The supersonic modelling of the earthquake ground motion on the Beijing depression

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ABSTRACT: The investigation of the earthquake damages during the Tangshan big earthquake in 1976 showed us that the distribution of the anomalous zones of shock calamities in Beijing City corresponds to the both wings of the Beijing depression in geology. Using the method of supersonic seismic model experiment, we study the earthquake ground motion on the Beijing depression. Cutting a section crossing over the long axis of the Beijing depression, and simplifying the coverlayers and bedrocks respectively into two homogeneous bodies, we design the model in the light of the requirements of similarity. The results are well in correspondence with the earthquake damages in Beijing City during the Tangshan big earthquake in 1976. The works of this paper indicate that supersonic modelling is a sufficient means for investigating the problems of earthquake ground motion.

1 INTRODUCTION

The earthquake ground motion is one of the direct causes which produce earthquake damages, and site condition is a main factor which effect the differences of the earthquake ground motion on a local area. The investigation on the earthquake damages in Beijing district after Tangshan big earthquake in 1976 showed that there were two anomalous zones of shock calamities along NE direction in Beijing City which correspond to the outline above the depression of the underlying bedrock (see Peng & Hao(1985)),and other examples of shock calamities also showed that underlying bedrock topography is a very important site factor effecting the earthquake ground motion.

In 1985, Hao et al. had studied the effecys of the underlying bedrock topography in Beijing City on earthquake ground motion by means of dynamic finite element method. Owing to the limit of means and the method, some important factors effecting the earthquake ground motion, such as the resemblance between modelling centrum and natural centrum and the incident direction of seismic wave etc. are not able to be considered.

The characteristics of the supersonic wave make it possible to consider the factors of centrum, propagation pathes and the geological structures of a site etc. simultaneously. This paper uses the method of supersonic seismic model experiment in the study about the effects of underlying bedrock topography on the earthquake ground motion, and it is a primary attempt.

2 THE SEISMOGEOLOGICAL BACKGROUND

Beijing district is situated in the northwestern part of North China plain, where developed faults along NE direction during the Yanshan Movement, forming the embryonic form of swell and depression structure. Babaoshan fault (Fb), Nanyuan - Tongxian fault (Fn) and Xiadian fault (Fx) cut out western Beijing uplift, Beijing depression, Daxing uplift and Dachang depression, and moved many times in the geological development later. The faults along NW direction, coming out mostly in the form of the faults across the above faults along NE direction are of special characteristics of movement. All of these make up of the basic outline of active structure there.

Since Quaternary, due to the contemporaneous fault features of each main fault in Beijing district (Peng et al.(1981)), the Palaeogene System in uplift region have been denuded. On the ground surface, the original topography of a depression between two uplifts has disapeared basically, but the form of original bedrock structure becomes more apparent, forming complicated

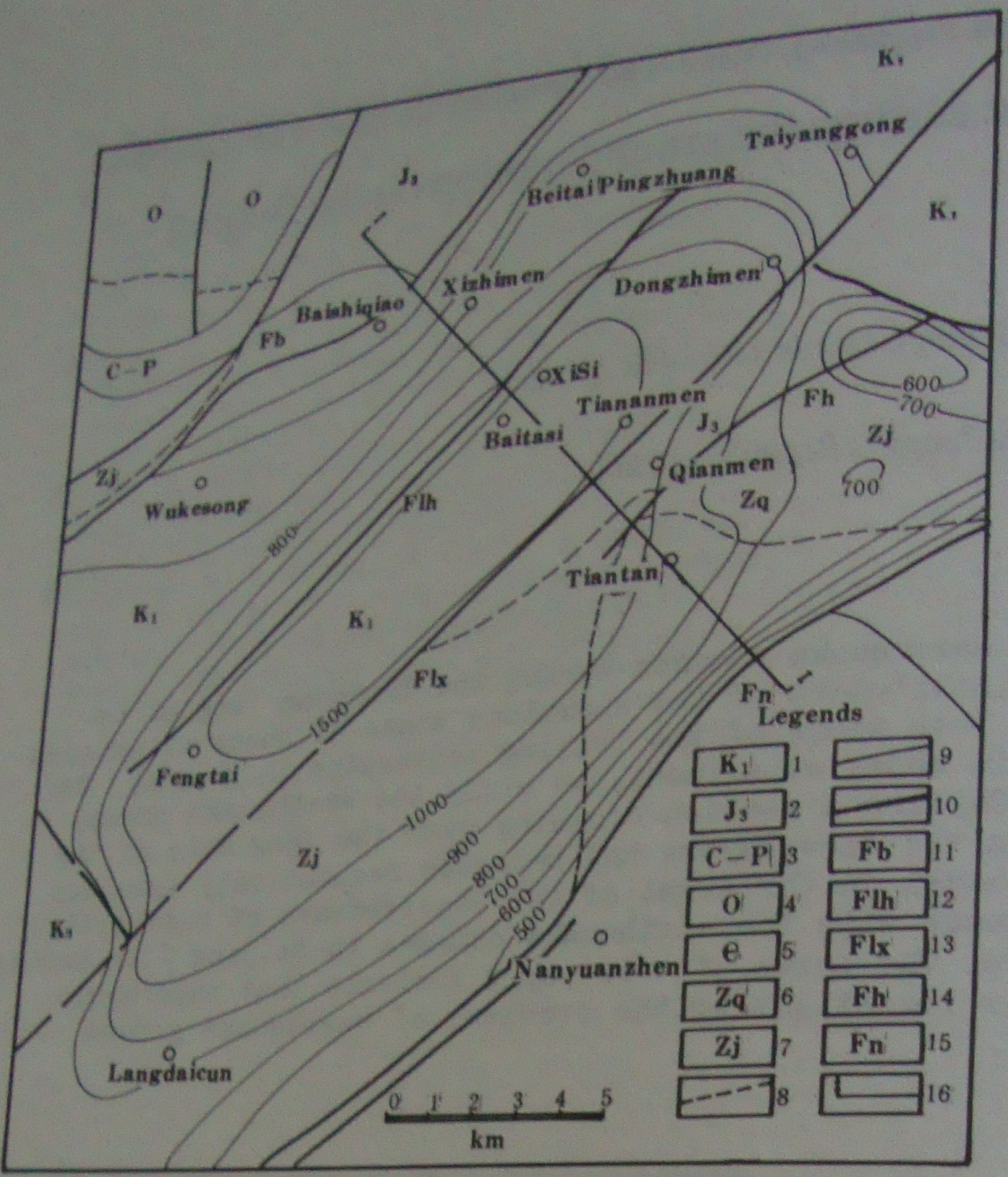


Fig.1 The bedrock geological structures in Beijing depression

1. Sandstone and conglomerate of lower Cretaceous Series
2. Andesite of upper Jurassic Series
3. Sand-shale of Carboniferous-Permian System
4. Limestone of Ordovician System
5. Limestone of Cambrian System
6. Shale and sandstone of Qingbaikou System
7. Siliceous dolomitic of Jixian System
8. Stratum boundary
9. Isobath line of underlying bedrock
10. Fault
11. Babaoshan fault
12. Lianhuachi fault
13. Liangxiang - Qianmen fault
14. Hujialou fault
15. Nanyuan - Tongxian fault
16. Section line

underlying bedrock topography.

Beijing depression appears as a long and narrow figure, the long axis of which is along NE direction (Fig.1). Its northwest wing is steeper, controled by Fb; and its southeast wing slopes gently, the side of which is Fn. There are also Lianhuachi fault (Flh) and Liangxiang - Qianmen fault (Flx) etc. in the middle of the depression. These faults cut out a complicated underlying bedrock topography.

The Precenozoic bedrock consists of solid strata of Mesozoic and Paleozoic erathem as well as Sinian suberathem, and the covering layer consists of half-cemented strata of Tertiary System (with thickness of 1000 - 1500 M) and loose soil of Quaternary System (with thickness of 20 - 100 M).

Crossing over the anomalous zone of shock calamities in the northwest of the City, the section of the site is cut over the long axis of the Beijing depression(section I - I in Fig.1, Xz, Xs, Qm, and Tt represent Xizhimen, Xisi, Qianmen and Tiantan respectively.), as shown in Fig.2.

According to the study of the historical earthquakes in Beijing district, recent period may still fall in the active period of earthquake, and earthquakes over 5 M may take place during the working and existing of buildings in the district, so it has important practical significance to investigate the earthquake ground motion on the Beijing depression.

3 MODEL DESIGN AND EXPERIMENT SYSTEM

The main object of the study in this paper

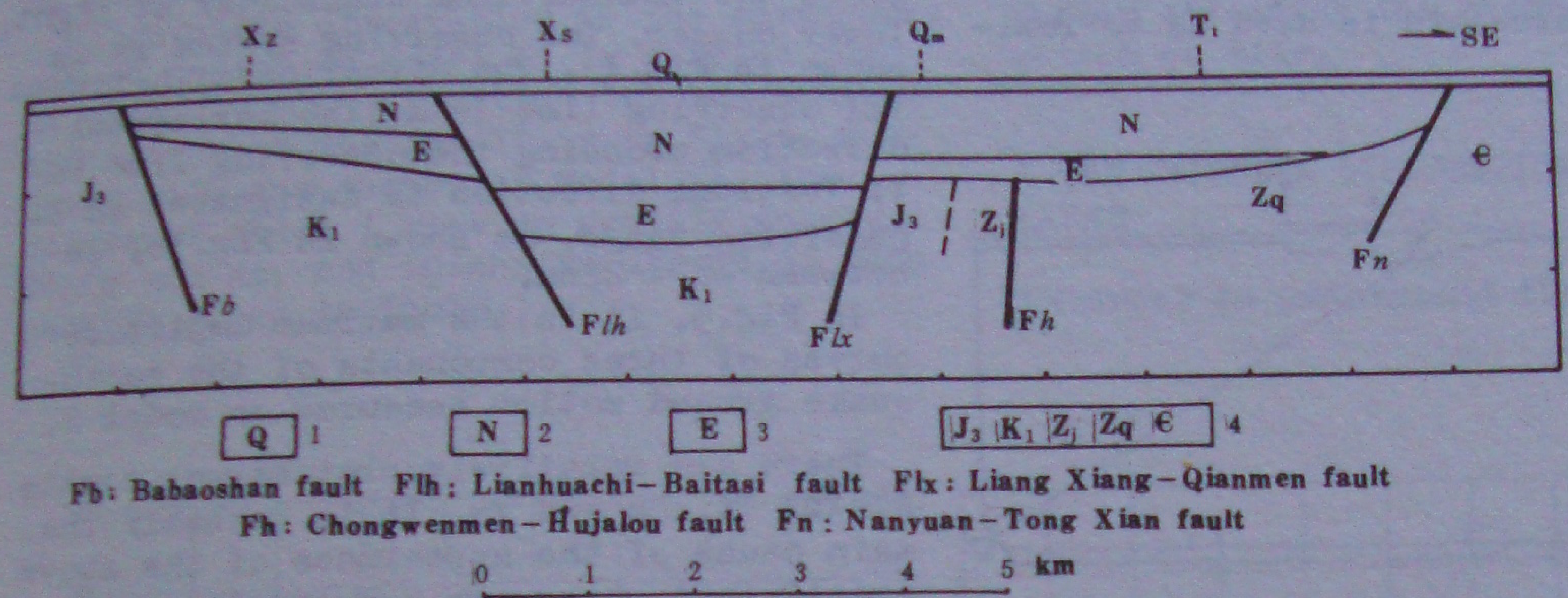


Fig.2 The section of the site
1. Quaternary System 2. Neogene System 3. Palaeogene System
4. Precenozoic

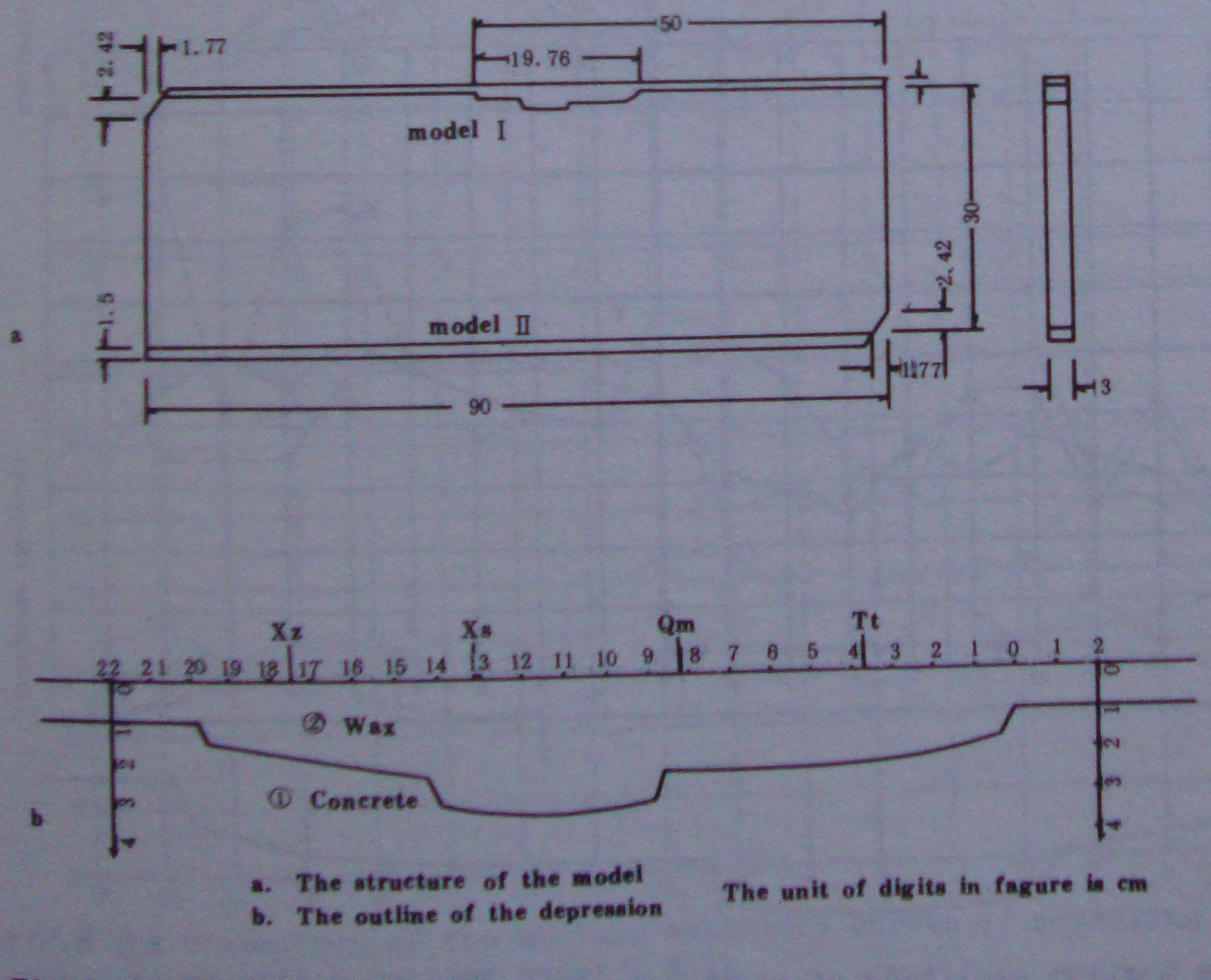


Fig.3 Experimental model

is the effects of underlying bedrock topography on the earthquake ground motion, therefore, covering layers and bedrocks are simplified into two homogenous bodies and simulated by wax and concrete respectively.

The experimental model from the section of site in Fig.2 is shown in Fig.3. The model similar to the surface of the bedrock depression of the site is called model I; and the other side is the model of horizontal surface of underlying bedrock, which is called model II and used as a comparison model.

The model and instrument make up a expermental system. The transducers of pressure-electric porcelain is used as to realize the transfer between sound and electricity. The transmitting transducer similar to the centrum of natural earthquake in radiant charactors is choosed as the simulating centrum, and placed at a certain depth under the southeast of the site on the model. At the same time, the receiving transducers with different sensitive receiving directions are adopted in order to pick up all the components of earthquake ground motion.

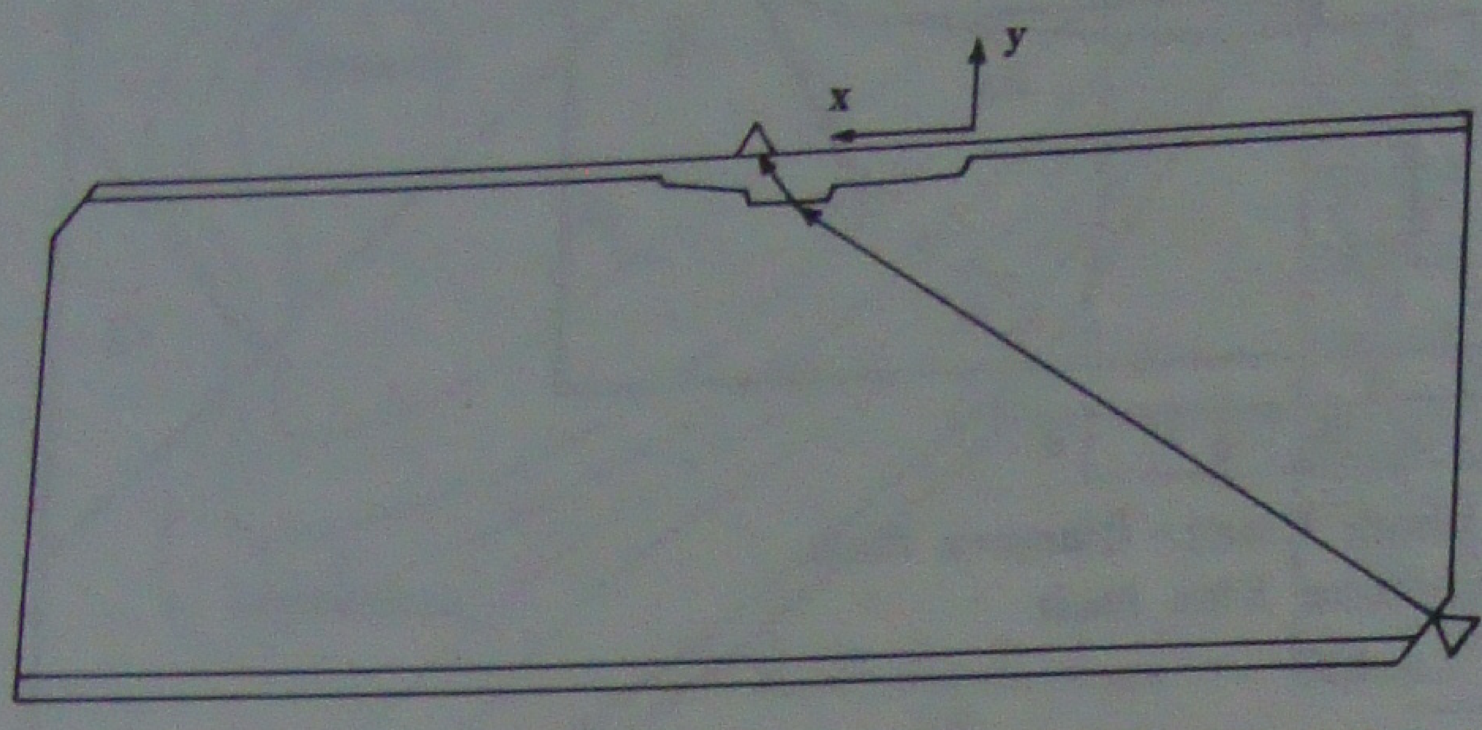


Fig.4 The observing system of model I

4 THE INTENSITY DISTRIBUTION

Place the transmitting transducer at right lower corner. The observing system is as shown in Fig.4 . The direction of horizontal observing line is X; the horizontal direction crossing the observing line is Y; vertical direction is designated as Z. Observing range, as shown in Fig.3b, is between -2 - 22cm.

In Fig.5, it is the maximum amplitude curves of three components of the earthquake ground motion measured on model I.

There are relatively protuberant crests nearby Tt, Qm and Xs. It is probably the main cause of the appearance of the above crests that waves are converged once or more by the inclination and concave of bedrock. Apparently, this convergence will vary with the change of the incident direction of waves. Comparing with the underlying bedrock topography, we find that

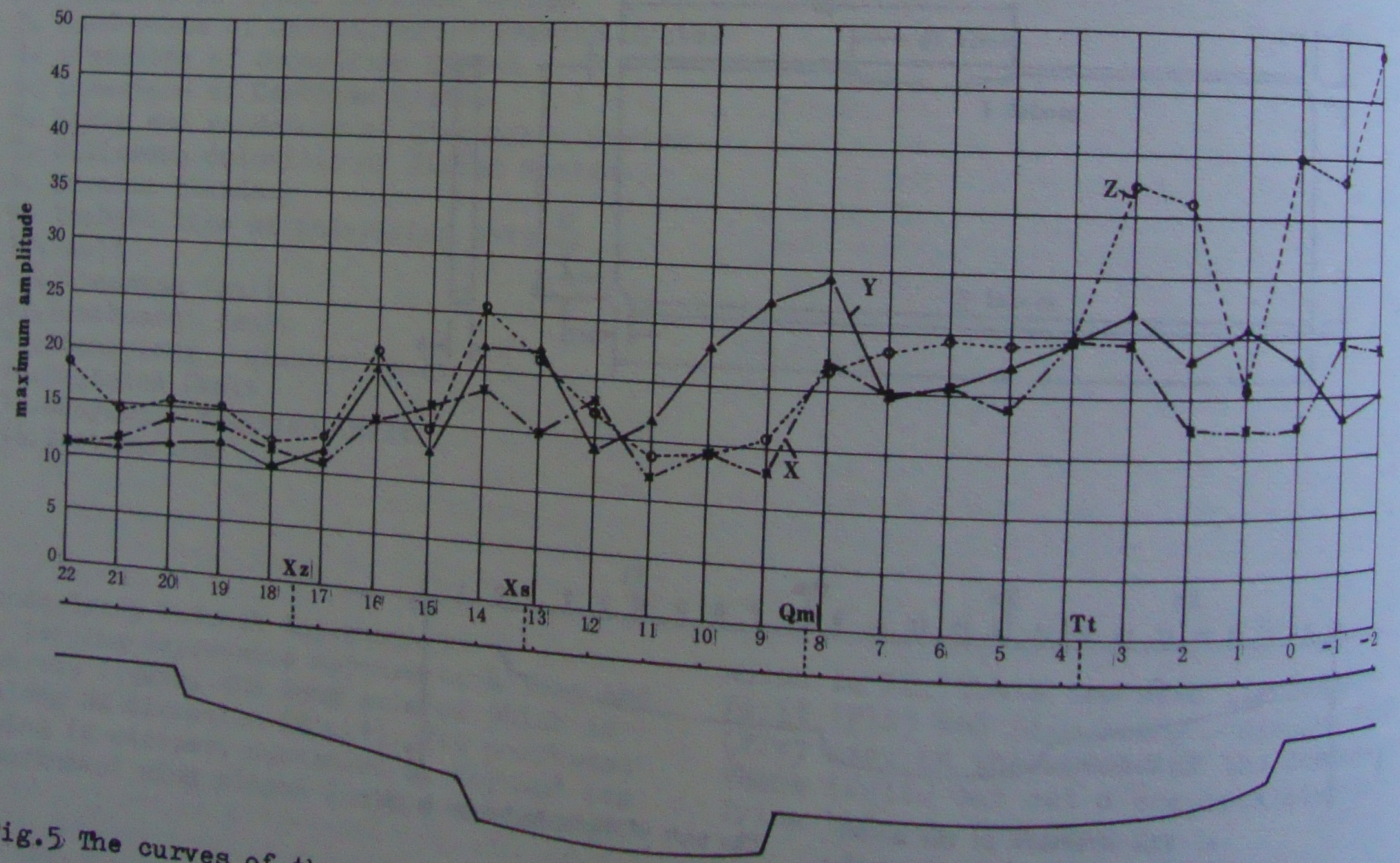


Fig.5 The curves of the maximum amplitude of earthquake ground motion on model I

corresponding to the deepest part of underlying bedrock in the depression, sharp falls and relative lower valley occur on some part of the maximum amplitude curves, reflecting the absorption of covering layer to the seismic waves. In addition, the analysis of raies show that the sharp falls of the maximum amplitude curves are related to the shadow areas caused by the steps of bedrock made up of faults as well. There are similar situations on faults, Flx and Fn, but there are not on the steps of the northwest wing of the depression. It obviously reflect the effects of the incident direction of seismic waves.

Comparative observation to the earthquake ground motion on model II is carried out at same relative location between centrum and site, and the result is in Fig.6. Compared with the curves of model II, the curves of model I rise up greatly nearby Tt,Qm and Xs, and intensive degree of each peak is shown in Table 1.

Table 1. The multiples of amplitudes on model I compared with model II

Component	Xs	Qm	Tt
Z	1.88	1.12	1.54
Y	1.33	2.03	1.47
X	1.64	1.08	1.96

The comparison of the observing results between model I and model II obviously shows that besides the varying of the thickness of covering layer, underlying bedrock topography is not a negligible factor effecting the earthquake ground motion on site.

5 THE STRENGTH DISTRBUTION IN COVERING LAYER

In order to understand the effects of un-

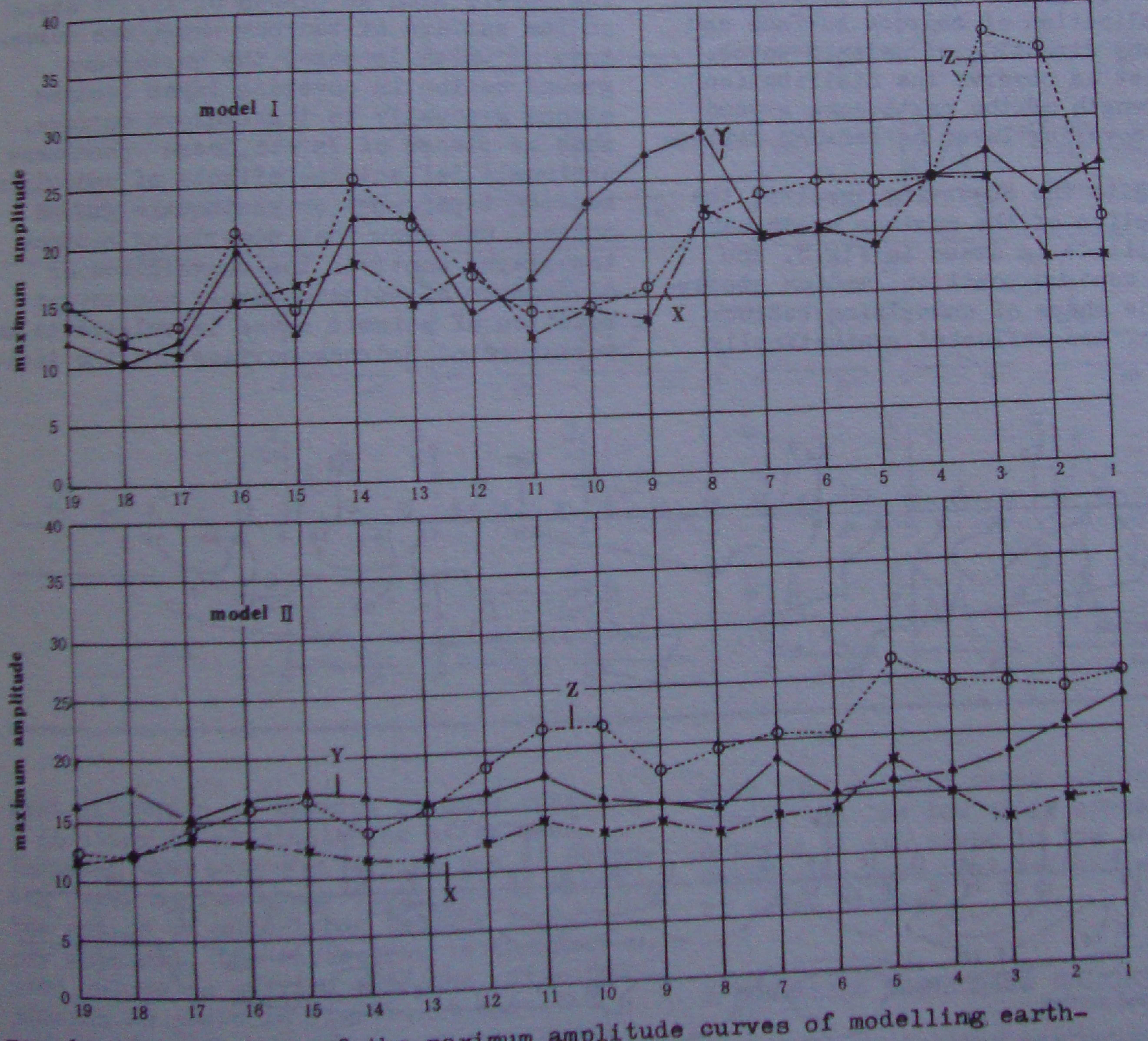


Fig.6 The comparison of the maximum amplitude curves of modelling earthquake ground motion between model I & II

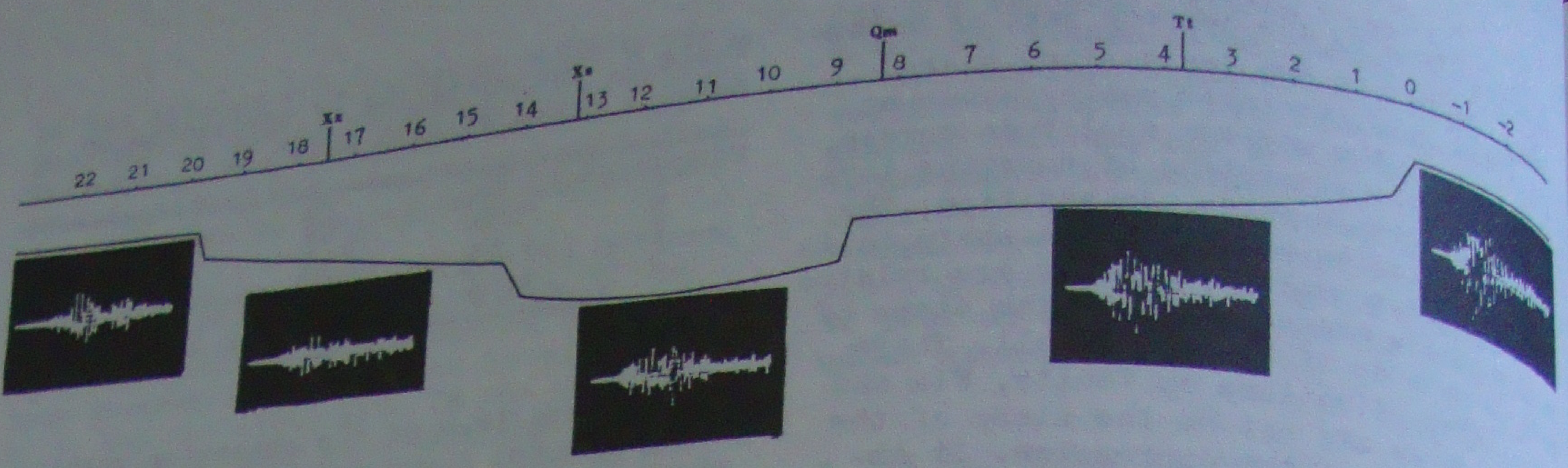


Fig.7 The comparison of the incident waves from different points of bedrock on model I

derlying bedrock depression on the earthquake ground motion of site, the observing investigation to the strength distribution of the earthquake ground motion in the covering layer on bedrock depression is carried out. The varying of incident wave strengthes at different parts of bedrock is shown in Fig.7.

It may be seen that the strength of the incident waves on the bedrock is related to the inclination of bedrock surface and the incident direction of seismic waves. Further, let us observe the distribution of the strength of the earthquake ground motion in covering layer on bedrock depression.

According to the observing results, the isogram section of the maximum earthquake motion amplitude is drawn in Fig.8. The effects of centrum position, medium absorption and the shape of underlying bedrock surface etc. are reflected synthetically in measured section (Fig.8 a). There is a decreasing tendency of vibration strength from southeast to northwest, this is due to seismic wave attenuation with increase of epicentral distance. Through the investigation of the maximum amplitude distribution along vertical direction, it may be found that on concave bedrock surface, the peak appear in the middle and top of covering layer, such as places of Xs, Tt etc.; on the surface of bedrock where the curvature of which is zero, the earthquake ground motion in covering layer becomes strong gradually to the bedrock surface, such as places of Xz etc.. These phenomena obviously reflect the effects of underlying bedrock topography on earthquake ground motion, and show that underlying bedrock topography controls the convergence or divergence of seismic waves, convergent location of seismic waves is related to the curvature of bedrock surface and the inci-

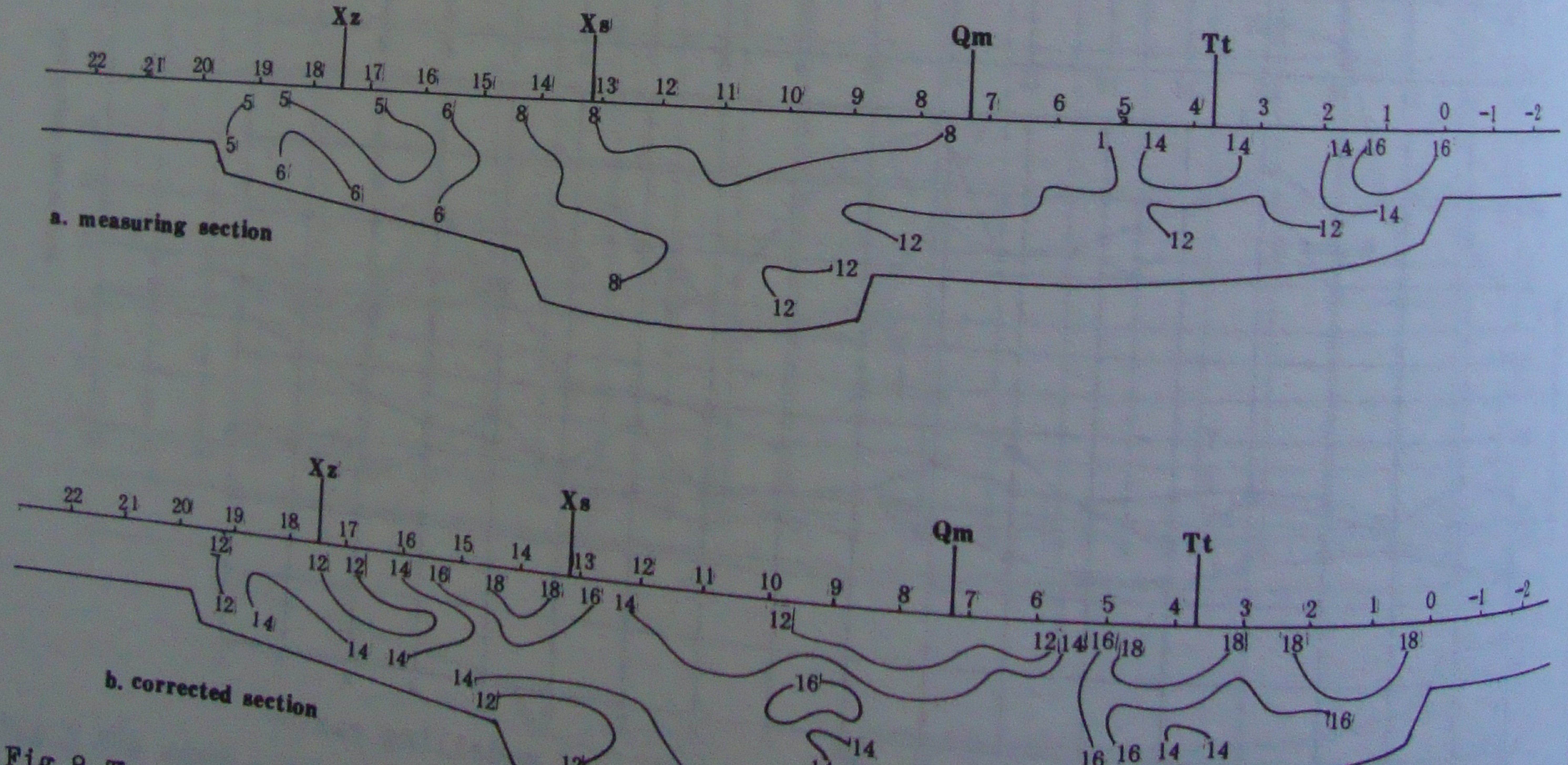
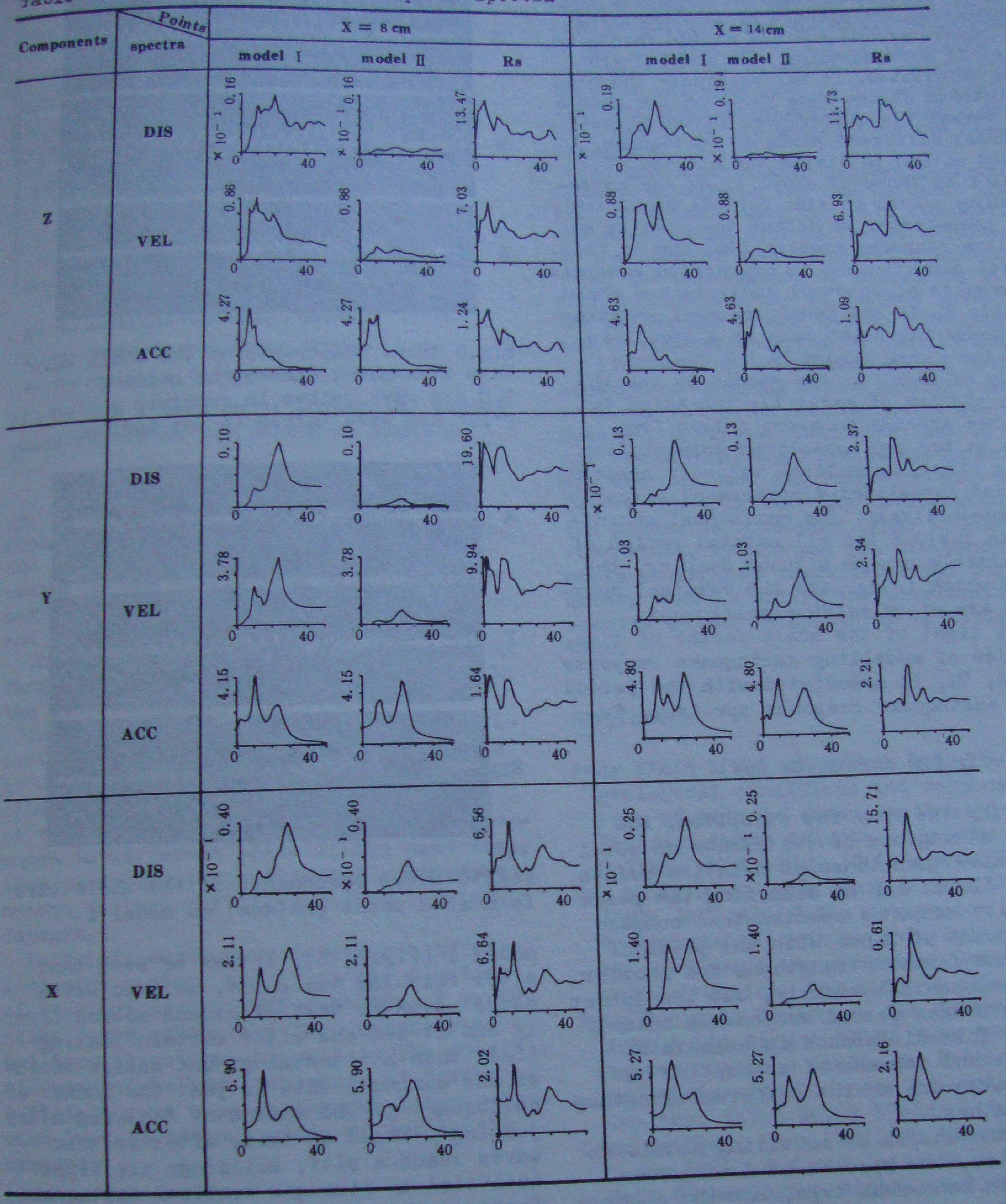


Fig.8 The equiamplitude cuve section of the maximum earthquake motion amplitude

Table 2. Modelling earthquake response spectra



dent direction of bedrock seismic waves.

In order to eliminate the effects of incident wave strength varying and of covering layer medium absorption, and to make the action of underlying bedrock topography apparent, the correction to the measured values is carried out. The corrected section is shown in Fig.8b. It make the effect of bedrock surface apparent somewhat. For example, the high value area appeared nearby the shalow parts at X=14cm show that seismic waves converge at this place, but the low value areas nearby the corners of two steps in the middle of the depression show that seismic waves diverge at these places.

6 MODELLING EARTHQUAKE RESPONSE SPECTRA

Select the modelling earthquake ground motions at two points of X=8cm and X=14cm on model I to make spectral analysis. For comparison, the spectra of the modelling earthquake ground motions at the points on model II corresponding with model I are also calculated. It may eliminate the contributions of the same parts on two models and reveal the differences in the effects of their different parts on earthquake ground motion to divide the spectra of model I by those of model II at the corresponding points in same periods about the same components. We define these value as relative response spectra (Rs) due to their special significance in comparison analysis. The results of spectral analysis are shown in Table 2. In the Tabel, several spectra of a measuring point make up a group, in which the first column is the response spectra of model I; the second is the response spectra of model II; the third is Rs. Three spectra in every column from bottom to top are normalized acceleration spectum (ACC), normalized velocity spectrum (VEL) and normalized displacement spectrum (DIS) respectively. The horizontal coordinates in Table 2 are all natural period of mono-particle system without damping, the unit of which is μs. And the vertical coordinates are of relative significance.

In the light of the scale factor of time, the period of modelling earthquake response spectrum, Tm, is associated with the period of real earthquake response spectrum, Tr, by

$$Tr\ (s) = 0.05\ Tm\ (\mu s)$$

Excepting the very few exception, the spectral strengthes of two points on model I is greater than those of relative points on model II. It may be seen from the peaks of relative response spectra that comparing the point of X=8cm with the point of X=14cm, the former strengthens the shorter period components obviously, but the latter makes the longer period components notably stronger. This difference is associated with different degrees of absorption to seismic waves due to the different lengthes of wave pathes.

Notice the shapes of modelling acceleration spectra, the spectra of Z component manifest in mono-peak type, but the spectra of Y and X components mainly show in double peak type. The superior periods of horizontal acceleration spectra is generally greater than those of vertical acceleration spectra, this coincides with the results of seismic phase analysis.

7 THE ACTION MANNER OF EARTHQUAKE FORCE

From three component wave forms of two measuring points, X=8cm and X=14cm, on

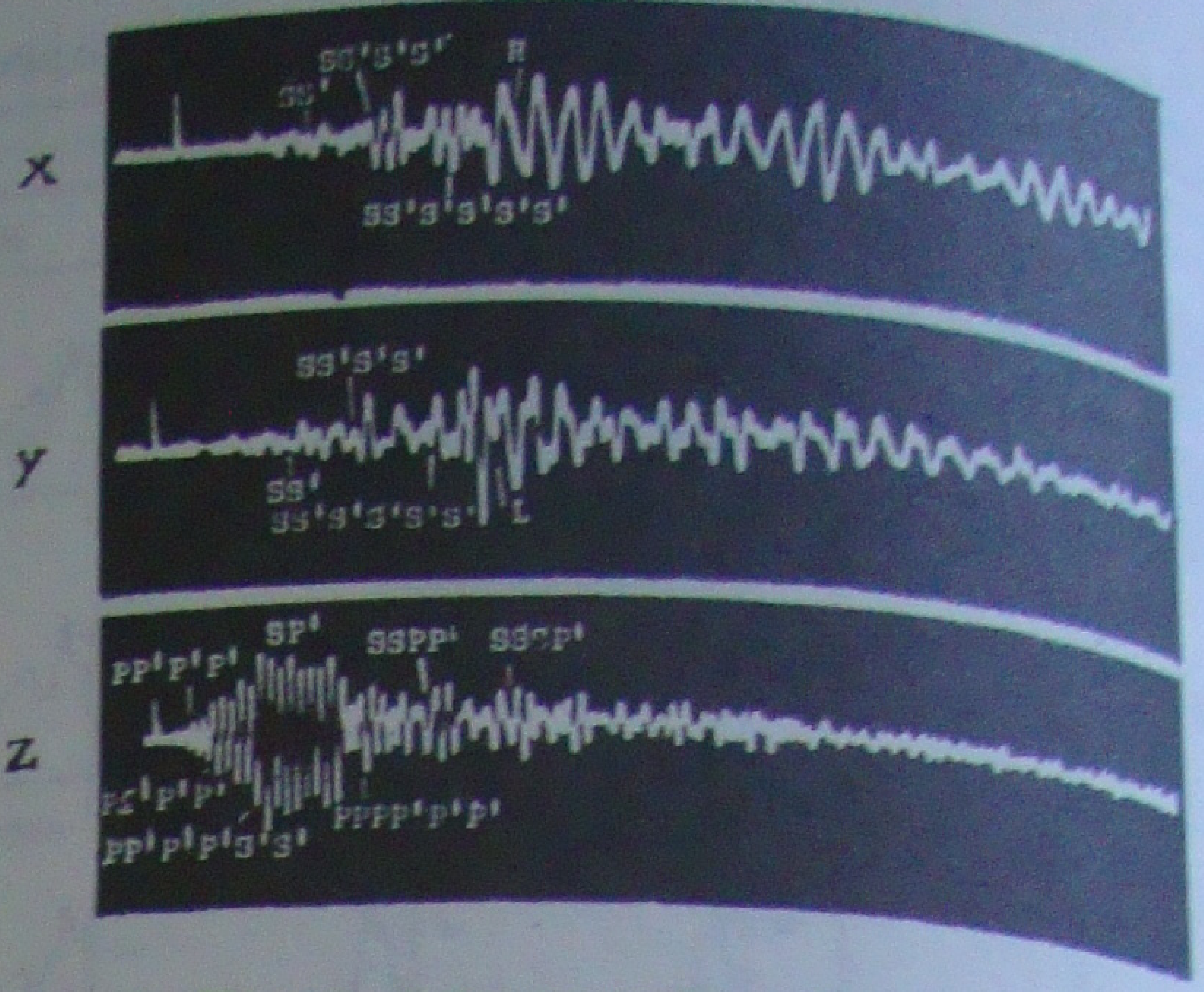


Fig.9 Three components of the whole wave form at a point (x=8cm) on model I
P,S are wave pathes in concrete medium
P',S' are wave pathes in wax medium

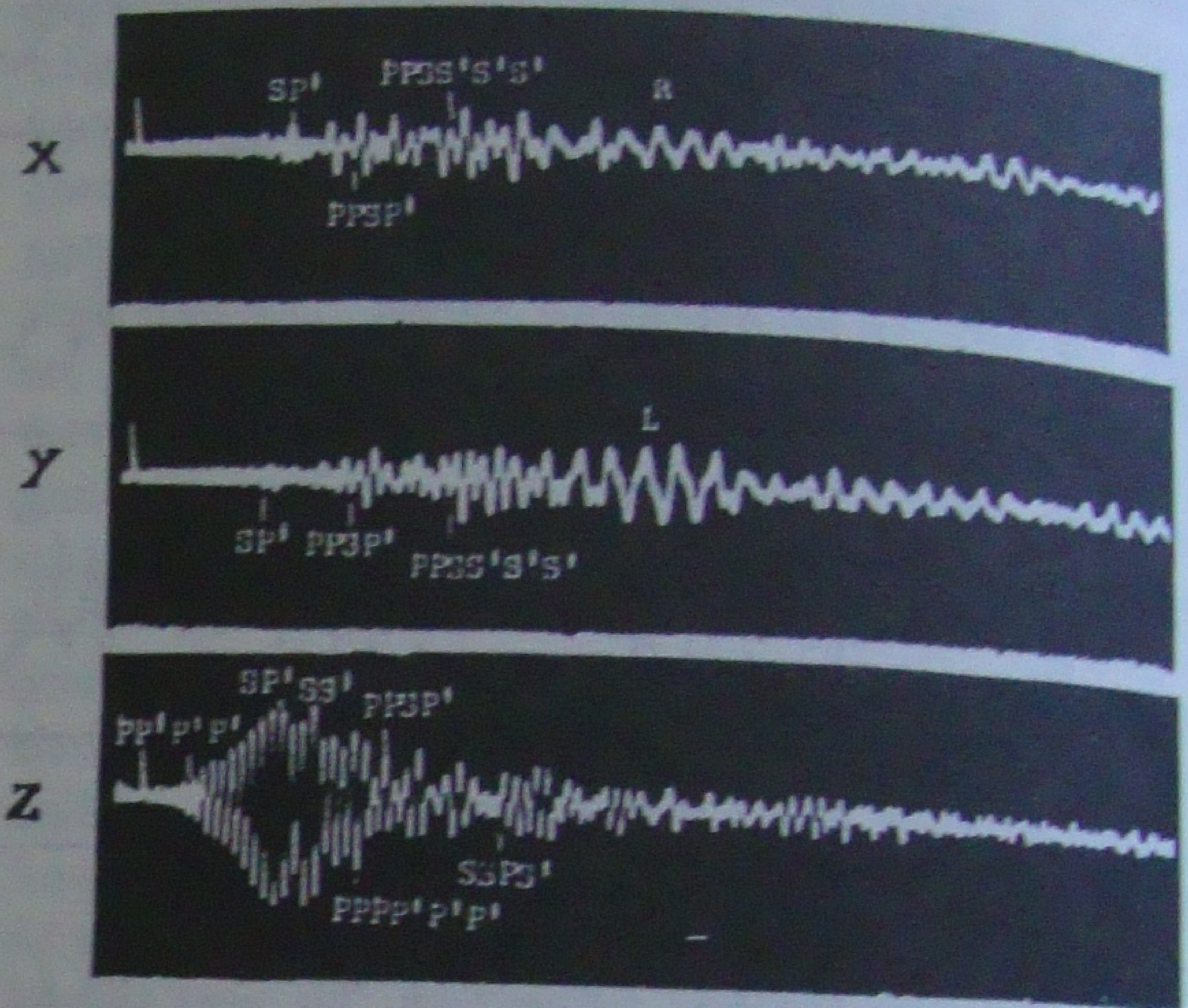
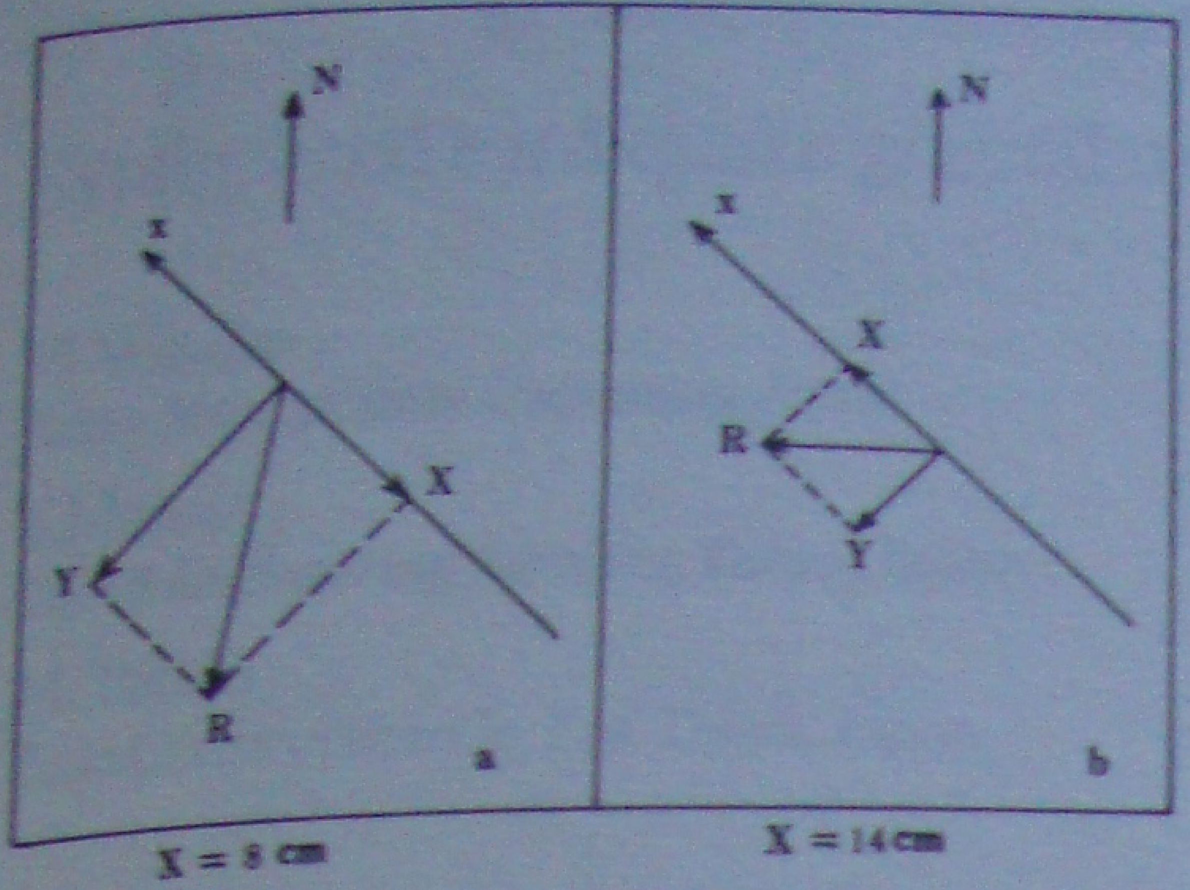


Fig.10 Three components of the whole wave form at a point (x=14cm) on model I

model I (Fig.9,10), it may be seen that after reaching the point, seismic waves cause stronger vertial ground motion firstly and it weakens after certain lasting time, then horizontal ground motion reaches the maximum. This is just the manner of earthquake ground motion of 'shaking after jumping'. Based on this, after seismic waves reach a site, buildings are first activated by stronger vertical earthquake force so that the structures are damaged in certain degree (Qian et al.(1982)), then they are sheared by horizontal earthquake force and damaged further, collapsing or inclining, and the direction of inclining is controled by the direction of horizontal earthquake force at the time when the structure is damaged.

According to the relationship between the directional property of transducer and seismic phase, determine the direction of earthquake force produced by superior seismic phase. As shown in Fig.11, nearby



X: the earthquake force along x direction

Y: the earthquake force along y direction

R: the resultant of horizontal earthquake forces

Fig.11 The direction of horizontal earthquake forces at two points on model I

Qm, the action line of horizontal earthquake force is along NNE - SSW direction, and the superior phase is SS'S'S'S'S'; nearby Xs the action line of horizontal earthquake force is along E - W direction, and the superior phase is PPSS'S'S'.

The damages in Beijing district made by Tangshan earthquake in 1976 coincide with the above analysis.

According to the Fig.11, the acting directions of horizontal earthquake forces at different points may not coincide each other, and because of the rise and fall of bedrock surface, there are also differences in different place at the same time, thus producing the horizontal earthquake moment so that buildings suffer turning damages.

In brief, earthquake force is a three dimension vector, and it is the function of time and place. Many fashions of earthquake force action and the diversity of building structures as well as the possible differences between responses of different buildings to a same earthquake force, these must lead to various kinds of earthquake damages.

8 CONCLUSIONS

The works of this paper show that:

(1) Under the condition of the experiment, the varying of the depth of underlying bedrock leads to the different attenuation of seismic wave in covering layer, generally, the strenth of earthquake ground motion weakens with the increase of the depth of underlying bedrock;

(2) The relationship between underlying bedrock topography and the incident direction of seismic wave controls the strength of the incident wave, and it is easily infered from the experimental observation that the incident wave is the strongest when its incident direction is along normal, but it is the weakkest in the case of tangential incident;

(3) The relationship between underlying bedrock topography and the incident direction of seismic wave controls propagation and strength as well as period component of the seismic wave in covering layer.

(4) The convergence of underlying bedrock concave surface to seismic waves makes the earthquake ground motion strengthened, and the convergence may be once or more;

(5) Modelling earthquake ground motion appears as 'shaking after jumping', and vertical vibration is also quite strong. Spectral analysis indicates that in vertical vibrations, high frequency components are dominant and the frequency band is relative concentrated, the acceleration spectra appear as mono-peak type; in horizontal vibrations, middle and low frequency components strengthen relatively, and the frequency band is wider, the acceleration spectra appear as double or multiple peak type.

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