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General Report — Session 8: Seismic Analysis and Retrofit of Foundations of Bridges and Other Sub-Structures, Seismic Retrofit Projects and Procedures in California

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General Report - Session 8

Seismic Analysis and Retrofit of Foundations of Bridges and Other Sub-Structures, Seismic Retrofit Projects and Procedures in California

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INTRODUCTION

Seven papers were received for Session 8 and included a wide variety of topics related to analysis and retrofit of sub-structures. Substructures are considered herein as foundations and earth structures and their soil-structure interaction. Some papers focused on the structural aspects of the superstructure but were still focused on the retrofit aspects. The papers came from four different continents including countries such as, Japan, Russia, Canada, Iran and United States of America.

SUMMARY

The papers in this session spanned a wide variety of topics focuses on earthquake assessment and retrofit. Almost all papers included numerical modeling of some degree to base their conclusions. However, many of the research or design projects were in the initial phase of the numerical analysis and were not able to report the complete detail.

Two papers included experiments performed on sub-structures that were scaled to a smaller size, but only one used a centrifuge to increase gravitational loading.

All the papers that included numerical analysis to evaluate the dynamic response of the sub-structures used elastic properties for the soil and structural members. It is expected by the reviewers that the response using non-linear or elasto-plastic material properties is more representative of real conditions. This continues to be a challenge in civil engineering numerical modeling.

This session attracted papers that described different analytical and experimental procedures. Papers that focused on particular procedures in California were not submitted.

PAPERS SUBMITTED

8.03 "Design of Tunnels Located Near Slopes in Seismic Areas"

by: Fotieva, N., Bulychev, N.S., and Sammal, A.S. (RUSSIA)

Objective:

The objective of the study was to quantify the embedment effect of near-slope tunnels on the design of circular tunnel linings under earthquake loading.

Scope of Work:

1. Considering a tunnel lining embedded in a rock mass at a certain slope, the tangential component of a normal stress on the lining was solved with the elasticity theory under the longitudinal (compressive) and shear waves of an arbitrary incident angle, respectively.
2. The maximum compressive and tensile stresses (tangential component) are determined under the combined effect of both longitudinal and shear waves.
3. The magnitude of the maximum tangential stress due to a specified earthquake was compared to that under the gravity load of the rock mass as well as under the static load distributed on the slope.

Results and Commentary:

Figure 2 presents the distribution of the maximum compressive and tensile stresses on the internal and external outlines of the lining cross-section.

These results indicate that the maximum compressive stress could increase by 26% on the internal and external outlines due to the shallow embedment of the tunnel (embedment depth/tunnel diameter = 0.83). They also show that the maximum tensile stress could increase by 86% on the internal outline and 96% on the external outline. Therefore, it is very important to take into account the embedment depth of tunnels in design.

Figure 4 presents the compressive stress distribution along the perimeter of a tunnel lining under the self weight of a rock mass at a 15° slope. The maximum tangential stress is approximately equal to 10% on the external outline and 20% on the internal outline of the corresponding maximum stress due to seismic effect, respectively.

Figure 6 shows the sensitivity of the maximum stress on the internal outline to the material used in lining construction and to the degree of the slope.

Figure 7 presents the distribution of the maximum compressive stresses on the internal and external outlines under a distribution load on the slope. The order of the compressive stress induced by the distributed load is comparable to that due to a seismic excitation.

8.07 "Centrifuge Characterization and Numerical Modeling of the Dynamic Properties of Tire Shreds for use as Bridge Abutment Backfill"

by: Rosebrook, K., Wilson, D., Jeremic, B., Kutter, B., Smith, A., Humphrey, D., Patenaud, S. (USA)

Objective

The objective of this experimental research was to develop the testing procedures for a centrifuge model made of tire shreds. New geophysical wave sources (air hammer) were used to determine dynamic material properties. Shaking scenarios using the shake table in centrifuge were tested.

Scope of Work

1. Construction of tire shred fill embankment (model scale, 40 cm. high) for centrifuge on shaking table.
2. Model testing at 10g, 20g, and 40g to simulate different size embankment and evaluate response.
3. Identification of dynamic soil parameters determined using a source (air-hammer) inserted at horizontal and vertical locations. Properties were measured by accelerometers at intermediate locations within embankment.
4. Available relationships were used to verify the measurements and compared to ranges for sands and clays.
5. Sinusoidal and seismic waves were used as motion in the shaking table and response spectra obtained at different depth locations of model.
6. An elastic FEM numerical model was used to analyze the tire shred embankment with some sections including soil layers.

Results and Commentary

The data collected from this new type of testing procedures and unconventional construction materials (tire shreds) were successful after modifications to the equipment (larger air hammers). The response spectra for the model showed amplification near the top of the tire shreds (location b) when compared to the base motion and a well-defined natural frequency at around 1.7 sec.

The numerical modeling claims a reduction of natural frequency of an abutment embankment by varying the amount, location and geometry of the tire shreds. However, no results were provided to support such statement.

The seismic performance of the light-weight tire shreds may allow for use of these waste materials in areas with seismic vulnerability.

8.09 "Seismic Design of Pile Foundations in Southern Indiana"

by: Loukidis, D., Salgado, R. and Bobet, A. (USA)

Objective

The objective was to evaluate the potential risk of earthquake-induced damage of pile foundations in Indiana. Perform a literature review of pile damage due to seismic loading. Evaluate the ground response for site-specific locations and perform numerical analysis for a bridge sub-structure.

Scope of Work

1. The seismicity, geology and soil properties for the southwestern portion of Indiana were established.
2. Based on borehole blowcount data and correlations the dynamic soil properties were determined for each bridge site. Site ground motion amplification liquefaction potential were evaluated.
3. Literature review of earthquake-induced damage to piles was completed. Cases were classified as severe, heavy, light and no damage based on their diameter.
4. Numerical analysis consisting of a 3-D finite element model using elastic pile and soil properties. Additionally, a frictional interface element was defined in the pile/soil boundary.

Results and Commentary

Evaluating the risk of pile foundations due to earthquake-induced loading in the Midwest will have a significant effect on future design procedures for bridges. The literature review of pile damage in recent earthquakes serves as a very good resource for future work. Classification of damage type and modes of failure are very important when considering new designs and retrofit measures.

The determination of soil properties using SPT data alone is considered preliminary in nature. However, for the scope of work intended including nine bridge sites it is considered appropriate for risk assessment. Therefore the numerical analysis should include a sensitivity analysis on the soil properties and consideration of non-linear soil models, especially if soil is susceptible to liquefaction.

8.10 "Foundation Sign Correction in Stochastic Analysis Procedures"

by: Parsa, K.Z. and Abyaneh, H.Z. (IRAN)

Objective:

This study was aimed at developing a sign correction procedure of member forces of structures analyzed with the response spectrum method.

Scope of Work:

1. A static analysis procedure of a structure under the joint forces determined from the response spectrum method was proposed to correct the sign of member forces and moments.
2. The procedure was validated by comparing the sign-corrected pseudo-dynamic analysis (response spectrum method) with the time history analysis of a four-story frame structure.

Results and Commentary:

Tables 2-4 present the shear forces, axial forces and bending moments of the four-story structure under the first few seconds of excitation of the 1940 El Centro Earthquake. The structure was analyzed using the time history analysis.

Table 6 shows the joint forces in the horizontal direction from the pseudo-dynamic analysis. These forces were applied to the frame structure to determine the member forces of the structure using a static analysis. The member forces and moments were tabulated in Table 7.

Comparisons were made between the member forces determined with the pseudo-dynamic analysis and with the time history analysis in Table 8. The signs of internal member forces and moments from the two analyses were corresponding to each other.

Caution must be taken to use the results of this study. It is likely that the procedure works well only when the fundamental vibration mode of a structure dominates the total response of the structure. If so, the importance of correcting the sign of member forces becomes less evident.

8.11 "Earthquake Resistance of New Type Viaduct Structure"

by: Wakita, E., Sato, M., and Tazoh, T. (JAPAN)

Objective:

The goal of the study was to investigate the effect of connection beams at the ground surface on the seismic behavior of viaduct structures.

Scope of Work:

1. A 1/50-scaled viaduct model was designed and fabricated. It consists of a RC frame deck, foundation embedded in two layers of soil. All pillars were framed into the frame deck at their top and the frame with connection beams at their bottom.
2. Both centrifugal test and numerical analysis were conducted to study the seismic resistance of a new viaduct structure without the connection beams.

Results and Commentary:

Figure 2 presents the acceleration transfer function from the ground base to the top of the viaduct, which was determined from a swept-sine vibration test. The fundamental frequency of the viaduct becomes appreciably smaller when the connection beams of the viaduct were removed. The time histories of the strains at the top and bottom of a pillar as well as at its supporting pile head are respectively compared in Figure 3 between two cases: with and with the connection beams. Under the near-resonant circumstances, the peak strains at the top and bottom of one pillar are smaller for the viaduct without the connection beams.

Figure 4 shows the comparison of the maximum strain distribution along one pillar and its supporting pile. Removing the connection beams can reduce the strain by 85% at the bottom of the pillar and significantly increase the strain at the pile head. Theses results were interpreted as a result of the rotational restraint of the connection beams.

Figures 7 and 8 respectively present the bending moment distribution of a viaduct with and without the connection beams from the numerical analysis of a 3D model. Their maximum bending moments together with the maximum displacement and axial force at the top and bottom of the pillar as well as at the pile head were compared for the two cases in Table 3 under the harmonic loading and Table 4 under the El Centro Earthquake. It was found that the maximum stress and the maximum displacement under harmonic loads are both small for the viaduct without the connection beams and such a viaduct is even safer. When subjected to the El Centro Earthquake load, however, the viaduct behaves similarly regardless of the presence of the connection beams. This is mainly because the dominant frequency of the earthquake excitation is not close to the fundamental frequency of the viaduct.

Tables 3 and 4 also indicated that numerical results are in good agreement with the experimental results.

8.12 "Seismic Evaluation and Retrofit of a Major Natural Gas Transmission System"

by: Wijewickreme D., Mitchell, A., and Fitzell, T. (CANADA)

Objective

Evaluation of the vulnerability of a natural gas transmission system to seismic hazards, including remedial measures implemented. Case histories are used to illustrate retrofit.

Scope of Work

1. Regional seismicity study to identify the gas pipeline system components that are most vulnerable. Seismic hazards (landslides, liquefaction and lateral spreading) were considered.
2. Site-specific seismic vulnerability assessment of critical sites. Geotechnical investigation and analysis followed by structural analysis.
3. Case history No. 1 – Ground improvement using vibro-replacement.
4. Case history No. 2 – Pipeline installation using horizontal drilling method.

Results and Commentary

The investment of a utility provider, such as, BC Gas Utility, Ltd., on the gas pipeline system is significant to justify site-specific studies on critical structures. Furthermore, the results of the studies lead to real world solutions that exemplify the state-of-the-practice in seismic retrofit of geotechnical system.

Both case histories required remedial measures against the threat of liquefaction immediately adjacent to pipelines. It is not clear in case history No. 2 how the "flow slide conditions" would develop to induce slope instabilities. The techniques used to describe this phenomenon are not provided and Bartlett and Youd's (1992) procedures are one-dimensional. It is of great interest to this reporter how the spatial component was analyzed to evaluate the south bank displacements or instability.

The structural retrofit of gas pipeline system was only mentioned as realignment to reduce stress concentrations and strengthening to provide increased resistance. Design details could be beneficial to the reading audience.

8.13 "Earthquake Assessment of Critical Structures in Route US 60 in Missouri"

by: Luna, R., Chen, G., Munaf, Y., Mu, H., Prakash, S., Santi, P., Fennessey, T., and Hoffman, D. (USA)

Objective:

The main goal of the study was to evaluate the liquefaction potential, slope and abutment stability, and structural vulnerability at two bridge sites on the designated emergency vehicle access route U.S. 60 near the New Madrid zone.

Scope of Work:

1. Earthquake ground motions at the St. Francis River and Wahite Ditch bridges were estimated corresponding to the 2% and 10% probability of exceedance in 50 years.
2. The susceptibility to the earthquake-induced slope instability and soil liquefaction were evaluated for each bridge.
3. The seismic vulnerability of the bridge structures was assessed.

Results and Commentary:

Figure 2 presents the soil profile, the earthquake ground motion with 10% probability of exceedance in 50 years and liquefaction potential at the St. Francis River bridge site. Both Standard Penetration Tests and Cone Penetrometer Tests were carried out to evaluate the potential for liquefaction and to estimate the shear wave velocity profile of the bridge site. Soils at the site consist of 18-foot clay of medium to stiff consistency on the top and 30-foot dense to very dense sand layer. Figure 2 indicated that the bridge site is unlikely susceptible to soil liquefaction under the specified earthquake.

Figure 3 shows the seismic displacement time history of a seat-type abutment subjected to various levels of earthquake excitations. It was predicated that as much as 1 ft of the abutment sliding could be anticipated.

Table 2 gives the factors of safety at several selected potential sliding surfaces. They indicate that the slope at the St. Francis River bridge site is stable under small earthquake shaking (10% probability of exceeding in 50 years) and likely to be unstable at the higher levels of shaking (2% probability of exceedance in 50 years) regardless of the ground water level. The Wahite Ditch bridge site has also been evaluated in detail for slope stability and soil liquefaction. Consistent results to the St. Francis River bridge site were observed.

Figure 6 presents the distribution of bending moments in structural members under the site-specific ground motion at the lower level. Preliminary evaluation on the strength of the members indicates that the bridge can survive a lower-level earthquake.

Conclusion:

Both St. Francis River and Wahite Ditch bridge sites are able to sustain the lower level earthquake load generated from the New Madrid faults. However, it is likely that both sites are susceptible to slope instability and soil liquefaction under a higher-level earthquake (2% probability of exceedance). The St. Francis River bridge structure can sustain the earthquake-induced shaking corresponding to 10% probability of exceedance in 50 years.