



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

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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 °C. 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>

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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 Kinometrics 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 accelerometers 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.

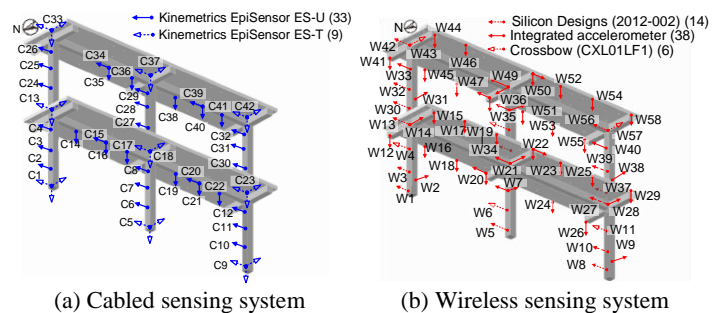


Fig. 2. Accelerometer instrumentation on Frame #1

Web Link to Data Repository Test ID numbers 17185659 ~ 17185720 contain the 61 data sets from Frame #1 (https://datacenterhub.org/deedsdv/static_main/view/389/experiments_dv/).

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

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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].

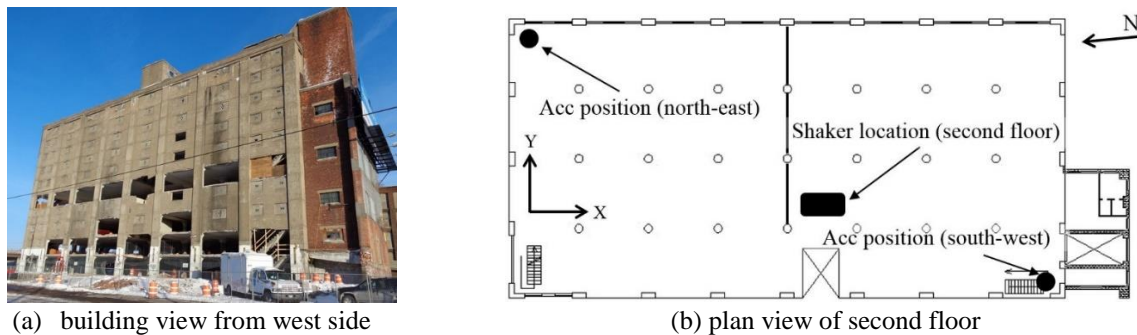


Fig. 1. Test structure and test setup.

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.

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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.

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.

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.

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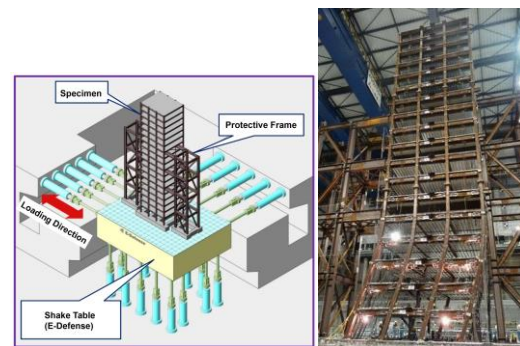


Fig. 1 18-story specimen at the E-Defense

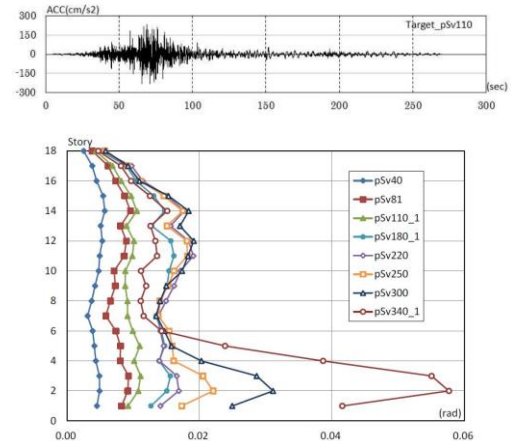


Fig. 2 Input motion and story drift responses

2.4 Dynamic Testing of a 4-Story Steel Shear Frame

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Test Structure Experimental data stems from a four-story structural steel model (Fig. 1), mounted on a uniaxial hydraulic shake table. The structure consists of four stories, with an interstory height of 533 mm and floor dimensions of 610 mm by 457 mm. The structure is braced to make it preferentially flexible in the direction of excitation, allowing for a clear spectrum of bending modes in this direction. All structural connections are bolted. The direction of excitation is referred to as the *weak* bending direction and the direction normal to excitation is referred to as the *strong* bending direction of the structure [1,2].

Instrumentation and Test Procedures The model is instrumented with piezoelectric accelerometers, with seven channels response on the structural model and one reference channel on the shake table's platform. The sensors are attached magnetically to the column connection plates at each floor.

Data Description Various input acceleration time histories are run on the structure in undamaged and damaged states (see references below for further information on damage locations): El Centro, Hachinohe, Kobe, Northridge earthquakes and band-limited white noise.

Web Link to Data Repository

<https://academiccommons.columbia.edu/doi/10.7916/d8-5tvb-8w36>

Acknowledgements This research was made possible by the shared facilities of the Robert A. W. Carleton Strength of Materials Laboratory at Columbia University.

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Fig. 1 Structural model on shake table

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>

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3.2 Aventa AV-7 ETH Zürich Research Wind Turbine SCADA and High Frequency Structural Health Monitoring (SHM) Data

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Test Structure(s) The three-bladed Aventa AV-7 wind turbine owned by ETH, installed in 2002, is located in Taggenberg, about 5 km from the city centre of Winterthur, Switzerland. The belt-driven generator wind turbine with a rated power of 7 kW has a production wind speed range of 2 m/s to 14 m/s. The turbine is controlled by a variable speed control system up to a maximum speed of 63 rpm and has a collective variable pitch control system. The tower is a steel-reinforced concrete structure supported on a concrete foundation, while the blades are made of fibreglass with a tubular steel main spar [1].

Instrumentation and Test Procedures The tower and nacelle are instrumented with 11 accelerometers distributed along the length of the tower, nacelle main frame, main bearing and generator. Two full bridge strain gauges, which can be converted to bending moments, are installed on the concrete tower. Temperature and humidity are measured at the base of the tower. In addition, operational performance data (SCADA) such as wind speed, nacelle yaw orientation, rotor speed, power output and turbine status can also be sampled [1].

Data Description In order to evaluate the various techniques for predicting the remaining useful life, a structural health monitoring campaign implemented by ETH Zürich started in 2020 and is still ongoing. In addition, the facility will be used as a research platform for topics such as system identification, operational modal analysis, failure/damage detection and classification.

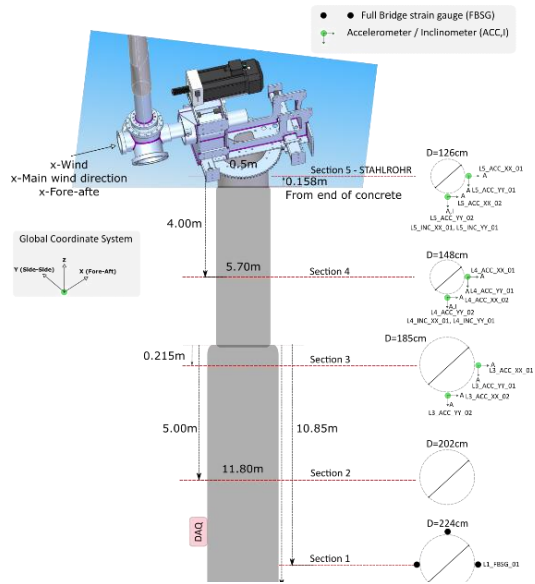


Figure 1: Tower measurement layout [1].

The ASCE-EMI Structural Health Monitoring for Wind Energy Challenge is based on this data, and runs from June 21st to November 14th, 2024. The goal of the challenge is to detect three fault events (pitch drive failure, aerodynamic imbalance, icing event) with the highest possible accuracy. Find out more here: <https://www.wedowind.ch/spaces/the-rtdt-research-affiliate-programme-space>.

Web Link to Data Repository:

<https://zenodo.org/records/8229750>

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