UPGRADING OF SEISMIC OSCULATION SYSTEMS ON “PIVA” DAM

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Strong earthquakes always draw attention to the behavior of engineering structures of major importance, such as large dams, in which the assessment of seismic risk is a very difficult task, mainly because of the lack of real records from the impact of strong earthquakes on this type of engineering structures and lack of data on their response to such type of excitement.

Modern, digital systems for seismic oscultation enable continuous and reliable monitoring of the seismic activity and recording the occurred earthquakes. The "Piva" dam is one of the highest concrete arch dams in the world and as early as its putting into operation in 1976, instruments for seismic oscultation were installed - 6 analogue SMA-1 accelerographs, supplied with a starter which is automatically triggered at a predetermined acceleration level. The results from the measurements are recorded on a film.

In 2013, given the importance of the construction for the Montenegrin economy, the seismic oscultation network was upgraded with the installation of equipment for digital recording of earthquakes manufactured by Kinemetrics - USA, in order to provide high quality data on the seismic activity and behavior of the dam during seismic actions.

Keywords: seismic monitoring, high dam, network, earthquake, damage

1. INTRODUCTION

The data on the ground motion during earthquakes in the close region in which the dam is located as well as the knowledge of the structural behavior are the basis for the evaluation of the seismic risk associated with the dam. This holds not only for definition of the earthquake parameters and design criteria but also for all the remaining dynamic tests. Without these data, all investigations and analyses would be based on assumptions only. The best way of obtaining high quality and reliable data is installation of a network with as many instruments as possible for recording of soil displacements, i.e., structural response to the seismic effects.

Lately, seismic monitoring has been of a great importance, not without reason, since the data obtained during the osculation contribute to the increase of the safety of the dam when exposed to seismic effects.

According to their genesis and effect on engineering structures, earthquakes represent very complicated phenomena of a big hazardous potential so that, within a relatively short time of action, they can cause extensive damage and even failure of structures. Considering the history and intensity of seismicity of Montenegro, there is a permanent threat related to earthquake occurrence so that preventive actions should be started as early as possible and should be permanently applied and upgraded. Many dams worldwide are constructed in areas characterized by high seismic activity. During their operation, there have occurred strong earthquakes causing smaller or heavier damages, while in some cases, even failure of dams (1958 Habgen, Montana, USA; 1964 Eklutna, Alaska, USA; 1971 Van Norman, California, USA; 1991 Shigh Kang, Taiwan). Here, one should also mention the possibility of occurrence of induced earthquakes due to the effects of the water reservoirs on the surrounding rock area. These can also have a significant magnitude (M = 6.4, Koyna, India) and can cause considerable damage.

2. MAIN TECHNICAL DATA ON HYDROELECTRIC POWER PLANT „PIVA“

HPP „Piva“ dam (i.e., „Mratinje“ dam) is among extremely high dams and among the 25 highest arch dams in the world (Fig.1). The stress and deformation state of the dam is dominantly affected by the reservoir level (hydrostatic pressure) and the temperature of the dam body. The rock massif at the dam location is composed of massive limestone originating from the Middle Triassic that was exposed to intensive tectonic motions. The structure of the damage in the form of cracks caused by these disturbances stretches in the direction that is approximately perpendicular to the river course, which is favourable from the aspect of safety against sliding. The cracks divide the rock mass into large blocks, but without crushed zones in their surrounding and are partially filed with clay and calcite. The size of the crack openings is reduced with depth so that they lose the characteristics of mechanical discontinuities. The mechanical characteristics of the rock massif at the sides of the dam are variable. The deformation modulus is within the range of 15000 N/mm^2 to 7000 N/mm^2 going from the bottom of the canyon toward the dam crest, with the exception of one part in the last fourth of the height on the right side where it drops to 2500 N/mm^2, wherefore in that zone, a massive abutment is constructed. Through the system of horizontal concrete piles, this abutment rests on deeper parts of the rock massif of approximately the same geotechnical characteristics as those at the corresponding heights of the left side.

Figure 1. Dam "Piva"

HPP „Piva“ dam represents concrete, asymmetric, arch dam with a double curvature (Fig. 1). Construction of this dam, created an artificial water reservoir used for production of electricity in the accompanying hydroelectric power plant „Piva“. The topographic, geological, geotechnical and geophysical documentation show that the dam profile is asymmetrical and has a pronounced „V“ shape meaning that HPP „Piva“ dam is a surface bearer with pronounced arch effect. The arch is asymmetrical and of variable thickness and curvature. The extrados and intrados of the arch are defined by the fragments of the circle, while the central line, i.e., the arch axis represents an ellipse, which is a combination of the circular curvatures drawn from three centres. The foundation joints of the dam represent parabolic curves. Such defined shape of the horizontal cross-section – arch has enabled the most favorable fitting of the dam into the profile considering the stretching of the main tectonic lines on which the entire stability of the structure depends. At the dam foundation, from the galleries, consolidation, connection and contact injection as well as sealing injection of the triple and single grouted apron was performed down to the depth of up to 150 m'. Dam body consists from 18 units (consoles) and there are there are 5 inspection galleries at levels: 482, 522, 562, 602 and 642 mnm. The main technical data on the dam a represented in Table 1.

Table 1 Technical data for "Piva" Dam

Year of construction	1976
Construction hight	220.00m
Length of arch axis at the crest	268.56 m
Length of arch axis at the bottom, at level 478	63.05 m
Thickness of the cross-section at the crest crown	4.51 m
Thickness at the crest abutment	6.46 m
Maximum thickness at the crown cross-section, at level 522	22.90 m
Maximum thickness at the bottom, at the supporting cross-section	45.00 m
Central angle of the arch axis at the crest	84.78º
Central angle of the arch axis at level 478	55.50º
Radius of the central arch axis at the dam crest	168.49 m
Radius of the central arch axis at level 478	54.52 m
Dam crest level	678.00 mnm
Maximum backwater level	677.50 mnm
Normal backwater level	675.25 mnm

Results of the study of the seismicity of the HPP "Piva" location done in 2008 (Civil Engineering Faculty, Podgorica, Energoprojekt-hidroinzenering A.D. Belgrade), showed that HPP "Piva" dam and its reservoir are situated in the seismically active area of the inner Dinarides that is generally characterized by moderate seismic hazard. According to the performed analyses of the seismic hazard elements, as it is usually done – for the so called design earthquake (with a return period of 200 years for engineering structures of the type of high dams) in the area in which HPP "Piva" dam is situated, there is a probability of 70% for occurrence of an earthquake that will cause at the bedrock of the dam location a maximum horizontal ground acceleration of 9.5%g, i.e., an earthquake with intensity of VII degrees according to the MSK-64 scale (or MCS). For the case of the so called maximum earthquake (with a return period of 1000 years) at this location, under the same conditions, it is realistic to expect maximum effects of local or distant earthquakes expressed by maximum horizontal ground acceleration of 17.0% g, i.e., earthquakes with intensity of VII-VIII degrees according to MSK-64. For the return period of 475 years (EUROCODE 8), also with a probability of 70%, one should expect maximum accelerations of up to 13.0% g at the dam foundation level.

3. SEISMIC MONITORING

Seismic monitoring of "Piva" dam started in 1976, when an seismic monitoring network comprised of 6 analog SMA-1 accelerographs was established. The instruments were located in such manner that enabled obtaining strong motion records on free field (bedrock) at the bottom of the dam and other 5 were located on the predefined points on the dam at elevations 510, 562, 602, 642and on the dam's crest (Fig. 2). In addition, in Pluzine (20 km away from the dam), at the electrical company's Headquaters building and the Hotel were installed two more SMA-1 instruments (both at ground level). These 8 instruments formed sort of local strong motion network. Later on two more instruments (digital QDR) were added, placed approximately at the middle of the dams body, so that the dam was fully instrumented along the height of its central segment. Well distributed instruments on the dam body and the surrounding soil enables obtaining of high quality data on the seismic activity and structural response, which represents a good basis for the understanding of the behaviour of the dam exposed to seismic action and making appropriate decisions for the case of a possible strong earthquake to which the dam could be exposed.

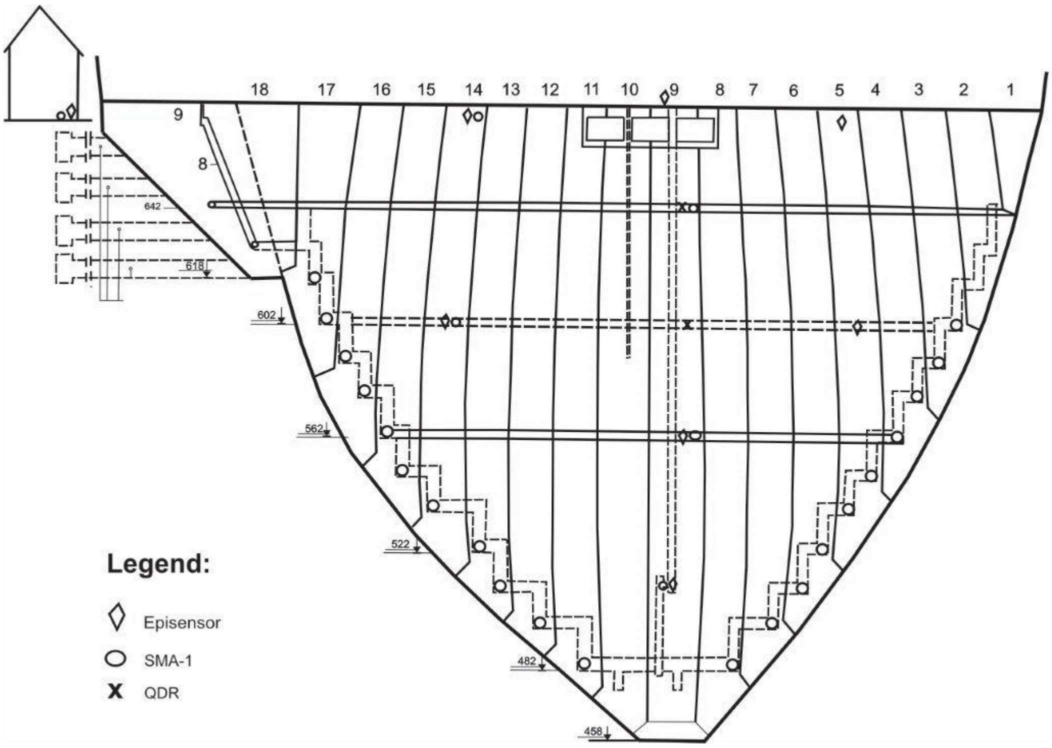

Figure 2. Location of the seismic monitoring instruments

The modern, digital system for seismic osculation enables continuous and reliable monitoring of the seismic activity and recording of occurred earthquakes. In 2013, a modern digital seismic monitoring network was installed (Fig. 3). Eight digital episensors are installed, tree on the crest, four on different locations on the dam's body and one on bedrock in the occultation building. Instruments are placed so that the full height of the central console is instrumented. Central unit is providing recording in real time.

There were no significant earthquakes in the period since the new seismic monitoring network is in operation, but network recorded some machine activity (Fig. 4). In the period of next two years, beside the new network, the analog SMA-1 accelerographs will be left in place, as a backup.

Figure 3. Installation of the seismic monitoring network

Recorded at bedrock (Osculation building) *Recorded on dam's crest (block 14)*

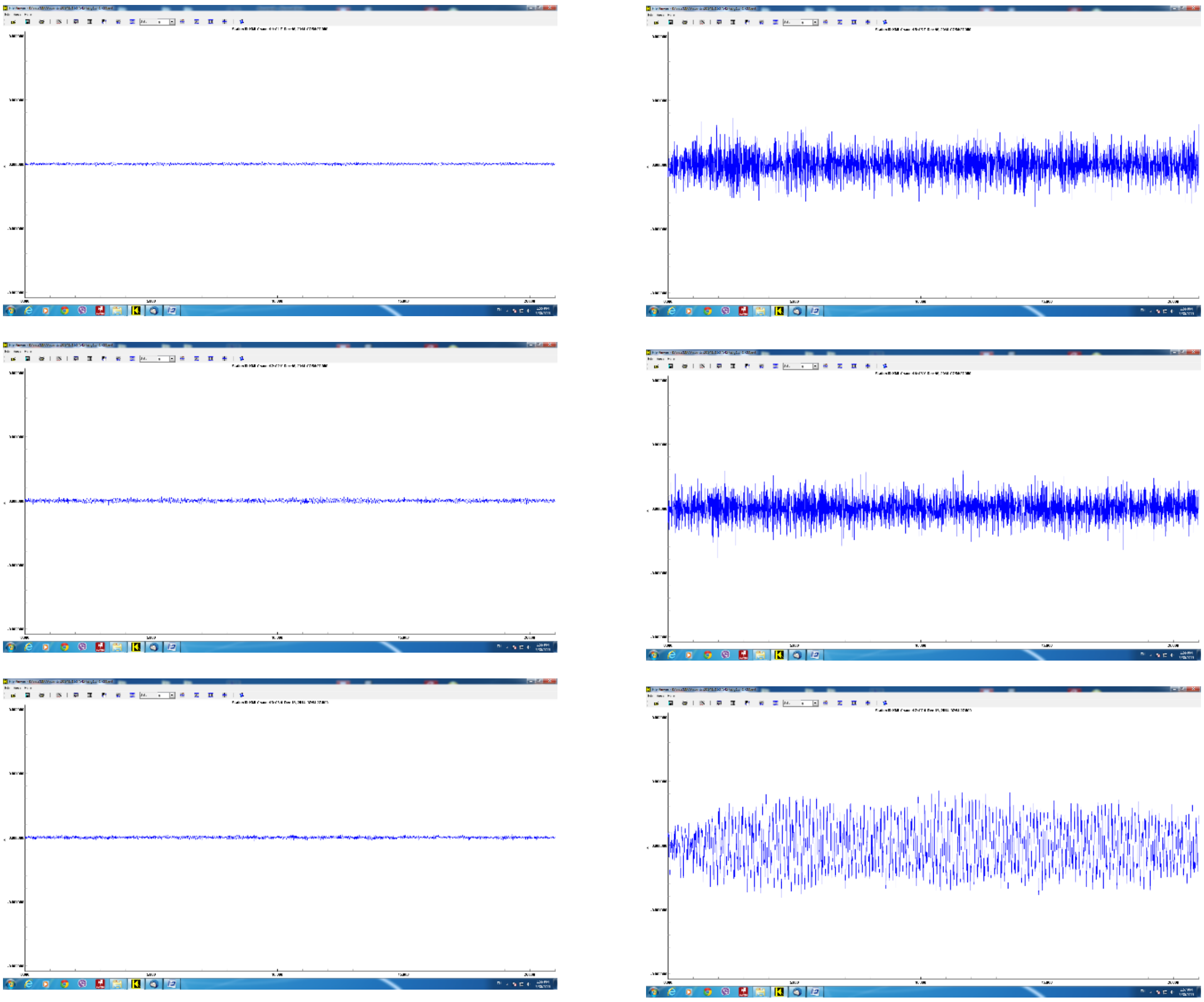

Figure 4. Three-component registrations obtained on two different instruments (bedrock and dam's crest)

4. CONCLUSIONS

The new seismic monitoring network is expected to enable obtaining quality digital records of the response of the dam in different points along it height and width thus creating a data base for reliable analysis of the behaviour of this type of structure exposed to strong seismic excitation. The data on basic seismic parameters (time histories of ground acceleration, velocity and displacement will help in decision making process in the immediate aftermath of eventual extreme event regarding the dam.