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DEVELOPMENT OF A CALIBRATION STAND FOR DEFORMATION SENSORS TESTING

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Abstract
In the 21st century, there is an increasing number of tasks that we allow electronics to perform autonomously. The monitoring of structural deformations is increasingly entrusted to automated systems based on high-precision sensors connected to monitoring systems. Engineers must be confident not only in the correct selection of the system and its components but also in the accuracy of the measuring sensors, which are at the forefront of deformation monitoring systems. This paper presents a comprehensive study on the calibration and accuracy verification of deformation measurement sensors used in structural health monitoring (SHM). Specifically, the focus is on accelerometers, inclinometers, and dynamic displacement sensor. The calibration process involves rigorous static and dynamic testing to ensure precise measurement capabilities. A test stand with the capability to control the deformation of the span was fabricated, enabling the comparison of real-life measurements with the data obtained from the sensors. The displacement sensor, accelerometer and inclinometer are subjected to controlled laboratory conditions to validate their performance under various deformation scenarios. The paper also discusses the integration of these sensors into a unified SHM system, emphasizing the importance of sensor calibration in maintaining the structural integrity and safety of engineering structures. Our findings indicate that with proper calibration, sensors can significantly enhance the accuracy and reliability of deformation measurements in SHM applications.
Keywords: deformation monitoring, accelerometers, inclinometers, dynamic displacement sensor, sensor calibration.

Introduction

Following the era of global industrialisation, society has not only experienced significant development but has also inherited a vast array of infrastructure that must be maintained in operational condition to ensure continued safe usage. Among these critical assets are various engineering structures, which require extensive time and resources for their structural health monitoring (Liu et al., 2023). Advances in electronics have introduced new possibilities for automated monitoring of engineering structures through the use of various types of sensors and computational capabilities, enabling real-time data processing (Hou et al., 2025).

However, sensors are not always calibrated and their accuracy is often uncertain (Zhu et al., 2020). In order to rely on automated monitoring systems equipped with deformation sensors, their precision must first be verified and, if necessary, calibrated. Only after this verification can the acquired data be used for accurate structural assessments, calculations, and long-term prognoses.

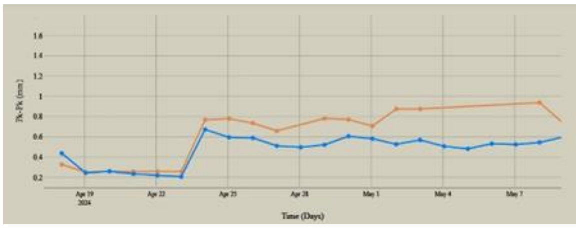
As part of the ongoing maintenance and repair programme of the Kalnciema overpass in Riga, Latvia, a project was commissioned to develop and install a deformation monitoring system for the central span, which is the highest section of the overpass. The monitoring of deformations in the Kalnciema overpass is crucial for estimating the remaining service life before major repairs are required and for assessing the current structural condition. After determining the optimal sensor installation points on the bridge span, three types of sensors were deployed: accelerometers, inclinometers and displacement sensors measuring vertical axis movement (Zhang et al., 2025).

Modern Dynamic Displacement Sensor (DDS) typically rely on acceleration-based measurements. These sensors determine displacement by integrating acceleration over time, using an internal algorithm rather than external computational resources. To assess the reliability of these sensors, two identical DDS sensors were installed at the same location to compare their readings.

During the analysis of data collected over a one-month observation period, discrepancies were observed between the two sensors, as illustrated in (Figure 1). This led to the conclusion that the sensors exhibit measurement errors, which may compromise the accuracy of long-term structural degradation assessments.

This study aimed to develop and implement a calibration stand to assess the accuracy of deformation sensors in structural health monitoring. Static and dynamic tests enabled error correction, improving data reliability for infrastructure assessment.

Figure 1
Deformation readings from two different DDS sensors installed in the same location



To improve measurement reliability, a decision was made to calibrate and evaluate the sensors under controlled laboratory conditions. This involved conducting tests on a calibration stand with adjustable, controlled and fixed deformation states to simulate bridge span behaviour. The experimental plan included identifying the measurement error of each sensor under controlled conditions, applying necessary corrections to their readings and thereby increasing confidence in the data collected.

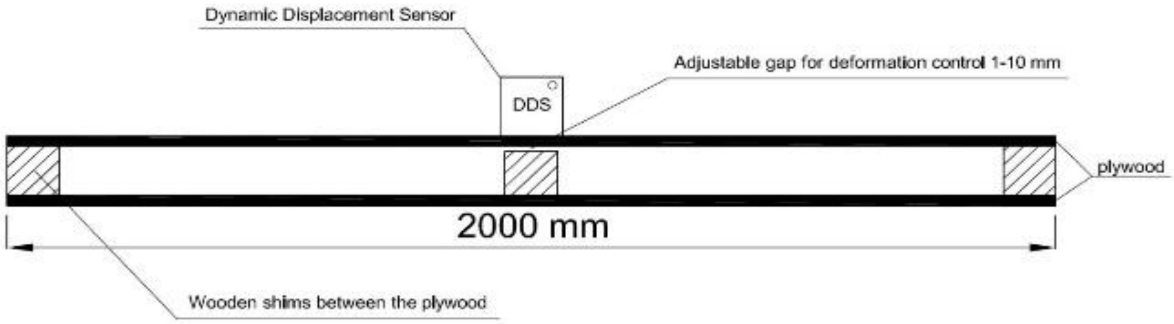
Following the completion of the calibration tests, the sensors were reinstalled on the overpass span, but their outputs were now adjusted in accordance with the derived correction factors. This adjustment ensures greater accuracy in deformation monitoring, improving the reliability of long-term structural assessments (Crognale et al., 2024).

Materials and Methods

A specialised calibration stand was designed and constructed to verify the accuracy of deformation sensors. The stand consisted of two plywood sheets with rigidly fixed corners and a central gap of 10 mm, allowing for controlled vertical displacement. The schematic diagram (Figure 2) presents the key parameters and external appearance of the stand, simulating the behaviour of a bridge span structure.

The stand was mounted on a welding table with a thick iron plate surface to ensure rigid fixation and stability against vibrations. One end of the stand was securely fixed, while the opposite end was designed to allow movement along the stand's axis. To achieve precise deformation measurements, the stand's surface was adjusted using 1 mm thick iron plates (Figure 3), which were inserted into the central gap. The gap width was measured using a vernier caliper before each test condition was modified structure. When the surface was abruptly released after being pressed down, damped real-world operational conditions of a bridge span oscillations occurred as the plywood span returned to its original position. Separate tests were conducted where the surface was smoothly returned to its initial state to eliminate damping oscillations and evaluate the effect of a steady deformation response.

Figure 2
Calibration stand



A total of ten primary tests were conducted, during which the readings from different types of deformation sensors were recorded and compared with the measurements obtained using the vernier caliper.

Figure 3
Adjustment of deflection using iron plates and a vernier caliper

In some test scenarios, additional vibration was introduced using two types of vibrators (20 mm and 35 mm in diameter) commonly used for concrete compaction. These vibrators generated different frequencies and amplitudes of oscillations, allowing an assessment of their influence on deformation sensor performance and potential measurement interference.

Additionally, different external forces were applied to the surface of the stand's movable section to simulate real-world various loads.

Beyond the primary tests, additional measurements were performed using a cylindrical iron mass, simulating a heavy vehicle travelling across a bridge. In these experiments, deformations gradually increased as the cylinder moved towards the centre of the stand. To introduce further oscillatory disturbances, a metal plate was placed at the beginning of the beam, simulating a heavy vehicle crossing an expansion joint (Figure 4).

For inclinometer testing, a location with the greatest change in tilt angle was selected. The inclinometer was mounted at the edge of the model, and both the initial and altered angles were calculated using a CAD-generated model, based on the deflection of the stand's surface and the distance to the sensor.

The sensors were simultaneously positioned at the centre of the model, as this region exhibited the highest deformation levels and was closely monitored using a vernier caliper. The accelerometer and vertical displacement sensor operate on the same principle, with the latter converting registered acceleration and impulse direction into displacement data. By comparing the readings of these sensors with those obtained from the vernier caliper, as well as with each other, it was possible to assess their accuracy and consistency.

Figure 4
Expansion joint simulating

Thus, the conducted tests enabled the evaluation of the accuracy of different types of deformation sensors under conditions closely resembling real-world operational environments.

Results and Discussion

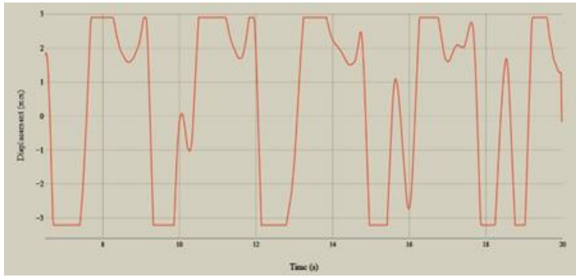
Table 1 present the key parameters of the ten tests conducted to evaluate the performance of the sensors in measuring the deformations of the span. The primary objective was to determine the discrepancies between the sensor readings, as well as to assess how these readings deviate from the physical measurements of the gap on the stand, obtained using a vernier caliper.

Table 1
Key parameters of the tests

Test	*Gap in mm*	*Vibrations*	*Damped oscillations*
1.	4.6	-	+
2.	1	-	+
3.	2	-	+
4.	1.5	-	-
5.	4	+	+
6.	1.8	+	+
7.	1	+	+
8.	9	-	+
9.	9	-	-
10.	9	+	+

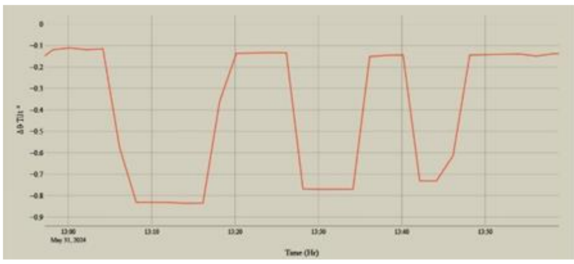
During the first test, the gap on the stand was set to 4.6 mm, with no vibrational noise applied, while damped oscillations were present. The graph in (Figure 5), derived from the data recorded by the DDS sensor, clearly illustrates the damped oscillatory behaviour following the release of the span, as well as the registered deformation value of 6 mm. This allows for a straightforward calculation of the discrepancy between the actual deformation and the sensor readings. Such a test enabled the determination of sensor measurement errors, which were subsequently used to correct the deformation data obtained from the real structure.

Figure 5
Readings of the DDS sensor



During the inclination angle test, the gap of the stand was set to 10 mm, resulting in an inclination angle of -0.57 degrees at a distance of 1 meter. The sensor readings at the upper position of the span indicated an angle of -0.1 degrees, suggesting that the table supporting the stand was not perfectly level. Consequently, the inclinometer readings should have displayed -0.67 degrees. The graph shown in (Figure 6) illustrates that, although minor variations are observed during identical oscillations, the average sensor readings correspond to the calculated inclination angle. Therefore, no correction to the inclinometer measurements is required when applied to the real structure and the sensor can be safely reinstalled on the Kalnciema Bridge.

Figure 6
Inclination test



Complex infrastructure assets, like other types of structures, are subject to dynamic loads, including wind. Such loads can induce vibrations that introduce undesirable noise into the recorded data. The objective of the test involving additional vibrations was to evaluate whether the sensor data would remain interpretable or if the readings would be obscured by digital noise. (Figure 7) and (Figure 8) present the accelerometer readings under calm conditions and under conditions of additional vibration, respectively. It can be observed that while the vibration is reflected in the graph, the data regarding the span movement remains clear and readable. In the case of vibrations at the monitored structure, this will ensure uninterrupted acquisition of deformation data.

Figure 7
Accelerometer readings without additional vibration

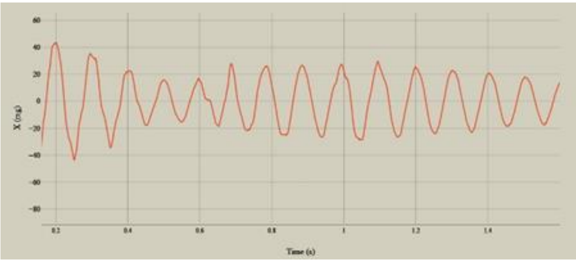
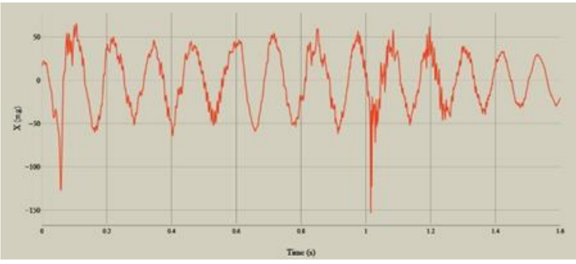


Figure 8
Accelerometer readings with additional vibration



The results of the conducted experiments revealed that the claimed accuracy of the sensors was not confirmed, and calibration is required. Additional tests were also performed to investigate the performance of sensors measuring vertical displacement. During these experiments, it was further identified that the limited data storage capacity of the sensor restricts the recording to a finite number of events. Consequently, if preliminary impulse deformations occur prior to a critical deformation event, there is a high probability that this significant event may not be recorded due to memory overflow. Moreover, the number of recorded events is dependent on the sampling frequency configured within the sensor's settings.

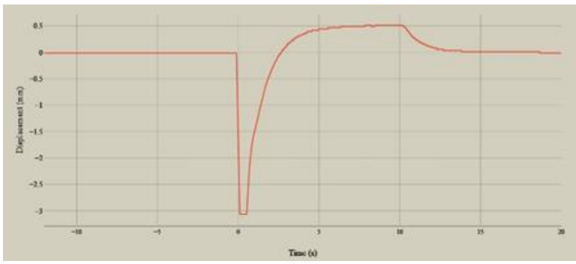
Under intensive traffic loads, the bridge span undergoes a continuous sequence of oscillatory vertical displacements, rendering this type of sensor unsuitable for deformation monitoring systems on bridges and overpasses, as the vast number of recorded events overwhelms the sensor's memory capacity.

Experiments involving vibrators connected to the calibration stand, which generated vibrational noise, demonstrated that such disturbances do not interfere with the sensors' ability to detect deformations. However, it was also found that the deviation sensor exhibited varying readings under identical deformation conditions although the average values remained within the specified accuracy range and corresponded to the actual deformations.

An interesting observation was made during the vertical displacement sensor test. When the span was deflected and subsequently fixed in its new position, the sensor returned the graph curve to the zero position by simply interpolating the data, rather than reflecting the actual sustained deformation. The span of the test stand was fixed in the lower position using a clamp to verify the readings of the DDS sensor (Figure 9). (Figure 10) illustrates how the displacement sensor recorded the deformation and then reverted to zero. Additionally, the experiment demonstrated that the recorded data showed significant discrepancies compared to the actual measured deformations. In real-life scenarios, where a bridge span or support gradually settles over time, the final sensor readings would consistently tend towards zero. In such cases, it is recommended that this type of sensor be replaced by levelling techniques, or laser-based tracking utilisation (LBTU) method, for long-term monitoring of structural settlement.

Figure 9
Span fixing in the lower position

Figure 10
Interpolated return of the graph to zero position, with the deformation fixed in the lower position



Conclusions

1. Displacement sensors do not retain data on their new position and instead interpolate measurements in a manner that returns them to the zero mark after an event. As a result, this type of sensor is unsuitable for monitoring structural settlement, where permanent

displacements need to be recorded. Such deformations should continue to be monitored using classical geodetic methods.
2. The experiment clearly demonstrates that by testing sensors on a calibration stand, it is possible to apply measurement corrections, thereby increasing the accuracy and reliability of the recorded data.
3. Traditional geodetic deformation monitoring systems, when integrated with high-precision sensors, facilitate structural condition assessment by generating continuous data trends and enabling predictive maintenance planning.
4. Sensor accuracy verification has shown that, to improve data reliability, calibration must be performed prior to sensor installation on the monitored structure.
5. The sensors exhibit resilience to vibrational noise, maintaining stable performance under dynamic loading conditions.
6. Long-term continuous monitoring enhances the operational safety of engineering structures and enables the efficient planning of maintenance and repair activities.

References

Crognale, M., Rinaldi, C., Potenza, F., Gattulli, V., Colarieti, A., & Franchi, F. (2024). Developing and Testing High-Performance SHM Sensors Mounting Low-Noise MEMS Accelerometers. *Sensors*, *24*(8). https://doi.org/10.3390/s24082435

Hou, S., Deng, Z., Wu, G., Wu, T., Chen, Q., Zhang, B., & Fan, X. (2025). Research on bridge spatial deformation monitoring using light poles and displacement-relay theory. *Measurement: Journal of the International Measurement Confederation*, 242. https://doi.org/10.1016/j.measurement.2024.115797

Liu, G., Wang, Q. A., Jiao, G., Dang, P., Nie, G., Liu, Z., & Sun, J. (2023). Review of Wireless RFID Strain Sensing Technology in Structural Health Monitoring. In *Sensors*, *23*(15). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/s23156925

Zhang, C., Sun, R., Wang, C., Zheng, X., Li, W., Cai, X., & Dou, D. (2025). Long-term operation state monitoring and stress–deformation mechanism research of bridge abutment anchorage structure. *Construction and Building Materials*, 458. https://doi.org/10.1016/j.conbuildmat.2024.139655

Zhu, J., Wang, W., Huang, S., & Ding, W. (2020). An improved calibration technique for mems accelerometer-based inclinometers. *Sensors (Switzerland)*, *20*(2). https://doi.org/10.3390/s20020452