One of the largest concrete bridge in Poland – crack detection

nerve-sensors.com

EpsilonRebar: Case Study

EpsilonRebars had been chosen for this project as the best solution dedicated to crack detection and estimation of their width changes. Four sensors were installed in the pylon's horizontal beam, supporting the deck slab. In this case, a near-to-surface installation method was applied (grooves) to provide appropriate integration of EpsilonRebars with the existing concrete and to create natural protection against the environmental impacts.

Benefits of application

- Easy and effective **installation within the existing concrete structure**
- Reliable and objective data supporting the experts for **optimal decision making**
- Detection of **all cracks** formed during years of bridge operation
- **Real-time estimation of crack widths** and changes under traffic loads

Example results

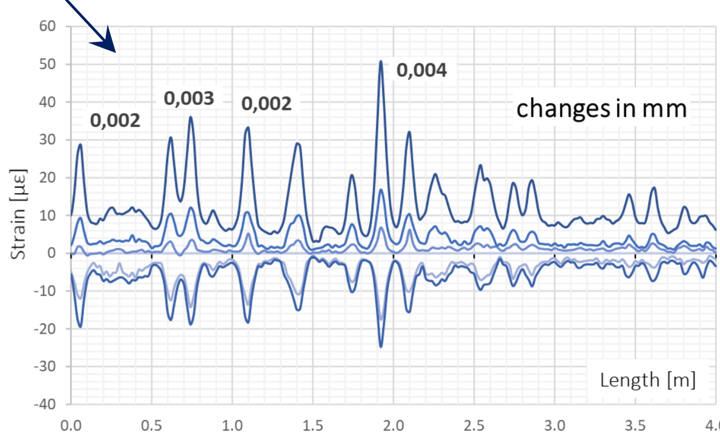
EpsilonRebars integrated with the bridge pylon allowed for detailed analysis of cracks' patterns along the supporting beam. It was also possible to observe real-time changes in widths, despite being extremely small – see example data in the plot below. Analysis of such tiny events was possible only thanks to the appropriate mechanical properties of the Nerve-Sensors and their perfect bonding with the surrounding concrete.

15 200 measurement points

152 m of sensing path

4 x EpsilonRebar

short & **long-term**



project **partner**:

Zespół Badawczo - Projektowy MOSTY-WROCŁAW s.c.

The first bridge in Germany equipped with embedded DFOS Nerve-Sensors

nerve-sensors.com

ER & ES: Case Study

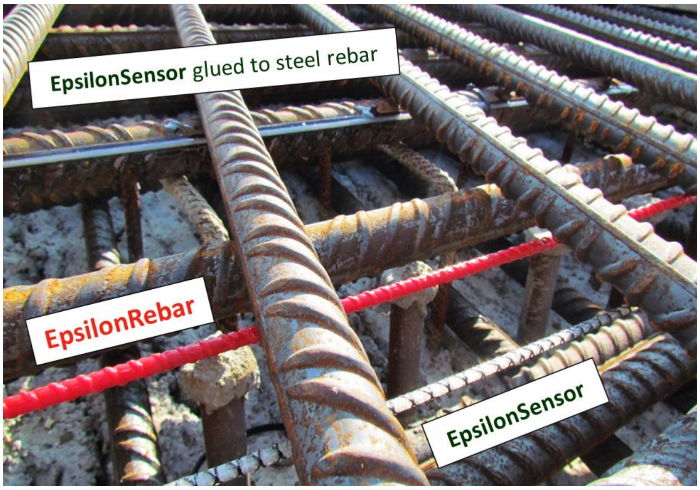
EpsilonRebars and **EpsilonSensors** were integrated (embedded) inside the steel-concrete bridge, which is the first such type of smart bridge in Germany. The DFOS-based monitoring system was designed to provide the possibility of analysing strains in concrete, in steel reinforcing bars, as well as to detect all the microcracks and calculate vertical displacements (deflections). Also, additional distributed temperature measurements were applied for appropriate thermal compensation.

Benefits of application

- Measurements of internal **strains of concrete and steel reinforcement**
- Integrated system for **crack (or microcrack) detection** and their width estimation
- Additional calculations of **vertical displacements (deflections)** and temperatures
- Precise and reliable **data for structural assessment** during long-term monitoring

Example results

EpsilonRebars (ER) and **EpsilonSensors (ES)** were secured by tightening them to the existing reinforcement. These sensors are dedicated to analysing strains and cracks directly inside the concrete (both within the lower and upper part of the slab). Moreover, a modified version of ES without an outer braid was successfully glued directly to the selected reinforcing bar to monitor its strains.



90 000 measurement points

117 m of sensing path

2 x ER, **3 x** ES

load tests & long-term

project **partner**:

MARX KRONTAL PARTNER

Museum of Modern Art: load tests of large-diameter piles

nerve-sensors.com

EpsilonRebar: Case Study

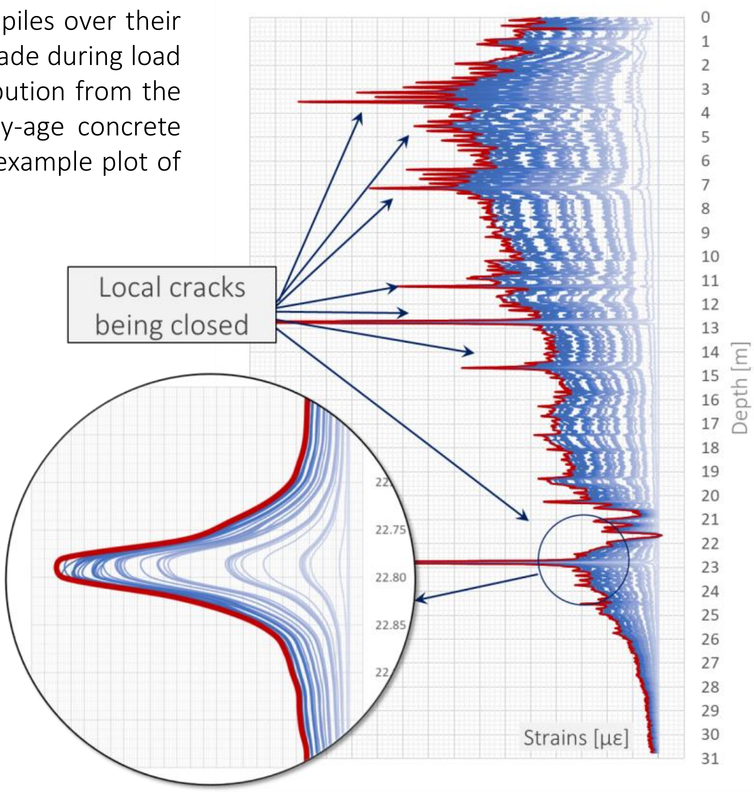
The project is one of the most prestigious investments built in the heart of Poland's capital. Museum of Modern Art is a structure with unique design, built close to existing infrastructure. Foundations include deep large-diameter piles equipped with EpsilonRebars for safety reasons. Measurements were done during load tests and allowed for detailed analysis of piles structural performance and force transfer to the surrounding ground.

Benefits of application

- **Analysis of force transfer** from large-diameter piles to the surrounding ground
- Detection of local **cracks and fractures** along the entire depth of more than 30m
- Control and **validation of load tests** in reference to theoretical predictions
- **Reliable data** for "observation method" proposed in geotechnical standards

Example results

EpsilonRebars were embedded in large-diameter piles over their entire depth up to 35 m. Strain measurements made during load tests allowed for detailed analysis of force distribution from the pile to the surrounding ground, as well as early-age concrete cracks being closed due to the compression. An example plot of this unique data is presented.



16 900 measurement points

169 m of sensing path

5 x EpsilonRebar

short-term (load tests)

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project **partner**: warbud

High pressure gas pipeline: measurements of safety-critical structure

nerve-sensors.com

ER & 3D: Case Study

The 500-mm diameter gas pipeline in question is located in a mining area, where extremely large displacements could appear. 180 m long section was equipped with a number of EpsilonRebars and 3DSensors, installed both directly on the steel surface of the pipe as well in the surrounding ground. Reliable structural control of such safety-critical structures is necessary due to the extremely high consequences of failure. Nerve-Sensors allowed for precise control during long-term monitoring.

Benefits of application

- Detection of **all the local events,** including welds, turns and potential leakages
- Full knowledge of **strains, stress, displacements and temp.** over entire length
- Measurements during high-pressure **water-tightness test** and in **annual cycle**
- Reliable health monitoring for **risk management** of the safety-critical structure

Example results

81 000 measurement points

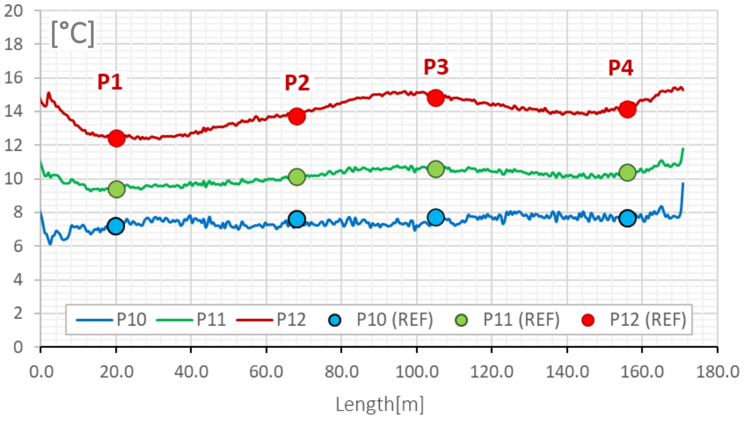
1 620 m of sensing path

6 x EpsilonRebar, **3 x** 3D

load-tests & **long-term**

project **partner**: Cracow University of Technology

Nerve-Sensors allowed for measurements of strains, displacements and temperatures over the entire gas pipeline section. All local events (including welds and turns) were clearly detectable during tightness tests and one-year monitoring. Sensors were read using different optical dataloggers at the same time. Also, a number of reference spot gauges proved the perfect accuracy and performance of Nerve-Sensors in difficult geotechnical conditions. Example results of temperature distributions from three subsequent months (April, May, June) are shown below.

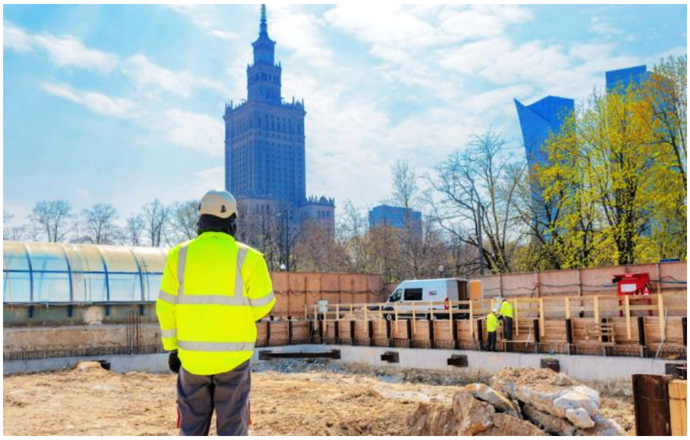


Foundation monitoring within the ’Central Point’ skyscraper

nerve-sensors.com

EpsilonRebar: Case Study

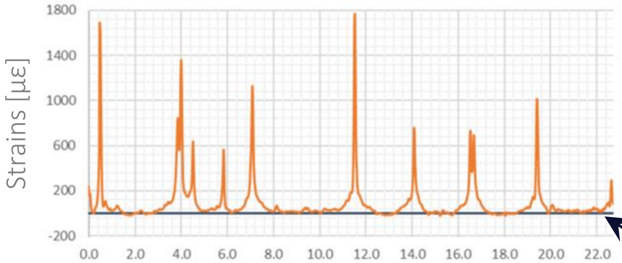
Nowadays, spectacular skyscrapers are built in the centres of large cities. This project refers to a structure located in the centre of Warsaw. Due to the proximity of the surrounding infrastructure, it is very important to monitor the interaction of the foundations with the ground during the entire construction (raising the subsequent floors). That is why **EpsilonRebars** were chosen to control Strains and cracks both in deep barrette piles as well as the foundation slab.



Benefits of application

- Strain measurements both in **barette piles** as well as the **foundation slab**
- Detection of **all the cracks** and localised events inside the concrete
- Full knowledge on foundation deformation state **during all construction stages**
- Information on events invisible to the naked eye and unreachable by other techniques

Example results



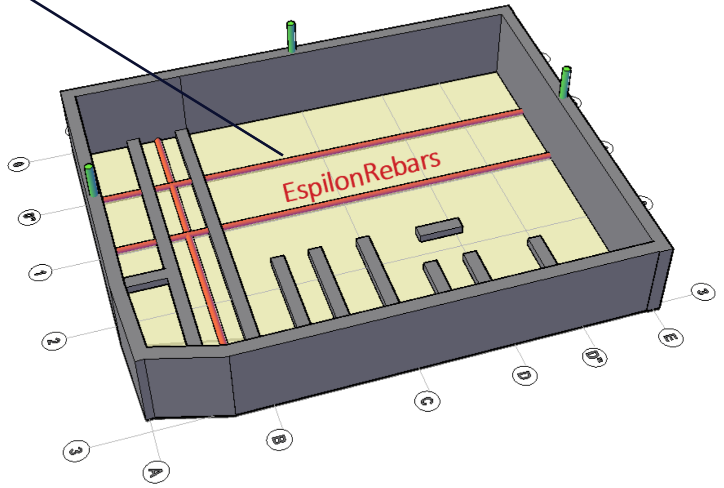
EpsilonRebars were used to measure strains and detect cracks during selected construction stages. Seven sensors were installed in both the lower and upper part of the foundation slab, while ten sensors were placed along the barrette piles to a depth of 22 m. Obtained results allowed for analysis of force transfer along deep piles as well as to detect all cracks in concrete foundation slab.

37 600 measurement points

376 m of sensing path

17 x EpsilonRebar

during **construction**



project **partner**: STRABAG

Industrial tower in the largest mining tailings reservoir in Europe

nerve-sensors.com

3DSensor: Case Study

Żelazny Most Reservoir is the largest reservoir for copper mining tailings in Europe, owned by KGHM Polska Miedź. It was put into exploitation on February 12, 1977. There are four industrial overflow towers on the site. One of them in 2018, was equipped with vertical 3DSensors to monitor temperatures and horizontal displacements. One of the reasons for DFOS-based monitoring system installation was the construction of the tower's new floors.

Benefits of application

- Knowledge of **horizontal displacements** and temperatures along the entire depth
- Full **assessment of tower deformation** state, including uneven settlements
- Detailed **control of construction work** in the upper part of tower (new floors)
- Unique data on old industrial structure for **FEM validation** and **safety assessment**

Example results

Seven segments of the **3DSensor** were delivered on site and installed on the walls of the tower's individual storeys, along its entire depth. Segments were connected together through the floors to create a continuous sensing line. The measurements were performed during the entire year to analyse the influence of significant temperature changes. This reliable system working in harsh environmental conditions allowed the horizontal displacements of the tower to be measured with extremely high spatial resolution.

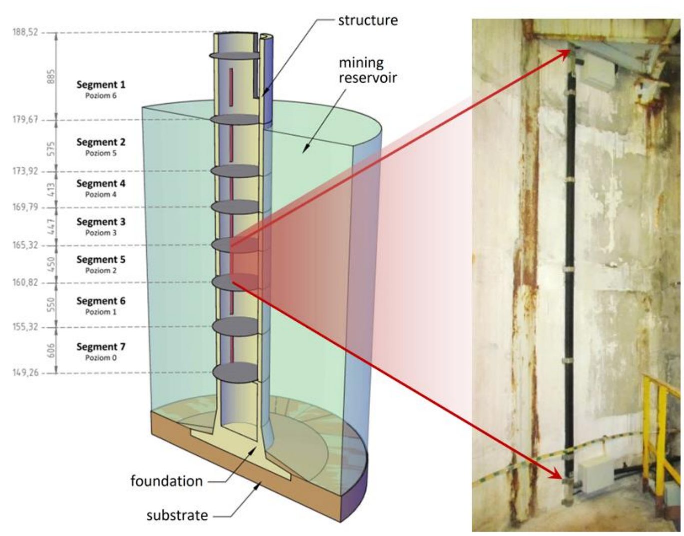
Successful application of unique 3DSensor was awarded in prestigious Copper Basin Master of Technology competition.

3 400 measurement points

34 m of sensing path

7 x 3DSensor

long-term monitoring



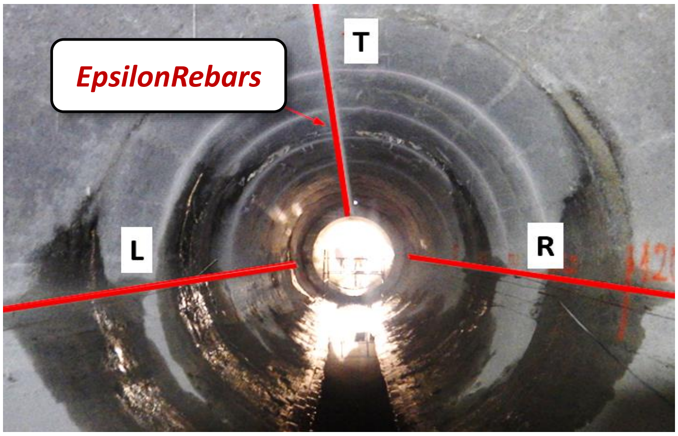
project **partner**: KGHM POLSKA MIEDŹ

Sewer concrete collector during its strengthening with GRP panels

nerve-sensors.com

EpsilonRebar: Case Study

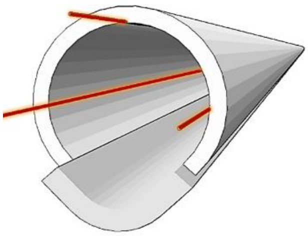
The concrete sewage collector was constructed in 1964 and is now reinforced with Glass-fiber Reinforcement Plastic (GRP) panels. EpsilonRebars (ER) and the EpsilonSensor (ES) from the Nerve-Sensors family were installed inside the near-to-surface grooves to verify the strengthening process. ERs were placed longitudinally over the entire 150 m long section, while ES was installed in selected key circumferences. The system allowed for detailed analysis of strains, cracks, displacements and temperatures.



Benefits of application

- Detection of **all the cracks** between the old segments (with width estimation)
- Calculation of **vertical displacement** profiles (settlements) along the length
- Full deformation **control during strengthening** process (injection + FRP panels)
- **Reliable monitoring system** working in extremely difficult external conditions

Example results



Nerve-Sensors allowed for direct measurements of strains and temperatures, as well as detection of extremely small cracks, including their width change estimation. Moreover, thanks to the appropriate sensors' arrangement, it was possible to calculate vertical displacements caused by the dead weight of GRP panels and mortar injection applied during strengthening. Example crack morphology along the safety critical section as well as vertical displacement profile over entire length are presented in the figures below.

51 000 measurement points

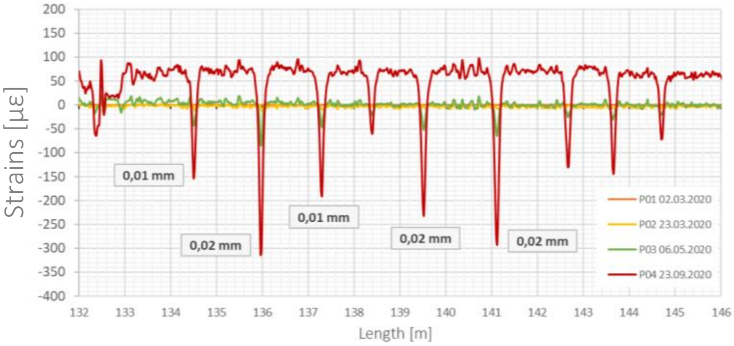
510 m of sensing path

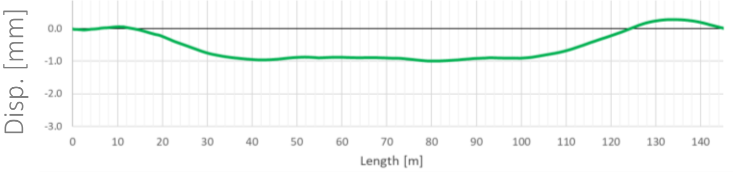
3 x EpsilonRebar, **1 x** ES

construction (strengthening)

project **partner**:

Warsaw University of Technology





24 m long prestressed concrete girders as a part of the smart production hall

nerve-sensors.com

EpsilonRebar: Case Study

Three 24 m long prestressed concrete girders were quipped with **EpsilonRebars** embedded inside. The sensors were delivered on-site in coils and tightened to the existing reinforcement. This fast and easy installation process allowed the creation of smart elements able to self-diagnose during all stages: concrete hardening, prestressing, mounting in the structure, as well as during the load tests. Currently, the girders are under continuous operation in one of Polish production halls.

Benefits of application

- Structural performance **control during all construction stages and load tests**
- Detection of **all the cracks** formed during early-age concrete (gardening process)
- Analysis of the **effectiveness of prestressing** process, including control of the cracks
- **Reliable system for short-term** load tests and **long-term** structural monitoring

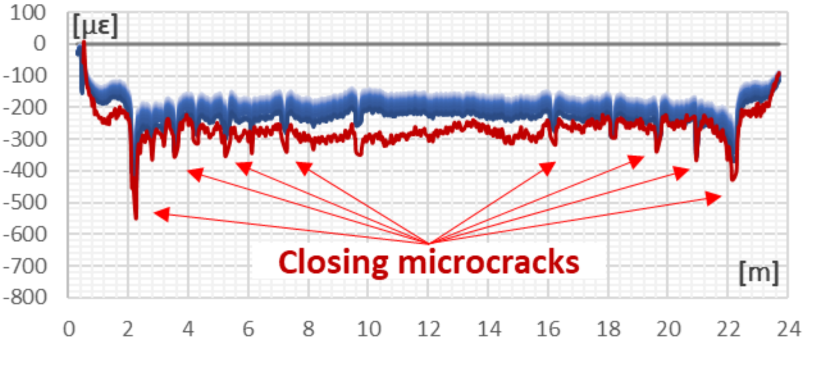
Example results

The monitoring system created based on **Nerve-Sensors** provided unique data for structural analysis. The first stage (1) was concrete hardening when a number of microcracks were detected. However, all of them were closed (see the plots) during prestressing stage (and activation of dead weight at the same time), so girders could be installed on columns (2) without any risk. Finally, the structural performance was checked during mechanical load tests (3), which showed that the girders work in uncracked conditions. This knowledge was extremely valuable for designers and could be successfully used, e.g. for optimisation.

1

2

3



57 600 measurement points

576 m of sensing path

24 x EpsilonRebar

short & long-term

project **partner**:

FABUD WKB S.A.

EpsilonRebars as a Nervous System of hybrid footbridge in Nowy Sacz

nerve-sensors.com

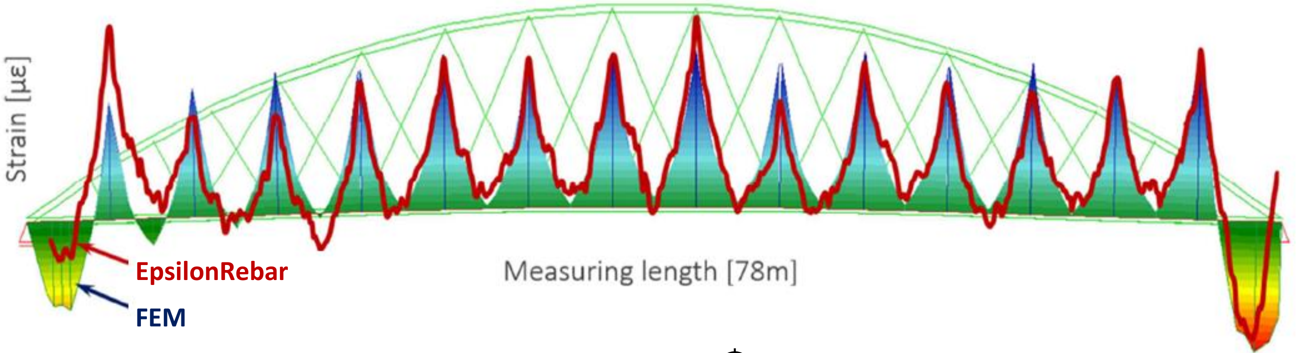
EpsilonRebar: Case Study

EpsilonRebars in the form of composite rods, being simultaneously the structural reinforcement for the concrete deck, were placed along the entire footbridge span of nearly 80 m. Thanks to the application of distributed optical fibre sensing technique, it was possible to perform measurements of strains, cracks, displacements (deflections) and temperatures during the hydration of early-age concrete (thermal-shrinkage strains) as well as during the load tests.

Benefits of application

- Full knowledge on **deformation state** along the entire length of the structure
- Ability to detect all **local damages**, including cracks
- Analysis of **bonding properties** between concrete and composite panels
- Verification of the **design assumptions** and **3D FE model**

Example results



Measurement results can be used for verification of theoretical assumptions made at the design stage as well as for calibration of the numerical model. We analyzed loads combination: slab dead weight + thermal-shrinkage strains after the first two weeks of hydration. Because of concreting the entire span without any dilatations, the knowledge on strain distributions (both in concrete and composite panels) was extremely important.

96 000 measurement points

almost **1 km** of sensing path

12 EpsilonRebars

load tests & **long-term**

project **partners**: Mostostal Warszawa, Politechnika Rzeszowska im. Ignacego Łukasiewicza

Vertical displacements of the ground around footing being pulled out

nerve-sensors.com

3DSensor: Case Study

This project aimed to determine the potential slip plane that occurred during the concrete footing pullout. For this purpose, 3DSensors (DFOS displacement sensors) were installed around the structure in two planes, and vertical displacements were measured. Thanks to the cutting-edge technology of 3DSensors, an advanced analysis of the interaction between the footing and the surrounding ground were possible without any distortions and reinforcing effect in the ground.

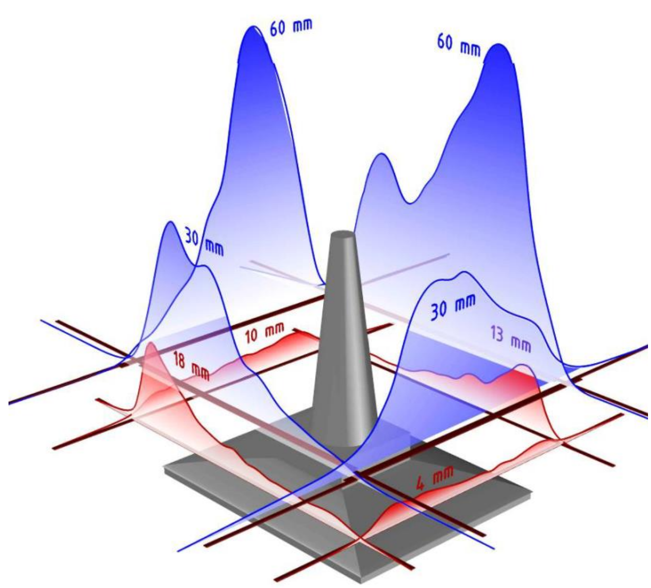
Benefits of application

- **Fast and easy installation** of lightweight sensors, standard compacting feasible
- **Flexible sensors** do not cause distortions or reinforcing effects in the ground
- **Results** seen as **displacement values** thanks to a data conversion algorithm
- Nervous system in the ground with **results unreachable for conventional sensors**

Example results

Two layers of 3DSensors were installed, parallel to the edges of the footing at 80 cm and 160 cm above the footing base. The structure was pulled out of the ground through a specially designed stand while strain measurements were taken step-wise with 3DSensors.

A designed algorithm for data conversion allowed to direct determination of vertical displacements in both layers around the footing. The figure presents the spatial visualization of example results expressed directly in mm for a chosen load step.



10 000 measurement points

72 m of sensing path

12 3DSensors

short term **load tests**

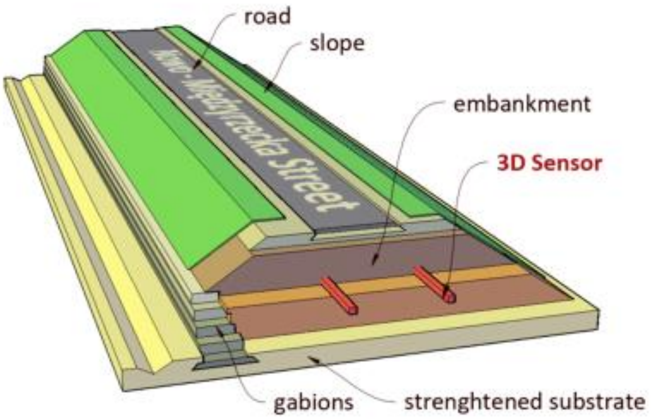
project **partner**: ENPROM®

Displacements of a road embankment above the strengthened substrate

nerve-sensors.com

3DSensor: Case Study

Within this project, two **3DSensors** were installed along a road embankment to measure its vertical displacements. Two independent lines of **3DSensors**, each 48 m long, were provided, together with multiple reference measurement techniques: longitudinal and transverse inclinometers, spot tiltmeters and geodetic benchmarks. Vertical displacements were measured in a distributed way with 3DSensors and compared with the results of reference methods.



Benefits of application

- Composite core with a **wide elastic measurement range** up to ±4%
- **Thermal self-compensation** system, no need to measure temperature
- **Results** seen in **displacement values (mm)** thanks to a data conversion algorithm
- Very **high compliance** with reference measurement methods (incl. inclinometers)

Example results

3DSensors with composite cores were applied, each equipped with four optical fibres precisely arranged around the core. Taking advantage of the strain measurements in all fibres and using a trapezoid calculation method, vertical displacements were calculated with very high precision and in a distributed way along the sensor, with a spatial resolution of 10 mm. The results from 3DSensor are presented in the figure below (red line) together with the results of reference inclinometer measurements (green line). The compliance of both methods was very high; the mean difference was less than 0.1 mm with a standard deviation less than 0.5 mm along the entire measurement length. It is worth noting that the **3DSensors** approach involves a thermal self-compensation system.

9 600 measurement points

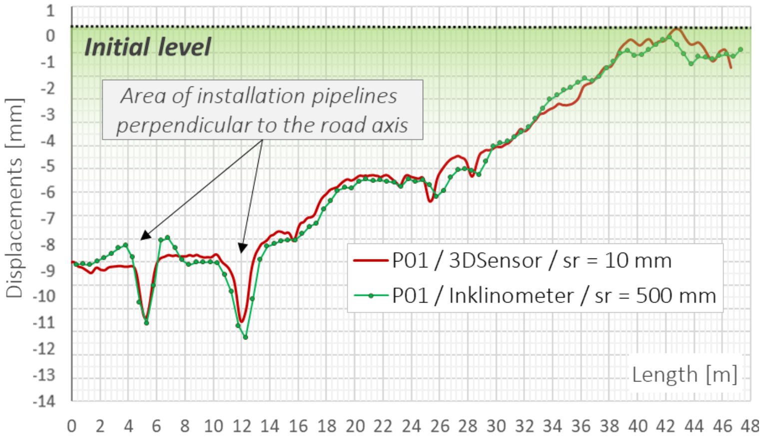
96 m of sensing path

2 x 3DSensor

long-term monitoring

project **partner**:

Silesian University of Technology



Cable-stayed bridge: localised effects due to the steel anchorage

nerve-sensors.com

Nerve-Sensors: Case Study

The steel cable-stayed bridge in Przemyśl was put into the service in 2012. At the time of construction, it was the fourth highest bridge in Poland. It is supported by two 61.5 meter high pylons, and its total length (inc. overpasses) is equal to 530 m. In 2017, the bridge was equipped with distributed fibre optic sensors **(DFOS)** dedicated for strain and temperature measurements. Two measurement sections were installed in collaboration with university graduate students.

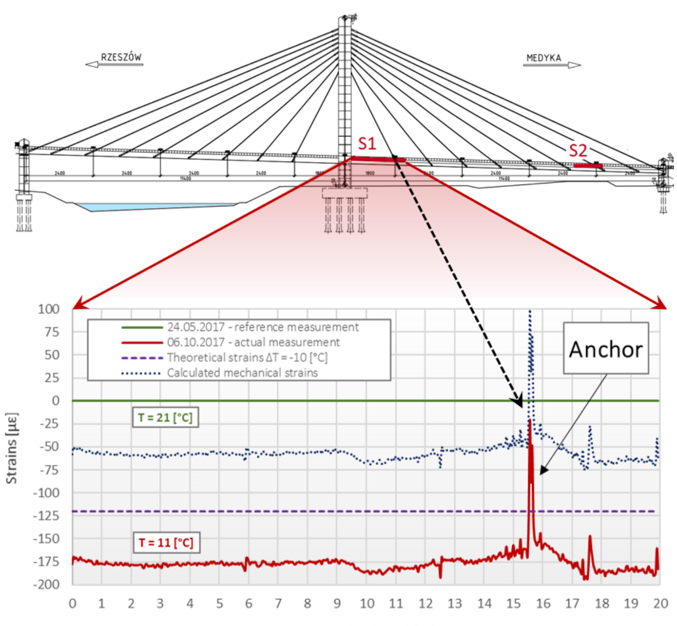
Benefits of application

- Detection of **local events**, including steel anchorages
- Distinguish between **mechanical and thermal strains**
- Observation of bridge performance due to the **non-uniform temperature load**
- Very **high compliance** with reference measurement methods (total station)

Example results

Distributed fibre optic strain sensors were installed at the bottom flange of the steel girder, which is suspended by 18 cables. Two measurement sections were created: the first 20 m and the second 13 m long.

The measurement sessions were performed acc. to the planned schedule, incl. periods with significant temperature differences. Thanks to our system, it was possible to detect localised effects in the steel girder caused by the cable anchorages – see the strain profile in the figure.



3 300 measurement points

33 m of sensing path

2 x strain sensor

long-term monitoring

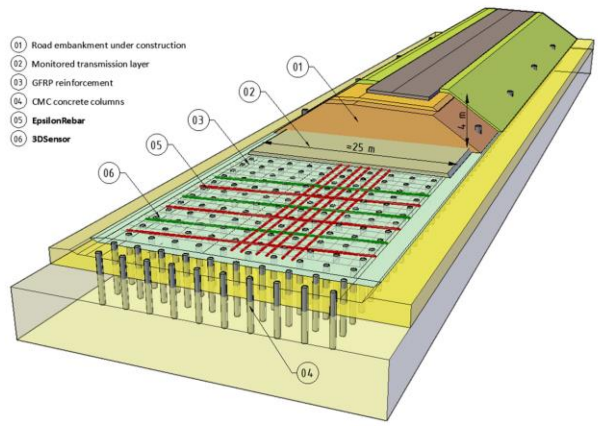
project **partner**: AGH

Strains and displacements at the base of a road embankment

nerve-sensors.com

3DSensor & ER: Case Study

The road embankment was designed above the substrate, strengthened with concrete columns. The transmission layer between the columns and earth body of the structure was equipped with Nerve-Sensors: EpsilonRebars (ER) and 3DSensors for measuring strains and vertical displacements respectively. A total number of 16 sensors were installed both in longitudinal and transverse directions. Furthermore, the sensors were used for simultaneous measurements of temperatures.



Benefits of application

- Measurements of **strains, displacements and temperatures** at the same time
- Full deformation control above the concrete columns during construction
- **Thermal self-compensation** for displacements, no need to measure temperature
- **Results** viewed as **displacement values (mm)** thanks to a data conversion algorithm

Example results

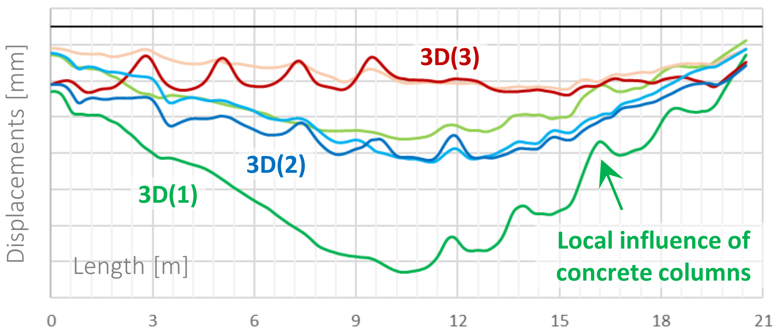
The measurement sessions took place during the construction process. The figure below shows example displacement profiles obtained from transverse 3DSensors. The local effects caused by the presence of concrete columns are clearly detectable. This comprehensive data could not be gained from conventional sensing techniques. It can be used for calibration numerical models and reducing uncertainties, which are especially important during geotechnical design.

37 800 measurement points

378 m of sensing path

4 x 3DSensor, **12 x** ER

during **construction**



project **partner**:

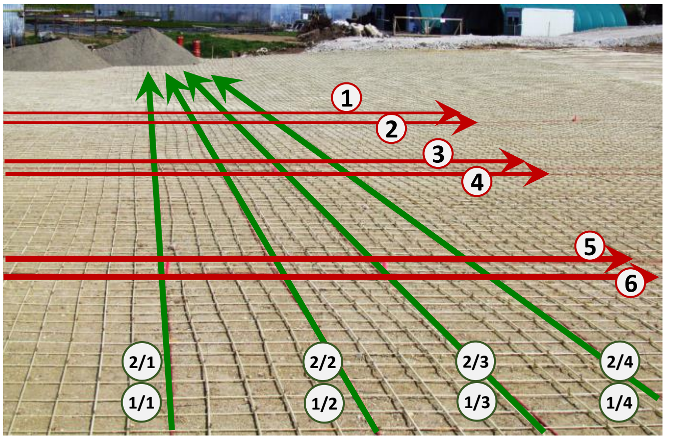
MENARD

Strains in composite reinforcement at the base of a road embankment

nerve-sensors.com

EpsilonRebar: Case Study

In the present case study, the base of the road embankment was reinforced by composite rebars in two directions. This solution is favourable in the context of durability due to the high resistance of composites to corrosion. Some of the bars were replaced with EpsilonRebars, which now have a double function in the structure: both sensing and reinforcing. Two measurement layers also allowed for the calculation of vertical displacement profiles.



Benefits of application

- Measurements of **strains, displacements and temperatures** at the same time
- Full **deformation control at the base** of ground embankment
- Thermal compensation for distinguishing **only mechanical effects**
- Knowledge on the **structural performance** of new reinforcement technology

Example results

61 800 measurement points

618 m of sensing path

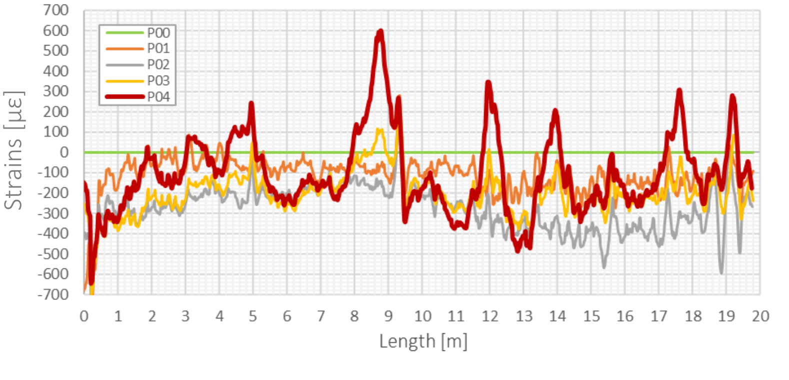
14 x EpsilonRebar

during **construction**

project **partner**:

MENARD

The measurement sessions took place during the construction process and the embankment operation. The figure below shows example strain profiles obtained from transverse EpsilonRebar during subsequent load steps (during construction of new embankment layers). Data interpretation was performed taking into account the initial topology of the substrate, as well as temperature distributions obtained thanks to Raman measurements. Vertical displacements at the base of this structure were calculated based on measured strains and known spacing between two measurement layers.



The highest road embankments in Poland – temperature measurements

nerve-sensors.com

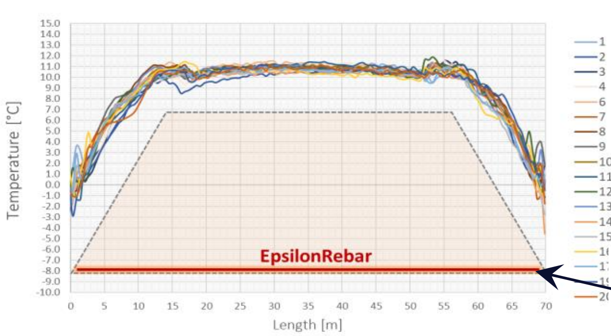
EpsilonRebar: Case Study

To monitor the structural behaviour of the largest road embankments in Poland, we applied three independent measurement solutions: Inclify, SHMProfiler and **EpsilonRebars** from Nerve-Sensors. The latter were used to measure temperature distributions at the base along the entire width of the structure. Temperature results were used, among other things, to compensate for data from the two other measurement techniques.

Benefits of application

- Measurements of **temperatures distributions** along the entire embankment width
- Reliable data for **thermal compensation** of other techniques
- Robust solution for fast installation in extremely difficult geotechnical conditions
- Unique knowledge for **scientific analysis** and numerical simulations (FEA)

Example results



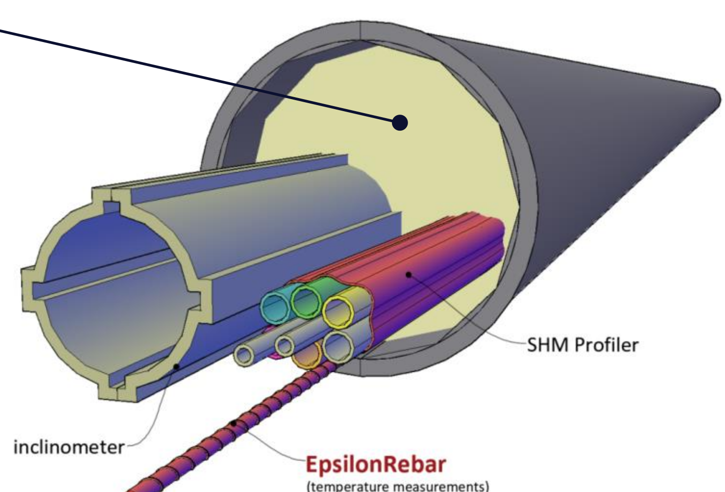
The measurements were performed at selected construction stages. The right figure shows example temperature distributions registered along the embankment base. We can observe high gradients (>10°C) depending on slope geometry, sun exposition and actual environmental conditions.

67 600 measurement points

676 m of sensing path

8 x EpsilonRebar

during **construction**



project **partner**: MOTA-ENGIL

Steel-concrete railway bridge: strains and cracks during load tests

nerve-sensors.com

Nerve-Sensors: Case Study

The composite (steel-concrete) bridge in Dąbrowa Górnicza was designed according to a new approach and put into the service in 2019. This is why verification of its structural performance under real operating conditions was of significant importance. The bridge was equipped with DFOS strain sensors, installed both on the concrete and steel surfaces. The measurements during load tests allowed for detailed analysis of the deformation state, including the detection of all microcracks.

Benefits of application

- Detection of **local events like cracks** on the concrete surface
- Simultaneous measurements of **strains in concrete and steel** part of the girder
- Observation of bridge performance during **load test** before opening
- Possibility of **calibration FE model** and **improvement of the a design** approach

Example results

Distributed fibre optic strain sensors were installed at the bottom and top flange of the steel girder, as well as at the side surface of the concrete. Such a sensing system setup allowed for detailed analysis of the interaction between these two materials and validation of a new design approach. Distributed measurements taken during load tests (locomotive load) prior to commissioning enabled the detection of all microcracks along the girder length. However, most of them were closed after removing the load, which was very important information for the engineer responsible for the long-term safety and durability of the bridge.

4 800 measurement points

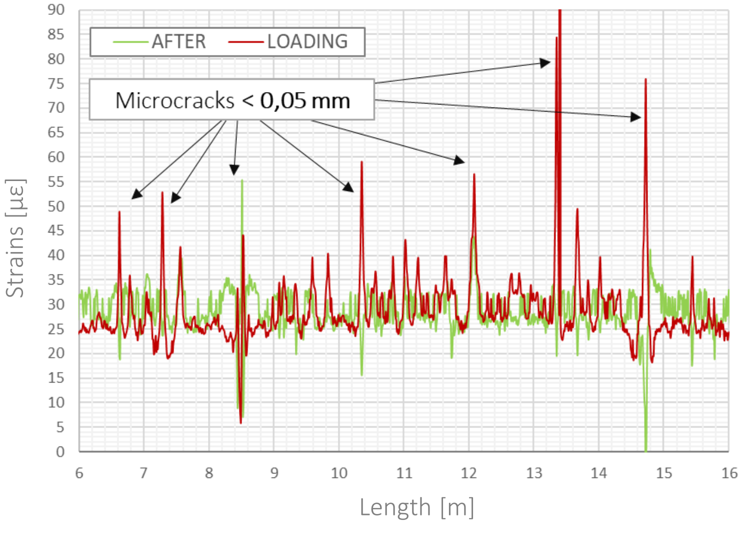
48 m of sensing path

3 x strain sensor

short-term (load tests)

project **partner**:

Wrocław University of Science and Technology



Strains and displacements in asphalt layers: static load tests & SHM

nerve-sensors.com

3DSensors & ER: Case Study

This project involved two types of road surface structures equipped with Nerve-Sensors, measuring both strains (EpsilonRebars) and displacements (3DSensor). All of them were embedded into the road layers during its construction, providing the possibility of analyzing its internal structural behaviour under static proof load tests. Our nervous system, supplemented by spot temperature sensors, was used successfully also in terms of long-term structural health monitoring (SHM).

Benefits of application

- Measurements of both **strains and displacements** inside the asphalt layer
- Observation of structural response and creep during **static load tests**
- Possibility of **validation and calibration of** the spatial numerical models
- Detailed **comparison between two types of road** construction technologies

Example results

10 600 measurement points

106 m of sensing path

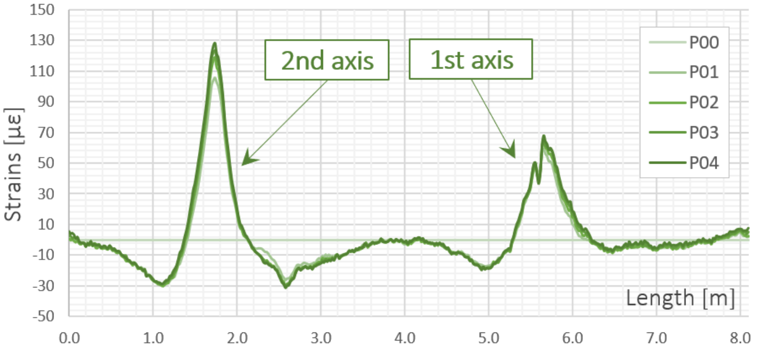
4 x 3DSensor, **16 x** ER

load tests & long-term

project **partner**:

Politechnika Świętokrzyska
Kielce University of Technology

The DFOS-based nervous system was used for short-term measurements during static truck load tests as well as for long-term monitoring during changeable thermal conditions. The figure below presents example strain profiles measured by EpsilonRebar embedded into asphalt layers along the longitudinal direction. Two axes of the loading track are clearly indicated by tensile strains, while in the surrounding area, the compression was observed. Furthermore, short-term creeping was monitored while vertical displacements were registered by 3DSensors.



Strains and displacements in asphalt layers: dynamic load tests

nerve-sensors.com

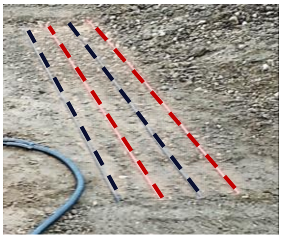
3DSensors & ER: Case Study

This project involves two types of road surface structures equipped with Nerve-Sensors, measuring both strains (EpsilonRebars) and displacements (3DSensor). All of them were embedded into the road layers during its construction allowing for analysis of its internal behaviour under dynamic load tests (truck's runs). Our system was successfully applied for analysing the structural response in real time, including all dynamic effects registered using high-frequency mode.

Benefits of application

- Measurements of both **strains and displacements** inside the asphalt layer
- Observation of **structural response in real time** during truck's runs
- Possibility of **calibrating** numerical models, including **dynamic effects**
- Detailed **comparison between two types of road** construction technologies

Example results



10 600 measurement points

106 m of sensing path

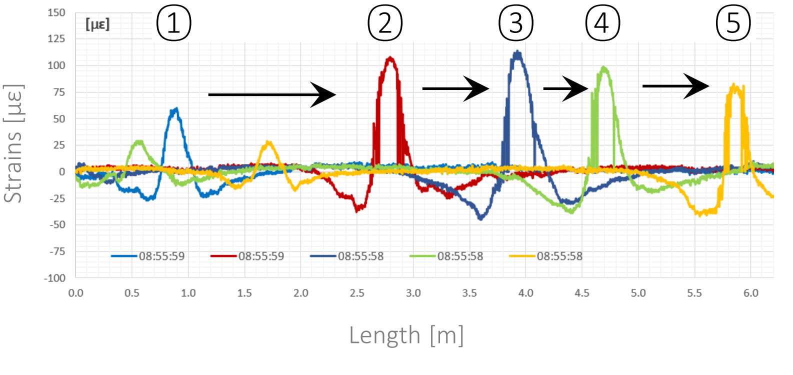
4 x 3DSensor, **16 x** ER

load tests & long-term

project **partner**:

Politechnika Świętokrzyska
Kielce University of Technology

Our DFOS-based nervous system was used for short-term measurements during static truck load tests as well as for long-term monitoring during changeable thermal conditions. Moreover, the same system analysed structural response in real time during the truck's runs. The figure below presents example strain profiles measured by EpsilonRebar embedded into the asphalt layer along the longitudinal direction in subsequent time steps during the run. Vertical displacements were simultaneously registered by 3DSensors.



Strains and cracks in a new type of slurry wall: research field (1)

nerve-sensors.com

EpsilonRebar: Case Study

The subject of the project was the slurry wall made of a new type of material: fibre-reinforced concrete mixed with the ground. As this technology must be carefully checked before use, the EpsilonRebars were used for this purpose. The structural performance of the wall was monitored during deepening of the excavation area as well as load tests. Thanks to Nerve-Sensors, it was possible to detect cracks and fractures invisible to other techniques.

Benefits of application

- Distributed measurements of **strains and cracks** invisible to the naked eye
- Full **deformation and temperature control** along the entire length of slurry wall
- Simultaneous analysis of **both compression and tension** zone
- Measurements during **deepening of the excavation** and **load tests**

Example results

The slurry wall was loaded using concrete slabs. The figure shows example strain profiles obtained from EpsilonRebar during subsequent load steps. It can be clearly observed that a fracture inside the wall was detected under the excavation level. As there was no access for visual inspection, no other technique was able to provide such key information.

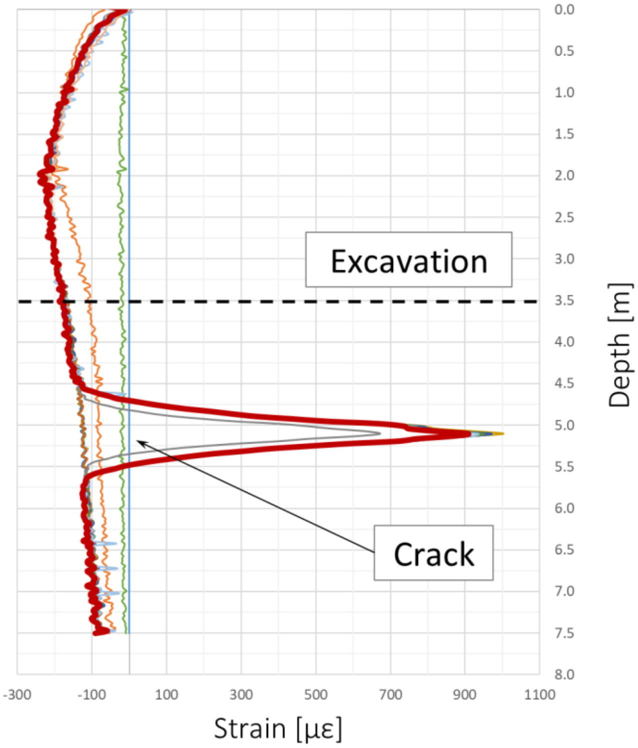
7 200 measurement points

72 m of sensing path

9 x EpsilonRebar

construction & load tests

project **partner**: Cracow University of Technology



Strains and displacements in a new type of slurry wall: research field (2)

nerve-sensors.com

EpsilonRebar: Case Study

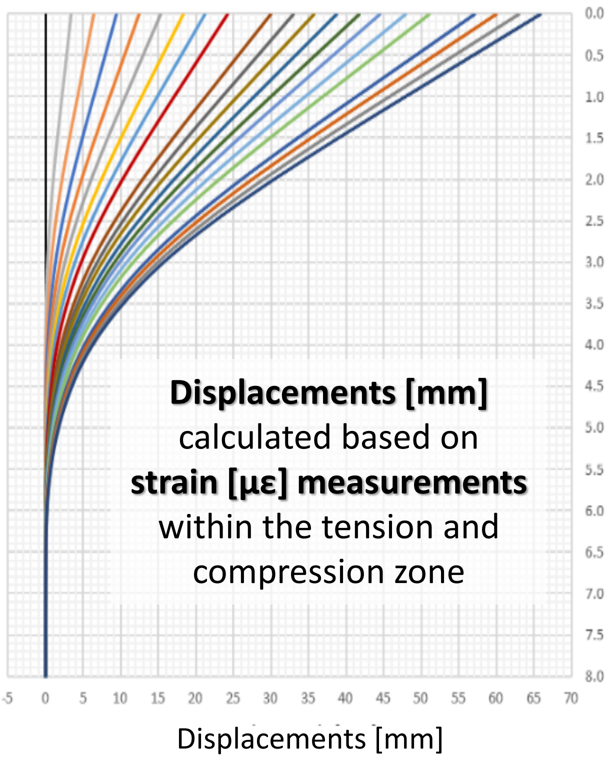
The subject of the project was a slurry wall made of a new type of material: fibre-reinforced concrete mixed with the ground. As this technology must be carefully checked before use, EpsilonRebars were used for this purpose. The structural performance of the wall was monitored during the deepening of the excavation as well as during the mechanical load tests. Thanks to Nerve-Sensors, it was possible to detect cracks but also to calculate horizontal displacements.

Benefits of application

- Distributed measurements of **strains, cracks and displacements** at the same time
- Full **deformation and temperature control** along the entire length of slurry wall
- Simultaneous analysis of **both compression and tension** zone
- Measurements during **deepening of the excavation** and mechanical **load tests**

Example results

The slurry wall was loaded using hydraulic jackets. The figure shows example horizontal displacement profiles calculated based on strains measured by EpsilonRebars during subsequent load steps. The structural performance of the Nerve-Sensor system was proved up to the total failure point of the wall. A very good agreement with reference techniques was obtained.



- **12 800** measurement points
- **128 m** of sensing path
- **16 x** EpsilonRebar
- **construction & load tests**

project **partner**:

Concrete column-slab system: simulation of column failure

nerve-sensors.com

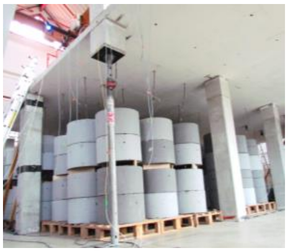
EpsilonSensor: Case Study

The performance of a full-scale concrete structure was investigated during the simulation of column failure. EpsilonSensors were installed inside the slab by tightening to the existing reinforcement. The main aim was to observe the crack morphology. Additional optical fibres were glued to the steel reinforcement to analyse its behaviour during the yielding process. The Nerve-Sensor system measured strains successfully during the entire research until the planned structural failure.

Benefits of application

- Detection of **all the cracks** inside the concrete up to **structural failure**
- Thousands of measurement points with **very fast and easy installation**
- Analysis of **steel yielding under extremely large strain levels**
- Max. registered strains **ten times higher** than in conventional foil strain gauges

Example results



4 000 measurement points

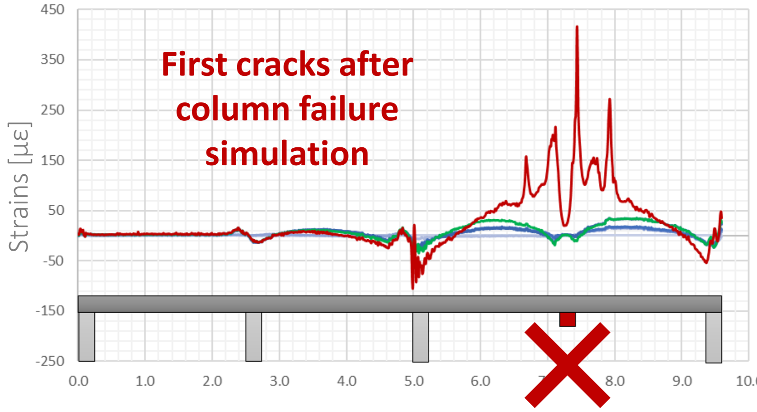
20 m of sensing path

2 x EpsilonSensor

short-term (load tests)

project **partner**: RZESZOW UNIVERSITY OF TECHNOLOGY

EpsilonSensors allowed for detailed structural performance analysis during key research steps: (1) mechanical loading in the elastic range, (2) changing the static scheme by removing the column (see the first cracks in the figure) and (3) additional loading through hydraulic jacket up to the total structural failure. Max. registered strains were ten times higher than in the case of conventional foil strain gauges, which were destroyed very early on.

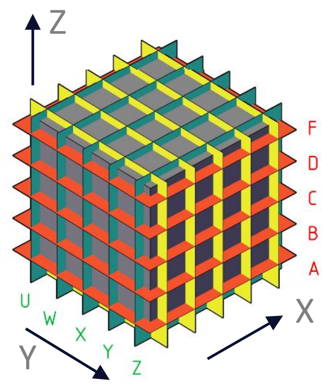


„Concrete tomograph” – early-age behaviour of massive element

nerve-sensors.com

Nerve-Sensors: Case Study

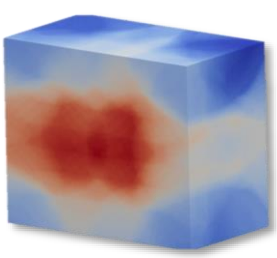
The very challenging experiment was a concrete cube equipped with embedded optical sensors in three directions XYZ. The total number of 75 sections for strain and 25 sections for temperature measurements were created without disturbing the structural performance of the concrete. The research aimed to analyse the spatial behaviour of the massive element during the hydration and shrinkage process, including temperatures and heat transfer.



Benefits of application

- Simultaneous measurements of **strains and temperatures in 3D space**
- Thousands of gauges in a small element **without disturbing its behaviour**
- Unique data about the massive structure for **designing purposes and FEM validation**
- Max. registered strains **ten times higher** than in conventional foil strain gauges

Example results



The 3D network of strain and temperature Nerve-Sensors was successfully embedded inside the cube concreted with self-compacting concrete. The installation process was challenging as there was no reinforcement inside the element. The aim of the cube (35 x 35 x 35 cm) was to simulate the behaviour of massive concrete element during its early age (hydration process). Finally, the spatial picture of thermal-shrinkage strains was obtained in all directions.

7 000 measurement points

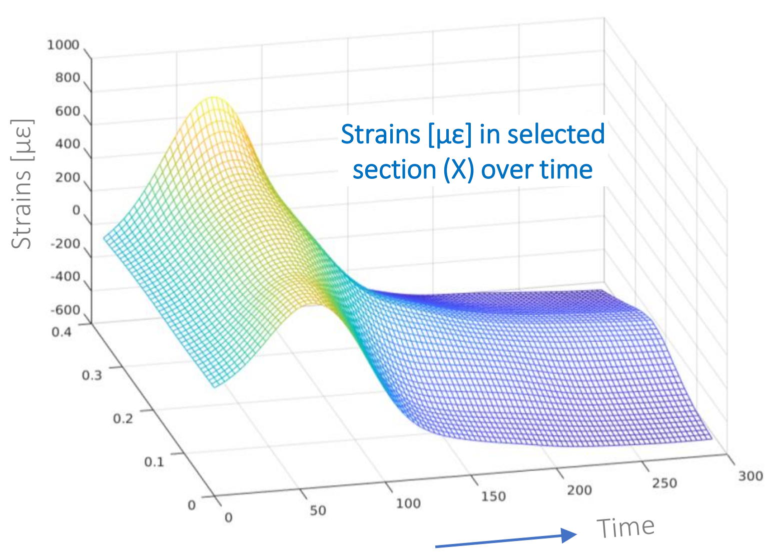
35 m of sensing path

100 x strain sensor

early-age concrete

project **partners**:

AGH



Concrete slab strengthened with FRP composites: strains & cracks

nerve-sensors.com

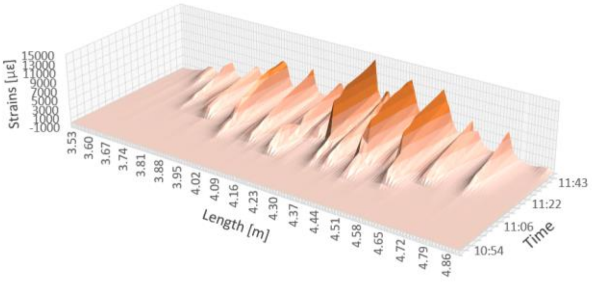
Nerve-Sensors: Case Study

The reinforced concrete slabs were investigated in laboratory conditions in mechanical four point bending tests. Some were strengthened with FRP material to analyse this solution's effectiveness. However, the application of FRP prevented visual inspection of cracks. That is why all the slabs were equipped with distributed optical fibre strain sensors placed in-between the concrete and the strengthening material, which allowed for the detection of all cracks invisible to the naked eye.

Benefits of application

- Detection of **all cracks** between the concrete and FRP material
- Knowledge about **cracks invisible to the naked eye and other techniques**
- Thousands of measurement points **without disturbing structural connection**
- Successful measurements **during the entire test until structural failure**

Example results



One of the research goals was to compare structural behaviour (including crack morphology) of concrete slabs with and without FRP strengthening. DFOS strain sensors installed within the structural connection allowed to complete this task successfully. The figure below shows the example strain profile and corresponding cracks detected during mechanical bending tests.

5 700 measurement points

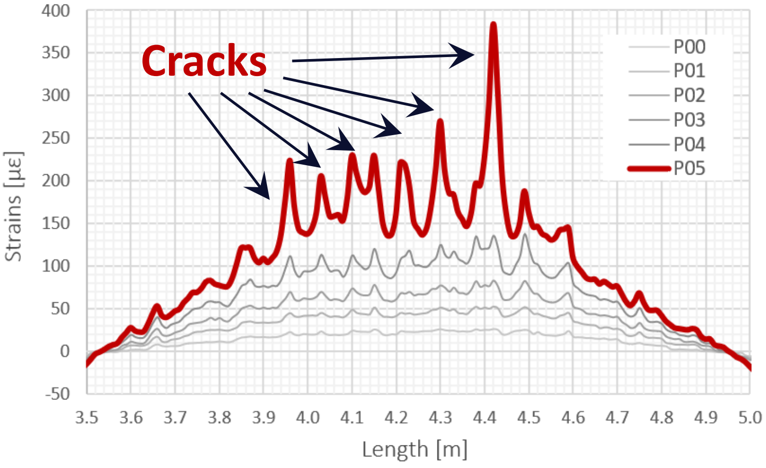
57 m of sensing path

38 x strain sensor

short-term (load tests)

project **partner**:

Wrocław University of Science and Technology

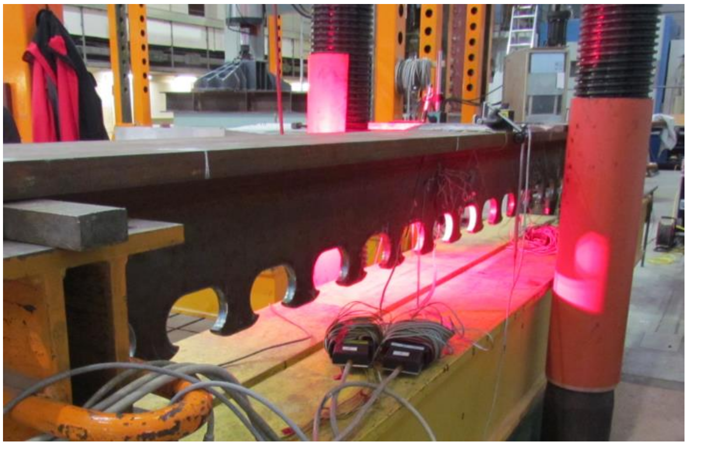


Steel girders during mechanical load tests: elastic and plastic strains

nerve-sensors.com

Nerve-Sensors: Case Study

A number of steel girders designed for bridge applications were investigated in laboratory conditions during mechanical tests. The research includes MCL girders as well as I- and H-beams. The challenge in this project was to measure extremely high strains, exceeding the range of elastic behaviour significantly. Thanks to DFOS strain sensors, it was possible to analyse the yielding process up to 20 000 με in tension and 10 000 με in compression.



Benefits of application

- Strain measurements **during elastic and plastic behaviour** of steel (20 000 με)
- Knowledge about **residual strains, both in compression and tension** zones
- Thousands of measurement points **over freely shape traces**
- Unique data for **scientific analysis, FEM calibration and PhD thesis**

Example results

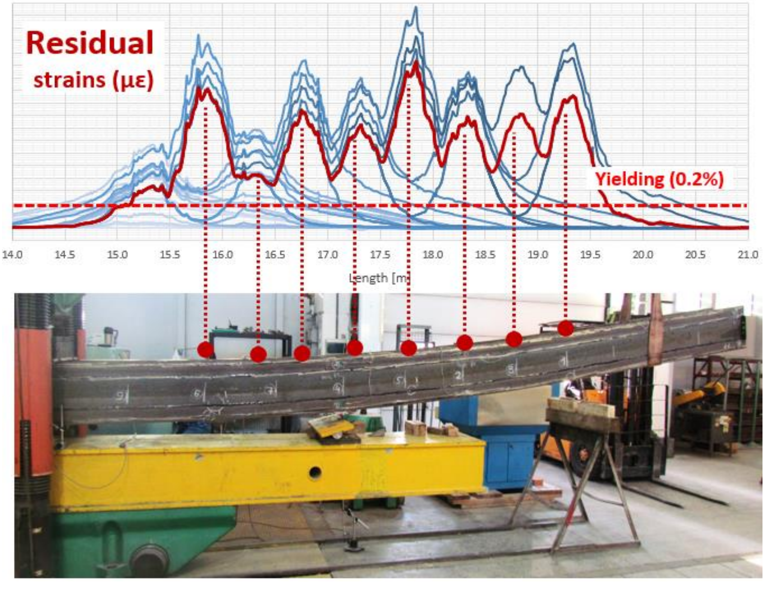
One of the research goals was to monitor the yielding process of steel girders, both in their compression and tension zones. The network of DFOS strain sensors installed within the structural elements allowed us to obtain a comprehensive picture of strains for different load schemes and force values. The figure below shows the example result of strain distributions for selected girder. The red line corresponds to residual strains, which remained after tests were completed.

28 800 measurement points

288 m of sensing path

26 x strain sensor

short-term (load tests)



project **partner**:

Wrocław University of Science and Technology

100 m long section of smart highway reinforced with composite bars

nerve-sensors.com

EpsilonRebar: Case Study

The project involves a 100 m long section of a highway in Poland, which was reinforced with only composite bars, including EpsilonRebars from the Nerve-Sensors family. The entire experimental section was concreted without any dilatations, which is a pioneering approach in road engineering. Our DFOS-based monitoring system provided essential information on strain profiles and crack morphology, while also becoming structural reinforcement.

Benefits of application

- Key information about **crack morphology** along the entire highway section
- Double function of EpsilonRebars: **both sensing and reinforcing** at the same time
- Unique data for scientific analysis and improvement of design procedures
- **Reliable long-term control** of a new experimental section of the highway

Example results

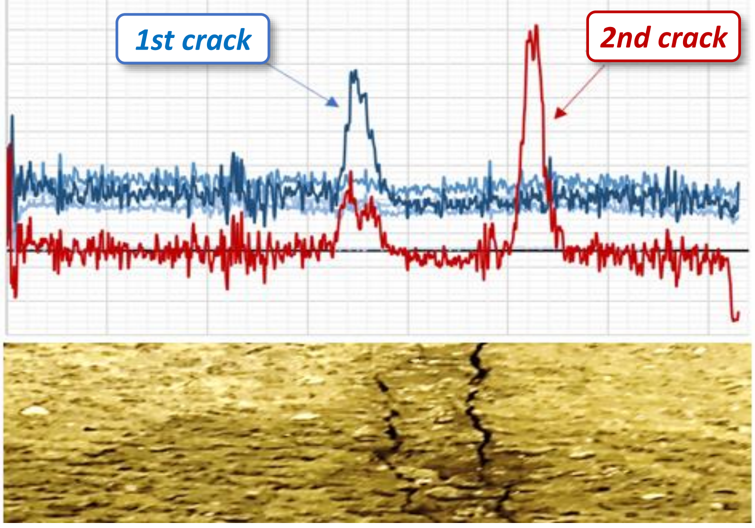
EpsilonRebars were installed in two lines along the entire length of the highway section, as well as at selected critical locations (including transvers direction). Two diameters of the sensors were applied in this project, corresponding to the design assumptions. Sensors had a double function in the structure: sensing and reinforcing at the same time. Measurements performed during long term monitoring allowed for detection of all the cracks formed during hardening of early age concrete – see example in the figure below.

28 000 measurement points

280 m of sensing path

8 x EpsilonRebar

long-term



project **partner**: TPA

Concrete cylinders – mechanical tests in laboratory conditions

nerve-sensors.com

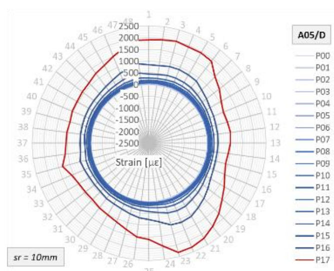
Nerve-Sensors: Case Study

Nerve-Sensors provide new tools for structural analysis of small-size laboratory specimens made of concrete. In this case, 20 standard cylinders were investigated in mechanical axial compression tests up to their failure. DFOS strain sensors allowed for measurements of both compression (longitudinal) and tension (circumferential) strains at the same time. Thanks to the unique data, advanced structural analysis was possible.

Benefits of application

- Simultaneous measurements of **compression and tension strains**
- New approach in structural **failure prediction** based on Poisson's ratio analysis
- Thousands of gauges in the small-size cylinder **without disturbing its behaviour**
- Unique data inc. impact of **aggregate size, eccentricity, pores, cracks, imperfections**

Example results



7 200 measurement points

36 m of sensing path

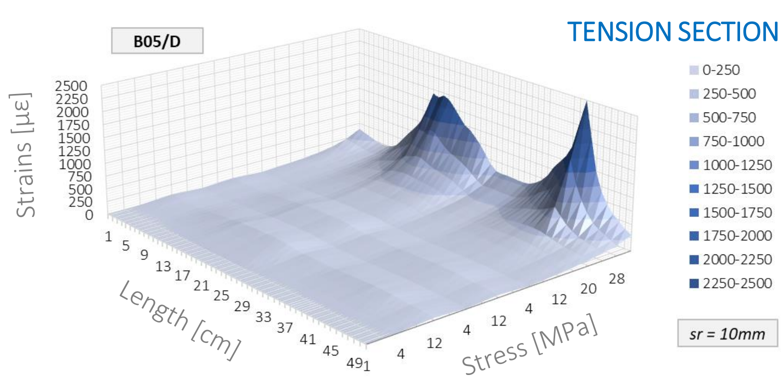
20 x strain sensor

short-term lab tests

Project **partner**:

Cracow University of Technology

This laboratory research shows the great advantage of DFOS-based strain sensors over conventional techniques. Compression and tension strains were recorded at the same time to calculate Poisson's ratio and predict the time of structural failure. Taking into account mechanical properties (such as elasticity modulus), other parameters were studied, e.g. size of the aggregate, pores, local imperfections and microcracks developed within circumferential (tension) sections – see example results in spatial and pie charts.

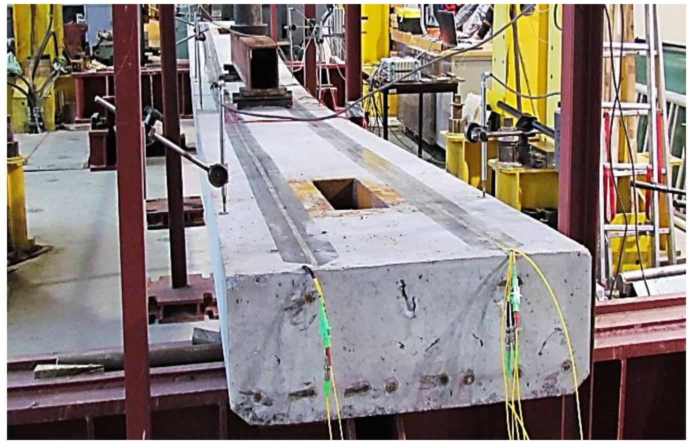


Experimental prestressed concrete truck scale platforms

nerve-sensors.com

EpsilonRebar: Case Study

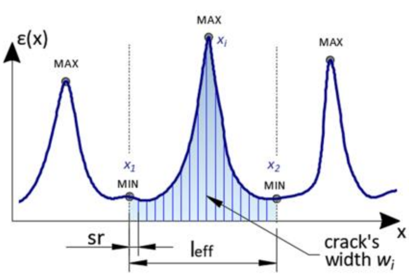
Three 8 m long prestressed concrete truck scale platforms were quipped with EpsilonRebars embedded along the main tendons both in the lower and the upper part. DFOS strain sensors were installed on both surfaces after concrete hardening. The structural performance of the slabs was investigated during all critical stages, including thermal-shrinkage strains of early-age concrete, prestressing & activation of dead weight and finally, during mechanical bending tests.



Benefits of application

- Structural performance **control during all critical construction stages**
- Analysis of **effectiveness of the prestressing** process, including deflection analysis
- Detection of **all the cracks** formed during mechanical tests within the **tension zone**
- Prediction of **the weakest place in compression zone,** where slabs were destroyed

Example results



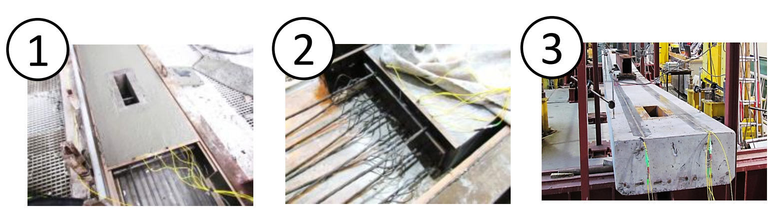
A monitoring system with Nerve-Sensors allowed for deep analysis of slabs' performance. The first stage was concrete hardening (1), while the second (2) prestressing with dead weight activation. Finally, mechanical bending tests (3) were done. A detailed investigation of crack morphology and its development was done over time.

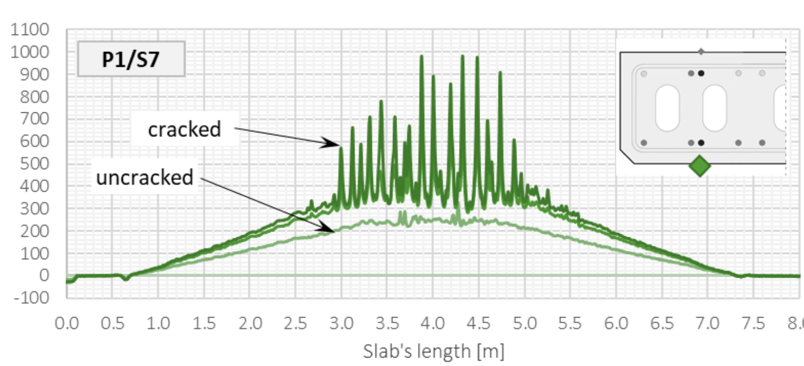
38 400 measurement points

192 m of sensing path

12 x ER, **12 x** strain sensor

short-term





project **partner**:

FABUD WKB S.A.

CFA concrete column: strains & shape analysis during mechanical load tests

nerve-sensors.com

EpsilonRebar: Case Study

The subject of the project was to analyse strain distributions in CFA concrete columns during their hydration (early-age concrete) as well as during mechanical load tests. **EpsilonRebars** were used for this purpose. Because there was no reinforcement inside the columns, a special mounting process had to be designed and implemented. **Nerve-Sensors** allowed for detailed assessment of columns' technical conditions along their entire depth.

Benefits of application

- Distributed measurements of **strains** along the entire depth of CFA columns
- **Detection of local cracks** and microcracks formed during early-age concrete
- Analysis of columns' **shape, stiffness and force transfer** (interaction with the ground)
- Full deformation control during **hydration** and **mechanical load tests**

Example results

The column in question was loaded using the means of the hydraulic jacket. The measurements were done step by step at selected force values. Detailed data analysis allowed for detecting localised events (like cracks) and to calculate the possible shape of the column along its entire depth. The example of this unique data in the form of strains and shape (column's radius) in-depth function is presented in the figures.

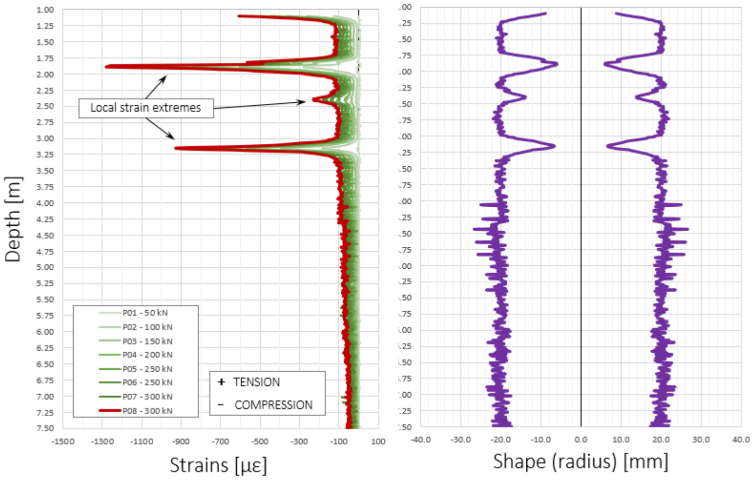
3 800 measurement points

19 m of sensing path

3 x EpsilonRebar

hydration & load tests

project **partner**: PORR

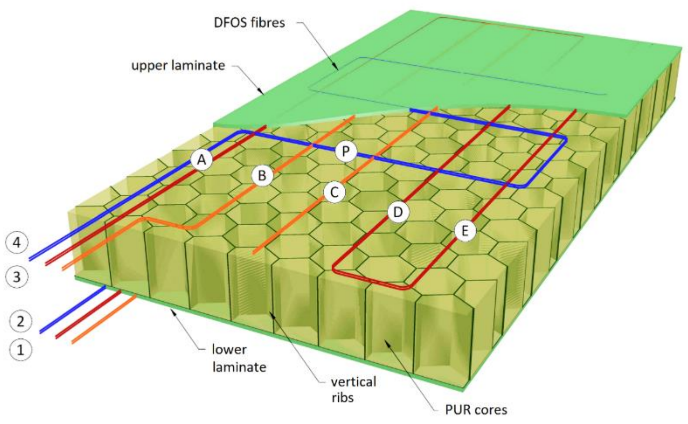


Smart composite FRP panel for bridge engineering

nerve-sensors.com

Nerve-Sensors: Case Study

In this unique project, it was possible to create a smart element capable of self-diagnosis. Nerve-Sensors, including full integration of optical fibre with composite core, as well as displacement (shape) calculation, was implemented in a single bridge panel dedicated for smart bridge engineering. Many laboratory tests with both strain and displacement measurements were performed under the control of independent reference techniques.

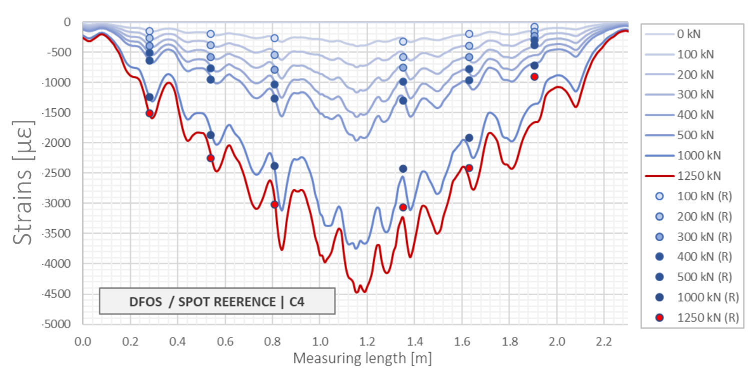


Benefits of application

- **Full integration** of the sensors with the panel at the production (infusion) stage
- Reliable data for **structural assessment** from a **real zero strain/stress state**
- Simultaneous measurements of **strains and displacements (shape changes)**
- **Thousands of measurements points** within a single element for self-diagnostics

Example results

Example measurement results obtained directly from the smart structural component are presented in the plots. We can observe both strains and displacements (shape changes) over length compared to reference techniques. It proves very good accuracy and high-quality performance of this measurement solution, which are the basis for the Nerve-Sensors idea.

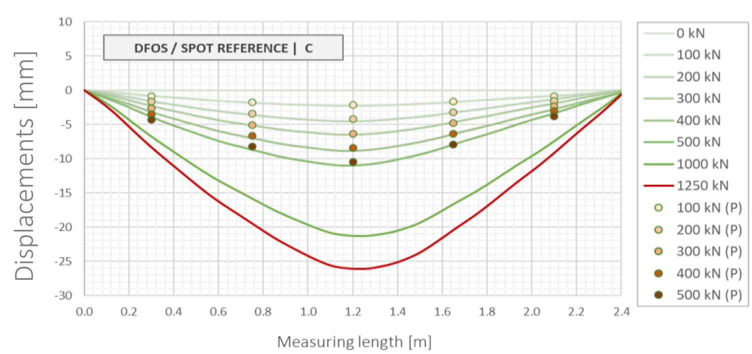


12 000 measurement points

60 m of sensing path

16 x DFOS strain sensors

short-term **(laboratory)**



project **partner**: RZESZOW UNIVERSITY OF TECHNOLOGY

Anchorage zone in 57-year-old post-tensioned precast girder

nerve-sensors.com

Nerve-Sensors: Case Study

Ageing infrastructure is a growing problem in many countries, making it a challenge to take optimal decisions for their further safe operation. Therefore, effective diagnostic solutions are being sought, enabling reliable technical condition assessments. The case study presents the results of **static and dynamic DFOS strain measurements of a 57-year-old girder** dismantled from one of the production halls. **Nerve-Sensors** were successfully applied for this purpose.

Benefits of application

- Detailed investigation of a **57-year-old post-tensioned girder**
- Real-time, **high-frequency measurements** while cutting the tendon off
- Detection of all the microcracks and estimation of their widths
- **Thousands of measurement points** without disturbing structural behaviour

Example results

DFOS sensors were glued to the upper surface of the girder using two-component epoxy to monitor strains within the anchorage zone (along longitudinal and transverse sections at the same time). Thanks to high-spatial-resolution strain measurements, and the transmission length of the tendon related to the quality of cement injection was analysed in a very detailed way. The measurements were performed in both static and dynamic (high-frequency) ways while cutting one of the tendons off. Moreover, detection of existing microcracks and estimation of their widths was possible. **The performed tests proved the great possibilities of DFOS technology for evaluating existing prestressed-concrete structures.**

106 000 measurement points

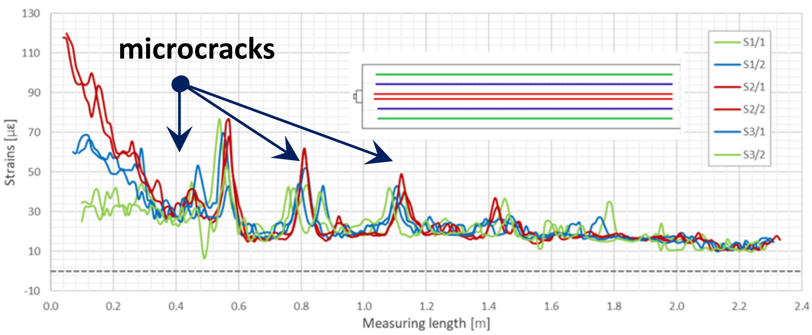
138 m of sensing path

48 x DFOS strain sensors

short-term **(laboratory)**

Project **partner**:

Cracow University of Technology



Famous University Bridge in Bydgoszcz: anchorage zone yielding

nerve-sensors.com

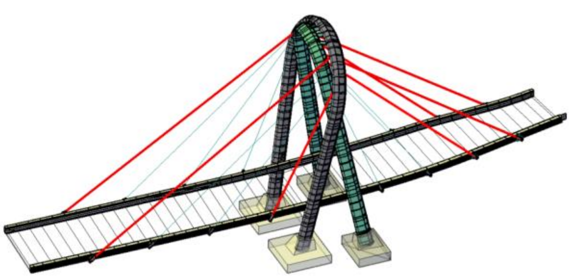
Nerve-Sensors: Case Study

After seven years of operation, University Bridge in Bydgoszcz became famous because of its structural failure. Significant deformations of the steel anchorage plates beyond the elastic range were identified. All the cables were relieved and then prestressed again after strengthening. **Nerve-Sensors** were used to monitor this process and identify the safety-critical areas most probable to yield. Now, this unique and essential to the city bridge came back to regular operation.

Benefits of application

- Detailed control of the real cable-stayed bridge **during its strengthening**
- Identification of **local and safety-critical areas** most probable to yield
- **Reliable diagnostic data** for expert analysis and 3D FEA validation
- **Integrated nerve system** capable of long-term structural health monitoring

Example results



1 600 measurement points

16 m of sensing path

16 x DFOS strain sensors

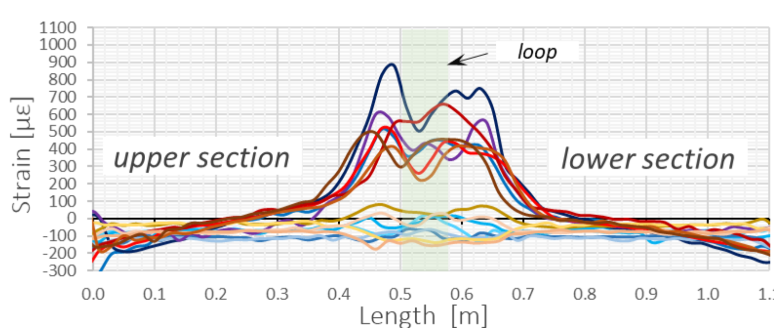
short-term **(strenghtening)**

Project **partner**:

KORMOST

DFOS sensors were glued to the steel anchorages using two-component epoxy. The cables suspended to the unique pylons (A-shaped and Ω-shaped) were relieved and prestressed again after strengthening. Nerve-Sensors were used to control this process in a very detailed way. Thanks to high-spatial resolution strain measurements, **identifying local and safety-critical areas (susceptible to yielding) was possible.**

DFOS measurements provided reliable data for the expertise and calibration of 3D finite element models. The installed sensor system can be successfully used for long-term structural health monitoring.



Gdański Bridge in Warsaw: DFOS-based monitoring of a historical monument

nerve-sensors.com

EpsilonSensor: Case Study

The Gdański Bridge is a six-span steel truss bridge, 406.5 m long and 17 m wide, across the Vistula River in Warsaw. It was opened in 1959 after three years of construction. Its characteristic features are two decks: the upper for road traffic and the lower for trams. EpsilonSensors from the Nerve-Sensors family were selected and installed on the bridge (surface installation with an appropriate adhesive) to monitor the structural performance of safety-critical steel elements.

Benefits of application

- Detailed monitoring and control of the **historic steel truss bridge**
- Evaluation of the structural performance within **local and safety-critical areas**
- **Reliable diagnostic data** for expert analysis and 3D FEA validation
- **Integrated nerve system** capable of long-term structural health monitoring

Example results

6 400 measurement points

64 m of sensing path

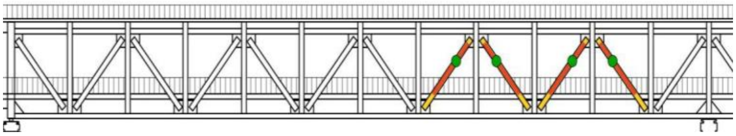
16 x EpsilonSensors

long-term

Project **partner**:

Mostostal WARSZAWA

EpsilonSensors were glued to the steel cross frames using two-component epoxy. The locations of the sensors were selected based on the analysis of results from 3D numerical simulations. Due to the importance of the bridge for traffic in the capital city and its historical character, ongoing structural health monitoring of its safety is invaluable. Nerve-Sensors are the perfect solution for this purpose, supported by the reference vibrating wire sensors.



Prestressed concrete beams working in the extreme large crack state

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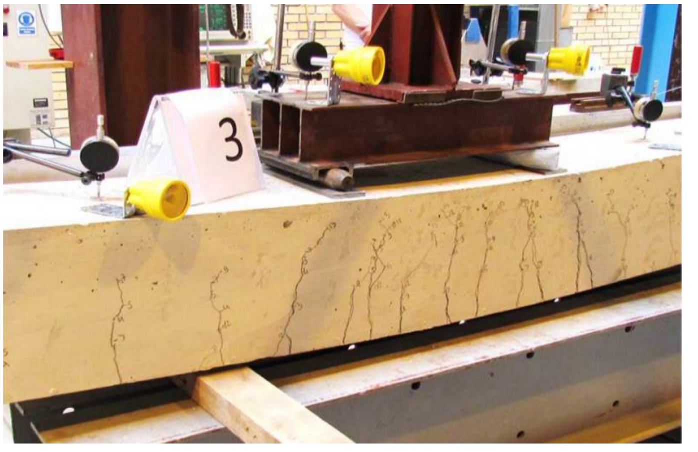
EpsilonSensor: Case Study

Prestressed concrete beams, equipped with **EpsilonSensors,** were investigated during prestressing and mechanical load tests. Twelve beams were made to provide statistical confidence about the obtained results. One EpsilonSensor was arranged in such a way to create four measurement sections at different beam heights. Thanks to that approach, it was possible to detect cracks and calculate their widths, but also to assess the crack depths depending on the load step.



Benefits of application

- **Full knowledge on crack morphology** during entire research (all load steps)
- No risk of sensor breakage **during the extreme crack-induced strains**
- Calculation of **crack widths**, but also identification of their **depths** inside the beam
- **Reliable scientific data** on structural performance

Example results

EpsilonSensors embedded inside concrete allowed us to assess the effectiveness of prestressing process. However, the critical research stage were mechanical bending tests, where the knowledge on crack morphology was of key importance. **EpsilonSensors provided spectacular results, measuring extensive cracks (> 2 mm) with crack-induced strains exceeding 2.7% (27 100 με).** Such values were not previously described in the literature. Our sensors provided reliable data for scientific analysis.

60 000 measurement points

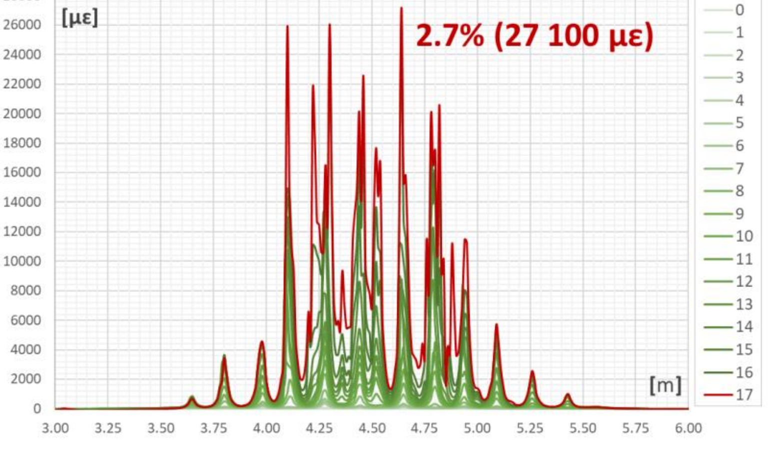
300 m of sensing path

12 x EpsilonSensor

short-term **(laboratory)**

project **partner**:

POLITECHNIKA POZNAŃSKA
Poznan University of Technology



Strains measurements in asphalt layers during dynamic truck runs

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EpsilonRebar: Case Study

This experimental project involved a road structure equipped with EpsilonRebars for strain measurements. Our sensors provided the unique possibility of analysing the internal behaviour of asphalt layers under dynamic truck's runs. The measurements were done in real-time with extremely high spatial resolution and extreme accuracy. This was due to the high elastic composite core, monolithic design and perfect bonding of the sensors with surrounding asphalt.

Benefits of application

- Measurements of internal **strains** inside the asphalt layer with a great accuracy
- Observation of **structural response in real-time** during truck's runs
- Possibility of **calibrating** numerical models, including **dynamic effects**
- Detailed **scientific data** for new road structure design procedures (optimisation)

Example results

Our DFOS-based nervous system with EpsilonRebars embedded into the asphalt was used for measurements during truck runs. Sensors could withstand harsh installation conditions, including high temperatures during asphalting. Perfect strain transfer, characteristic of the monolithic design, was clearly visible in the obtained results. For example, we indicated the differences in structural response caused by the action of the front (single wheels) and rear (dual wheels) axles.

100 770 measurement points

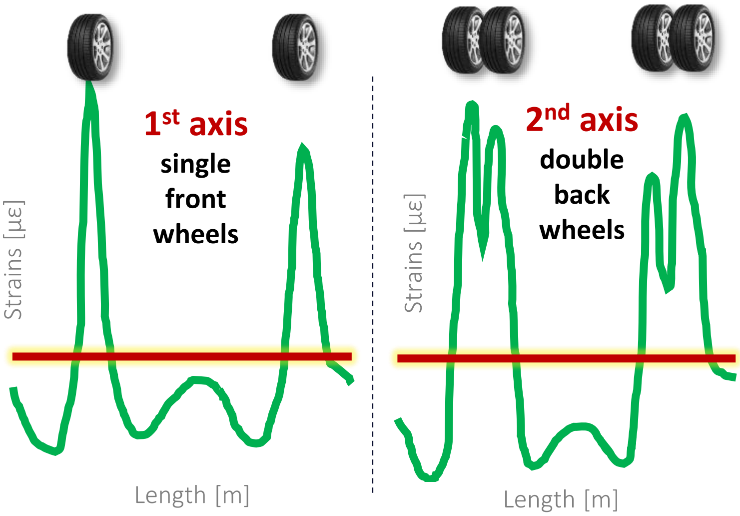
131 m of sensing path

13 x EpsilonRebar

short-term **(load tests)**

project **partner**:

Silesian University of Technology



Strain measurements in asphalt layers during dynamic truck runs

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EpsilonRebar: Case Study

This experimental project involved a new type of road with a foam-concrete substructure. EpsilonRebars were used to monitor structural response on mechanical load tests. Thanks to the appropriate installation methods, it was possible to provide measurements not only along the horizontal sections but also along with the vertical ones. It's worth noting that there was no reinforcement facilitating the installation within the entire structure.

Benefits of application

- Measurements of internal **strains** inside the foam-concrete substructure
- Strain analysis along the **horizontal and vertical** sections inside the structure
- Possibility of **calibrating** numerical models, including **dynamic effects**
- Detailed **data** for new road structure design procedures (optimisation)

Example results

EpsilonRebars, as a part DFOS-based nervous system, allowed for detailed analysis of the deformation state of the new type of road caused by the mechanical loads (truck). Sensors were successfully installed despite difficult conditions within the construction site. Strain measurements within the horizontal and vertical sections, including the short-term slippage, were performed with high-spatial resolution.

3 200 measurement points

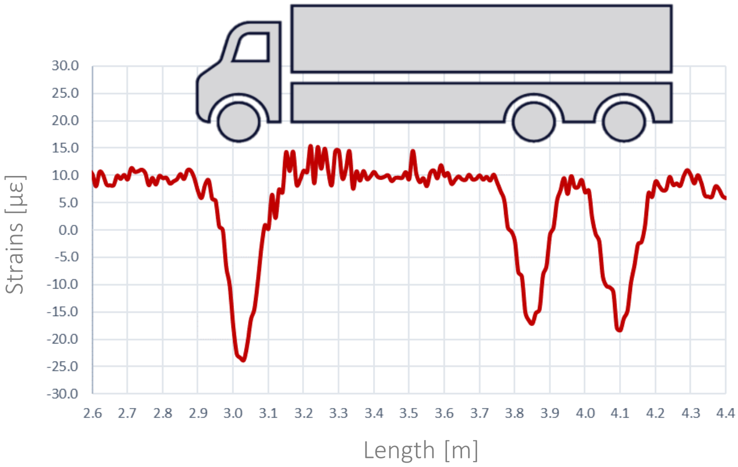
32 m of sensing path

8 x EpsilonRebar

short-term **(load tests)**

project **partner**:

Instytut Techniki Budowlanej



DFOS monitoring of an active road located within mining area

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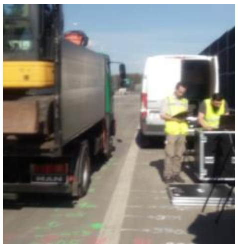
EpsilonRebar: Case Study

EpsilonRebars were integrated (embedded) inside the asphalt layer of a real road structure running in mining areas, i.e. where very large deformations are expected. A new road's structural performance was first investigated during shot-term mechanical load tests. They were performed a few times over the year analyse temperature influence. However, the DFOS-based nervous system will also be a useful diagnostic system for long-term monitoring.

Benefits of application

- Measurements of **internal strains inside the asphalt** layer of a new road
- Comprehensive deformation control of the structure **located in mining areas**
- Realiable assessment of **short- and long-term structural performance**
- Detailed **scientific data** for design procedures and FEA calibration

Example results



EpsilonRebars were embedded inside the asphalt layer of the road structure in mining areas. Both longitudinal and transverse sections were formed to analyse the complex state of deformations caused by mechanical load (truck). The example results are presented in the below figure from the transverse EpsilonRebar. We have obtained unique measurement data, unobtainable with other measurement techniques and gauges.

8 400 measurement points

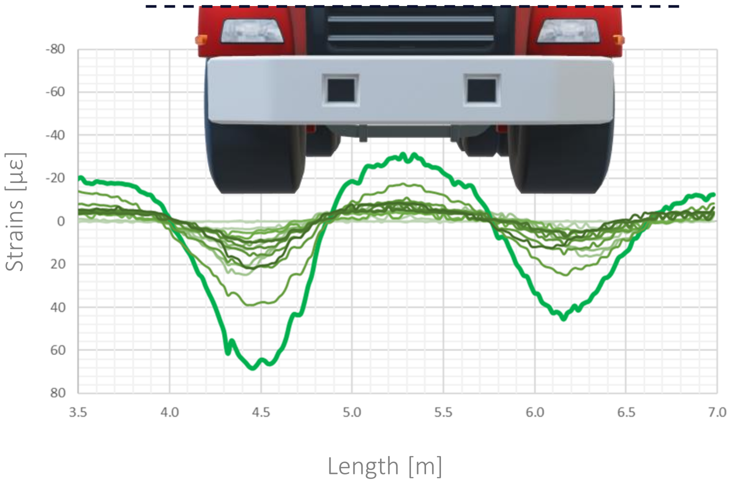
42 m of sensing path

6 x EpsilonRebar

load tests & long-term

project **partner**:

Silesian University of Technology



Steel truss bridge with concrete slab with embedded Nerve-Sensors

nerve-sensors.com

EpsilonRebar: Case Study

EpsilonRebars with lengths of 60 m and 90 m were installed within two similar steel truss bridges, crossing the Noteć River in Poland. **Nerve-Sensors** were embedded inside the concrete slabs over their entire length. They were delivered on-site in coils and secured to the existing reinforcement along the main prestressing tendons. The designed and implemented nervous system of the structure is a perfect solution for both short-term load tests and long-tem monitoring.

Benefits of application

- Full control of the bridge structural performance under mechanical loads
- Possibility of additional **crack detection** or **distributed temperature** measurements
- **Reliable measurement data** for expert analysis and 3D FEA validation
- **Integrated nerve system** capable of long-term diagnosis and structural monitoring

Example results

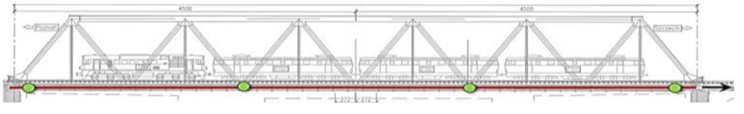
EpsilonRebars provided spectacular strain results with extremely high spatial resolution. Thus, a detailed structural performance analysis, including actual static and load schemes, was possible. The example plot below shows the results from load tests obtained from the longer (90 m long) bridge. Strain profiles exactly correspond to the geometry of the truss superstructure.

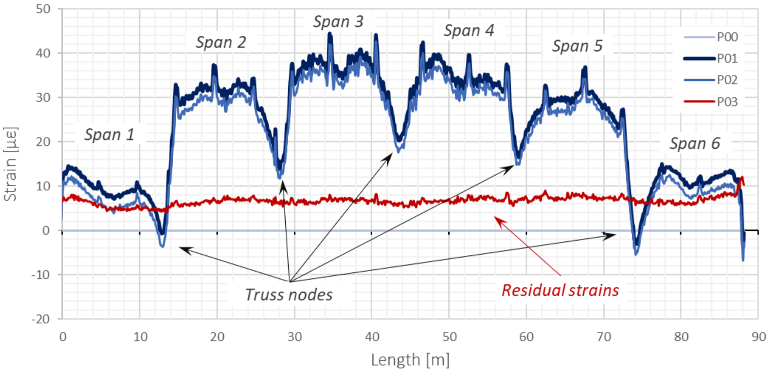
60 000 measurement points

300 m of sensing path

4 x EpsilonRebar

load tests & long-term





project **partner**: STRABAG

Smart composite pipelines capable of DFOS-based self-diagnosis

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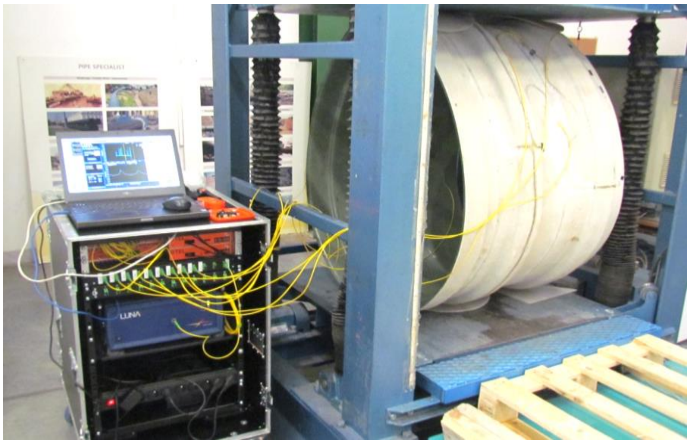
Nerve-Sensors: *Case Study*

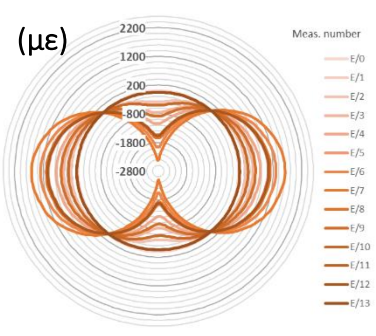


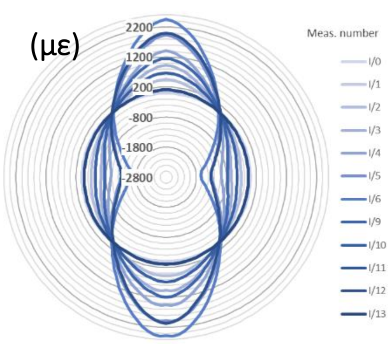
Composite collectors and pipelines were investigated in collaboration with the Warsaw University of Technology. The specimens were equipped with surface-mounted optical fibres for internal and external strain measurements. Thanks to that approach, 3DSensor could be utilised to calculate displacements (shape changes) expressed directly in millimetres. The research included pipe specimens with different geometry of the cross-section.

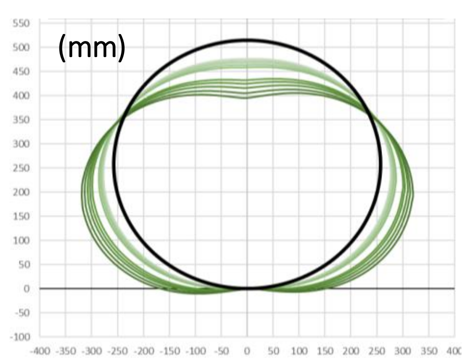
Benefits of application

- Simultanoues strain analysis over the **internal and external surface of the pipe**
- **Shape change calculations** according to the 3DSensor's algorithm
- **Thousands of measurements points** within a single element for self-diagnostics
- **Unique scientific data** on structural performance

Example results







9 200 measurement points

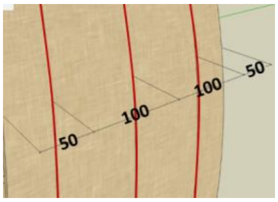
46 m of sensing path

7 x DFOS strain sensors

short-term **(laboratory)**

project **partner**: Warsaw University of Technology

The above figures show the example results obtained during laboratory load tests. The raw data for further calculations are external strains (left Fig.) and internal strains (middle Fig.). Using the algorithm of 3DSensor, it was possible to estimate the shape changes during subsequent load steps (right Fig.).



Renovation and monitoring of the historical brick masonry walls

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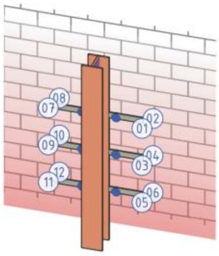
Nerve-Sensors: Case Study

This unique research was performed at the Cracow University of Technology. Even though it was a laboratory test, the lessons learned will be beneficial during the monitoring and maintaining the real brick masonry walls of the barracks located in Auschwitz Birkenau camp. Thus, the project is of significant historical meaning. DFOS strain sensors were used to monitor the wall response (built with all imperfections corresponding to the actual state) during mechanical load tests.

Benefits of application

- Detailed strain measurements **over the entire height** of the brick masonry wall
- **Non-invassive diagnostics** important for historical structures
- Thousands of virtual gauges capable of **local damage and imperfection detection**
- Unique scientific data for **expert analysis**

Example results



DFOS strain sensors were glued to the surface of the brick masonry wall using two-component epoxy. Eight measurement sections were formed on both sides for detailed structural response control during the mechanical load test. By means of hydraulic jacks, an attempt was made to bring the deformed wall back upright. Thanks to the precise and high spatial resolution strain measurements, it was possible to identify the weakest areas and calculate horizontal displacements (shape changes).

3 200 measurement points

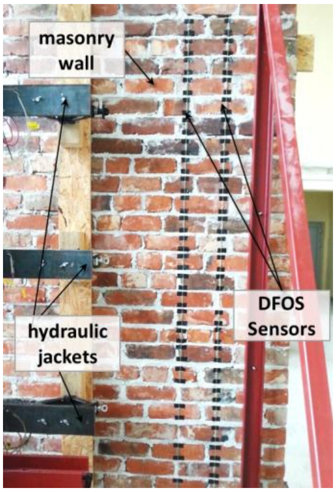
16 m of sensing path

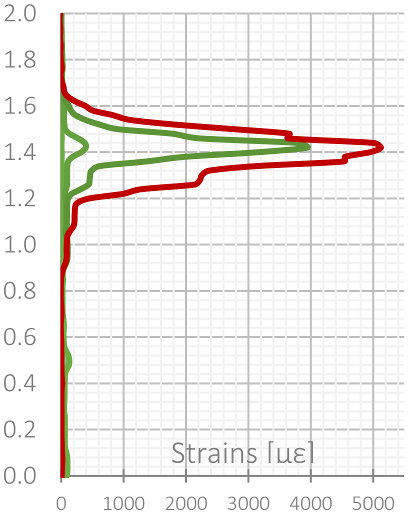
8 x DFOS strain sensors

short-term **(laboratory)**

Project **partner**:

Cracow University of Technology





Strain and displacement monitoring inside a road structure

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ER & 3DSensors: Case Study

EpsilonSensors and **3DSensors** were used to create embedded nervous systems in a test environment, simulating the structural behaviour of the actual road substructure. Both longitudinal and transverse sections were investigated at two levels. Despite many sensors installed inside the box, they were not acting as reinforcement and thus, they did not influence the response of the substructure. Strains and displacements were measured at the same time during mechanical loading.

Benefits of application

- Measurements of **strains and vertical displacements** inside the substructure
- **Same sensors used for multiple tests** with changeable conditions (e.g. humidity)
- Thausands of measurement points **without reinforcing** ground layers
- Detailed **scientific data** for design procedures and FEA calibration

Example results

The example plots on the right correspond to the substructure deformations in one of the tests with increased ground humidity. Both strains [με] and vertical displacements [mm] (settlements, sinkholes) were measured with extremely high spatial resolution.

5 600 measurement points

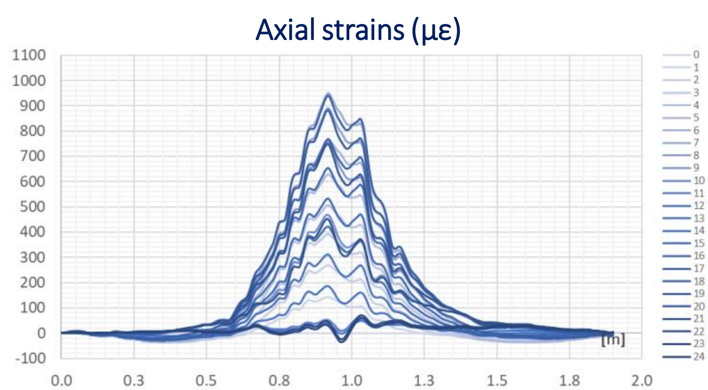
28 m of sensing path

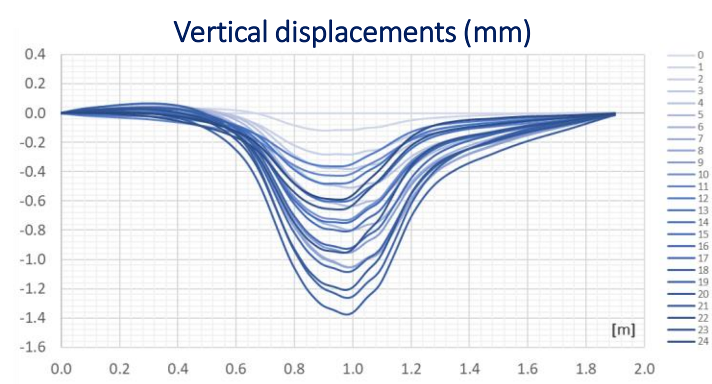
8 x ER, **6 x** 3DSensor

short-term **(laboratory)**

project **partner**:

Silesian University of Technology





EpsilonSensor and 3DSensor used in a composite deck

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ES & 3DSensor: Case Study

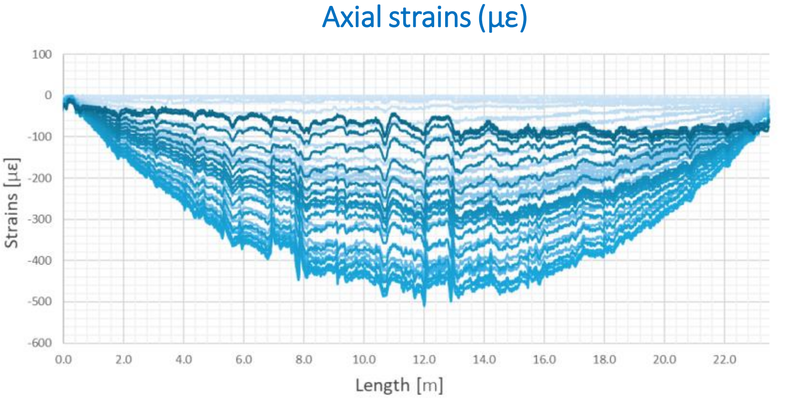
The innovative foot deck was designed and implemented within an existing bridge in Rzeszów. DFOS fibres were integrated within the composite panels during their production (infusion), so sensors became an integral part of the entire structure. Appropriate fibres arrangement and their full integration inside the composite panels allowed us to utilise the idea of both strain sensing with the **EpsilonSensor** and vertical displacement sensing with **3DSensor**. The ready-to-use smart panels were delivered on-site.

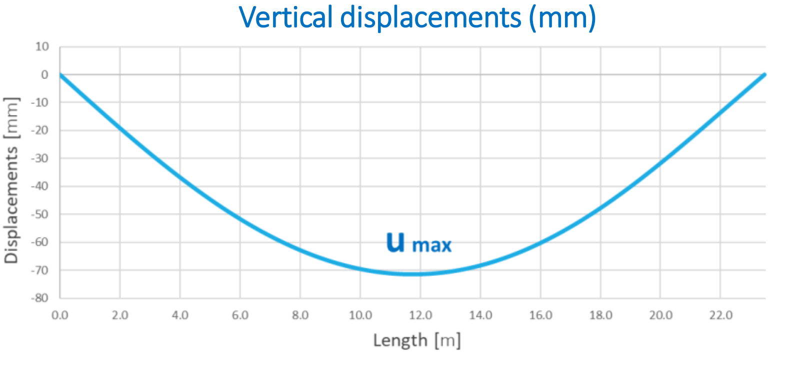
Benefits of application

- **Full integration** of the sensors with the panel at the production (infusion) stage
- Reliable data for **structural assessment** from a **real zero strain/stress state**
- Simultaneous measurements of **strains and displacements (shape changes)**
- **Thousands of measurements points** within a single element for self-diagnostics

Example results

Example DFOS results (both strains and displacements) obtained during load tests are presented on the plot graph. Very good agreement with reference techniques proved the accuracy, reliability and high-quality performance of the applied solution, which is in line with the basic design of **Nerve-Sensors.**





70 800 measurement points

354 m of sensing path

25 x DFOS strain sensors

load tests & long-term

project **partner**: RZESZOW UNIVERSITY OF TECHNOLOGY

The first Polish full composite bridge with DFOS-based monitoring system

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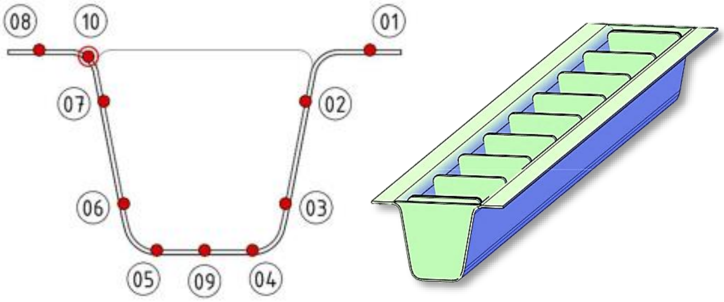
ES & 3DSensor: Case Study

The innovative DFOS-based monitoring system was applied within the first Polish full composite bridge (composite girders + composite slabs). DFOS strain fibres were installed on the surface in the production hall, and then pre-prepared smart elements were delivered on-site. The system's design, including the appropriate arrangement of the fibres, allowed us to utilise the idea of both strain sensing with the EpsilonSensor and vertical displacement sensing with the 3DSensor.

Benefits of application

- **Prefabrication of the smart structural element** in the production hall
- Reliable data for **structural assessment** from a **real zero strain/stress state**
- Simultaneous measurements of **strains and displacements (shape changes)**
- **Thousands of measurements points** within a single element for self-diagnostics

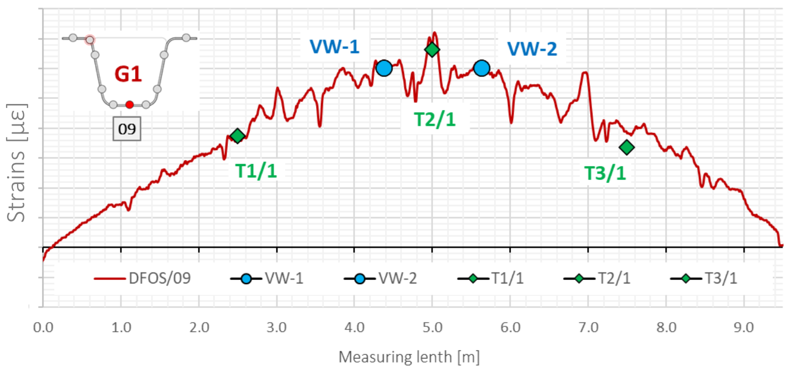
Example results



The DFOS-based monitoring system was used to verify the bridge's structural performance during its load tests and during long-term monitoring. Thanks to the negligible costs of the DFOS fibres, there was no need to limit the number of measurement sections. The figure below summarises example strain results obtained during the load tests, confirming very good compliance with other reference and spot techniques.

- **50 000** measurement points
- **100 m** of sensing path
- **10 x** DFOS strain sensors
- **load tests & long-term**

project **partner**: RZESZOW UNIVERSITY OF TECHNOLOGY



Cable-stayed bridge in Rzeszów: steel girder as a displacement sensor

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Nerve-Sensors: Case Study

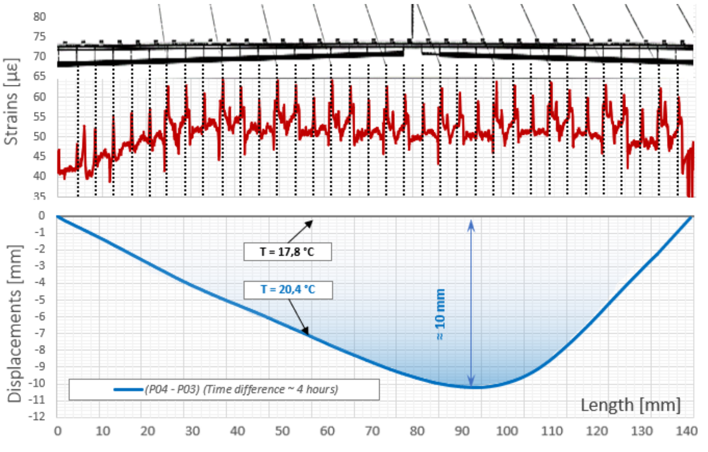
The T. Mazowiecki cable-stayed bridge in Rzeszów was put into service in 2015. The bridge is 482 m long, with two traffic lanes in each direction. The structure is supported by a 107-m long A-shaped pylon with 64 cables. In 2018, the bridge was equipped with distributed fibre optic sensors for strain and temperature measurements. One of the main aims was to create the displacement 3DSensor from the steel girder itself along the 150-metre long river span.

Benefits of application

- Detection of **local events**, including steel anchorages, welds and ribs
- Distinguish between **mechanical and thermal strains**
- Calculation of **vertical displacement profile** (deflection line)
- Creating a **smart sensor from the real, full-scale structural element** (steel girder)

Example results

Distributed fibre optic strain sensors were installed at the bottom and upper part of the steel girder, along a 150 m long river span. All local effects, including perpendicular ribs, welds and anchorages, were clearly detectable in strain profiles. It was also possible to calculate vertical displacements [mm] based on the measured strains and the 3DSensor. Example results are shown in the figures.



6 000 measurement points

600 m of sensing path

4 x strain sensor

long-term monitoring

project **partner**:

AGH