Communication Document

TPF-5(180)
DRI Task: 1731

Prediction Exercise of Column Performance Reveals Capabilities and Limitations of Non-Linear Structural Modeling

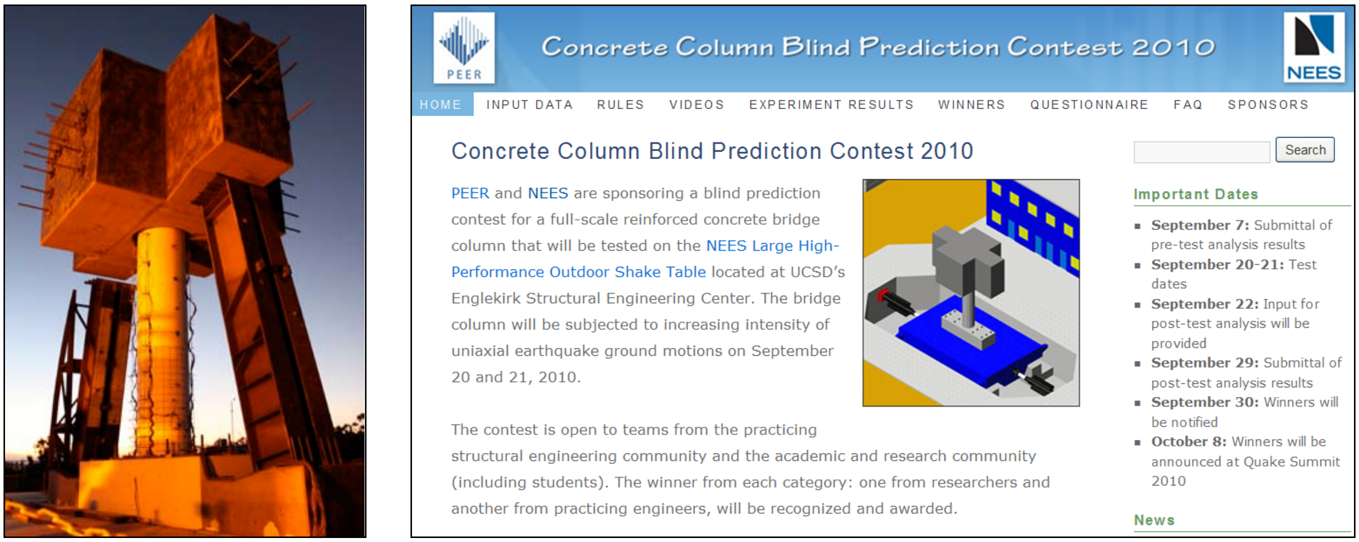

Figure 1: A spinoff of the Caltrans co-sponsored research on the seismic performance of a full-scale bridge column was the conduct of response prediction exercise that involved 41 entries from the professional engineering and academic communities.

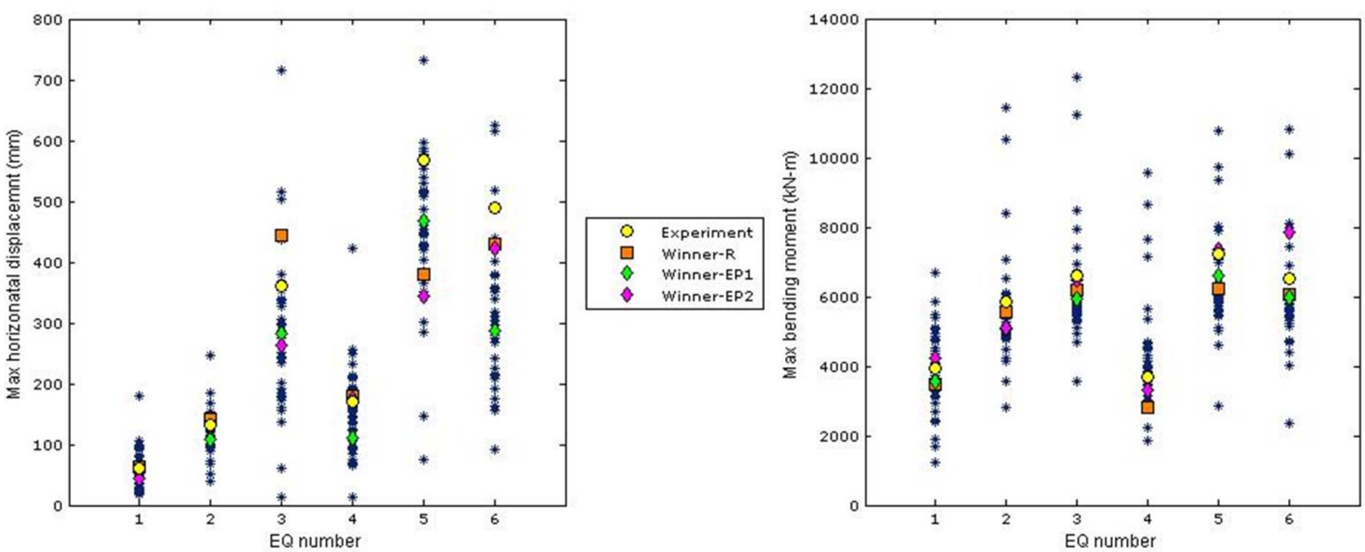

Figure 2: Clusters of predictions for two example response parameters for each of six simulated earthquakes. Experimentally measured values are highlighted in yellow. Predictions of three 'contest winners' having highest overall fidelity to test results are highlighted in other colors. Note the high degree of scatter overall, and that even the winning submittals were unable to accurately predict all response parameters for all earthquakes.

WHY THIS RESEARCH WAS UNDERTAKEN

Seismic design strategies used for Caltrans bridges are based on ductile response which allows a component such as a column to yield but not break during extreme earthquake shaking. Ductile response is very challenging to accurately model using even the most sophisticated non-linear analysis software. Clear understanding of the capabilities and limitations of current non-linear modeling strategies is important to maintain proper engineering perspective and to make future advances. The work presented here is a valuable spinoff of Caltrans co-sponsored research into the performance of bridge columns.

WHAT WAS DONE

This research, sponsored by the Pacific Earthquake Engineering Research (PEER) and the Network of Earthquake Engineering Simulation (NEES), grew out of an unprecedented bridge-column testing program co-sponsored by Caltrans and others. The testing program consisted of measuring the engineering response of a full-scale Caltrans-designed bridge column to a series of strong earthquakes (described in a separate document).

The full-scale column test provided a truly unique combination of an exceptionally well-documented and yet extremely simple engineering structure undergoing a precisely-controlled series of extreme earthquake motions that aimed to induce highly non-linear structural response. The earthquake research community took advantage of this opportunity to conduct a blind prediction exercise aimed at exploring the capability of the profession to accurately predict highly non-linear structural response using both production- and research-level analysis tools. In addition to the technical joy of the competition, this exercise provided an exceptional scientific opportunity to quantify typical levels of modeling uncertainty for use in future research.

Details of the prediction exercise can be found at http://nisee2.berkeley.edu/peer/prediction_contest/. Details of the column specimen design, materials testing results, and the planned series of ground motions were made available prior to the test. Participants were asked to submit predictions for a suite of engineering response parameters such as maximum column displacement, maximum bending moment, maximum base shear, etc. After the test, results were compared with experimentally measured response, and scored by an independent panel using posted rules.

41 teams from the US and abroad submitted complete entries. Participants competed in two categories: 'professional engineer' and 'researcher'. Teams were allowed to use any software. Contest 'winners' were those teams in each category which scored highest overall for all response parameters over all earthquakes. A tie in the professional category led to identification of three winners.

RESULTS OF THE RESEARCH

Figure 2 shows a representative selection of prediction results for two of the 14 required response parameters: a) maximum horizontal displacement at the top of the column, and b) maximum bending moment at the base of the column. Results for all 41 entries are shown for each of the six simulated earthquakes. Actual experimentally-measured responses for each earthquake are identified as a yellow dot. Predictions of the three 'contest winners' are highlighted in other colors.

Four important trends can be observed in these results:

- The scatter in predictions is very large and generally increases as the system is driven into higher levels of non-linear response.
- The distribution of predictions is not always centered on actual measured response.
- Even the winning modeling teams were unable to accurately predict all response parameters for all earthquakes.
- Some response parameters are substantially better predicted than others by even the best modeling teams. For example, results in Fig. 2 for bending moment show close agreement between all 'winner' predictions and measured response for all earthquakes. However, winner predictions for displacement show considerable scatter as well as an inconsistent pattern of error relative to measured response.

RESEARCHER RECOMMENDATIONS

These results illustrate typical capabilities and limitations of current non-linear structural analysis procedures. They show that predictions become increasingly unreliable as the system is pushed further into the non-linear regime. For high levels of non-linearity, these results suggest that an abundance of caution should be exercised when interpreting predictions of any single analysis. Overall, they point to the continuing need to rely on sound seismic design methodologies that are not overly-reliant on analysis, and which provide adequate margins of safety in the absence of precise knowledge about system response.

These results also point to the need for a systematic program of continued development of non-linear analysis procedures as well as comprehensive training on how to effectively use these analyses and properly interpret results.

IMPLEMENTATION STRATEGIES

Dissemination of these results to Caltrans bridge designers and management is recommended to assure technology transfer.

CONTACTS

Mike Keever, Chief
Office of Earthquake Engineering
Caltrans Division of Engineering Services
Office Phone: 916-227-8806
E-Mail: mike_keever@dot.ca.gov