Documentation on “Dataset for acceleration measurements at the research bridge openLAB in Bautzen, Germany - Change of dynamic behavior in the concrete hardening process”

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Dataset link: 10.5281/zenodo.10782663

Abstract.
Data were collected over a period of 99 days during the construction phase of a prestressed concrete bridge at the openLAB research facility. The primary objective was to monitor and analyze changes in the dynamic behavior of the structure to determine the optimal starting point for the monitoring system's reference phase.

Keywords: Acceleration measurements, Construction phase, Eigenfrequencies, Prestressed concrete bridges, Structural health monitoring, Temperature measurements

Table 1. Specification table.

Characteristics	Description
Subject	Civil and Structural Engineering
Specific subject area	Non-destructive evaluation of bridges (acceleration and temperature measurement)
Type of data	Tabular data
How the data were acquired	Raw data were read, stored, and summarized directly in tabular form.
Data Format	Raw data in *.CSV format
Data Acquisition	Storage of the raw data at 6-hour intervals, directly on a USB stick connected to the measuring amplifier. The data was retrieved from the measuring amplifier once every two weeks and stored locally.
Data Source Location	Institution: Institute of Concrete Structures, TUD Dresden University of Technology, Dresden, Germany
Data Access	Repository name: Zenodo
	Data identification number: 10.5281/zenodo.10782663
	Direct URL to data: https://doi.org/10.5281/zenodo.10782663

1 Value of the Data

- Data include temperature and acceleration measurements on a prestressed concrete bridge during construction over a period of 99 days. During this time, continuous data was measured at a sampling rate of 200 Hz.
- Useful to analyze the change in dynamic structural behavior during the construction phase of a prestressed concrete bridge structure.
- It is useful to analyze the temperature dependence of the structure’s eigenfrequency.
- Valuable data set for building a numerical model that is equivalent to an as-built model and can be adapted to the measured conditions of the real structure through a model updating process.

2 Objectives

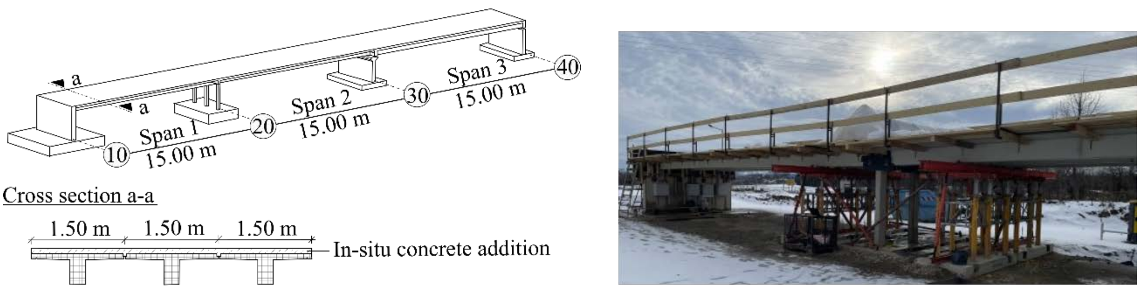
The objective of this measurement task is to record the time-invariant behavior of a prestressed concrete superstructure of a bridge during the construction phase using acceleration measurement data. This knowledge can be used, for example, to define the initiation of the monitoring reference phase or to design optimal and robust monitoring systems for bridges after the construction phase. For a detailed analysis, see, for example, [1].

3 Experimental Design and Boundary Conditions

This section first describes the structure used for the tests and the monitoring system applied to it. The bridge was built as part of the IDA-KI research project and is used to validate data-driven methods for evaluating infrastructures. More information can be found in [2], [3]. The bridge is used as an object for scientific exchange and joint experimental campaigns and is therefore referred to as the “openLAB” bridge.

3.1 The bridge structure

Monitoring activities are carried out on a research bridge, the openLAB, which is designed to be loaded up to the area of severe damage. This structure is a three-span prestressed concrete bridge with a total length of 45 meters (3 x 15 m) and a width of 4.5 meters (Figure 1).



(**a**) (**b**)

Figure 1. Visualization of openLAB. (**a**) Isometric view and cross-section; (**b**) View at the time of monitoring system installation.

The recently completed bridge is located on the premises of HENTSCHKE BAU GMBH in Bautzen, Germany. Spans 1 and 2 consist of three 1.5-meter-wide precast elements (PE), realized as slab beam cross sections, connected using traditional in-situ concrete. However, Span 3, uses pre-cast elements from a rapid construction system without additional in situ concrete, with reinforced joints to ensure a transverse load distribution. The use of cylindrical void formers reduces the dead weight of the rapid construction system [2]. The openLAB design applies only 25% of load model 1 to achieve significant stress states up to the ultimate limit state. This results in a relatively high slenderness ratio of l/d = 15 m/0.59 m ≈ 25, where l is the length of the span and d is the height of the cross section (including in situ concrete).

The openLAB features notable structural innovations. The precast elements on axes 10 and 20 are monolithically connected to the substructures, ensuring complete structural integration. The transition from span 2 to span 3 on axis 30 uses a cementitious ultra-high-performance fiber reinforced composite (UHPC), making the joint watertight and bearing and ensuring rapid driveability. Another unique feature is the foundation on axis 20, which allows controlled displacements to be introduced into the structure through a planar sliding bearing. This setup simulates imposed stresses, enabling the assessment of impacts on the semi-integral bridge. Each of the three bridge spans covers a different research focus. Span 1 models typical damage mechanisms in prestressed concrete bridges. Span 2, constructed to current technical standards, serves as a reference for comparing specific damage mechanisms in prestressed concrete bridges. Span 3 primarily tests the novel precast construction method, contributing to resource-efficient construction practices. The construction status at the time of the monitoring system installation is shown in Figure 2.

(a)

(b)

Figure 2. The openLAB in the construction phase shortly before concreting the additional in situ concrete in January 2024. (**a**) View of the entire structure; (**b**) view of the construction status of the superstructure.

It can be seen that the structure itself is still under construction. The monitoring system has been applied even though the in situ concrete addition has not yet been cast and the superstructure itself is still supported by a temporary scaffolding. This change in the support system must be taken into account when defining the boundary conditions for the bridge structure.

3.2 Boundary conditions of the bridge structure

The analysis of the measurement data must consider various events during the construction process. There are three different structural systems within the measurement period, described in detail in the following and illustrated in the corresponding subfigures (a), (b), and (c) of Figure 3.

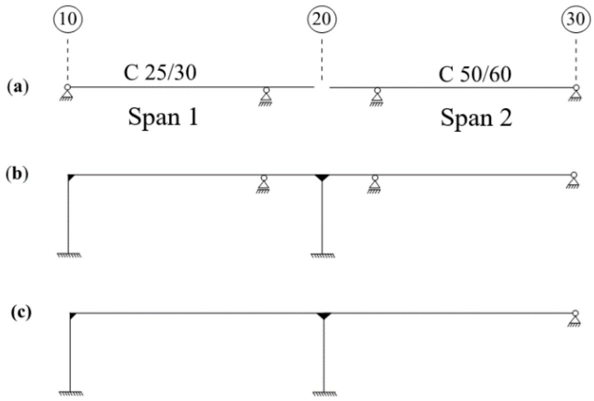
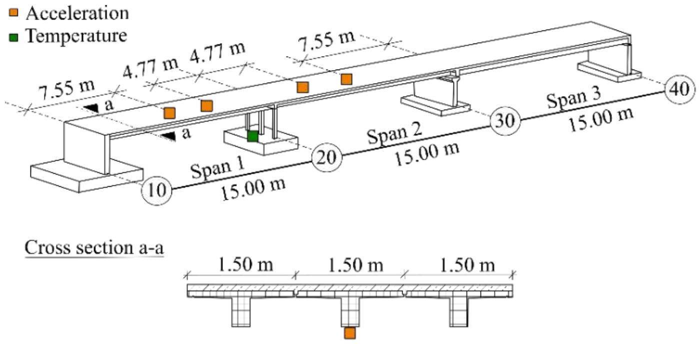


Figure 3. Structural systems in the construction phase: (a) Phase 1: Lifting of the pre-cast concrete slab; (b) Phase 2: In situ concrete addition; (c) Phase 3: Lowering of the temporary scaffolding.

Structural system 1 describes the phase in which the precast beams were placed. In span 1, the PEs were supported on the previously completed abutment (axis 10) and a temporary scaffold positioned 2.5 m in front of the actual pier in axis 20. The PEs in span 2 were similarly supported on a temporary setback scaffolding and the pier on axis 30. Since the PEs did not rest on the pier on axis 20, this stage represents a single-span beam with a cantilever (Figure 3 (**a**). In phase 2, in situ concrete was added to the PEs, creating a monolithic connection between the superstructure and the abutment (axis 10) and the pier (axis 20) through the concrete curing process. In axis 10, the abutment wall and the PEs form a frame corner, and in axis 20, a moment-resisting connection is established to the pier. There is no rigid connection to span 3 at axis 30, thus a hinged support is assumed at this point. This is structural system 2 (Figure 3 (**b**), where the PEs still rest on the temporary scaffolding on either side of the pier (axis 20). In phase 3, the temporary scaffolding was lowered, achieving the final structural system 3. This system is illustrated in Figure 3 (**c**).

3.3 The monitoring system and possible target values of measurements

During the construction phase, four acceleration sensors and one temperature sensor are placed on the structure to detect changes in the global structural behavior. The location of the sensors is shown in Figure 3. The four acceleration sensors are installed in bays 1 and 2 in the center of the bay and at the quarter point. The sensor placement is determined using the optimal sensor placement method and the Fisher information matrix. In this method, each potential sensor location is assigned an independence value that represents the effectiveness of the sensor. The value indicates how significant the contribution of a sensor is to the overall result of the eigenmodes. Taken together, the effectiveness values of the individual sensors are entered into the Fisher information matrix, and the trace of this matrix can be calculated, allowing a statement to be made about the effectiveness of the entire measurement system, where increasing effectiveness of the measurement system is accompanied by a decreasing trace of the matrix.



(a)

(b)

Figure 4. The monitoring system at openLAB during the construction process. (a) Location of the acceleration sensors and the temperature sensor in isometric representation and in section; (b) Photo of an acceleration sensor attached to the underside of the center bar.

The iteration process is continued until the specified criteria are met, e.g. the maximum number of sensors (in this case four acceleration sensors) or the independence of all sensors exceeds a minimum value (e.g. 95%). Further explanations can be found, for example, in [4]. A temperature sensor is attached to the base of axis 20 to measure the temperature of the concrete surface. The aim of acceleration measurement is to record the dynamic load-bearing behavior of the bridge superstructure over time and to make a statement about when the reference monitoring phase should start for prestressed concrete bridges. For this purpose, the natural frequencies of fields 1 and 2 are analyzed as result variables.

IEPE (Integrated Electronics Piezo Electric) accelerometers are used to measure the dynamic behavior of structures. This type of sensor has the advantage over MEMS (Micro Electro Mechanical Systems) accelerometers of being able to detect low frequency structural vibrations more reliably, without the noise influence being too great. Specifically, uniaxial IEPE sensors are used to measure acceleration in the vertical direction of the structure. Experimental investigations with these IEPE sensors show that particularly low eigenfrequencies and less noisy measurements can be recorded compared to the MEMS sensors. The authors in [5] have performed a detailed investigation of the specific behavior of the sensor. Temperature is measured with a PT 100. The sensor works according to the principle that the electrical resistance changes proportionally to the temperature, where a resistance of 100 Ω corresponds to a temperature of 20 °C. The period in which the dynamic response of the building is determined is listed in Table 2.

Table 2. Measurement period and information on the manufacturing process.

Date	Day	Description
22.01.2024	-10	Installation of the monitoring system
01.02.2024	0	Concreting the in-situ concrete extension
22.02.2024	21	Lowering the temporary scaffolding
28.02.2024	27	Achieving the 28-day concrete compressive strength
30.04.2024	89	End of measurement

A total of 99 days of continuous measurements at a sampling rate of 200 Hz are performed without traffic impact on the research bridge, with the concreting of the in-situ concrete extension being interpreted as day 0, since the successive changes in the structure's behavior in the manufacturing process begin at this time. The lowering of the load-bearing structure and the achievement of the 28-day concrete compressive strength are also important points in time that lead to an abrupt change in the state of the structure.

4 Measurement System

A detailed description of the measurement system used in this series of tests can be found in [5]. This section only briefly describes the acceleration measurement chain used. The chain consists basically of four components: the IEPE sensor, the cable, the signal conditioner, and the measurement system. The measurement chain is shown in Figure 5.

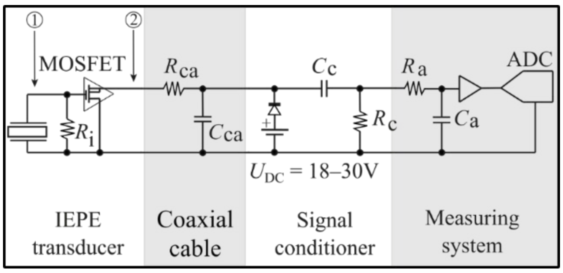


Figure 5. Used acceleration measurement chain.

The IEPE transducer is a two-wire system with an integrated amplifier implemented as a metal oxide semiconductor field effect transistor (MOSFET) circuit. This allows high-impedance voltage signals to be amplified to low-impedance voltage signals, resulting in better noise performance and lower signal loss. This means that inexpensive coaxial cable can be used, even over several hundred meters, without any loss in the quality of the measurement signal. The signal conditioner, the next element in the measurement chain, consists of a DC voltage source and a current control diode that supply constant current to the IEPE transducer via the coaxial cable. This generates a positive bias voltage of 13 V for the IEPE sensor used. The sensor characteristics are shown in Table 3.

Table 3. Characteristic properties of the acceleration sensors.

	Manufacturer and model	Frequency Range	Sensitivity	Noise density
IEPE	WILCOXON Model 786LF-500	0.10–13,000 Hz	500 mV/g ± 3 dB	2.0 µg/√Hz

As the last element in the measurement chain, the measurement system contains an analog-to-digital converter (ADC) that converts the analog voltage signal to a digital signal with a sufficiently high sampling rate. A low-pass anti-aliasing filter, consisting of a capacitor Ca and a resistor Ra, filters noise from the raw data signal to produce a digital, discrete-time measurement signal for further processing. The measurement module used, manufactured by GANTNER INSTRUMENTS, includes both the signal conditioner and the measurement system. The Q.bloxx XL A111 measurement module is specially designed for the measurement of IEPE sensors, whose transfer characteristics are shown in Table 4.

Table 4. Frequency-dependent transmission behavior of the Q.bloxx XL A111 measuring module.

Frequency	Sensitivity of Q.bloxx XL A111
0.1 Hz	70.7 % (−3 dB)
0.2 Hz	90.0 % (−1 dB)
0.3 Hz	100.0 % (0 dB)

The cut-off frequency of the measuring module, i.e., the frequency at which the amplitude of the output signal reaches only 70.7 % (−3 dB) of the input amplitude [45], is 0.1 Hz. At 0.3 Hz, the ratio is 100 % (no amplitude reduction). In the measuring module, delta-sigma modulation with a sampling depth of 24 bits is employed for analog-to-digital conversion.

5 Data Description

5.1 Data format

The data set contains data summarized in tables. The files were created using Excel (Version 2108) and have the file format *.CSV (comma separated values), which can be read by most evaluation programs. The *.CSV files are named on a daily basis and have the following file label format:

YYYY-MM-DD_DatasetOpenLABBrigde.csv

Within each *.CSV file, the data are prepared in tabular form. The designation and structure of each file are described in Table 5.

Table 5. Structure of each *.CSV file.

Name	Date	Temperature in °C	Acc01_Girder1Middle in mV
Unit	DD.MM.YYY hh:mm:ss.ffff	°C	mV
Decimal operator	None.	.	.

Name	Acc02_Girder1Quarter in mV	Acc03_Girder2Middle in mV	Acc04_Girder2Quarter in mV
Unit	mV	mV	mV
Decimal operator	.	.	.

The first column is defined as a time stamp, the second column shows the temperature using the PT100 sensor, and columns 3 to 6 show the acceleration measurement using the four IEPE sensors.

5.2 Data acquisition

The data were recorded continuously measuring the acceleration and temperature at a sampling rate of 200 Hz over the entire period of 99 days. The data were saved directly in CSV format, retrieved manually once every 2 weeks from the monitoring system, and saved locally.

5.3 Location and accessibility of the data source

The original raw data is stored locally at the Institute of Concrete Structures of the TUD Dresden University of Technology, Dresden, Germany. All raw data available herein have been uploaded to Zenodo in their original format (without further adjustment or postprocessing of the raw data).

5.4 Example of a data set for a potential evaluation

Raw data recorded for temperature and acceleration sensor are shown as examples in Figure 6 and Figure 7.

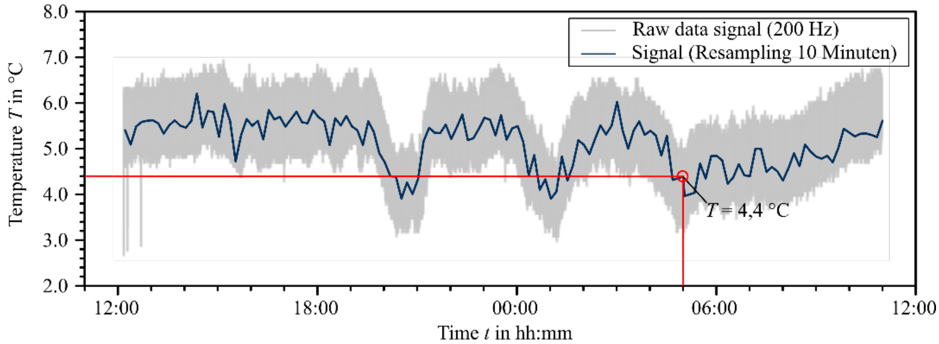


Figure 6. Concrete surface temperature from 22.01. - 23.01.2024 in day-night alternation as raw data signal with a sampling rate of 200 Hz and in 10-minute intervals.

The structure itself is excited by ambient vibrations, i.e. exclusively by excitation from the environment. The B156 highway, which runs between the Saxon cities of Großräschen and Bautzen, runs in the immediate vicinity of the structure. Vibrations in the ground are transmitted by agricultural traffic, and in particular by heavy goods vehicles, which dynamically excite the structure.

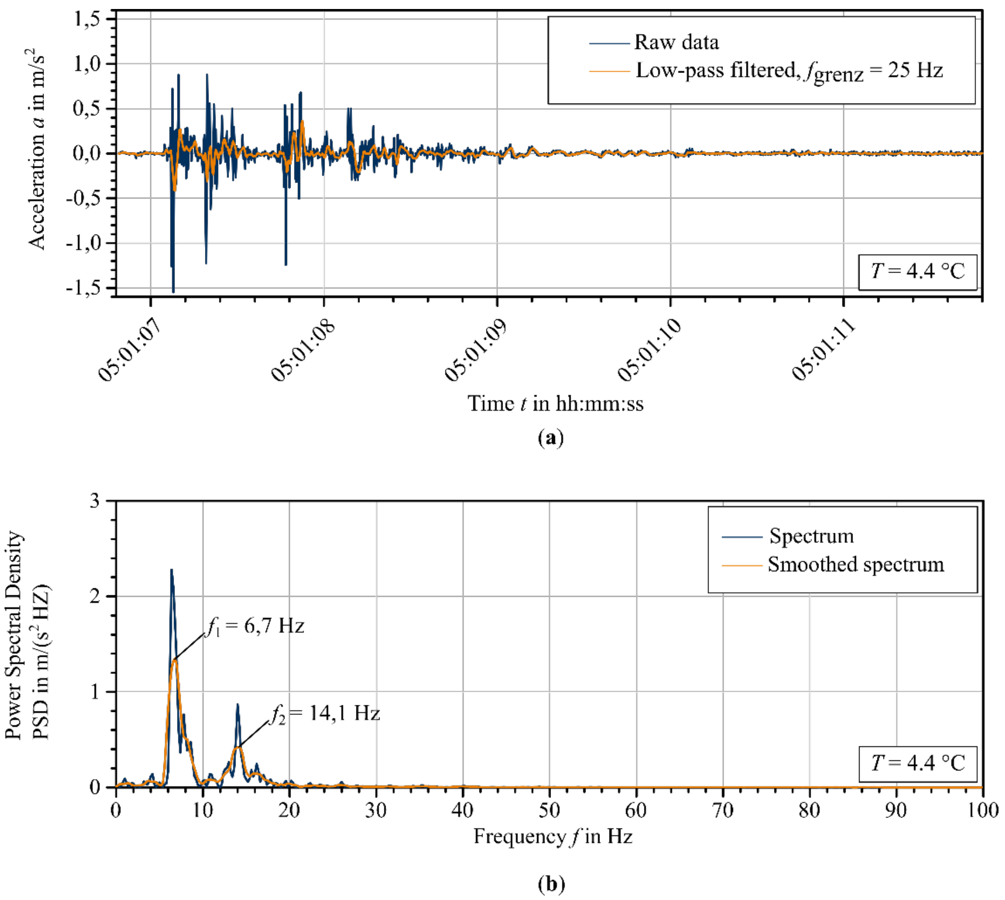


Figure 7. Typical acceleration measurement data, here on 23.01.2024 at 05:01 in field 2 at a concrete surface temperature of T = 4.4 °C. (a) Measurement data in the time domain (without and with low-pass filtering); (b) power density spectrum (without and with smoothing). The sampling rate is 200 Hz.

This measurement data can be used, for example, to monitor the eigenfrequencies of the structure over time and to analyze the sensitivity of the eigenfrequency to significant changes in the condition of the structure.

5.5 Missing data

- 23.01.2024 missing datat from 11:21:01.6140 to 23:59:59.9950
- 06.02.2024 missing datat from 08:23:26.0150 to 12:59:59.9950
- 15.02.2024 missing datat from 11:05:20.1450 to 14:59:59.9950
- 15.02.2024 missing datat from 17:26:16.5950 to 20:59:59.9950
- 15.02.2024 missing datat from 23:13:22.8700 to 23:59:59.9950
- 16.02.2024 missing datat from 00:00:00.0000 to 02:59:59.9950
- 16.02.2024 missing datat from 04:53:38.2500 to 08:59:59.9950
- 16.02.2024 missing datat from 10:45:16.5500 to 14:59:59.9950
- 16.02.2024 missing datat from 16:31:31.7200 to 20:59:59.9950
- 16.02.2024 missing datat from 22:32:19.7400 to 23:59:59.9950
- 17.02.2024 missing datat from 00:00:00.0000 to 02:59:59.9950
- 17.02.2024 missing datat from 04:32:59.2300 to 08:59:59.9950
- 17.02.2024 missing datat from 10:26:20.8190 to 14:59:59.9950
- 17.02.2024 missing datat from 16:26:04.0000 to 20:59:59.9950
- 17.02.2024 missing datat from 22:26:31.5550 to 23:59:59.9950
- 18.02.2024 missing datat from 00:00:00.0000 to 02:59:59.9950
- 18.02.2024 missing datat from 04:19:57.3150 to 08:59:59.9950
- 18.02.2024 missing datat from 10:20:03.3190 to 14:59:59.9950

- 18.02.2024 missing datat from 16:20:19.1440 to 20:59:59.9950
- 19.02.2024 missing datat from 16:50:31.6690 to 20:59:59.9950
- 19.02.2024 missing datat from 22:00:02.9650 to 23:59:59.9950
- 20.02.2024 missing datat from 00:00:00.0000 to 02:59:59.9950
- 20.02.2024 missing datat from 03:59:58.3000 to 08:59:59.9950
- 20.02.2024 missing datat from 10:00:06.1500 to 14:59:59.9950
- 20.02.2024 missing datat from 16:00:13.8050 to 20:59:59.9950
- 20.02.2024 missing datat from 21:04:04.7200 to 23:59:59.9950
- 21.03.2024 missing datat from 00:00:00.0000 to 02:59:59.9950
- 21.03.2024 missing datat from 03:40:01.4300 to 08:59:59.9950
- 21.03.2024 missing datat from 09:40:00.0000 to 14:59:59.9950
- 21.03.2024 missing datat from 15:39:52.9850 to 20:59:59.9950
- 21.03.2024 missing datat from 21:39:59:9050 to 23:59:59.9950
- 22.02.2024 missing datat from 00:00:00.0000 to 02:59:59.9950
- 22.02.2024 missing datat from 03:40:04.4450 to 14:59:59.9950
- 03.03.2024 missing datat from 14:55:24.9150 to 23:59:59.9950
- 04.03.2024 missing datat from 00:00:00.0000 to 13:30:52.3150
- 09.03.2024 missing datat from 00:59:59.9950 to 06:59:59.9950
- 12.03.2024 missing datat from 10:58:53.7650 to 23:59:59.9950

6 Limitations

The present measurement has a significant value for the verification of dynamic structural behavior based on measurement data during the construction phase. However, there are also limitations that should be taken into account in the analysis. On the one hand, the excitation of the structure was caused by ambient vibrations, i.e., by the environment, e.g., by trucks, concreting, compaction, shoring work on the structure. Impulse excitation with the help of a hammer blow, with which a clear identification of the system could be carried out, was not carried out. On the other hand, not all *.CSV files are complete. As the measuring system partially failed, the data packages could not be processed and made available without gaps in time. However, the majority of the measurement period was actually recorded, so a valid analysis of the measurement can be carried out.

Ethics statements

These data do not include any human subjects, animal experiments, or social media platforms.

CRediT author statement

Jan-Hauke Bartels: Methodology, Investigation, Data Curation, Writing - Original Draft, Visualization, Project administration. **Stephan Dunkel**: Data Curation. **Steffen Marx**: Resources, Supervision, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could appear to influence the work reported in this paper.

Data availability and support

All data collected during this study are freely available at the following link:

https://doi.org/10.5281/zenodo.10782663

In case of questions regarding the data or for suggestions, feel free to contact the authors via the E-mail address jan-hauke.bartels@tu-dresden.de

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