04 Jun 1993, 8:00 am - 10:00 am

General Report Session No. 14: Geotechnical Aspects of Recent Earthquakes

Ahmed-W. Elgamal
Rensselaer Polytechnic Institute, Troy, New York

G. L. Hempen
U.S. Army Corps of Engineers, Geotechnical Branch, St. Louis, Missouri

Recommended Citation

Elgamal, Ahmed-W. and Hempen, G. L., "General Report Session No. 14: Geotechnical Aspects of Recent Earthquakes" (1993). *International Conference on Case Histories in Geotechnical Engineering*. 3.
https://scholarsmine.mst.edu/icchge/3icchge/3icchge-session14/3

Proceedings: Third International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, June 1-4, 1993, General Report Session No. XIV

Geotechnical Aspects of Recent Earthquakes

Ahmed-W. Elgamal
Civil & Environmental Engineering Department, Rensselaer
Polytechnic Institute, Troy, New York

G. L. Hempen
U.S. Army Corps of Engineers, Geotechnical Branch, St. Louis,
Missouri

CLASSIFICATION OF PAPERS

The fourteen papers of this session discuss earthquakes in North America (8 papers), Central America (1 paper), South America (1 paper), Asia (2 papers), and Africa (2 papers). Topics covered may be classified as follows:

SOIL LIQUEFACTION	
Earthquake Reconnaisance	Papers 8, 12, 18, 19
Computational Analyses	14, 26
Remedial Measures	5
Risk Assessment	21
SITE RESPONSE ANALYSES	
Observational	23
Computational	7, 17
SOIL-STRUCTURE INTERACTION	
Foundation Failures	13
Building Response	24
SLOPE STABILITY	10

SOIL LIQUEFACTION

Earthquake Reconnaisance

Green and Sawyer submitted paper 14.08, "Geotechnical Aspects of the Petrolia Earthquake." The earthquake ($M_S = 6.9$, $M_L = 6.4$) occurred on April 25, 1992 along the Lost Coast of Northern California where the Pacific, North American and the much smaller Gorda plates converge. Peak acceleration at the Cape Mendocino strong motion accelerograph were in excess of 1.5 g (currently being verified for accuracy). Other large peak ground accelerations were recorded at Petrolia (0.69 g), and Rio Dell (0.55 g) during the main shock. The road from Ferndale to Petrolia was closed for 8 days due to numerous (mostly minor) landslides.

Liquefaction appeared to be confined within an old channel along Riverside Road which runs parallel to the Salt River. The ejected silty sand (48% passing sieve No. 200) was very fine grained and produced many sand boils along a three to four mile stretch of the road. Most of the damage to structures was associated with buildings that were knocked off their foundations due to inadequate lateral resistance between the foundation and the first floor. Seismic upgrades of existing older residential structures in Northern California, Oregon, and Washington, are needed in the event of a similar future earthquake.

Yasuda, Watanabe, Yoshida and Mora C. submitted paper 14.12, "Soil Liquefaction During the 1991 Telire–Limon, Costa Rica, Earthquake." The April 22, 1991 Telire–Limon Earthquake of magnitude 7.5 caused significant damage in Costa Rica and Panama. Soil liquefaction occurred widely in the low lying area in Eastern Costa Rica, which caused severe damage to embankments, bridges, and houses. The liquefied sites were classified into three categories: 1) inland areas along rivers, 2) sand bars along beaches, and 3) coastal areas along rivers. In the inland area, a main road was severely damaged due to liquefaction, causing fissures (parallel to the road) and lateral spreading. At coastal areas along the rivers, three bridges were severely damaged due to liquefaction, which resulted in large lateral and vertical displacement of the supporting piers and abutments. Landslides occurred in the areas North from the epicenter for about 2,000 km^2.

The Rio Vizcaya bridge and the Rio Bananito bridge collapsed completely. At these sites, the ground at one riverbank or both riverbanks liquefied down to the depth of the pile tip or more, and flowed laterally towards the river center, pushing and/or sweeping off abutments and causing complete collapse of the supported bridge span.

Elgamal, Amer and Adalier submitted paper 14.18, "Liquefaction During the October 12, 1992 Egyptian Dahshure Earthquake." This moderate earthquake $M_B - 5.9$ ($M_S = 5.2$) occurred about 18 km southwest of the center of Cairo and resulted in significant damage to numerous poorly constructed structures. Soil liquefaction associated with the occurrence of large sand–boils was observed close to the epicenter. As a consequence, a main road suffered a maximum settlement of about 1.75 m. In this study, the earthquake characteristics, soil profiles and resulting liquefaction are discussed. The liquefied soil profiles might bear significant similarity to large areas along the densely populated Nile Valley and Delta. Consequently, this liquefaction case history is of particular importance, and might be representative of the seismic response of vast areas along the Nile Valley. A thorough analysis of this case history would establish a valuable benchmark for liquefaction susceptibility analyses of Nile sedimented soils throughout its valley.

Gupta submitted paper 14.19, "Liquefaction During 1988 Earthquakes and a Case Study." Liquefaction effects from two, 6–magnitude earthquakes were evaluated by the author. The first event ($M = 6.8$) was the August 6, 1988 earthquake in India (the same event of paper 14.10 by **Lavania, et**

al.). Widespread liquefaction in the Assam area of India occurred due to this earthquake causing damage to roads, bridge abutments, and buildings. In the Assam area, an approach road embankment for a bridge across the Brahmaputra River was designed to resist liquefaction with the aid of a draining soil surcharge (5 m high). Design of this liquefaction-countermeasure was based on a method developed by **Prakash and Gupta** using laboratory and shake table test data. The designed embankment was found to have performed satisfactorily during the August 6, 1988 earthquake.

The second earthquake ($M = 6.6$) of August 21, 1988 occurred on the Bihar Nipal border. Extensive damage to lifelines and buildings occurred due to liquefaction, as described in this paper.

Computational Analyses

Inel, Roth and de Rubertis submitted paper 14.14, "Nonlinear Dynamic Effective-Stress Analysis of Two Case Histories." Two case histories were analyzed to determine the validity of using nonlinear numerical analysis methods together with simple and familiar descriptions of soil behavior, in order to predict shaking-induced excess pore pressures and permanent deformations within soil. The first case focused on the prediction of liquefaction during centrifuge testing of a silt layer underlain by sand. A model was studied that corresponds to 3 m thick layers of sand and silt in prototype scale. There was large scatter in the centrifuge test results, and the predicted response lies well within this range.

The second case involves the prediction of behavior of the Upper San Fernando Dam during the 1971 San Fernando earthquake. A modified form of the Pacoima Dam record was used as input excitation. The numerical predictions agreed well with the observed crest settlement of 3 feet, and the 2 foot pressure ridge observed at the downstream toe. However, the results do not agree with the observed horizontal shifting of the crest in the downstream direction. The employed computational techniques should be used to investigate additional documented response of other case histories before being generally employed as a reliable predictive tool.

Finn, Wu and Ventura have submitted paper 14.26, "Preliminary Studies of Ground Motions at Treasure Island and Yerba Buena Sites During the 1989 Loma Prieta Earthquake." They conducted dynamic response analyses at the Treasure Island Site using the nonlinear dynamic effective stress computational model "DESRA-2." Rock acceleration records at nearby Yerba Buena Island were used as input motions. Porewater pressure model parameters for DESRA-2 were calibrated to match the onset of liquefaction as noted from the available surface acceleration records. The results of the conducted numerical analyses were in good agreement with the recorded Treasure Island acceleration response.

In certain period ranges, there were some differences between recorded and computed response in the N-S direction. A coherence study showed that there are several frequency ranges (up to 1.25 Hz) of low coherence between the motions recorded at Yerba Buena (recorded input) and Treasure Island (recorded output). In these ranges, it will not be possible to obtain a good simulation between recorded input and output motions.

Remedial Measures

Sobol, Baez and Swekosky submitted paper 14.05, "Liquefaction Risk Mitigation — Manchester Airport." A densification program of loose sandy soil by Vibroflotation was designed and constructed to mitigate the risk of seismically-induced liquefaction for a proposed 15,000 square meter terminal building. Design phase borings at the Manchester (NH) Airport revealed a subsurface profile of delta-deposited clean uniformly graded saturated fine to medium sands of loose relative density from depths of 3.7 to 13.7 m. Vibroflotation was used for in-situ densification of the loose sands. The vibrator is inserted into the ground to the maximum depth requiring densification and the soil is compacted in lifts from the bottom up. More than 2,600 compaction centers were installed (2-3 m grid spacing) to 8 m - 11 m depths.

Comparison of pre- and post-vibro SPT revealed strong evidence that relative densities were significantly increased in sands and nonplastic silts throughout, and up to 2 m below, the treatment depth.

Quality Assurance programs are extremely important to document the success of the densification scheme. As performed in this study, Standard Penetration Tests demonstrated that the densification criteria have been met.

Risk Assessment

Candia-Gallegos, Sprenke and Perez have developed paper 14.21, "Geotechnical Aspects on Seismic Risk Assessment in Cusco, Peru." A seismic risk analysis of Cusco, a very old Peruvian town in a highly seismic region, was undertaken. The geology and seismic history of the area were investigated. Eight major earthquake events were reported to have occurred in Cusco since 1650. Based on geology and documented seismically induced damage and ground failure, a map of probabilistic accelerations for the region was proposed. An extensive inventory of structures and an approximate evaluation of their natural frequency ranges allowed a damage model to be developed.

The Cusco area was devided into four zones of seismic risk hazard. Locations of potential seismically-induced mud flows, slope failures, liquefaction, and significant reduction of soil strength were identified. The paper presents the results of a significant effort towards an accurate seismic microzonation of Cusco, Peru.

SITE RESPONSE ANALYSES

Observational

Ovando, Romo and Diaz have written paper 14.23, "Ground Movements in Mexico City During Recent Earthquakes." It was noted that, at the time of the 1985 earthquake, there were eleven operational accelerographic stations in Mexico City. By the end of 1987 there were 40 new accelerographic stations, and in 1988, about the same amount was added. Recent additions to the network include stations installed inside buildings as well as within boreholes, at different depths.

On February 8, 1988 and on April 25, 1989, two earthquakes having surface wave magnitudes of 5.4 and 6.8, respectively, were recorded by the etwork. In the February 8, 1988 event, the picenter was located 290 km Southwest of Mexico ity, whereas in the April 25, 1989 event the picenter was sited some 400 km South of it. In the wo earthquakes analyzed, the zones of maximum ntensity (in Mexico City) were roughly the same and oincided with the zones which had repeatedly ndergone significant damage during past large vents.

A small tremor also shook Mexico City in May of 990. For the May 1990 event, the authors analyzed he movements recorded in Mexico City at the base of eformable soils at three downhole–surface tations. Overall, it can be concluded that the ovements at the base of the three stations are airly uniform, i.e., that the uniform motion ssumption at the base of the compressible strata is ot far fetched for most practical applications. his assertion must be verified in future events. verage shear wave velocities obtained from cross orrelation functions yielded reasonable values.

omputational

S. J. Serhan submitted paper 14.07, "Response nalyses of Recorded Earthquake Motions." In this aper, computational response analyses of three ecorded earthquakes at nuclear power plant acilities were reported. Acceleration records ere available inside the buildings and at a nearby ree–field ground motion station. Peak recorded trong motion at the soil surface was 0.53 g. Two– nd three–dimensional models for the soil/ tructure system have been developed using the inite–element substructuring method.

Soil nonlinearity, material damping, groundwater able, structural embedment, and structure/ tructure interaction were investigated. However, o data concerning the above analyses was reported in this short paper. In addition, the results were ot shown. This paper should be extended in order to resent the conducted analyses and the computed results. While the topic of investigation is of importance, the paper in its current form is ssentially only a brief summary of conclusions.

Sun, Chang, Bray and Mejia submitted paper 14.17, "Damage Patterns/Response of Deep Stiff Clay In Oakland." During the 1989 Loma Prieta earthquake, ground accelerations in the downtown Oakland area (0.08 g – 0.1 g) were amplified by a factor of 2 to 4 and a significant number of structures were heavily damaged, depsite the fact that much of the area was underlain by deposits of deep stiff clay. Recorded accelerations at Oakland were as high as 0.29 g while nearby rock accelerations reached a maximum of 0.13 g.

A preliminary one–dimensional site response analysis was performed based on subsurface soil information obtained from a recent field investigation program. The nonlinear, strain–dependent moduli and damping relationships for the cohesive materials were selected based on their Plasticity Index. For the sandy materials, the relationships proposed by Seed, et al. were used. The program SHAKE91 was used to perform site response analysis, and was able to capture the tendency of this deep stiff clay site to amplify motions (in accordance with the observed response).

The response at Oakland thus appears to be significantly underestimated by the 1991 Uniform Building Code. For the Oakland area, the general East Bay region, and at other similar deep stiff clay sites, continued use of the UBC site factor appears to result in significant underestimation of seismic hazard.

SOIL–STRUCTURE INTERACTION

Foundation Failures

Marino submitted paper 14.13, "Response of House Foundations During the 1989 Loma Prieta, California Earthquake." In this paper, the author reviews the foundation failure conditions of residential structures. Various types of foundation failures were related to ground modes of seismic response such as: inertial horizontal shaking, faulting and deposit spreading at ridges, landslides, non–uniform fill conditions, soil densification, and liquefaction.

This paper is useful in that it documents failures for given site conditions and foundation types. The reported data can be used in decisions for strengthening current structures, and for better foundation choices in new residences. This paper is informative and useful for seismic hazard assessments of light frame structures with comparable site conditions.

Building Response

El–Sohby, Bahr and Riyad submitted paper 14.24, "Some Aspects on the Faiyum–Egypt Earthquake of October 12, 1992." The paper describes the behavior of two identical residential buildings constructed on two sites of different soil conditions in the City of Faiyum. The first lies in the Western side of Faiyum and consists of alluvial deposits of clayey layers followed by sandy layers. The Eastern site (25 km closer to the epicenter) is a hilly area consisting of diluvial layers of weak limestones (second site).

The buildings investigated in this study were of reinforced concrete skeleton type, consisting of 5 stories and supported by a system of shallow foundation of isolated footings. The Eastern site building was severely damaged as compared with that of the Western site partially due to: i) distance from epicenter, and ii) local site conditions. The paper only focussed on the role of site conditions in dictating the observed structural damage.

SLOPE STABILITY

Lavania, Pandey, Singh and Singhal submitted paper 14.10, "Design of Safe Slopes After Failure During an Earthquake." Four slope failures are investigated at a hilltop industrial complex. The failures resulted from the August 6, 1988 Earthquake (M = 6.8) in the north–east region of India. Initial soil testing analyses in the 1970's were compared to 1989 soil tests. Considerable unresolved variation of soil parameters led to an attempt to analyze the seismically–induced slope failures by conducting an analytical parametric investigation. Both pseudo–static slip circle procedures and Finite Element Methods were used to match the known failure surfaces of the site by varying the soil cohesion (c), and friction angle (ϕ). Based on the back–figured c and ϕ values, a safe slope design was recommended for this site (e.g., 5 horizontal on 1 vertical).

This paper provides a methodology based on observed seismic slope failure to achieve a satisfactory slope-stability engineering solution. The adopted approach is original in that the employed soil properties were obtained from analyses of observed slope failures.