Risk analysis of soil liquefaction in earthquake disasters

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Abstract. China is an earthquake-prone country. With the development of urbanization in China, the effect of population aggregation becomes more and more obvious, and the Casualty Risk of earthquake disasters also increases. Combining with the characteristics of earthquake liquefaction, this paper analyses the disaster situation of soil liquefaction caused by earthquake in Indonesia. The internal influencing factors of soil liquefaction and the external dynamic factors caused by earthquake are summarized, and then the evaluation factors of seismic liquefaction are summarized. The earthquake liquefaction risk is indexed to facilitate trend analysis. The index of earthquake liquefaction risk is more conducive to the disaster trend analysis of soil liquefaction risk areas, which is of great significance for earthquake disaster rescue.

1 Risk analysis of earthquake liquefaction

Earthquake disasters often cause serious damage to us because they are unpredictable. Search the US Geological Survey (USGS) website for the number of earthquakes with magnitude 6 and above in the last 50 years, about 7,000 times. Earthquake liquefaction has existed since ancient times, but its real importance began with two earthquakes in 1964. Large-scale soil liquefaction occurred in both the Niigata M7.5 earthquake in Japan and the M8.5 earthquake in Alaska, USA, resulting in building collapse, sand blasting and water gushing on the surface. Academic circles began to pay attention to earthquake liquefaction.

1.1 Summary of earthquake liquefaction

Earthquake liquefaction disasters are associated with earthquakes. In the process of sand liquefaction, shear strength is no longer available and bearing capacity is lost, resulting in large-scale collapse. If liquefied areas are densely populated, they will have disastrous consequences. Earthquake disaster is a kind of disaster that is difficult to predict and continue to occur. With the progress of building anti-seismic design, building collapse is no longer the main factor of earthquake losses. Soil liquefaction leads to building collapse and casualties, which has become the focus. I will give an example of the 2018 Palu M7.5 earthquake in Indonesia.

1.2 Indonesia earthquake liquefaction disaster

Indonesia is located in the southwestern segment of the Pacific Rim Seismic Belt, including land and oceans. In this area, plate movement is frequent and violent, and earthquake disasters often occur. On September 28, 2018, an earthquake of M7.5 occurred in the Palu region of Indonesia. The liquefaction caused by the earthquake is evident in its severity and spatial range. According to the report of Indonesia's National Disaster Response Agency (BNPB), more than 3,000 people were missing in Petobo and Balaroa, two of Palu's worst-hit areas. These situations were compared with remote sensing images before and after the disaster. The whole village, including houses and roads, was flooded by yellow mud after liquefaction, as shown in Figure 1.

The process of soil liquefaction photographed by satellite was quite shocking. The original solid ground turned into mud. Thousands of houses moved or collapsed or sank along with the debris flow. Such disasters are difficult to rescue. With the collapse of houses and roads, people will be asphyxiated by mortar in a few minutes.

Fig.1. Remote sensing image

In order to improve the efficiency of rescue, we need to ensure that disaster information is timely and accurate. Real-time information includes climate information, geographic information and even public opinion information in disaster areas [1]. Real-time information can be obtained from remote sensing images and large data on the Internet. Indonesia's backward information technology and poor equipment reliability lead to low
pre-warning and post-disaster command capabilities. Earthquake liquefaction is very dangerous and causes huge losses.

2 Disaster Types of Earthquake Liquefaction

2.1 Lateral displacement

Lateral displacement is a common phenomenon of ground lateral deformation induced by seismic liquefaction. Since the shear strength of the lower soil layer decreases after liquefaction, the upper structure cannot be supported and lateral displacement occurs under the action of load. In many earthquakes, liquefaction causes large-scale lateral displacement of foundation, resulting in a large number of destruction of underground facilities and building structures.

2.2 Subsidence

During the dissipation of excess pore water pressure in liquefied layer after earthquake liquefaction, the rearrangement of particles results in surface subsidence caused by drainage and consolidation. The lateral displacement caused by liquefaction will have subsidence phenomenon. The liquefaction subsidence of Niigata earthquake exceeded 3 meters, in 1964. The 1976 Tangshan earthquake in China subsided more than 1 meter. Subsidence led to the collapse of a large number of houses.

2.3 Sandblasting and watering

After soil liquefaction, pore water pressure exceeds the effective stress of the upper surface, breaks through the overburden, and sand particles with liquefied layer spray out from the surface. The damage caused by sand blasting and water bursting is not obvious in the city, but in the countryside it will lead to soil erosion, damage farmland and silt up rivers.

3 Cause Analysis of Sand Liquefaction

3.1 Definition of soil liquefaction

It takes place when a quake has increased water pressure in saturated soil and made particles in the soil lose contact with each other, making the soil- particularly sandy soil- act like liquid. Karl Terzaghi [2] calls sudden liquefaction the state of structural damage of sandy soil and loss of bearing capacity of foundation caused by non-seepage factors. The Japan Association of Soil Mechanics and Foundation Engineering define liquefaction as a state in which the shear stress and effective stress of saturated sand decrease due to the increase of pore water stress. At present, more and more scholars generally agree that the definition of liquefaction is defined by the Dynamic Committee of the Geotechnical Engineering Division of the American Association of Civil Engineers [3]. Liquefaction refers to the process in which any substance is converted into liquid. Because of the rise of pore pressure and the decrease of effective force, cohesionless soil can be converted from solid state to liquid state.

3.2 Influence factor

Firstly, there are many factors affecting liquefaction. Secondly, the critical conditions of liquefaction can be calculated in artificial experiments. However, the critical conditions of soil liquefaction induced by earthquake disasters are not accurate, that is, earthquake does not necessarily cause soil liquefaction. I will introduce the basic conditions leading to soil liquefaction from both internal and external factors. As shown in Figure 2.

![Fig.2. Internal factors of liquefaction](image)

3.2.1 Internal factors can be regarded as the basis of solid-liquid state transition

First, soil characteristics. Seed draws a conclusion through shear stress experiments. When the relative compactness of soil is less than 70%, the shear stress required for solid-liquid transformation is linearly and positively correlated with the soil compactness [3]. The thicker the soil surface and the more difficult it is to liquefy. It is necessary to accumulate more pore water pressure in the sand to resist the longitudinal stress of the surface soil in order to achieve liquefaction.

Second, water characteristics. The better the permeability of the soil, the more difficult it will be to liquefy. The groundwater level also affects the difficulty of sand blasting. According to Chinese Architectural Design Standard [4], the possibility of liquefaction disaster can be reduced.

| Table 1. Cover thickness and groundwater level limit to prevent soil liquefaction |
|---------------------------------|-------|-------|-------|
| Soil Type | Thickness Type | Numerical Value |
| mixed soil | magnitude (M) | 7 | 8 | 9 |
| overburden (m) | 7 | 8 | 9 |
| water table (m) | 6 | 8 | 9 |
| silt | overburden (m) | 6 | 7 | 8 |
| water table (m) | 5 | 6 | 7 |
Third, stress characteristics. According to the factors of soil quality, water content, temperature, pressure, vegetation and topography, the forms and mechanisms of soil liquefaction are also different, which can be roughly divided into three categories. They are flow slip, sand boiling and circulating flow. Flow-slip refers to the irreversible volume compression of saturated sand under unidirectional shear stress without drainage, which results in the increase of pore water pressure and the decrease of effective stress, and finally the deformation of flow-slip state. Sand boiling refers to the phenomenon of liquid floating when the pore water pressure in saturated sand exceeds the effective stress of overburden. This process is related to osmotic pressure, but has nothing to do with soil density. Soil completely loses its bearing capacity, leading to ground subsidence and great harm. Circulating flow refers to two alternating states of saturated sand under shear stress. When the shear stress level is low, the volume of soil is compressed and liquefaction occurs, while when the shear stress level is high, the volume expands and the shear strength of sand is restored. In combination with earthquake disasters, boiling is more common.

Chengshun Xu Chinese scholar, conducts liquefaction tests of saturated soils under limited conditions by means of dynamic triaxial apparatus[5]. The conclusion is that the pore water pressure and environmental pressure of saturated sand change synchronously with the axial dynamic load after initial liquefaction, and the generalized shear stress and effective average stress remain at the liquefaction stress level. The shear stress produced in the process of vibration represents the magnitude of the force acting in the process of vibration. The larger the shear stress of soil, the stronger the dynamic load of soil liquefaction, the more difficult it is to liquefy.

3.2.2 Earthquake has become the most important external factor of soil liquefaction in natural environment

The first is the selection of evaluation factors of soil liquefaction. As mentioned above, earthquakes do not necessarily cause liquefaction of sand. Solid-liquid transformation occurs only when the magnitude factor index exceeds the critical point. Under the condition that the internal factors of soil are fixed, the greater the dynamic load strength and the longer the duration, the greater the possibility of liquefaction. There are two indexes related to liquefaction of sand caused by dynamic loads caused by earthquakes, vibrant wave type and vibration frequency.

The second is the experimental analysis of evaluation elements. Because the variation of seismic wave is irregular, it is difficult to grasp the influence of seismic wave on soil liquefaction. K. Ishihara and Yasuda [6] used triaxial tests to find that the dynamic load of shock wave is larger than that of vibration wave. Xiaoyun Gu, a Chinese scholar, compared the effects of the frequency of wave and seismic cyclic loads on liquefaction, experimented on indoor soil at the frequency of 0.1Hz-1Hz [7]. It was found that the frequency had little effect on the dynamic characteristics of soil. There is also another point of view. Ying Guo and Lin He[8] carried out triaxial tests under different consolidation ratios, relative densities and confining pressures at frequencies of 0.05Hz-1Hz. They found that soil liquefaction resistance increased with increasing frequency. The cyclic triaxial tests of saturated sandy soils were carried out by using the same consolidation ratio under the frequency of 0.05Hz-2Hz by Tugen Feng and Liming Zhang [9]. They found that the number of vibrations needed for liquefaction increased with the increase of vibration frequency.

4 Conclusion

In this paper, the types and hazards of earthquake liquefaction are introduced firstly, then the mechanism of earthquake liquefaction is analyzed, and the intrinsic and external dynamic factors leading to soil liquefaction are put forward. Based on the dynamic characteristics of earthquake ground motion, two evaluation factors of earthquake liquefaction are proposed. The effect of seismic waveform and frequency on soil liquefaction is clear, but the mechanism of disaster is still controversial. Earthquakes do not necessarily cause soil liquefaction, but the greater the magnitude, the greater the possibility of liquefaction. The index of earthquake liquefaction risk is more conducive to the disaster trend analysis of soil liquefaction risk areas, which is of great significance for earthquake disaster rescue. In the future, mathematical models and evaluation factors will be used to make probability analysis and statistics on the possibility of seismic liquefaction.

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