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CONSIDERATIONS ON THE GEOTECHNICAL BEHAVIOR OF STRUCTURES DURING EARTHQUAKES

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ABSTRACT

In this paper a brief description of the activities of TC4 "Earthquake Geotechnical Engineering" is given. The characteristics of Northridge and Kobe Earthquakes are described. A summary of each paper for this STS is given. Finally some remarks and topics for discussion are presented.

KEYWORDS

Earthquake Geotechnical Engineering; Northridge and Kobe Earthquakes; Topics for Discussion.

INTRODUCTION

The activities of Technical Committee n°4 (TC4) Earthquake Geotechnical Engineering are summarized. The characteristics of Northridge and Kobe earthquakes are described.

A summary of each paper for this Special Technical Session is given.

Some questions that deserve further discussion are presented.

ACTIVITIES OF TC4 "EARTHQUAKE GEOTECHNICAL ENGINEERING"

We have had a large number of earthquakes throughout the world in the last decade. These include the Mexico city earthquake, 1985, Arménia earthquake, 1988, Loma Prieta earthquake, 1989, Philippines earthquake 1990, Manjil earthquake, 1990, Teleri-Limon earthquake, 1991, Erzican earthquake, 1992, Latur earthquake, 1993, Northridge earthquake, 1994 and Kobe earthquake, 1995, to name a few.

The geotechnical engineering problems caused by these earthquakes have been a motif of concern and a great challenge for the search of new solutions.

The Technical Committee n° 4 (TC4) Earthquake Geotechnical Engineering under the auspices of ISSMFE has begun its activity in 1985 and during the last two tenues 1985-1989 and 1989-1993 has developed its activities under the leadership of Prof. Kenji Ishihara.

The very successful activity of TC4 during this period includes the publication of the following special volumes and manual:

- Earthquake Geotechnical Engineering (1989)
- Performance of Ground and Soil Structures during Earthquakes (1993)
- Manual for Zonation of Seismic Geotechnical Hazards (1993).

For the period 1993-1997 the main activities of TC4, under the leadership of Dr. Pedro Sêco e Pinto are related with the application of "Manual for Zonation on Seismic Geotechnical Hazards" and "Application of Eurocode 8", and the organization of conferences and several symposia.

Related with cooperation and exchange of information the Manual for Zonation in Seismic Geotechnical Hazards has been divulged in the following events:

- 3rd National Earthquake Engineering Conference, Turkey
- Short Course on Geotechnical Aspects of Earthquake Engineering Pile Dynamics, in Bangkok
- 2nd Coloquio International about seismic Microzonation, in Venezuela
- 5th International Conference on Seismic Zonation, in Nice.

The First International Conference on Earthquake Geotechnical Engineering held in November 1995, in Tokyo, organized by the Japanese Geotechnical Society was an excellent Conference and gave the international forum the opportunity to exchange our ideas on this stimulating and challenging topic.

The Second International Conference on Earthquake Geotechnical Engineering will take place on June 1999, in Lisboa, organized by the Portuguese Geotechnical Society.

Following the Terms of Reference of TC4 it is important to continue liaison with the International Association for Earthquake Engineering.

With this in mind this Special Technical Session was organized.

On behalf of TC4 I would like to express my deep thanks to the Steering Committee of XI World Earthquake Conference for giving us this opportunity to organize this Special Technical Session intitled "Lessons learned from Northridge and Kobe Earthquakes".

CHARACTERISTICS OF NORTHRIDGE AND KOBE EARTHQUAKES

The Northridge Earthquake occurred at 4.31 AM (PST), on January 17, 1994, with a moment magnitude of 6.7. The main release occurred on an unmapped blind thrust fault, which dips to the south under the San Fernando Valley.

Recorded motions indicate that the duration of strong shaking (acceleration values > 0.05 g) ranged from about 5 to 15 seconds.

The coordinates of the hypocenter at 14 km depth are 34° 13' N and 118° 32' W.

The strong-motion records have shown very high peak acceleration and long-duration pulses (varying between 1-4 sec.)

These long duration pulses have produced large velocities and consequently have transmitted significant percentage of their energy within the duration of the pulses.

The Great Hanshin Earthquake (Kobe Earthquake) occurred at 5.46 AM, on January 17, 1995, with a moment magnitude of 7.2.

The coordinates of the hypocentre at 14 km depth are 34° 36' N (latitude) and 135° E (longitude). Recorded motions indicate that the duration of strong motions ranged from about 8 to 12 seconds.

The acceleration time-history indicates NS component of 818 gal and an EW component of 617 gal, implying a significantly large horizontal acceleration. The vertical acceleration component is likely large at 332 gal.

PAPERS FOR THIS STS

For this STS the following written contributions were presented:

For Northridge Earthquake

Celebi pointed out that the Northridge earthquake generated motions with large peak (horizontal and vertical) accelerations, exceeding or close to 1g at many sites, attributable mainly to the thrust faulting.
Aftershocks records show that there are significant local (geological and/or topographical) effects.

The author concludes that Northridge earthquake ground motions are unique and have significant engineering implications.

Vucetic et al. developed a 3D data base for a region of Los Angeles using a Geographic Information System (GIS) software called "Techbase".

The parameters and information incorporated into the geotechnical data base include soil stratification, soil classification properties, standard penetration test profile, shear wave velocity profile, ground water table and estimated both to "baserock" or stiff deposit. This information will allow: (i) to make comparisons with other information from digitized maps and (ii) estimate input parameters for 1D non-linear analyses to understand, analyze and forecast earthquake damages and corresponding social impacts.

The comparison of the results with earthquake damages has shown future potential of the data base and GIS.

Prakash and Wu developed design charts for rigid retaining walls considering both sliding and rocking displacements. Soil nonlinearity and frequency dependent stiffness and radiation damping of the base soil and backfill have been considered.

From the comparison of observed behavior during Northridge, Kobe and other recent earthquakes with predicted performance the authors have concluded that the method is promising in predicting both displacements and failure of rigid retaining walls.

For Kobe Earthquake

Iwasaki describes the characteristics of the strong ground motion during the Kobe earthquake.

The attenuation of the horizontal maximum accelerations correspond well with the experimental attenuation relation.

The author points the effect directivity which is caused by the energy concentration towards the rupture propagation.

It was recognised that the vertical motion is comparatively larger than the past records and was caused by SV-wave and also by the large amplification ratio given by surface layer structure.

For the weak motions it was observed a deamplification due to non-linear soil characteristics and for strong motions the accelerations of soil ground surface were amplified by a factor of two to three.

The damage distribution was different for various ground conditions and decreases with distance away from the fault.

Ishihara and Yasuda analyzed liquefaction induced ground failures assuming the soil strength from cyclic triaxial tests and back calculation analyses based on records acceleration on the ground surface.

The observed settlements are compared with the procedures developed for estimating ground settlements resulting from liquefaction proposed by several researchers. Nevertheless this comparison has shown values of the same order the authors point the need of extending the use of clean sands to gravel silty sands that occur in the Kobe area affected by earthquake. The authors have shown that lateral displacement decreases with increasing distance from the waterfront, but evidences were found 150 m backward from the revetment line.

Yanagisawa and Kazama using the records observed by the vertical array have estimated average stress-strain relationship in the ground at Kobe Port Island. The stress was directly evaluated from earthquake acceleration records. The strain was evaluated from the relative displacement divided by the distance between adjacent observation points.

The hysteretic deformations properties were analyzed from softening of the ground stiffness during the earthquake, liquefaction process during the main shock and the aftershocks. The damping ratio evaluated from relatively obvious loops show the values about 20% to 35%.

Yoshida and Wakamura analyzed the Daikai subway station which is the first subway structure that completely collapsed due to an earthquake.

Dynamic response analysis of soil-structure system was conducted using two dimensional finite element method considering non linearity of soil by equivalent linear method.

The analytical code Super-Flush was used assuming converged non-linear characteristics under both horizontal and vertical input motion to analyse the mechanism of the collapse of the station.

FINAL REMARKS AND TOPICS FOR DISCUSSION

These written contributions have covered several areas of geotechnical earthquake engineering e.g. ground motions, soil amplification, laboratory and field techniques, liquefaction, retaining structures and underground structures.

The limitations of space have not allowed the inclusion of other topics such as slopes, embankment dams, soil structures interaction and lifelines.

In spite of the impressive advances made in the mentioned fields we feel that several questions still remain without a definitive answer.

Some questions that deserve further discussion are outlined below.

The purpose is to establish a systematic communication between the delegates of this Conference in order to create a dialogue between everyone.

Ground Motions

1) - Unusually large number of pulses with very high peak acceleration values in the two horizontal directions and in the vertical direction (higher than 1.0 g) can be attributed to topographic effects. As this effect plays a significant role in contributing to the failure of structures it seems that these effects need further investigation.

2) - There is a need to identify and characterize the seismically active blind thrusts faults. Can the geophysical and geodetic techniques be efficient to locate them?

3) - Several attenuation relationship e.g. Joyner and Boore (1988), Idriss (1991), Sadigh et al. (1993), Abrahanson and Silva (1993) are used to predict peak acceleration values. How reliable are they?

4) - Amplification of long period motions at sites underlain by soft and/or deep soil deposits has deserved recently more consideration. As these local effects play an important role are further improvements of building codes not necessary?

5) - How should the directivity effects be characterized?

6) - The downhole seismic arrays are useful to: (i)understand the seismic ground response; (ii) the source for refining and calibrate experimental and computational procedures; and (iii) to characterize the behavior of seismic wave fields to attenuation of earthquake induced ground motions.

Are they a sufficient powerful tool to point the conditions under which 1D site response modelling is sufficient and conditions under which more complicated models 2D and 3D and non-linear models are required?

Liquefaction

1) - The assessment of liquefaction induced deformations has become an important issue in evaluating seismic risks of structures and underground structures. Two approaches were proposed: (i) relationship between cyclic stress ratio, SPT tests and volumetric strain; (ii) correlating the post-liquefaction volumetric strain with maximum shear strain for different values of relative density. What are the reliability of these approaches?

2) - The determination of the loss of strength of soils i.e. the residual strength is important for the assessment of lateral flow of sand deposits.

Correlations between SPT and CPT values with residual strength were proposed. Which correlation is more efficient?

3) - In order to assess the liquefaction of gravel material should the correlation between BHT-SPT and the use of shear wave velocity be encouraged?

4) Are the centrifuge tests efficient to calibrate constitutive models that include simulation of generation and dissipation of excess pore water pressure during cyclic loading and to assume non-linear elastic or plastic behavior for the material?

5) - Efforts to improve design practice in liquefaction remediation using deep mixing method, sheet piles and gravel compaction piles are getting more popular. How efficient are they?

Retaining walls

1) - For rigid nonsliding wall the dynamic increment of pressure is higher in magnitude and position than the distribution given by Monnobe-Okabe method. The elastic approach is straightforward. To overcome this situation the computed dynamic correction increment for the rigid wall is added to the free-field distribution. How satisfactory is this procedure?

2) - Flexible nonsliding walls develop plastic hinge lines during earthquakes. The movement of the wall will reduce the seismic pressure distribution from the maximum rigid distribution to the minimum free-field. How reliable is the general procedure that considers a hinge at the base of a non-sliding wall?

3) - For walls that will slide at the base the elastic solution will not be accurate as plastic shear flow occurs with subsequent redistribution of the stress field. Two methods have been used to deal with this complex problem. The first one uses a finite element model and incorporates a non linear behavior for material associated with a strength degradation. The second one considers base sliding and rotation, combining the Coulomb failure wedges with the Newmark sliding block to calculate the displacement.

While the magnitude of the seismic thrust on walls which move enough to develop a failure mechanism can be determined with sufficient accuracy from the equilibrium equations the position of this seismic force still remains an open question.

Embankment Dams and Slopes

1) - The seismic response of dams has been analysed considering synchronous (in phase) oscillations to provide the excitation. However seismic shaking is the result of a multitude of body and surface waves with resulting oscillations that differ a phase and amplitude from point to point along the dam-valley interface. Is it important to analyse the response of a canyon to incident SH waves impinging at different angles in the vertical plane of the dam axis?

2) - The hydrodynamic effects of the reservoir water upon concrete face rockfill dams have received more attention as these dams have slopes 1 (V): 1.3 (H) and water pressures are applied directly to the concrete facing, concentrating the loads in that area (Bureau et al., 1985).

The more effective approach is to treat the dam-water system as composed of two substructures: dam and fluid domain coupled through the interaction forces and appropriate continuity conditions at the face of the dam. Two formulations can be used: Westergaard method and Galerkin method (Sêco e Pinto, 1993). What will be the adequate procedure to deal with this subject?

3) - What time-acceleration data should be used in estimating permanent deformations of an embankment dam using Newmark procedure. Since the acceleration response varies throughout the embankment the engineering practice in the selection and use of time-acceleration data is not consistent.

Soil Structure Interaction

1) Spatial arrays have been used in the vicinity of a building or bridge to study free-field motions and how these motions are altered by interaction with the foundation of a building structure or bridge.

Ratio of peak acceleration recorded at the foundation building and the free field is always less than 1. The opposite seems to have been the case in some bridges.
It seems that more comprehensive and systematic studies are needed related with soil-structure interaction to clarify this question.

2) - It is important to check the accuracy of numerical prediction of the amount of translations, torsional and rocking motions of the foundation and structure.

Are superstructure and foundation instrumentation such as accelerometers, sensors connected to digital records efficient to reach these purposes?

FINAL COMMENT

The occurrence of past earthquakes with particular reference with Northridge and Kobe earthquakes, where major tragedies have occurred, will provide the engineering profession with a number of valuable lessons and opportunities for research and they will have inevitably a great impact in the future studies of structures in order to design and built them more safe and economical.

It may be anticipated that further improvements in seismic building codes related with local effects and refinement and verification of analytical techniques will develop from the lessons learned from these two earthquakes.

The floor discussions that we hope lively will give us the unique opportunity to share our experiences and will also contribute to the advancement of the knowledge.

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