Experimental Data Sharing for Structural Health Monitoring and Control

ASCE EMI Technical Committee on Structural Health Monitoring and Control

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CHAPTER 1. BRIDGES

1.1 Continuous Monitoring of the Dowling Hall Footbridge

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Test Structure(s)

The Dowling Hall footbridge is a continuous two-span (22 m long for each span) steel frame bridge with a concrete deck (3.9 m wide) located at Tufts University campus, as shown below:

Figure 1. Dowling Hall Footbridge (photo on the right from www.maps.bing.com)

Instrumentation and Test Procedures

Two phases of instrumentation were deployed on the footbridge. Phase I of the monitoring system was performed in the fall of 2009, which included an array of eight accelerometers and ten thermocouples, a rugged and remotely operable data acquisition system, and a reliable communication system. The monitoring system had been running continuously from January 2010 to March 2012. At phase II, four additional accelerometers and four strain gages were added on the bridge.

Data Description

The monitoring program continuously samples the acceleration response at a 2048 Hz sampling rate. Temperatures are recorded at a rate of one sample per second. A 5-minute data sample is recorded to the storage drive at the beginning of each hour. The program also performs automatic triggering by continuously monitoring the one-second RMS value of each acceleration channel and will record a 5-minute sample if the values exceed 0.03 g. An automated stochastic subspace identification method is used for continuous modal analysis of the footbridge for each of hourly measured records. A stabilization diagram is used to automatically select the physical modes of interest.

Web Link to Data Repository

https://engineering.tufts.edu/cee/shm/research_BM_continuousMonitoring.asp#weeks.

Acknowledgements The authors acknowledge partial support of this study by the National Science Foundation Grant number 1125624 and Tufts University Faculty Research Award Committee.

References

[1] Moser, P., and Moaveni, B. (2013). "Design and deployment of a continuous monitoring system for the Dowling Hall Footbridge." Experimental Techniques, 37(1), 15-26.

[2] Moser, P., and Moaveni, B. (2011). "Environmental effects on the identified natural frequencies of the Dowling Hall Footbridge." Mechanical Systems and Signal Processing, 25(7), 2336-2357.

[3] Moaveni, B., and Behmanesh, I. (2012). "Effects of changing ambient temperature on finite element model updating of the Dowling Hall Footbridge." Engineering Structures, 43, 58-68.

1.2 Continuous Monitoring of Chillon Viaduct under Environmental and Operational Variability Conditions

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Test Structure. Constructed in 1969, the Chillon viaducts were strengthened in 2015 via a layer of Ultra High Performance Fiber Reinforced Cement-based Composite (UHPFRC) cast atop their decks. In order to assess the efficacy of this rehabilitation solution, and further evaluate its long-term performance, a Structural Health Monitoring (SHM) campaign was implemented by ETH Zurich. Three months of monitoring data have been shared with the community, with more to follow, allowing to study the influence of Operational and Environmental Conditions on the modal parameters and to further infer Performance Indicators (PIs) for assessing structural behavior [1].

Instrumentation and Test Procedures The data was analyzed by means of both an operational modal analysis (ERA-NeXT), as well as a non-stationary analysis (SP-TARmodel) to investigate environmental and operational influences. The bridge behavior was further simulated via an updated shell-based Finite Element (FE) model, set up in SAP2000. Defining properties such as elastic modulus of concrete, asphalt and bearing stiffness have been modeled as a function of temperature in the operational range of 5 to 30 ºC. Relying on the data, different Performance Indicators (PIs) were obtained in order to quantify the effects of UHPFRC strengthening. We distinguish the function of these PIs into a) purely data-driven, i.e., fatigue accumulation calculated from the installed strain gauges and damage detection by monitoring frequency evolution, and b) hybrid PIs, where a FE model is coupled to the data for the purpose of more intricate investigations, such as reliability analysis.

Data Description A span of 98 m, in the central portion of the viaduct, has been instrumented with 11 accelerometers distributed along the span, as well as four strain gauges and environmental sensors (measuring temperature and humidity) installed at mid-span. The strain gauges were located directly on the rebar, aiming to capture fatigue effects in both the longitudinal and transverse direction.

Web Link to Data Repository https://zenodo.org/record/3234805#.XooIVogzZaR

Acknowledgements (optional) The authors would like to acknowledge the Swiss National Science Foundation (SNSF), which has supported this research (project # 154060).

References

[1] Martín-Sanz, H., Tatsis, K., Dertimanis, V. K., Avendaño-Valencia, L. D., Brühwiler, E., & Chatzi, E. (2020). Monitoring of the UHPFRC strengthened Chillon viaduct under environmental and operational variability. Structure and Infrastructure Engineering, 16(1), 138-168.

CHAPTER 2. BUILDINGS

2.1 Dynamic Testing of a Full-Scale 2-Story 2-Bay Reinforced Concrete Frame

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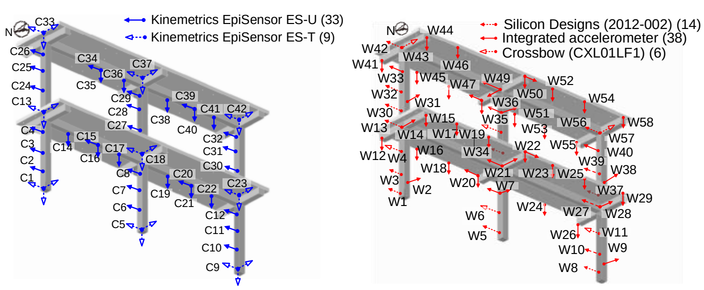
Test Structure Four identical concrete test frames were built at full scale outside the Structural Engineering and Materials Laboratory on Georgia Tech campus (Fig. 1). The frames are individually separate from each, with a gap between every two neighboring frames. Each frame consists of two bays and two stories and was meant to be representative of non-ductile reinforced concrete office buildings in the central and eastern United States built in the 1950s-1970s[1]. Frame #1 is an as-built bare frame as the reference structure, while different seismic retrofit measures are applied to the other three frames for comparison. This data sharing is for testing results from Frame #1.

Fig. 1. Full-scale frames and the 75-kip shaker on Frame #1 under test

Instrumentation and Test Procedures A 75-kip hydraulic linear inertial shaker provided by NEES@UCLA is mounted on the second elevated slab, i.e. roof top. Tens of shaker excitations were applied, with gradually increasing amplitude and causing damage to the concrete frame. The frame is first installed with 42 Kinematrics cabled accelerometers on columns and girders to capture the acceleration responses (Fig. 2a). Most of the cabled measurements are uniaxial, while a few are bi-axial or tri-axial; they provide a total number of 60 acceleration channels. To increase spatial resolution of the instrumentation, a total of 66 wireless acceleration channels are interspersed between cabled accelerometers (Fig. 2b).

Data Description There are a total of 126 acceleration channels installed on the structure, including both cabled and wireless channels [2]. Through the course of a few days, 61 sets of dynamic data sets are recorded. In addition, the cabled sensors recorded ambient vibration response of the structure, including vibrations of the mat foundation.



(a) Cabled sensing system (b) Wireless sensing system

Fig. 2. Accelerometer instrumentation on Frame #1

Web Link to Data Repository Test ID numbers 334847085 ~ 334847146 contain the 61 data sets from Frame #1. https://datacenterhub.org/dv_dibbs/view/1631:dibbs/experiments_dv/

Acknowledgements This research is partially sponsored by the National Science Foundation (#CMMI-1041607 and #CMMI-1150700).

References

[1] T. R. Wright, Full-scale Seismic Testing of a Reinforced Concrete Moment Frame Using Mobile Shakers, Ph.D. Thesis, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA, USA, 2015.

[2] X. Dong, X. Liu, T. Wright, Y. Wang, and R. DesRoches, "Validation of wireless sensing technology densely instrumented on a full-scale concrete frame structure," Proceedings of the International Conference on Smart Infrastructure and Construction (ICSIC), Cambridge, U.K., 2016.

2.2 Dynamic Tests of a Ten-Story RC Building at Multiple Damage Levels Using a Portable Shaker

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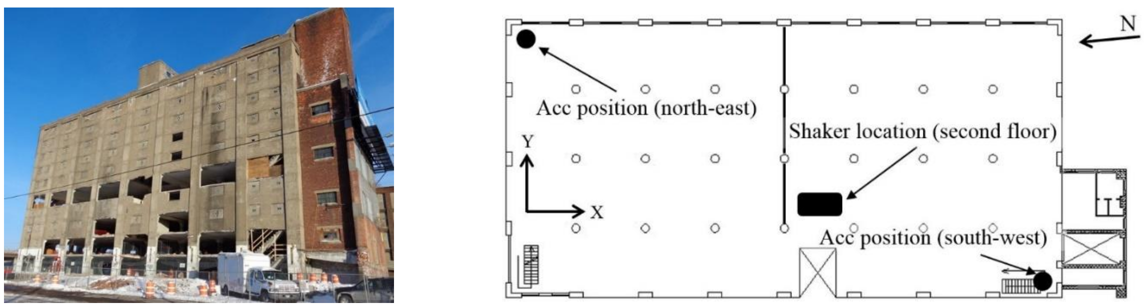
Test Structure. Dynamic tests were performed on the ten-story warehouse building shown in Figure 1 to obtain its dynamic properties and their changes due to the damage introduced during the tests. The structure had a slab-column structural system and concrete infill walls in the exterior bays. In plan, the building was 24.4 m by 48.8 m (80 ft. by 160 ft.). A typical floor had the plan view shown in Figure 1 and a story height of 2.6 m (102 in.). More information about the test structure and the tests can be found in [1 and 2].



(a) building view from west side (b) plan view of second floor

Figure 1. Test structure and test setup.

Instrumentation and Test Procedures. The test structure was instrumented with an array of 60 accelerometers installed at two opposite corners of each floor slab except for the roof, as shown in Figure 1b. An eccentric mass shaker was installed on the second story slab to introduce harmonic excitations along the two horizontal axes of the building, and at a 45-degree angle between those.

Data Description. A total of 87 forced vibration excitations were performed and 52 hours of ambient vibrations were recorded during the testing period. Moreover, during the wall demolition process, free vibration responses of the structure due to the impulses imposed by a jack hammer used for infill demolition were recorded. More information can be found in [3].

Web Link to Data Repository. https://doi.org/10.17603/DS28382

Acknowledgments. The study was supported by the National Science Foundation (award No. 1430180). The tests were conducted thanks to the permission and remarkable cooperation of the New York State Department of transportation (NYSDOT), and director Andrew Roberts.

References

[1] S. Yousefianmoghadam, Investigation of the Linear and Non-Linear Dynamic Behavior of Existing Reinforced Concrete Buildings through Tests and Simulations, *Ph.D. Dissertation*, University at Buffalo, Buffalo, NY, 2019.

[2] S. Yousefianmoghadam, I. Behmanesh, A. Stavridis, B. Moaveni, A. Nozari, A. Sacco, System Identification and Modeling of a Dynamically Tested and Gradually Damaged 10-Story Reinforced Concrete Building, *Earthquake Engineering & Structural Dynamics*, 47.1 (2019) 25-47. https://doi.org/10.1002/eqe.2935

[3] S. Yousefianmoghadam, A. Stavridis, B. Moaveni, Dynamic shaker testing of a ten-story reinforced concrete building, *DesignSafe-CI*, Dataset, 2017. https://doi.org/10.17603/DS28382

2.3 Quantification of Collapse Margin for Steel High-rises

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Test Structure(s) A one-third scale specimen of 18-storey steel hi-rise and a protective frame were rationally constructed and installed properly on the E-Defense shake table. The specimen represents the behavior of a typical steel high-rise and responds to earthquake as a steel moment-resisting-frame. The specimen is based on a steel high-rise constructed in 1980s to 90s where the column-to-beam strength ratio of 1.5 is provided to achieve a weak-beam strong-column mechanism. No inherent deficiencies are intentionally given.

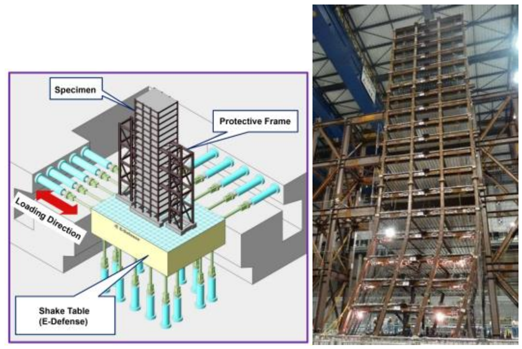

Fig. 1 18-story specimen at the E-Defense

Instrumentation and Test Procedures The specimen was excited only in one direction. The input ground motion was a design synthetic ground motion with long-period characteristics for a Tokai-Tonankai-Nankai subduction-zone earthquake with the epicenter in the Nankai trough. The ground motion was synthesized assuming a building site and phase, and was processed properly for shake table use with the scaling law and a band-pass filter

Data Description Various types of sensors were mounted and, in total, 879 data channels were measured. Data of the all channels were successfully obtained for all loading cases including main earthquake loadings and white-noise loading. In particular, images from digital cameras captured clearly the behavior of the overall specimen and fracture at beam ends. The total size of the recorded data was 194 GB.

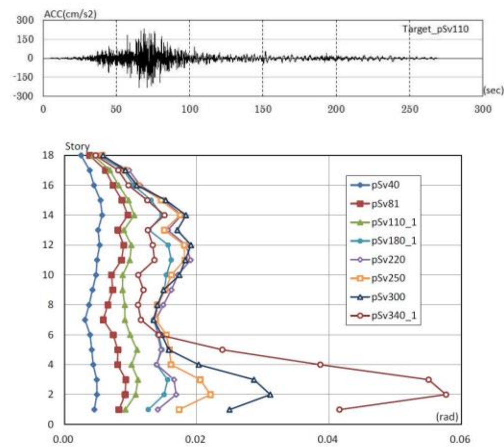

Fig. 2 Input motion and story drift responses

Web Link to Data Repository

http://www.steel.dpri.kyoto-u.ac.jp/dummy/18steel_Edefense/3_1_1/project.html.

Acknowledgements The study was conducted as part of research sponsored by Japan's Ministry of Education, Culture, Sports, Science and Technology under the title (ii) Maintenance and Recovery of Functionality in Urban Infrastructure, which is a sub-project of the Special Project for Reducing Vulnerability in Urban Mega Earthquake Disasters.

References

[1] K. Suita, Suzuki, Y., and M. Takahashi, "Collapse Behavior of an 18-Story Steel Moment Frame during a Shaking Table Test," Int. J. High-Rise Buildings, 4(3), pp. 171-180, 2015

[2] J. Kubota et al., "Experimental study on the collapse process of an 18-story high-rise steel building based on the large-scale shaking table test," 16WCEE, Santiago, Chile, No. 792, 2017

CHAPTER 3. OTHER STRUCTURES

3.1 The DR-Train Dataset: Dynamic Responses of Train Vibrations, GPS Positions, and Environmental Conditions of the Pittsburgh Light Rail System

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Test Structure(s)

We monitored the Pittsburgh Light Rail System from sensors placed on passenger trains. The Pittsburgh Light Rail is a 42.2-km network, owned and operated by the Port Authority of Allegheny County. The rail system, including imbedded street running track, direct fixation track and ballasted track, uses the Pennsylvania Trolley gauge rail whose track gauge is 1,588 mm. Also, the network contains bridges, viaducts, and tunnels, and is exposed to variable environmental conditions.

Instrumentation and Test Procedures

We instrumented two trains with accelerometers and GPS to collect train vibration responses (due to the interactions with rail tracks) and positions [1]. Our data management system consists of four modules: sensing, data-acquisition, data-storage, and data-processing modules. In papers [2-4], our group used the collected dataset to detect changes in the track conditions and track geometry.

Data Description

This dataset provides 3 years of dynamic responses of in-service trains via acceleration data with sampling frequency of 1.6 kHz, which enables low-cost continuous track monitoring. The dataset also includes corresponding GPS positions of the trains sampled at 1 Hz, environmental conditions (including temperature, wind, weather, and precipitation at 1 Hz), and track maintenance logs collected weekly. The data is stored in a MAT-file format and can be conveniently loaded for various potential uses, such as validating anomaly detection, data fusion, and investigating environmental influences on train responses.

Web Link to Data Repository

https://doi.org/10.5281/zenodo.1432702.

References

[1] J. Liu, S. Chen, G. Lederman, D. B. Kramer, H. Y. Noh, J. Bielak, J. H. Garrett, J. Kovačević, M. Bergés, Dynamic responses, GPS positions and environmental conditions of two light rail vehicles in Pittsburgh, Scientific Data, Accepted.

[2] G. Lederman, S. Chen, J. Garrett, J. Kovačević, H. Y. Noh, & J. Bielak, Track-monitoring from the dynamic response of an operational train, Mechanical Systems and Signal Processing, 87, (2017) 1-16.

[3] G. Lederman, S. Chen, J. Garrett, J. Kovačević, H. Y. Noh, & J. Bielak, Track monitoring from the dynamic response of a passing train: a sparse approach, Mechanical Systems and Signal Processing, 90, (2017) 141-153.

[4] G. Lederman, S. Chen, J. Garrett, J. Kovačević, H. Y. Noh, & J. Bielak, A data fusion approach for track monitoring from multiple in-service trains, Mechanical Systems and Signal Processing, 95, (2017) 363-379.