01 May 1981, 9:00 am - 12:00 pm

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Proceedings: First International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, April 26 - May 3, 1981, St. Louis, Missouri

Mechanism of Surface Faulting and its Seismic Effect

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SYNOPSIS The mechanism and reoccurrence rule of surface faulting have been analysed based on macroscopic inspection and testing in the background of Tangshan earthquake 1976 and other events. It has been proved that such surface faulting has only limited effect on surface structures nearby. And most of the surface ruptures in soil layer occurred in most earthquake zones are not the causative faults from focus up to the ground surface. Thus its seismic effect should be reestimated.

1. SOME DOUBTFULNESS OF THE SURFACE FAULTING IN TANGSHAN EARTHQUAKE AND ITS ENLIGHTMENTS

During the Tangshan earthquake of July 28th 1976, a surface faulting took place with a total length about 8 km. oriented NE 20-30 in the central area of the city. (Fig.1.1)

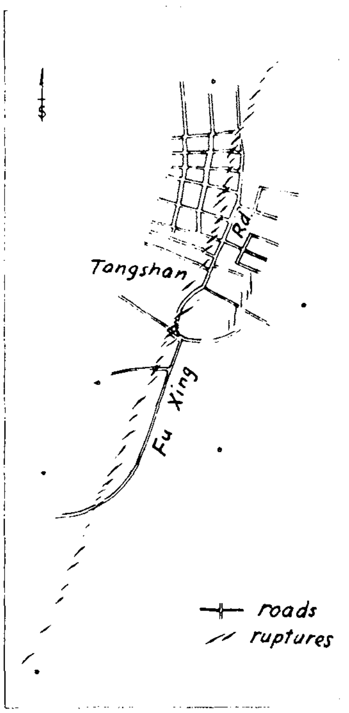

Fig.1.1 Layout of surface faulting in Tangshan earthquake

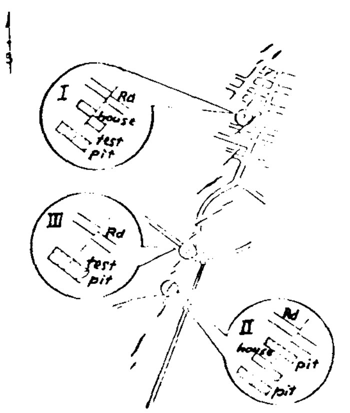

Fig.1.2 Exploration sites along the surface faulting in Tangshan

Many of the investigation reports on the macroseismic damage pointed out that this very faulting is definitely the causative fault of Tangshan earthquake. However, many doubtfulness of such a conclusion encountered in the authors' research, e.g.:

(1) The strike of the surface faulting was not in good agreement with the epicentres' trend of aftershocks.

(2) The surface ruptures were not associated with the fault in deep formation, in view of their figures and scopes.

(3) So far as the ground damage nearby is concerned, no evidence of accumulating damaging effect of surface faulting was proved. From these view-points, the surface faulting in Tangshan could neither be considered as the cause of the main shock, nor the source of the ground movement.

The surface faulting in Tangshan earthquake is much similar in nature to that of other events in the world, so this topic would have a general significance in dealing with the mechanism and seismic effect of surface faulting in strong earthquake zones. For further evidence, we performed exploration work on three sites where underground facilities had been constructed before. (Fig.1.2)

New concepts about the surface faulting in Tangshan have been achieved in our research, i.e.:

(1) According to data listed in Tab.I, it is shown that surface rupture dislocations diminish immensely both in horizontal and vertical direction with depth. Tensional ruptures on the dislocated area obey the same rule and vanishes down to -2 m. So the surface faulting will by no means associate with the faults in deep strata.

(2) From the convergence of the shearing deformation of surface faulting with depth, it is believable that shear stress does not come from the deep strata. By analyzing the dislocation of the underground sewerage, we can calculate the shearing strength existing

in the horizontal plane of dislocation in order to check the shearing stress necessary for the dislocation of ground surface and the plane 0.7m below the ground. Say, $C = 0.15\ kg/cm^2$, $\phi = 25°$, $\gamma = 0.0018\ kg/cm^3$, and using the upper limits of the data in Tab.I. Thus,

$$S_s = \Delta D_x B (C+\gamma h \tan\phi) = 130 \times 250 (0.15 + 0) = 4.9\ T$$

and that on the -0.7m level,

$$S_3 = 90 \times 250 (0.15 + 0.0018 \times 70 \tan 25°) = 4.7\ T$$

Fig.1.3 Dislocation of Bound Ground

Fig.1.4 Dislocation of Wall Footing of a single storey Classroom

Fig.1.5 Dislocation of Brick Subway

Fig.1.6 Dislocation of Buried Sewerage Pipe

It is obvious, the shearing stresses represented by the dislocation on/under ground do not even show any evidence of stress increment in depth.

(3) Therefore, surface ruptures are supposed to be caused by directional ground movement. If there exists a structure with certain rigidity nearby the rupture, then it will reduce the degree of rupture. For example, the dislocation of the footing in Fig.1.3 is much smaller than that of free fround. It shows that dislocation is a locally sheared zone and has a very limited range.

The same rule as that mentioned above in other seismic zones can be visualized too. For instance, the Liao Ning (Hai Cheng) earthquake (M=7.4) of Feb.4, 1975, a series of oriented surface ruptures took place to the southeast of the epicentral area. The general strike of it was nearly EW, and single ruptures goes NE35-40 for 5.5 km. long. (Fig.1.7) Surface faulting occurred in the hilly field where the bedrock is schist overlain by a residual soil layer 1.0-1.5 m thick. The ruptures had their features of brittle materials as the earthquake happened in frozen seasons.

Fig.1.7

This surface faulting was deemed before as the ruptures resulted from tectonically causative fault in deep strata, but test pit shown the ruptures only existed in the top residual soil and largely vanished when intact rock encountered. (Fig.1.8)

Fig.1.8 Tectonic surface ruptures in residual soil

The ground and subsurface conditions are listed in Table I.

Table I

Site	Horizontal Dislocation D_H (m)	Width of Surface Rupture B (m)	Mode of Horizontal Dislocation	Vertical Dislocation D_V (m)	Mode of Vertical Dislocation	Remarks
#1 (Free Ground)	1.4-1.5	3.0-4.0	right turn	0.4-0.5	normal dip	cinder concrete floor (Fig.1.3)
#1 (Bound Ground)	0.75	2.5-3.5	-"-	0.34	-"-	floor of single storey classroom (Fig.1.4)
#1 (Brick Subway 2m below)	1.00	2.5-3.5	-"-	0.24	-"-	(Fig.1.5)
#2 (Free Ground)	1.2-1.3	2.5	-"-	0.2	-"-	pavement and curb trees
#2 (Bound Ground)	0.8	2.5	-"-	0.2	-"-	floor of single storey house
#2 (Sewerage 0.7 m below	0.85-0.9	2.5	-"-	0.1	-"-	(Fig.1.6)
#3 (Free Ground)	1.5	3.0-4.0	-"-	0.4-0.5	-"-	
#3 (Sewerage 0.4m below	1.1	3.0-3.5	-"-	0.3-0.4	-"-	

2. MECHANISM OF TECTONIC RUPTURES IN TOP SOILS

By surface tectonic ruptures we mean a kind of surface faulting caused by oriented ground movement induced by earthquake. The behaviors of such ruptures are:

(1) Strike of surface tectonic ruptures should be in good conformity with ground deformation caused by the main shock.

(2) Surface tectonic ruptures would be effected by the causative fault in deep strata even they are not directly associated with each other.

Despite no strong motion recorded in Tangshan and Liao Ning earthquakes, a series of permanent ground deformation and relative displacement after events may be considered as indirect records which might be more reliable for illustrating the occurrence of the tectonic ruptures in top soils.

Fig.2.1 (A)

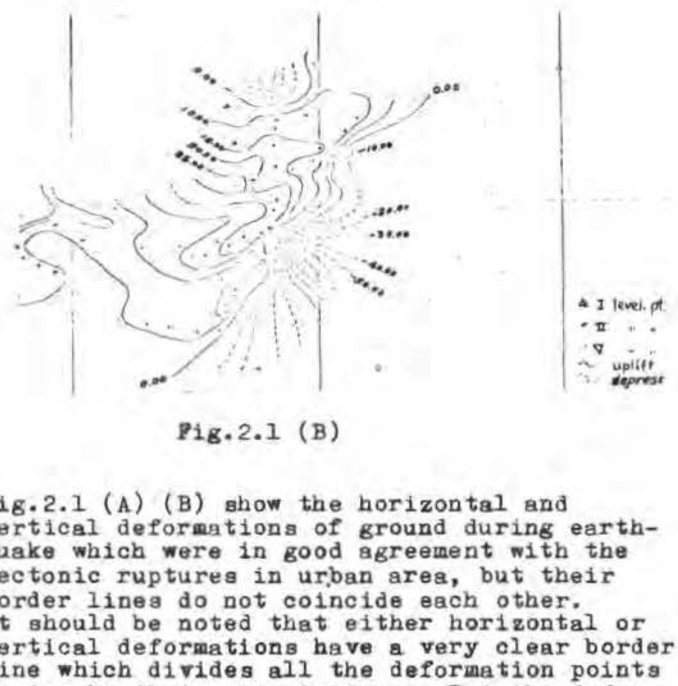

Fig.2.1 (B)

Fig.2.1 (A) (B) show the horizontal and vertical deformations of ground during earthquake which were in good agreement with the tectonic ruptures in urban area, but their border lines do not coincide each other. It should be noted that either horizontal or vertical deformations have a very clear border line which divides all the deformation points in two by their orientations. But the deformations near by the border line become even smaller. This characteristic may be a very important criteria to distinguish tectonic soil ruptures from causative fault. From theoretical analysis of a fault (1) (2) as shown in Fig.2.2, there is a gradual increase of deformation near by the fault instead of decrease. So this would be another reasoning to say that the tectonic soil rupture is by no means associated directly with the deeply embedded causative fault.

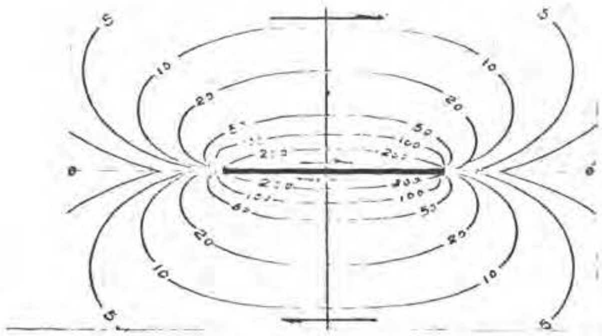

Fig.2.2 Horizontal component (u_1) to total dislocation (u) of a strike-slip fault at a depth (Z) of 1/10 its vertical length D

3. THE REOCCURRENCE OF THE SURFACE FAULTING

When the surface faulting encountered in top soil it would be most likely to be a tectonic rupture which might be of a new geological age, say, Holocene. If it is a strike-slip surface faulting, it might be most repeatable at its original place. As this might be the general rule, we have performed some exploration work to verify the Tangshan surface faulting. Excavations were made at the very sites where ruptures went by.

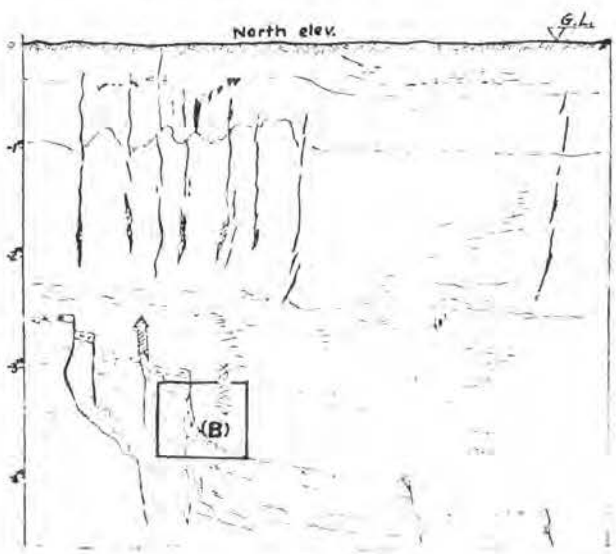

Fig.3.1 (A)

Fig.3.1
(B)

Fig.3.1 (A) (B) are profiles of the excavations in Fig.1.3, 1.4, which show there had been prehistorical faulting in the same test pit. But obviously it did not have any further displacement in the 1976 event. It should be well noted that tectonic ruptures and fissures have the same mechanism of dislocation as that in 1976 event. Fig.3.2 is another evidence at the site No.2.

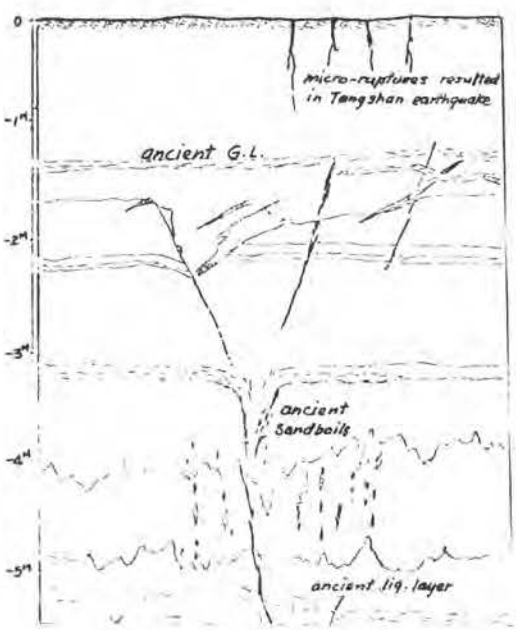

Fig.3.2

We can find more examples on the reoccurrence of surface faulting in other earthquakes in our country. For instance Fig.3.3 is a multiple rupture successively encountered in the Quaternary deposit. For each "step" of dislocation, there was a corresponding strong earthquake movement. This may be used to bear witness for predicting the possibility of reoccurrence of surface faulting.

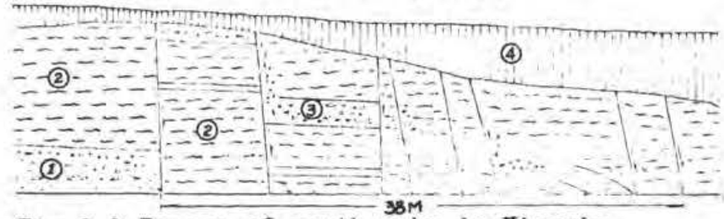

Fig.3.3 Traces of earthquake in Ningxia

(1) Steketee, J.A.: "Some Geophysical Applications of the Elastic Theory of Dislocation" Can. J. Physics, Vol.36

(2) Chinnery, M.A.: "The Stress Changes that Accompany Strike-slip Faulting" BSSA Vol.53 No.5

4. THE SEISMIC EFFECT OF SURFACE FAULTING

There are two kinds of seismic effect of surface faulting so far as our investigation is concerned:

(1) The instability of a site or failure of foundation soils in a manner of discontinuity of ground due to surface ruptures. This kind of faulure will result in unavoidable break in a certain part of the structure.

(2) The magnification of amplitude, or prolongation of time duration of ground movement, or influence on frequency character. Thus the damages of ground facilities will be increased.

In the following, we will give a brief discussion on this topic.

4.1 The Breaking Effect of Surface Faulting in Soil

This kind of breaking effect is quite different from that of causative fault. In the prescribed cases of Tangshan and Liao Ning (Hai Cheng) earthquake, the surface tectonic ruptures in soil are characterized by the following features:

(1) The rupture occurs from the ground surface and extends downward with diminishing relative displacement. (Fig.2.2, 2.5, 2.7)

(2) Dislocation and tensile cracks take place only in top soil, thus the shear or tensile stress transmitted are largely depending on the flexibility and plastic deformability of the surrounding soil layers. When there exist a certain structure directly on the rupture, the rigidity of the local ground will be increased, and the strength of soil layer will not be overcome and ruptures will never occur on this very location. As a result, nearby rupture will take place instead.

Fig. 4.1 (A) (B) gives the actual damage of a single storied storehouse of the Metallurgical Bureau situated at the central part of Tangshan city (ref. to Fig. 1.2). A broad rupture occurred in front of the storehouse, the horizontal offset was about 1.2 m. and vertical offset was about 0.3 m, the dislocation was in right turn too. The rupture went eastward across the highway for over 20 m long. But the rupture vanished suddenly in front of the house. So the bearing wall stood still without any breakage made by surface faulting.

In Fig.4.2, a surface tecotonic rupture wnet through the spacing of curb trees without cutting the roots like that in Tung Hai earthquake. Generally speaking, the ruptures will escape the trees to seek an easy path to get through. This is because the roots of trees will reinforce the soil layer and increase its rigidity and strength.

Fig.4.1 (A) storehouse with on harm of surface rupture which broke up suddenly at the front of the house

(B) Location of the storehouse

Fig.4.2 Surface tectonic rupture went through crub trees with no harm to the tree

We notice that in san Fernando earthquake, the breaking effect is almost the same as that mentioned above. From Fig.4.3 (photo by Mr. Youd of USGS)(3)the author notice the following enlightment.

(1) The ruptures on the covered ground by housing is much smaller than that on the free ground surface.

(2) The damages of the house directly caused by faulting ruptures is seemingly in static manner rather than dynamic and far from disastrous.

Fig.4.3

(3) Youd, T.L. et al: San Fernando Faulting Damage and Its Effect on Land Use.

"Earthquake Engineering and Soil Dynamics" 1978

(3) The nearby houses and other facilities stand still whereas the faulting makes the land broken.

4.2 The Vibrational Effect of Surface Faulting

In the vibration of soil ground, the permanent plastic deformation will instentaneously increase the amplitude of local ground displacement, whereas the elastic deformation of ground will remain unchanged.

On the other hand, the time duration of ground vibration will play an important part of the seismic effect of surface tectonic ruptures which will be discussed below.

4.2.1 The Attenuation or Excitation of Surface Tectonic Ruptures to Vibration

Conclusions drawn from investigations on many causative fault zones show that structures nearby the surface rupture damaged slighter or heavier without definite rule. The possible causes of such phenomenon might be either the cases: (1) The surface rupture has nothing to do with damages on ground. (2) Surface rupture might have contrary effects which could be cancelled each other to a certain extent. According to the author's research, the latter case is closer to the fact.

The intensification of earthquake damages due to surface tectonic ruptures is supposed to be the sudden raise of instantaneous acceleration during the breaking out of the rupture.

The decrease of earthquake damages due to surface tectonic ruptures is considered to be the shortening of time duration in vibration, i.e. diminishing the number of cycles according to the concept of the equivalent number of cyclic stress.

In addition, this view point can be explained by law of conservation of energy. Suppose the structure on it forms a lumped mass system. Let M be the mass of structure, $\dot{x}$ be the velocity of particle's vibration, then the kinetic energy gained during instantaneous ground movement is

$$E_d = M\dot{x}^2/2$$

The potential energy E_p will be the product of the spring (K) force and the displacement x,

$$E_p = Kx\,x/2$$

The energy transmitted instantaneously to the structure should be

$$dE_d = \frac{\partial E_d}{\partial t}dt = \frac{\partial}{\partial t}(M\dot{x}^2/2)dt = M\ddot{x}\dot{x}dt$$

$$dE_p = \frac{\partial E_p}{\partial t}dt = \frac{\partial}{\partial t}(Kx^2/2)dt = K\dot{x}x\,dt$$

The energy exhausted during vibration is mainly due to damping of the system, and will be transferred into heat energy to be dispersed. So the energy exhausted in a certain moment is the product of the damping force and the particle velocity in vibration, namely

where C is the damping factor, or written in the form of critical damping ratio

$$\zeta = \frac{C}{2\omega_n M} = \frac{CT}{4\pi M}$$

$$dE_v = C\dot{x}\cdot\dot{x}\Delta t = \frac{4\pi M\zeta}{T}\dot{x}^2dt$$

and ω_n —— frequency in cycle of the particle vibration

T —— period

The total energy gained by the structure is the sum of the three, thus

$$\Delta E = \Delta E_d + \Delta E_p + \Delta E_v$$
$$= (M\ddot{x} + C\dot{x} + Kx)\dot{x}\Delta t$$
$$= -M\ddot{x}\dot{x}\Delta t$$

or, another form can be written in terms of the circular frequency,

$$\Delta E = (-M\omega^2 + C\omega + K)x\dot{x}\Delta t$$

When the surface rupture occurs in an instant, i.e. $\Delta t \neq T/4$, then $x \rightarrow x'$ $(x' \gg x)$, and M, ω, C remain constant. Therefore by law of conservation of energy, $\dot{x} \rightarrow \dot{x}'$ $(\dot{x}' \ll \dot{x})$. This means the velocity of ground movement near the rupture will suddenly diminish, then ground shaking will stop quickly. Consequently the structure will likely stand still after a shorter time duration of vibration. Fig.4.4 is an example of such case in Liao Ning earthquake.

Fig.4.4 Houses nearby surface faulting (tectonic rupture about hundred meters apart) in Liao Ning earthquake stands still

ACKNOWLEDGEMENT

The authors wish to extend their gratitude to Mr. Yuan You-jun and Miss Lou Ming-jiu who have been busy enough in making this literature ready.