# THE CHARACTERISTICS OF SURFACE RUPTURES AND LANDSLIDES IN THE CHI-CHI EARTHQUAKE OF SEPTEMBER 21TH, 1999

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Abstract: The Chi-Chi, Taiwan Earthquake provides an exceptional opportunity to study surface rupture of an earthquake fault. Detailed maps of the lateral distribution of fracturing adjacent to main traces show the different amount of offset and the slip rational in vertical to lateral. The maximum value of offset is up to 10 meters and it is much higher than documented in past studies of earthquake fault. Earthquake faulting also triggers the different types of landslide hazards, and these high-risk areas of landslides hazard should be treated immediately and carefully. Based on investigations on Nantou area, we observed lots of landslides located in tableland that composed by red soil around Puli basin. Lots of landslide debris filled ravines, they pose a continuing hazard from remobilization and flow during future intense, prolonged rainfall.

Keyword: The Chi Chi Earthquake, Surface Rupture, Landslide

## A. Forward

On September 21st, 1999 at 1:47 a.m., a strong earthquake rated 7.3 in Richter's scale occurred in Taiwan area. It caused 2200 person's death, more than 7 thousands persons wounded, and many buildings were damaged and ruined. The earthquake also produced a more than one hundred kilometer's surface fault, its length was rarely seen in the world, the maximum offset between hanging wall and foot wall was about 10 meters which was rarely appeared in the world records. The rupture of this earthquake fault and the surface offset caused by fault-induced slope hazards of rock falls, landslide, impeded river, ineffective drainage, and roadway interruption. Besides those direct hazards caused by the earthquake and after shocks, the landslide hazards caused by earthquake fault will form the 2nd time hazard by the rainfall of future typhoon and deluge. This paper would like to explain the characteristics of mountain hazards caused by earthquake fault through the exposed earthquake fault investigation and the landslide hazards along the earthquake fault line.

## B. The factor of earthquake and surface fault distributing locations

The Chi Chi earthquake was caused by the faulting activity of Chelungpu fault, the apparent earthquake fault offset appeared on the surface which rarely happened in past earthquake records, the total length of the earthquake fault was more than 105 kilometers. Kuken Fault was the south border of this fault, it passed through several towns from Chushan, Mingeng, Nantou city, Tsaotun, Wufeng, to Fongyuan; it stretched 83 kilometers to north in the south-north direction. The fault extends to Fongyuan, Shikang areas and turned to east-north-east and west-south-west direction in here for about 15.5 kilometers from Fongyuan to Neiwan section. After the fault stretched to Neiwan village in northwest and southeast direction, it turned to south-north direction (about 6.5 kilometers) and connected with Shungtung fault in the east. (Fig.1) This earthquake fault appeared in a zigzag shape, the fault location from Kuken to Fongyuan section was similar to Chelungpu fault, the fault in north of Fong-Yu had never seen in historical records. Following will explain the distributing characteristics of fault on each section:

## C. The offset caused by earthquake fault

Most of the exposed earthquake faults were in zigzag shape, and parallel or sub-parallel surface rupturing composed them. The difference between that surface rupturing and other tension crack caused by slope collapse is they have clear vertical or horizontal offset, and their distributing directions have same orientation feature in the aspect of area scale. The width of the surface rupturing is from several meters to several hundred meters; the longest surface rupturing can be seen as the main earthquake fault. Regarding the direction feature of the fault distribution, although the extended direction of the earthquake fault vary according to the topography, but in the aspect of area scale, the surface fault of this earthquake can divide into south-north section extended south to north from Kuken to Fongyuan, and west-east section extended west to east from Fongyuan to Shuanchi. There are many differences in their surface features of those two sections.

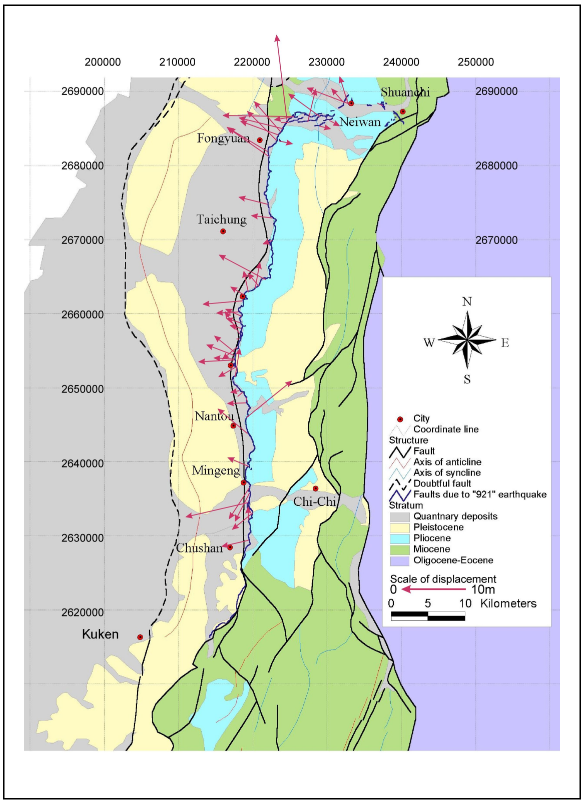



Fig 1.Geoglical map of central Taiwan, dark blue line represents surface rupture and red arrow show the plane vectors of offsets.

The offset in south-north section from Kuken to Fongyuan was several centimeters from south to 3 meters near Chushan in north, then reduced to 1 meter near Chung-Hsin new village, and increased to 2~3 meters in Wufeng and Taiping city. It increased gradually from here to north; the largest difference was 6.7 meters in north of Fongyuan City. Due to the zigzag shape of the earthquake fault trace, the surface rupturing adjacent to the fault appeared left lateral and right lateral. The horizontal offset is as the same characteristic as the vertical offset; they are various amounts in different locations. They appeared more frequently between 1~2 meters and the left-lateral offset is more than right-lateral offset. The largest horizontal offset appeared in Fong-Shi Road of Taken and north of Fongyuan; its offset almost reached 8 meters.

The vertical offset caused by earthquake fault of west-east section from Fongyuan to Shuanchi are 6~8 meters across surface fault in Neiwan area, but due to the lack of clear surface marker, it is unable to calculate its detail amount of vertical and horizontal offset, the maximum vertical offset of the fault is about 11 meters. As for the amount of horizontal offset, they appeared a great difference between different locations. The middle part of the fault located in mountain area and riverbed, there weren't any ground building or marker, and it is unable to calculate their offset. Although its apparent offset is less than south-north section, but from the surface change and damaged slopes point of view, its offset is not less than south-north section; the horizontal offset was 5 meters in Neiwan area. The offset between hanging wall and footwall of the single fault in Neiwan and Shuanchi area reached 2 meters, its shorting amount can reach to 50 cm. Besides those vertical offsets, part of the fault had a clear right-lateral offset; the maximum right-lateral offset in single fault can reach 2.5 meters.

The width of the distorted zone of the surface fractures concentrated on north-south section, the width of the earthquake fault from Kuken to Fongyuan section was narrower, and the width of the earthquake faults in southern part were between several meters to 10 meters. The offset was achieved by major trust fault, the back trust fault in west-east section and the sub-parallel reverse fault with minor horizontal amount appeared only in the flat area like Wu-Shih Bridge and Chung-Cheng Park in Fongyuan City. The fault in north of Wu-Shih bridge became wider and the major fault diversified from here, the width of the fault can reach several hundred meters, 3 to 4 fault among them were trust faults inclined to east side, among them with few trust faults inclined to west side. The faults in west-east section were more complicated, except those major trust faults, they also included the back trust fault caused by volume adjustment, and the sub-parallel reverse fault with minor offset. The width of the fault distorted zone reached 3 kilometers in Shihkang and Shih-Cheng area due to its structure, but most of the surface fractures still concentrated near major fault and did not distribute evenly.

## D. Landslides caused by surface fault and its distributing area

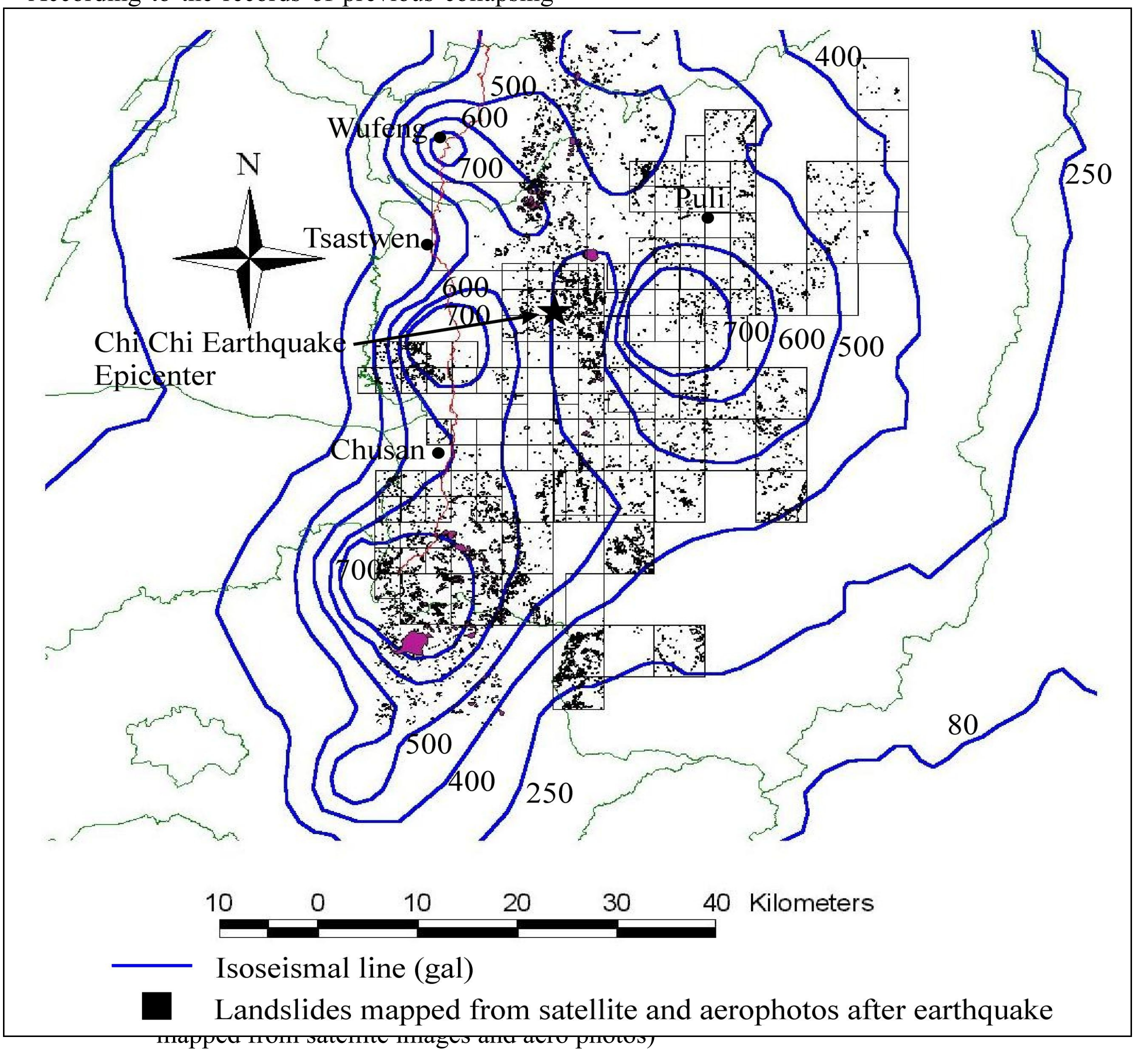
The landslides hazards caused by this earthquake divided into the following types:

(1) Collapse caused by earthquake

When the earthquake occurred, due to the seismic wave transmitted to surface and produced shaking, vibration can cause the collapse in the potential collapsing area. According to the records of previous collapsing hazards after strong earthquakes [1], the reasons that might influence the collapse include the characteristics of earthquake itself, the physiography, hydrology and meteorology.

The earthquake itself can divide into position of epicenter and surface vibration two parts. The character of position of epicenter includes depth of epicenter, earthquake magnitude, damaged form of soil layer, and the surface vibration includes surface acceleration, cycled feature, continuous time and the scale of earthquake. The potential reasons of the collapsing location are vibrating features of geography, topography and soil layer, the structure of soil layer and the rainfall before and after earthquake.

The collapse that far away from the fault is affected by the surface vibration transmitted by seismic wave, and triggered the potential collapsing locations and caused by instability and damage of slope




mapped from satellite images and aero photos)

. According to the combination of the satellite changing points information of Nantou County after 0921 earthquake provided by Water

Reserve Bureau of Agriculture Committee and the aerial photo of the collapsing distribution drawing after 0921 earthquake by the Disaster Prevention Center came out the result as shown in Fig.2. The surface quake vibrations were not evenly distributed due to the influences of topography, geography and underground structure, the quake vibration in Tsaoling, Minggeng, Wufeng and Dili areas were the

highest. The mountain area of those places had intensive collapse and in accord with the foreign relevant results; which will be the continuous observation locations in the future. The major difference between the collapse caused by earthquake and the collapse caused by deluge is the higher the elevation is, the speeder the surface acceleration will be, therefore, most of the collapse caused by earthquake happened near crest line.

(2). The collapse along the Chi Chi earthquake fault

When the earthquake fault was moving, the hanging wall was raised by it and caused the collapse of the slope by losing its stability. The damage can be part of the base of slope be cut by the fault due to the surface raising, the slope lost its stability. Or when the fault line cut into the mountain area, the different raising strength caused a series of horizontal and well-stretched tension cracks and then produced the collapse.

There were 26 collapses along the earthquake fault line from Taiping city to Chulan area. Those collapses were triggered by chain reaction of old collapse caused by surface fracturing and offset when the fault cut through the surface. Most of the collapse were composed by many weathering soil, weathering bedrock and the old collapse material, most of the collapsing size is less than 3 hectare, most of the collapsing slope were larger than 25°. The collapsing locations were directly influenced by the fault exposed location; especially the collapsing materials were composed by weathering soil and weathering bedrock. Part of the soil could have the illusion of large-area landslides caused by earthquake, especially to those slope, unless it is the old collapsing location which could have larger deep collapse, others were the shallow collapses less than 1 meter.

(3). 2nd time hazard caused by earthquake: debris flow

The 2nd time hazards caused by earthquake include debris flow, landslide, and the expansion of collapsing, these hazards were mainly caused by collapses or large scaled earth loose caused by earthquake. Other factors after earthquake such as deluge, typhoon, malapropos human disturbance caused the mass movement of soil and rocks accumulated in river or soil on slope and pouring downstream and caused the hazards. The most serious collapse of this earthquake was Chi Chi town, Chungliao village, Sheili village, Puli town, Kuohsin town and Tsaoling; it is still investigating dangerous stream of the debris flow. After investigation, we found that some of the steams did not list in the dangerous streams had soil and rocks accumulation in the upper stream after this earthquake, and it could become the new source material of debris flow. Most of those streams had many collapses, and the most serious one was red soil tableland around Puli basin and red soil pebble layer on the west trim of Nantou County. Three conditions to produce debris flow are: sufficient slope of the streambed, abundant soil and rock source and plenty of rainfalls. From above we can tell how serious the problems of the red soil tableland and pebble layer are. Loose pebbles compose most of these layers and weathering red soil; they provided abundant sources of debris flow. In the aspect of topography slope, although the topography on the top of the platform is flat, but its rim is easy to form the steep cliff with large difference in height and slope, some places even formed a steeper slope than the terrain. The most serious problem is those tableland usually distributes on the flood plain or on the rim of basin, residents and land use usually are under the edge of platform slope, plus the stream ravines in these areas are not common water flow ravines, people won't pay attention to them. The upper stream had many collapses of the wild stream ravines around Pipa sub-ward in Puli town, and the locations of the residential houses are near the bottom of slope, it should well prepared before the raining season.

The debris flow problem caused by earthquake is more than these, some river ravines were cut through by fault, and the riverbed of the down stream section raised and caused the river and formed the natural dam. Most of those natural dams are composed by the loosely materials; once the rainfall of the upper stream increases the water flow, the reserved water behind the dam produces pushing pressure. If the natural dam breaks, the large volume of water flow could bring large volume of the accumulated materials piled in riverbed. Then it could cause debris flow or mud flow.

## F. Conclusion

Taiwan locates on the young mountain-building belt of the active convergent plate boundary; the occurrence of the earthquake is the natural destiny of this island. Although the 0921 strong earthquake caused the greatest hazard of this century, but it also warned us at the proper time that we need to understand more about our living environment. Due to the lack of information and accuracy, we are unable to use the existing active fault-distributing map to precede any construction or land-use planning to avoid any improper construction site selection and improper land-use planning. Learning the experience from this earthquake, the emergent mission of planning earthquake hazard prevention system is to assure the exact locations and their characters of the active faults in this island.

The landslides caused by Chi Chi earthquake and the possible 2nd time hazards along with the future typhoon and deluge could be expanded. We hope we could well prepared for the future rain season and typhoon season and arise the alert of neighborhood in dangerous locations to avoid another sever blow on the reconstructed homeland. We also hope through the strike of the strong earthquake, no matter if they are the workers in academic field or practical work, we should enhance our anti-hazard ability and live harmony with our natural environment.

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