2 Surface fault and Ground damage

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1. Introduction

The 21 September 1999 Chichi Earthquake (Ms7.7-7.9) occurred in Taichung-Nantou area, central Taiwan. An obvious surface fault appeared to 80 km long from east of Shichien to south of Tontun. The damage represented along the fault as a line. I joined with the Reconnaissance Team of Kobe University for Taiwan Earthquake during 2nd to 10th of October, and investigated the surface fault and ground damage in Chichi Earthquake.

After our investigation, I have already reported them in the Geological Society of Japan (11/25), Research Group on Lifelines (11/8) and our University (10/18 and 12/3).

2. Sites visited

1 Shikung（石岡） (10/4)
2 Takou（大坑） (10/7)
3 Taipin（太平） (10/7)
4 Tsanton（草屯） (10/5, 10/6)
5 Wufong（霧峰） (10/7)
6 Mingchien（名間） (10/5, 10/6, 10/8)
7 Tsushan（竹山） (10/7, 10/8)
8 Chichi（集集） (10/5)
9 Tontun (桶頭) (10/8)

3. Feature of Failure

1 A surface fault forms a scarp due to uplifting of the east side (hanging wall). The scarp appeared along the N-S-striking Chelungpu active fault, except for north of Shikung.

2. The scarp has a large vertical displacement of 4-5 m at Tsusan and Shikung. The vertical displacement is lager in its northern part than in its southern part.

3. At Mingchien, en echelon ridges are developed in a thrust sheet of the Chelungpu fault. This supports a west-directional movement of the thrust sheet.

4. The strong ground movement, inferred from the fallen utility poles, is a width of less than 100 m on both sides of the surface fault. Within the 100 m in width, the remarkable damages of buildings and houses took place commonly.

5 Area of epicenter indicates generally an east-west-directional ground motion, based on analysis of the inclination of utility poles.

4. Near-fault Damage

The following photographs show fault scarps and damages near the fault:

Plate 1

a. Monoclinal flexture (arrow) and a broken house at Tsanton.

b. Fault scarp at Wufong.

c. En echelon bulges and an inclined electoric towor at Mingchien.
d. Fault scarp and broken bridge (arrow) at Mingtsu Bridge.

Plate 2
a. Damage of a 3-story housing on the fault along Route 3 at Shikung. The displacement of a fault scarp is vertically about 5 m and horizontally 3.4 m. Red line; Fault.
b. Damage of a school on the fault at Wufong.
c. Damage of housing along the fault at Takon. The fault scarp has a vertical displacement of 2.5 m.
d. Damage of building on the fault at Tsushan.

5. Findings (Comparison with 1995 Kobe Earthquake)

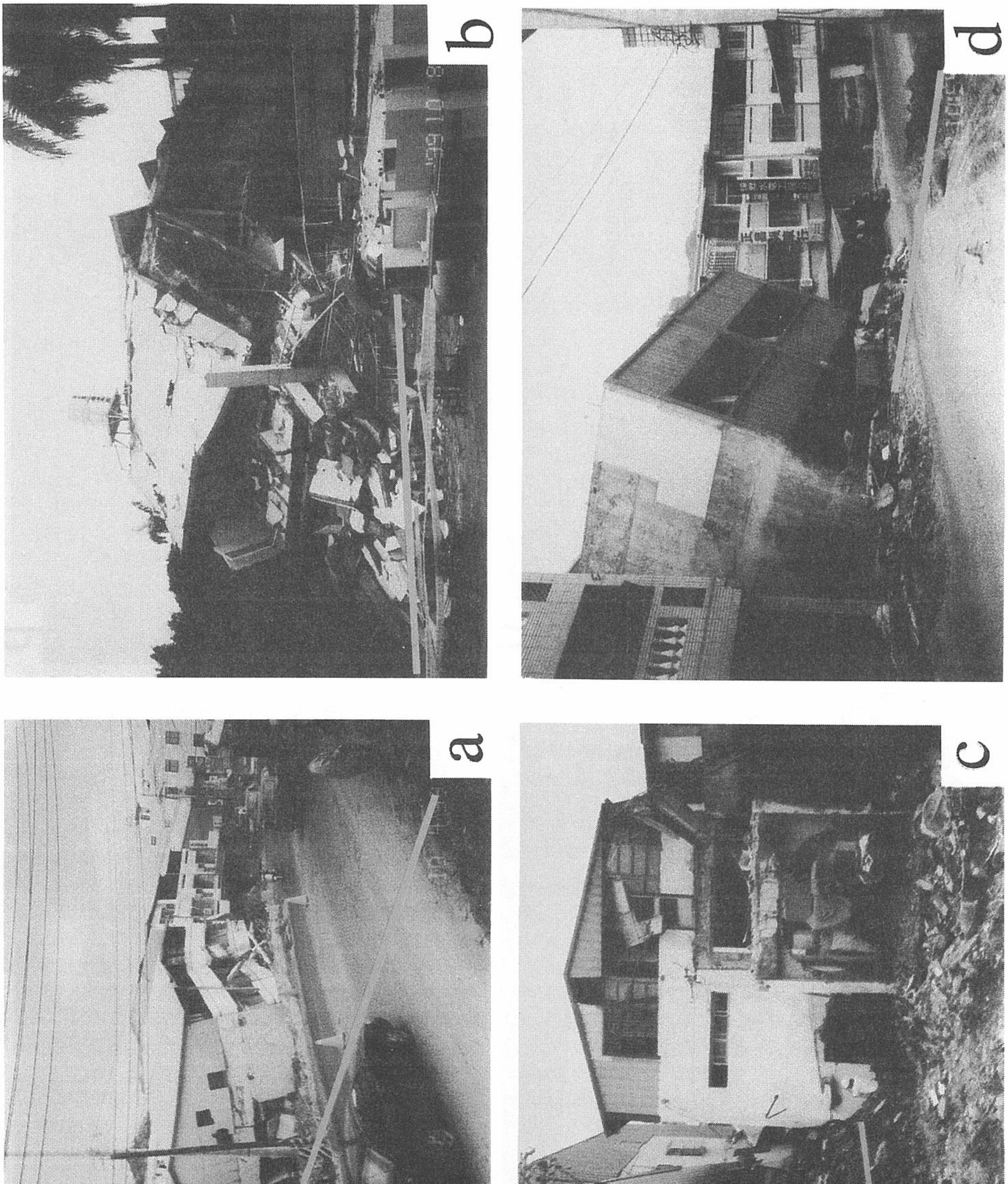
1 The surface fault in Chichi Earthquake is characterized by more predominant vertical displacement. The displacement becomes lager from south to north along the fault.
2 Damages appeared remarkably as a zone just above the Chelungpu seismic fault. The earthquake strong damage distributes along the fault.
3 Damage of the hanging wall of the surface fault tends to be generally larger than that of the footwall.

6. Recommendations

1 Building should be avoid as just above and near the active fault as possible.
2 To get information on concealed active fault needs for safety of city. Hereto, we need to survey the location of the concealed active fault, the subsurface structure of the fault, and the activity of the fault.

7. List of publication

Miyata, T. and Reconnaissance Team of Kobe University for Taiwan Earthquake in 1999, 1999. Examination of Surface Fault in Chichi Earthquake, Taiwan. *Proceedings of the 9th Symposium on Geo-Enviroment and Geo-Technics,* p. 47-52.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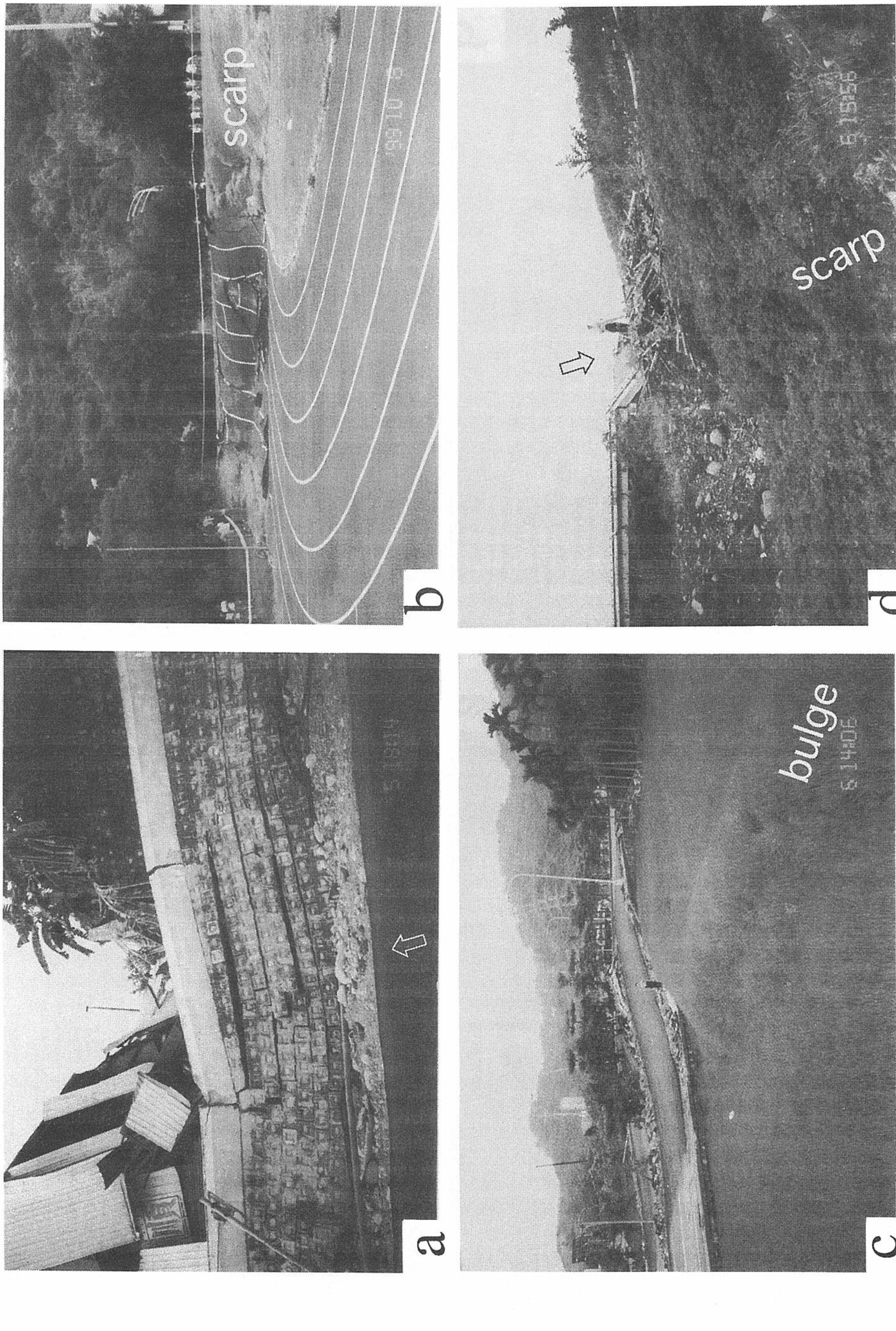
a
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Examination of Surface Fault in Chichi Earthquake, Taiwan

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for Taiwan Earthquake in 1999

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Abstract

We derived the amount of vertical displacement on surface fault scarps from leveling and co-seismic ground movement from an inclination of utility poles during the Chichi (Taiwan) Earthquake: (1) The surface fault has lager vertical displacement, 4 to 5 m, in the northern segment than in the southern segment. (2) Judging from the analysis of inclined utility poles, it is concluded that the area of strong ground movement is less than 100 m wide on both sides along the surface fault. (3) The ground movement tends to become lager on the hanging wall than on the footwall of the surface fault.

Key words: Chichi (Taiwan) Earthquake, surface fault, thrust fault scarp, vertical displacement, inclination of utility pole, Chelungpu Fault,

1. Introduction

On 21 September 1999, the Chichi Earthquake with magnitude 7.3 (CWB) occurred in Nantou-Taichung area of Taiwan. The earthquake took more than 2,200 lives and de-stroyed too many houses, buildings, bridges, railways, lifelines, etc.

Research Center for Urban Safety and Security (RCUSS) dispatched a team of scientists and engineers to investigate the effects of the earthquake mainly during 2nd to 10th of October. The purpose of this study is to describe observations of the surface faults and ground damages of the earthquake.

2. Seismic and tectonic setting

According to CWB (Central Weather Bureau), this area has the seismic intensity 6. The forcal mechanism of the mainshock indicates an eastward-dipping low-angle thrust fault with a strike of NNE-SSW (USGS and Harvard). The two faults, Chelungpu fault and Tamoupu-Hsuangtung fault, were thought to have moved during the earthquake. The Chelungpu fault is an active fault (Chang *et al*, 1998) and is one of thrust faults, extended northward from the plate boundary (e.., Central Geological Survey, 1997)

Taiwan is located tectonically between the Eurasian Plate and the Philippine Sea Plate (Fig. 1). The Philippine Sea Plate is subducted beneath the Eurasian Plate on northeast of Taiwan. On southwest of Taiwan, the Eurasian Plate is however subducted conversely beneath the Philippine Sea Plate (e.g., Ho, 1986). The rate of convergence between two plates is 7.3 cm/yr. (Seno, 1977). Maximum compressive stress, σ_1, in Taiwan is characterized by the NW-SE direction due to the plate convergence.

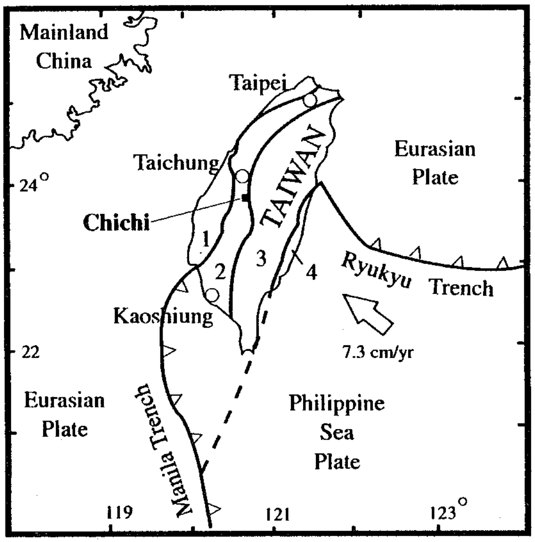

Fig. 1 Schematic tectonic map of Taiwan (modified from Central Geological Survey, 1997). 1; Western coastal plain, 2; Western foothills, 3; Central range, 4; Coastal Range.

The geological framework of Taiwan is divided into four belts from west to east: Western coastal plain, Western foothills, Central range and Coastal range (e.g., Ho, 1986). The collision plate boundary is believed to run through in the Western foothills of Taiwan (e.g., Angelier et al., 1986). East-dipping thrust faults are densely developed in the Western foothills, in which the plate boundary extends northward. Tsai (1986) is pointed out a high seismisity in the Western foothills as well as in the Coastal range.

3. Surface seismic fault

Fault length appeared

Appeared surface seismic fault extends to a length of 80 km from east of Shichien, through Shikung, Takon, Taipin, Wufong, Tsanton, Nantou, Mingchien, Tsushan, to south of Tontun (Fig. 2). Its strike is almost to the north, except for the northeast direction in its northern part. The fault scarp appeared between Tontun to Shikung is just along the Chelungpu active fault (Chang *et al.*, 1998), but that between Shikung to Shichien is not consistent with it. On the north, we could not observe surface fault rupture across the road between Shuiyi and Zhuolan, except that there is a small-scale collapse in a boulder gravel bed at the east of Shuiyi Pass. On the south, the Chelungpu fault is presumed to extend to the south into mountains.

Morphology

At Tsanton, a monoclinal flexure (Fig. 3a) was formed along a side wall of a road by co-seismic uplift during the earthquake. Along a river floor, composed of the black silt and boulder gravel, a fault scarp is formed at south of Tsanton. Also we observed the co-seismic fault scarps at Wufong, Mingchien and Mingtsu Bridge (Fig. 3b-d). We measured its morphology at Tsanton, Mingchien and Mintsu Bridge by leveling. As a result of the leveling, the morphology of reverse fault scarps was obtained. Many extensional fractures

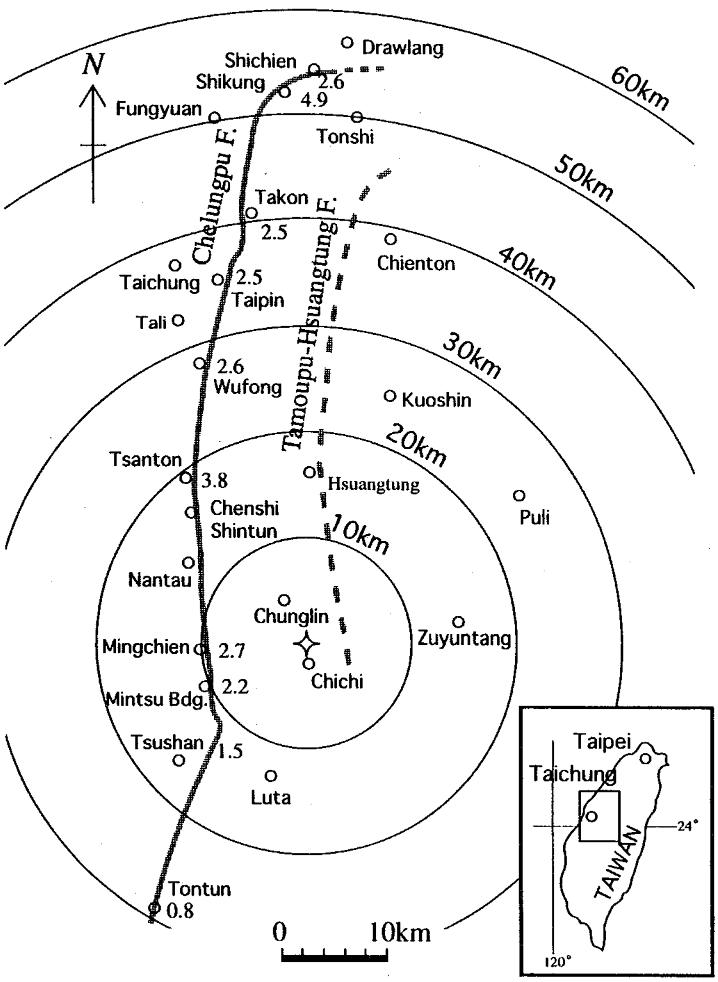

Fig. 2 Surface fault of the Chichi Earthquake. Figure; Amount of vertical displacement, Solid line; Fault with the activity during the earthquake, Star; Epicenter.

are developed sometime on the hanging wall of the fault. At Mingchien, *en échelon* bulges are developed in a rise field. This supports that a thrust sheet (hanging wall) moves to the west.

Strikes of the fault scarp change from N28° E to N20° W (mean N4° E). This feature supports that a dip of the fault is not a high angle, but a low angle.

Displacement

We measured an amount of displacement along the surface fault from Shichien to Tontun, based on an offset of the ground surface and sidewalk, which were at the same height before the earthquake.

Shichien A steep cliff was formed in the terrace deposits, composing of boulder gravel. Its scarp has a height of 2.6 m. East of Shichien, we observed also a scarp with a horizontal movement of 2.2 m and a vertical movement of 2 m across a road. The east side of the scarp (hanging wall) rose relatively against its west side (footwall).

Shikung A steep scarp was formed across the Route 3. The scarp has a vertical component of 3.5 m or 4.9 m and a horizontal component of 3.4 m, based on the offset of a sidewalk.

Takon We obtained a vertical displacement of 2.74 m, based on the offset of an asphalt ground, which is the same height before the earthquake.

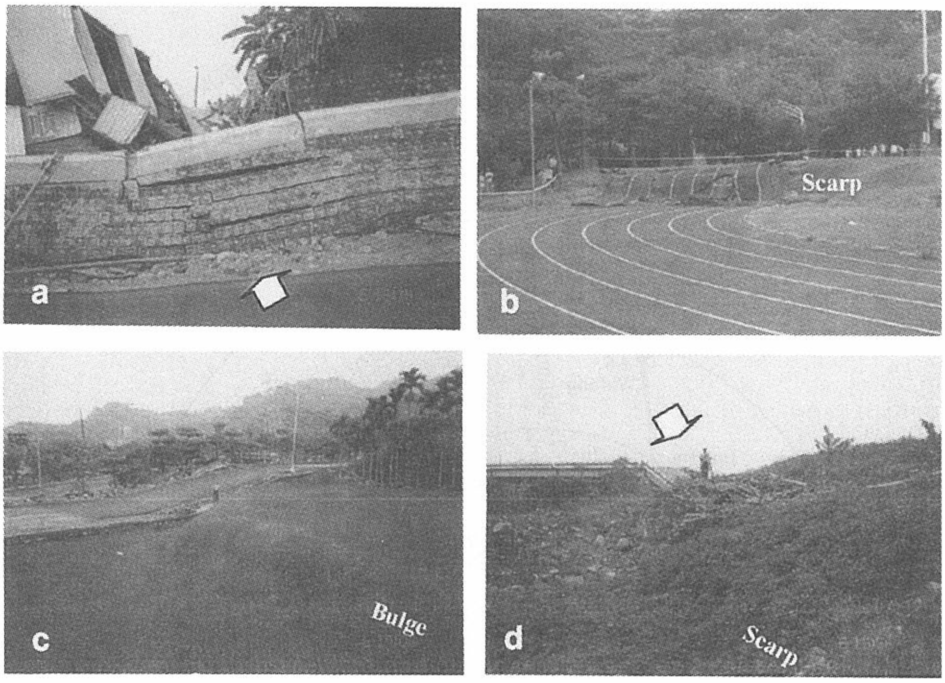

Fig. 3 Photographs of thrust fault scarp. a) Monoclinal flexture (arrow) and a broken house at Tsanton, b) Fault scarp at Wufong, c) *En échelon* bulges and an inclined electric tower at Mingchien, and d) fault scarp and broken bridge (arrow) at Mingtsu Bridge.

Taipin We observed also low scarps, having the difference of height of about 2.5 m.

Wufong Steep scarps with a vertical displacement, 2.60 m, appeared on a school ground (Fig. 3b). The scarp continues furthermore across an asphalt road and a river wall.

Tsanton Low scarps appeared across roads (Route 3 and 14) and a river (R. Ailiaoqi). The scarp of the river floor has a vertical displacement of 3.83 m.

Mingchen Steep scarps also appeared across the Route 3. The east block of the scarp rose against its west block. The scarp has a vertical displacement of about 3m, based on the offset of asphalt road. At south of Mingchen, we measured a vertical displacement of 2.70 m by leveling in a rise field (Fig. 3c).

Mingtsu Bridge We found a fault scarp with a vertical displacement, 2.20 m, in a peanut field (Fig. 3d). The fault continues the broken Mingtsu Bridge (arrow).

Tontun The fault cuts terrace and levee deposits along a river. We obtained a vertical displacement of 80 cm from a low scarp, having the uplift of the east block (hanging wall) against the west block (footwall). The fault, developed in the Miocene massive mudstone, has a striation of almost dip slip on the fault plane, and a bend of an overlying gravel bed. The fault extends to the direction of the damaged bridge with a pressure ridge.

Figure 4 shows a relationship between the vertical displacement and the distance from the epicenter. The north side of the epicenter is lager than the south side (Fig. 4). Larger displacements appeared a 20 km (Tsanton) and 50 km (Shikung) away from the epicenter. The Chelungpu seismic fault commonly has a 2-4 m vertical displacement, except for 4.9 m of Shikung. However, it is difficult to estimate at present a net slip of the thrust fault, because the fault plane is blind and the horizontal component, perpendicular to a strike of the fault, is almost unknown.

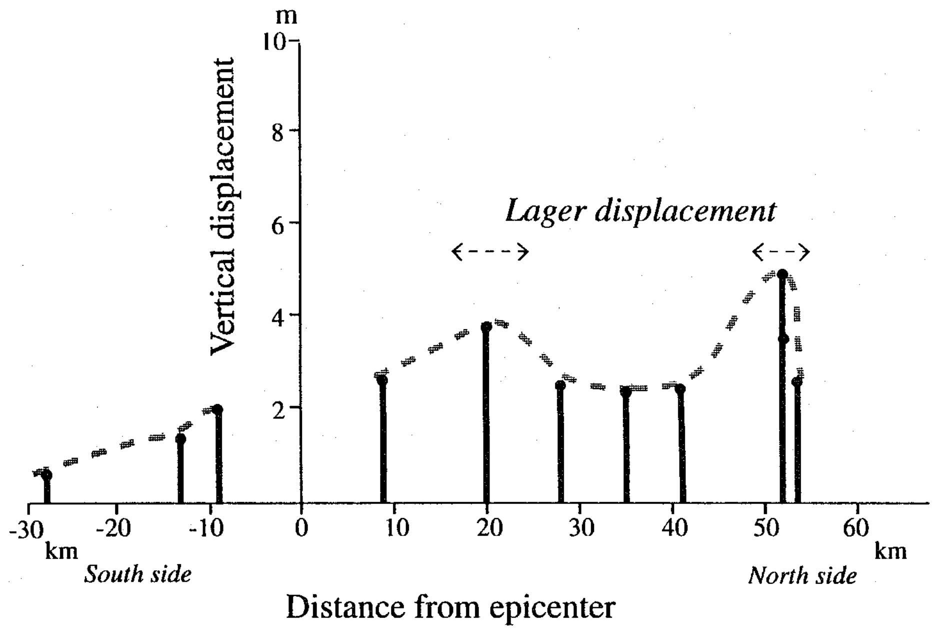

Fig. 4 Relationship between vertical displacement and distance from epicenter.

4. Relationship between the Chelungpu seismic fault and earthquake disaster

In order to obtain data of co-seismic ground movement, we measured an inclination of utility poles (see Miyata *et al.*, 1997) on asphalt roads across the Chelungpu fault. Figure 5 shows an example of the distribution of the opening, caused between a utility pole and asphalt road. The strong ground movement inferred from the opening, *S*, of more than 2 cm has a range of 100 m wide on both sides of the fault. Comparison with amounts of the opening of the hanging wall and the footwall, the ground movement is larger on the hanging wall than on the footwall. This is consistent with the distribution pattern of remarkable damages of buildings, houses, RC bridges, etc. along the Chelungpu fault. Therefore, it is very important to avoid a building just above active fault for mitigation of earthquake disaster.

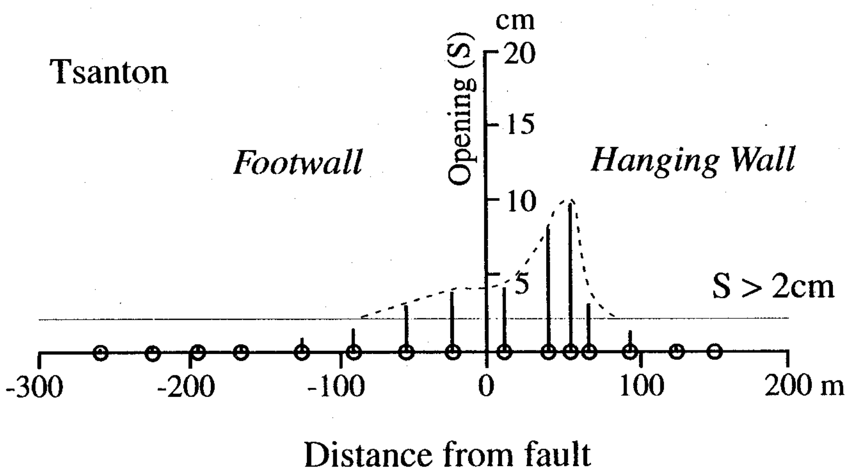

Fig. 5 Ground movement inferred from the inclination of utility poles.

5. Conclusions

(1) Along the Chelungpu seismic fault, the vertical displacement of its northern segment is larger than that of its southern segment. At localities of 20 km (Tsusan) and 50 km (Shikung) away from the epicenter, the Chelungpu seismic fault has a large vertical displacement, 4 to 5 m.

(2) The strong ground movement, estimated from the inclination of utility poles, has a range of less than 100 m on both sides of the surface fault. The ground movement of the hanging wall is generally lager than that of the footwall.

(3) It is important to use information on active fault for mitigation of earthquake disaster in urban area.

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