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FINITE ELEMENT MODEL OF KURPSAI DAM IN KYRGYZSTAN BASED ON ACTUAL RESPONSE MEASURED BY EXTENSIVE NETWORK OF VARIOUS SENSORS

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Abstract. The paper presents recent results of an ongoing collaborative research project focused on modelling the Kurpsai water dam in Kyrgyzstan. The research team includes scientists and engineers from the USA, Kyrgyzstan, and Uzbekistan. This water dam was selected for modelling because of the recent installation of an extensive network of various sensors aimed at monitoring its performance under seasonal changes, ambient vibration, and seismic excitation. The installed instrumentation network includes the following sensors: (1) a set of fiber-optic strainmeters and temperature meters, (2) a set of velocimeters for seismic monitoring, and (3) a set of GNSS receivers to measure absolute static displacements. A 3D model of the water dam was generated based on a utilization of the finite element approach. As a starting point the water dam's concrete was assumed to be elastic material. The latter assumption is considered acceptable, because (as of today) only responses to relatively small excitations were measured by the sensors. The actual responses of the dam were compared to that of the finite element model to achieve a close correlation with each other. Resonant frequencies of the water dam and its vibrational modes were estimated from the model. In the

next phase of the project, the research team is planning to update the geometry of the model based on laser scanning that will be conducted this year. Local anomalies (bulging areas, cracks and so on) of the water dam will be studied via an analysis of point clouds collected by the laser scanner. The fully developed model will be used in an extensive numerical study to predict the dam's performance and its response to strong seismic events and other hazards.

1 INTRODUCTION

Ongoing global warming imposes new challenges worldwide. Although this warming trend of the planet has been going on for a long time, its rate of warming has increased significantly in the last one hundred years. It results in another issue, the so-called climate change, that relates to changes in weather patterns on the planet. As a result, a number of severe drought cases has increased worldwide. Water dams are traditionally used for water collection and controlled distribution to ensure that the water supply remains available for use by the population, industry, and farming. Structural monitoring of the water dams is crucial to maintain the proper operation of the dams and minimize the effect of climate change. This paper is focused on the Kurpsai Dam in Kyrgyz Republic, which was built in the 1980s and provides water to many countries in the region of Central Asia. The dam was modelled based on digital images. The laser scans and performance of the model was compared to that of the actual dam. Recently, this dam has been instrumented with various sensors [1,2]. The data collected from this extensive instrumentation array was used to calibrate the model and develop a model that can be used in future predictions of the dam's performance under static and dynamic loads.

The work on the project was divided into two phases. In the first phase, a simplified model of the dam was developed based on images available to the public. A numerical model obtained in this phase was used to estimate the dam's deformation under static (gravitational and hydrostatic) loads and to assess the feasibility of the laser scanner to capture this deformation. The resonant frequencies of the dam were also estimated from this model. In the second phase, the dam was scanned by means of a terrestrial laser scanner. The simplified model was updated based on the captured geometry of the dam.

2 PHASE 1: SIMPLIFIED MODEL

During this phase of the project, a simplified model of the Kurpsai dam was created. It was based on a digital image processing of photos available on the Internet in combination with the overall dimensions of the dam published earlier [1,2].

2.1 Digital image processing

There are quite a few images of the Kurpsai dam available on the Internet and only a few are mentioned herein. A history of the Kurpsai's dam construction is presented in [3]. It includes a few images taken during the construction, which are useful for understanding how it was built and its major structural and nonstructural components.

An image provided in [4] was processed to estimate the geometry of the dam from the frontal view. The digital image processing was conducted in the Matlab environment [5] with a typical result presented in Figure 1. All the dimensions are provided in pixels which were converted to meters by using the overall dimensions of the dam reported earlier [1,2].

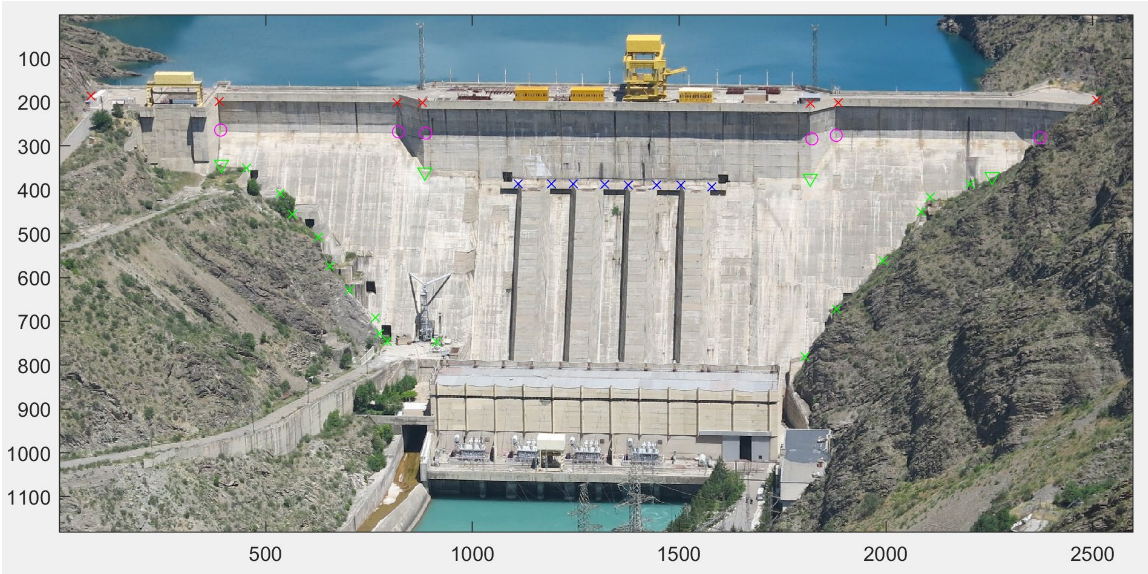

Figure 1: Major geometry points of frontal view taken from [4]

A similar approach was taken for the top view of the dam. The respective satellite image was purchased from Shutterstock [6]. The key points of the geometry are presented in Figure 2.

Figure 2: Major geometry points of top view taken from [6]

The key points detected from the images in pixels shown in both Figure 1 and Figure 2 were converted to meters based on the overall dimensions of the dam [1,2] and were used for geometry of a simplified model described below.

2.2 SAP2000 model

The result of this digital image processing was used for the generation of the finite element model in the SAP2000 environment [7], which is discussed in this section.

For the simplified model it was assumed that the body of the dam is solid throughout and does not have openings. Since the simplified model was used for the initial assessment, this approach was considered to be acceptable. A front view of the finite element model of the dam is presented in Figure 3.

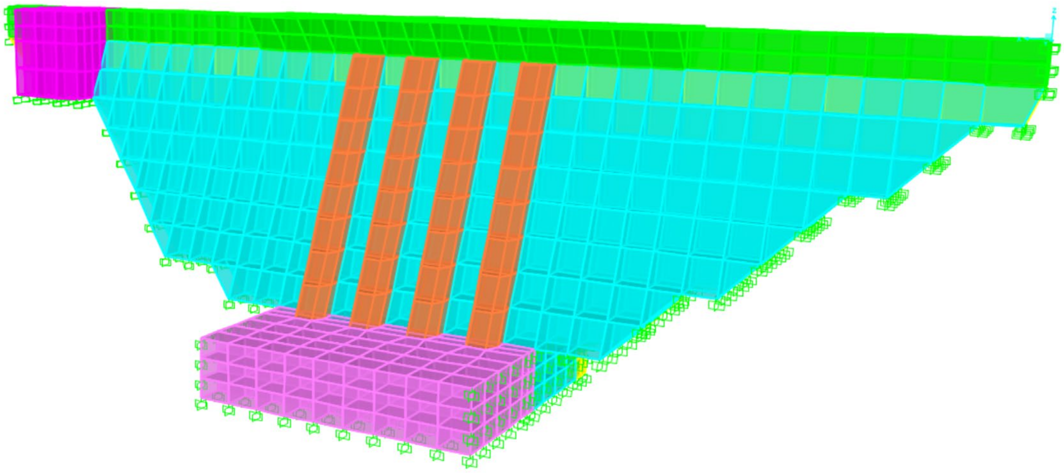

Figure 3: Numerical model in SAP2000: frontal view

Since the information about the rear side of the dam was not available at the time the simplified model was generated, it was assumed to be vertically flat on the upstream side as presented in Figure 4.

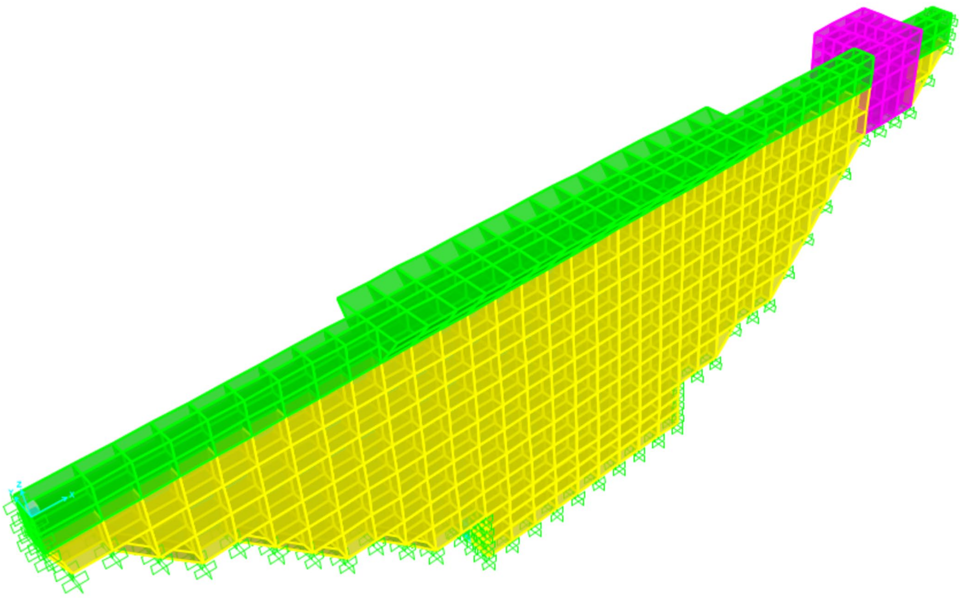

Figure 4: Numerical model in SAP2000: rear view

2.3 ANSYS model with fine mesh

The overall geometry of the dam was imported from SAP2000 to ANSYS and the mesh was refined. A front view of the water dam created in the ANSYS environment is presented in Figure 5.

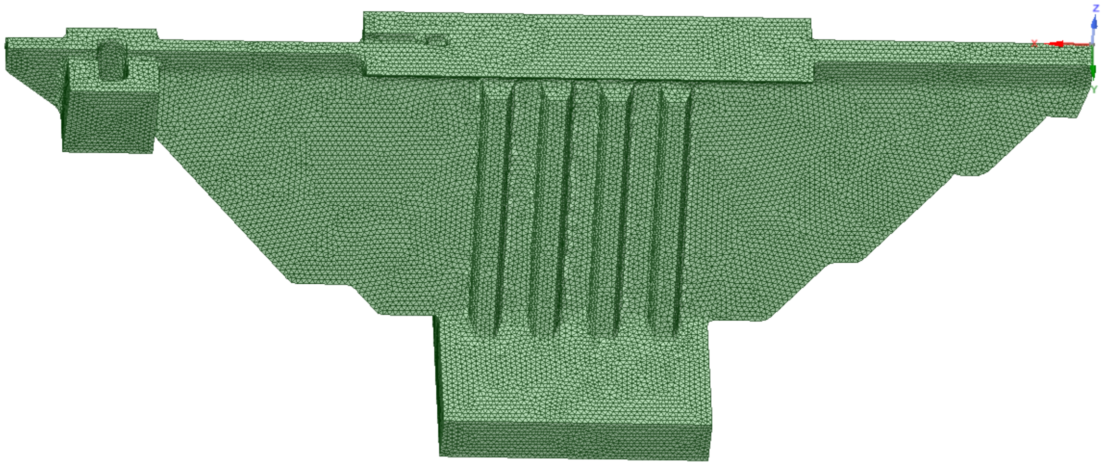

Figure 5: Numerical model in ANSYS: frontal view

A respective rear view of the ANSYS model is shown in Figure 6.

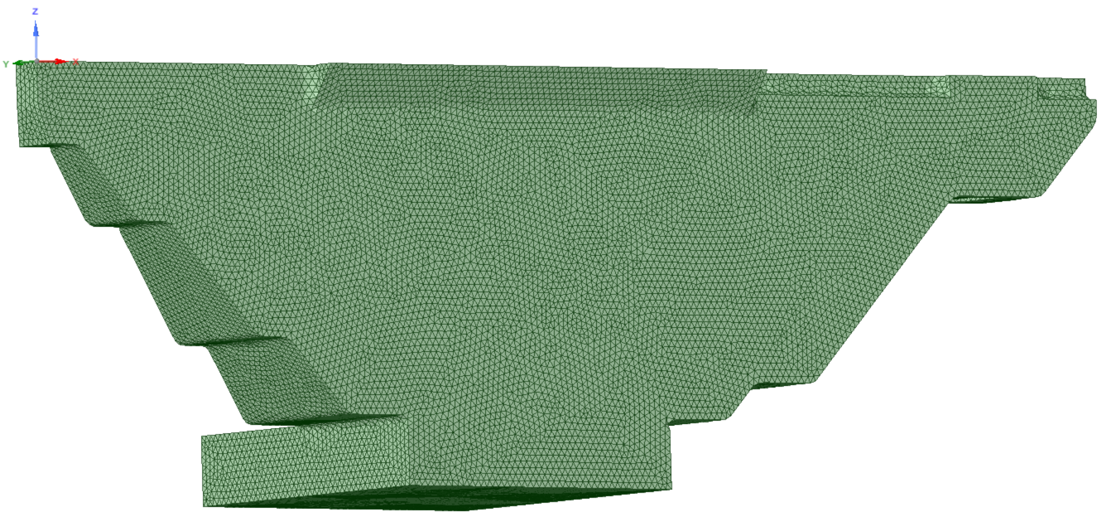

Figure 6: Numerical model in ANSYS: rear view

2.4 Comparative analysis of two simplified models

The SAP2000 and ANSYS models were compared to each other based on the analysis of the primary modes of vibration. As presented in Table 1 the frequencies of the models are close to each other. The remaining analysis of the water dam was conducted by utilizing the ANSYS model.

Table 1: Frequencies of two simplified models

Model	F_1, Hz	F_2, Hz	F_3, Hz
SAP2000: rough mesh	2.87	3.85	5.15
ANSYS: fine mesh	2.83	3.78	5.05

3 PHASE 2: ANALYSIS OF SIMPLIFED MODEL IN ANSYS

The ANSYS model was subjected to two types of loading: (1) gravitational and (2) hydrostatic pressure. In the second case it was assumed that the water reservoir is completely full.

3.1 Gravitational load

A distribution of the residual displacement of the water dam under static gravitational load is presented in Figure 7. The largest displacement of the dam happens at its crest because of a sagging action of the dam's body under its own weight. It is worth noting that the maximum displacement is about 12.4 mm.

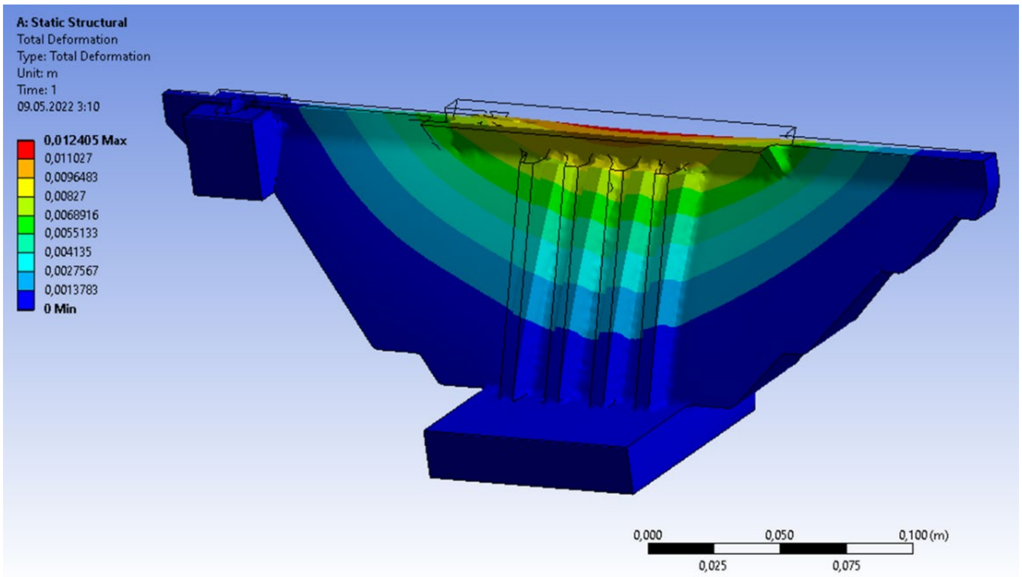

Figure 7: Displacements of the water dam under static gravitational load

3.2 Hydrostatic load

A distribution of the water dam's residual displacement under static gravitational load is presented in Figure 8. The largest displacement of the dam happens at the its crest because of preying action of the water. It is worth noting that the maximum displacement for this case of loading is about 137.1 mm which is greater than the respective displacements for the gravitational load.

These displacements show a difference between a completely empty and a completely full dam. The former will most likely never happen in the future, and the water level on the upstream side of the dam will vary within more reasonable values, for instance from completely full to half-full. Hence, this estimate of the maximum displacement is very conservative.

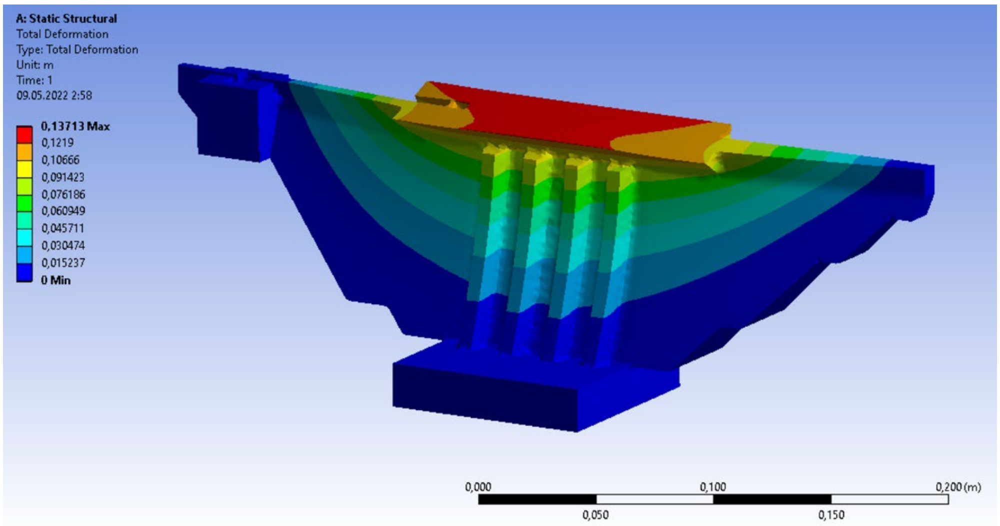

Figure 8: Displacements of the water dam under hydrostatic load

A distribution of the maximum stresses throughout the dam's body is presented in Figure 9. This image shows the rear side of the water dam. The model assumes a rigid connection between the rock and the dam's body, which leads to the large tension stresses at the rock-concrete interface. Most likely this assumption is too conservative, hence this simplified model will be updated based on the drawings of the dam which will be provided by the authorities managing the dam.

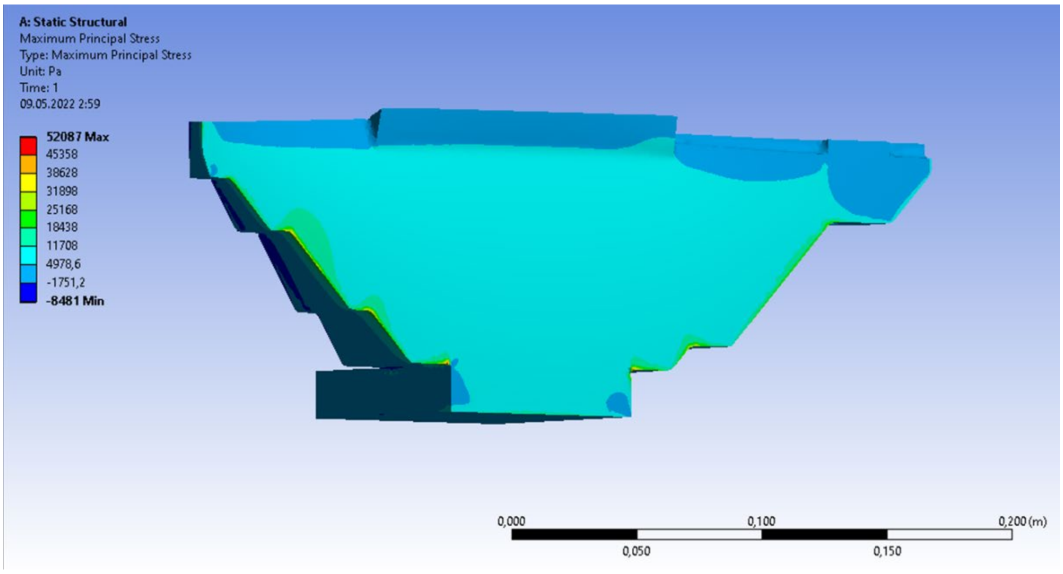

Figure 9: Maximum stresses under hydrostatic load: rear side

A distribution of the maximum stresses throughout the dam's front side is presented in Figure 10. Similar to the upstream side there are large compressive stresses close to the rock-concrete interface. These stresses need to be investigated by monitoring the displacements of the dam under changing loading conditions; for instance between a completely full and a half-full water dam. The thermal loading needs to be added to this analysis too. The monitoring will be done by combining the existing instrumentation and laser scanning. This work is ongoing.

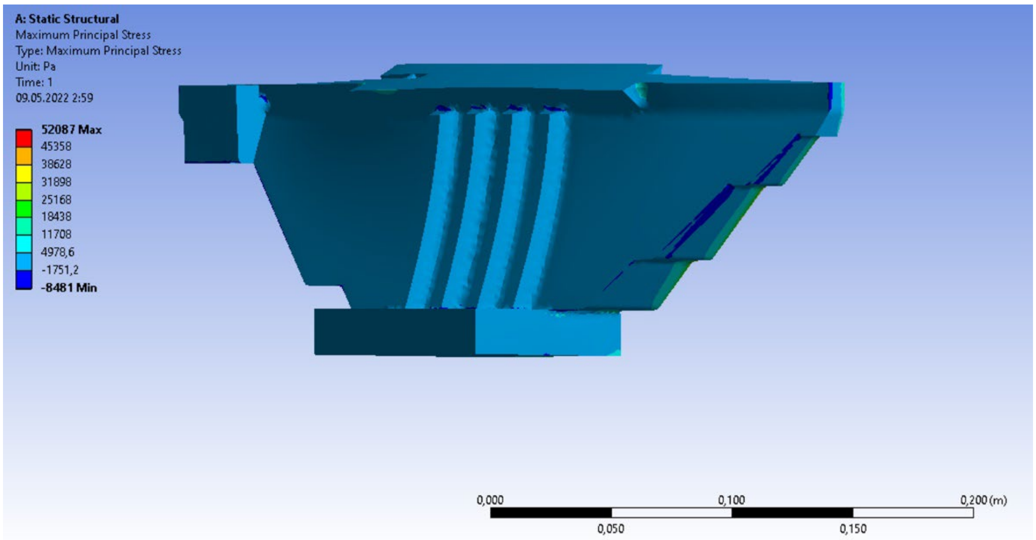

Figure 10: Maximum stresses under hydrostatic load: front side

3 PHASE 2: LASER SCANNING AND MODEL UPDATE

3.1 Laser scanning

A laser scanning of the water dam was conducted in May 2022. A terrestrial laser scanner, C10 [9] was used in this part of the study. The maximum range of this laser scanner is 300 m, so it was considered suitable for this application. The scanning was conducted from a total of 5 stations.

A typical point cloud from one of the stations is presented in Figure 11. It shows a laser scan of the downstream side of the dam. The scans from all stations are stitched together in a single point cloud, the so-called registration. The latter was performed in Cyclone [10].

Based on the collected point clouds the model will be updated. In addition to the load types discussed above a thermal loading will be considered. This part of the work is ongoing.

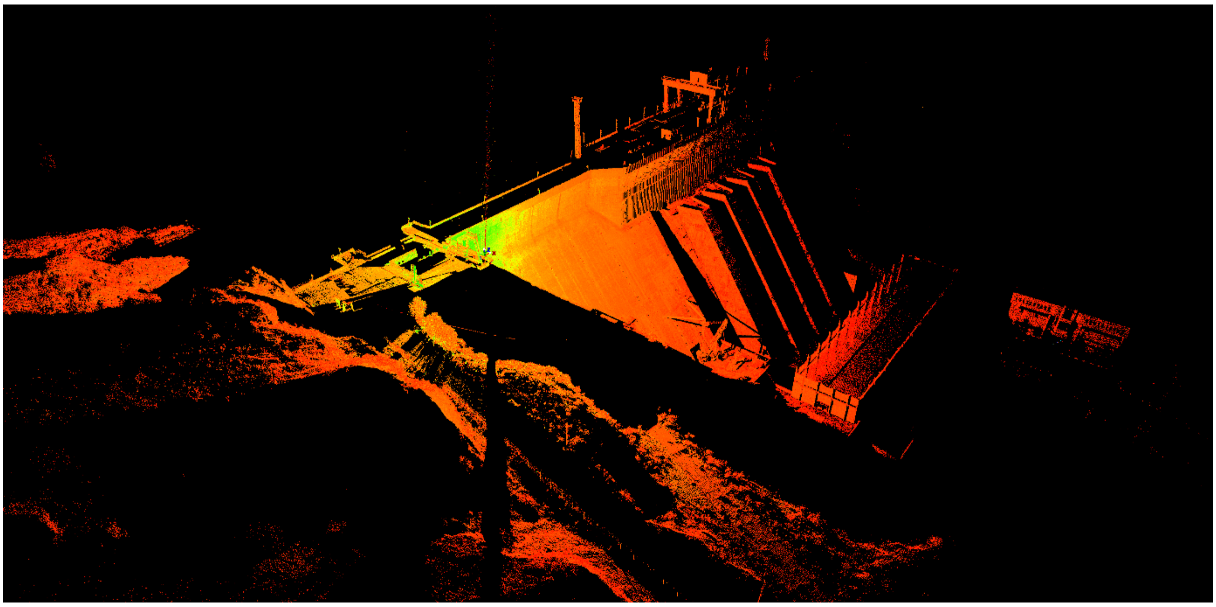

Figure 11: Laser scan of the downstream side: a typical station

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5 CONCLUSIONS

- This paper is focused on the Kurpsai Dam in Kyrgyz Republic, which was built in the 1980s and provides water to many countries in the region of Central Asia. The dam was modelled based on digital images, and the laser scans and performance of the model were compared to that of the actual dam. The data collected from an existing extensive instrumentation array was used to calibrate the model and develop a model that can be used in future predictions of the dam's performance under static and dynamic loads.
- The work on the project was divided into two phases. In the first phase, a simplified model of the dam was developed, and it was based on publicly available images. A numerical model obtained in this phase was used to estimate the dam's deformation under static (gravitational and hydrostatic) loads in order to assess the feasibility of the laser scanner to capture this deformation. The resonant frequencies of the dam were also estimated from this model. In the second phase, the dam was scanned by means of the terrestrial laser scanner. The simplified model was updated based on the captured geometry of the dam.

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