US-JAPAN WORKSHOP ON GEOTECHNICAL ASPECTS OF RECENT EARTHQUAKES

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SUMMARY

The US–Japan Workshop on Geotechnical Aspects of Recent Earthquakes was held at the Kansai Kenshu Centre, Osaka, Japan on 22–24 January 1996. The objectives of the workshop were to summarise lessons learned from the Loma Prieta, Northridge, and Kobe earthquakes, to identify ongoing research needs, to summarise available data, and to identify areas of possible co-operation for future research.

The society was invited to send a representative from New Zealand with observer status provided that person present a report summarising current and ongoing research on geotechnical earthquake engineering within New Zealand. The author was selected to be the New Zealand observer and the summary report accompanies this article.

Thirty two participants attended from the US and thirty from Japan including most of the well known, active researchers from the two countries. A complete list of participants is given in Appendix A.

The draft workshop report, with contributions from many of the participants, is summarised below. A full copy of the report is held by the author.

1. GEOLOGIC AND SEISMOLOGIC ASPECTS OF EARTHQUAKE GROUND MOTIONS

a) Rupture directivity effects.

These recent earthquakes have provided a large number of additional near-fault recordings, including the largest peak velocities (175 cm/s) recorded to date. The rupture directivity effect was in evidence with most of the seismic energy arriving in a single large pulse of motion at the beginning of the record. An important opportunity has been provided to test computational procedures for predicting near-fault strong motions. The need to calibrate seismological models against all available near-fault recordings of large earthquakes was identified.

b) Basin response.

The long period ground motions recorded in the San Fernando and Los Angeles basins during the Northridge earthquake are compatible with our understanding of basin response. The overall character of the strong ground motions recorded in the West Los Angeles region has been modelled adequately for periods longer than one second using two dimensional models of geological structure. The effects of basin structure on prolonging the duration of ground motion are clearly evident in the recordings of the Kobe earthquake in Osaka prefecture. Synthetic seismograms computed using three dimensional basin structure as input matched actual records much better than computations with either one- or two-dimensional models. Basin response was important for both the Northridge and Kobe earthquakes and the available strong motion recordings provide an important opportunity to develop and test methods for predicting the ground motion response of sedimentary basins.

c) Causes of local site amplification and local zones of damage

The Loma Prieta earthquake provided a relatively large set of data for testing methods for predicting site response, both in the near field region and at large distances. In most cases it was found that simple one-dimensional models of shallow geologic structure gave satisfactory predictions of recorded amplification. The main exception was the Marina district where the use of a shallow three-dimensional models gave a significantly improved prediction. The causes of local zones of damage in the Northridge earthquake are poorly understood, with a suggestion that deeper lying structure may have as much influence on strong motion patterns as shallow structure.

d) Soil amplification/de-amplification

The strong motion data from these earthquakes encompass a wide range of soils and in general appears to be compatible with our understanding of non-linear soil behaviour. However, soft soils strongly de-amplified high level ground motion recorded at close distances to the Kobe earthquake, and stiff soils in the

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near-source region of the Northridge earthquake did not de-amplify ground motions in the manner predicted by most empirical attenuation relations. Geotechnical data for these recording sites are required to better understand these effects.

e) Variations of ground motions with depth

The strong motions of the Kobe earthquake were recorded by at least three down-hole arrays providing a valuable opportunity to validate models of site response and to develop procedures for estimating variation of ground motion with depth.

f) Topographic amplification

Intensity data has suggested the presence of topographic amplification in all three earthquakes. Further research is needed to explore the evidence and to develop satisfactory models.

2. GEOTECHNICAL ASPECTS OF EARTHQUAKE GROUND MOTIONS

a) Attenuation relationships

One lesson learned from the Loma Prieta and Northridge earthquake data sets is that many of the attenuation relationships available for the Western U. S. are starting to exhibit "first order robustness" , i.e., the new data set may force refinements, but not necessarily major changes. Also, a good comparison was achieved between preliminary peak horizontal accelerations recorded in the Kobe earthquake and the attenuation relationship for soil sites of Idriss (1991). The need to incorporate near-field directivity effects into attenuation relationships was identified as a research need. Also, the need to make new and up-dated relationships more readily available to researchers and practitioners was highlighted.

b) Strong ground motion parameters and specification for design and analysis

The possible difference between strong motion parameters at the base of a building and those for the free field needs clarification. Also, the variation of strong ground motion with depth requires investigation with application to the design of underground structures.

c) Time histories for analyses

These earthquakes have added numerous additional records for time history analysis. The effects of spectral smoothing and matching of recorded time histories on non-linear analysis were identified as requiring further investigation. Also, the duration effects in selecting analysis time histories require additional research.

d) Understanding of overall soil behaviour and site response

The down hole array data from the Kobe earthquake at the Port Island site have already been used to improve understanding of soil. Additional efforts to use recorded time histories directly to improve understanding of overall soil behaviour should be made.

e) Availability of data

Every agency that has an on-going strong ground motion instrumentation program should be encouraged to collect, process, and distribute recorded strong ground motion as soon as possible after an event.

3. SOIL LIQUEFACTION

For all three earthquakes, most deposits which liquefied were hydraulic or other poorly compacted granular fills. Methods of analysis based on SPT and CPT resistance correctly predicted the occurrence or non-occurrence of liquefaction. Most liquefaction, however, occurred at sites with very low penetration resistance. Few case histories of marginal sites have been provided to test the boundary between liquefaction and non-liquefaction. Several sites which liquefied during the 1971 San Fernando earthquake re-liquefied during the 1994 Northridge earthquake, but with much less ground displacement and disturbance. For the future, instrumental data is essential for development and verification of analytical techniques for evaluating pore-pressure response and ground deformation at liquefaction sites.

4. PILE SUPPORTED STRUCTURES

There is a strong need for physical data on the performance and behaviour of pile foundations in soft or liquefied ground under earthquake loading. Such physical data would ideally be available from the detailed documentation of case histories. Physical modelling, such as dynamic centrifuge or shaking table tests, with detailed instrumentation can also be used to obtain physical data and insight into the mechanisms involved. An associated need is to evaluate the ability of available analysis and design procedures to predict the performance of pile foundations in soft or liquefied ground during earthquakes.

For these recent earthquakes, apparently good performance of piled foundations was observed in many areas, many of which involved liquefied ground. However, the absence of visible damage to pile-supported structures has in many cases resulted in no direct inspections of the piles or their connections below ground surface. It is therefore possible that damage to piles has gone undetected. In Kobe a multitude of pile supported structures were located in soft and liquefied ground and their performance ranged from poor to excellent. Damage was caused by several mechanisms: failure of the pile head under lateral loading, axial failure of pile with large overturning moment, pile settlement after bearing capacity failure, and structure tilting caused by unequal pile settlement. Many case studies from the Kobe earthquake are under investigation and should yield much useful information.

The most pressing needs for future research were seen as detailed documentation of case histories and physical model studies of pile foundations in soft or liquefied ground.

5. LIFELINES

The lifelines of the Hanshin area, particularly in transportation systems, were totally devastated by the Kobe earthquake. The societal and economic impact of the lifeline system interruption was enormous. From a geotechnical viewpoint, the most interesting situations are those like the Dakai subway station where both the soil and structure were involved. It is evident that details of the design and construction process need to be examined along with soil data and strong motion records. A detailed case study of the Dakai failure was seen as a pressing need.

The 1989 Loma Prieta earthquake, together with the 1906 San Francisco earthquake have provided clear evidence for a strong relationship between ground deformation associated with liquefaction and the seismic performance of buried pipelines. The thickness of submerged loose fill and loose sand deposits is seen as one of the most significant factors affecting the severity of liquefaction and can be correlated with magnitude of lateral spread, settlement, and magnitude of horizontal surface movement. Mapping the thickness of these deposits is an excellent means of locating areas where severe liquefaction will affect underground utilities.

The events of the Loma Prieta earthquake show that the flexibility provided in San Francisco by the portable water supply system was of critical importance in controlling and suppressing the fire that erupted in the Marina district.

A detailed summary of the performance of lifelines during the Kobe earthquake and their rate of restoration after the earthquake is included in the report (Shinozuka et. al. 1995).

6. WALL, RETAINING STRUCTURES, AND UNDERGROUND STRUCTURES

The Kobe earthquake has provided a great wealth of observed behaviour of retaining structures and walls, both along quay fronts and inland as well. Many walls failed catastrophically, but some survived virtually intact. Probably the most notable feature was the generally poor behaviour of the numerous quay walls on both the man made islands and on the mainland. Only a few quay walls did not fail and, these seem to have been designed for somewhat higher accelerations than the others.

A great deal of work is needed to try to understand the observed behaviour. At least four factors could have contributed to the movements of the waterfront caisson structures: inertial forces on the caissons, dynamic lateral pressures from the backfill, static and dynamic pressures caused by liquefaction of the backfill, and reduced resistance to base sliding because of liquefaction of soils surrounding the base. It will be necessary to carry out studies using numerical and physical models to try to identify the relative contributions from each. Much further work is required.

By contrast to the very poor behaviour of the quay walls, mechanically stabilised walls, constructed variously by reinforced earth or soil nailing techniques, generally behaved well. There are good opportunities for case studies to compare the predictions of various design procedures with actual performance.

7. REMEDIATION

The three earthquakes have provided a number of valuable case studies of potentially liquefiable sites that had been subject to ground improvement prior to being shaken by the respective earthquakes. The preformance of many of these sites have already been summarized by Mitchell et. al. (1995). There are additional improved sites in the Kobe-Osaka area which were not inlcuded in this review but which are now under investigation.

From these studies the following lessons have been learned: (1) Remediation of liquefiable ground provides excellent protection against damage from moderate intensity shaking, and (2) high intensity shaking such as experienced at Kobe can cause some settlement and deformation of previously densified sites, but with considerably reduced magnitude. Further study is required to give a better understanding of the extent, depth, and degree of soil improvement required to attain desired levels of protection for given soil conditions and given input motions.

8. OTHER ISSUES

a) Response and performance of waste fills

These recent earthquakes have provided some useful case histories but many more are needed. No major failures of landfills were documented, but minor damage in the form of soil cracking was common. Cracks generally were located at contacts between fill and native ground and at changes in geometry. However, in Kobe, there was more widespread cracking caused by liquefaction and lateral spreading of the underlying fills.

The main need for additional research is to instrument additional waste sites with strong motion instruments. More data is needed on the properties of waste fill including unit weight and shear wave velocity. Detailed case histories of waste fills affected by the Kobe earthquake are also needed.

b) Fault rupture propagation through soils

Field data and observations of damage in the Takarazuka area suggest that there may be a correlation between some concentrations of heavily damaged areas and active fault segments that expressed some ground movement during the Kobe earthquake. Additional study is warranted to confirm these preliminary observations.

c) Seismic stability of natural slopes and soft clay deposits

Slope instability during these recent earthquakes caused extensive economic damage and some loss of life. The Loma Prieta earthquake produced numerous rockfalls and landslides in the epicentral area in the Santa Cruz mountains. Recent analytical studies by Ashford and Sitar (1994) have found that topographic amplification is important with steep slopes (>60 degrees), but that in other cases site amplification due to impedance contrasts and the response of surficial soils is more important.

At present, the main thrust in the U.S. is the development of regional hazard identification techniques that can be used to map potential landslide and rockfall hazard areas. Effective mitigation measures require additional development.

In Kobe, seismically induced landslides were limited generally to shallow slips and ravelling of boulders, the notable exception being the large Nigawa landslide which killed 34 people. Documenting the cause of this landslide was seen as the most important immediate research need.

Structural fills for roads and house pads experienced cracking and lateral deformation in the hills above Kobe. In many cases these movements caused disruption of underground utilities as well as structural damage to houses and retaining walls.

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