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STRUCTURAL VIBRATION MEASUREMENT IN DAM MONITORING

Hydropower dams are, due to their operation on turbines and hydrodynamic effects of water continuously subjected to dynamic loading. In this paper, we present a study of structural vibrations using a laser Doppler vibrometer (LDV). Using this measuring gauge velocities are directly obtained, which is a considerable advantage to the accelerometer based measurements. Our aim is to research the impact of dynamic loading due to regular operation of dams. In Slovenia, we are increasingly faced with the problem of aging of dams. At the same time, we are also faced with changes in the environment, especially with variability in time-dependent loads such as new patterns of operation with turbines, with several starts and stops on a daily basis. The in situ structural response measurements are performed on Brežice dam. We have chosen several experimental points on the structure of the dam, where vibrations are captured on a regular basis. The LDV enables measurements of surface velocities in time domain. Since we are interested in analysis of eigen frequencies, measured data is transformed from time to frequency domain for further analysis. Investigation on Brežice dam started already during the construction and will continue in the future. With this study, we aim to present the advantages of structural vibration monitoring of the concrete used as a part of regular structural health monitoring of dams.

Keywords: Optical measurements, vibrometry, concrete gravity dam, measurements

1. INTRODUCTION

Recently a new pilot study to monitor vibrations on massive concrete is implemented on HPP Brežice. This research for the first time introduces the Laser Doppler Vibrometer as an experimental equipment used for vibration monitoring on dams. The device enables non-contact and continual data acquisition at preselected surface points. The vibrometer records surface velocities, which is a considerable advantage to the accelerometer based measurements. Application of vibrometer has also other advantages. Firstly, measurements are not demanding; we just have to find the position from where the laser beam has unhindered access to the object, the device is also portable and does not require any special installation on site.

In this paper we present the methodology and equipment used for experimental work. Various types of time-dependant loads are constantly present on hydro power plants. These loads represent irregular excitation patterns that consist of various dominant frequencies among which the ones close to the eigenfrequencies of the structure are of major concern. These excitations could be the cause for damages on the structure, noticed on some dams during regular inspections. The aim of this study is introduce the advantages of the proposed methodology to be further used as a part of a regular structural health monitoring of Slovenian dams. With the regular observation of vibrations on structures it is possible to monitor the aging process, and detect changes before they are visible on the surface.

1. DESIGN OF THE INVESTIGATION

1.1. HYDRAULIC POWER PLANT BREŽICE

Brežice HPP (Fig. 1) is a fifth hydro power plant in the chain of six hydropower plans on the Lower Sava River. It is a run-of-river type of power plant with a limited storage capacity, which will enable partial compensation of the discharge once the hydro scheme on Sava will be finished. The dam is a combined type of dam; the central concrete-gravity part of dam consists of powerhouse and five overflow sections. The two earthen embankments with maximum height of 9.5 m are connecting the riverbanks to the 160 m long concrete part. Structural height of cross-section of the concrete dam varies, maximum structural height is 36.5 m in the cross section of the powerhouse, and spillway section reaches maximum height at 16 m respectively. The spillway section consists of five 15 m wide overflow sections, each with a maximum discharge capacity of 1,000 m^3/s. Each spillway is installed with a segment gate with a flap for fine level regulation [1].

Figure 1: HPP Brežice

In the power station three vertical Kaplan turbines with a design rated power of 45 MW are installed with estimated annual production of 161 GWh. Rated flow rate is to be 500 m^3/s

and a hydraulic head of 11 m. This is a newly built dam, the construction began in April 2014 and should be finalized by the end of the year 2017. Powerhouse is currently in phase of trial power production with all three aggregates [1].

1.2. LASER DOPPLER VIBROMETER

Laser Doppler Vibrometer is used for non-contact measurements of surface vibration velocities in the frequency range between 0 and 22 kHz. The device is an optical transducer, it works on the basis of optical interference and Doppler effect, it detects the frequency shift of back scattered light from a mowing surface. One of the main advantages of the vibrometer is that the device is portable and easy to use. Once we establish visible contact with the vibrating surface on the distance of maximum 30 m, the recording can begin [2,3]. One example of a measurement of HPP is presented in Figure 2.

Figure 2: Example of a measurement with the Laser Doppler Vibrometer

2. THE DESIGN OF THE FIELD INVESTIGATION

The surface under the investigation has to deflect laser light. In order to improve deflection deflective tiles were installed on all experimental points. Our experiment launched in April 2016, roughly two years after the beginning of the construction works on site. We established a first set of experimental points on several locations in the powerhouse and in the spillway section of the dam. The first set consisted of 4 points (Fig. 3):

- two in the engine room: in the middle of the engine room wall located between aggregate 1 and 2 (S2), and at the upper part of the engine room wall located next to the aggregate 1 (S1);
- two points in the first stilling basin: one in the end and one in the middle of the wall (P1, P2).

These points served to record the initial state of dam. We recorded the response of the dam triggered with the construction work and also at rest.

During trial run operation we continued with our investigation. To the set of initial investigation points new points were added (Fig. 3):

- one point to the outside part to each of the three turbine shafts (A1, A2, A3);
- one point on a pillar next to the turbine 2 (ST1);

- one point on the side pillar in the engine room (ST1);
- two points on the wall between the 4th and 5th stilling basin (P4, P5);
- two points on the wall between the 3rd and 4th stilling basin (P6, P7).

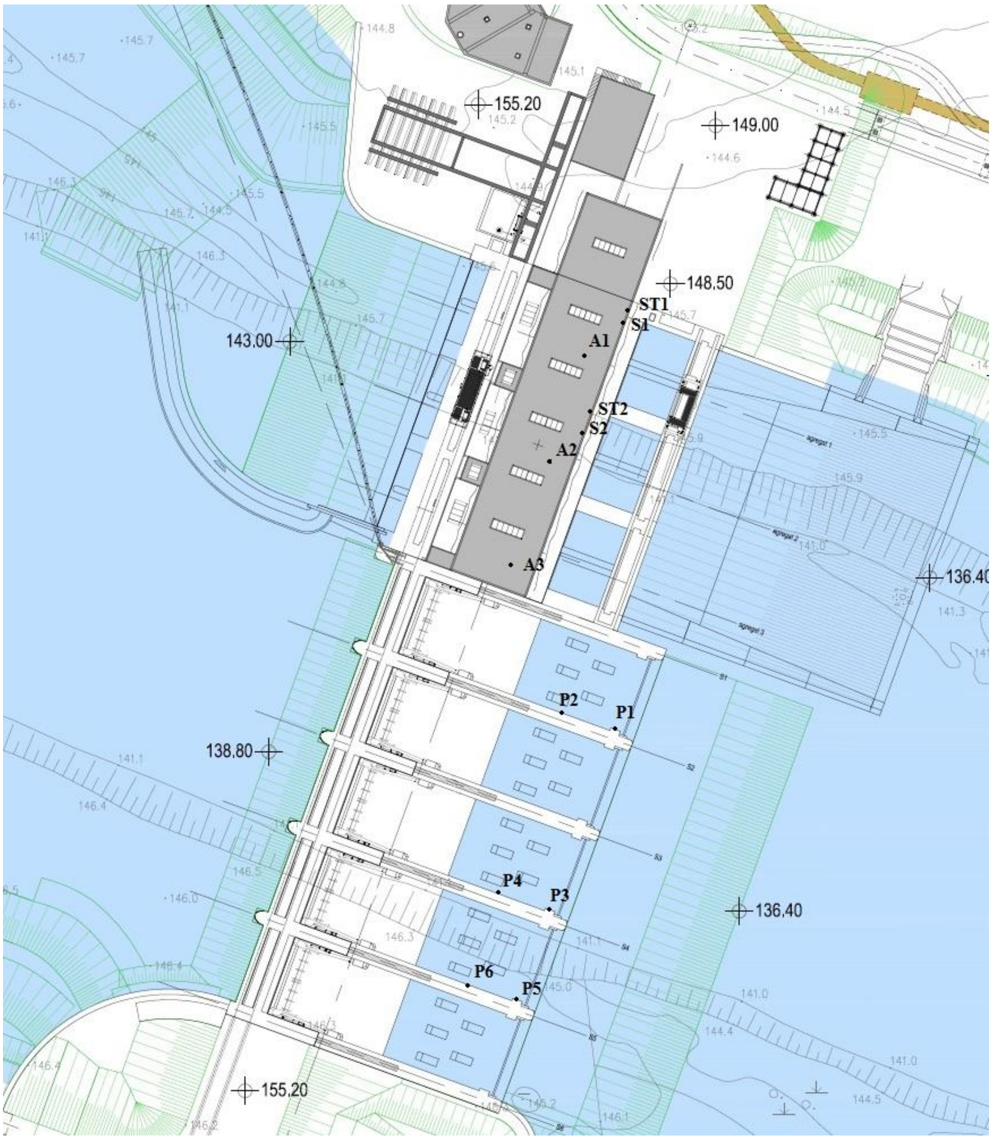

Figure 3: Layout of the experimental points

Currently there are 13 experimental points to monitor vibrations allocated around the structure of the Brežice dam. The investigation is still ongoing; our aim is to monitor the dam also during regular operation.

3. EXECUTION OF THE INVESTIGATION AND ANALYSIS

In this paper we will present measurements recorded during different events on the dam. First example in Figure 4 is a time-history of surface velocities at rest recorded on position P1. We can observe very small magnitudes and the presence of higher frequency oscillations.

The next example presents a time-history of a stilling basin wall triggered with the construction work, this measurement was taken on May 7th 2016. On that day work on the construction site was focused on installation of the components for the hydraulic gates. Example is presented in Figure 5 and shows an increase in the vibration amplitudes that were caused with the construction work. Velocity amplitudes rise up to the 0.08 m/s.

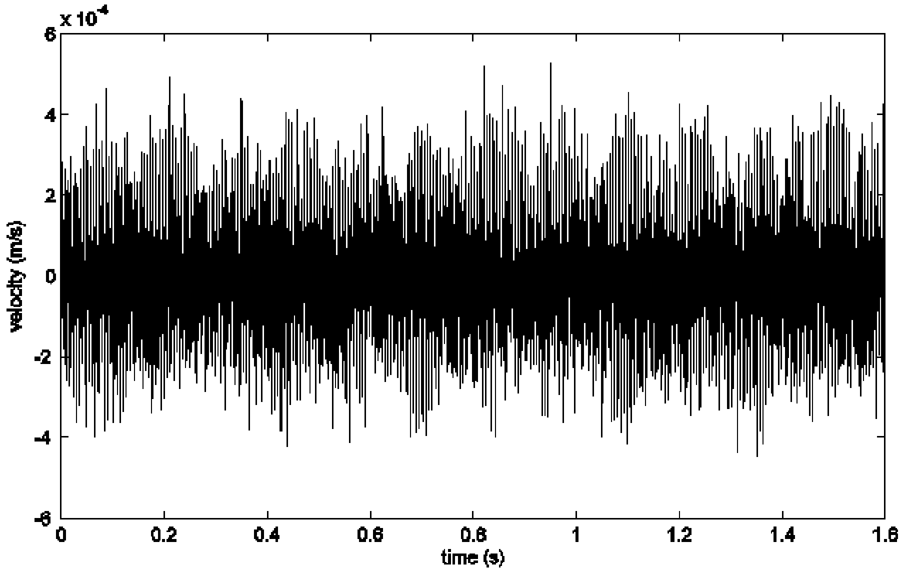

Figure 4: Typical time history of velocities at the stilling basin side wall

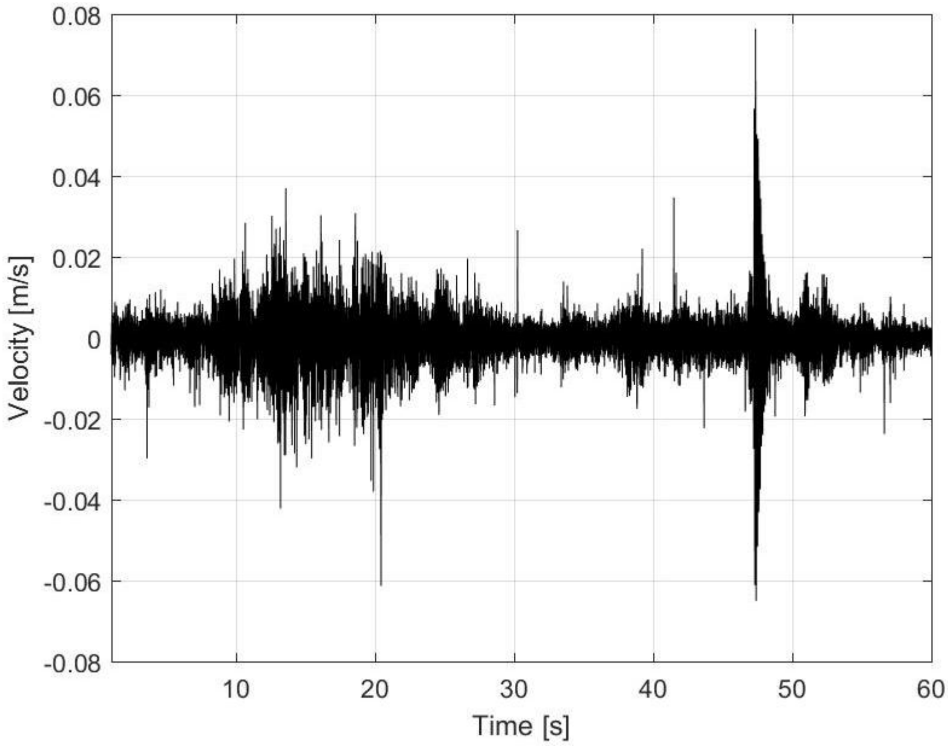

Figure 5. Time history of velocities at the stilling basin sidewall during construction work

Next figure 6 presents the recording in the powerhouse, on the position (S2), this recording was also taken on May 7th 2016. Since the majority of work on the dam was concentrated on the spillway sections, as expected the response of the powerhouse wall has smaller magnitudes in comparison to the measurements in the spillway section.

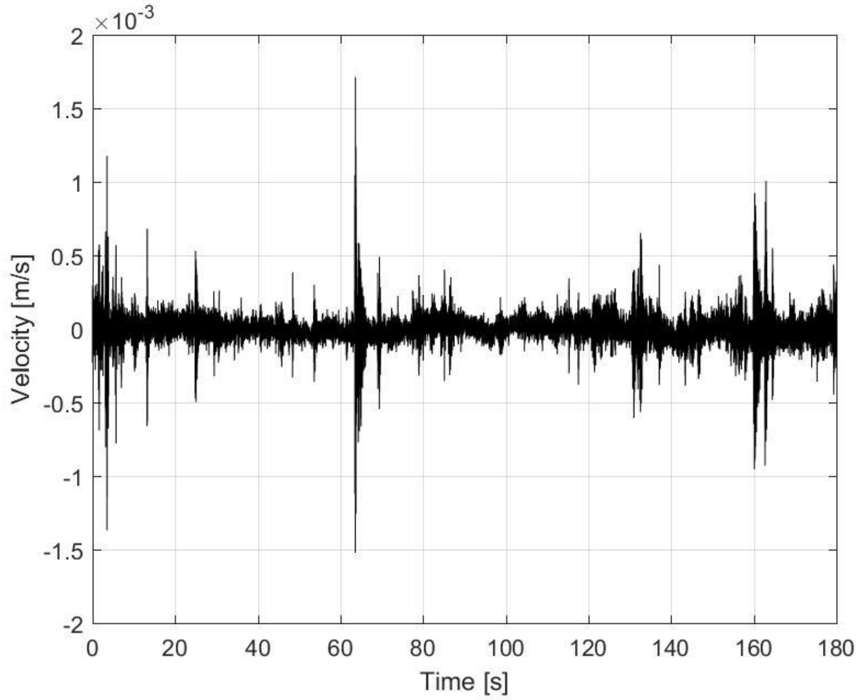

Figure 6: Time history of velocities at the wall in the powerhouse during construction work

On August 16th, 2017 the impoundment behind the dam reached nominal operational level at 153 m a.s.l. On August 21st, 2017 diagnostic test for hydro mechanical equipment began, alongside these testing also vibrations of the structure of the dam are recorded. Figure 7 presents a time-history measured during alteration of power on a turbine, the response is measured on the position A3. An increase in velocity amplitudes is evident, the velocities rise up to 0.5 m/s.

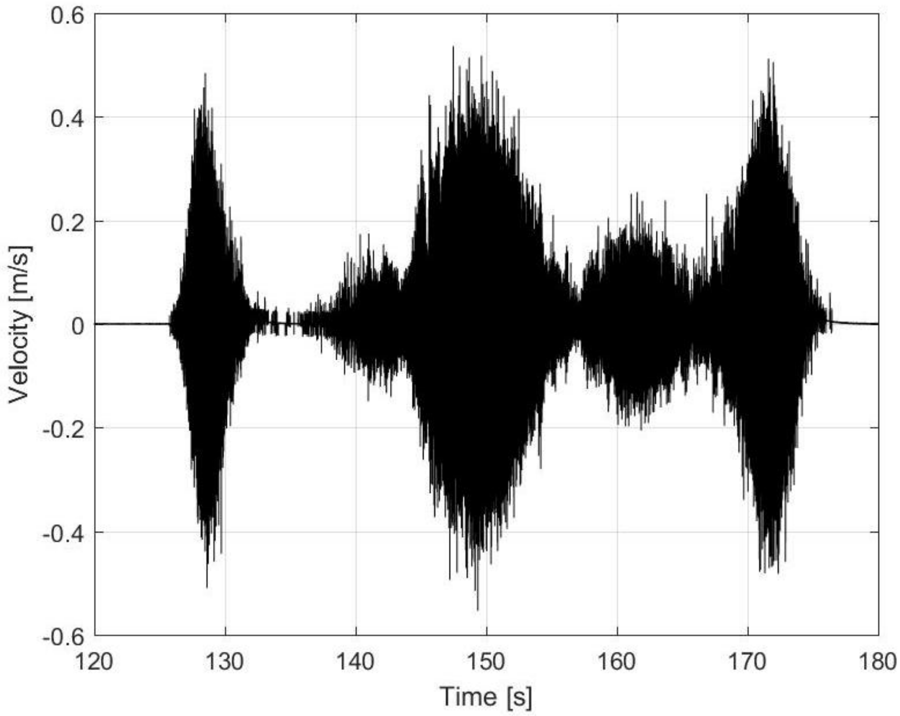

Figure 7: Vibration during on position A3 during the manoeuvring with the turbine, adjustment of power

4. CONCLUSIONS

In this paper we presented the implementation and some preliminary results of the experiment on HPP Brežice. The presented results gave us the insight of the dynamic properties of the structure before it becomes fully operational. The experimental data was obtained by non-contact measurements using laser vibrometers. The measured time history reveals the influence of the construction work on the structure resulting in much higher amplitudes as for the cases where structure vibrates naturally. Despite their massive construction, the hydraulic power plants are sensitive to dynamics loads. Therefore, it is important to monitor dynamic properties of dams as a part of a regular structural health monitoring process.

Our investigation is still ongoing. Future investigation will reveal the effect of the water flow on the structure of the dam. With analysis in the frequency spectrum we will also be able to identify operational maneuvers that are crucial from the structural point of view. With the regular vibration monitoring it is possible to monitor aging process of the structure, with our investigation we established the initial or reference state, and with the continuation we will be able to monitor the aging of the Brežice dam.

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REFERENCE

[1] HESS (2016) Hidroelektrarne na Spodnji Savi, Ltd. - Hess d.o.o. Available at: http://www.he-ss.si/eng/ (Accessed: 5 February 2017).

[2] Nassif, H. H., Gindy, M. and Davis, J. (2005) 'Comparison of laser Doppler vibrometer with contact sensors for monitoring bridge deflection and vibration', NDT & E International, 38(3), pp. 213–218. doi: 10.1016/j.ndteint.2004.06.012.

[3] Polytec (2016) 'Portable Digital Vibrometer PDV-100 High Resolution Digital Velocity Measurement', pp. 1–3.