VI WORKING GROUP SESSIONS

REPORT FROM WORKING GROUP 1

MODELING LIQUEFACTION AND ITS RELATED GROUND DEFORMATION

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SUMMARY

The meeting opened with a presentation of the main results of recent Japanese research. Key areas where their thinking has changed were presented during the workshop. Past thinking was that sloped ground became level following liquefaction, but more recent experimental results indicate that initially sloped ground may retain some degree of sloping following liquefaction. Perhaps previous shaking table experiments involved too much shaking, which was not representative of real conditions. Current thought is that small, unstable regions develop during cyclic loading, which causes lateral spreading, but during continuous shear the strains cause stiffening which limits deformations preventing the slopes from becoming fully level. The main findings were discussed of the following several groups:

Yasuda and Yoshida have developed experiments and analytical models for soil behavior following liquefaction. These models incorporate large static strain. Low stiffness zones were identified. These zones are affected by the amount of cyclic load, relative density, and perhaps seepage forces.

Kawakami et al. performed experiments in which 1-g models were shaken then tilted. These experiments showed that limited deformation occurred after tilting, but the final surfaces were not level.

Hamada et al. developed a model in which zones of zero stiffness transformed into zones of high stiffness during lateral movement. This model predicts non-level slopes following liquefaction and lateral spreading.

Toyota and Towhata performed 1-g shake-table experiments with impulse and cyclic loadings to study further final surface configurations. Impulse loading resulted in non-level ground and cyclic shaking experiments resulted in level ground.

The recent Japanese findings have emphasized the nature of low stiffness regions and transformation states when large strains are imposed on liquefied soil. These new concepts are very different from the ideas of residual strength.

General Discussion - The primary contributions to the discussion topics are paraphrased below.

Discussion Topic 1: What Do We Know and What Don't We Know About Mechanisms of Liquefaction and Pore Pressure Generation?

We have the least experience with what happens after liquefaction. This is the highest priority topic. Most recent experiments suggest that we should use the new data with existing predictive models. We should concentrate on what we know about liquefaction and how we can get a better handle on it. We have a reasonable handle on the potential for liquefaction, and should focus now on the consequences. It would be good to understand the new material about low stiffness regions and transitional states.

We have poor ability to predict pore pressures for collapse susceptible soils.

What do we know about the mechanisms? We understand the mechanism of pore pressure generation, i.e., disturbance to the ground, related to stresses, strains, energy , leads to a tendency for compaction or compression that leads to development of pore pressures under undrained conditions. We have techniques for predicting pore pressure generation up to near 60 to 80% for material that is not extremely loose. For very loose sands we have a collapse mechanism that is not well understood. We can predict pore pressures for cyclic loading, but our predictions are not so good for sloped ground and flow slides.

Field predictions are limited by heterogeneity.

If the soil is contractive in sloped ground, there can be flow. If the soil is dilative then there will be limited deformation. The ability to predict pore pressure for contractive sands with a single triggering event is uncertain.

This is a question of triggering or non-triggering of a collapsible structure from a single event, which is different than pore pressure buildup resulting from cyclic loading.

For clean sands under known conditions we're OK. Three-dimensional effects and variability in nature are major issues. Analytical models at present cannot represent this complexity.

Soil characterization is complex. We may need to rely on probabilistic modeling of soil properties.

Maybe we just get gross stiffness properties and global characterizations. Until we can understand fundamental mechanisms better we won't make totally accurate field predictions.

We deal with pore pressure as a local condition but we might need to consider it as a bifurcation problem.

Summary of Topic 1 Discussion.

We "know" that we can predict pore pressures reasonably for cyclic loading in a laboratory environment. Field difficulties may be related to site characterizations. Very unstable, structured soils are in a different category, and pore pressure predictions for these soils are difficult. Triggering mechanisms differ and response may be catastrophic. We "don't know" how to handle unstable structure effects and sudden collapse, or how to deal with nonhomogeneity and proper extrapolation of lab results to more complex field conditions

Discussion Topic 2: What Do We Know and What Don't We Know About Mechanisms and Prediction of Ground Deformation?

The mechanism for granular soil deformation has been treated as a solid that strain softens during loading to a point where the stress reaches a yield surface. If the soil is contractive, flow deformation will occur. If the material is dilative then after some limiting strain, pore pressures will decrease and motion will stop Continued deformation occurs as a complex sequence of cycles of softening and stiffening driven by a combination of gravity and inertial forces How much yielding occurs is a function of density and dilatancy The Wildlife site provides a good model for understanding how ground motions and pore pressures interact and how deformations accumulate

The amplitude of motion should be small after shaking stops

We know that horizontal deformations occur during and after the earthquake

Do we know how to include rate effects? How do we include diffusion and distribution of pore pressure with time because deformations occur, in some cases, long after the earthquake? During large shear strains there is dilation, and in the field water will be sucked toward the dilating zone. For large field strains how do we use lab results? Granular soils in the field are not truly undrained, so how do undrained lab tests apply?

Summary of Topic 2 Discussion.

We "know" that horizontal deformations occur during and after the earthquake. Also, lab tests seem consistent with respect to dilatancy stiffening at large strains. We "don't know" the point at which the material softens sufficiently to initiate motion, perhaps a pore pressure ratio of 70%, as suggested previously. What is the role of pore pressure diffusion in time dependency? How do we include strain dilatancy and locking into simplified predictive methods like Newmark analyses? How do we evaluate volumetric strain in the field? Post-liquefaction compressibilities are very different. How do we reconcile lab data? For example, how do we relate laboratory tests, that are usually fully undrained, to field behavior, that may respond to a variety of drainage possibilities?

Discussion Topic 3: What New Research Tasks Are Needed to Improve Our Knowledge to be Able to Answer the Questions Listed Above?

What about properties of liquefied soil? What do we know about residual strength?

Almost nothing. It has such a wide range and has very different definitions.

Are embankment residual strengths the same as those that might develop in lightly sloping ground? The stress conditions are very different for these cases

Two important issues are how to characterize the sites, and how to predict deformations that occur during and after earthquakes.

We need to develop indices to quantify the severity of liquefaction, since properties can be influenced by post-liquefaction conditions. This is particularly evident in terms of continued straining after soil has become liquefied, and the transition from low to higher stiffness zones as a result of large deformations

We need to develop a common code for practitioners to use

The best route is to know whatever code you have, that is select one and stick to it. One can get consistent answers with many codes, as long as you know how to select the properties for that program.

Water velocities are important. Seepage and drainage patterns can affect the buildup and dissipation of pore pressures, and may effect the magnitude of lateral movements

Post-liquefaction studies in the lab should be continued, but should include varying levels of static shear They should include large strain We need detailed analytical studies of lateral spread to see if we can predict what happened We need to continue fundamental analytical studies

We need more investment in characterizing lateral spreads This would be a good area for continued U.S -Japan cooperation

We need more information on the influences of silt content on soil behavior, and the nature of the silt, including plasticity and varying grain size distribution The influence of texture needs to be extended to include gravely soils as well

Is maximum acceleration a meaningful parameter? Maybe a more useful index is energy input How do we apply lab data to field conditions? Present numerical models seem OK for certain problems, but new ways are needed to handle the complexities of liquefaction For example, two-phase instabilities cannot be modeled presently Do we understand microscopic effects? What do we mean by "undrained" problems?

Residual strengths are uncertain. Back-calculated values have high uncertainty We need to separate gravity and inertial components of motion We may need to consider statistical characterization of sites

Comparisons between measured response at instrumented sites and analytical predictions are important

Summary of Topic 3 Discussion

Residual strength concept in terms of actual soil behavior may be applied incorrectly for shallow slopes Very flat ground and more steeply sloping ground (i e , embankments) have very different stress conditions, which lead to different mobilized strengths We need to develop reasonable engineering methods and appropriate "strengths" for predicting deformations, as they are used in practice now

REPORT FROM WORKING GROUP 2
GROUND DEFORMATION RESPONSE OF LIFELINES AND UNDERGROUND STRUCTURES

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SUMMARY

The charge to the Working Group was as follows "Evaluate what we currently know, what we currently do not know, and what we should know"

The working group activity began with brief presentations on the current state-of-the-art with respect to pipelines, piles and tunnels. These presentations and observations by the working group members led to the following summaries for pipelines and piles

Pipelines

It was the group view that "what we currently know" regarding pipeline response to permanent ground deformation (PGD) could be summarized as follows

- Soil structure interaction for pipelines in non-liquefied ground (i e., pipeline located in competent soil above a layer which liquefied) is well established There has been recent progress in determining appropriate load deformation relations for pipelines in liquefied ground However, the procedures are not, as yet, well established

- Analytical procedures utilizing computer models for pipeline response to PGD are commonly used in practice Analytical procedures utilizing closed form solutions (i e , hand calculations) are available for many situations However, for some, particularly involving segmented pipe, closed form solutions are currently not available At present, there is a lack of verification of these procedures, either computer or closed form using case history benchmarks or full scale laboratory tests

- Failure criteria for modern welded steel pipe are fairly well established. Appropriate failure criterion for segmented pipe is not as well established and may be characterized as "spotty"

Based on what the group felt is currently known, a list in priority order of what is needed (i e., "what we currently do not know and should know") was developed as follows

- Verify existing analytical relations and failure criteria with benchmark case histories and/or full scale laboratory tests

- Establish failure criteria for old steel pipe welds in tension and quantify variability of weld quality

- For steel pipe which has wrinkled due to longitudinal compression, quantify the additional strain or deformation along the wrinkling zone which results in tearing of the pipe wall.

- For large diameter concrete pipe, established failure criteria for crushing at the joints due to longitudinal compression

- Establish the force-deformation and moment-rotation characteristics for segmented pipe joints

- Establish failure criteria for plastic gas distribution pipe

Piles

The working group felt that the state-of-knowledge (i e , "what we currently know") for the seismic behavior and design of piles is well established for everything except piles subject to PGD

The following lists in priority order "what we currently do not know and should know

- Quantify the reduction factor (i e , load deformation relation at the liquefied soil/pile interface) in terms of realistic design parameters

- Quantify through laboratory or numerical studies "group" or "pile cap" effects for piles subject to PGD

- Evaluate through full scale testing the effectiveness of flexible pile joints, and determine pile moment-curvature relations where this information is unknown

Geotechnical Inputs

The group felt that certain characteristics of permanent ground deformation were currently ill defined Listed below are the types of information needed for analysis, evaluation, and design of buried facilities

- Given a map of expected PGD (in feet or meters), what is the likely number of separate isolated PGD zones.

- Given a map of expected PGD (in feet or meters), what is the expected spatial extent (i.e., length and width) of separated, isolated PGD zones.

- For a given zone of PGD as shown in Fig. A, what is the relative likelihood of abrupt offsets at the margin (see. Fig. B) versus distributed ground movements across the zone (see Fig C)

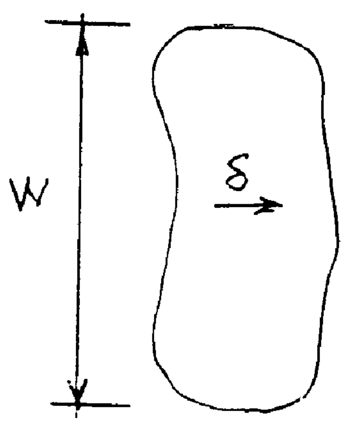

Fig. A
Isolated PGD zone with width W & maximum ground movement δ

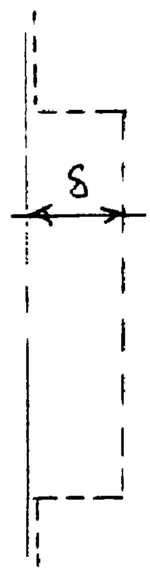

Fig. B
Uniform PGD of amount δ across width (i.e. abrupt offset at margin)

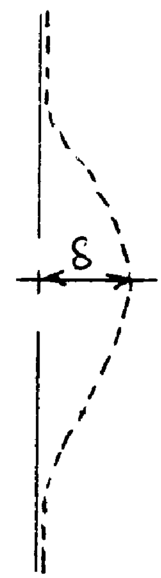

Fig. C
Non uniform PGD across zone

REPORT FROM WORKING GROUP 3
DAMAGE ASSESSMENT AND HAZARD MITIGATION OF LIFELINE NETWORKS

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SUMMARY

The Group reviewed the three questions presented in the guidelines for group activities 1) What do we know?, 2) What don't we know?, and 3) What activities should we be engaged in for the next several years to enhance mitigation of earthquake hazards for lifeline networks? Following an extended discussion, the Group concluded

1. What do we know?

a Recent past earthquakes have permitted collection of valuable data and experience on performance These events have included the Kushiro-oki, Hokkaido-nansei-oki and Northridge earthquakes However, information about the system response and restoration are generally not available Electric power, gas, sewage, etc agencies are separated in exchanging their experiences Little effort has been made to collect and develop databases of experiences in Japan In the U S , more effort has been made, notably by TCLEE for underground pipe in the Loma Prieta earthquake, but more could be done

b The primary modes of damage for buried facilities have been identified as associated with permanent ground deformations (PGD) We have general knowledge regarding liquefaction hazard, modes, and areas for western U S and Japanese cities Quantification of PGD is still difficult

c While much remains to be done in quantifying hazards and lifeline network analysis methods, a spectrum of mitigation techniques is available, including strengthening of facilities, reduction in liquefaction potential via soil improvement or other techniques, and development of enhanced network performance via redundant links and nodes, emergency, response and recovery planning, etc

2. What don't we know?

a The primary need is for consistent and complete quantified mapping of PGD hazards Specifics include (i) areal extent, (ii) distribution of PGD (quantified fields), (iii) lurching probability, and (iv) ridge shattering Techniques to accomplish this are data intensive, and methods for efficient collection and analysis of requisite data are needed GIS technology offers some assistance in this area, but geotechnical engineering needs to develop better methods

b Researchers need more interaction and information from system operators Communications and involvement of system operators in lifeline earthquake engineering is sparse This includes system response and restoration data

3. What activities should we be engaged in for the next several years, to enhance mitigation of earthquake hazards for lifeline networks?

a Encourage GIS (Geographic Information Systems) methods for data collection and analysis Additionally, explore applications of GPS (Geographic Positioning Systems) for mapping of ground deformations

b Increase involvement of lifeline operators, and institutionalize damage assessment, ground characteristics, and failure mapping program within lifeline organizations This should include involvement of utility owner associations and development of standardized data protocols

c Engage in technology transfer, in usable formats, to lifeline organizations This needs substantial interaction between researchers and lifeline organizations to determine their needs, appropriate formats for effective communications, etc

d Address methods for extending the life of buried pipelines This need is associated with the finding that most damage to buried pipe is associated with older pipe, often poorly welded Rather than a major replacement program, ways of repairing welds in-situ, lining pipes in-situ, or other technologies should be explored, since similar techniques are presently being employed for re-lining of water pipe, etc

Lastly, the Group suggested that the organizers of the workshop focus on

a Encouraging attendance and participation of lifeline operators and organizations

b Several sessions be devoted to lifeline end-user applications

c Several sessions be devoted to data collection and mapping, particularly applications of GIS and GPS technologies

REPORT FROM WORKING GROUP 4
COUNTERMEASURES AND EARTHQUAKE RESISTANT DESIGN

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SUMMARY

Following introductions by the Group Leaders, the workshop session commenced with brief presentations by several participants on various aspects of the countermeasure problem

A description was given of remediation options for stabilizing a new construction site at the Port of Seattle Because of the high fines content and to minimize costs, a timber pile reinforcement scheme at the toe of a wharf slope was adopted No densification was assumed and reinforcement was used to minimize lateral spread potential

A retrofit remediation plan was discussed for approach spans of a bridge over the Fraser River in Vancouver Analyses indicated as much as two meters of liquefaction induced horizontal displacement of pile supported piers during the design earthquake The proposed remediation plan entailed the construction of a densified "donut" around each pier using vibroreplacement Design concerns included the potential migration of high pore water pressure from adjacent liquefied zones into the densified zone, and the extent of protection the densified donut provided to prevent liquefaction beneath pile tips

A case history was presented about soil performance at Treasure Island during the Loma Prieta earthquake It was observed that an area treated with vibroreplacement performed well in comparison to nearby non-treated areas

A discussion ensued on bridge sites in Costa Rica during the 1992 earthquake, where in some cases, several meters of lateral spread of approach embankments occurred However, only limited movement of piers supporting abutments occurred The quest...

was posed, "can computer codes match observed performance"? The need for good soil data at such sites for analysis purposes was noted and also the difficulties and expense of obtaining such data With respect to dynamic compaction, needs were emphasized for improved methods for estimating increases in density utilizing deep dynamic compaction and the possible use of deacceleration measurements for this purpose.

Problems were discussed associated with potential liquefaction of oil tanks constructed in Japan before 1985 Tanks built after 1985 required ground remediation before construction, whereas many tanks before 1985 were sited on potentially liquefiable soils Details of ongoing research on a variety of retrofit options were presented Research included centrifuge model tests, where it had been observed that liquefaction was not induced directly below tanks but occurred outside the perimeter of the tank, leading to lateral spread Retrofit criteria included the avoidance of oil leakage and the desire to keep post liquefaction settlement less than 1% of the tank diameter The pros and cons of retrofit options, including gravel drains, sheet pile rings, underpinning, grouting, and dewatering were presented and discussed

The mitigation of liquefaction hazards at California bridge sites was discussed In particular, the need for improved soil-struction interaction analyses for the case of foundations supported by ductile piles, where the piles extended through liquefiable sand layers into denser sands The question of post liquefaction stiffness and residual strength as related to p-y curves for liquefied soils has yet to be finally resolved Proposals for centrifuge tests at UC-Davis and analytical methodologies to address these problems were described

The increasing levels of peak acceleration being observed in recent earthquakes and the effect on liquefaction evaluations utilizing the Seed simplified approach was discussed. It was noted that a new text on "Remedial Treatment of Liquefiable Soils" was published in 1993 by the Japanese Society of Soils Mechanics and Foundation Engineering An English version is scheduled to be published in 1995

Following the above presentations, discussion ensued on what we know, what we do not know, and how do we improve our knowledge with respect to countermeasures It was observed that in past U S /Japan Workshops the emphasis was primarily on site remediation methods and countermeasure case histories Whereas site remediation methods are generally well established and countermeasure case histories are increasing as a result of recent earthquakes, it is clear that more concern and interest is now being directed toward the problem of retrofit of existing structures where liquefaction problems are present Because of the difficulties of retrofit involving ground remediation and the need to optimize cost, increasing attention is being paid to performance criteria, i e , how much deformation can a structure tolerate from a lateral spread In addition, there is increasing interest in structural design of foundation systems as a countermeasure technique, such as the design of ductile piles and the use of large diameter piles to resist deformation With respect to the latter problems and the retrofit of existing structures, the following research needs were summarized by the working group

1) The development of an improved mechanistic understanding of the performance of various countermeasure methods, such as the use of densification "donuts"

2) The development of improved analytical methods to assess lateral spread deformations and soil structure interaction with liquefied soil for existing structures, with an emphasis on simplifications related to design needs.

3) The need for validation of design methods through either/or instrumented sites and centrifuge model tests

4) The need for improved understanding of the behavior of very silty sands or sandy silts with respect to liquefaction potential and the development of improved ground remediation techniques

5) Further, detailed case histories of structures which have successfully or unsuccessfully resisted earthquake loading

6) Further studies of the potential applications and design approaches utilizing compaction grouting and blasting techniques

7) Continued research on improving in-situ testing techniques for evaluation of ground densification