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2020 Blind Prediction Competition for Integrated Complex Structural and Nonstructural Assessment on Steel Hospital Building

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ABSTRACT

Testing of a steel hospital building that represented a complex two-building multi-story hospital - with both fixed and isolated bases, various nonstructural components, and critical medical equipment - was conducted at the E-Defense facility in Japan. The test presented an opportunity to host a multi-phase Blind Prediction Competition (BPC). The contestants competed for modeling accuracy of structural, nonstructural, and functional responses in the two phases, before and after the tests. The prediction of overall structural responses was mostly accurate. However, the local behavior modeling of structural components still needed improvement, even with the preliminary component test results given. Some teams predicted the damage state of the equipment well, but response histories were not as accurate.

Introduction

Modern-day structural design engineers rely heavily on the accuracy of commercial modeling software and its analysis toolkits. Many available software packages cannot produce reliable solutions for complex systems, especially when dealing with delicate hospital ecosystems. Identifying the uncertainties in modeling analysis, including nonstructural components and medical equipment behavior, will lead to more reliable predictive models. In December 2020, researchers conducted full-scale shake table testing of a complex two-building steel structure representing a multi-story hospital with both a fixed and isolated base, various nonstructural fitout, and critical medical equipment at the E-Defense facility in Japan. The testing presented an opportunity to host a multi-phase Blind Prediction Competition (BPC) to examine the current integrated structural/nonstructural modeling capability.

This paper presents the overview and the results of the BPC held from August 2020 to July 2021. Students, researchers and practicing engineers participated in this competition. The results helped to identify areas of uncertainty and determine current, reliable modeling techniques related to structural and nonstructural damage and functionality, while also pinpointing future research opportunities.

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Competition Outline

Overview

The shake table test in December 2020 [1] quantitatively measured functionality and the current resilience in a typical hospital setting by adopting a full-scale experimental model of a complex two-building multi-story hospital with: (1) both fixed and isolated bases, (2) various nonstructural components, and (3) critical medical equipment. The testing led to a two-phased BPC held before and after the testing. Phase I challenged participants to develop structural, nonstructural behavior, and functional predictions prior to the shake table tests. While Phase II required detailed nonstructural behavior and functional predictions with limited experimental data provided. Teams were invited to participate in both phases but could only compete in one Phase.

Key Dates: Phase I start: August 2020; E-Defense tests: December 2020; Phase I prediction submission: December 2020; Recorded acceleration data uploaded to the website: December 2020; Phase II start: December 2020; Phase II prediction submission: May 2021; Top three teams notified: July 2021

Rules: Contestants were invited to participate as teams or individuals, with students, researchers, and professionals encouraged to participate. The contestants could use commercial or non-commercial software for their analysis. All participants were provided with building drawings, room configurations, nonstructural component details, and medical equipment specifications. Results were submitted and assessed through a provided spreadsheet and a one-page summary of the numerical approach

Table 1 shows the prediction categories. Contestants competing in the complex structural discipline were required to submit the results of a minimum of five categories with at least one fixed and base-isolated result. For Phase I, nonstructural/functional contestants were required to submit a minimum of five categories with at least one result from the nonstructural and functional discipline. For Phase II, nonstructural/functional contestants were required to submit a minimum of five categories with at least one result from the nonstructural and functional discipline. Table 1 also shows the damage state classification for the partition wall and functional equipment response, which were defined by the BPC committee based on literature reviews.

Table 1. Prediction categories and damage state classification

Competition	Categories
Complex Structural	Fixed-base: floor acceleration / story drift / beam end rotation / column base rotation Base-isolated: floor acceleration / isolator displacement / displacement in expansion joint
Nonstructural	Acceleration amplification factors of piping, elevated tank/displacement of surgical lights, ceiling pendant/damage states for partition walls
Functional Equipment	Rocking, overturning and/or sliding of NICU Incubator, dialysis machine, surgical bed

Classification	Partition wall	Functional Equipment Response
DS1	No damage	Minimal sliding (0.0-4.0 cm range)
DS2	Marginal displacement, screw loosening, continuous crack and/or displacement along joints and outer edges	Sliding (4.1-16.0 cm range), rocking, collapse of a support, part needs replacement but still functional
DS3	Deformed out-of-plane, mounting part or base damaged, continuous crack (<20% wall surface)	Overturning, sliding displacement (>16.1 cm range), collapse of multiple supports, nonfunctional
DS4	Total separation, continuous crack (>20% wall surface) mounting part or base completely damaged or detached	

Information Packets

The contestants were provided with the design concept, drawings, and key properties of the specimen in the information packets. This also included the quasi-static test results of major structural components, design strength, coupon test results, and the nonstructural components characteristics. Table 2 summarizes the information packets provided to the contestants.

Table 2. List of Information Provided to the Contestants

Complex Structural Response	Nonstructural Response	Functional Equipment Response
Drawings: Floor plans / Elevations / Member sections / Foundation detailing / Floor slab detailing / Isolator detailing / Column base details / Expansion joint details Data: Design strength of the columns and column bases / Component test data (beam-to-column connection) / Column base strength / Material properties	Drawings: Layout / Piping arrangement plan at 3F (fixed base) / Elevated tank dimensions and anchor plan at RF (fixed base) / Anchor for elevated tank / Partition arrangement plan at 2F (fixed base) / Members for partition wall / Surgical lights dimensions and anchor plan at 3F (fixed base) / Surgical light / Ceiling pendant dimensions and anchor plan at 3F (fixed base) and 3F (base-isolated) / Ceiling pendant details	Drawings: Layout / Incubators at 4F (fixed base) / Dialysis Machine at 3F (fixed base) / Multi person dialysis monitor DCS-27 Dialysis machine / Surgical bed at 2F (fixed base) / Ceiling pendant dimensions and anchor plan at 3F (fixed base) and 3F (base-isolated) / Ceiling pendant details / Floor conditions

Results

In Phase I, 81 teams from 19 countries registered initially despite the COVID-19 pandemic. There were finally 18 submissions for structural prediction (8 students / 6 professionals / 4 researchers), and six for the nonstructural and functional prediction (2 students / 3 professionals / 1 researcher). In Phase II, three teams submitted their predictions (2 professionals / 1 researcher). The eight BPC committee members reviewed team reports and independently ranked the prediction results. Table 3 presents the champion teams for each phase and the respective team status.

Table 3. Competition results

Competition	Champion team	Member status
Phase I Structural	Love512	Researcher /Professor
Phase I Nonstructural	KPFF - San Francisco	Professional
Phase II Nonstructural	Team KKE	Professional

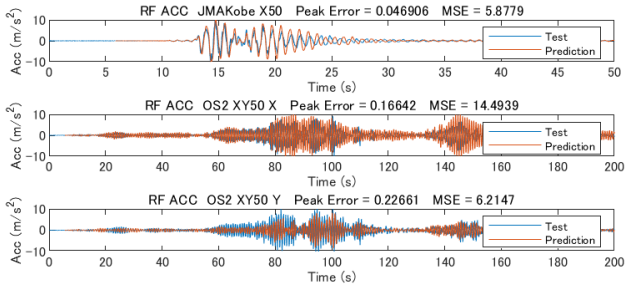
The champion team for Phase I structural category was Love512 (Ye-Ying JAN, Keh-Chyuan TSAI, Ming-Chieh, CHUANG, Jui-Liang LIN from National Taiwan University). The team consisted of researchers and professors. This team utilized OpenSees, Version 3.0.0.1, and Gid+OpenSees 2.8.0 as the GUI for building the model. The model was a 3D model, with inelastic ZeroLength rotational spring elements specified at the column bases, and a self-centering material model simulated the flag-shape cyclic responses.

The champion team for Phase I nonstructural category was KPFF-San Francisco (John-Michael WONG, Kenneth OGORZALEK, Jakub VALIGURA, Derek AVRIT, Matthew SEIDEL, Samuel DELWICHE). The responses of nonstructural elements were determined using a combination of structural engineering software. The analysis results for each individual equipment or nonstructural component were obtained from the main ETABS building model, which was analyzed using ETABS Ultimate 64-Bit, v19.0.0 by Computers and Structures, Inc. The acceleration time histories at the location of equipment were extracted from the building model.

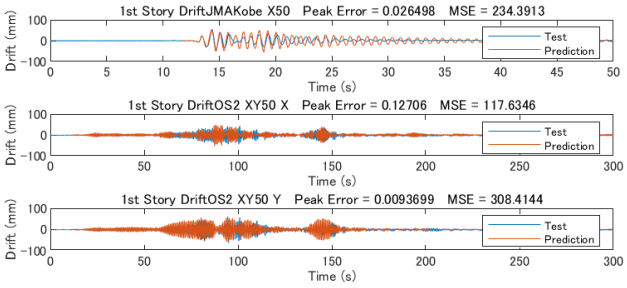
The champion team for Phase II was Team KKE (Yukimori YANAGAWA, Kaiwei ZHANG, Jingye LIU, Hiromasa AIDA, So SUZUKI, Takumi NODA, Naoya GOTO, Ryo YONAO, Ippei HATA, Toshiyuki MASATSUKI from KOZO KEIKAKU ENGINEERING Inc.). They used Midas for the piping model; RESP-F3T for modelling the elevated tank, surgical light, ceiling pendant; direct estimation for partition walls; Springhead2 for modelling the incubator, dialysis, and surgical bed response.

In summary, all teams constructed a frame model for Phase I structural, but the details were different. In Phase I nonstructural category, one team used the capacity spectrum method to predict the input to nonstructural components while the others used the time-history responses simulated from the frame model. Most teams constructed the analysis model of the nonstructural component and equipment to predict time-history responses. Some teams used a code-based approach for the amplification factor of piping and tanks, and fragility curves for partition walls' damage state.

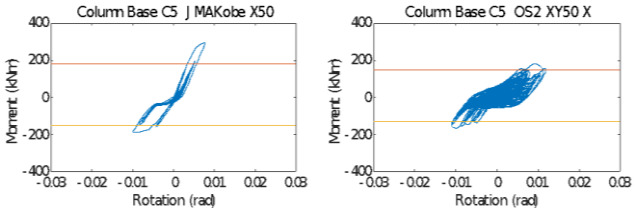
Fig. 1(a)-(d) collects the most accurate predictions from Phase I structural. The overall structural responses of the fixed frame, i.e., roof acceleration and story drift, were well predicted. However, the local component behavior was not well traced, despite the component test results were provided in advance to the shake table test. Several teams impressed the committee with almost exact roof accelerations and the isolation displacement of the base-isolated frame



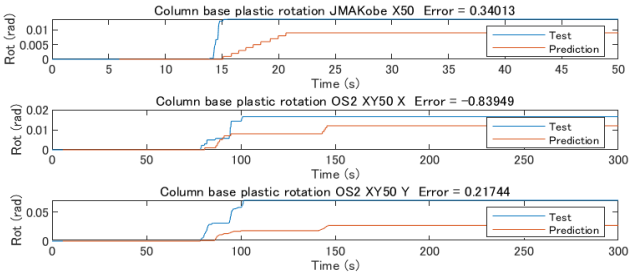
(a) roof acceleration (Fixed)



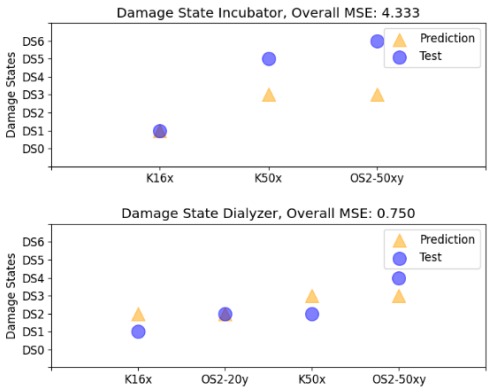
(b) 1st story drift (Fixed)



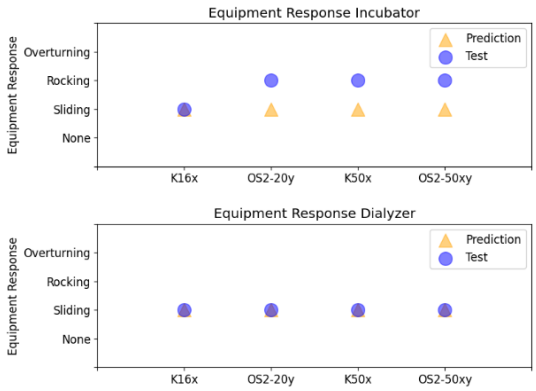
(c) column base rotation (C5 in X dir.)



(d) cumulative plastic rotation (C5 in X dir.)



(e) damage state (incubator and dialyzer)



(f) equipment response (incubator and dialyzer)

Fig. 1 Top prediction collection

predictions. Fig. 1(e)-(f) summarizes the results from Phase II nonstructural. The champion team predicted the damage state and equipment responses very well. However, their displacement response histories were not as accurate.

Summary

This paper provided a very short overview of the blind prediction competition on a full-scale test of a steel hospital specimen. The contestants competed for modeling accuracy on structural response, nonstructural response, and functional prediction. The overall structural response predictions were mostly accurate. However, teams did not achieve the same level of accuracy with the local structural behavior prediction. The top team predicted the equipment damage state very well, but accurate time history tracking remained elusive.

Acknowledgements

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References

1. Kurata M, Kawamata Y, Kanao I, Ohtsuru S, Fujita K, Matsuo S, Kojima K, Cho K, Tsutsumi T, Aida S, Akazawa M, Saburi K, Nishitani A. 2020 E-Defense Test for Integrated Structural, Nonstructural and Functionality Assessment of Medical Facilities. *Proceedings of the 12th National Conference in Earthquake Engineering*, EERI, Salt Lake City, UT. 2022.