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HYDROTECHNICAL STRUCTURES DYNAMIC RESPONSE DUE TO TURBULENT WATER WAVES

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Abstract: *This paper briefly presents the investigation results of the dynamic response of the flume RC structure due to turbulent water flow (case study). The purpose of the dynamic diagnosis of the reinforced concrete structure (RCS) of the OORS (COSS) channel (Danube Gabčíkovo - Nagymaros Waterworks) was to verify the flume structure dynamic resistance due to turbulent water flow with a rate from 30 m^3/s to 90 m^3/s and 120 m^3/s (COSS – collection object shoulder system).*

Keywords: environmental actions, experimental analysis, water structure dynamic diagnosis, spectral analysis

1. Introduction

The *dynamic action* (DA) of the turbulent waves (TW) on *water structures* (WS), such as offshore platforms, floating vessels, breakwaters, etc., is an essential aspect that should be considered to improve structure safety during service periods. Due to different turbulence sources in flumes, canals, basins, etc., extreme waves also arise with DA on WS. The experimental tests of RCS vibrations due to TW were recorded in relevant points of the structure simultaneously, assuming it is a random and statistically stationary function of time. This kind of vibration, if excessive, can damage similar water structures. Vibration, which usually also harms the security and stability of the WS, should be controlled by similar *experimental analysis* (EA) and spectral analysis results (picks limit, vibration levels, etc. – e.g., Tab.1, Fig.4) and compared with relevant standards prescription values (e.g., Eurocodes, BS 7385, DIN 4150, SN 640 312, STN EN 1998–1/NA/Z1, STN 73 0036, etc.), and as well as criteria used in tasks of technical seismicity. This paper also shortly reviews the knowledge required to design hydraulic structures in WDS, emphasizing quantifying the resistance to flow. It also shortly presents some recent theoretical results, which connect traditional design formulations to modern analyses of turbulence. The study of the mechanics of fluid and fluid systems is focused on the theoretical and experimental investigation of the flow of suspension, the movement of particles and sediment in closed and open conduits, tanks, and reservoirs, fluid system mixing processes, etc.

Fig. 1: View of the Gabčíkovo - Nagymaros Waterworks

2. Principles and Methods of Analysis

Current knowledge and understanding of resistance of flow in open channels are the results of contributions by many scientists and engineers over the last three centuries. These contributions can be broadly classified

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as coming from the classic field of hydraulics (Dooge, 1992) and those from the traditional fluid mechanics field (Kundu and Cohen, 2008). Interestingly, the empirical contributions by engineers in the field of hydraulics were made before the seminal experiments of Reynolds in 1883, which addressed the existence of two main flow regimes: laminar and turbulent (Pope, 2000) and others. In addition (Benčat and Lukáč, 2023), there are other relevant sources regarding the mentioned theme.

3. Dynamic response of the WS due to turbulent flow

In the previous part of the paper, the basic theoretical (empirical and numerical) approaches to solving problems of turbulent water flow (TWF) in hydraulic structures → water structures, closed and open channels, flumes, water pipes, etc., were briefly described. A common feature of the water flow in WS is the turbulent character of the flow. TWF can be classified as shear flows, where the velocity is essentially dimensional but varies in space in a direction perpendicular to the main direction of water flow. Shear currents include ripples, boundary layers, and submerged currents, specific currents through open channels, flumes, → and rip currents. The given relationships summarize the knowledge needed for designing hydraulic structures, emphasizing quantifying resistance to fluid flow and emphasizing the quantification of resistance to fluid flow. In the next part of the paper, the EA procedure of the *dynamic response of the **Flume RC Structure (FRCS)** due to turbulent water flow* (case study) is briefly described (Project documentation, 1988). The purpose of the dynamic diagnosis of the flume reinforced concrete structure (which is part of the channels system of the *Gabčíkovo–Nagymaros Waterworks*), was to ***verify the flume structure's dynamic resistance due to the turbulent flow*** with a rate from 30 m^3/s to 90 m^3/s (1st stage) and 30 m^3/s to 120 m^3/s (2nd stage) of measurements in the flume. This paper also briefly presents the flume RC structure EA results with the following ***assessment of its dynamic stiffness according to relevant Eurocodes.***

4. Characteristic data on FRCS Dobrohošt branch system and experimental measurements

The collection object for the Dobrohošť shoulder system (COSS → OORS) is built at km 1,800 of the Hrušov Reservoir Connecting Dam (Fig. 2). Its purpose is to provide water subsidies to the left–side inundation area of the old Danube bed in the area of rkm 1820.0 + 1840.0 and into the small hydroelectric plant (SHP). The structural–static solution of the flume RCS consists of individual parts of reinforced concrete components, while the flume itself consists of 7 + 4 dilated concrete blocks. Proposals are being submitted to re-evaluate the maximum permitted flow at the OORS to a value of 120 m^3/s. The extreme dynamic excitation of an OORS is expected in the area of water flow between the inlet wings and the outlet supply channel and the transition from the drainage flume to the supply channel. It causes a significant turbulent flow of water, with subsequent dynamic effects on the walls of the channel. These assumptions were confirmed by experimental measurements, where extreme values were used. The dynamic response amplitudes max $v(t)$ were detected in the area of dominant frequencies 0.5 ÷ 2.0 Hz. The measurement of the dynamic response of the flume structure at all measured points was carried out by the pickups (absolute acceleration sensors) of the standard measuring line. The accelerometer positions are detailed plotted in (Benčat et al., 2021). The output signals from the accelerometer were preamplified and recorded on a portable PC equipped with BK software packages for A/D converters (Brüel & Kjaer). The experimental amplitude analysis and spectral analysis have been carried out in the Laboratory of the ICI (Institute of Competitiveness and Innovations), UZ (University of Žilina).

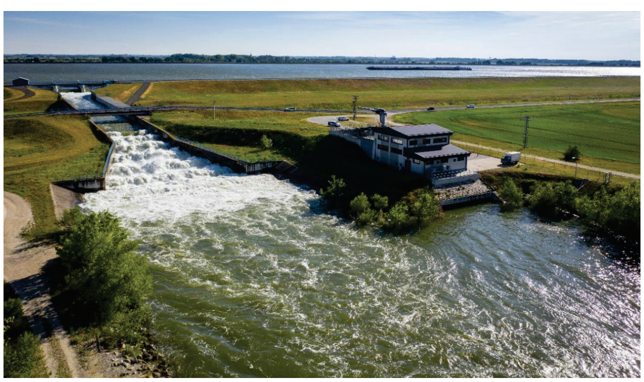

Fig. 2: View of the FRCS object and SHP Dobrohošť

4.1. Results of Amplitude Analysis

The results of the amplitude analysis of the experimental measurements of the dynamic response of the drainage flume structure (FRCS) were determined based on calculations by the program *Statistics* (Tab.1). Summarizing of the extreme values max $v(t)$ vibration velocities amplitude and the *effective value* (integral characteristic) of the vibration velocities amplitude v_{ef}, v_{rms} (*root mean square value*), at measured points of both series measurements are detail described by Benčat et al. (2021).

4.2. Results of Spectral Analysis

Frequency analysis of time records $a(t)$ was performed by spectral analysis algorithms (Bendat and Piersol, 1993) and displayed in the form of *power spectral densities* of acceleration or velocities ($G_A(f)$ or $G_V(f)$ at points B1 … B5 in both series of measurements. As a result, the areas of dominant vibration frequencies of the FRCS were found in the experimentally observed frequency band of 0.4 ÷ 20 Hz. Fig. 4 shows examples of spectral analysis results of flume structure in the form PSD at points B1y.

Fig. 3: View of the section of the evaluation line VL – UZ

The *spectral analysis* of the FRCS response time history was enabled to identify a relatively wide response *vibration spectrum* of the monitored structure, forming a complex dynamic system. In the given case, significant vibration power peaks of the monitored structure appeared in the frequency bands of 0.4 ÷ 3 Hz (1st band) and 12 ÷ 16 Hz (2nd band). Those two frequency bands indicate possible resonance areas of vibration of the monitored structure FRCS due to excitation by the turbulent flow in the channel. The indication of resonance in the 1st frequency band is more pronounced than in the 2nd band. Still, the values of the velocities (acceleration) amplitudes of the *flume vibration are too low (max* $v(t) \leq 9.78$ *mm/s,) to be able to raise signs of structure damage.*

Tab. 1: . Extreme values of amplitudes of velocities and accelerations of vibration at the measured points (program Statistics)

12.4.2021	Velocities [m/s]			
Points	**max *v*(t)**		**V_{rms}**	
Flume	**1.Set**	**2. Set**	**1.Set**	**2.Set**
B1y	1,96E–03		2,81E–04	
B2y	1,36E–03		2,57E–04	
B3y	3,97E–03	5,10E–03	3,51E–04	4,89E–04
B3z	5,63E–03	9,78E–03	2,80E–04	3,93E–04
B4z		5,00E–03		9,29E–04
B5z		3,49E–03		6,59E–04

12.4.2021	Accelerations [m/s^2]			
Points	**max *a*(*t*)**		**a_{rms}**	
Flume	**1.Set**	**2. Set**	**1.Set**	**2. Set**
B1y	0,0506		5,15E–03	
B2y	0,026		4,44E–03	
B3y	0,0762	9,50E–02	4,64E–03	6,93E–03
B3z	0,0774	3,25E–01	4,17E–03	6,34E–03
B4z		0,0967		0,0128
B5z		5,72E–02		9,03E–03

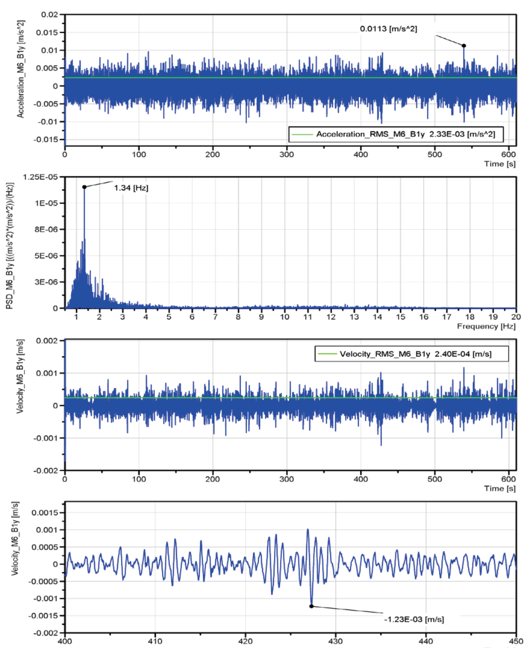

Fig. 4: Time histories of acceleration $a(t)$, velocity $v(t)$, and spectral response $G_A(f)$ at B1$_y$ of structure vibration

5. Conclusion

From the experimental measurements of the dynamic response of the FRCS due to the turbulent flow of water in the flume, the extreme values of the vibration amplitudes of the FRCS and the dominant frequencies of the vibration amplitudes in the frequency spectra were determined by the methods of amplitude and spectral analysis. The results obtained from the turbulent water flow of 90 m^3/s (*1st stage*) give the required information about the values of monitored variables and functions, comparable to those to be expected in the *2nd stage* of the study solution at higher water flows in the channel (120 m^3/s). Based on the obtained results of the time histories of the dynamic response amplitudes of the sidewall of the drainage RCS, the following facts can be stated: The values of the amplitudes of the vibration speed in all five measured points of the drainage FRCS did not exceed the value of $\max v(t) \leq 9.78$ mm/s, and $v_{\mathrm{RMS}} \leq 0.93$ mm/s, while the acceleration amplitudes acquired values of $\max a(t) \leq 96.7$ mm/s^2 and $a_{\mathrm{RMS}} \leq 12.80$ mm/s^2. The detected amplitude values of the FRCS vibration are lower than the permissible amplitude values of technological and microseismic (microtremor) vibration of constructions of the given type. (EC8 – National annex: STN EN 1998 – 1/NA/Z1, STN 73 0032, relevant national standards – BS 7385, DIN 4150, SN 640 312 and others.). From the results of the preliminary frequency analysis (power spectral densities $G_A(f)$ and $G_V(f)$, it is clear that in the given case, it is a broad–spectral vibration of the FRCS trough with higher powers in the frequency range ≈ 0.2 ÷ 2 Hz and ≈ 8 ÷ 14 Hz. At the same time, the detected values of the spectral powers confirmed the results of the amplitude analysis of the time histories $v(t)$ of the vibration of the drainage FRCS. The emergence of resonance effects on the FRCS due to the turbulent of water flow in the channel at the given intensity of the water flow is unrealistic. The results obtained from the experimental analysis of the OORS drainage channels dynamic response to the turbulent water flow of 90 m^3/s (*1st stage*) provide the required information on the monitored quantities' values, which are comparable with the values expected in the *2nd stage* of the study solution. From the mentioned dynamic vibration results and the analysis of the dynamic action of the supporting elements of the structure in question, it can be concluded that the reinforced concrete structure of the OORS drainage channel shows the required design dynamic stiffness with a turbulent flow of water in the channel of 90 m^3/s and also fulfilled relevant national criteria for microtremor vibrations.

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