Source Mechanism and Seismic Effect of Tangshan Earthquake

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SYNOPSIS By analyzing the seismic mechanism of the Tangshan earthquake and its pattern of movement through the study of ground deformation and ground strain of the Tangshan earthquake area it is clear that the breeding and occurrence of this event are controlled by a long-term intense active fault zone. By the ground deformation, displacement, tectonic features and seismic effects after the event, this causative fault is known to be composed of a group of NNE trending right-turn strike-slip faults and thus we call it the Tangshan active fault zone.

A strong earthquake which had a magnitude of 7.8 occurred in Tangshan, northeast China, on July 28, 1976. It caused the most serious damage since there was not any prediction before the event. For the purpose of summarizing the lessons drawn from this event and replanning the construction projects and shock resistance work for the strong seismic area, the study on the formations of Tangshan earthquake, mechanism of source, features of activity, position of causative fault, seismic damage effects and all such important problems as these are highly attracting the attention of the professional departments.

The large extent of ground deformation and historical geologic feature caused after this event indicate that fault activities are characterized with repeated motions historically. From the study of tectonic ground rupture in the epicentral zone (1) we learnt that during the long historical period before the "7.28" event there occurred many a times of strong earthquake accompanied by tectonic ground ruptures. By analyzing the dimensions of those ground ruptures it is clear that the magnitude of the historical earthquakes were more than once above 8. The results of repeated geodetic surveyings provided the relative patterns of the fault activities. With these patterns we can make further analysis of the source mechanism of Tangshan earthquake 1976 and the seismic effect of a fault like this in broader sense.

1. TECTONIC BACKGROUND OF THE STRONG EARTHQUAKE AREA

This area is situated at the south boundary of the east part of Yanshan fold zone, the intersection of Ji-Dong plain and Huang Hua subsidence. It is a very brisk tectonic active region. The activity of regional tectonic behaves not only in the changes of deposit rock facies with time and space, but also presented in the difference of topographic and ground features. The main controlling factors are the following tectonic systems:

The first one is the latitudinal tectonic system, which is the major factor causing difference in topographic and ground features in the early period of this zone. It makes the north part upheaving successively and forming an uplifted land. The relative depression in the south part forms subsidence plain. Analyses based on the depths of deposit since the Tertiary show that the total amplitude of relative uplift and depression on both sides of the latitudinal tectonic zone is more than 8000 m.

The second one is the tectonic system of NNE trending which is a branch extended northward from the well-known Cang Dong fault zone and formed by the grouping vertical fault nearly parallel to each other. There are two major active fault zones in this system, i.e. the Tangshan and Luan Xian active fault zones. The tectonic system in NNE-trending forms on the one hand the tilting, rising in the NW part and the rapid sink in the SE and on the other hand, a series of longitudinal subsidences and upheavals. (Fig.1)

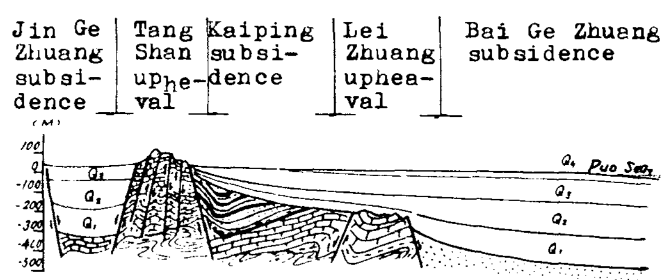


Fig.1

(1) Wang Zhong-qi, et al.: The Mechanism of Surface Faulting and its Seismic Effect (Conference Session 8-13)

The third one is the NNW tectonic system, which comprises mainly the fault of Ji Yun river and that on Luan Xian and Le Ting. This system has a great influence on the formation of subsidence of Tangshan plain. The two systems mentioned above construct the marginal fault of the rhombic Tangshan subsidence zone.

Data from measurements show: the intersection position of the 2 tectonic systems mentioned above at Tangshan and Luan Xian is just the coincidence of the epicentres of the past strong earthquakes. It is also the position where the gravity anomaly is the most obvious, especially the active fault zone in the NNE direction. They are main fault zones which bear strong earthquakes.

The ground uplift and sink caused in accompany with fault activities change the terrestrial hydraulic condition, drainage intensity, flow, transport of water body and direction of deposit. In reverse, they also become prominent factors in changing the land feature and land form. All of them provide powerful evidence for us to study and identify the formation mechanism of the Tangshan active fault zone from which the "7.28" earthquake is bred and also the active effect.

2. THE GROUND DEFORMATIONS OF STRONG EARTHQUAKE AREA (Fig.2)

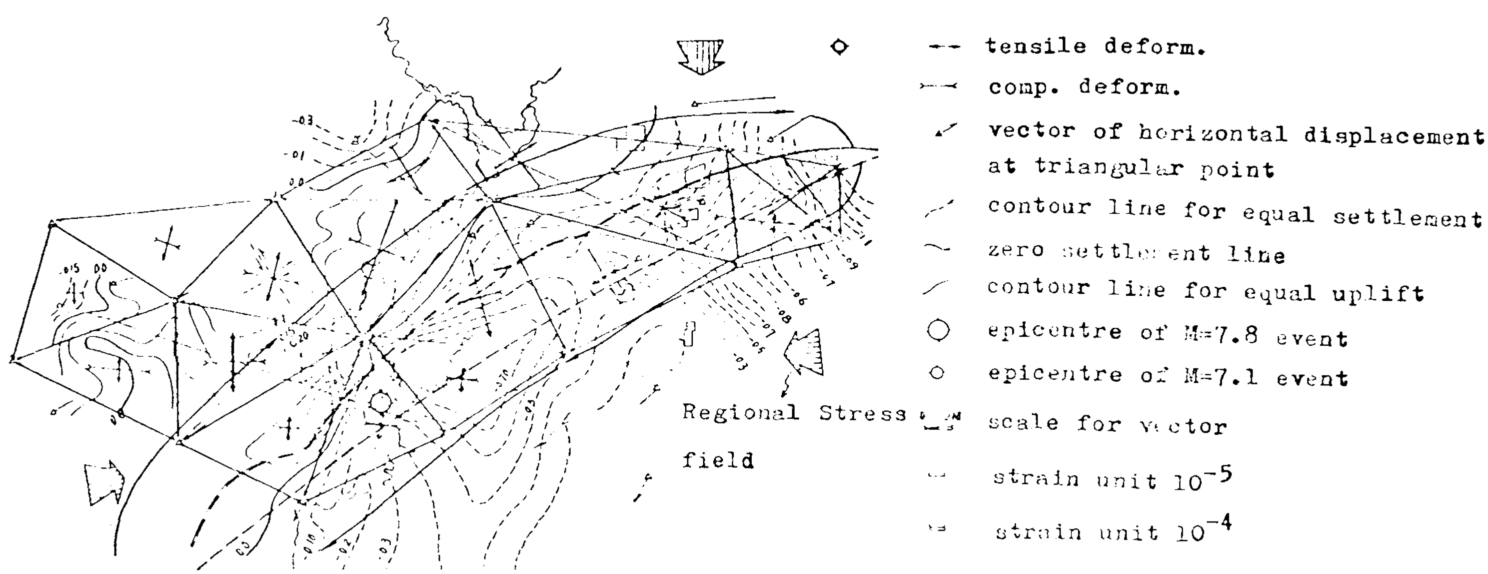


Fig.2

(1) Horizontal Deformation

Based on the coordinate of the overlapping points of state triangle points, class I, II, III and IJK class I triangle points before and after earthquake, compute the horizontal displacement and displaced azimuthal angle after earthquake of the overlapping triangle points in the 6 and 1.5 zones separately. The displacement is larger when the vector of the horizontal displacement of the triangle points plotted is nearer to the epicenter, and it will be smaller when the distance between the two is longer. According to the variation of displacements and azimuthal angles a right-turn displacement is caused around Tangshan city and the epicentral area at both sides of the Tangshan active fault zone. Hence, controlled by the tectonic stress field of fault zone, in addition to the vertical displacement occurred on both sides of the fault after the earthquake, both sides of the fault zone are pushed by massive horizontal stresses resulting in horizontal dislocation.

(2) Vertical Deformation

Based on the analysis of the overlapping data of the regional existing bench marks the vertical deformation caused in the strong seismic area controlled by the fault stress field is very regular.

(a) With fault No.V at the east side of Tangshan active fault zone as boundary the NW part (fault zone No. I-IV) uplifts obviously. (the maximum vertical displacement is +0.732m) and the SE part depresses relatively. (vertical displacement at the point. Shan-jin No.26 is -0.717m, the maximum value is at the peak point of the NE area where the vertical displacement is up to -1.40m)

(b) The position of the zero line of the deformation value is roughly parallel to the direction of the Kai Pin synclinal axis line and basically coincides with the position of the main fault at the east of Tangshan active fault zone. This is the most active position of Tangshan seismic deformation and stress release as viewed from the amplitude of deformation.

(c) Analysis from the difference of the depth of the deposits at both sides of the fault and the characteristics of multi-rotated vertical deformation is endowed with the features that it repeated itself at the right spot in space and it is continuous in time. The fault and subsidence side of SE part is the hanging wall of the strike normal fault of the Tangshan active fault zone.

(3) Ground Strain

With the coordinate of the overlapping points of triangles of the intense earthquake region as the base and in respect to the position of the epicentre, geologic structure and diagram condition of surveying triangle, a virtual triangulation could be formed. Calculate first the side lengths and azimuths of the triangles respectively according to the overlapping coordinate before and after the shock, then the strain of each side could be obtained by the changes of side length. This is so called the ground strain.

The strain of each side in the same triangle is:

$$\varepsilon_i = \varepsilon_{xi}\cos^2\theta_i + \gamma_{xiyi}\sin\theta_i\cos\theta_i + \varepsilon_{yi}\cdot\sin^2\theta_i$$

or

$$\varepsilon_i = \frac{\varepsilon_{xi}+\varepsilon_{yi}}{2} + \frac{\varepsilon_{xi}-\varepsilon_{yi}}{2}\cos 2\theta_i + \frac{1}{2}\sin 2\theta_i\cdot\gamma_{xiyi}$$

where θ is the angle between any side of the triangle and the X axis.

Altogether 72 equations of 14 triangles are calculated and the strain in 3 directions ε_x ε_y γ_{xy} are achieved. Then calculate the main strain ε_1, strain of the vertical main strain axis ε_2 and the angle between them φ , and get the following equations:

$$\varepsilon_1 = \frac{\varepsilon_x+\varepsilon_y}{2} - \frac{\varepsilon_x-\varepsilon_y}{2}\cos 2\varphi + \frac{1}{2}\sin 2\varphi\cdot\gamma_{xy}$$

$$\varepsilon_2 = \frac{\varepsilon_x+\varepsilon_y}{2} - \frac{\varepsilon_x-\varepsilon_y}{2}\cos 2\varphi + \frac{1}{2}\sin 2\varphi\cdot\gamma_{xy}$$

$$\theta = (\varepsilon_y-\varepsilon_x)\sin 2\varphi + \gamma_{xy}\cdot\cos 2\varphi$$

where φ is in radian

Get the surface expansion Δ and shear component γ_1 , γ_2 by computer. Plot the diagram of the distribution of strains. The triangular strains show the following regularities:

(a) 1,6,7 and 2,3,5 triangles near the strong earthquake area receive stronger forces of seismic stresses, while those farther from the strong seismic area change less in the various strains.

) The seismic stresses received by the three triangles 1,7,6 near the strong seismic area are tensile force near NS-trending, and compression forces near EW-trending and move slightly leftward.

(c) A strong ground stress squeezed northward during stress release and turned to the NNE subsequently.

(d) The shear stress in the direction of the main strain axis, based on the stress distribution diagram (Fig.2), occurred just along the main causative fault at the east part of Tangshan active fault zone and caused two apparent right-lateral horizontal dislocations.

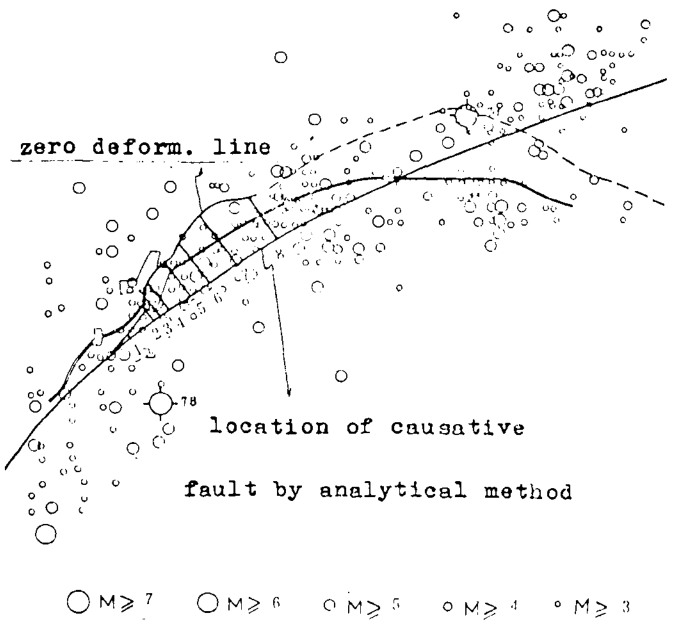
3. MECHANISM OF THE EARTHQUAKE

It is clearly illustrated by the results of the study of ground deformation and the repeated mechanisms of seismic and geodetic points provided that both sides of the fault may cause elastic stress relaxation and relative displacement after long-term slow elastic-plastic creep deformation. Thus the elastic strain energy accumulated in the fault for a long period transformed into a dynamics for redislocating of fault and radiate out of seismic focus with the form of strong elastic wave, and formed serious seismic damage. Therefore, this is an active fault. In addition, it is also the causative fault of "7.28" earthquake based on the facts that it passes through the epicentre and strong seismic region and the different seismic damage effects demonstrated by both sides of the fault. The most obvious ground deformation after the "7.28" event occurred at the axial area parallel to Kai Ping syncline, which is an unsymmetric fold with its east wing even and its west wing steep. The steep wing is the place where stresses concentrated. The south part of the zero deformation line is roughly coincide with the fault No.V, while the north part of the zero deformation line is compressed by the southward stress and makes the Kai Ping synclinal axis deflecting eastward.

The Tangshan active fault zone is a horst-like uplifiting block which is in the NNE-trending at the south end. In the vicinity of Ma Jia Gou, Ye Li, it changed into 2 branches: one passed through Fan Ge Zhuang and led to Lei Zhuang, the other one passed through Dou He reservoir, Zhen Zi Zhen and joined up with the Da Ba Li Zhuang fault and extended to Ye Ji Tuo, then turned to the NE-trending. The NW boundary of this fault zone is formed by the Dou He fault. By the young fault basin distributed about the belt from Liu Zhuang to Jia An Zi in the west of Dou He (Liu Guan Tun subsidence -- the maximum amplitude of Quaternary subsidence is more than 400m) though the Dou He fault was very active within the whole period of Quaternary it had not formed into an obvious ground deformation and surface displacement and kept in relative stable condition in the recent Tangshan event. Wide relative deformation and displacement are caused at the sides of Tangshan fault in the event.

According to the transform computation of the horizontal distance between the ground project of the depth of seismic focus(take it averagely as 13 km) of aftershock, which is over M=3, and the position of the zero deformation line the Tangshan causative fault is in perpendicular with large angle. The fault at the epicentre is nearly vertical with inclination of 86°28' 43'' which is getting smaller towards the north and becomes 76°10' 17'' at the macro-epicentre. On the other hand, the inclination of fault is in the order of 80° calculating with the statistics of seismic focus depth of aftershock and diagram. Those two results are in good conformity.

The length of the sliding portion of the Tangshan active fault is more than 90km judged by the ground deformation and ground effect at both sides of it. The plan and profile are shown in Fig. 3.

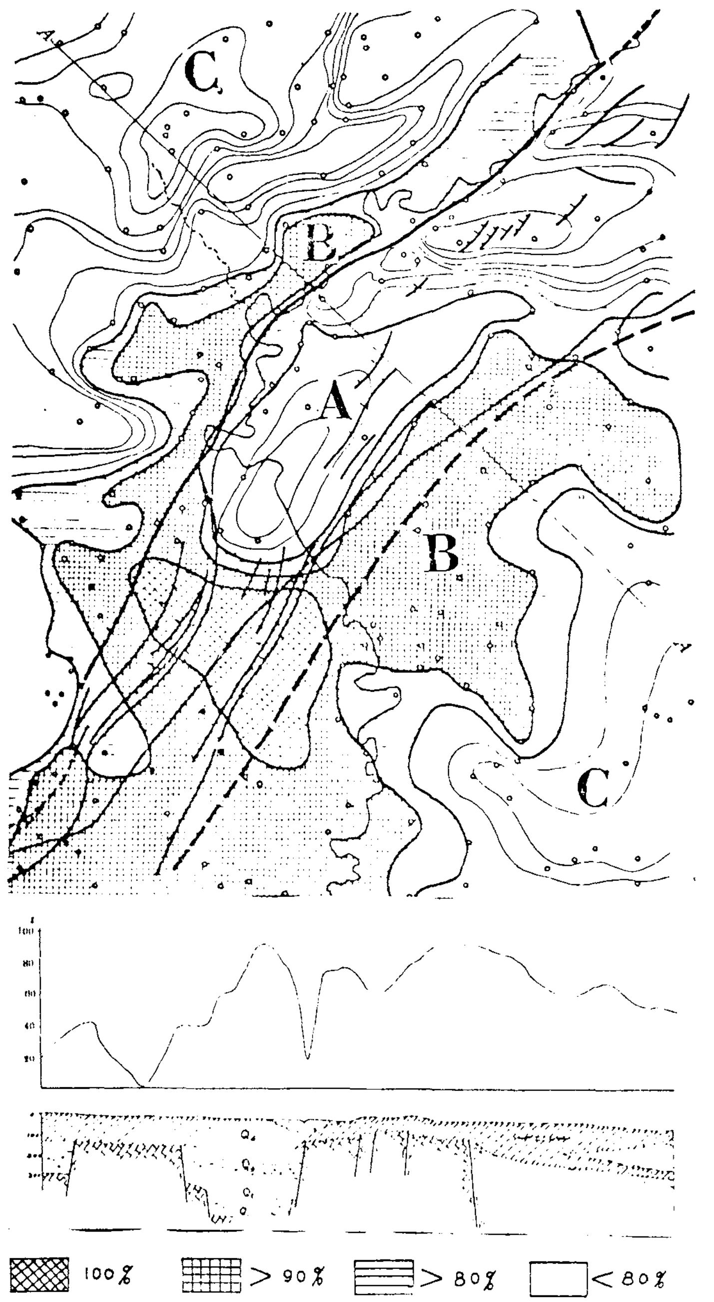


Profile No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
dip of profile	86°	81°	76°	70°	65°	60°	51°	58°

Fig.3

4. DAMAGING EFFECT OF THE FAULT

Fault is a negative factor to engineering construction in most cases. It may cause not only various destructive stress waves through its large release of strain energy but also induces ground movement and ground deformation in large scale which will destroy the engineering construction. Generally, ground movement and ground deformation decrease with the increase of the distance to epicentre and that to the causative fault, the stronger the ground seismic damage, and also the more obvious the deformation and displacement. Besides, it is also controlled by the influences of a series of factors such as geological structure (the formation) topography and geomorphology, distance to the seismic focus and intensity field, etc. Hence, within the same epicentre area the effects of seismic damages are different in strength and degree, so 3 units of seismic damage can be classified: (Fig.4)



(1) Foot Wall of the Fault (A)

This region situated in the uplift block between the Tangshan fault and Douhe fault. The bedrock is exposed directly on the ground surface or covered only with a very thin overburden (ground soil class I). Since the rigidity of the ground soil is better, the ground water is deeper, the intensity fall-off is faster, this region shows that the ground is provided with better earthquake resistant energy no matter it is in the epicentre zone. The rate of seismic damage is generally 30-40% and that of Da Cheng Shan in the epicentre area is only about 50-70% which forms a low extraordinary zone with the high intensity area.

(2) Fractured Subsidence Zone (B)

The thickness of the overburden of Quaternary increases obviously along the long narrow subsidence belt of the hanging wall in Tangshan fault and Dou He fault. Some of them form into steep slope. Compared with bedrock of foot wall the soil layer of Quaternary is provided with features of prolonging the seismic period and vibration time and also a larger amplitude so it is harmful to buildings in shock resistance. It is a high extraordinary area for seismic damage. The rate of seismic damage is usually over 80%. Since seismic elastic wave will change obviously in its amplitude during spread in different media it is possible to have energy concentration in this area.

The ground seismic damage is enlarged by the focus function derived from the elastic wave at Kai-Ping syncline in addition to the large energy density formed by the seismic wave at the fault surface of Tangshan fault.

(3) Faulting Outskirts (C)

The amplitude of ground acceleration and the rate of seismic damage under its control are usually in inverse proportion with its distance from the causative fault. This can be clearly seen from section A-A' of Fig.4. The rate of seismic damage decreased gradually at the outskirts and formed low intensity extraordinary region outside the seismic high intensity extraordinary region. However, the seismic damage effects of Dou He and Tangshan fault are not all alike. On side of the hanging wall of Dou He fault is the pseudo-plain formed by upper pleistocene. Soil layer is mostly overconsolidated. Furthermore, there were no obvious fault and displacement or deformation in the "7.28" event so the rate of seismic damage decreased rapidly. One side of Tangshan fault is a dipping plain formed by upper pleistocene and Holocene. The soil on top is not consolidated and the fault quaked violently in the "7.28" event. Therefore, though the rate of seismic damage also decreased gradually the land liquefaction, seismic sink and ground deformation increase gradually in accompany with the increasing of the thickness of the loose soil layer and the intense ground movement.

5. CONCLUSION

(1) According to the complicated phenomena of the deposit depth of Quaternary overburden in the subsidence on both sides of Tangshan fault zone, ancient liquefaction, ancient tectonic ground rupture and tectonic traces, it is clear that the fault zone is endowed historically with characters of in-situ repeatation in space and continuity in time.

(2) The amplitude of horizontal and normal ground displacements measured by the precise geodetic triangle not and repeated level measurements of the Tangshan fault is a causative fault breeding the "7.28" seismic event.

(3) The ground deformations caused after earthquake are situated mainly at both sides of the fault along the Kai-Ping synclinal axis. Identified from the amount and direction of displacement of the horizontal and normal deformation this is a dextral strike-slip normal fault.

(4) A group of large goose-shaped tectonic ground ruptures, which is 8 km long, is not a causative fault but an accompanying (secondary) structure of Tangshan active fault.

(5) The ground (seismic damage) effect of the fault is controlled by many factors, such as the type of fault, stratum structure, topographic and ground feature and the distance to causative fault, etc. For the strike-slip normal fault with large angle similar to Tangshan active fault zone the seismic damage at its hanging wall (subsidence) is much more serious than that at the foot wall (relative uplift) and also that nearer to fault shear surface is more serious than that far from it. Seismic damage units classified according to this standard may be used as technical data for planning of construction and seismic resistance measurement for engineering in the region of strong seismic active fault zone.