PM Comments regarding measurements with DAS at the Experimental dam at Älvkarleby

Orientation

This PM is written upon request from Energiforsk. It complements the two reports written about the Distributed Acoustic Sensing (DAS) measurements made in 2020 at filling (Phase 1) and 2021 at lowering (Phase 2) the reservoir at the dam at Älvkarleby (Johansson et al., 2021; Johansson et al., 2022). It also includes comments regarding the ability to detect defects, revealed after the reports were written.

The dam had six built-in defects and contained fibre optic cables enabling measurements of acoustic signals, temperature, and strain. It had a length of 20 m and a height of 4 m.

Monitoring and imaging with ANI

The optical fibres were used to record existing background noise. Cross-correlated noise between two different locations could be used to map the seismic wave velocity of the material, so-called Ambient Noise Interferometry (ANI). Such a passive method eliminates the cost of a dedicated active source.

We used two methods to evaluate the wave velocity: imaging, using surface (Rayleigh) waves, and monitoring, based on coda waves. Imaging produces velocity versus depth profiles, whereas monitoring provides relative velocity changes in the dam. Both methods used recordings from the fibre cable installed at the core crest. Therefore, predictions of the defect sections are believed to be more accurate than depths for a dam of this size.

Defects and expected changes to be measured

The size and material of the six defects were known at the start of the project, summarised in Table 1. The locations of the defects were revealed in June 2022 and are given in the table and shown in Figure 1. Unintended areas with higher seepage flow in the right part were also reported.

Both surface and coda wave velocities are mainly determined by the shear wave velocity and only slightly by the compressional wave velocity. The expected changes of shear wave velocity V_S with varying water levels were discussed in the second report and are given in the table below. All defects are considered to increase V_S locally in the drained state. However, the cavity and the boulder (1 and 4) do not significantly influence the water pressure in the dam. They only have minor effects on V_S downstream, whereas the other defects decrease (increase) V_S downstream during filling (draining).

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Table 1 Description of dam defects and their effects on shear wave velocity (Johansson et al., 2022; Lagerlund et al., 2022). The defect locations were revealed in June 2022.

DEFECT					POSITION (center)			Effect on VS downstream of defect with filling/draining
No.	**Type**	**Material**	**Shape**	**Size (m)**	**x**	**y**	**z**	
1	Cavity	Wood	Cube	0.4 x 0.4 x 0.4	13.0	7.5	1.0	Little effect
2	Horizontal permeable zone - centrally	Crushed rock, 4-8 mm	Square	0.5 x 0.1	10.0	7.5	2.5	Decrease with filling/increase with draining.
3	Vertical loose zone	Crushed rock, 8-64 mm	Circular	0.3	7.0 7.0	7.5 7.5	3.5 1.0	Decrease with filling/increase with draining.
4	Boulder	Concrete cube	Cube	0.5 x 0.5 x 0.5	4.0	7.5	2.0	No change
5	Horizontal permeable zone - at abutment	Crushed rock, 4-8 mm	Square	0.2 x 0.2	0.0	7.5	3.0	Change in velocity faster than surrounding medium both in defect & downstream. Decrease in Vs downstream with filling/ increase with draining.
6	Fine filter defect on upstream side	Crushed rock, 8-64 mm	Square	0.3 x 0.3	15.0 15.0	6.6 6.6	1.5 1.0	No significant effect expected compared to surroundings in steady state. Any velocity changes would initially occur quicker than surrounding areas.

Result and experience from Phase 1

The measurements of Phase 1 were performed using the Silixa intelligent DAS (iDAS) system. Data from Vattenfall and temperature measurements showed large transient effects at first filling (Lagerlund et al., 2022).

Monitoring detected velocity changes with high accuracy, including daily variations. The results can be combined with the water level time history to locate defects. Imaging has a reduced accuracy but provides more detailed spatial information. Both methods identified potential areas of defects, with some regions overlapping. The monitoring method identified five regions of interest (with regions close to defects 2, 4, and 5) and the imaging seven regions (with regions close to defects 2 and 6).

The seepage flow rates increased clearly at filling but were later reduced to about 20% after some months. We believe that this transient state reduced the reliability of the results of Phase 1. Due to the higher data quality of Phase 2, these results are of greater significance.

Result and experience from Phase 2

The measurements of Phase 2 also used Silixa's iDAS system. The DAS interrogator was updated for Phase 2, showing a lower instrumental noise level than in Phase 1, and a higher spatial resolution. The improved setup and the steadier flow resulted in more reliable data.

The monitoring method identified potential defects in the vicinity of 3, 4, and 6. With six potential defect areas identified, three cannot correspond to known defects. Velocity changes close to the dam edges were not captured, due to the refractions from the concrete structure. Therefore, defect 5 could not be detected. Also, the wooden cube and the boulder (defects 1 and 4, respectively), giving negligible changes in V_S with time, cannot be expected to be picked up by the method. Despite these disadvantages, the accuracy of the monitor method makes it a valuable complement to the imaging method.

Figure 1 shows high-velocity zones corresponding to potential defects identified by the imaging method of Phase 2. There are high-velocity zones in Figure 1 in the vicinities of defects 3 and 4. Also defects 2 and 5 can be considered identified if section is regarded. Defect 6 should not give significant deviations from the surroundings. The two remaining right-most zones must be caused by other irregularities. It is possible that they are due to the unintended higher seepage flow in this area.

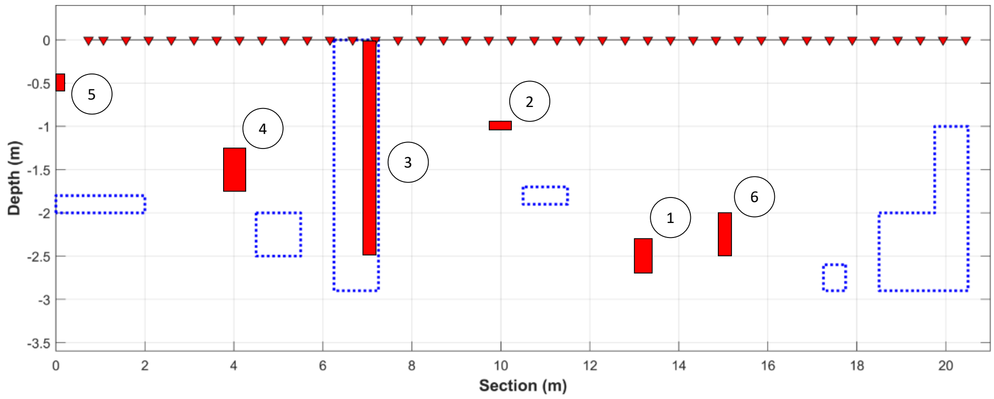

Figure 1 Location of potential defects identified by imaging in Phase 2 (Johansson et al., 2022). Red squares indicate locations of revealed dam defects, with numbers corresponding to Table 1 (Lagerlund et al., 2022).

Final comments and further need

Being able to see traces of most defects, especially locations along the dam, we believe that the imaging method might be used to identify anomalous water content in short- and long-term measurements in larger dams. The depth could be improved using data from multiple cables. Parameters that cause seismic velocity changes remain to be explored to better understand material changes in embankment dams. This would improve the ability to make good data interpretation and learn how to adopt the technology in the best way for dam monitoring.

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References

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Lagerlund, J., Bernstone, C., Viklander, P., Nordström, E. (2022). Embankment Test Dam of Älvkarleby - Description of installed defects and their position. Mendeley Data, V1. doi: 10.17632/k7zrrbxxnb.1.