

# Design spectra for vertical earthquake action in the new version of guidelines for seismic design of highway bridges of China

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**Abstract.** The design spectra for vertical earthquake action in the new version of guidelines for seismic design of highway bridges of China is presented in this paper. The spectra are stipulated with the same formula, same figure as the horizontal one, but different parameters in another parallel table. The parameters are generalized from the vertical mean spectra and the comparison of vertical with horizontal mean spectra those are calculated from 4435 sets of ground motion data of NGA-west2 database.

**Keywords:** ground motion, response spectra, vertical component, spectra ratio.

## 1 Introduction

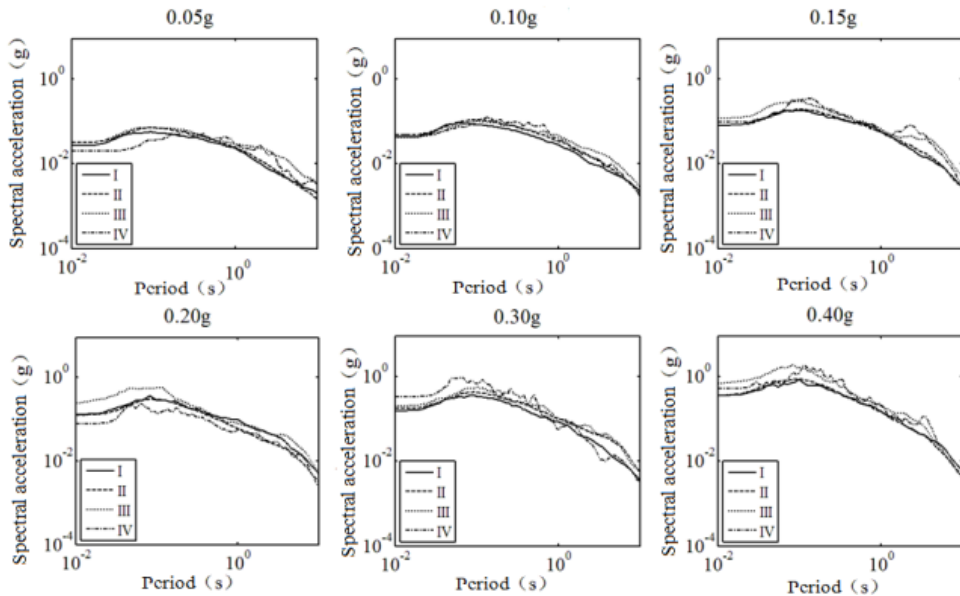
For checking calculation in seismic design of large scale and/or complex structure, the combine effect of earthquake actions in two or three directions should be taken into account. In most of seismic design codes, e. g. [1], vertical action is stipulated simply as the half or two third of the horizontal one, so that the shape of the design spectrum keeps the same as the horizontal one. The guidelines for seismic design of highway bridges of China [2] was issued in 2008 soon after the great Wenchuan earthquake as the first version, and is ongoing to be revised now at the end stage. The vertical earthquake action in the old version is stipulated differently from the horizontal one in both amplitude and shape, by a spectra ratio function. The authors pointed the unreasonable and inconvenient shortcomings under some conditions by the ratio function, and suggested a new way to stipulate the vertical design spectrum with two preliminary tables of vertical site coefficient and characteristic period from 1551 sets of ground motion data of NGA-west1 database [3]. Li and Zhi presented results from NGA-west2 data, with two ways to evaluate the site classification by Chinese specification from VS30, the average shear wave velocity of soil in ground 30 meters, respectively [4], [5]. A table of horizontal site coefficient was recommended by the new national seismic ground motion parameter zonation map of China [6] last year. A new scheme of vertical design spectral parameters is worked out to follow the horizontal one, by NGA-west2 data, but with Chinese site classification in this paper.

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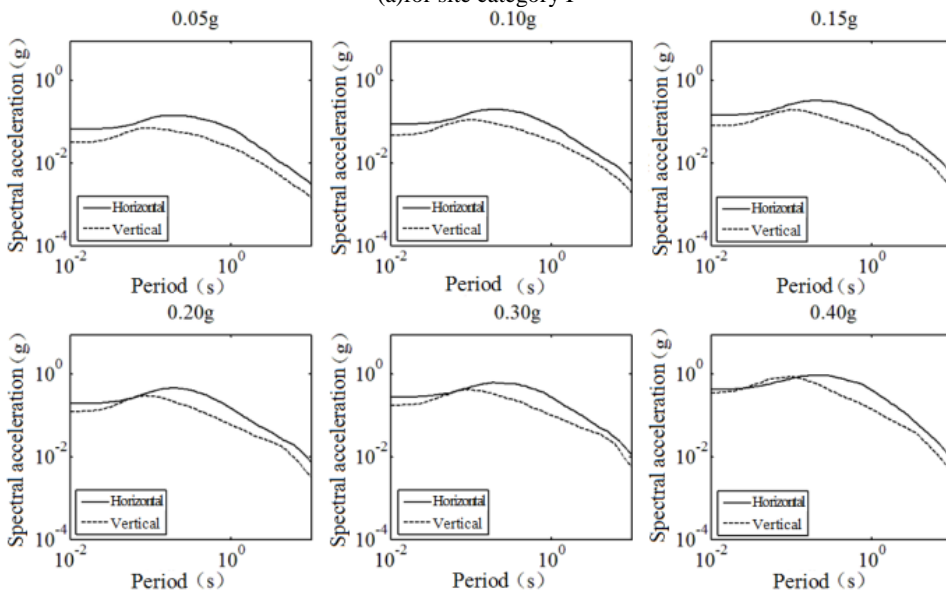
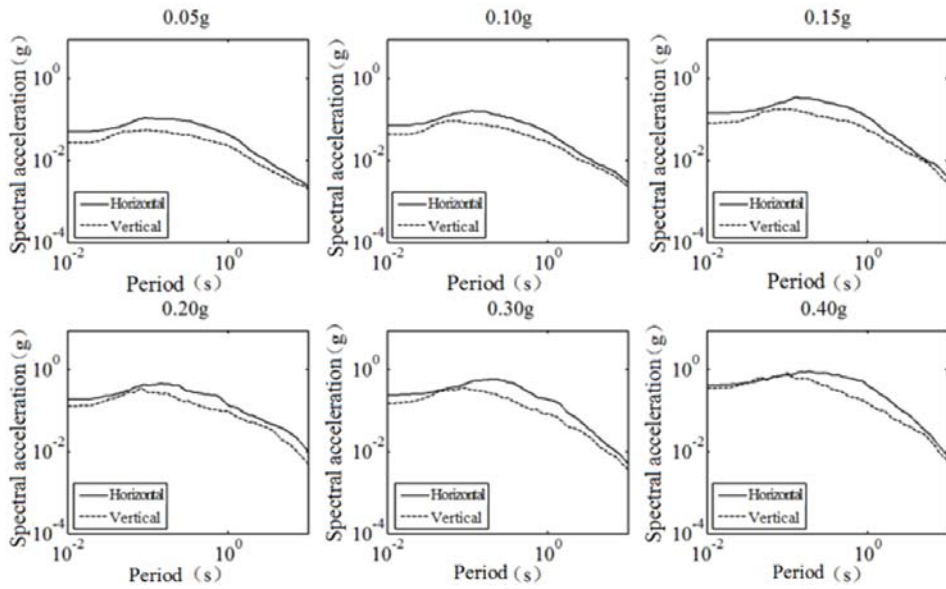
## 2 Vertical mean spectra and comparison with the horizontal one

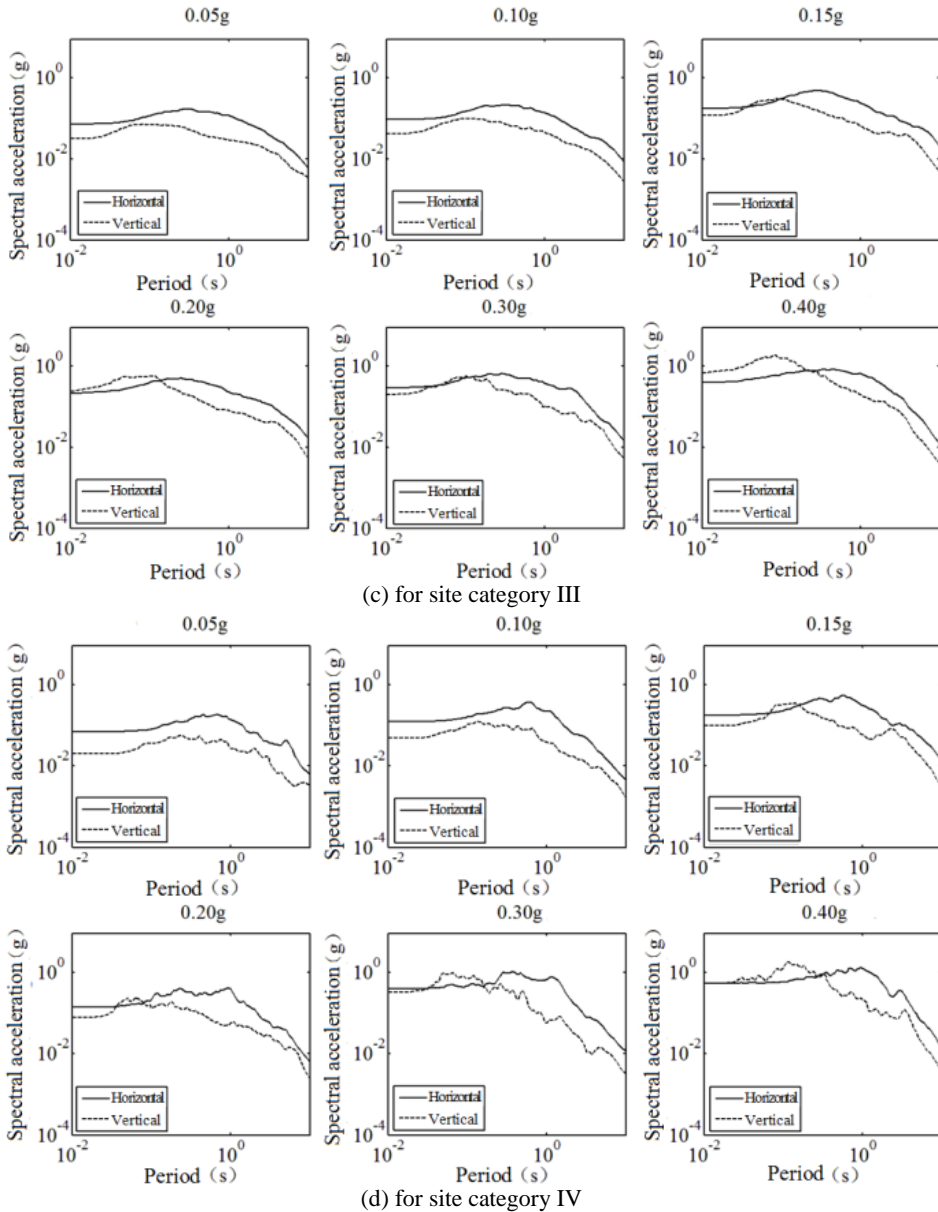
NGA-west2 data is the largest strong ground motion database in the world up to now, contains 21539 sets of ground motion recorded during 607 earthquakes with magnitude 4.2 to 7.9 not only in the western US but also in Wenchuan and Taiwan Jiji regions of China, some regions of Japan, Italy, New Zealand, Mexico and so on [7]. Distances from the station to the epicenter are 0.44 km to 1162 km. The data set of this paper consists of 4435 sets of motion recordings chosen from the database with criterions of PGA no less than 20 gals, site condition data available. Each data set includes both horizontal (RotD50) [7] and vertical records available. All data are grouped from their own magnitude and distance matching with those calculated by the CB13 ground motion prediction equation [8] developed in NGA program, for horizontal Peak Ground Acceleration (PGA) groups 0.05g, 0.10g, 0.15g, 0.20g, 0.30g and 0.40g or greater.

Mean spectrum is calculated by arithmetical average of spectra for each site classification in each PGA group, as shown in figure 1. One can find from the figure that the mean spectra are getting larger as PGA increasing, and they are getting wider as site category increasing from I, II, III to IV, as well as getting larger for PGA group greater than 0.10g.



**Figure 1.** The vertical mean spectra for the four site categories in the six PGA groups.





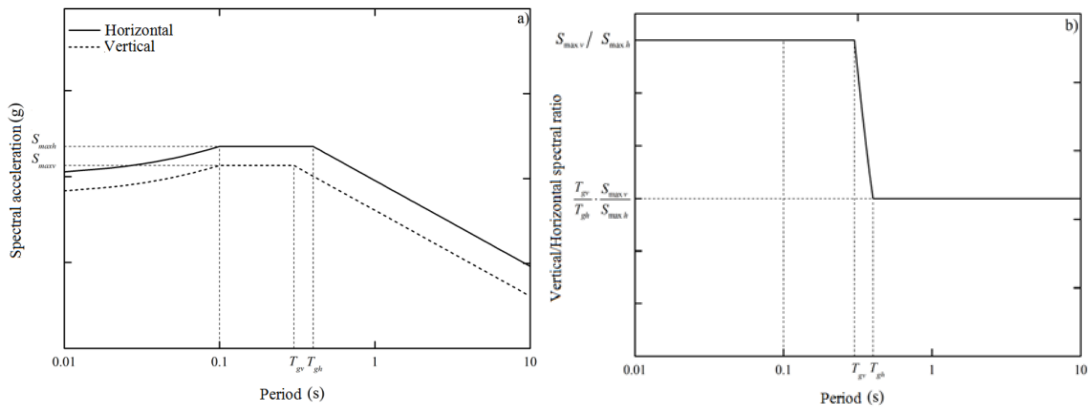
**Figure 2.** Comparison of vertical mean spectra with horizontal one.

The horizontal and vertical mean spectra in six PGA groups for each site category are shown in figure 2 (a) to (d) respectively. One can find from the figures that the horizontal mean spectra are larger and wider than vertical one on the whole.

### 3 Vertical and horizontal design spectra and their ratio

As mentioned above, vertical earthquake action is defined as design spectrum with the same formula, same figure as horizontal one, but different maximum amplitude  $S_{\max}$  and characteristic period. From the spectra with maximum amplitudes  $S_{\max h}$  and  $S_{\max v}$ , characteristic periods  $T_{gh}$  and  $T_{gv}$ , for the two components respectively in Fig.3 (the upper), the spectral ratio  $R(T)$  could be calculated as shown in the Fig. 3 (the lower), and as in Eq. (1).

$$R(T) = \begin{cases} S_{\max v} / S_{\max h}, & 0.1 \leq T < T_{gv} \\ \frac{T_{gv}}{T} \cdot S_{\max v} / S_{\max h}, & T_{gv} \leq T < T_{gh} \\ \frac{T_{gv}}{T_{gh}} \cdot \frac{S_{\max v}}{S_{\max h}}, & T_{gv} \leq T \end{cases} \quad (1)$$



**Figure 3.** The shapes of vertical and horizontal design spectra and their ratio.

One can see from the equation and the figure that the difference between the two characteristic periods governs the beginning and ending of the descending segment of the spectral ratio, and amplitude of ratio function at long period range. Therefore the fact that the vertical characteristic period must shorter than horizontal one could be inferred from the findings in above section of this paper.

4 The vertical site coefficients and characteristic periods

For convenience of design engineers, the vertical site coefficients are defined as the ratios of  $S_{\max v}$  for the four site categories to  $S_{\max h}$  for the site category II in each PGA group. The proposed values of vertical site coefficients and characteristic periods are listed in Table 1 and Table 2, respectively. In the tables the site category  $I_0$  and  $I_1$  are the two sub-categories of classification I from the Chinese code[1].

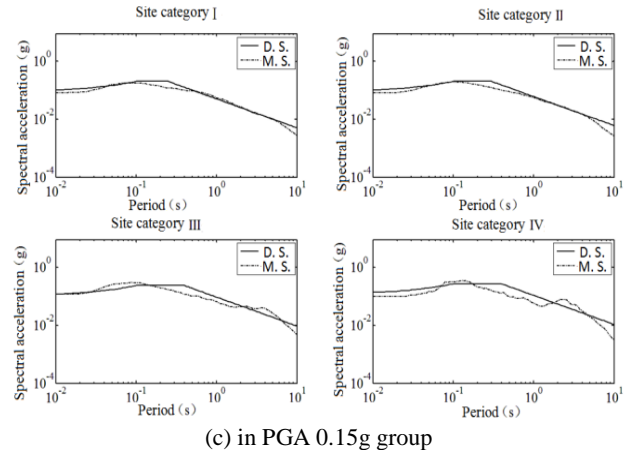
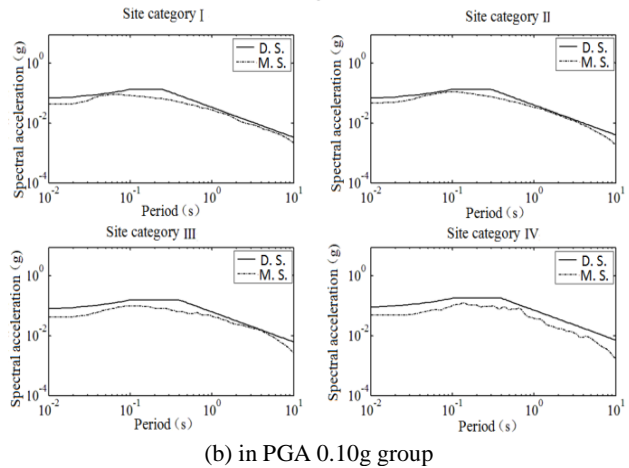
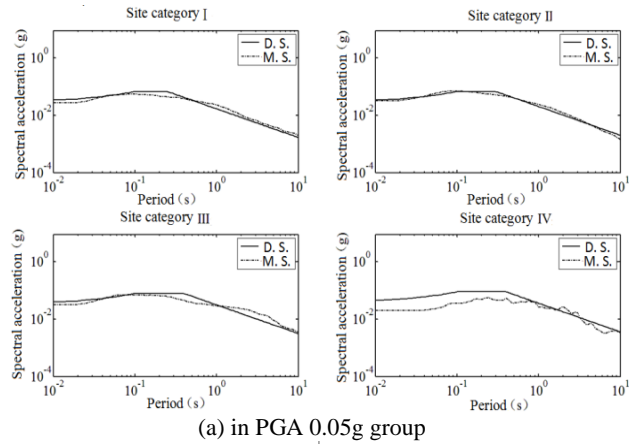
One can see from the tables that the values of the vertical site coefficients are all larger than 0.6, and getting larger slightly with PGA increasing, as well as getting larger with site category increasing, the values for site category IV in groups with PGA no less than 0.20g are reaching up to the value in the same group for site category II. And the values of characteristic periods for vertical component are all shorter than the corresponding values of horizontal one[1].

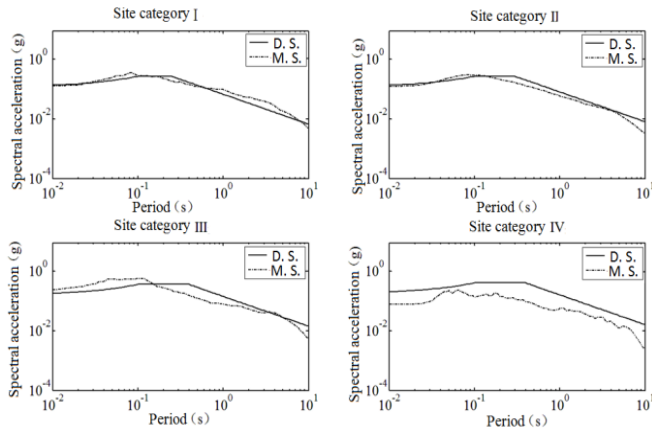
**Table 1.** The proposed values of vertical site coefficients.

| Site category | PGA (g)  |          |          |          |          |          |
|---------------|----------|----------|----------|----------|----------|----------|
|               | 0.0<br>5 | 0.1<br>0 | 0.1<br>5 | 0.2<br>0 | 0.3<br>0 | 0.4<br>0 |
| $I_0$         | 0.6      | 0.6      | 0.6      | 0.6      | 0.6      | 0.6      |
| $I_1$         | 0.6      | 0.6      | 0.6      | 0.6      | 0.7      | 0.7      |
| II            | 0.6      | 0.6      | 0.6      | 0.6      | 0.7      | 0.8      |
| III           | 0.7      | 0.7      | 0.7      | 0.8      | 0.8      | 0.8      |
| IV            | 0.8      | 0.8      | 0.8      | 0.9      | 0.9      | 0.9      |

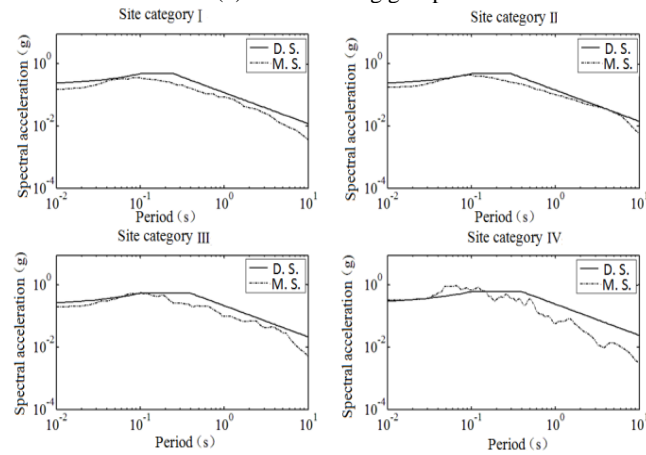
**Table 2.** The proposed values of characteristic periods for vertical component.

| Characteristic period value<br>from national zoning map | Site category  |                |      |      |      |
|---|----------------|----------------|------|------|------|
|   | I <sub>0</sub> | I <sub>1</sub> | II   | III  | IV   |
| 0.35  | 0.15           | 0.20           | 0.25 | 0.35 | 0.55 |
| 0.4   | 0.20           | 0.25           | 0.30 | 0.40 | 0.65 |
| 0.45  | 0.25           | 0.30           | 0.40 | 0.50 | 0.75 |

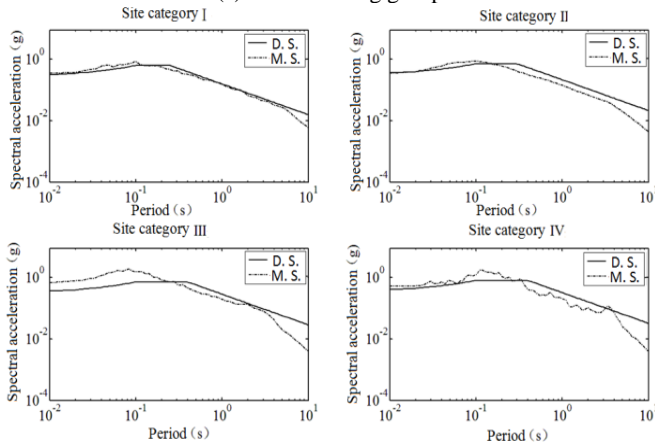




(d) in PGA 0.20g group



(e) in PGA 0.30g group



(f) in PGA 0.40g group

**Figure 4.** Comparison of vertical design spectra (D. S.) with the statistic mean (M. S.).

To validate the feasibility of these values of the two parameters, design spectra constructed by characteristic period values and  $S_{max}$  from Eq. 2 are plotted with the corresponding mean spectra for the same site category in the same PGA group together, as shown in Fig.4.

$$S_{\max} = 2.25C_i C_s C_d A \quad (2)$$

Where  $A$  is design basic acceleration of ground motion with value of each PGA group,  $C_i$  is the important coefficient with value of 1.0,  $C_s$  the site coefficient;  $C_d$  the damping adjustment coefficient, with value of 1.0.

One can identify from the figure that reliable with some degree of safe redundancy on whole, especially at long period range which is significant for design of bridges.

## 5 Conclusions

A new scheme of vertical design spectral parameters is worked out following the horizontal onerecommended by the new national zoning map, from NGA-west2 data with Chinese site classification in this paper. The design spectrum is adopted as the same as the horizontal in shape and in formula with just different parameters. Two tables of values of vertical site coefficients for four (five) classifications in six PGA groups are proposed. The values are reliable by comparing with the statistic mean spectra in the corresponding site classification and PGA group.

## Acknowledgments

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