Acoustic Emission as Large Cracked Foundation Response on Static and Dynamic Loading

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Abstract.Large scale long time experiment is carried out in situ on foundations of hydro power station located on soft soil. Loading assessment and analyses of recorded response are developed. Foundation load may bee varied from quasi static to strong motion regimes. AE spectra configuration is the same in quasi static and slow dynamic and its energy carried frequency show frequency shift by loading-unloading. AE spectra are high sensitive to static load changes. By regime strong motion in some measurement points fracture opening are observe. Development of AE as the sum of the nonlinear resonance frequencies of fractals and cracks under dynamic loads is discussed. Experiment results future applicability may bee in non destructive nonlinear testing of large objects in-situ and in modeling fractured media response to long time dynamic with goal to estimate dynamic loading time and amplitude limits for intensification of filtration of fluids through porous media.

INTRODUCTION

The non-linear methods of investigating the earth's crust were rapidly developed in the recent decades; soft soil, rocks, concrete cracked and fractured massifs were under research. The non-linear methods of analysis of response require a medium with a clearly expressed non-linearity. The requirement of the practice of forecast and analysis of the response of cracked media to dynamic loading - this is the main stimulus of concentration of attention to intensive studies of non-linear processes [1] in these media. Information about the non-linear phenomena in geophysics was accumulated from the last quarter of the past century [3, 4] during the study of the propagation of waves in the earth's crust, in the grainy media, with the vibration action to the earth's crust and with studies of strong earthquakes. Concrete belongs to the class of non-linear materials, beginning from a certain stage of hardening [6]. Non-linear wave methods for the examination of damage in materials are the new frontier of acoustical non-destructive testing [6,8]. As practice shows, in the process of operation concrete is cracked and it becomes an ever more non-linear material. The non-linearity of concrete plus the non-linearity of soil [2] under it not only complicates the task, but also considerably increases practical interest in it, that also made us use the non-destructive testing methods of non-linear acoustics. They are the only and unique methods, which are able to clear up the complex spectral picture of the

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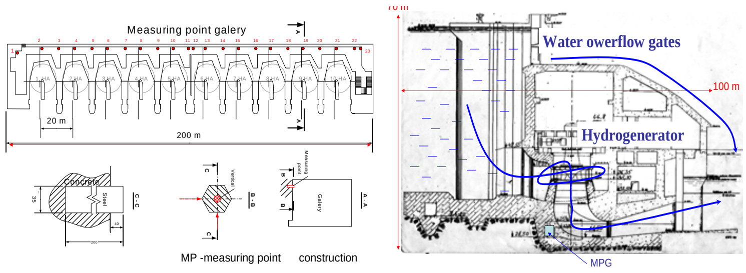
response. The evaluation of changes in the foundation after the boosting regimes and recommendations regarding the selection of the saving regimes with the daily operation - these are the primary tasks of this investigation.



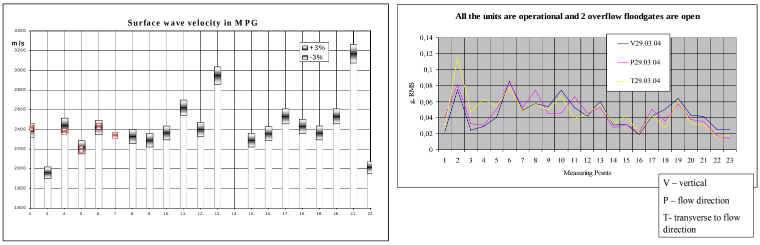
(a) **(b)**

FIGURE 1. There are 23 MPs (measurement points) in the MPG (measurement point gallery); their locations and configuration are shown on Fig. 1(a). Cross-section of the dam along the axis of a hydraulic turbine generator in the flow direction, Fig.(1b).

Measurements

Measurement location.

The work was carried out investigating foundation concrete structures of an operational hydroelectric power station, site and setup description was published in[2], in short form it is seen in Fig.1.



(a) **(b)**

FIGURE 2 (a) Surface wave propagation velocity along the MPG**. (b)** Response RMS by overflow in 23 MP

The surface wave propagation velocity along the gallery is distributed as given in Figure 2(a). Vertical polarized Rayleigh wave propagation velocity is measured between MPs and it is within 1850-3200 m/s. The latter reflects the fractures inside the concrete body (the less is the wave velocity, the higher is the crack concentration). Propagating impulse spectral changes allow to assess the fracture size. Measurements are made in silence.

Equipment.

The following equipment was used during the work: 8 accelerometers manufactured by Wilcoxon Research, a SONY 8-channel digital data recorder, type PC208A, an 8-channel data analysis software PCscan MKII and a specialised 8-channel spectrum analysis programme. In some cases, a one-channel data collector-analyser CMVA55 and vibration sensor manufactured by SKF Condition Monitoring were used, allowing carrying out the signal analyses in situ. The data analyses of all kinds were aimed at determining vibration acceleration.

Load assessment

Dynamic load assessment is made for future analysis of response spectra within the framework of non-linear elasticity.

Quasi-static realization: the power station foundation is 200 m long and it is based on soft soils and preloaded with total vertical stress approximately 350 kPa. In the basement of the foundation, there are silty-clayey and clayey-silty soils with non-uniform settlement and non-uniform relaxation time. All hydroelectric generators are idle. Static stressed state of the foundation changes with the change of the previous history of grouping of working hydroelectric units and duration of their work. The possible explanation for that phenomenon: the impact of vibrations of the working hydroelectric unit acts on the bearing capacity of weak soil directly under the unit, as well as the difference in consolidation time for clayey sand and sandy clay. That means that the relaxation processes take place in a different way, and the process of consolidation of weak soils is at a different stage under each unit, causing slow and weakly changing stress in the body of the foundation. Thus, in the "silent" regime, the conditions of "quasi-static" loading of the dam foundation due to relaxation processes are complied with.

- response RMS in MP = 0.001 – 0.004 g

Slow dynamic realization: Working some hydroelectric generators.

- response RMS in MP = 0.002 – 0.02 g

Strong motion realization : Working 10 hydroelectric generators + water overflow

- response RMS in MP = 0.02 – 0.08 g
- assessment of the emitted and dissipated energy: 25-73 MJ

Response RMS of the foundation by overflow

RMS vibration accelerations by overflow (Fig.2b) (0.02 – 0.08) g, corresponding to: a strong or very strong earthquake (Force 5-7) on the seismic scale of the Institute of the Earth Physics (Moscow), slight to medium on the Richter scale, Force 3-4 on the Mercalli scale.

Based on approximate estimates, the maximum lost energy, which is, consequently, 1% from the generated energy, the possible seismic event comprises 25-73 MJ with all the units in operation plus water discharge that corresponds to a slight to medium earthquake. The bulk of the energy was emitted in the high frequency range – (1- 4) kHz, thus ensuring that the event is local. There still remained a possibility of the excitation of the medium by high-frequency energy, which later is emitted in the low-frequency range.

Measurement results and analysis

What do we measure?

Two little simple experiments on the samples (diameter 7 cm, length 40 cm) of foundation concrete give an answer to that question. The sensor is glued on the one end (cross section) of the specimen, see Figure 3.

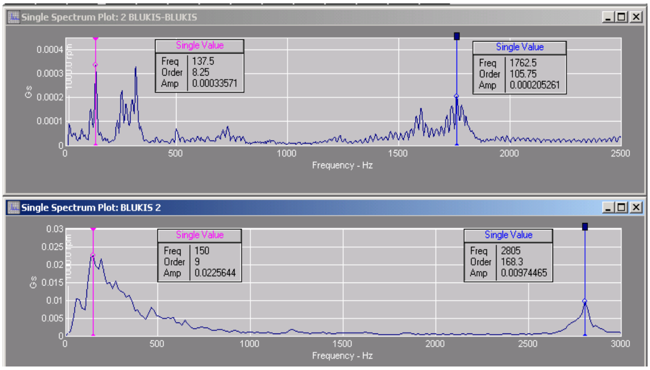
Experiment 1

Compression of a sample in metal clamps acts from two sides in the middle of the specimen length; The response contains the low-frequency part - sample oscillations and the high-frequency part. It is shown in Fig. 3 (b). The high-frequency area is caused by friction of metal about a granular surface of concrete, that is acoustic emission (AE). AE frequencies depend on the pressure on a sample and on amplitudes of sample low-frequency oscillations.

Experiment 2

Two samples are in contact with the end of a rough surface. They are squeezed manually. Response spectra are shown in Fig. 3(a). The dynamic contact metal - concrete is absent, see Fig. 4. The high-frequency area is caused by friction granular surfaces of concrete against concrete that is acoustic emission (AE). AE frequencies depend on the pressure between the samples and on amplitudes of sample low-frequency oscillations.

(a)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Single Spectrum Plot: BLUKIS 2

Single Value
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Order 9
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Single Value
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(b)

FIGURE 3 (a) Response spectra: two samples are in contact with the end of rough surface.(b). Response spectra: compression of a sample-pressure is transferred through metal tips and acts from two sides in the middle of specimen length. In both cases the gauge is glued on one end face of one specimen

FIGURE 4 The collector-analyzer CMVA55 was used. Sensor is glued on one end of the specimen

We measure the wide range response spectra. The response contains the low frequency part – the part of foundation oscillations and the high-frequency part, caused by friction of metal over concrete against the granularar surface concrete, that is acoustic emission (AE).

Detailed response analysis in MPs

Figure 5(a) gives a comparison of spectra V17 of the response in silence before (18-Mar -04) and after (14-May-04) floods of 2004, the same forV18 on fig.6. Fig. 5 (b), (c) show V17 response spectra development from 2003 to 2005 in two frequency bands. Fig.5 (d) shows the response strength growth. By the application of maximum loading 16-Mar-2004, resonance occurred. Real response in MP, Fig. 5, and response in laboratory experiment, Fig. 3 (a, b) are similar, only in situ energy-carrying frequencies are in the range (2000– 5000) Hz, but low-frequency oscillations (0.3 – 1000) Hz exist at low amplitudes. It is explained simply: a laboratory sample is extracted from a borehole in solid concrete, MPs in situ are located in cracked concrete and close to cracks. High signal level is obtained from there, the source of which is friction of crack edges.

Response analysis simultaneously in 23 MPs.

Informatively, V,P,T spectra from 23 MP considerably expands and deepens the research. It is possible to track the resonances arising in iron rods of Ferro-concrete, and their distribution in space, on distance some tens meter. In a concrete body, it is possible to single out volume into some hundreds cubic meters, which oscillates as a single whole on the nonlinear resonant frequency. Volume border cracks on three dimensions in space create it. For great volumes it is required to enter significant energy into system that these oscillations in general have occurred.

Summary

The purpose of the publication is to show an opportunity of a method of auscultation of an object with the subsequent analysis of the recorded signals, applying latest developments in the theory of non-linear dynamic elasticity and in acoustic emission. The simple and non-destructive mode of detailed research and monitoring of so big an object needs future development. It is necessary to have 3D visualisation of accumulated spectra and detailed laboratory experiments for the exact assessment of the interdependence of the emitted frequencies of the material and the applied stress for the object under investigation.

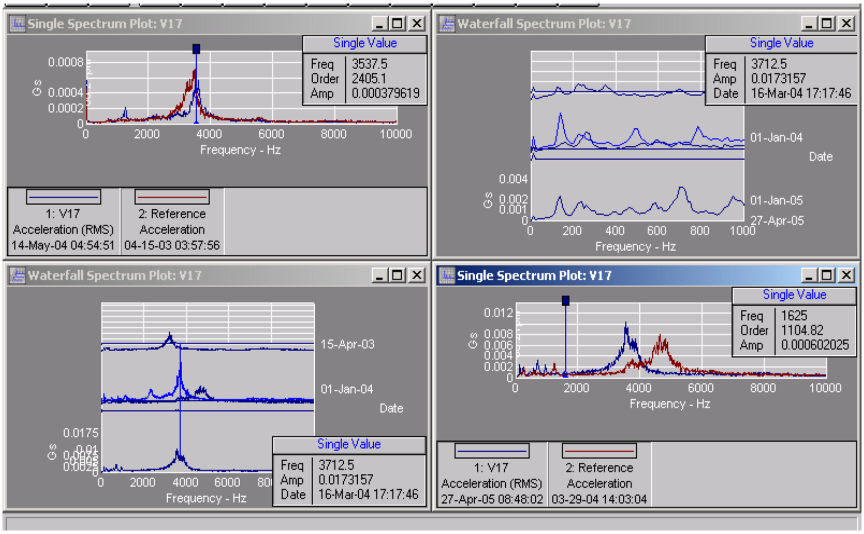

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FIGURE 5. (a) Comparison of spectra of the response in silence before (18-Mar -04) and after (14-May-04) the floods of 2004. (b), (c) Response development in V17 (MP17). 7 measurements were made: 1) 15-Apr -03 - silence, 2) 27-May-03 8 HG worked, 3) 18-Mar-04 - silence, 4) 29-Mar-04 –10 HG + 2 overflow, 5) 1-Apr-2004 (in the report it is 16-Mar-2004 but it is operator’s mistake) -10 HG + 3 overflow (it is the maximum dynamic load), 6)14-May-04 - silence, 7) 27-May-05 - 10 HG worked, (d) Response spectra on maximum load, 2005 and equivalent load + overflow, 2004.

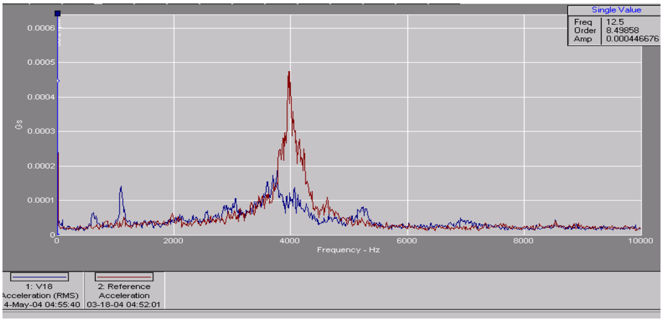

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Figure 6. V18 till and after floods 2004 Analyze in details two silences /High pressure drop down as results of strong oscillations. Q-factor is changed. Additional 2 max. in low frequency range are seen

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