EARTHQUAKE RESISTANT BASES AND FOUNDATIONS

Kohji Tokimatsu
Tokyo Institute of Technology, Tokyo, Japan

Keywords: Slope failure, debris flow, soil liquefaction, lateral spread, ground motion, base isolation, remedial measures, damage

Contents

Summary

This chapter describes seismic design and remedial measures of foundations, after reviewing earthquake disasters relating geotechnical problems.

1. Introduction

Most of the catastrophic disasters during earthquakes are closely related to dynamic soil behavior including soil amplification characteristics and ground failures. One should consider the effects of soil behavior on the seismic design of structures, if they are founded on soils that are invulnerable to ground problems. This chapter describes seismic design and remedial measures of various foundations, after reviewing earthquake disasters associated with geotechnical problems.

2. Ground Failures Other than Soil Liquefaction

2.1. Slope Failures

Slope failures occur if the driving force to move the soil exceeds the shear strength of the soil to resist it. Prior to an earthquake, the slope maintains its stability, as the soil resistance is generally greater than the driving force. The horizontal acceleration developed in the potentially sliding mass during an earthquake tends to increase driving force and decrease soil resistance, each of which decreases the safety factor against sliding. Slope failures often occur at the following places: (1) steep slopes and unstable slopes with eroded toes, (2) slopes on weak or weathered layers, and (3) artificial filled slopes. The uplift of ground water table also tends to increase driving force and decrease soil resistance, thereby triggering many landslides when an earthquake follows heavy rainfall or melting snow. Slope failures often occur in fills constructed in valleys and streams where the fills are saturated and thus prone to decrease in their strength during earthquakes.

2.2. Debris Flow

Debris flow, or avalanche, is a phenomenon in which a mass of soils containing a large amount of water run rapidly down the mountain torrent as a liquid or slurry. Debris flow is initiated by landslide or slope failure. If the collapsed soil mass contains a large amount of water, it runs down the stream directly. Otherwise, it temporarily dams a stream and, after the collapse of the dam, it turns into debris flow. Debris flow can travel long distance from its source, growing in size as it picks up materials along the way. Debris flow runs at 5-20 m/s, much faster than that of landslide, and thus attacks downstream without a time for evacuation. Depending on the grain sizes involved in the mass, it may be called rock flow or mud flow.

3. Ground Failures Associated with Soil Liquefaction

3.1. Soil Liquefaction

Soil liquefaction is a typical ground problem in alluvial and reclaimed deposits during earthquakes. Liquefied soil becomes a liquid of sand and water mixture that cannot resist shear strength nor support any vertical load, resulting in bearing capacity failure, shear failure, and sliding failures. As a loss of bearing capacity, buildings and other structures founded on saturated sands settled and tilted, as shown in Figure 1. In contrast, buried structures tend to uplift due to increased buoyant forces, as shown in Figure 2, since the unit weight of liquefied soil becomes about twice that of water.

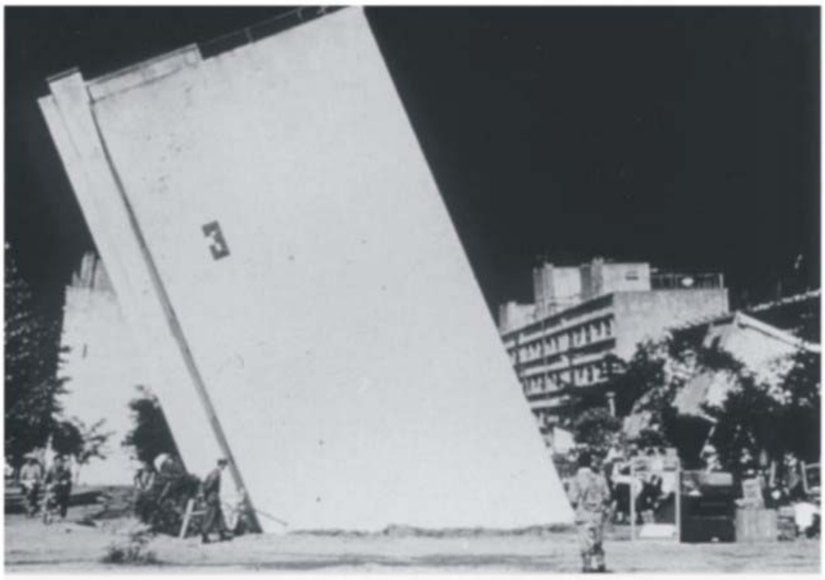

Figure 1. Liquefaction-induced Bearing Failures

Figure 2. Uplift of Underground Structure

Soil liquefaction also occurs in fills under or back of retaining walls, causing them to tilt or slide, as shown in Figure 3. Soil liquefaction can also trigger landslides or slope-failures. Figure 4 shows Lower San Fernando dam that suffered an upstream-underwater slide during the 1971 San Fernando earthquake. Figure 5 shows damage to a town caused by landslide of sandy soils during the 1964 Alaska earthquake. The phenomena shown in Figures 4 and 5 may be regarded as liquefaction-induced lateral spread or flow, as described later in this chapter.

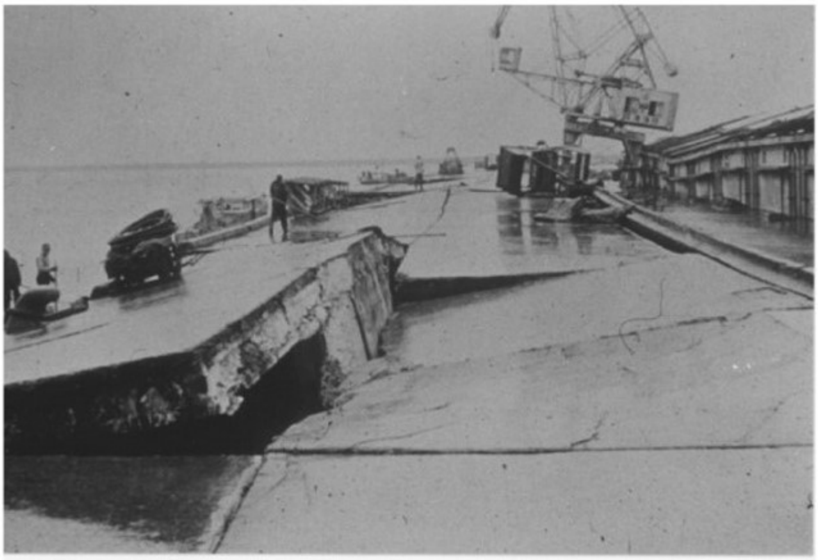

Figure 3. Damage to Port Facilities

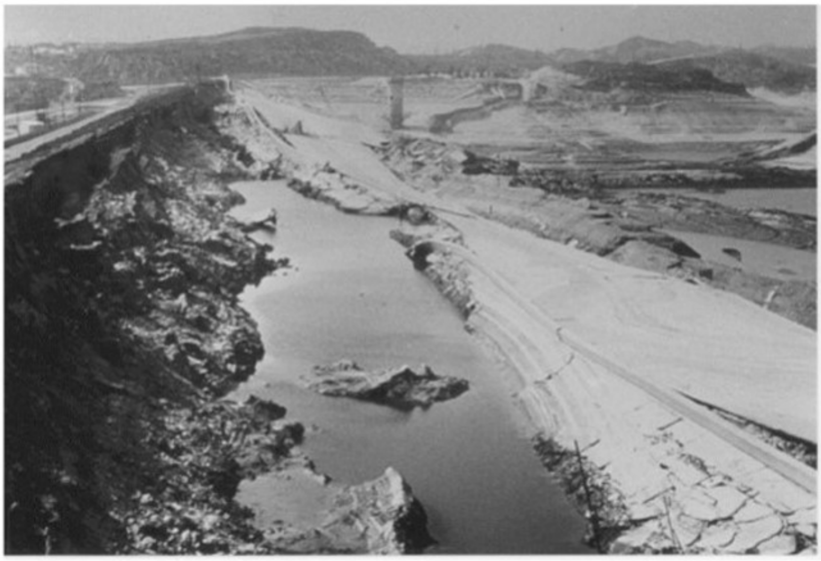

Figure 4. Upstream Slide of the Lower SanFernando Dam (after H. B. Seed)

Figure 5. Landslide at Ternagen Hight (after H. B. Seed)

3.2. Mechanism of Soil Liquefaction

Figure 6 shows schematic behavior of sand grains in a soil deposit during liquefaction. Liquefaction and related phenomena occur in saturated, loose, cohesionless sandy soils, because these three adjectives constitute liquefaction-prone soils. If a loose sandy sand is subjected to ground vibrations, it tends to compact and decrease in volume. The decrease in volume in saturated sand can however be achieved only by the drainage of the equivalent amount of pore water. Since the drainage of pore water is unable to occur completely within a short period of vibration, the tendency to decrease in volume results in the generation of excess pore water pressure, which decreases the effective stresses acting between soil particles. If the excess pore pressure becomes equal to the initial effective stress, namely, the effective stress becomes zero in a cohesionless sand, the sand loses its shear strength and behaves like a liquid.

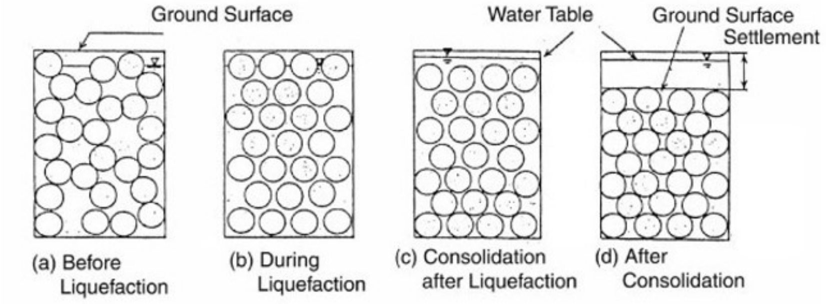

Figure 6. Mechanism of Soil Liquefaction (after Yoshimi, 1991)

The highly pressurized water in the sand spouted out from the ground during and after shaking, inundating the ground surface as shown in Figure 7. With the dissipation of pore water, the effective stresses between particles increase to regain the initial value.

The completion of pore water dissipation results in the settlements of ground surface with crater-like sinkholes, called sand volcanoes such as shown in Figure 8, through which the pore water was expelled with sands.

Figure 7. Ground Inundated with Spouting Sand (Taken by H. Takeuchi)

Figure 8. A Large Sand Volcano

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Biographical Sketch

Kohji Tokimatsu is a professor, Department of Architecture and Building Engineering, Tokyo Institute of Technology. He received a Doctor of Engineering degree in 1979 from Tokyo Institute of Technology. He was a research assistant of the university from 1980-1986, a visiting scholar with Professor H. Bolton Seed, University of California, Berkeley, from 1982-1984, and promoted to an associate professor and a professor of the department in 1986 and 1993, respectively.

Professor Tokimatsu's research has been mainly in geotechnical earthquake engineering with emphases on liquefaction and its remediation, seismic soil-pile-structure interaction, and geophysical exploration using micro-tremors for site characterization. His research has also involved: advanced dynamic testing of soils in the laboratory and in-situ; dynamic full-scale and centrifuge shaking table studies on soil-pile-structure systems; field studies of sites damaged during recent earthquakes; as well as various problems related to building foundation. His major awards include prizes for outstanding technical papers from Japanese Geotechnical Society in 1988 and Architecture Institute of Japan in 2003.