# Seismic Damage and Disaster Reduction Analysis of Building Structures along the Surface Rupture Trace Line of Strong Earthquakes

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**Abstract: The damage and setback distance of nearby buildings caused by strong earthquake surface rupture is one of the hot topics in the relationship between earthquake engineers, structural designers, and geotechnical earthquake geology experts. This article provides recommended values for setback distance under reverse, normal, and strike slip faults through the discussion and analysis of seismic damage to structures on the distribution trace of surface ruptures and adjacent areas. At the same time, for structures near surface ruptures, if seismic measures for the cover layer and foundation under the effect of surface ruptures are considered or strengthened, and the basic setback distance is about 30-50m. This provides an important data source and basis for revision of the active fault setback distance in seismic code.**

**Keywords: Surface Rupture; Building Structures; Fault; Disaster Reduction**

## 1. Introduction

The phenomenon of damage, destruction, or collapse of engineering structures caused by surface rupture during a strong earthquake is called structural damage under surface rupture, abbreviated as structural damage. In recent years, with the multiple destructive occurrences of strong earthquakes, surface fractures, and structural damage, structural engineers, geotechnical engineers, and geological engineers have increasingly focused on the study of this issue. For example, in 2023, the strong main earthquake (Mw 7.7) and major aftershocks (Mw 7.6) triggered by Kahramamaras in Türkiye led to serious damage to many buildings due to fault surface rupture[1].

Therefore, it is urgent to solve the problem of the damage of engineering structure on the surface rupture of the fault dislocated site. From the most direct perspective, it is the problem of setback distance and avoidance measures for engineering structures to avoid surface ruptures.

## 2. Seismic Damage Analysis of Structures on Surface Ruptures

The seismic damage analysis was carried out on engineering structures such as buildings on the distribution trace of surface rupture of strong earthquakes, mainly sorting out and analyzing typical cases of urban “straight down” earthquakes, such as the 1999 Chi Chi Mw7.6 earthquake event, the 2008 Wenchuan Ms8.0 earthquake event, the 2011 Yushu Ms7.1 earthquake event in Qinghai, the 1999 Izmit Mw7.4 earthquake event in Türkiye, and the 2010 Darfield Mw7.1 earthquake event in New Zealand. These events are mainly the impact of surface rupture on structural seismic damage on thrust faults and strike-slip faults.

### 2.1 Mw7.6 Chi-Chi Earthquake

The 1999 Chiji earthquake generated a strong seismic surface rupture zone along the Chelongpu thrust fault, running almost north-south with a total length of about 100km[2]. The surface rupture zone caused a four story residential building near Fengzhen Park in Fengyuan City to be traversed by a strong earthquake surface thrust fault during the earthquake, causing serious damage. Due to being located on a continuous stiffness foundation, it did not collapse. The ratio of buildings on both sides of the trace is 40:60, forming a 4m steep slope (gentle slope). At the same time, the building slopes downwards by 10 °, as shown in Figure 1.

Kelson et al. provided an investigation into the damage to buildings passing through Guangfu Middle School on the Chelongpu Fault (trace): buildings over 50 meters around the fault trace were mostly undamaged, while some buildings at around 50 meters were inclined to some extent; All buildings on the fault trace were spared, completely destroyed or collapsed. The foundation type of the collapsed structure is an independent foundation under the column[3], with a vertical displacement of 1.6m-3.2m on the main trace and 0.5m on the secondary trace.

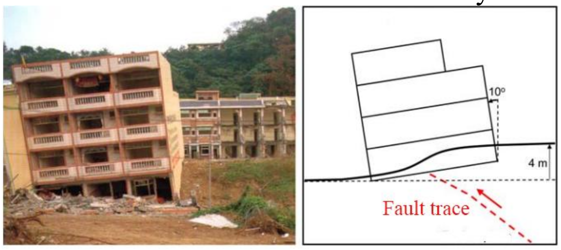


**Figure 1. Analysis Diagram of Structural Failure on Fault Traces**

Lin Fengtian [4] used an earthquake investigation team led by the Construction Planning and Management Bureau (ACP) of the Ministry of the Interior, consisting of 21 academic and professional units, to provide survey data on the damage of buildings around the Chelongpu fault trace. He drew a spatial relationship map between the Chelongpu surface fault trace and the buildings above and adjacent to it.

In short, for thrust faults like Chelongpu, there is a serious surface rupture effect within a distance of 50m in the upper and 25m in the lower walls, which is a distance that engineering structures completely need to avoid. Of course, this is in the case where the ground trace on the engineering site is completely accurately located. If for some reasons the trace is not accurately located and factors such as the engineering structure type and site conditions are not considered, a conservative approach of increasing the safety factor can be adopted. After analyzing the seismic damage of the above seismic structures, this article believes that on engineering sites with reverse fault surface ruptures caused by earthquakes of magnitude 7 or above, the setback distance of the upper wall of the fault is 100m and the setback distance of the lower wall is 50m.

### 2.2 Ms8.0 Wenchuan Earthquake

The surface rupture zone of the Wenchuan earthquake has very distinct characteristics in terms of surface rupture type, rupture width, geometric structure, and co-seismic displacement distribution. It is the most complex surface rupture structure, longest rupture length, and a major internal reverse fault earthquake event with both thrust and right-handed strike slip components.

Zhao Jisheng et al. conducted a comprehensive survey on the distribution of seismic damage to buildings near the surface rupture trace of this earthquake. Except for Yingxiu Town and Beichuan County, which did not have detailed survey data, they conducted statistical analysis on the seismic damage of 1699 buildings (structures) around 15 rupture survey points. It has been confirmed that the surface rupture effect of strong earthquakes exacerbates the impact of seismic damage on buildings near the trace line. At the same time, the seismic damage index of engineering structures within a distance of 150 meters from the surface trace line gradually decreases, beyond this area, and there is no obvious pattern.

Jianyi Zhang and others have sorted out the seismic damage of engineering structures at a certain distance from the Wenchuan earthquake rupture line (see Figure 2). According to the principle of quantifying the relationship between structural seismic damage index and fault distance (trace distance from the building), the formula for seismic damage index (I) and rupture distance (S) is given as $I=0.7463-0.00195S$.

Xiaoyudong Town is a typical place where the damage to buildings on both sides of the surface rupture zone was studied the most during the Wenchuan earthquake. The author conducted a survey on it during the earthquake scientific investigation, and it can be said that the location is an experiment of natural strong earthquake surface rupture on the avoidance distance of buildings. Because the buildings on both sides of the rupture track were uniformly planned by the nearby townfolk for the construction of "Farmhouse music" tourism in the past two years, the structure and construction of the houses are almost identical, that is, a 3-story brick and concrete structure with a strip foundation (complete ring beam and structural columns, basically meeting the requirements for resisting strong earthquakes), and the surface rupture zone (trace) almost passes through in the most dangerous vertical way. The author's investigation found that houses within 20 meters from the trace completely collapsed. Serious damage to houses ranging from 20 to 50 meters (see Figure 3), moderate damage to houses ranging from 50 to 100 meters, and minor damage beyond 100 meters.

**Figure 2. Detailed Drawing of Buildings at Main Traces on Surface Rupture**

**Figure 3. Damage to Houses in the Secondary Branch Rupture of Xiaoyudong**

### 2.3 Ms7.1 Yushu Earthquake

On April 14, 2010, an Ms7.1 earthquake occurred on the Ganzi-Yushu fault section. The length of the rupture zone was about 30-40km, and the rupture was left-handed strike-slip, with the maximum strike-slip displacement located on the main rupture on the north side, about 1.8m.

In this paper, the author investigated and analyzed the earthquake damage of the buildings near the surface fracture trace, and provided the earthquake damage index for each individual building in order to further provide more detailed data for the quantitative study of the distance between buildings (structures) to avoid active faults. In the VIII degree zone, if the distance between the hollow brick structure and the surface rupture trace is greater than 50m, it is basically in line with the principle of "not collapsing during a major earthquake"; To achieve repairable damage below moderate, the distance from the rupture trace should be at least 150m; In the VIII degree zone, as the distance from the surface rupture (S) increases, the seismic damage index (I) of the hollow brick structure (Class D) greatly decreases, and the fitting formula is $I=0.8132-0.0026S$， in Figure 4.

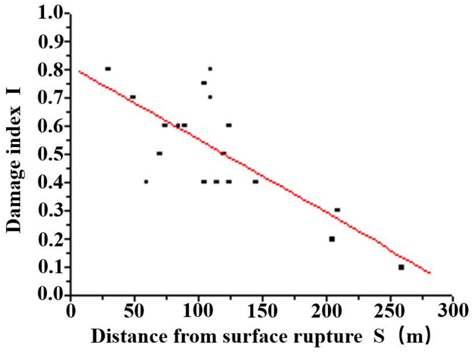


**Figure 4. Trace Distance and Seismic Damage Index of Hollow Brick Structure**

### 2.4 Mw7.4 Izmit Earthquake

In 1999, a strong Mw7.4 earthquake occurred in Izmit, the capital of Türkiye's Kojaeli Province. The North Anatolian fault zone has a length of about 180km and is dominated by right-handed strike-slip, accompanied by clear seismic surface rupture zones with disorientation. The maximum horizontal dislocation at the epicenter of GOLCUK town is 3.8m, the nearby vertical dislocation is 2m, and the maximum width of the surface rupture zone is 51m.

Anastasopoulos et al.[5] investigated 10 typical buildings in the Denizevler area of a normal strike slip fault, and obtained structures that span the surface fracture trace. In fact, the main structures that span the building foundation on the seismic fault trace are collapsed or severely damaged.

R. Ulusay[6] et al. investigated and analyzed 8 five-story apartments in Kullar Village on the positive strike-slip fault trace. Among them, the types and sizes of ①, ②, ③ and ④ apartments were almost the same. 7 apartments became "fragmented" on or near the surface rupture track, while only 1 apartment was still standing (lower wall). The horizontal dislocation of normal fault rupture is 2.4m, and the northern part of the vertical dislocation (i.e. the hanging wall) throws down the inclined upward wall 0.2-0.25m. The two apartments adjacent to the rupture trace line, one on the south side of the trace line collapses, while the other (the north side of the trace line) collapses in a “crumbled pie” shape as the foundation deforms to the east. The five buildings on the north side completely collapsed in a “crumbled pie” shape under the action of the earthquake (facing west after collapse).

This article believes that this typical case occurred in 8 residential buildings with the same height, size, and construction quality, which is highly representative and reflects the hanging wall effect under the normal fault, as shown in Figure 5. However, the lower wall area hardly undergoes significant deformation under the surface rupture effect. The observation of a two-story building closer to the lower wall in the figure also stands, while the damaged buildings are all in the reverse steep slope area formed by the hanging wall. Through the analysis of the strong earthquake rupture effect of the buildings ③ and ④ and the damage of other houses, it can be seen that the distance between the upper wall and the trace line is at least 50-100m or more, which may not lead to the collapse or destruction of the buildings under the effect of surface rupture and vibration.

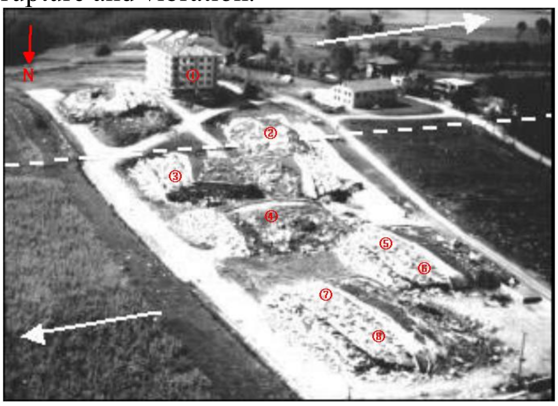


**Figure 5. Damaged of the Building in Kular Village with Normal Strike-slip Fault Trace**

### 2.5 Mw7.1Darfield Earthquake

In September 2010, the Mw7.1 Darfield earthquake occurred in the west of Christchurch, New Zealand. The surface rupture occurred on the Greendale fault, mainly due to dextral strike slip, with an average horizontal dislocation of 2.5m and a maximum of 5m. The vertical dislocation generally did not exceed 0.7m, and the width of the surface rupture zone was 30-300m

On the strike slip seismic fault, there is a simple building with a wooden frame, brick load-bearing and lightweight roof on one floor, a concrete strip foundation, which is traversed by a strike-slip main seismic fault (the red arrow in the figure 6 shows the trace). During the earthquake, the wall has shear cracks, and the wooden column is crooked[7], which is judged to be seriously damaged.


**Figure 6. Analysis Diagram of House Damage on Strike-slip Fault Trace**

## 3. Disaster Reduction Analysis of Structural Foundation on Surface Rupture

In recent years, foreign scholars[8] have found that some buildings (structures) located on faults with surface main rupture can still ensure public safety or the basic functions of buildings (structures) will not be lost after earthquakes. For example, Bray from the United States used seismic damage investigation cases of buildings (structures) crossing active faults in the world in recent years to obtain the principle of resistance or reduction of ground deformation on faults based on the improvement of construction site foundations or soil layers that meet certain fault characteristics and site conditions. The design of foundations and structures includes: (1) in geotechnical engineering analysis, soft fill soil is used to dissipate fault deformation, sliding layers are used to reduce horizontal movement of foundations, and compression materials are filled near soil walls to reduce horizontal movement of foundations. etc; (2) When analyzing structural engineering, design flexible endurance foundations, flexible structures, and expansion joints[8].

In this paper, the authors simulate the rupture resistance test of a typical frame structure of an independent foundation under a bedrock dislocation pair column by using a hydraulic cylinder that can control the loading process with high precision, and satisfy the reliability ratio of the box device and the foundation covering soil layer (Figure 7). The results showed that the seismic damage to the structure was most severe on the main rupture zone of the ground. Due to the rupture zone at this location, the maximum amount of surface non-uniform deformation caused by plastic deformation of the foundation increases the additional internal force of the upper structure. Therefore, foundation treatment and reinforcement are required at the location of the rupture[9-11].

**Figure 7. Experimental Device for Frame Structure of Strong Earthquake Ground Rupture Site**

## 4. Conclusion

Based on the systematic discussion of the surface rupture distribution trace and the structural earthquake damage in the immediate vicinity, this paper gives the recommended value of the avoidance distance under the reverse fault, positive fault and strike-slip fault: when the reverse fault is mainly ruptured, the avoidance distance is 50-150m, the distance between the upper and lower plates is 3:1, and the general avoidance distance is 100m; When strike-slip rupture is the main problem, the avoidance distance of hollow brick structure (Class D) is 100-150m, the frame structure is at least 20m, and the general structure avoidance distance is 40-50m; When the normal fault is mainly ruptured, the avoidance distance is generally 50m, which can be reduced when the structural foundation is good. In short, if the structure near the surface rupture considers or strengthens the (foundation) seismic measures under the surface rupture effect, basically the avoidance distance can be about 50m.

This article analyzes typical structural seismic damage examples and points out that in the study of surface rupture and upper structure seismic damage, the focus is on the analysis of rupture traces or the relationship between faults and foundations. For continuous foundations with high stiffness such as strip foundations and raft foundations, and even for structures that pose serious risks when crossing faults, it is recommended to use “flat and thin” small box foundations; At the same time, in the analysis, attention should be paid to coordinating the relationship between the maximum displacement under surface rupture dynamic deformation and the maximum deflection of the foundation that meets the requirement of not collapsing. In fact, this is the basic anti fracture measure.

## Acknowledgments

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