Application Note

High Pressure Water Pipe

Optical Monitoring System for Strain Measurement

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APPN001 en

Content

1 Introduction

Overview

A fiber Bragg grating (FBG) monitoring system was installed to measure strain on the inner surface of a steel pipeline operating at 100 bar.

HBM was contracted to provide and install an FBG monitoring system to continuously monitor the strain on specific points of the internal contour of a recently built penstock water pipeline (Ø=~4m) in Austria, within the scope of a structural loading test.

This supplied system included the following items:

- Measurement System – 3 Industrial BraggMETERs SI (Fig. 1) with BraggMONITOR software.
- Arrays of Sensors – 18 arrays of FS62 Weldable Strain Sensors (Fig. 2.).
- Optical Cable – 10 000 meters of fiber optic armored cable

Fig. 1: FS22 Industrial BraggMETER SI

Fig. 2: FS62 Weldable Strain Sensors

The pipeline was instrumented in 9 sections: A1, A2, A3, A4, B1, B2, B3, S1 and S2 with 18 arrays of FS62 Weldable Strain Sensors totalizing 203 optical sensors. To interrogate the sensors 3 Industrial BraggMETERs SI were used: 2 interrogators with 8 optical channels and 1 interrogator with 4 optical channels.

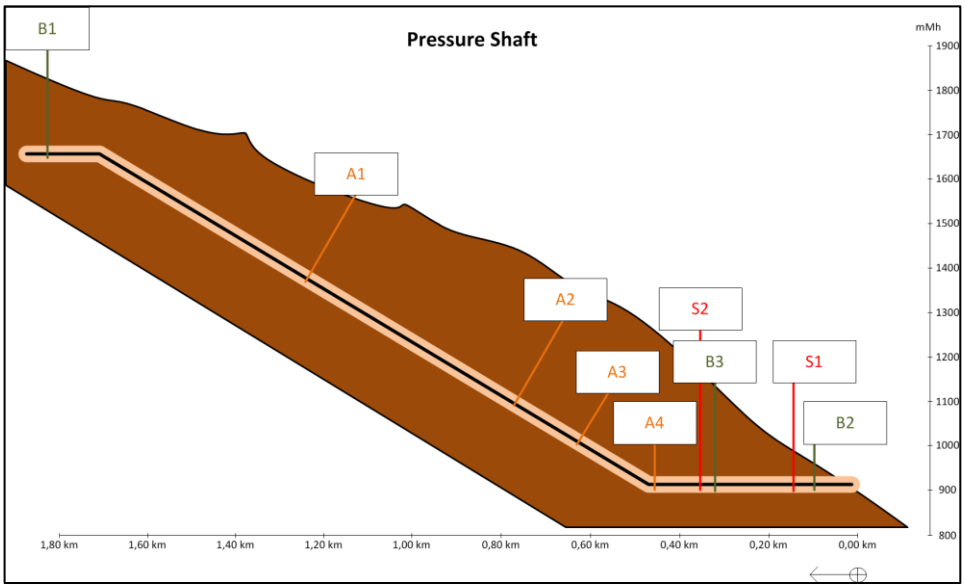

Fig. 3: Geotechnical profile (pipeline elevation)

2 System Architecture

System Architecture Overview

The architecture of the monitoring system is represented in Fig. 4**.**

The arrays were connected to interrogators placed in 2 technical racks: 1 and 2.

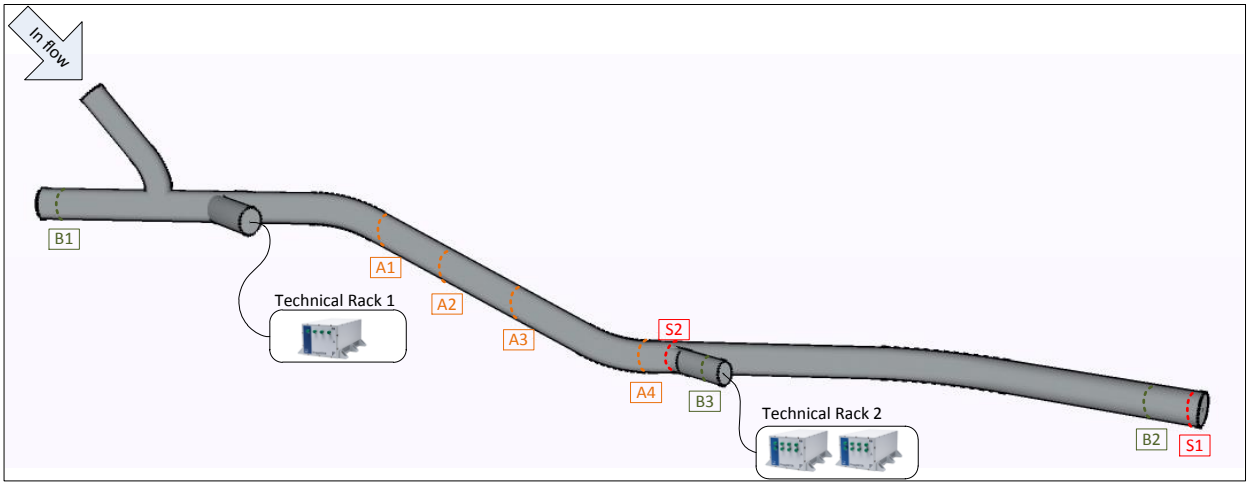

Fig. 4: Architecture of the system installed in the field

The instrumented sections A1 and B1 were connected to the Technical Rack1 and the remaining instrumented sections were connected to the Technical Rack 2. The connection between the interrogators and the arrays deployed on each section is represented on the following table and in Fig. 14.

BraggMETER	Section	Position	Array	Optical	Nº of Sensors
0	B1	l	Array 9.B1l	CH0	13
		r	Array 10.B1r	CH1	12
	A1	a	Array 1.A1a	CH2	12
		b	Array 2.A1b	CH3	11
1	A2	a	Array 3.A2a	CH0	12
		b	Array 4.A2b	CH1	11
	A3	a	Array 5.A3a	CH2	12
		b	Array 6.A3b	CH3	11
	A4	a	Array 7.A4a	CH4	12
		b	Array 8.A4b	CH5	11
	B2	l	Array 11.B2l	CH6	13
		r	Array 12.B2r	CH7	12
	S2	a	Array 16.S2a	CH0	14
		b	Array 17.S2b	CH1	10
		c	Array 18.S2c	CH2	7
	B3	l	Array 13.B3l	CH3	13
		r	Array 14.B3r	CH4	12
	S1	-	Array 15.S1	CH5	5

Arrays

The sensors were organized in 18 arrays. Sensors in the same array operate in series, which is commonly known as Multiplexing. The example of Array 16 is shown in Fig. 5. It was installed in section S2, position “a”. HBM FiberSensing Arrays are produced as individual sensors that are then joined together (spliced).

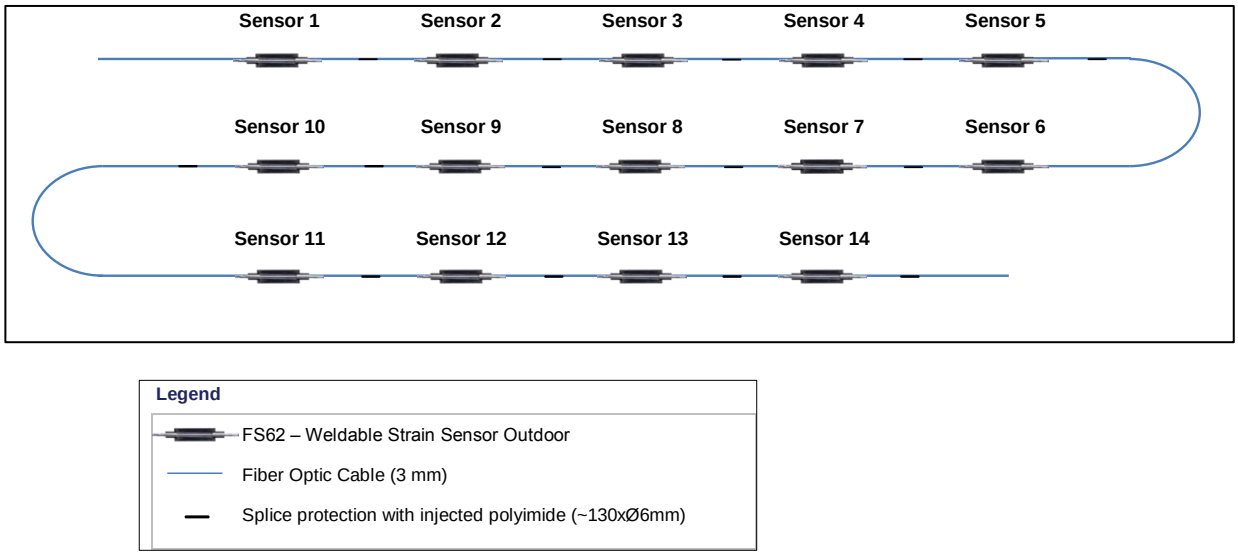

Fig. 5: Scheme of Array 16 - S2a

The splice connection is very fragile if not protected, therefore, a splice protection with injected polyimide (~130 x Ø6mm) is applied, refer to Fig. 6.

Fig. 6: Splice protection with injected polyimide

There are 3 main groups of instrumented sections where the sensors were installed. This organization considers the Sections types: A, B and S (special), as described in the following pages.

- Section-Type A

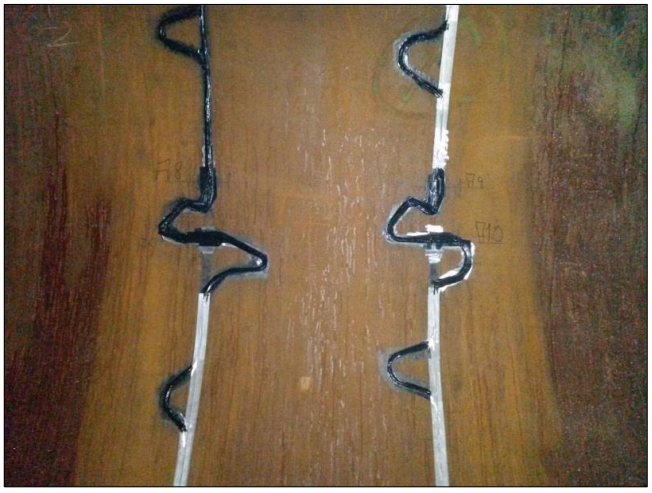

Fig. 7: Installation of sensors in section-type A

The sections type A include 2 arrays of sensors that materialize 2 instrumented rings, a and b (see Fig. 8**)**. The rings have an offset of 1 meter between them.

Each section type A includes 14 transverse, 8 longitudinal strain sensors and 1 reference sensor for pressure and temperature compensation (see Fig. 8).

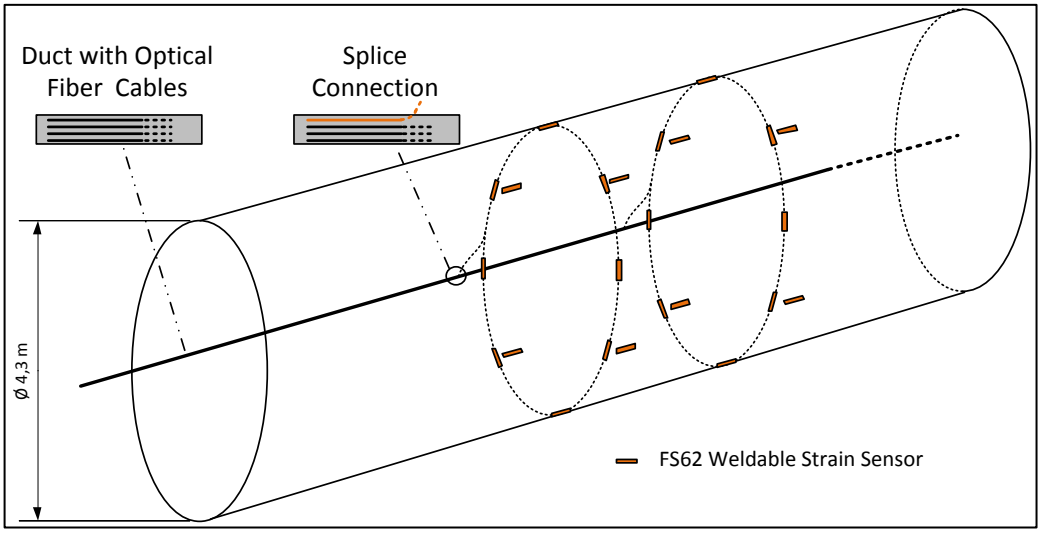

Fig. 8: Position of sensors on section type A.

- Section-Type B

Fig. 9: Installation of sensors in section-type B

The sections type B include 2 arrays of sensors, identified as l and r (Fig. 9). The distance between the sensors depends on the diameter of the pipe in the specific instrumented section.

Each section type B includes 12 transverse, 12 longitudinal strain sensors and 1 reference sensor for pressure and temperature compensation (see Fig. 10).

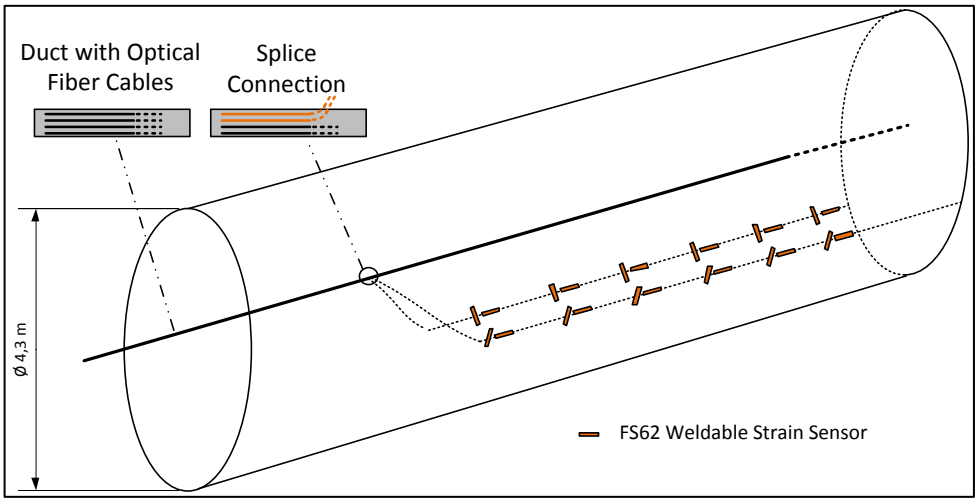

Fig. 10: Position of sensors on section type B

- Section-Type S

Fig. 11: Installation of sensors in section-type S

The sections type S refer to special cases where each array is different. The section S1 includes 1 array of sensors (Fig. 11) and the section S2 includes 3 arrays of sensors (a, b and c). These arrays were installed in particular details of the structure.

The section type S1 includes 4 sensors and a reference sensor for pressure and temperature compensation (see Fig. 12). The section type S2 includes 30 sensors and 1 reference sensor for pressure and temperature compensation.

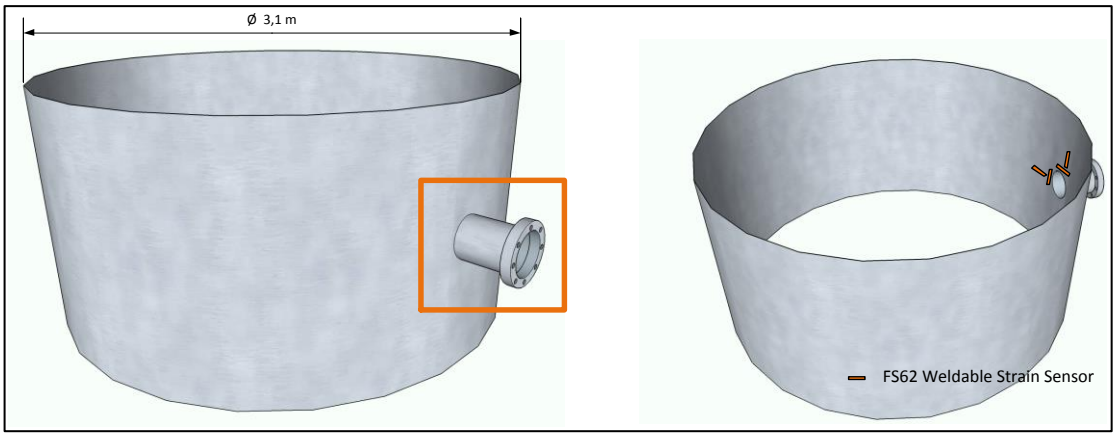

Fig. 12: Position of sensors in section type S1

Main Cables

The arrays of sensors were delivered to the construction site already assembled as shown in Fig. 5. After the installation of the arrays they were connected to the main cables. The main cables make the connection between the arrays and the interrogators.

Note: For each array there are 2 cables, being one of them for redundancy purposes.

The protection of the cables was done with flexible tubes fixed to the pipeline.

Flanges

The flanges are sealed transition pieces to make the passage of the cable from the inside to the outside of the pipe. In this case a stainless steel flange adapted with X120 Adhesive was used for the specific quantity of cables.

Fig. 13: Flange

Technical Racks

The technical racks included the interrogators to read the sensors and record the measurements, LCD screens, PCs with BraggMONITOR software and UPS. Both Technical Racks were connected to the internet working as a remote station.

Installation Scheme

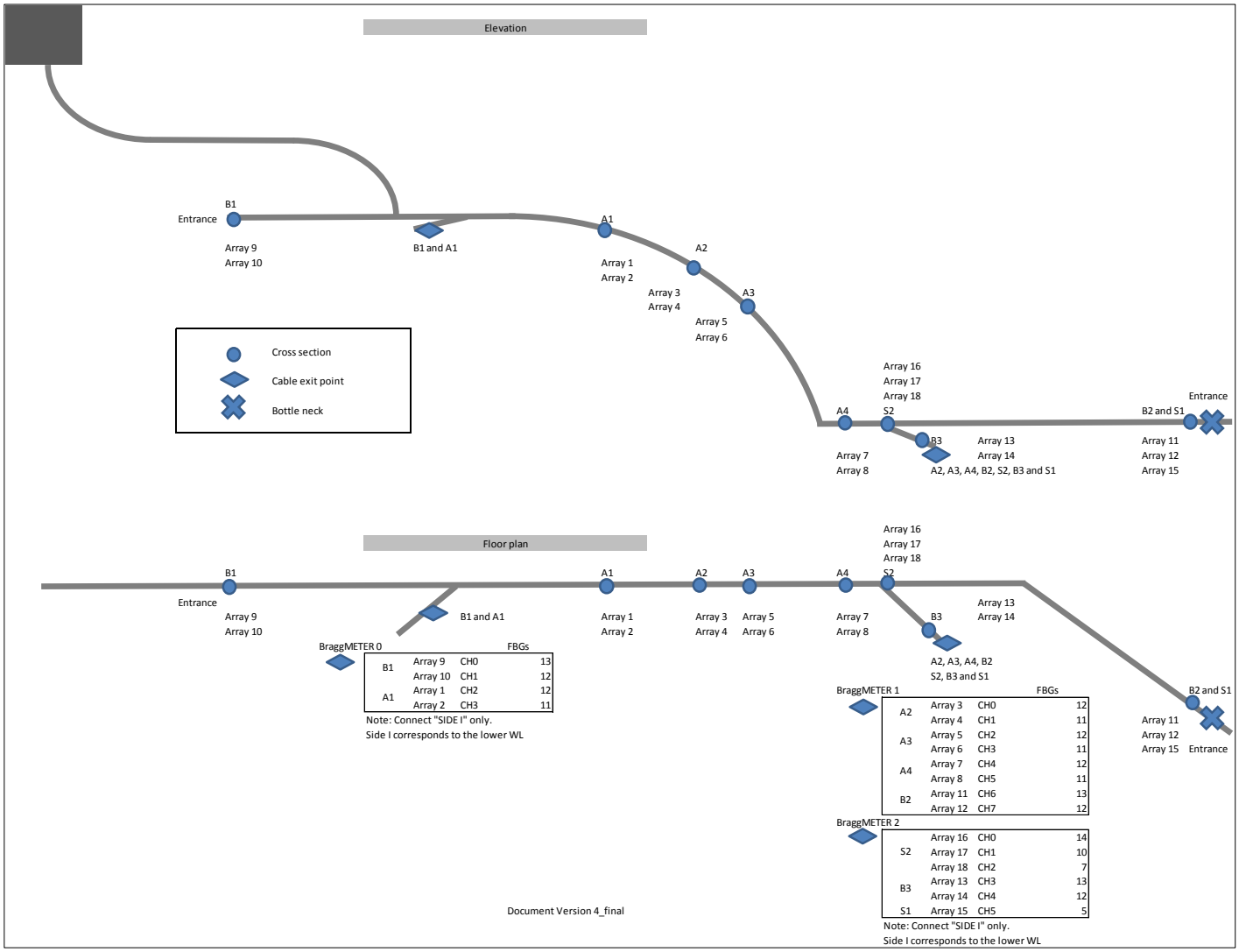

Fig. 14: Installation scheme

3 Installation Details

Mark Sensors Position

The positioning of the sensors was targeted with a laser reference and then marked with a permanent marker, before deburring the surface.

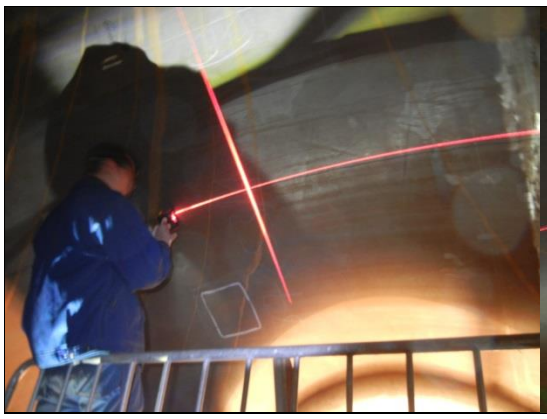

Fig. 15: Laser positioning

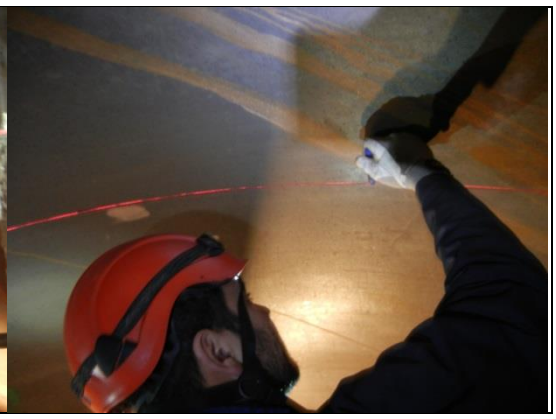

Fig. 16: Cross-section marking

Preparation of Surface

The surface was deburred along the path of the fiber to allow the correct installation of the sensor and to assure a correct bonding of the protection glue.

Fig. 17: Deburring the surface

Fig. 18: Cleaning the surface with alcohol

Installation of Sensors

The installation of the sensors is a spot welding sequence. During the spot welding process the wavelength shift of the sensors were monitored with a portable interrogator (FS42 Portable BraggMETER).

Fig. 19: Sensor welding

Fig. 20: Sensor A12 after welding

Protection of Sensors

The protection of the sensors was done with X120 Adhesive. Besides protection, the glue also provides waterproofing to sensors and connections. The fiber optic cable between the array of sensors and the main fiber optic cable was protected with a water proof bi-dimension resistant tape.

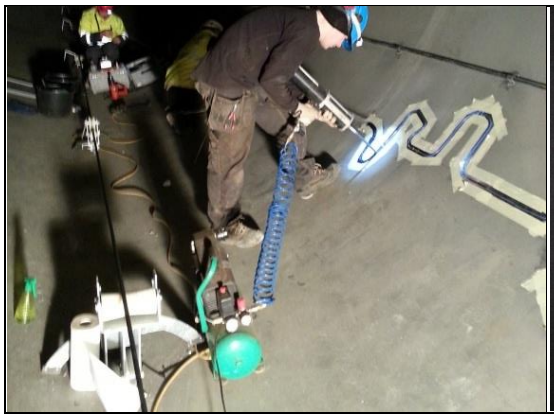

Fig. 21: Application of X 120 adhesive

Fig. 22: Fiber optic cable protected with water proof bi-dimension resistant tape

Installation of Cables

The main cables between the arrays and the interrogators were protected with a flexible tube. The flexible tube was fixed to a stainless steel cable in the sloped part of the pipe to support its own weight.

Fig. 23: Fixing the flexible tube to the stainless steel support cable

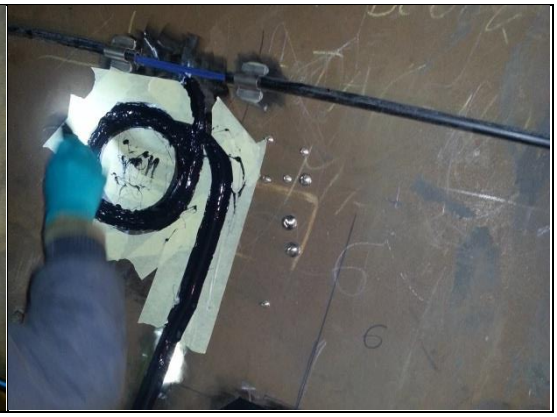

Fig. 24: Interface of the array cable with the flexible tube

Installation of Flanges

The flanges as referred above were used to make the transition of the cabling from the inside of the pipe to the outside. In order to avoid high curvatures of the cables in the vicinity of the flanges, metallic “L” shaped pieces were used to support the cabling.

Fig. 25: Cable egress (seen from the outside of the pipe)

Fig. 26: Flanges (seen from the inside of the pipe)

Installation of Technical Racks

In the technical racks, the main fiber optic cables were connected to the interrogators and the software was configured.

Fig. 27: Technical rack

Fig. 28: Interrogators and BraggMONITOR configuration

4 Conclusion

General Project Outcome

The FBG based monitoring system was installed in a new penstock water pipeline for a structural load test. All the 203 sensors (FS62 Weldable Strain Sensors) were installed during 3 months with a 100% success rate, thus no need for replacements.

Results

The Phase 1 of measurements included 46 days of measurements, measured between 06-05-2015 and 20-06-2015. During this period 2 water load cycles were recorded and the following behavior was observed:

- Transverse sensors showed higher strain values than the longitudinal sensors
- The maximum observed tensile strain was +1246,7 με in the Array 4 (Section-Type A) and the maximum compression strain value was -707,2 με in the Array 17 (Section-Type S).
- Longitudinal sensors were subjected to very low strain
- Temperature daily cycles do not influence the pipe temperature
- Temperature did not change significantly during the overall measuring period.

After the Phase 1 of measurements, the pipeline was drained and a visual inspection was performed to the complete monitoring system. Water pressure and flow did not alter the sensor's behavior. Applied protection is suited and well dimensioned. Although no major problems were identified, some maintenance actions were performed to the flexible tubes for cabling protection. The second phase of measurements was completed in 30-08-2015. After this date, the monitoring system, including the sensors, was completely removed due to environmental reasons.

Note: The measurements are confidential and could not be published by HBM.

5 Attachments

List of Documents

- FS62 Weldable Strain Sensor datasheet
- FS22 Industrial BraggMETER SI datasheet
- Array 8.A4b Calibration Sheet

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