2nd Workshop of IWGoRS

Research on Rotational Ground motions in Wenchuan Earthquake

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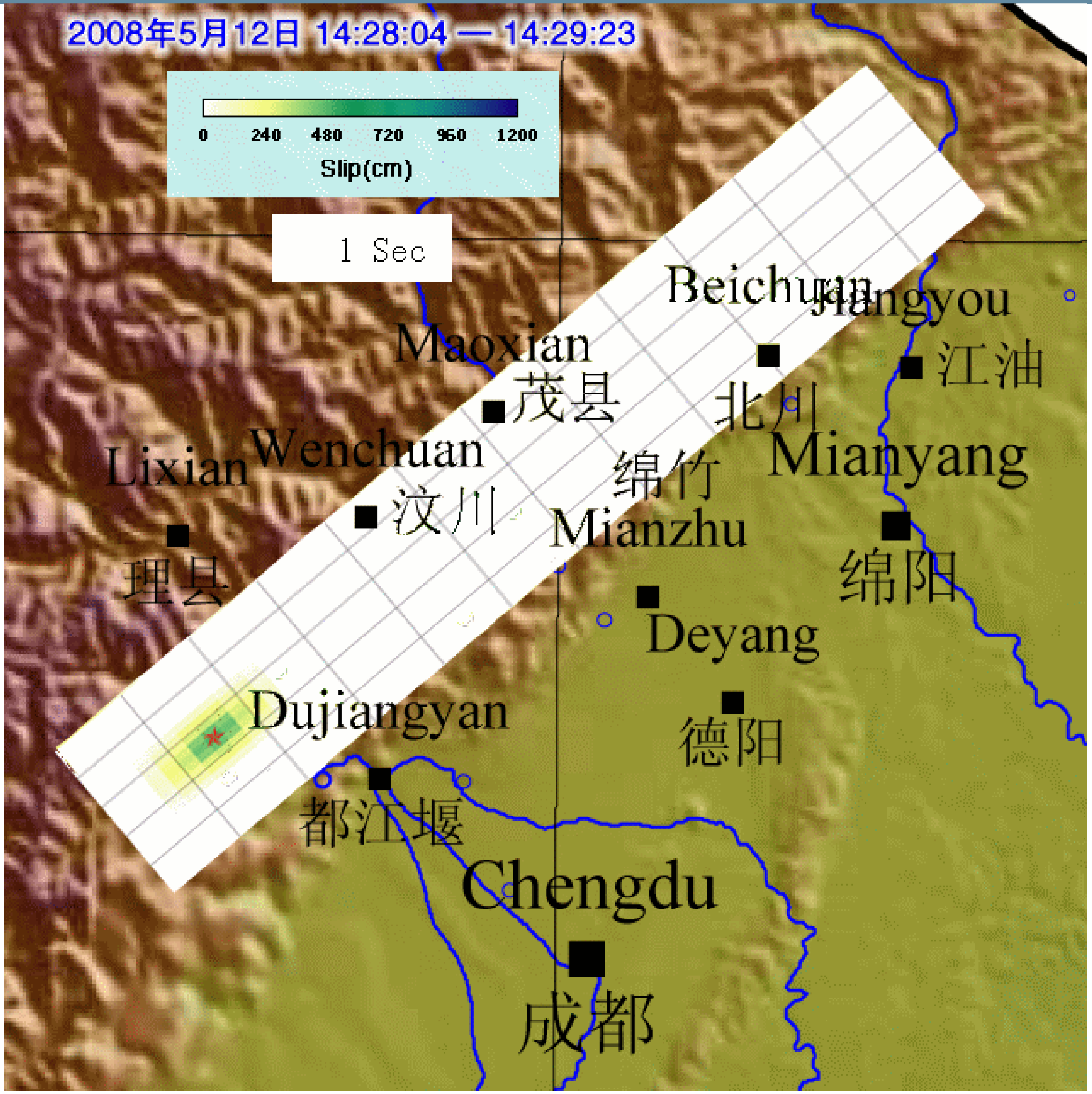
CONTENT

I About Wenchuan Earthquake

2008/5/12,A shocking earthquake(M8.0) happened in Sichuan Province, China, which killed **69197** persons and **18222** persons were disappearance. **374176** persons were injured.

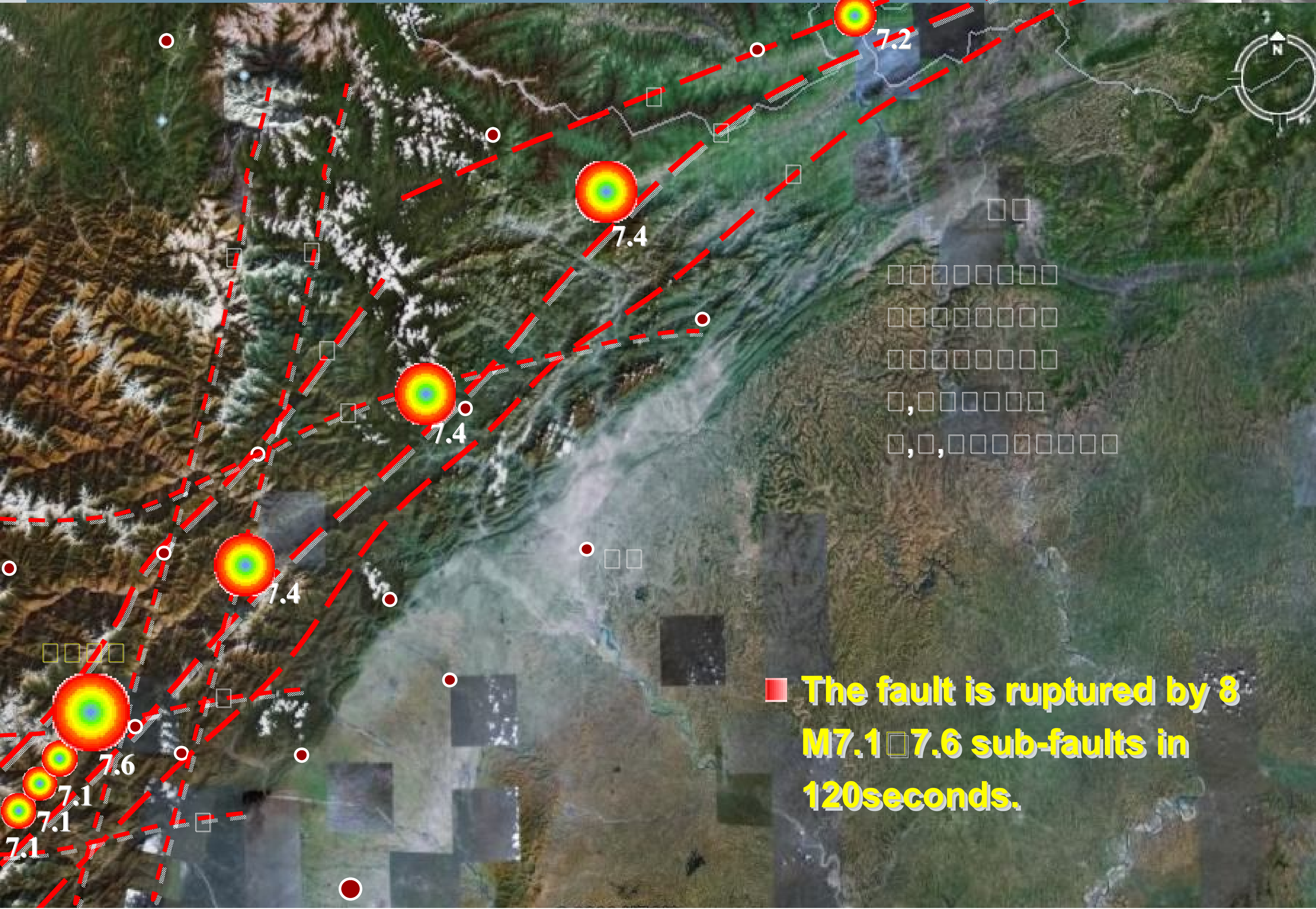
Rupture process of Wenchuan Earthquake



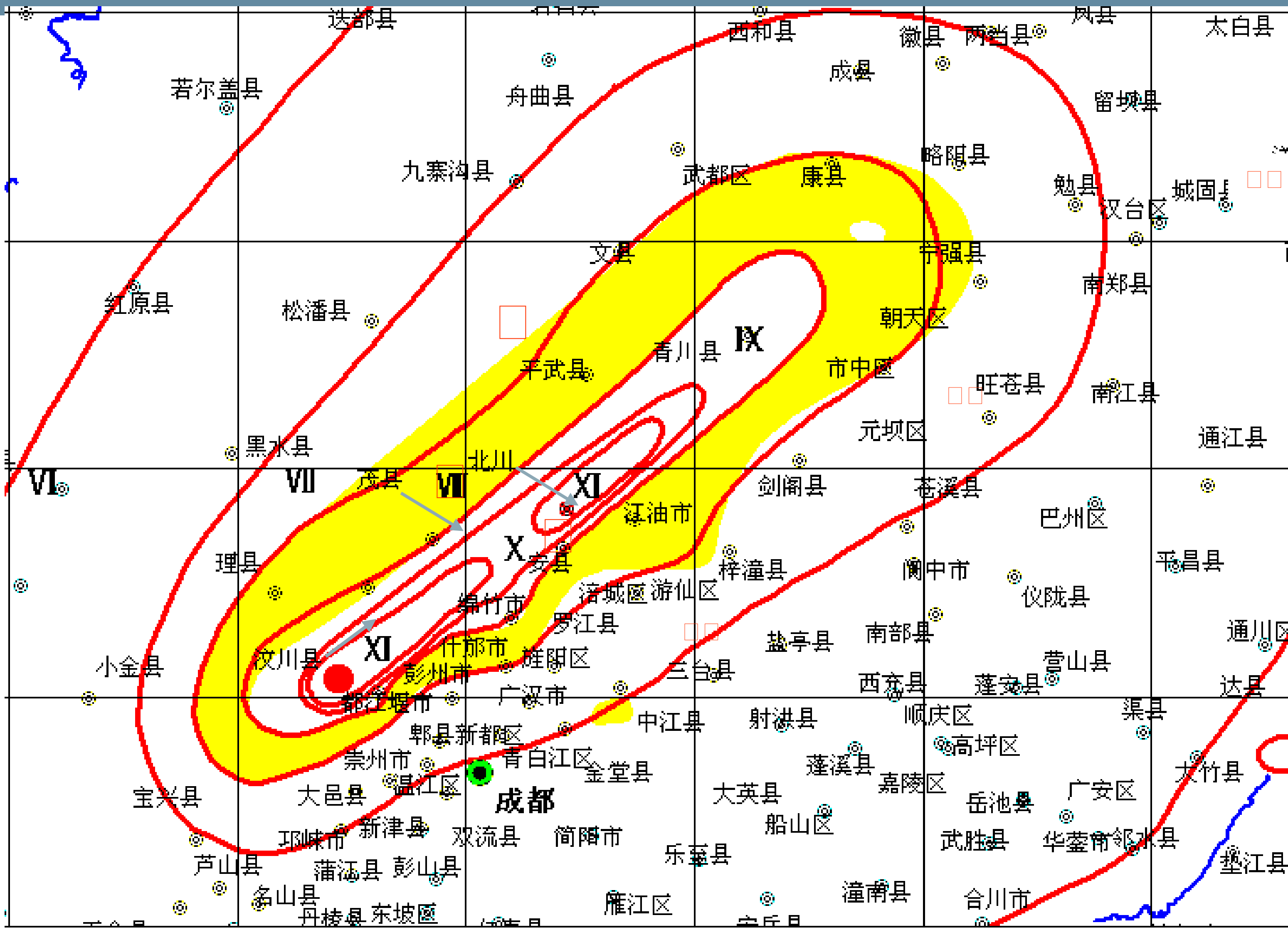
Rupture velocity:
□km/s

Duration:
120second

(Y.Chen et.al)


7.2
7.4
7.4
7.4
7.6
7.1
7.1
7.1
The fault is ruptured by 8 M7.1□7.6 sub-faults in 120seconds.

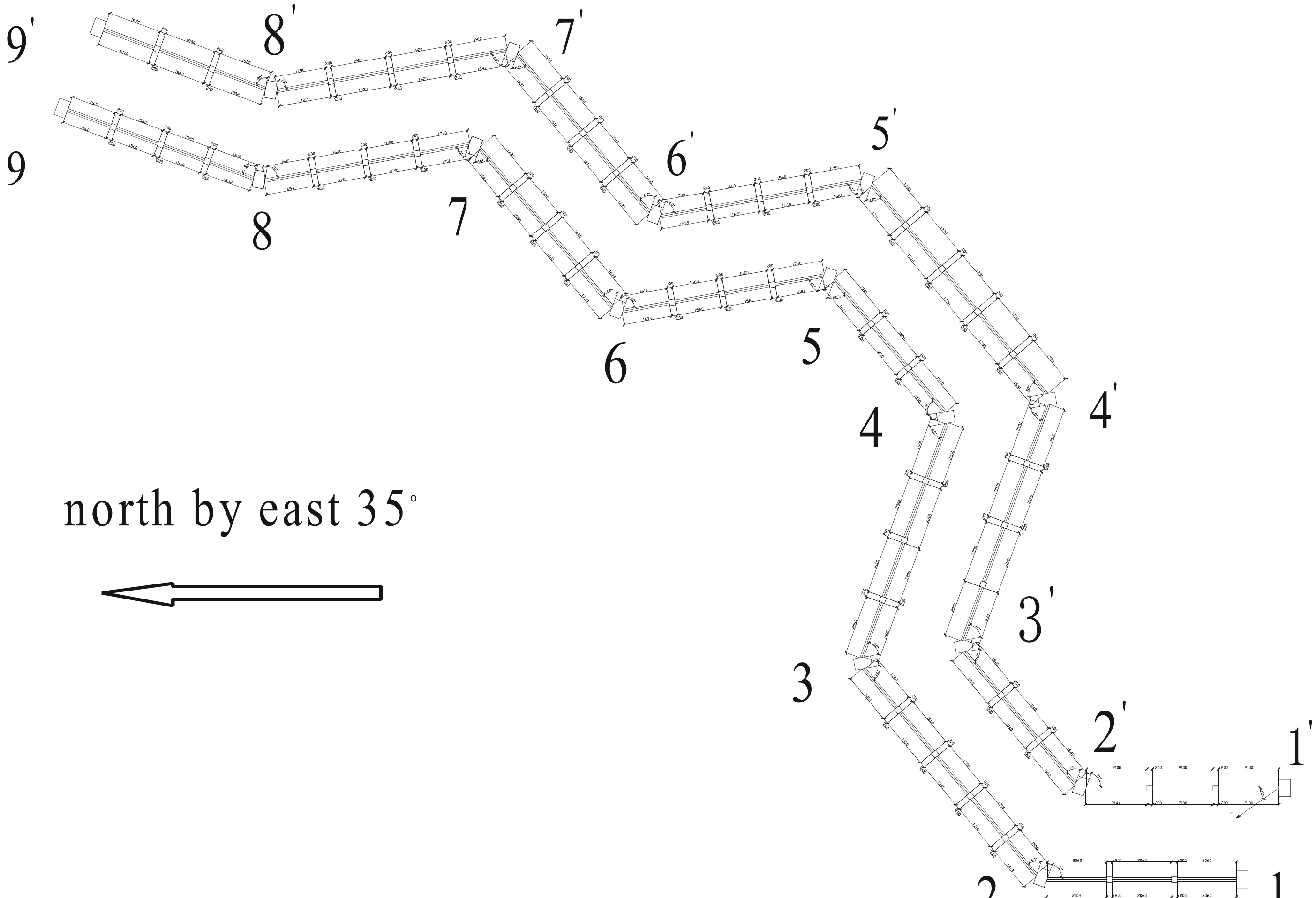
Distribution of seismic intensity



II Rotational Phenomena

Panorama of one zigzag bridge in one park in Jiangyou city

The Plan of the zigzag bridge



Rotational Phenomena of the stone statues

No.1 stone statue

No.1’ stone statue

Rotational Phenomena of the stone statues

No.2

No.2’

No.3

No.3’

Rotational Phenomena of the stone statues

No.4

No.4’

No.5

No.5’

Rotational Phenomena of the stone statues

No.6

No.6’

No.7

No.7’

Rotational Phenomena of the stone statues

No.8

No.8’

No.9

No.9’

Torsional displacements of stone statues

N_O	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Torsion z/°	0	0	-10	-5	+5	+20	+15	-5	0
N_O	**1’**	**2’**	**3’**	**4’**	**5’**	**6’**	**7’**	**8’#**	**9’#**
Torsion z/°	-5	0	-60	-30	-15	0	+20	0	+5

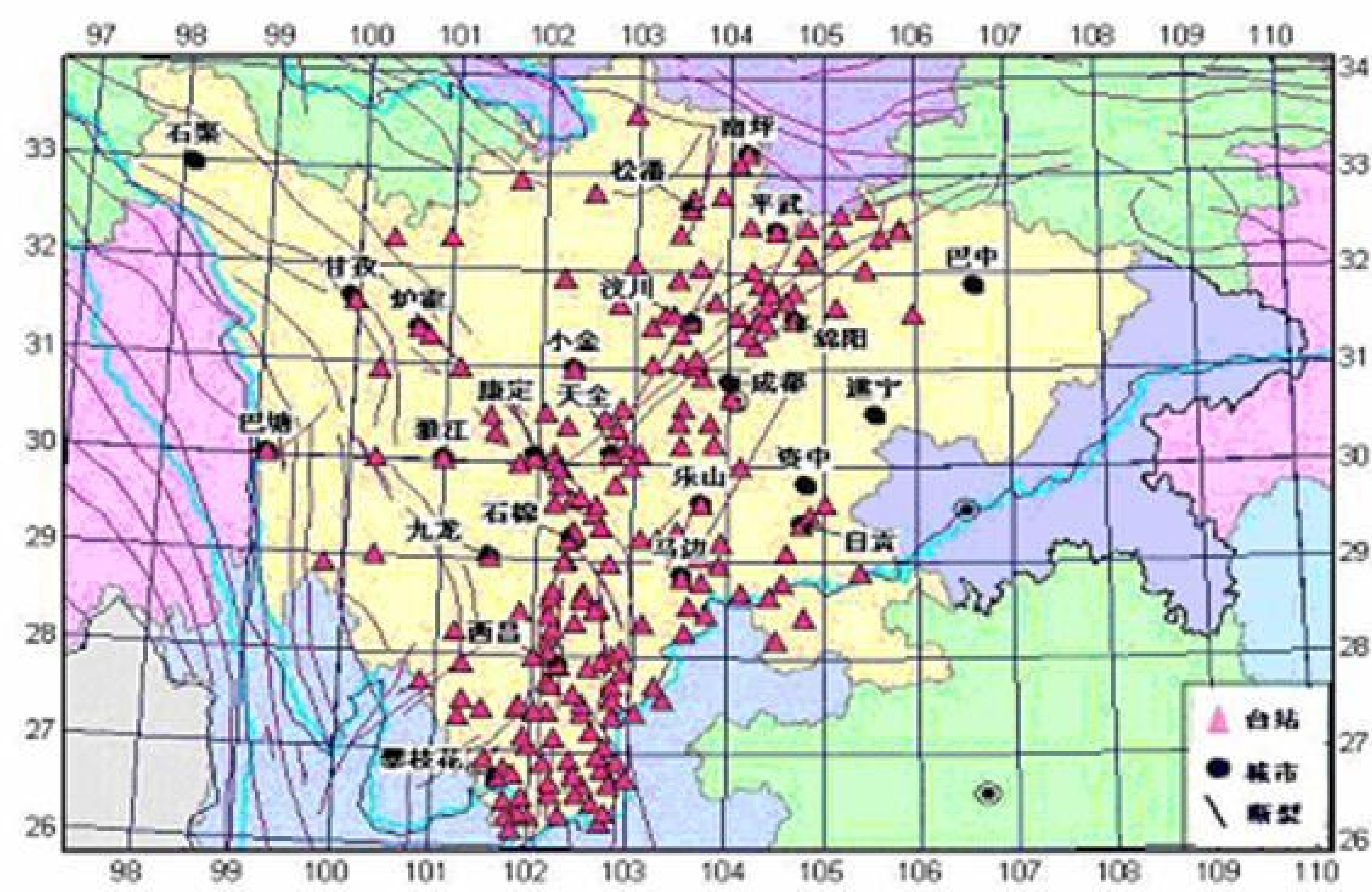
Question: the causes of torsional statues

Caused by torsional ground motion ?

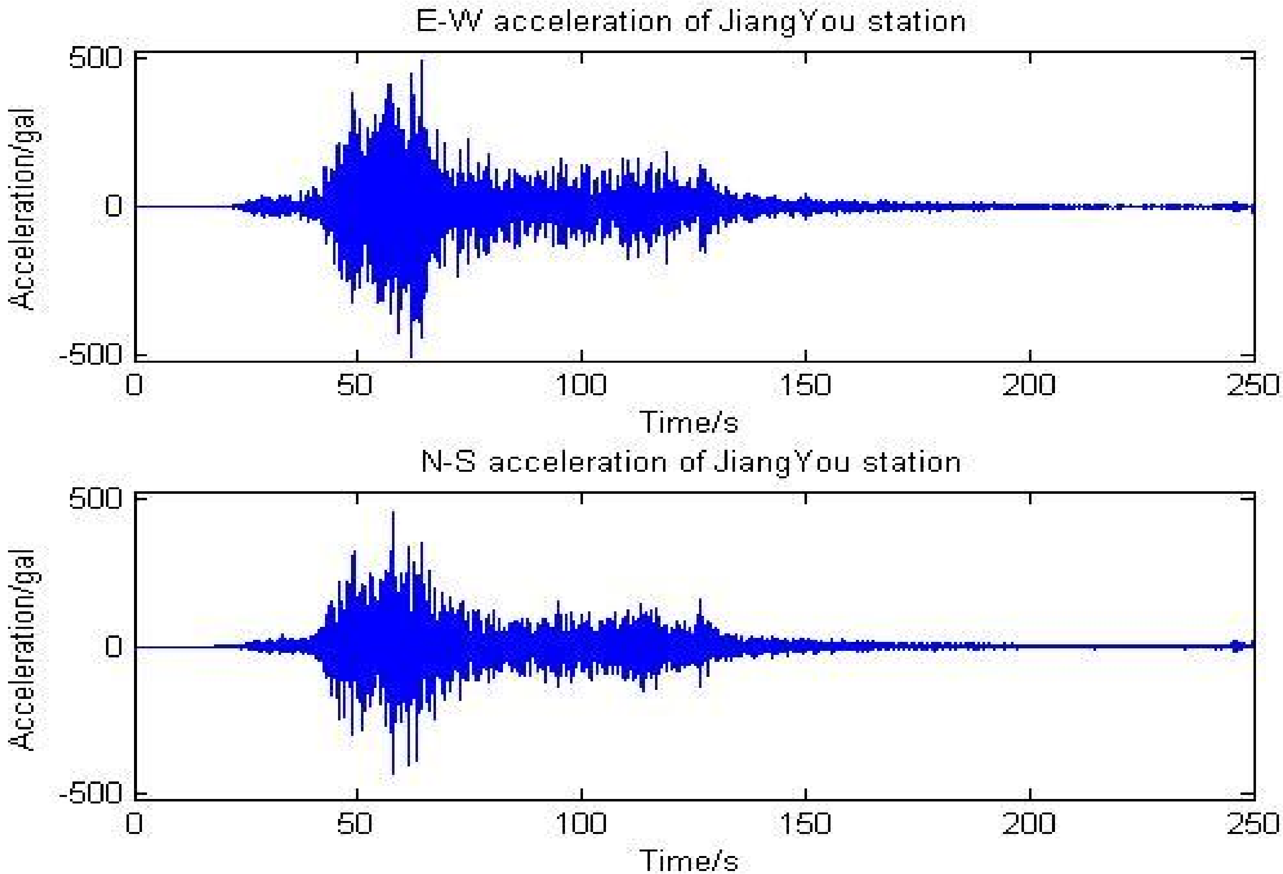
Caused by eccentricity of statues ?

Caused by no consistent input motion?

III Rotational ground motions

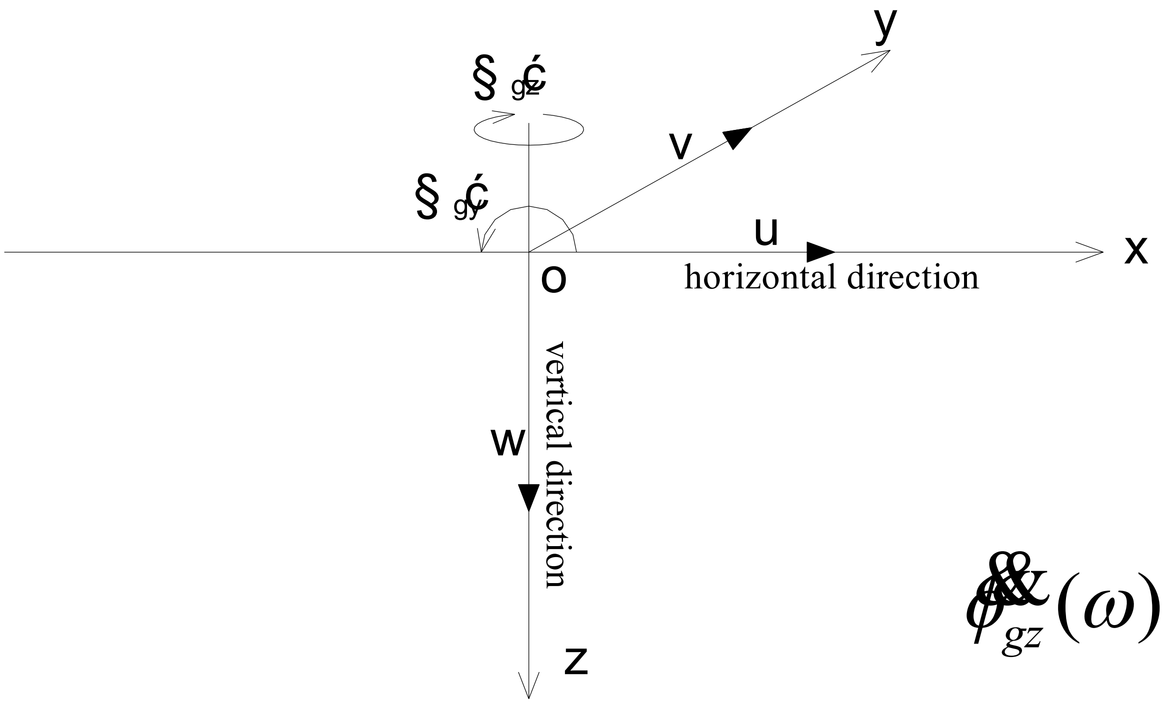


Translation records at Jiangyou station



Acceleration recorded at Jiangyou station

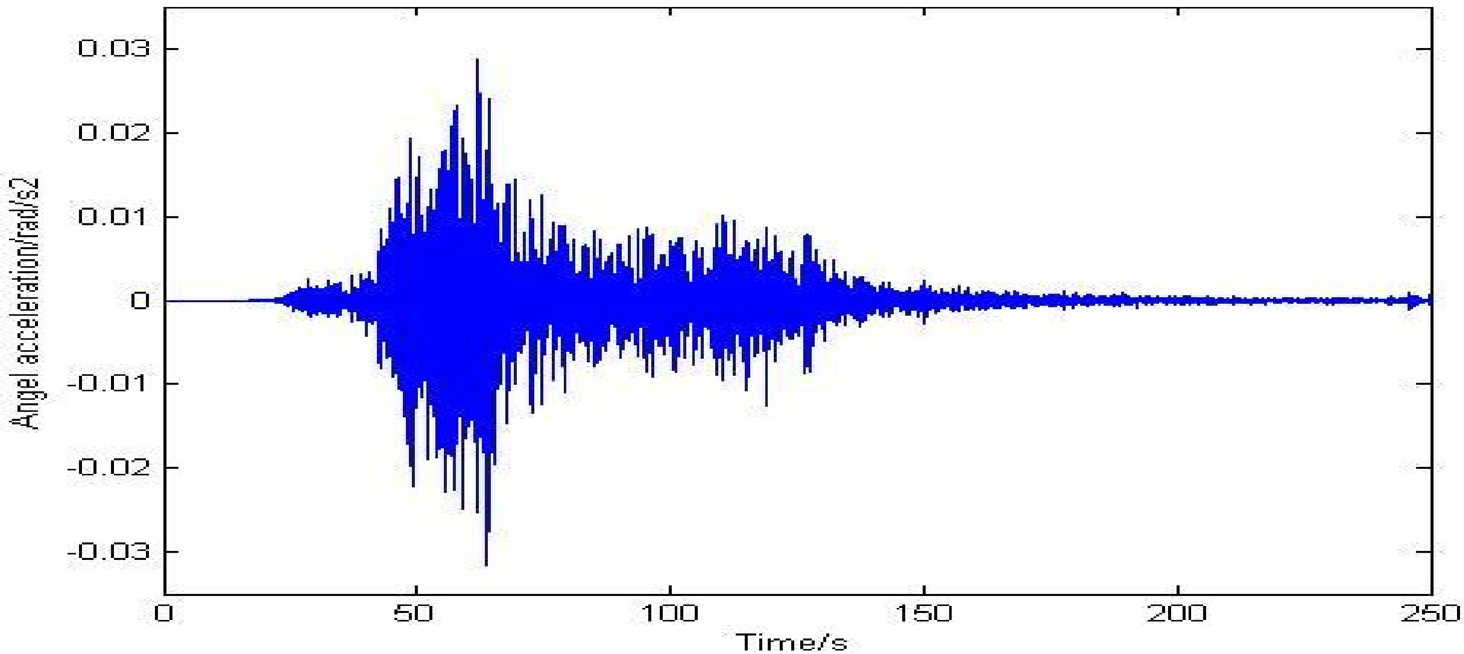
Simulation method of rotational motions



$$\ddot{\phi}_{gz}(\omega) = \mathrm{i}\omega \frac{\ddot{u}(\omega)}{2c(f)}$$

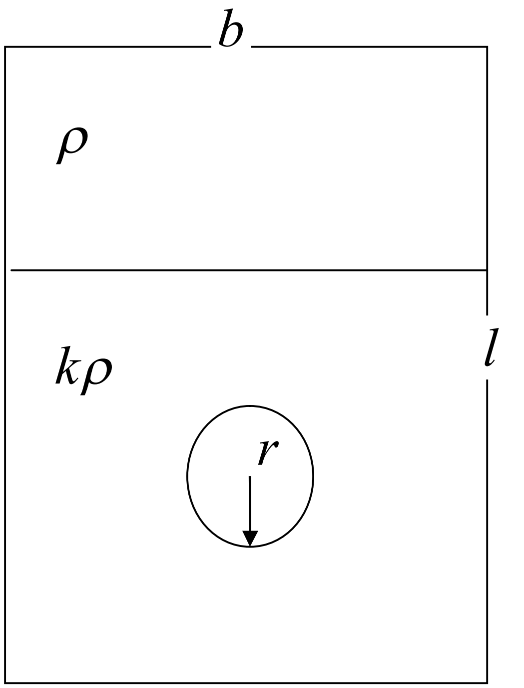
$$\ddot{\phi}_{gy}(\omega) = -\mathrm{i}\omega \frac{\ddot{w}(\omega)}{c(f)}$$

Simulated rotational motion from translation components

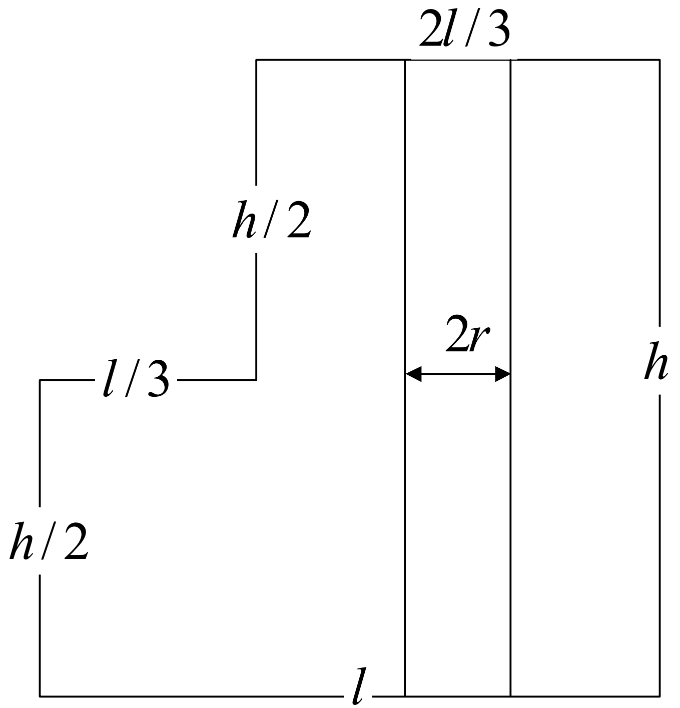


Synthesized torsional acceleration at Jiangyou station(max.0.03rad/s2)

IV Equivalent torsional acceleration



Plan of the model



Side face of the model

Calculation model of stone statue

Suppose the input acceleration along width direction is a, the inertia torque which results from eccentricity is:

$$L = [\int_{l/6}^{l/2} \rho b\tau \cdot d\tau + \int_{-l/2}^{l/6} k\rho b\tau \cdot d\tau + k\rho\pi r^2 (l/6)] \cdot a$$
$$= (\frac{1-k}{9} bl^2 + \frac{k}{6} \pi r^2 l)\rho a$$

where τ is an integration variable and the moment of inertia I of the statue is

$$I = \int_{l/6}^{l/2} \rho b r^2 \cdot dr + \int_{-l/2}^{l/6} k\rho b r^2 \cdot dr - [k\rho\pi r^4/2 + k\rho\pi r^2 (l/6)^2]$$
$$= [(\frac{13}{324} + \frac{7k}{162}) b l^3 - \frac{k\pi r^4}{2} - \frac{k\pi r^2 l^2}{36}]\rho$$

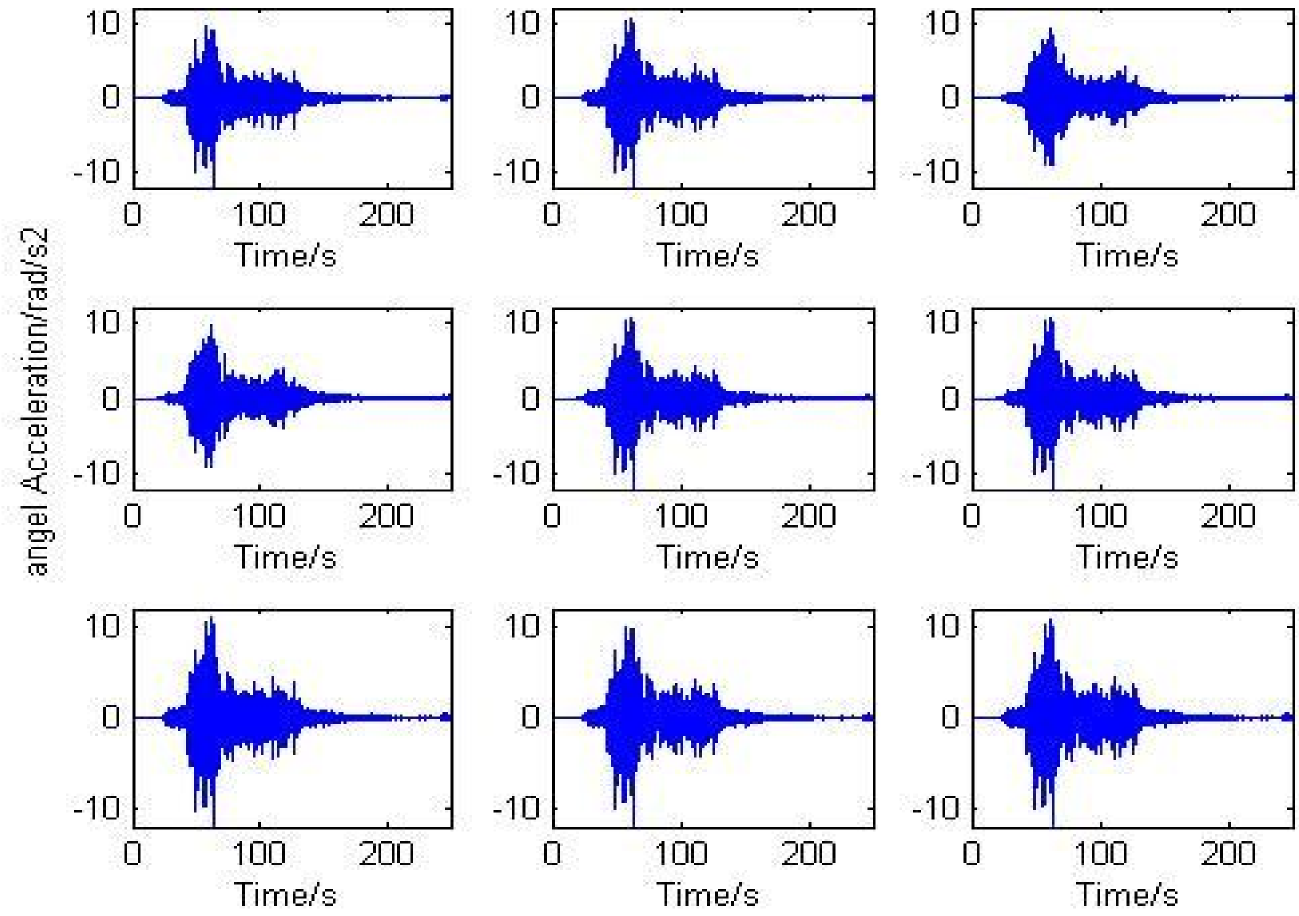
According to inertia torque equivalence principle, equivalent torsional acceleration is as follows:

$$\ddot{\varphi} = \frac{L}{I} = \frac{\left(\frac{1-k}{9} b l^2 + \frac{k}{6} \pi r^2 l\right) \rho a}{\left[\left(\frac{13}{324} + \frac{7k}{162}\right) b l^3 - \frac{k \pi r^4}{2} - \frac{k \pi r^2 l^2}{36}\right] \rho}$$

$$= \frac{\left(\frac{1-k}{9} b l^2 + \frac{k}{6} \pi r^2 l\right)}{\left(\frac{13}{324} + \frac{7k}{162}\right) b l^3 - \frac{k \pi r^4}{2} - \frac{k \pi r^2 l^2}{36}} (u \cdot \sin\theta + v \cos\theta)$$

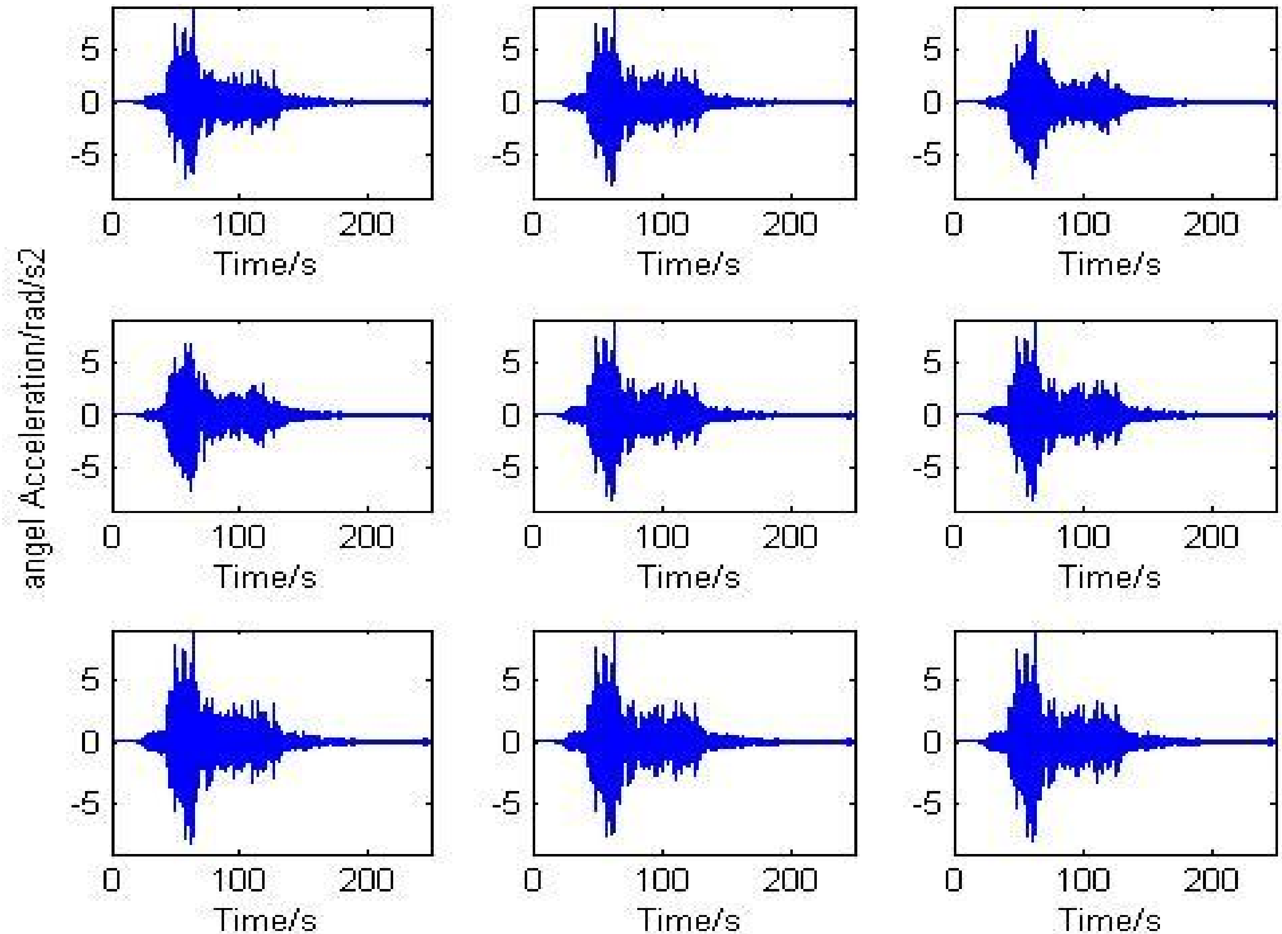
where, *u* is the input acceleration in east-west direction, *v* the input acceleration in north-south direction and θ an included angle between width direction of the statue and the north-south direction. By the equation, the equivalent torsional acceleration in case 1 (there is a stone lantern on the top of the statue head) and case 2 (there is not stone lantern) can be calculated.

Calculated equivalent torsional acceleration



Equivalent torsional acceleration of nine stone lions in case 1(Max.10rad/s2)

Calculated equivalent torsional acceleration



Equivalent torsional acceleration of nine stone lions
in case 2(max.6rad/s2)

Experiment: **Shaking Table Testing**

- Shaking Table (MTS

Size: 4m x 4m

Max specimen weight:

25 tons

Degree of Freedom: 6

- Performance

Horizontal X:

1.2 g 100cm/s 100cm

Horizontal Y:

0.8 g 60cm/s 50cm

Vertical (Z):

0.7 g 60cm/s 50cm

V Characteristic of rotational motions

For calculating the rotational motions from the translations, we should consider two problems:

One is the dispersive curve of wave group velocities, another is the influence of the input angle of wave.

How do calculate the wave group velocity ? (Liao et.al)

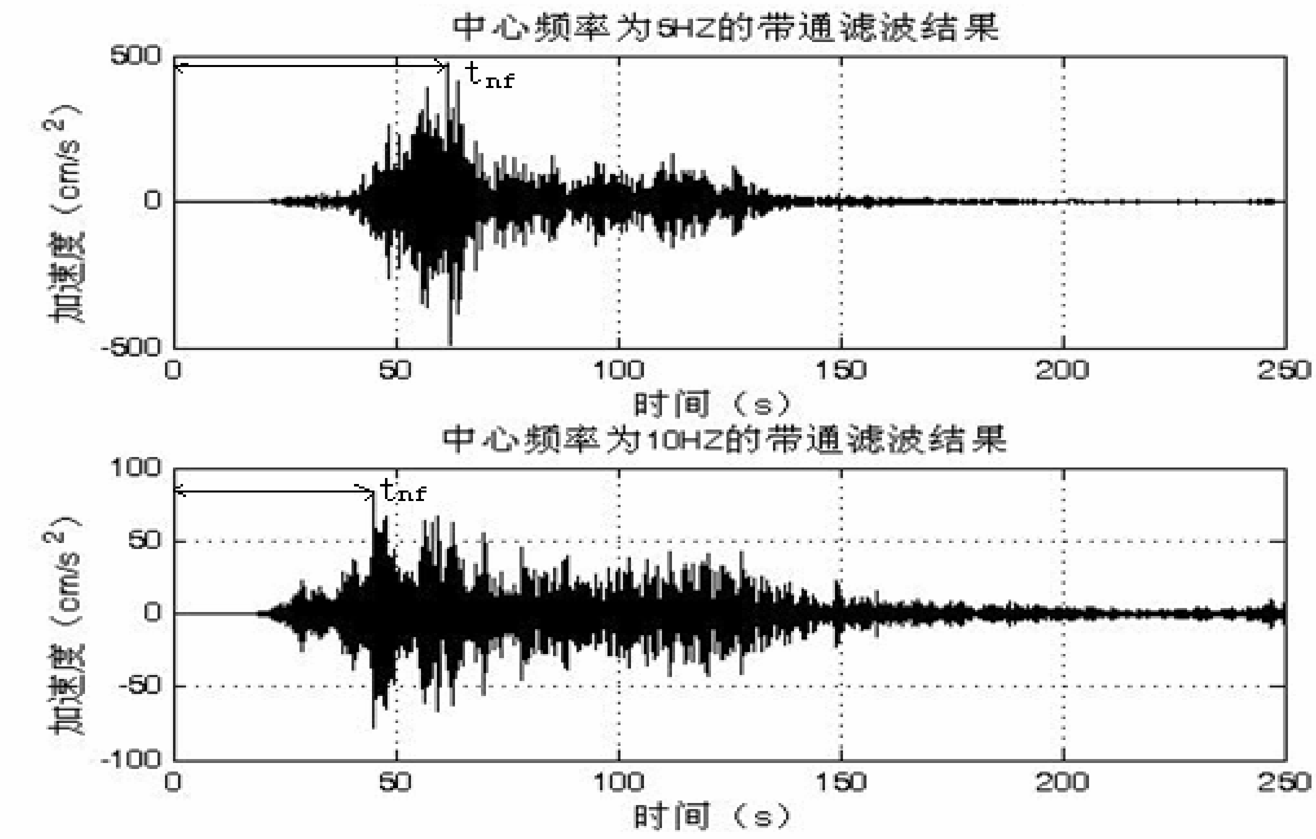
$$\overline{v_T}(f) = r / t_f \longrightarrow t_f$$

How do get t_f ?

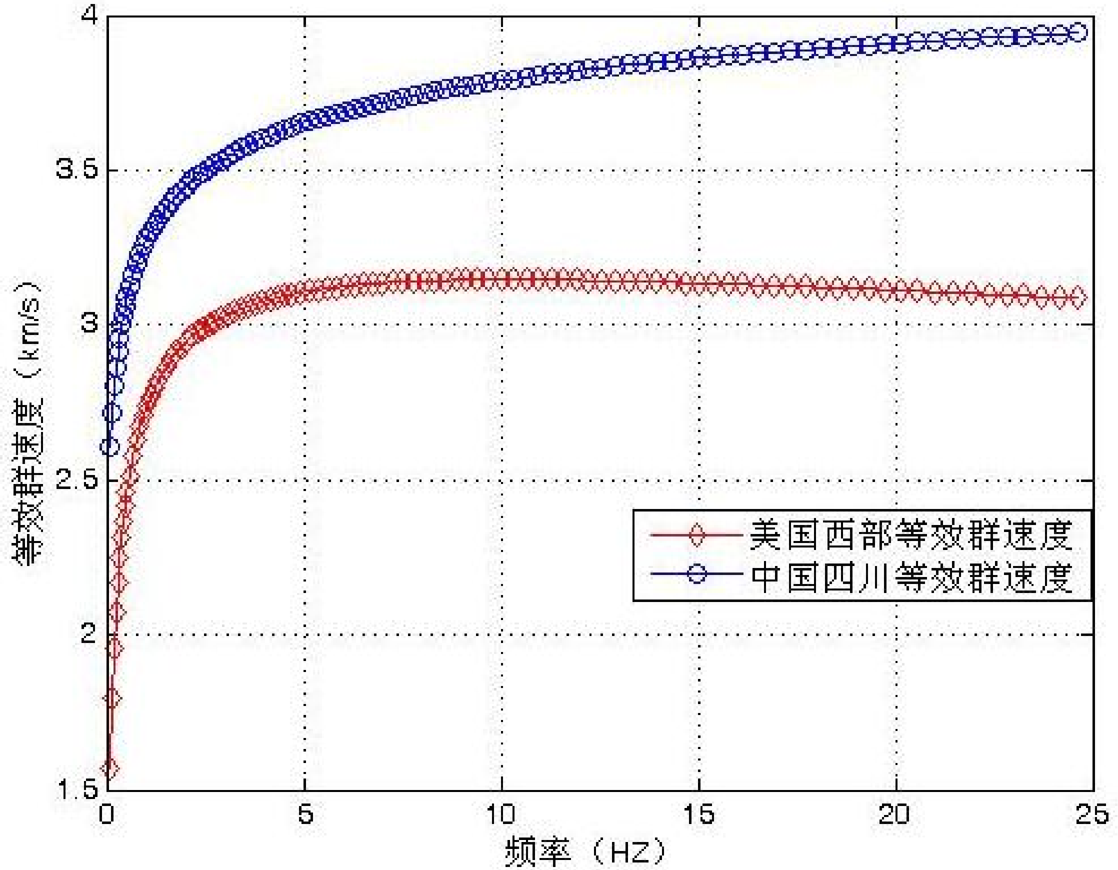
$$t_f = t_{nf} - t_{cf} + r / c_m$$

t_{nf} is arrive time of the nth narrow wave group, which dominant frequency is f. t_{cf} is arrive time of the fastest wave group, which velocity is . In one special area, c_m can be chosen as one value. In Sichuan, c_m is chosen as 6.5km/s. We could use band filter method get t_{nf} and t_{cf}.

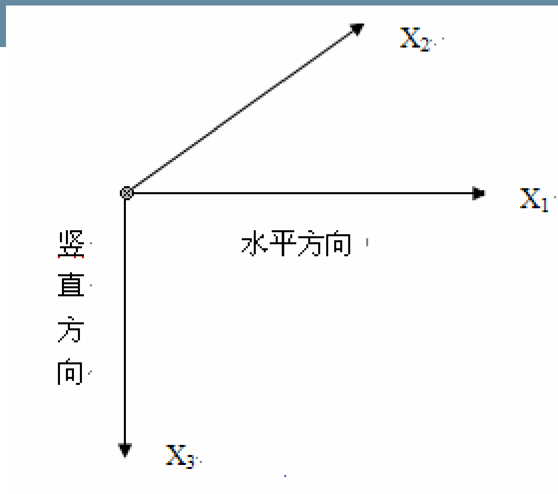
Example of band filter method

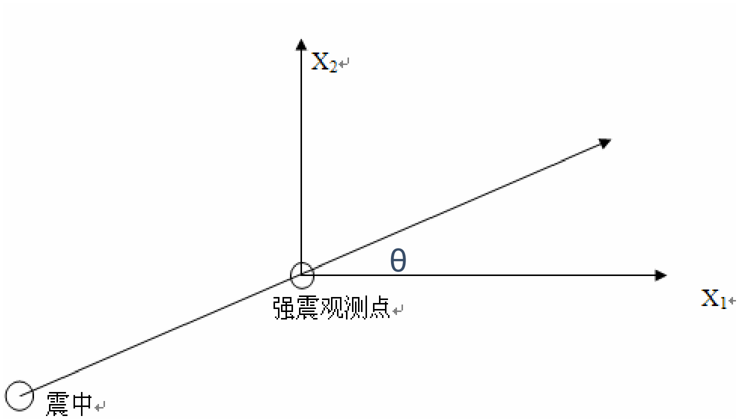


Comparison of dispersive curve of group velocities in China and US



Frequency influence on input angles





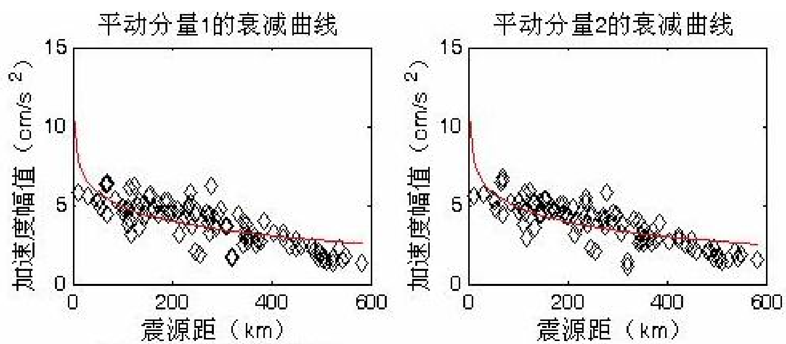
$$
\begin{cases}
\ddot{\varphi}_1(\omega) = \dfrac{i\omega}{C}\ddot{u}_3(\omega) \\
\ddot{\varphi}_2(\omega) = \dfrac{i\omega}{C}\ddot{u}_3(\omega) \\
\ddot{\varphi}_3(\omega) = \dfrac{1}{2}\cdot\dfrac{i\omega}{C}[\ddot{u}_2(\omega) - \ddot{u}_1(\omega)]
\end{cases}
$$

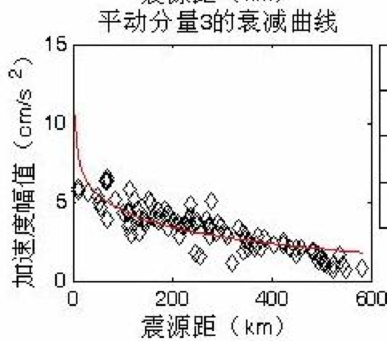
Consider input angle

$$
\begin{cases}
\ddot{\varphi}_1(\omega) = \dfrac{i\omega}{C}\ddot{u}_3(\omega)\sin\theta \\
\ddot{\varphi}_2(\omega) = \dfrac{i\omega}{C}\ddot{u}_3(\omega)\cos\theta \\
\ddot{\varphi}_3(\omega) = \dfrac{1}{2}\cdot\dfrac{i\omega}{C}[\ddot{u}_2(\omega)\cos\theta - \ddot{u}_1(\omega)\sin\theta]
\end{cases}
$$

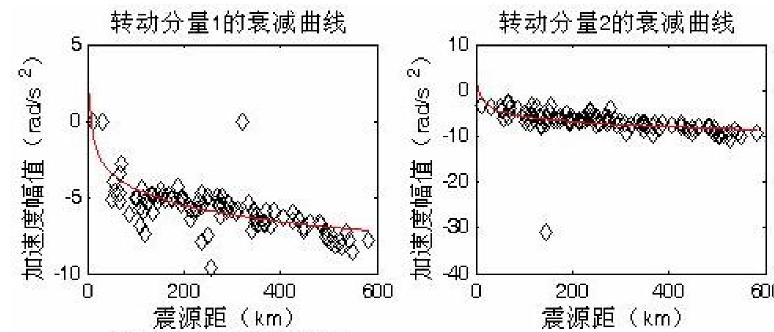
Attenuation of translation and rotation motions

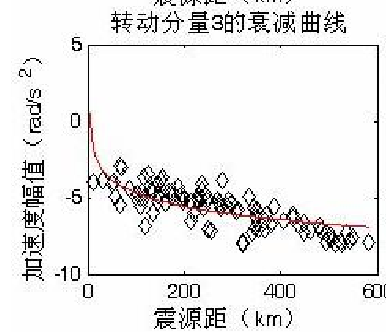
$$\ln\alpha = a + \mathrm{b}\ln(R + R_0)$$





	参数 a	参数 b
平动分量 1	11.0077	-1.3247
平动分量 2	11.0339	-1.3385
平动分量 3	11.3775	-1.5046



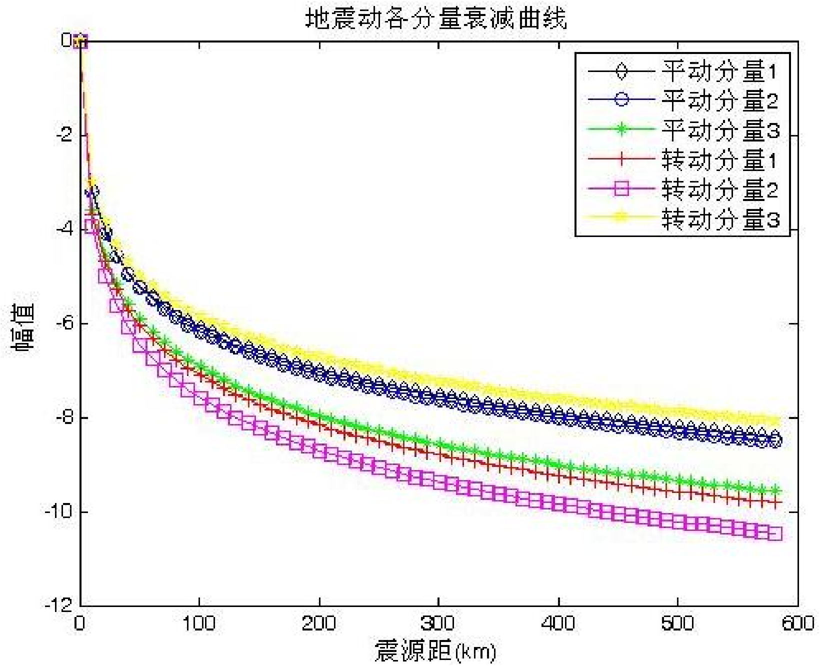


	参数 a	参数 b
转动分量 1	2.6302	-1.5411
转动分量 2	1.8840	-1.6429
转动分量 3	1.1556	-1.2699

Translation motions

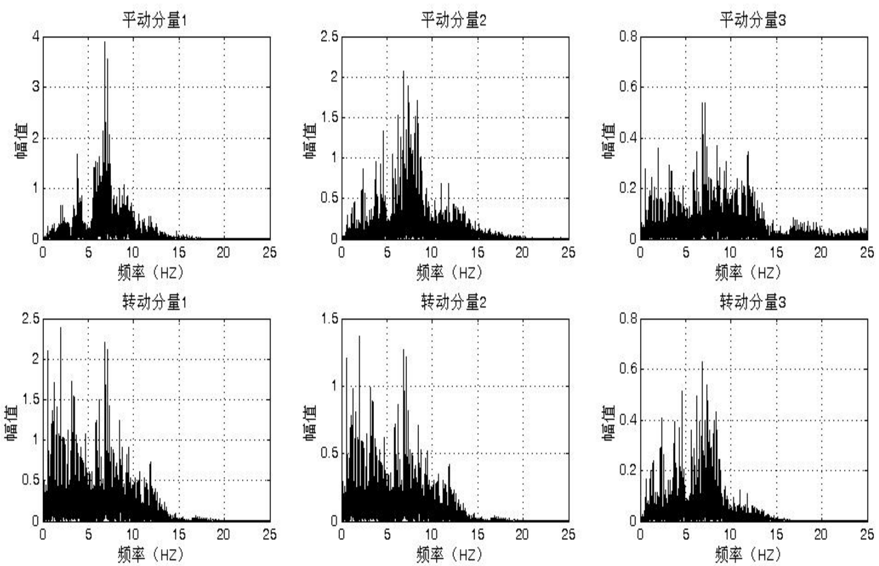
Rotation motions

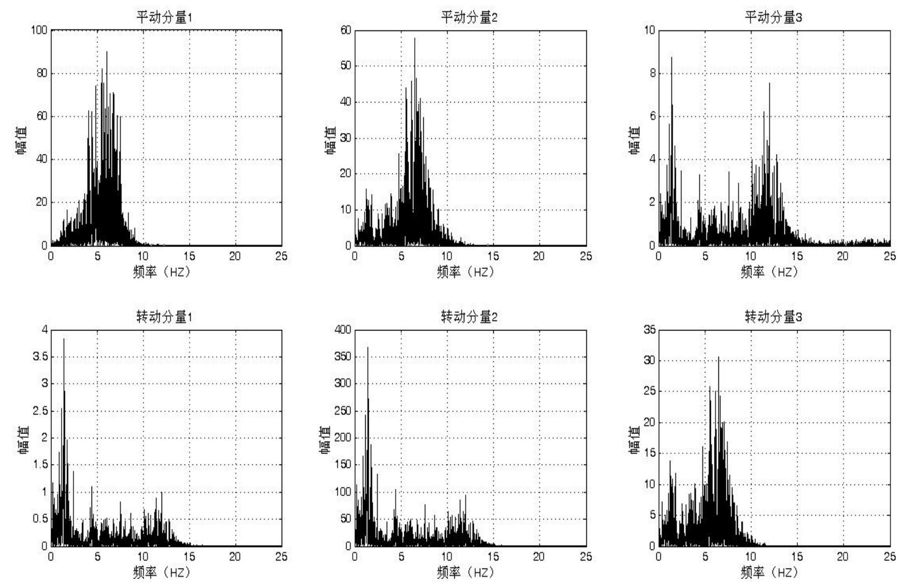
Comparison of Attenuation of translation and rotation motions



The fast attenuation is rocking component, then the translation, the slowest is torsion component.

Power spectra of translation and rotation components





At Baoxing station

At Jiangyou station

At Jiangyou station

VI Conclusion

1 the peak equivalent torsional acceleration is about 10 rad/s^2 in case 1 and is about 6 rad/s^2 in case 2,but the peak torsional acceleration is about 0.03rad/s^2.

2 There are different dispersive curve of group velocities in different area.

3 The rocking component attenuates fast then the translation and torsion component.

4 The long period components of rock motions are richer than that of rotation motions.

5 The torsional phenomena of the statues on the zigzag bridge is mainly affected by its eccentricity, the anti-torque caused by structural eccentricity should be considered in seismic design.

Great earthquake could stop the clock

But it couldn't stop us marching□□□


Thank you for your attention
Especially thanks to
Prof. Igel,
Dr. Brokesova and
Ms. Munzarova, et. al.