factor $V/(W_d \times C)$ are greater than one for all the cases considered, from 1.1 to 7.7.

CONCLUSIONS

The dynamic responses of a two span slab-on-girder bridge subjected to earthquake ground motions, taking into consideration the amplification effects of different type and depth of soil, have been investigated. The seismic base shear values determined from dynamic analyses are found to be greater than the design code values, which indicates that the seismic load provisions in the current design code for the considered bridge may not be conservative. However, the effect of ductility of the bridge during strong ground motions has not been included in this study. Therefore, in order to more accurately determine the adequacy of the seismic load provisions in the current design code for highway bridges, more detailed studies are needed.

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Table 1 Ground Motion Records Used for Response Spectra Analysis

No.	Earthquake name	Station Name	Date	PHA	PHV	Site Cond.
1	Saguenay Qub.	Chicoutimi-Nord	Nov. 25, 1988	0.131	0.025	Rock
2	Nahanni N. W. T.	Site 1, Iverson	Dec. 23, 1985	1.101	0.462	Rock
3	Parkfield Calif.	Temblor No. 2	June 27, 1966	0.434	0.255	Rock
4	Helena Montana	Carrol College	Oct. 31, 1935	0.146	0.072	Rock

Table 2 Pier Base Shear and the Factor of Base Shear to Directional Weight

Cases	Load Direction	Envelop of Input Spectra		Mean of Input Spectra		OHBDC Resp. coeff. C	Max.	Mean
		Base Shear V (KN)	V / W_d	Base Shear V (KN)	V / W_d		$\frac{V}{W_d \times C}$	$\frac{V}{W_d \times C}$
Bedrock	L	871	0.14	692	0.11	0.06	2.3	1.8
	T	610	0.12	380	0.08	0.06	2	1.3
Soft Soil	L	23414	0.76	19498	0.63	0.10	7.6	6.3
d = 15m	T	5817	0.25	4531	0.19	0.10	2.5	1.9
Soft Soil	L	14863	0.48	10132	0.33	0.10	4.8	3.3
d = 25m	T	14678	0.63	7778	0.33	0.10	6.3	3.3
Soft Soil	L	NA	NA	8766	0.28	0.11	NA	2.5
d = 45m	T	12002	0.39	6447	0.28	0.11	3.5	2.5
Firm Soil	L	13299	0.43	9176	0.29	0.10	4.3	2.9
d = 15m	T	11687	0.51	6794	0.29	0.10	5.1	2.9
Firm Soil	L	6019	0.19	5063	0.16	0.10	1.9	1.6
d = 25m	T	3945	0.17	2622	0.11	0.10	1.7	1.1
Firm Soil	L	6537	0.21	5555	0.18	0.11	1.9	1.6
d = 45m	T	5326	0.23	3455	0.15	0.11	2.1	1.3
Stiff Soil	L	15598	0.5	14629	0.47	0.10	5.0	4.7
d = 15m	T	4570	0.2	3579	0.16	0.10	2.0	1.6
Stiff Soil	L	5376	0.18	4719	0.15	0.10	1.8	1.5
d = 25m	T	5420	0.23	3300	0.14	0.10	2.3	1.4
Stiff Soil	L	26134	0.85	21320	0.69	0.11	7.7	6.2
d = 45m	T	7331	0.31	5398	0.23	0.11	2.8	2.0

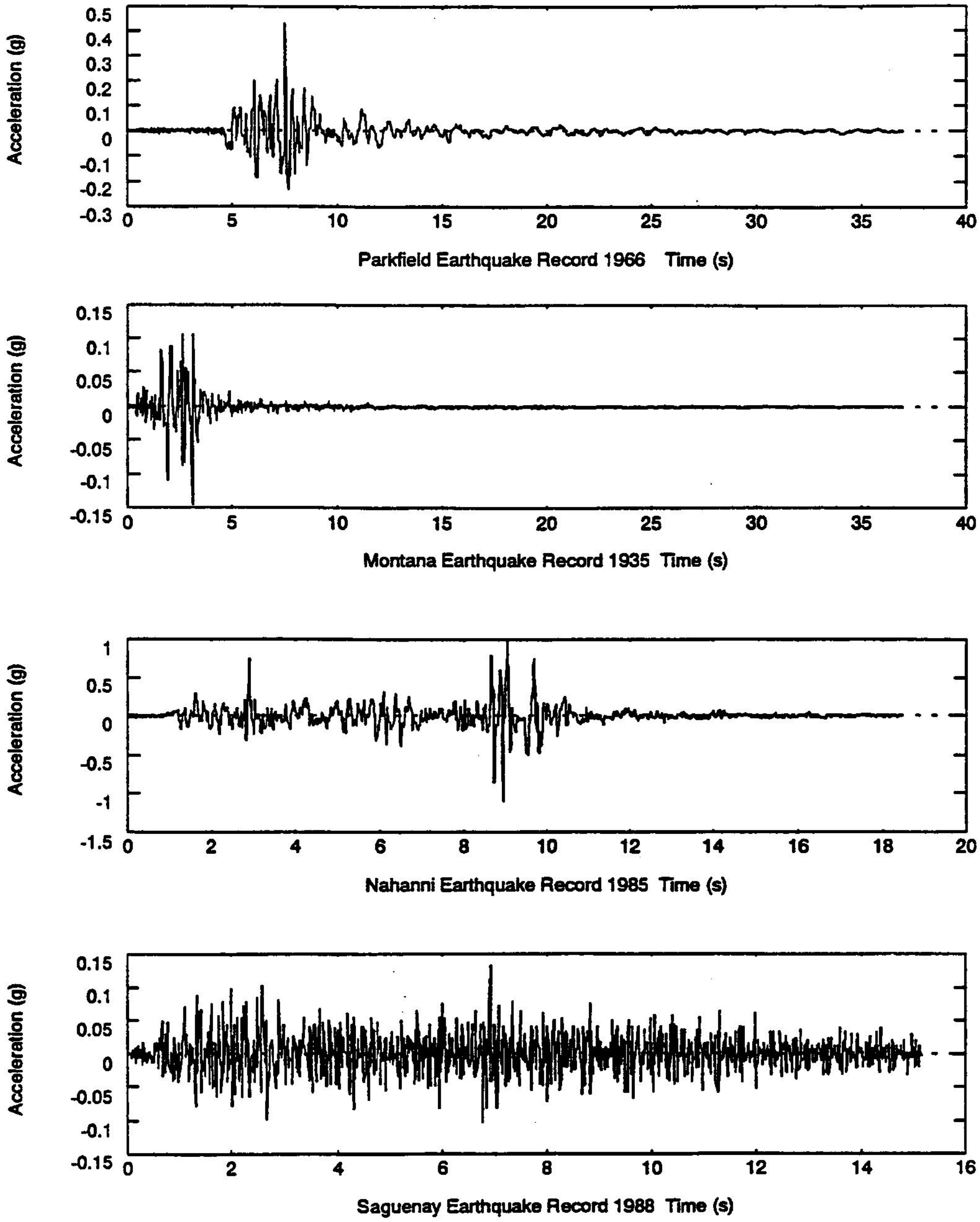
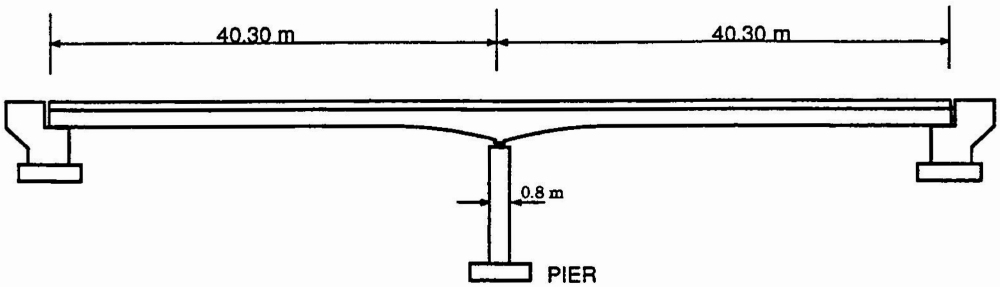
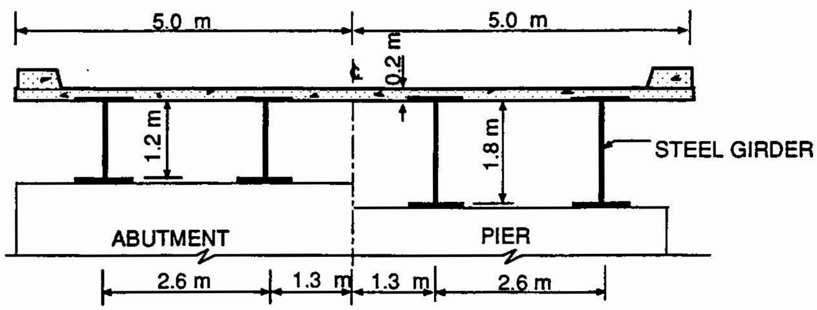


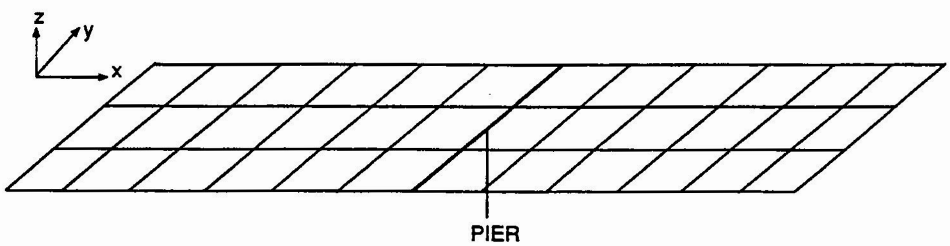
Figure 1 Time History of Earthquake Records



(a) Bridge Elevation

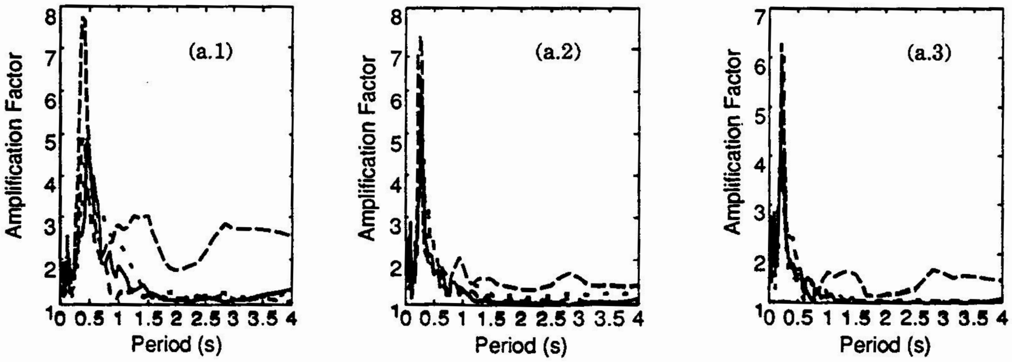


(b) Typical Deck Cross Section

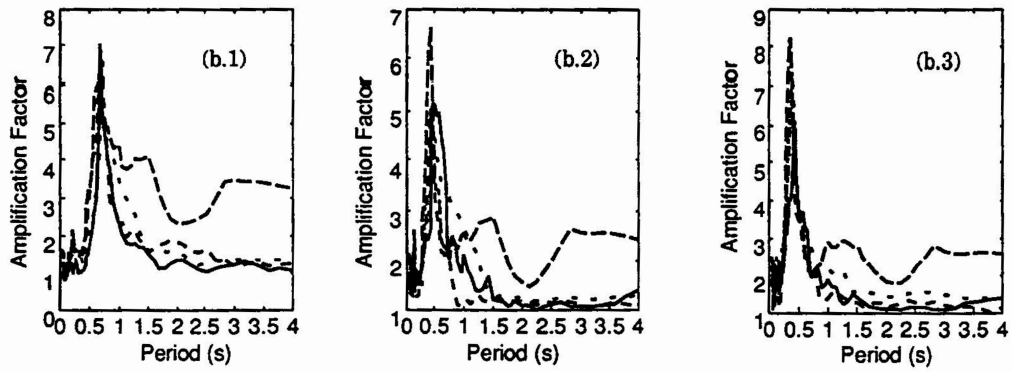


(c) Finite Element Model of Slab on Girder Bridge

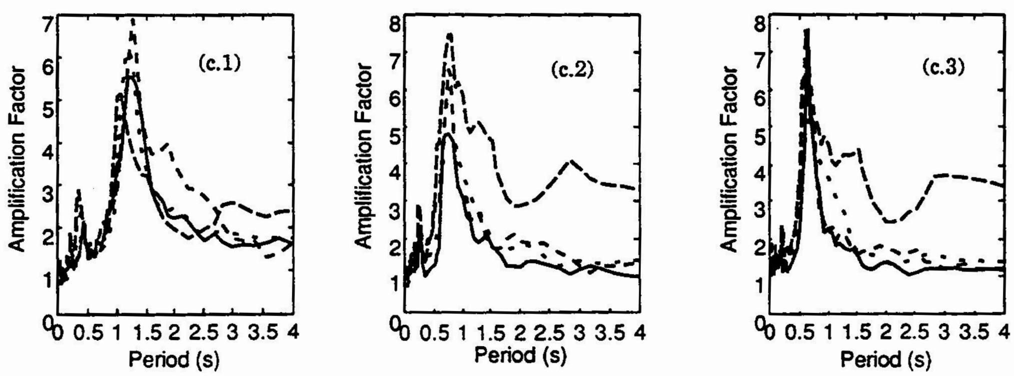
Figure 2 Slab on Girder Bridge Dimensions and Computer Model



Low Strain Shear Modulus: (a.1) 58MPa, (a.2) 120 MPa, (b.3) 168 MPa
Soil Depth: 15 m



Low Strain Shear Modulus: (b.1) 58MPa, (b.2) 120 MPa, (b.3) 168 MPa
Soil Depth: 25 m



Low Strain Shear Modulus: (c.1) 58MPa, (c.2) 120 MPa, (c.3) 168 MPa
Soil Depth: 45 m

Figure 3 Soil Amplification Factor for Different Soil Profiles and Depths