1 D Nonlinear Analysis in Time Domain Of Hanyuan City Site Amplification Effect In 2008 M_w8.0 Wenchuan Earthquake

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SUMMARY:
In 2008 M_w8.0 Wenchuan Earthquake, Hanyuan county of Sichuan Province was an area of abnormally high intensity. The building damage in Hanyuan city is more serious than in surrounding cities.
For explaining the phenomenon, in the work, an 1D nonlinear method in time domain was proposed for the site effect analysis, based on an explicit discretization of dynamic equations, local transmitting boundary conditions and dynamic constitutive relation fitting G/Go-γ curve and λ-γ curve, the analysis models was established for 1D nonlinear analysis, according to on-site borehole data, and six nearby region main shock accelerograms recorded in 2008 M_w8.0 Wenchuan Earthquake was used as input.
The result shown that the site amplification effect was significant in 2008 M_w8.0 Wenchuan Earthquake not only in acceleration time history peak value but also in spectra, and surface-to-input spectral ratio has a peak at 0.1second, that is about the natural frequency of building damaged most seriously. A conclusion could be drawn that the relatively serious building damage in Hanyuan city is associated with the site amplification effect, the earthquake motion was amplified significantly by shallow soil layer in the site, at about 0.1 second in particular, it produced some buildings that their natural period is about 0.1 second damaged seriously.

Keywords: Nonlinear Analysis in Time Domain; Wenchuan Earthquake; Site Amplification Effect

1. GENERAL INSTRUCTIONS

In 2008 M_w8.0 Wenchuan Earthquake, Hanyuan county of Sichuan Province was an area of abnormally high intensity. The building damage in Hanyuan city is more serious than in surrounding cities. Fig. 1.1. is Hanyuan city damage index contour basing on damage survey result after Wenchuan earthquake in 2008. In this figure, civil building damage index (D_1) contour lines were given to characterize the degree of seismic damage of building on a region. damage index value is more large and the building damage is more serious in earthquake, the damage index contour is calculated by statistics based on single building’s value In the figure, the degree of buildings damage in the region surrounding by D_1=0.5 contour line is like the degree seen in Ⅸ intensity region.

According to results of preliminary survey in 2008 (T.Lu,2009), the special site condition was the main reason leading to so serious damage in Hanyuan city. For explain the phenomenon, the further study was done, five boreholes, from ZK1 to ZK5, were drilled in the site, the drilling positions is shown in Fig.1.1. According to the data got in-site and in laboratory, nonlinear analysis in time domain was done to evaluate Hanyuan city site amplification effect in 2008 M_w8.0 Wenchuan earthquake, the contents in the paper are the part of the study.

The result of the study was proven the relatively serious building damage in Hanyuan city is associated with the special site condition, which led to seismic wave’s amplification significantly and serious building damage on the site.

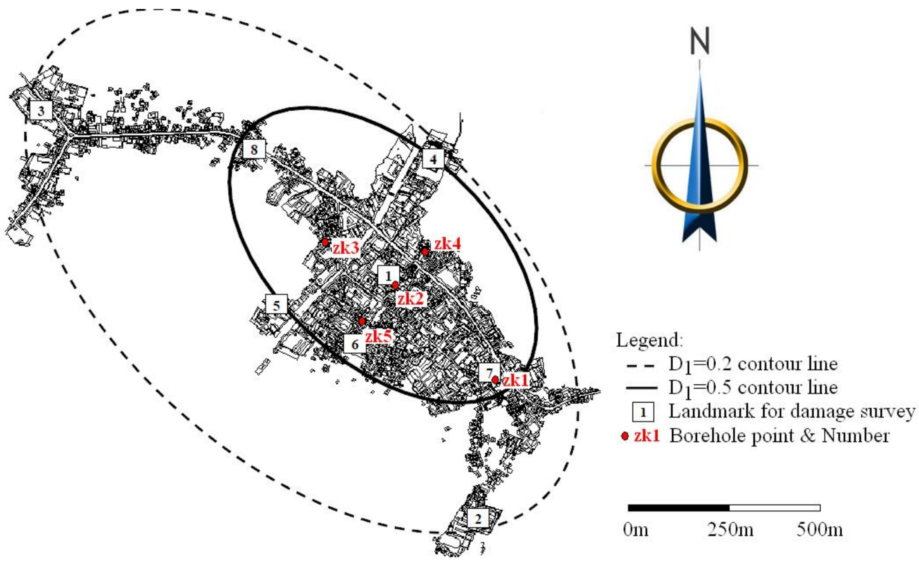


Figure 1.1. Hanyuan city damage index contour and borehole point

2. 1D NONLINEAR ANALYSIS METHOD IN TIME DOMAIN

The equivalent linear method is a common way to evaluate the site effect in engineering, but surface response is often underestimated in the case of considering site response under rare earthquake load, which is due to the exaggerated resonance effect caused by the equivalent linear method in the cases (Z. Liao, 2002).

For analyze the Hanyuan city site amplification effect in 2008 M_w8.0 Wenchuan earthquake, a 1D nonlinear method is proposed in the study.

2.1. Numerical Scheme

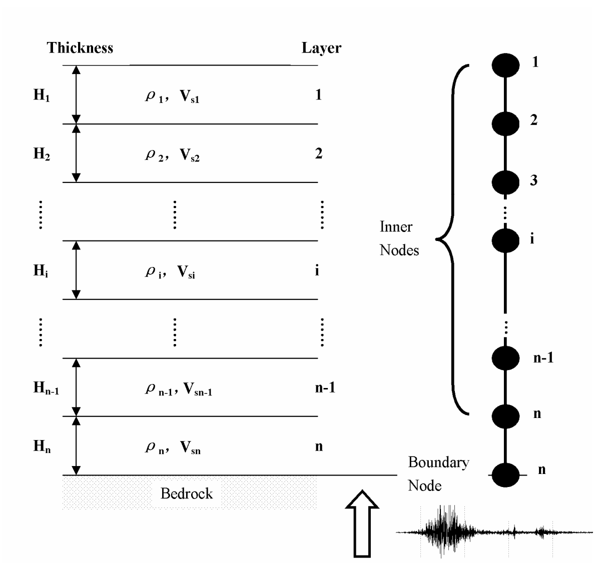


Figure 2.1. Proposed model for 1D nonlinear response analysis of horizontal layered soil layers Under lateral earthquake load

In Fig. 2.1., it is proposed model for 1D nonlinear response analysis of a horizontal layered soil layer under lateral earthquake load, the problem is simplified to an initial boundary value problem; an integration scheme of space-time overlap based on central differential equation is used to solve the problem in this study.

In the model, soil layers is divided N sub-layer for numerical analysis in time-domain, every sub-layer's thickness is Δh_n (n=1, 2… N), and time step is Δt, and they have to consistent with the requirements of stability and accuracy in numerical analysis.

When t=pΔt, the velocity on the upper surface of *n*th sub-layers

$$v_n^p = v(z_n, p\Delta t) \qquad n = 1\ ,2\ ,\ \cdots\ ,N \tag{2.1}$$

In Equ.2.1., the vertical coordinate of nth sub-layers upper surface $z_n=h_0+\Delta h_1+\ldots+\Delta h_{n-1}, h_0=0$. When t=(p+1/2) Δt, the shear stress and strain at the midpoint of *n*th sub-layer could be marked

$$\left.\begin{aligned} \tau_n^p &= \tau\left(z_n+\frac{h_n}{2}\ ,\ (p+\frac{1}{2})\Delta t\right) \\ \gamma_n^p &= \gamma\left(z_n+\frac{h_n}{2}\ ,\ (p+\frac{1}{2})\Delta t\right) \end{aligned}\right\} n=1\ ,\ 2\ ,\ \cdots\ ,\ N-1 \tag{2.2}$$

According to free boundary condition and central differential equation, the velocity on the upper surface of nth sub-layers

$$\left.\begin{aligned} v_1^{p+1} &= v_1^p + \frac{\Delta t}{m_1}\tau_1^p \\ v_n^{p+1} &= v_n^p + \frac{\Delta t}{m_n}(\tau_n^p - \tau_{n-1}^p) \quad n = 2\ ,\ 3\ ,\ \cdots\ ,\ N \end{aligned}\right\} \tag{2.3}$$

In Equ.2.3.

$$\left.\begin{aligned} m_1 &= \frac{1}{2}\rho_1 h_1 \\ m_n &= \frac{1}{2}(\rho_n \Delta h_n + \rho_{n-1}\Delta h_{n-1}) \quad n = 2\ ,\ 3\ ,\ \cdots\ ,\ N \end{aligned}\right\} \tag{2.4}$$

According to deformation compatibility condition, get the central differential equation

$$\frac{v_{n+1}^{p+1} - v_n^{p+1}}{\Delta h_n} = \frac{\gamma_n^{p+1} - \gamma_n^p}{\Delta t} \tag{2.5}$$

So

$$\gamma_n^{p+1} = \frac{\Delta t}{\Delta h_n}(v_{n+1}^{p+1} - v_n^{p+1}) + \gamma_n^p \qquad n = 1\ ,2\ ,\ \cdots\ ,N \tag{2.6}$$

When t= (p+1/2) Δt, nonlinear stress-strain relationship at the midpoint of nth sub-layer is

$$\tau_n^{p+1} = \tau\left(\gamma_n^{p+1}\right) \tag{2.7}$$

Equ. 2.1.- Equ. 2.7. are the proposed integration scheme of space-time overlap in this study.

2.2. Dynamic Constitutive Relations of Soil

Dynamics constitutive relationship of soil is first thing in the nonlinear seismic response analysis of soil layer, in this study; we adopted a direct nonlinear model in time-domain for simulating 1D shear stress-strain relationship of soil under earthquake load.

The proposed stress-strain relationship is a dynamic skeleton curve including damp ratio degeneration coefficient based on hyperbolic line type, the hysteretic rules of this relationship could fit soil dynamic parameter curve, which is used by equivalent linear method. The relationship is shown by Equ.2.8, more details could be referenced the papers written y T. LU(2008,2011).

$$
\tau(\gamma)=\begin{cases}\tau_C+K\left[\dfrac{G_0(\gamma-\gamma_C)}{1+\left|\dfrac{(\gamma-\gamma_C)}{2\gamma_r^{'}}\right|}-\dfrac{\pm\tau_M-\tau_C}{\pm\gamma_M-\gamma_C}(\gamma-\gamma_C)\right] & \\ \quad+\dfrac{\pm\tau_M-\tau_C}{\pm\gamma_M-\gamma_C}(\gamma-\gamma_C) & |\gamma|\le\gamma_M \\ \dfrac{G_0\gamma}{1+\dfrac{|\gamma|}{\gamma_r}} & |\gamma|>\gamma_M\end{cases} \tag{2.8}
$$

In Equ.2.8., K is damp ratio degeneration coefficient, the equation is

$$
K(\gamma_0)=\frac{2\pi(\tau_M-\tau_C)(\gamma_M-\gamma_C)\lambda(\gamma_0)}{2G_0\left\{4\gamma_r^{'2}\left[\pm\dfrac{\pm\gamma_M-\gamma_C}{2\gamma_r^{'}}-\ln\left(1\pm\dfrac{\pm\gamma_M-\gamma_C}{2\gamma_r^{'}}\right)\right]\right\}-(\tau_M-\tau_C)(\gamma_M-\gamma_C)} \tag{2.9}
$$

2.3. Dynamic Boundary Condition

The transmitting boundary is used to treating incident wave input and wave scattering (Z. Liao, 2002). Based on the equations (Equ.2.1.-Equ.2.9.) and transmitting boundary, a time-domain nonlinear analysis method in time-domain could be formed. In this study, a FORTRAN program- DynaSoil1D is coded by the method, and used in the nonlinear response analysis of a soil layer under strong motion in the work, the validity of the method and the program could be verified by T. Lu (T.Lu,2008).

3. 1D NONLINEAR ANALYSIS OF HANYUAN CITY SITE AMPLIFICATION IN M_W8.0 WENCHUAN EARTHQUAKE

3.1. Site Data

Basing on the boreholes data, shown in Tab. 3.1, the site was classified Class Ⅲ according to China seismic code. For numerical modelling, the G/G_o-γ curve and λ-γ curve of typical soil samples was gotten by test, shown in Fig.2.2, and the borehole soil layer data gotten on-site, for example, borehole ZK2 data is shown in Tab.3.2.

Table 3.1. $V_{s,eq}(20)$, Overburden Thickness And Site Classification Based On China Seismic Code

Borehole Number	$V_{s,eq}(20)$	Overburden thickness	Site classification
ZK1	171.06	56	III
ZK2	160.44	58	III
ZK3	156.23	>50	III
ZK4	157.70	>50	III
ZK5	163.92	>50	III

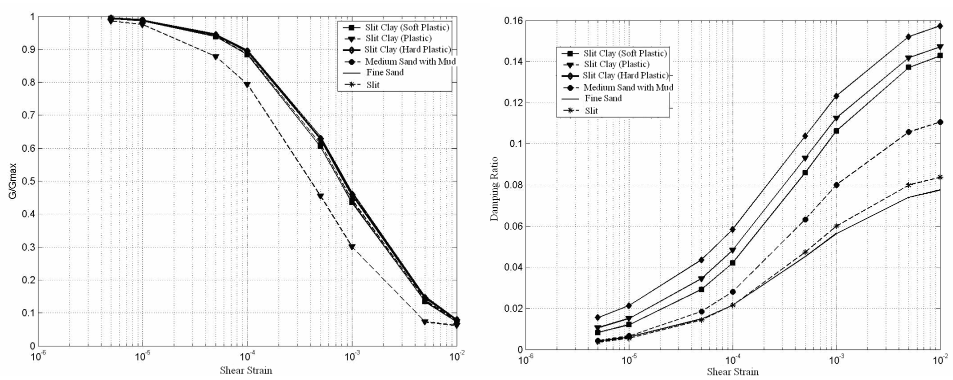
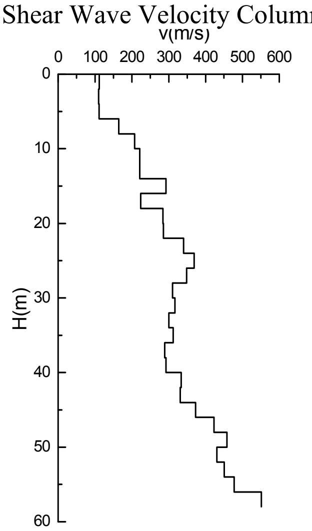


Figure 3.1. G/G_o-γ curve and λ-γ curve of typical soil

Table 3.2 Zk2 Borehole Soil Layer Data

Number	Thickness (m)	Soil Type	Density (g/cm3)	Shear Wave Velocity Column
1	2	Miscellaneous Fill	1.81	
2	5.6	Slit Clay (Soft Plastc)	2..02	
3	2	Slit Clay (Soft Plastc)	2.04	
4	3.8	Slit Clay (Soft Plastc)	2.02	
5	1.3	Medium Sand with Clay	2.04	
6	3.3	Cobble Layer	2.12	
7	3.2	Slit sand	2.05	
8	18.3	Slit Clay (Plastc)	1.97	
9	4.7	Cobble Layer	2.01	
10	7.8	Slit Clay (Plastc)	2.03	
11	6.0	Cobble Layer	2.11	
12	4	Mudstone	2.2	

3.2. Input: Accelerogram Recorded at Three Stations near Hanyuan City in M_w8.0 Wenchuan Earthquake

For study the site amplification effect in Wenchuan earthquake, six pieces of horizontal accelerogram recorded at three strong motion observation stations were chosen as the input for nonlinear analysis. The simple information of stations and records is shown in Tab.3.3. , and the time history curves and response spectra of the records are shown in Fig.3.2 and Fig.3.3.

Table 3.3. Horizontal Accelerogram Peak Value Recorded And Distance Of Station To Hanyuan City

Station Name	Distance (kM)	Accelerogram peak value（gal）	
		EW direction	NS direction
Jiuxiang station (JX)	22	142.330	125.190
Qingxi station (QX)	34	74.896	83.035
Wusihe station (WSH)	48	63.221	49.023

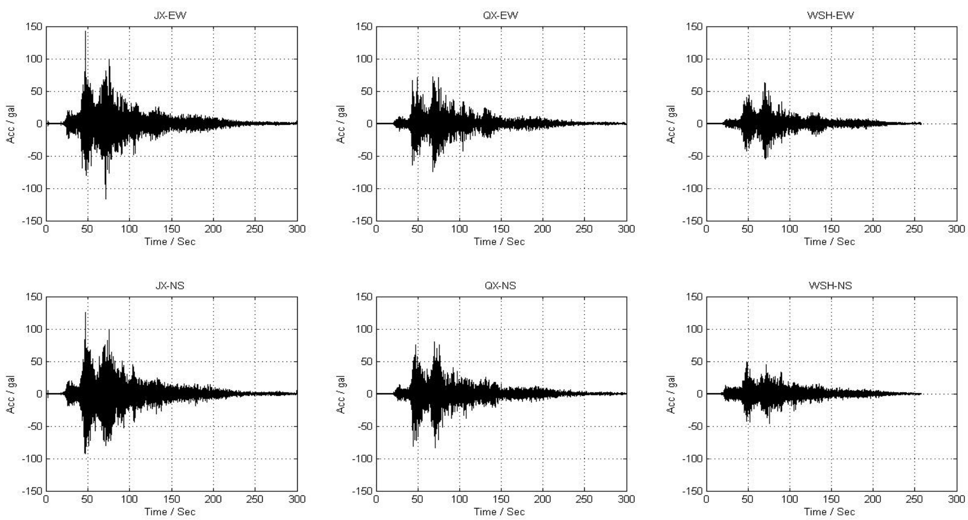


Figure 3. 2. Horizontal accelerogram recorded at Jiuxiang (JX), Qingxi (QX) and Wusihe (WSH) station

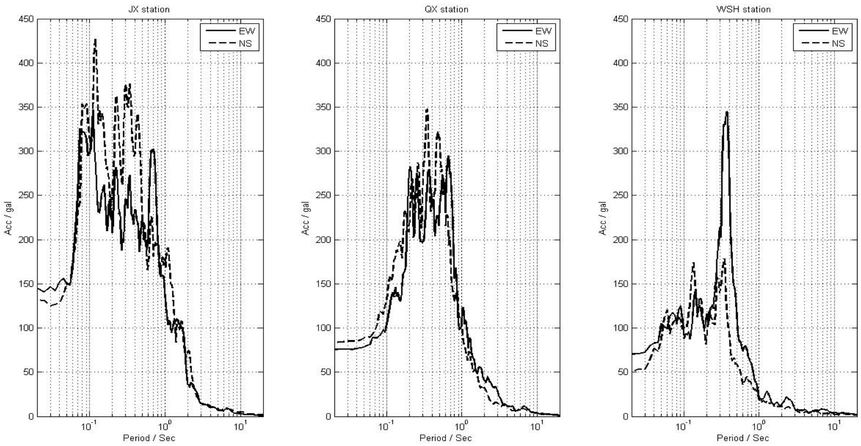


Figure 3.3. Acceleration response spectra of horizontal accelerogram recorded at three stations

3.3. Analysis Results

Basing on the borehole data, five numerical models were created, and six horizontal records wre chosen as inputs for calculation, some results were gotten. Some results are introduced below in brief, more details will be shown in subsequent papers.

3.3.1. Time history of surface acceleration response

For engineers, time history is the most direct and understood manifestation of surface acceleration response, and the peak values are key parameters. In this paper, no more details about surface response acceleration were discussed, except for surface response acceleration peak value.

Surface response acceleration peak values are listed in Tab. 3.4., according to different numerical model and under different inputs. The values are lager than the acceleration peak value (150 gal) for aseismic design in Hanyuan city in China code, some values in Tab.3.4. are more than two times of the design value, which is a reason led to serious damage of building.

The peak value ratio of surface response to inputs could show the degree of site amplification in time domain, the value in brackets in Tab.3.4 is the peak value ratio of surface response to inputs in every case of analysis. It is that, in most of cases, strong motion is significantly amplified by the site, even to above four times of the peak value of input.

Table.3.4. Surface Response Acceleration Peak Value

Number of Borehole	Surface response acceleration peak value under different inputs (gal)					
	JX accelerogram		QX accelerogram		WSH accelerogram	
	EW	NS	EW	NS	EW	NS
ZK1	243.14 (1.71)	274.05 (2.19)	204.43 (2.73)	169.32 (2.04)	189.12 (2.99)	217.74 (4.44)
ZK2	307.17 (2.16)	407.08 (3.25)	265.76 (3.55)	276.12 (3.33)	203.52 (3.22)	156.00 (3.18)
ZK3	319.73 (2.25)	341.17 (2.73)	229.75 (3.07)	249.59 (3.01)	185.27 (2.93)	151.02 (3.08)
ZK4	311.94 (2.19)	311.31 (2.49)	225.05 (3.00)	252.60 (3.04)	252.65 (4.00)	208.09 (4.24)
ZK5	230.43 (1.61)	224.73 (1.78)	186.48 (2.49)	198.23 (2.39)	184.11 (2.91)	172.42 (3.52)

3.3.2. Response spectra of surface acceleration response

Response spectrum is the basis of aseismic design, for analyze the reason led to serious damage of building on site, in the study, an introduction of response spectra and normalized spectra in brief is seen from Fig.3.4. and Fig.3.5.

For an example, it is shown surface acceleration response spectra of borehole ZK2 in different cases in Fig.3.4. It could be seen the response spectra values are large, many curves have a peak value at period value about 0.1 second, which is more clearly in the case of two pieces of accelerogram inputting recorded in Jiuxiang station, the value is more than 1.2g. Unfortunately, there are so many one-storey brick house in Hanyuan city, which natural period under earthquake load is also close to 0.1 second, so this type of building is damaged most seriously, which is founded in building damage survey after earthquake.

Normalized acceleration response spectra are shown the amplification effect of buildings with various natural periods. In the study, normalized surface acceleration response spectra under various case were all calculated, then mean value curve of same borehole is calculated, which are shown in Fig.3.5.. It is could be seen that the amplification effect of buildings with about 0.1 second natural period is very significant.

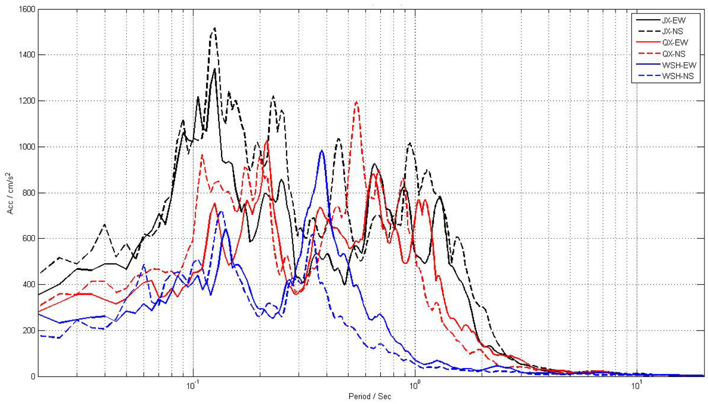


Figure.3.4. Surface acceleration response spectra of borehole ZK2 in different cases

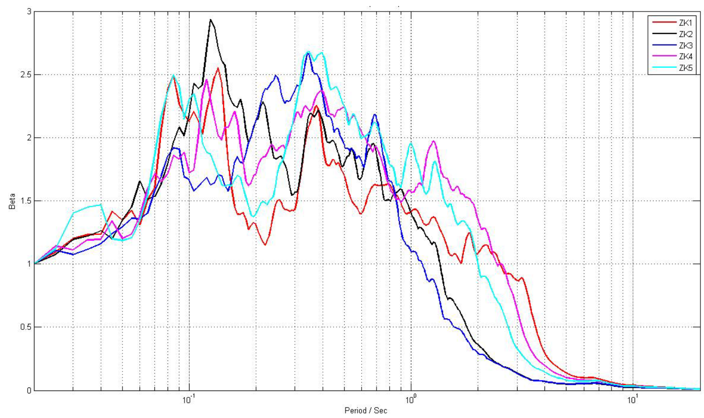


Figure.3.5. Mean value curves of normalized surface acceleration response spectra of different boreholes

3.3.3. Surface-to-input response spectra ratio

What did bring so rich content of 0.1 second shown in surface strong motion, the input motion or alternative site amplification effect? For further study, surface-to-input response spectra ratio (or Transfer Function) is calculated and then mean value of every bore hole, which is shown in Fig.3.6..

It is could be seen that many curves have a peak value at period value about 0.1 second still, so it is considered that site amplification is alternative on period, in the significant amplification effect at the period of about 0.1 second, amplification value could reach the degree of 3-4.5 times, which made the resonance effect of one-storey brick house more violently, even to damage seriously.

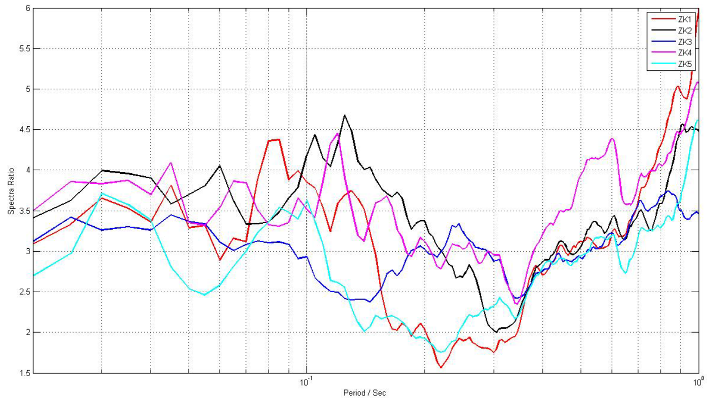


Figure.3.5. Mean value curves spectra ratio of different boreholes

4. CONCLUSION

The analysis above shown that site amplification effect is main reason led to relatively serious building damage of Hanyuan city in 2008 M_w8.0 Wenchuan Earthquake. Shallow soil layer in Hanyuan city site amplified the earthquake motion, at about 0.1 second in particular, which excited the same period content of surface earthquake motion, and damaged so many one-storey brick houses seriously because of strong resonance effect.

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REFERENCES

LU,T. Bo,J. Li, J. Liu,X. et al. (2009). Damage to buildings in Hanyuan county town during 2008 M_s8.0 Wenchuan earthquake.*Chinese Journal of Earthquake Engineering and Engineering Vibration*.**29:6,88-95**

Liao,Z.(2002), Introduction to wave propagation(2nd Edtion), Science Press, Beijing,China

LU.T, Zhou,Z. Huo,J. (2008).1D nonlinear seismic response analysis of soil layers in time domain .*Chinese Journal of Rock and Soil Mechanics*,**29:(8),2170-2176**