Soil Liquefaction, Large Ground Deformation and Earthquake Resistant Design of Lifelines

by Thomas O'Rourke

Abstract

The U.S.-Japan Research Program on Soil Liquefaction, Large Ground Deformation, and Earthquake Resistant Design of Lifeline Facilities focuses on the earthquake performance of vital systems, such as water supply, transportation, gas and liquid fuel, telecommunications, electric power, and wastewater conveyance and treatment. Emphasis is placed on liquefaction-induced soil movements and their effects on lifelines. There is recognition in the civil and earthquake engineering communities of the importance of large ground deformations, yet our understanding of the mechanisms of movement and our ability to predict magnitude and distribution of displacements are limited and in need of substantial improvement. Permanent ground movements are known to have been the most troublesome source of subsurface structural damage during previous earthquakes. Both U.S. and Japanese researchers have coordinated their efforts to collect case history data and recommend analytical and design methods on the basis of a careful data review.

The program was initiated formally in November, 1988 with the signing of a Memorandum of Understanding between the Japanese and United States sides. The document was signed at a ceremony during a workshop in Tokyo, Japan by K. Kubo, Professor Emeritus of Tokyo University, and M. Shinozuka, Sollenberger Professor of Civil Engineering of Princeton University. Professor Kubo signed on behalf of the Association or the Development of Earthquake Prediction (ADEP), the Japanese sponsoring agency. Professor Shinozuka signed on behalf of Robert L. Ketter, then Director of the National Center for Earthquake Engineering Research (NCEER), the U.S. sponsoring agency. A second Memorandum of Understanding was signed in December, 1990 to continue the cooperative program of research. The signatures were K. Kubo, representing ADEP, and M. Shinozuka, the Director of NCEER.

The products of the research include case history volumes with assessments of the most important geologic features, siting criteria, and structural characteristics which have influenced previous lifeline performance in response to soil displacements; U.S.-Japan workshops and associated publications covering case history data, analytical modeling, and improved practices; recommendations for improved modeling, siting, earthquake resistant design, and construction of buried structures; and countermeasures against soil liquefaction.

Major instruments for collaboration and cooperative exchange are program workshops. To date, there have been five workshops, held in the United States and Japan. Published proceedings of the workshops provide for a state-of-the-art assessment of the technology pertaining to large ground deformation and lifelines.

Collaboration

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In total, 27 U.S. and 38 Japanese universities, governmental agencies, utility companies, and engineering and construction firms have been involved in the research program.

Objectives and Approach

U.S.-Japan research on soil liquefaction, large ground deformation and the earthquake resistant design of lifeline facilities is being performed to accomplish four major objectives. The first is to develop comprehensive case histories of liquefaction and large ground deformation and their effects on lifelines and deep foundations in response to U.S. and Japanese earthquakes. The second is to develop analytical and physical modeling procedures to quantify the mechanisms of liquefaction-induced ground deformation and soil-structure interaction under large soil displacements. The third is to develop improved methods of siting, earthquake resistant design, and retrofitting of lifelines to reduce damage from liquefaction-induced ground displacement. Finally, the fourth is to develop and improve countermeasures against soil liquefaction.

The approach to this research involves detailed collection and synthesis of data from a variety of sources to produce each case history. Research to meet project objectives has made use of archival investigations, laboratory testing of soil samples, centrifuge studies, photogrametric analyses, theoretical derivations, and computer modeling.

This research task is part of NCEER's Lifeline Project. Task numbers are 86-5012, 87-5001, 88-3014, 88-6009B, 89-3008, 90-3008, 90-6003, 90-6012, 91-2341, 92-2302, 93-2304A and 93-2701.

Accomplishments

The study of lifeline performance and large ground deformation should be viewed as a logical extension of research and practice-oriented developments associated with soil liquefaction and with the emergence of lifeline earthquake engineering. U.S.-Japan cooperative research has helped to promote and consolidate this merger of lifeline and geotechnical interests, and has led to improved engineering practices.

The research effort has concentrated on case histories because they represent the only real basis for assessing the effects of an earthquake and for establishing a baseline of performance with which to verify analytical and physical models, develop design procedures, and guide the planning and siting of future facilities. Case histories are also of great value in developing countermeasures against liquefaction, such as site improvement and retrofitting procedures for existing lifelines.

Earthquakes were chosen for case history study on the basis of three principal factors. First, there needed to be accurate records of permanent ground deformation, sufficient in detail to evaluate the magnitude, direction, and areal distribution of soil movements. Second, substantial soil explorations were required to provide a reliable view of subsurface conditions and soil properties at the locations of large ground deformation. Third, accurate records were required of ground movement effects on lifeline facilities.

Comprehensive case histories were developed for five U.S. and five Japanese earthquakes, and published by NCEER in two volumes. The U.S. case histories include the 1906 San Francisco; 1964 Alaska; 1971 San Fernando; 1979, 1981, and 1987 Imperial Valley; and 1989 Loma Prieta earthquakes. The Japanese case histories involve the 1923 Kanto, 1948 Fukui, 1964 Niigata, 1983 Nihonkai-Chubu, and 1990 Luzon, Philippines earthquakes. Work is in progress to develop case histories for the 1993 Kuchiro, 1993 Hokaido Nansai-oki, and 1994 Northridge earthquakes.