SMART Bridges – Vibration measurements on a laboratory bridge model with controllable damage

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Acceleration measurements on a 6 m laboratory model of a box-girder bridge made of aluminium profiles and sheets. The model was excited by two electrodynamic shakers with uncorrelated band-limited white noise, and damage was introduced in a controlled way by loosening or removing bolted connections at the joints between its six segments. Each run records 20 accelerometers for 600 s at 600 Hz.

The dataset contains the raw measurements and the information needed to use them: the test setup, sensor and shaker positions, damage states, and the excitation signals. It contains no processed results.

At a glance

Runs	250 (213 experiments, 23 check-ups, 13 faulted runs, 1 baseline without excitation)
Period	2026-03-19 to 2026-10-27
Per run	600 s at 600 Hz = 360 000 samples; 20 accelerometers (18 on the structure, 2 on the shaker pads)
Damage	5 damage types (A–E) × 3 segments (1, 2, 4) × intensities Low / Medium / High
Excitation	2 shakers, 9 positions, 3 intensities each
Sensor layouts	4
Size	7.6 GB uncompressed

Contents

Path	Content
`data/<ID>.npy`	one file per run, named by its experiment ID (e.g. `EXP_0001.npy`)
`metadata/experiments.csv`	one row per run: type, date, damage, sensor layout, shaker positions and intensities, measured excitation level, remarks
`metadata/experiments.pdf`	the same table, formatted for reading
`metadata/locations.csv`	coordinates of all measurement locations (sensor and shaker pads)
`metadata/sensor_layouts.csv`	location of Sensors 1–18 in each of the four sensor layouts
`metadata/sensors.csv`	the 20 sensors: role, type, measuring range
`metadata/damages.csv`	the damage types A–E and the bolts loosened per intensity
`excitation/excitation_signals.npy`	the six shaker drive signals (2 shakers × 3 intensities)
`drawings/`	`bridge_overview.pdf`, `segment_layout.pdf` (sensor and shaker points), `damage_locations.pdf`
`docs/`	`setup.md` (test setup), `naming.md` (IDs and table columns), `data_quality.md` (known issues)
`documentation.pdf`	this README and the three documents in `docs/` as one PDF
`scripts/load_dataset.py`	loader, requires only Python and NumPy
`examples/`	`plot_examples.py` loads three runs and writes `plot_examples.png`
`checksums.sha256`	SHA-256 checksums of all files

The dataset is distributed as two zip files. Part 1 contains everything except the second half of the data files, which is in part 2. Extract both into the same folder to obtain the complete dataset; each part can also be opened on its own.

Data format

Every `data/<ID>.npy` holds a NumPy array of type `float32` with shape `(360000, 21)`:

Column	Content	Unit
0	time since the start of the recording	s
1 … 20	Sensor 1 … Sensor 20	g (1 g = 9.80665 m/s²)

Sensors 1–18 measure the structure; where they sit depends on the run's sensor layout (`metadata/sensor_layouts.csv`). Sensor 20 and Sensor 19 are mounted on the pads of Shaker 1 and Shaker

2 and record the excitation (`shaker1_location`, `shaker2_location` in `experiments.csv`). The sensor values are the recorded values without any processing; their conversion to `float32` is lossless. The time column equals sample number / 600 Hz (rounded to `float32`, i.e. to within 0.03 ms).

`.npy` is NumPy's documented open format and can also be read by MATLAB (e.g. the `npy-matlab` package), Julia (`NPZ.jl`) and R (`RcppCNPy`).

Quick start

```
import sys; sys.path.insert(0, "scripts")
from load_dataset import Dataset

ds = Dataset(".")                                    # path to this folder
run = ds.load("EXP_0001")
run["acc"].shape                                     # (360000, 20), Sensor k = column k-1
run["meta"]["state"], run["meta"]["sensor_layout"]
ds.ids(run_type="EXP", damage_code="E", damage_segment="1")   # select runs by metadata
```

Without the loader: `numpy.load("data/EXP_0001.npy")`, and `metadata/experiments.csv` with any CSV reader.

Before using the data

Read `docs/data_quality.md`. In particular:

- runs whose ID starts with `FLT_` are faulted (dead channel, misplaced or loosened sensor); the fault is described in the `remarks` column, and most of them were repeated under the same number without `FLT_`;
- a few runs have a reduced excitation level on one shaker (`remarks`); the measured excitation level of every run is given in `shaker1_ref_rms_g` / `shaker2_ref_rms_g`.

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Citation

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Test setup

Structure

The test structure is a laboratory model of a box-girder bridge, about 6.1 m long. It consists of six bolted box segments (`drawings/bridge_overview.pdf`). Each segment is a 980 mm frame of aluminium profiles (Rose+Krieger BLOCAN F) plus a 30 mm transverse frame, so segments repeat every 1010 mm. The box is closed by 2 mm aluminium sheets (top, bottom, two side walls), clamped to the profiles with bolted clamping strips. A trapezoidal stiffener (1 mm sheet) runs below the top sheet. Neighbouring segments are bolted together at their transverse frames through a 2 mm joint plate.

The bridge rests on two transverse support bars, about 300 mm from both ends (span about 5.49 m).

Coordinate system

All coordinates are in mm:

- **x** along the bridge, from the outer face of the first end frame (segment 1 covers x = 0 … 1010);
- **y** vertical, upwards, from the centre of the cross-section;
- **z** horizontal across the bridge, from the centre of the cross-section; z+ points towards the side wall that carries sensors (points 03/04).

Measurement locations

Every segment has the same set of points (`drawings/segment_layout.pdf`): points 01–18 are sensor pads, points 51–55 shaker pads on the top sheet. A location is identified by **location id = 100·s + p** with segment s (1…6) and point p, e.g. 405 = segment 4, point 05. `metadata/locations.csv` lists the coordinates of all locations; they refer to the pad centre on its outer surface.

- 01–02 top sheet, 03–04 side wall z+, 05–07 bottom sheet;
- 08–09 joint plate at the x+ end of the segment;
- 10–18 trapezoidal stiffener (web z+, bottom flange, web z−, at its x+ end, middle and x− end).

Point 07 lies at the x− end of its segment. Sensor layouts 1–3 use point 07 of the *following* segment (e.g. location 207 in layout 1), so that both sides of the instrumented joint are covered.

Next to the supports the outer stinger holes had to be moved 160 mm inwards: points 51/52 lie at local x = 172 mm in segments 2–6 (332 mm in segment 1), points 54/55 at local x = 610 mm in segment 6.

Sensors and measurement system

- 20 accelerometers ADXL354 on evaluation boards (`metadata/sensors.csv`); measuring range ±2 g for Sensors 1–18 and ±8 g for Sensors 19 and 20.
- Each accelerometer records one axis, normal to the surface of its pad: y on the top sheet, the bottom sheet, the stiffener's bottom flange and the shaker pads (Sensors 19 and 20); z on the side wall; x on the joint plate; normal to the inclined web on the stiffener webs (column `measuring_direction` in `metadata/locations.csv`). The sign of the axis is not specified.
- Data acquisition: two HBM QuantumX MX1615B modules (Sensors 1–10 and 11–20), software catman Easy/AP 5.4, sampling rate 600 Hz, recording length 600 s.

Sensor layouts

Sensors 1–18 were moved between four sensor layouts (`metadata/sensor_layouts.csv`, table on `drawings/segment_layout.pdf`):

Layout	Sensors 1–18 on
1	all points of segment 1 (point 07 of segment 2)
2	all points of segment 2 (point 07 of segment 3)
3	all points of segment 4 (point 07 of segment 5)
4	points 01, 02, 03, 05, 08, 13 of segments 1, 2 and 4

Excitation

Two electrodynamic shakers stand on the floor below the bridge. Their stingers pass through the bottom sheet and are fastened to the top sheet at a shaker pad. Shaker 1 was used at locations 351, 354, 451, 452, 552 and 554, Shaker 2 at 152, 251 and 253. The reference accelerometers Sensor 20 (Shaker 1) and Sensor 19 (Shaker 2) sit on the shaker pads and record the excitation actually introduced.

Both shakers were driven with band-limited Gaussian white noise, flat from 0.6 Hz to 200 Hz, the two shakers mutually uncorrelated. The signals were played as displacement commands from the analog outputs of an Instron 8800 classic controller. There are three intensities per shaker; the two shakers can run at different intensities in the same run.

Intensity	Peak of command	RMS of command
Low	0.025 mm	≈ 0.005 mm
Medium	0.05 mm	≈ 0.01 mm
High	0.1 mm	≈ 0.02 mm

The commands are 650 s long at 1 kHz; each of the six (2 shakers × 3 intensities) is an independent noise realisation. They are provided in `excitation/excitation_signals.npy` (float64, columns: time [s], Shaker 1 Low/Medium/High, Shaker 2 Low/Medium/High, in mm). The recordings were not synchronised with the playback, so the drive signals cannot be aligned with the measured data sample by sample. Measured at the shaker pads, the levels Low : Medium : High are about 1 : 1.9–2.0 : 3.6–3.9 in acceleration.

Damage

Damage was introduced at the joint between two segments by loosening bolts (`drawings/damage_locations.pdf`, `metadata/damages.csv`). A damage is identified by its **code** (A–E), the **segment** it was applied to (1, 2 or 4) and its **intensity** (Low, Medium, High). A damage of segment s lies within segment s, at its joint with segment s+1, and grows away from that joint with increasing intensity.

Code	Connection	Bolts loosened Low / Medium / High
A	angle brackets connecting the end of the trapezoidal stiffener to the transverse frame	High only: both brackets detached
B	trapezoidal stiffener to top sheet	2 / 3 / 5
C	upper edge of side wall z+ (clamping strip)	2 / 4 / 7
D	lower edge of side wall z+ (clamping strip)	2 / 4 / 7
E	bottom joint to the next segment, inner / outer bolts	1+2 / 2+4 / 4+6

Test procedure

The campaign was organised in blocks with a fixed sensor layout and fixed shaker positions. Within a block the undamaged structure and the damage states were measured at several combinations of shaker intensities. **Check-ups** (`CHK_`) repeat the undamaged reference measurement of a block (column `reference_run`) to show how well a setup is reproduced. One **baseline** run (`BASE`) was recorded with the shakers switched off.

Naming and table columns

Run IDs

Prefix	Meaning
EXP_nnnn	experiment: undamaged or damaged structure, numbered in the order of the test plan
CHK_nnnn	check-up: repetition of the undamaged reference run of a block (see reference_run)
FLT_EXP_nnnn, FLT_CHK_nnnn	faulted run: a recording of EXP_nnnn / CHK_nnnn with a measurement fault (see remarks); if the run was repeated, the fault-free recording carries the number without FLT_ (repeated_as)
BASE	baseline: shakers switched off

The numbers follow the test plan, not the time of recording. Gaps in the numbering are runs that were planned but not measured. FLT_EXP_0120 is the only recording of experiment 0120.

Location IDs

location id = 100·s + p, with segment s = 1…6 and point p = 01…18 (sensor pads) or 51…55 (shaker pads), see docs/setup.md and drawings/segment_layout.pdf.

Damage

A damage is described by three columns: damage_code (A–E, see metadata/damages.csv), damage_segment (1, 2 or 4) and damage_intensity (Low, Medium, High). All three are empty for undamaged runs.

metadata/experiments.csv

Column	Content
experiment_id	run ID (see above); also the name of the data file
run_type	EXP, CHK, FLT_EXP, FLT_CHK or BASE
date	date of the recording (local time, Germany)
run_of_day	running number of the recording on that date (1 = first run of the day)
state	Undamaged or Damaged
damage_code, damage_segment, damage_intensity	damage, see above
sensor_layout	sensor layout 1–4 (positions of Sensors 1–18)
shaker1_location, shaker2_location	location id of the shaker pad (Sensor 20 sits on Shaker 1's pad, Sensor 19 on Shaker 2's)
shaker1_intensity, shaker2_intensity	drive intensity Low, Medium, High (None for BASE); where the measurement shows that a different drive signal was played than planned, the intensity actually played is given
shaker1_ref_rms_g, shaker2_ref_rms_g	measured excitation level: RMS of Sensor 20 / Sensor 19 in 5–200 Hz in g (Welch PSD, 4096-point Hann window)
reference_run	CHK and FLT_CHK: experiment whose undamaged setup is repeated; BASE: experiment with the same setup
repeated_as	FLT runs: ID of the fault-free repetition, if one exists
remarks	faults and quality notes, see docs/data_quality.md
file	path of the data file relative to the dataset folder

metadata/locations.csv

Column	Content
location_id	100·segment + point
segment, point	segment 1–6, point 01–18 / 51–55
kind	sensor or shaker pad
x_mm, y_mm, z_mm	coordinates of the pad centre on its outer surface
measuring_direction	axis measured by a sensor on this pad (normal to the pad): x, y, z or web normal (inclined stiffener web); sign not specified
description	position of the point within its segment

Column	Content
used	yes if a sensor or shaker was placed there in at least one run

metadata/sensor_layouts.csv

One row per layout and sensor: `sensor_layout`, `sensor` (1–18), `location_id`. Sensors 19 and 20 are not part of the layouts; they sit at the shaker locations of each run.

metadata/sensors.csv

Column	Content
`sensor`	sensor number 1–20
`npy_column`	column in the data files (column 0 is time)
`role`	bridge response, or reference sensor of Shaker 1 / Shaker 2
`sensor_type`	accelerometer type
`measuring_range_g`	measuring range ± in g
`unit`	unit of the data
`amplifier_module`	data acquisition module

metadata/damages.csv

Column	Content
`damage_code`	A–E
`component`, `connection`	where the damage is applied
`loosened_low`, `loosened_medium`, `loosened_high`	number of bolts loosened at each intensity (E: inner / outer bolts)
`application`	order in which the bolts are loosened

Data quality

The data files contain the recorded values without processing. This document lists everything known about their quality. Every run concerned also carries a note in the `remarks` column of `metadata/experiments.csv`.

Faulted runs (FLT_)

Runs with a measurement fault are kept in the dataset, under the prefix `FLT_`, so that users can see what can go wrong in such a test and how it shows in the data. Do not use them as regular measurements.

Run	Date	Repeated as	Fault
FLT_CHK_0006	2026-04-10	–	Sensor 4 delivers no signal (dead channel).
FLT_EXP_0120	2026-05-26	–	At t = 130.3 s a spike appears in almost all sensors; afterwards Sensor 18 shows an offset step of about -1.3 g and a changed spectrum (sensor came loose). No fault-free repetition exists.
FLT_EXP_0168	2026-06-15	EXP_0168	Sensor 8 delivers no signal (dead channel).
FLT_EXP_0163	2026-06-15	EXP_0163	Sensor 8 delivers no signal (dead channel).
FLT_EXP_0164	2026-06-29	EXP_0164	Sensor 8 delivers no signal (dead channel).
FLT_CHK_0019	2026-09-08	CHK_0019	Reference sensor of Shaker 1 not mounted at its shaker; the Shaker 1 level cannot be assessed.
FLT_EXP_0179	2026-09-28	EXP_0179	Reference sensor of Shaker 1 mounted at a wrong position; the Shaker 1 level cannot be assessed.
FLT_EXP_0180	2026-09-28	EXP_0180	Reference sensor of Shaker 1 mounted at a wrong position; the Shaker 1 level cannot be assessed.
FLT_EXP_0181	2026-09-28	EXP_0181	Reference sensor of Shaker 1 mounted at a wrong position; the Shaker 1 level cannot be assessed.
FLT_EXP_0188	2026-10-06	EXP_0188	Sensor 5 delivers no signal (dead channel).
FLT_EXP_0189	2026-10-06	EXP_0189	Sensor 5 delivers no signal (dead channel).
FLT_EXP_0190	2026-10-06	EXP_0190	Sensor 5 delivers no signal (dead channel).
FLT_EXP_0191	2026-10-06	EXP_0191	Sensor 5 delivers no signal (dead channel).

A dead channel shows only electrical noise and mains interference (standard deviation about 0.001 g instead of 0.01–0.3 g). A misplaced reference sensor makes the measured level of that shaker meaningless. The structure was excited as planned in these runs, and the other sensors are unaffected.

Excitation level

The excitation level of every run was checked from the reference sensors on the shaker pads (Sensor 20 for Shaker 1, Sensor 19 for Shaker 2): RMS in 5–200 Hz, given in `shaker1_ref_rms_g` / `shaker2_ref_rms_g`. The level of a shaker depends on its position and on how it was mounted, so each run is compared with the usual level of the same shaker at the same position and intensity.

Wrong drive signal. In 40 runs the measured level of one or both shakers matches a different intensity than planned, within the normal scatter. In these runs another drive signal was played than planned (mostly from 8 to 29 June 2026, when all runs were driven at Low). The intensity columns give the intensity actually played: CHK_0003 (both shakers), EXP_0137 (Shaker 2), EXP_0141 (Shaker 1), EXP_0143 (both shakers), CHK_0015 (Shaker 2), EXP_0144 (both shakers), EXP_0146 (both shakers), EXP_0149 (both shakers), EXP_0152 (Shaker 2), EXP_0156 (Shaker 1), EXP_0153 (Shaker 2), EXP_0145 (both shakers), EXP_0157 (Shaker 1), EXP_0147 (both shakers), EXP_0151 (both shakers), EXP_0150 (both shakers), EXP_0158 (Shaker 1), EXP_0148 (both shakers), CHK_0016 (both shakers), EXP_0159 (Shaker 1), EXP_0162 (both shakers), EXP_0165 (both shakers), EXP_0167 (Shaker 2), EXP_0160 (Shaker 1), EXP_0161 (Shaker 1), EXP_0166 (both shakers), FLT_EXP_0168 (Shaker 2), FLT_EXP_0163 (both shakers), CHK_0017 (Shaker 1), EXP_0169 (Shaker 2), EXP_0171 (both shakers), EXP_0173 (both shakers), EXP_0175 (Shaker 1), EXP_0174 (both shakers), EXP_0172 (both shakers), EXP_0176 (Shaker 1), EXP_0170 (Shaker 2), CHK_0018 (Shaker 2), FLT_EXP_0164 (both shakers), FLT_CHK_0019 (Shaker 2).

Reduced excitation. In the following runs the level of a shaker was below 0.72 of its usual level (the value halfway, on a logarithmic scale, between two neighbouring intensities). The remark gives the factor: EXP_0063 (Shaker 2: 0.60), EXP_0066 (Shaker 2: 0.62), EXP_0068 (Shaker 2: 0.65), EXP_0071 (Shaker 2: 0.66), EXP_0064 (Shaker 2: 0.72), EXP_0069 (Shaker 2: 0.72), EXP_0079 (Shaker 2: 0.70), EXP_0085

(Shaker 2: 0.67), EXP_0091 (Shaker 2: 0.62), EXP_0205 (Shaker 2: 0.46), EXP_0206 (Shaker 2: 0.47), EXP_0207 (Shaker 2: 0.48), EXP_0208 (Shaker 2: 0.47), EXP_0209 (Shaker 2: 0.48), EXP_0210 (Shaker 2: 0.48), CHK_0023 (Shaker 2: 0.48).

Apart from these runs, the level of a shaker at a given position is reproduced within about ±15 %. It is not always the same between mounting episodes: Shaker 2 at location 253 delivered about 0.76 of its usual level throughout sensor layout 2 (EXP_0063 to EXP_0102), and about 0.87 in layout 4. Use the measured levels when the absolute excitation matters.

Offsets

The channels were zero-balanced in the acquisition software before the runs, but not necessarily exactly in every run. The mean value of a channel therefore carries no physical information (it contains no gravity component either) and can differ between runs by up to a few tenths of a g. Remove the mean or apply a high-pass filter (e.g. 5 Hz, below the excitation band of interest) before analysing the data.

Drive signals

The drive signals in `excitation/excitation_signals.npy` are stored by the controller in steps of 0.00305 mm, so the Low signal has only about 16 distinct values (Medium 32, High 62). The resulting quantisation noise above 200 Hz lies 20–40 dB below the in-band level of the signal.

Not included

- Validation runs, in which single bolts were loosened outside the damage scheme A–E, are not part of this dataset.
- No analysis results or derived quantities are included, except the excitation levels described above.