Far-field Ground Motion of the Wenchuan M8.0 Earthquake and Influences on a Large Span Bridge

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Summary: In this paper, according to the digital strong motion record of the South-East China provinces, the characteristics of far-field ground motion of the Wenchuan M 8.0 extraordinary earthquake are analyzed, and the characteristics of long-periodic and its diversity are researched. Based on the dynamic characteristic of a large span bridge，seismic response analysis of the bridge is carried out by the use of very long seismic record(685s) of the A050 macroseismic ground motion station, which is built on the site with deep and soft soil layers. The results show that, far-field ground motion of a site with deep and soft soil layers,has very outstanding effect on a large span bridge structures with long natural vibration cycle, it should be fully considered in aseismic design of long-periodic structures.

Key words: far-field ground motion,Wenchuan M 8.0 earthquake,large span bridge,seismic response analysis

1. INTRODUCTION

Large span bridges are essential parts in communication projects. If a bridge is damaged in an earthquake, not only the project itself loses its function, the work of disaster relief would be seriously affected, resulting in substantial direct and indirect economic losses. In the past 20 years, more than 10 large span bridges such as Sutong Bridge, being the largest stayed-cable bridge presently in the world, have been built over the Yangtze River in Jiangsu Province,China. High towers, large spans and long natural-vibration cycles are characteristics of these bridges. In particular,the bridge site is covered with a soil layer of 200-300m or more thick.

Wenchuan M8.0 huge earthquake on May 12, 2008, not only affected half of China, and even shocked half of Asia. After the earthquake, the Southeast Strong Motion Network Centre (SSMNC),one of the three centres in China,which has 252 macroseismic ground motion station, 45 units obtain the main shock records. These units have epicentral distance of about 700-1800km,and the records are typical strong,far earthquake records. Duration of these seismic records is generally longer , the long-period component is extremely rich. Especially the deep soft sites ,durations close to the 700s,the longest length of the seismic records of ground motion in the area. These seismic records are very useful to seismic response of long-period structures and earthquake safety countermeasures. The results show that, far-field ground motion of a site with deep and soft soil layers,has very outstanding effect on a large span bridge structures with long natural vibration cycle, it should be fully considered in aseismic design of long-periodic structures.

In this paper, part of the station's digital ground motion records in Jiangsu Province is used to study the characteristics of ground motions of far field during the Wenchuan M8.0 earthquake. The results show that, far-field ground motion of a site with deep and soft soil layers,has very outstanding effect on a large span bridge structures with long natural vibration cycle, it should be fully considered in aseismic design of long-periodic structures.

2. FAR-FIELD GROUND MOTION CHARACTERISTICS OF THE WENCHUN ERTHQUAKE

Wenchuan M8.0 earthquake shake the whole earth, its long-period seismic waves even spread more than two laps around the earth. After the main shock , aftershocks of M≥4.0 occurred nearly 300 times. In the Wenchuan earthquake event, more than 400 stations obtain the seismic records in China. The far-field earthquake records, are mainly dominated by the far-field station in the main shock. SSMNC, under its jurisdiction of the 10 provinces in China , 210 fixed-strong earthquakes, two cross-fault array and southeast of strong ground motion flow observation base, a total of 252 sets of digital strong motion, 45 sets of earthquake Instruments obtain records in the main shock (Fig.1). Accelerations of the far-field units,the epicentral distance of 700-1800km, are typical of the earthquake, and teleseismic records. A small number bedrock units, the ground motions are relatively small, only 12 bedrock units for the acceleration record, including Jiangsu 6 stations.

From the analysis of the results of seismic records, the vibration characteristics of the far field for the long Earthquake duration, low vibration intensity, but the displacement of a larger, long-period component of ground motion is extremely rich.

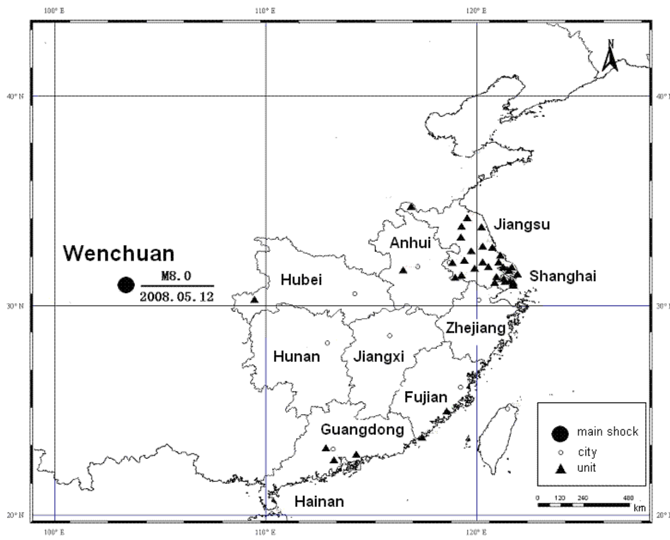

Figure 1 Distribution of stations with main earthquake motion records in South-East provinces

2.1. Long Earthquake Duration

Although the epicenter of most earthquake stations in the southeast region is beyond 1000km, and peak ground acceleration is relatively small, but the vibration time of the bedrock up to 151s. Seismic records of soil site stations is generally longer, mostly more than 150s. The longest record in the site of A050 station with deep and soft soil layers in Jiangsu (epicenter of about 1750km), is up to 685s (Fig.2), bout 4.5 times of the longest recording length a of bedrock sites. So long digital seismic records is rare in China,and is valuable to study of long-period seismic ground motion and aseismic design of long-period structures.

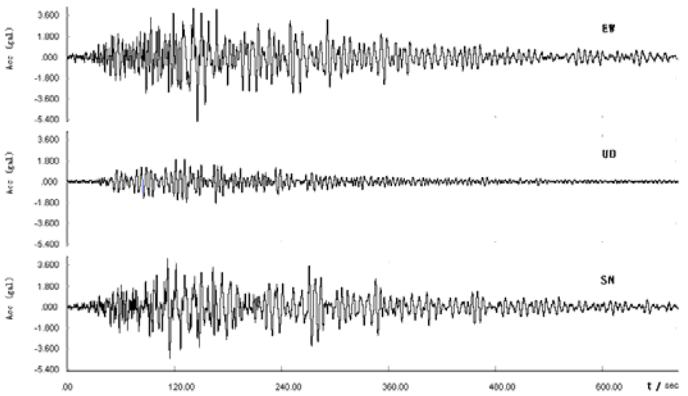

Figure 2 Main earthquake ground motion records of A050 station in Jiangsu province

2.2. Low Ground Motion Intensity and Large Displacement

Near-field strong ground motion of the Wenchuan earthquake is very remarkable, the epicenter area of seismic intensity of up to 11 degrees, the maximum peak acceleration of near-fault strong motion near of as 957.7gal (Wenchuan Wolong station, away from the seismogenic fault 1.28 km ,epicentral distance of 22.2 km), the estimated maximum peak acceleration of fault position may be over 1.0g. Bedrock maximum acceleration obtained by the Southeast Network Center under the jurisdiction of the regional is only 7.99gal (epicentral distance of 700km), while the other stations (beyond 1000km) are generally less than 2.0gal. Soil site, only Jiangsu and Shanghai, 32 stations received a seismic record, of which 23 stations of Jiangsu and 9 stations of Shanghai. The maximum horizontal peak acceleration of Jiangsu 23 stations is 6.513gal. Seismic records of the stations of the different venues of the southeast area in the Wenchuan earthquake shows that the peak ground acceleration of the surface of the soil station site is significantly greater than the bedrock stations, about 2 -6 times of bedrock stations surface maximum peak ground acceleration.

Table 1 shows the seismic record data comparison of a typical far-field station and near-field station. Far field vibration intensity is low, the maximum horizontal displacement of the rock site stations is generally around 2-4cm, the maximum displacement in Jiangsu is recorded as 4.23cm. However, for deep soft overburden site, ground motion displacement significantly increased. The maximum horizontal displacement of the A050 seismograph record of 11.27cm, is 2.7 times of the rock site. Wenchuan Wolong station, only 22.2km from the epicenter, its horizontal peak ground acceleration is 162 times of Jiangsu A050 station of far-field, while the displacement is only 1.66 times of that of A050 station, the displacements of the two stations are almost the same.

Table 1 Comparison between the typical far-field and near-field ground motion records

Station	epicenter(km)	Amax(cm/s2)	Dmax(cm)
Wolong	22.2	652.9-957.7	12.66-18.66
Jiangsu A050	1750	5.19-5.90	8.79-11.27
rock sites of jiangsu	1480-1525	<2	2.0-4.23

2.3. Rich Long-period Component of Ground Motions

The shock of the far field, due to the high-frequency component attenuation of ground motion in long distance propagation, is a wealth of long-period ground motion generated during fault rupture process and long period surface waves excited in the communication process.

Fig.3 is the recorded acceleration response spectrum of three bedrock stations in Jiangsu Province. It can be seen from the graph, the horizontal acceleration response spectrum β in the 1.5-10.0s range are about 3.0, the vertical acceleration response spectrum β in the 1.5-8.0s range are also about 3.0. The epicenter distance of these stations are about 1500km (1480-1525km) , the acceleration response spectrum β in the 1.5-5.0s range is closer to each other, but quite different in the range of 5.0-10.0s. This shows that ground motion of strong earthquakes is mainly long-period component, and there is a big difference due to dissemination process of the topography, geomorphology and site conditions which can excite different surface waves.

Fig.4 is acceleration response spectra (damping ratio 0.05) of A050 station site. The station was built in the deep soft site, its Quaternary overburden thickness is up to several hundred meters. Compared with the bedrock spectrum, it can be seen from the diagram, spectral values significantly decrease between

1.5-3.5s of response spectrum period. However, horizontal maximum value βmax is about 3.0 in the range of cycle 3.5-11.0s, it closes to the response spectrum of bedrocks in the region.

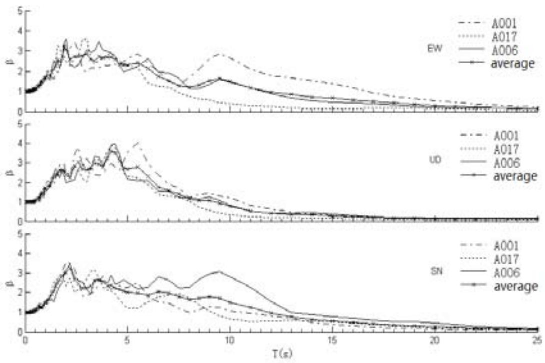

Figure 3 Acceleration response spectra of bedrock site

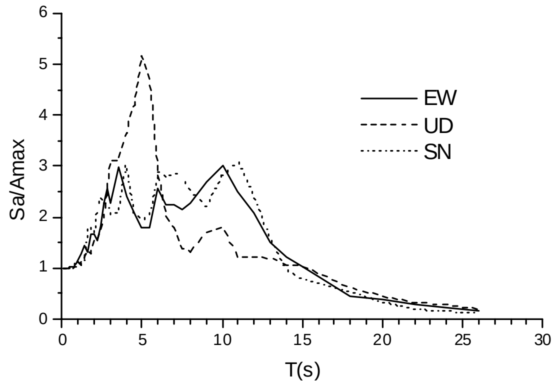

Figure 4 Acceleration response spectra of ground motion records（A050 station，damping ratio：0.05）

3. SITE CONDITIONS

A large-span bridge will be built in the Yangtze River Delta plain, and the project site has a flat and open terrain, as low beach of Yangtze River. Considering the importance of the project, the massive economic loss that might be caused by the damage to the project in the event of an earthquake and the resulting social impact, it is necessary to fully study the seismic geological environment and seismic activity characteristics of the project site, perform seismic hazard analysis for the site, determine the static and dynamic performance parameters of the ground through in-situ test and laboratory tests, to perform in-depth study of the seismological effect of the ground with thick, loose and soft soil layers of the project, and to finally determine the design response spectrum of the ground for different anti-seismic protection levels, for use in the aseismic design of the project.

According to engineering geological survey and geotechnical survey results, the project site is covered with thick layers of Quaternary period strata, which can be divided mainly into 6 major layers (Tab.2). The Quaternary period strata are over 250m in thickness, with dozens of meters in the top mainly constituting weak layers of Holocene epoch, and the project site is of a Class IV ground.

Table 2 Quaternary period capping in the bridge area

Layer	age	Main lithology	Geotechnical features	Layer thickness (m)
1	Q_4	Silt sand, sludge clayey soil and loam	Loose, medium dense, flowing ~ soft plastic	5~44
2	Q_4	Clayey soil and silt sand	Flowing ~ soft plastic	12~32
3	Q_4	Silt fine sand and medium coarse sand	Dense	62~80
4	Q_3	Clayey soil and silt fine sand	Hard plastic and dense	44~62
5	Q_2	Silt fine sand and coarse gravel sand	Dense	46~70
6	Q_1	Coarse sand, gravel sand and clay	Dense	38~90

The soil layer elastic wave speed in-situ test results obtained by boring in the project site show that the shear wave velocity Vs in the soil layer about 120m deep under the ground is as high as 500m/s (Fig. 5).
When the Wenchuan earthquake happened, the high-rise buildings on the deep covering of soft soil layers from the epicenter of 1300-1800km of the regions of Jiangsu and Shanghai, ground motion near the large span bridge is significantly enlarged , office staff can be able to feel a few minutes strong vibration after the main shock.

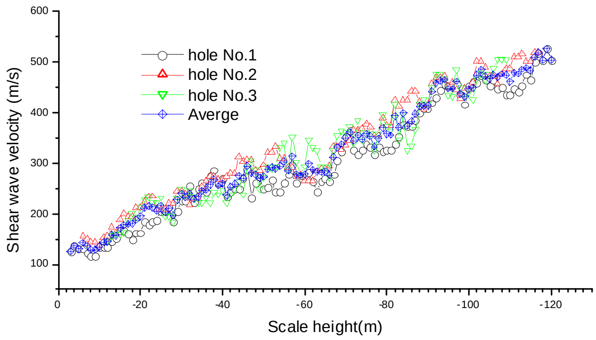

Figure 5 Shear wave velocities of soil layers

4. STRUCTURAL CHARACTERISTICS AND DYNAMIC CHARACTERISTICS

A large span bridge discussed in this paper, has the main bridge's span arrangement of 2 × 100 + 278 + 1088 + 278 + 2 × 100 m, the total length of 2 084 m, inverted Y-shaped reinforced concrete towers, high tower 279.7m, and the basis of a group piles.
In the analysis of the seismic response of pile, the pile - soil - structure interaction has been a difficult problem. For decades, many scholars, have been put forward a number of models and methods, but because of the complexity of the soil medium, the pile - soil - structure interaction problem has not been a better solution so far. In the seismic response analysis of long-span bridges, the simulation of group pile as follows: 1) the lumped mass method (lumped mass model), 2) mounted in a certain depth below the scour line (embedded model), 3) Simulation of pile foundation with six spring (six-spring model).
For pile platform, engineers use a simplified analysis of pile embedded 3 to 5 times the diameter at the erosion line, to simplify the calculation. Is generally believed that ,the structural dynamic problem, the pile below the scour line, the embedded depth H, in fact, more reasonable to determine in accordance with the principle of equivalent level of single pile stiffness. However, the calculation of many pile foundation analysis showed that the embedded depth H determined in accordance with the principle of Horizontal Stiffness of Single equivalent is still in the diameter range of 3 to 5 times of piles. By the use of the finite element model, analysis of the dynamic characteristics of the main bridge structure is carried out. The first ten of its natural frequencies is shown in table 3.

Table 3 dynamic characteristics of the main channel bridge

modal order	frequency (Hz)	modal order	frequency (Hz)
1	0.106	6	0.221
2	0.155	7	0.287
3	0.192	8	0.288
4	0.200	9	0.365
5	0.201	10	0.410

5. SEISMIC RESPONSE ANALYSIS

For long-period structures, their displacements are often more larger because of the longer natural

period during a event of strong earthquake. Especially ,when the long-period component of seismic waves equal or close to the natural cycle of structures, it is easy to produce resonance phenomenon.
The structure is discreted into a multi-degree-of-freedom system in seismic response analysis, its equation is as follows.

$$\boldsymbol{M}\ddot{\mathbf{U}} + \boldsymbol{C}\dot{\mathbf{U}} + \boldsymbol{K}U = -\boldsymbol{M}\,\boldsymbol{I}\,\ddot{u}_g \tag{5.1}$$

Where M, C and K, respectively discreted system mass matrix, damping matrix and stiffness matrix. $\ddot{U}$ 、 $\dot{U}$ 、 $\boldsymbol{U}$,respectively, the nodal acceleration, velocity and the displacement vector. I is the identity matrix. $\ddot{u}_g$ is earthquake acceleration process.

Modal decomposition method is used for solving equation (5-1), its solution can be expressed as:

$$U = \sum \Phi_i \gamma_i q_i \tag{5.2}$$

Where , Φ_i is i-th vibration mode; γ_i is the modal participation factor for the i-th vibration mode, it can be expressed as

$$\gamma_i = -\frac{\Phi_i M I}{\Phi_i^T M \Phi_i} \tag{5.3}$$

q_i is the generalized coordinates of the i-th vibration mode amplitude, the decoupling of the multiple degrees of freedom (MDOF), the solution of q_i is converted to a single degree of freedom system (SDOF) modal , its equation is as follows

$$\ddot{q}_i + 2\zeta_i\omega_i \dot{q}_i + \omega_i^2 q_i = -\ddot{u}_g \tag{5.4}$$

Where, ζ_i, ω_i are respectively circular frequency of the i-order damping ratio and vibration.
Figure 6 shows the displacement response spectrum(0.05 damping ratio) of ground motion of A050 station. It can be seen from the figure, the response spectrum value in the range of long period is bigger than that in the range of short period, the horizontal response spectrum peak near the point in the cycle of 10-11s. The seismic record data of EW direction of A050 station, respectively, the maximum acceleration, maximum velocity, maximum displacement 5.89cm/s^2, 6.71cm/s, 11.27cm, and that of SN direction respectively 5.07cm/s^2, 5.79cm/s, 8.79cm.
By the use of the data to analyze the seismic response of the large span bridge, the seismic responses of different damping ratios are shown in table 4. Due to the damping of long-period structure is relatively small, a large-span bridge sometimes has small damping ratio of 0.01-0.03. Figure 6 is the displacement histories of the bridge structure of different damping ratios corresponds to EW and SN record of A050 station site. It can be seen from the graph, the vibration time, that the vibration displacement

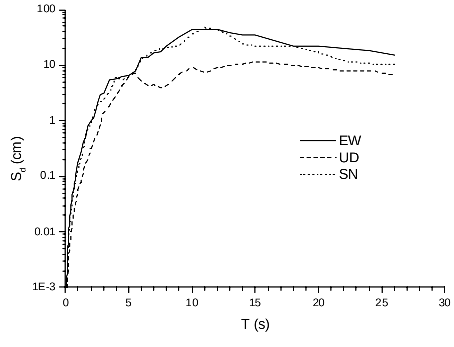

Figure 6 Displacement response spectra of ground motion records (A050，damping ratio：0.05）

amplitude is more than 40cm, reaches a few minutes long, the maximum displacements of 0.01 damping ratio is up to 70cm in particular(Fig7-Fig.8).

Table 4 Structural seismic responses

input	damping ratio	Amax(cm/s^2)	Vmax(cm/s)	Dmax(cm)
A050 EW	0.01	27.61	44.85	69.91
	0.02	24.60	40.53	62.25
	0.05	17.66	30.27	44.51
A050 SN	0.01	23.49	39.30	59.48
	0.02	19.39	31.11	49.08
	0.05	14.24	24.08	35.86

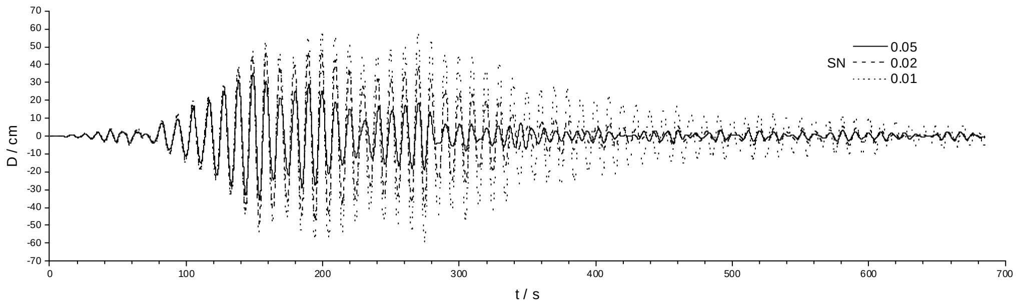

Figure 7 Structural response displacement time histories(SN)

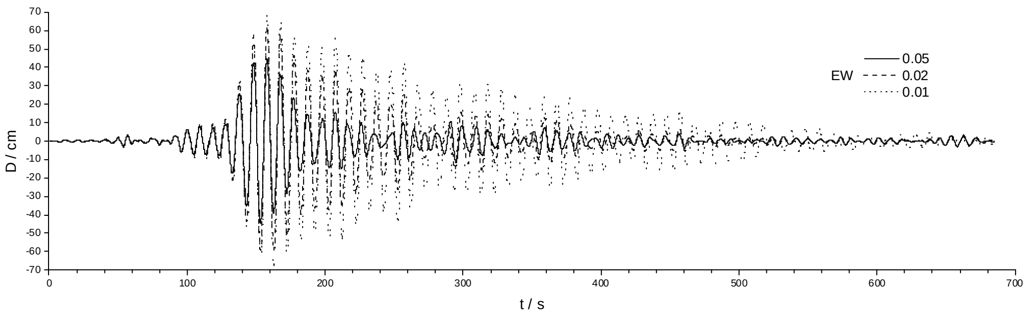

Figure 8 Structural response displacement time histories(EW)

6. CONCLUSION

According to the vibration characteristics of far field of the Wenchuan earthquake and seismic response analysis of a large-span bridge structure, the following conclusions can be given:

6.1. The shock acceleration of the far field is relatively low, but the ground motion displacement in a site with deep and soft soil layers is larger. Large-span bridge structures, because of their long vibration periods, should be considered to control the role of displacement, velocity, rather than just acceleration during the seismic performance analysis.

6.2. The durations of far-field ground motions of the Wenchuan M8.0 earthquake can be up to hundreds or even near 1000 seconds, the performance in far field vibration is mainly of low frequency vibration. In the analysis of direct time history dynamic responses of long-period structures, especially for inelastic response analysis, the selected earthquake records should be long enough, and the short earthquake record may lead to underestimate the seismic response of long-period structures.

6.3. The analysis results of the far-field seismic records from the May 12 Wenchuan earthquake shows that , long periodic component of far-field ground motions is extremely rich, long-period response spectra regardless of shape or spectral values, are very different from the current seismic design codes. Particularly, for long-period structures based on a deep and soft site, it is very important to fully consider the strong earthquakes far from the site and their differences to the current specification in long-period part during determining the design response spectrum and selecting seismic waves.

6.4. The long-period ground motions of the actual earthquake may be affected by many factors, and more seismic waves, including the simulation of artificial seismic waves and seismic records, should be used for seismic response analysis of long-period structures.

6.5. Far field stations seismogram analysis showed that, by the dissemination process of the topography, geomorphology and site conditions, the long-period surface waves excited by the same types of sites may also be quite different, even the epicentral distance is the same or closed to the station,
and the long-period ground motion attenuation law may be more complex than the current understanding of the researchers.

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