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ASSESSMENT, MEASUREMENT AND MONITORING OF THE OLD BRIDGE CROSSING DANUBE IN BRATISLAVA

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Summary: *A large number of existing bridges need to be rehabilitated due to increasing traffic and/or loading requirements. A procedure is presented for estimating the the ultimate capacity of steel bridge over the Danube in Bratislava – Old Bridge (built in 1945). The development of a simplified Finite Element Model (FEM) and basic modal parameters calculations forewent the bridge experimental investigations via static and dynamic in situ loading tests, so that the main assumptions adopted in the FEM were assed through the comparison between measured and predicted dynamic and modal parameters of the bridge structure. The bridge structure computational model was then optimized by structure variable values (mainly steel structure joints mass and corrosion grade) to achieve the minimum differences between the experimental and theoretical results. The calibrated FEM with the optimal combinations of the mentioned variable values was defined and finally used for structure calculations and strengthening design of the real bridge structure.*

1. Introduction

Riveted bridges account for the majority of steel bridges that were built in different parts of the world before the middle of the last century. A large number of these bridges are still in service today. However, some of these bridges are more than 100 years old. Therefore, it is clear that while many existing bridges are structurally adequate with respect to the maximum design axle loads, they may suffer from fatigue related to the cyclic application of modern freight equipment axle loads. It should be noted that, generally, bridges designed within the past 50 years have considered fatigue effects, but that earlier bridge design did not include such considerations, even though, in some cases, the bridge may be found to be adequate for fatigue loads. The problems came up how the resistance against repeated loads of the bridges is today. Usually, the authorities ask about two important issues, the first is the bridge should be sufficiently safe for actual service conditions and if so the second issue is, what is the expected residual life and what are the requirements for inspection and maintenance to ensure the expected residual life. An essential part of the safety check of existing road bridges is the assessment of the static load –carrying capacity, and in some cases a static or dynamic load test (even fatigue strength test) becomes necessary. There are presently no regulations for the assessment of existing road bridges, expert opinions are normally used to obtain fatigue life estimates. It must be underlined; however, that fatigue is a far less relevant issue for road

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bridges than it is for railway bridges. As traffic density and traffic loads are constantly increasing, it is assumed that fatigue will be increasingly important for road bridges too. Because of the fatigue strength test time and financial seriousness it is the better way to perform static or dynamic loading tests of the bridge structure as a part of the long time monitoring to control its ultimate capacity.

2. Case – Study Bridge

The steel bridge over the Danube in Bratislava – Old Bridge was built in 1945. The bridge load bearing structure is created partly by continuous truss main beams over the river of 75,71 m – 91,50 m – 75,64 m (spans 2,3,4) and partly by single adjacent truss beams of 32,42 m + 75,82 m (spans 0,1) and 75,18 m + 32,22 m (spans 5,6). The bridge deck is composed by steel grate system (cross and longitudinal beams) bearing the reinforced double T–prefabricated road panels, fig.1. The soil conditions for foundations of the two abutments are very similar on both riversides the resistant substratum (gravel and sandy gravel) is a depth of more than 22 m.

Figure 1 View of the Old Bridge in Bratislava

Foundations of the pylons are big reinforced concrete blocks on the same substratum as the both abutments. The 91,5 m longest span (span 3) and two of ≈ 75,0 m adjacent truss main beams (spans 2, 4) was chosen for the case study presented in this paper. These three truss continuous spans are more representative and more failed part within of the 461,07 m long bridge. The most of the cracked stringer – to – floor –beam connections were located in this part of the bridge. Fig. 3 shows a cross–section of the bridge.

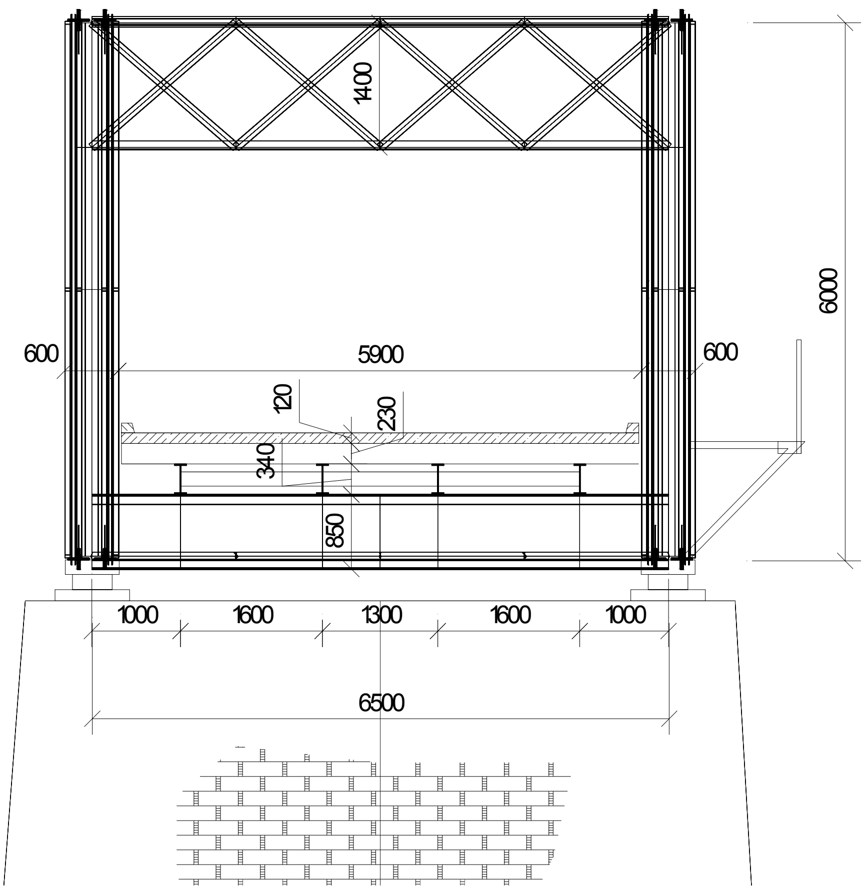


Figure 2 Cross section of the Old Bridge over the Danube in Bratislava

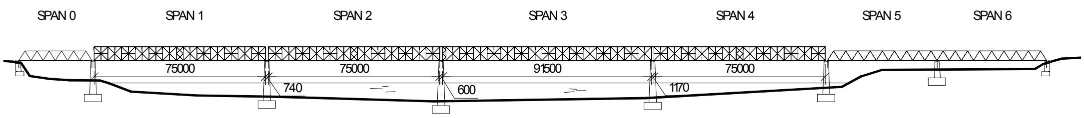


Figure 3 Schematic view of the Old Bridge over the Danube in Bratislava

3. Finite Element Model

Analysis of the bridge was performed using the IDA NEXIS software. The 3D global model incorporated all primary and secondary load – carrying members in the bridge; were, however, excluded at this stage. Heavily gusseted connections, such as those between the main truss members and between wind – bracing elements and the main truss, were modeled as moment – stiff connections, while pin connections were adopted for secondary members, such as sway and cross–bracing elements. Eccentrically connected members, such as floor beams and wind–bracing elements, were coupled in the model. Longitudinal and transverse floor beams created as built–up section from double – angles with riveted steel plate were modeled using beam elements.

The connections between longitudinal and transverse floor beams were made using Multi Point Constraints (MFC) and eccentric node – to – node gap elements were employed to simulate the contact condition between the double angles and the longitudinal floor beam web. All nonbearing elements of the truss girders and the bridge deck were included as a mass load of the structure. Four variations of expected conditions were simulated: with and without corrosion effect, lower and higher joint mass estimation. The simplified FE model is created by 2758 joints, 5904 beam elements. Rendered of the computing model layout is presented on Fig. 4.

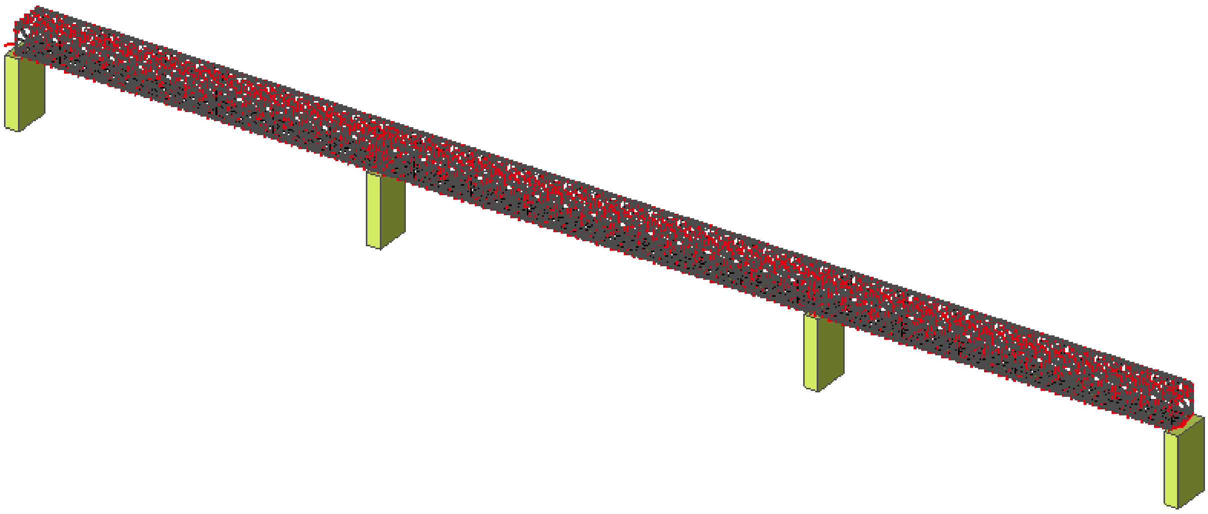
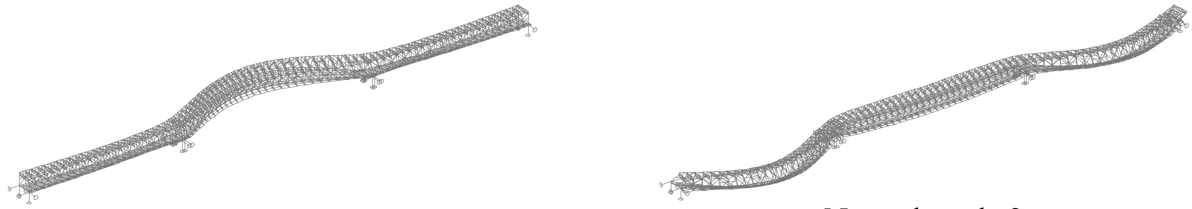


Figure 4 Global FEM model layout

Bridge deflections calculation for SLT and DLT. The maximum static vertical deflections values in the middle of the spans, positions of measured points, load positions and the effectiveness of the testing loads (SCANIA lorry of 15,7 t mass) according to the Slovak Standard for the Static Loading Test (SLT) were taking into account and also calculated via IDA Nexis software package. Results from the calculations of static deflection were also used for DLT testing load effectiveness. Model of the bridge structure the first fifteen natural frequencies and modes of natural bridge vibration were calculated to comparison to their experimental values from the Dynamic Loading Test measurements. As an example, some of them are shown in the Fig. 5. Variations of expected conditions and comparison of results is explained in Fig. 6.



Natural mode 1　　Natural mode 2

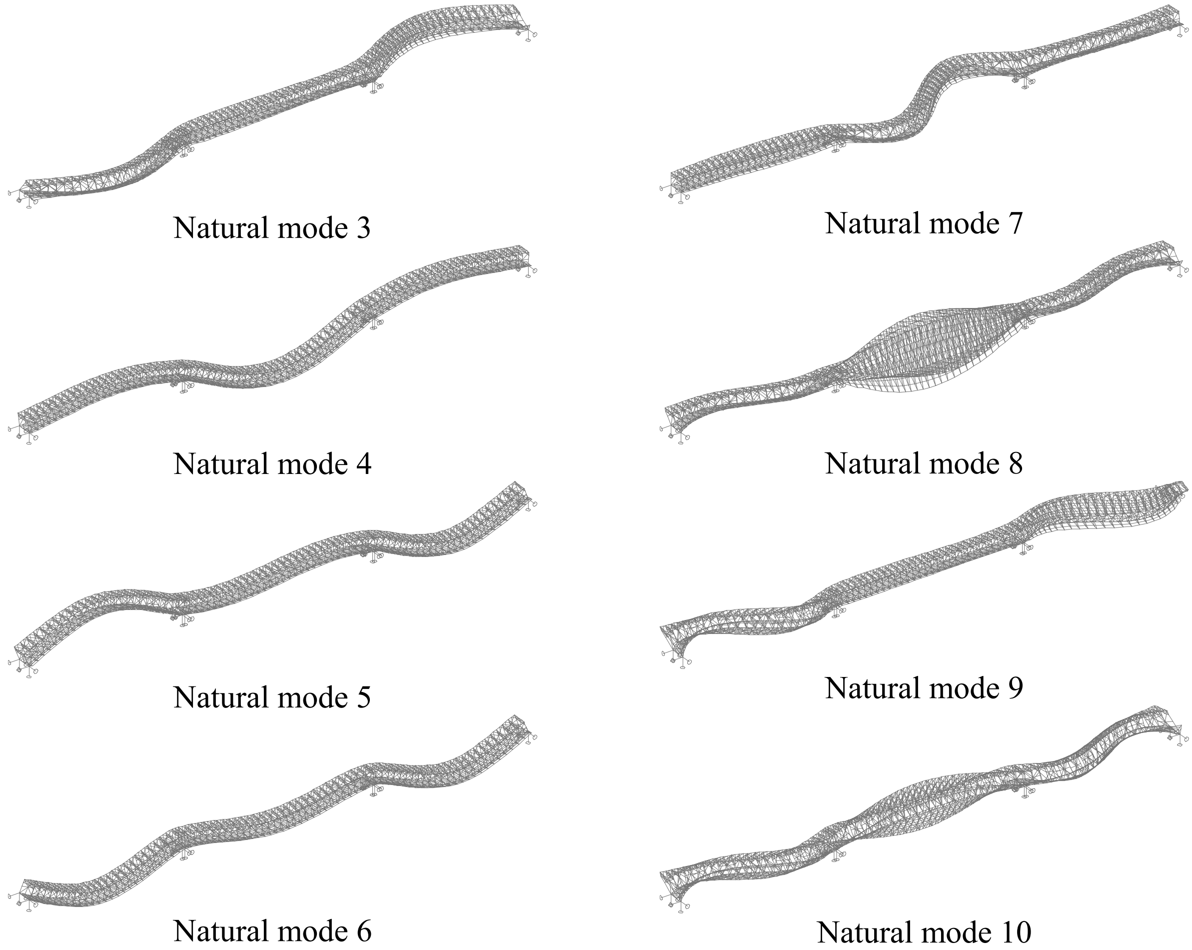


Figure 5 Calculated modes of the bridge natural vibration

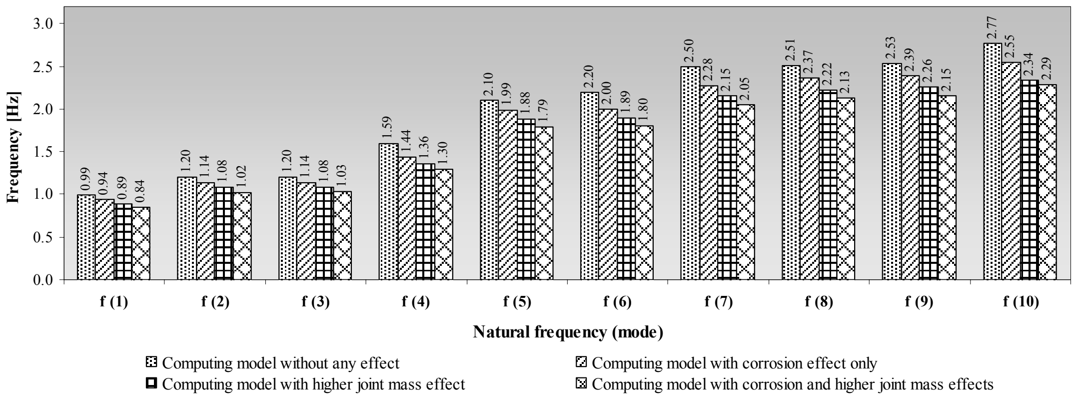


Figure 6 Calculated natural frequency comparisonerror next year

4. Dynamic Loading Test

Before the bridge dynamic loading test performance the static loading test was carried out using load vehicle *SCANIA* with weight of 15 700 kg. The deflections values in the middle of the tested spans (3,4,5 spans) were measured using precise geodesy leveling method with Leica equipment.

The dynamic response tested four spans of the bridge was also induced by passing load vehicle SCANIA in the both directions with various speed. The operating dynamic loading test (DLT) started with a load speed of c = 5 km/h (crawling speed) which increased up to the maximum achievable speed c = 62 km/h.

A computer – based measurement system (*CBMS)* was used to record the dynamic response of the bridge excitations induced by testing vehicle over DLT period. The investigated vibration acceleration amplitudes were recorded at selected points with maximum calculated deflection in each of the investigated four spans (Fig. 7). In the same points the vibration amplitudes in both horizontal direction were recorded, too. Output signals from the accelerometers *(Brüel–Kjaer, BK4500)* were preamplified and recorded on two PC facilities with A/D converters software packages *DAS 16* and *DISYS*, and four – channel portable tape FM recorder *(BK–7005)*. The experimental analysis has been carried out in the *Laboratory of the Department of Structural Mechanics, University of Žilina.* Natural frequencies were obtained using spectral analysis of the recorded bridge response dynamic components of the structure vibration, which are considered ergodic and stationary. The vibration ambient ability has been investigated by means of the correlation and spectral analysis in order to obtain cross correlation functions R_{xy} (t) and coherence function $\gamma_{xy}^2(f)$. The frequency response spectrum has also been obtained by using two – channel real time analyzer BK–2032 in the frequency range 0 ÷10 Hz. Output signal in the form of Fourier frequency spectrum (power spectrum) was also recorded by computer and printed by laser printer and x – y plotter. Spectral analysis was performed via *National Instruments* software package *NI LabVIE*.

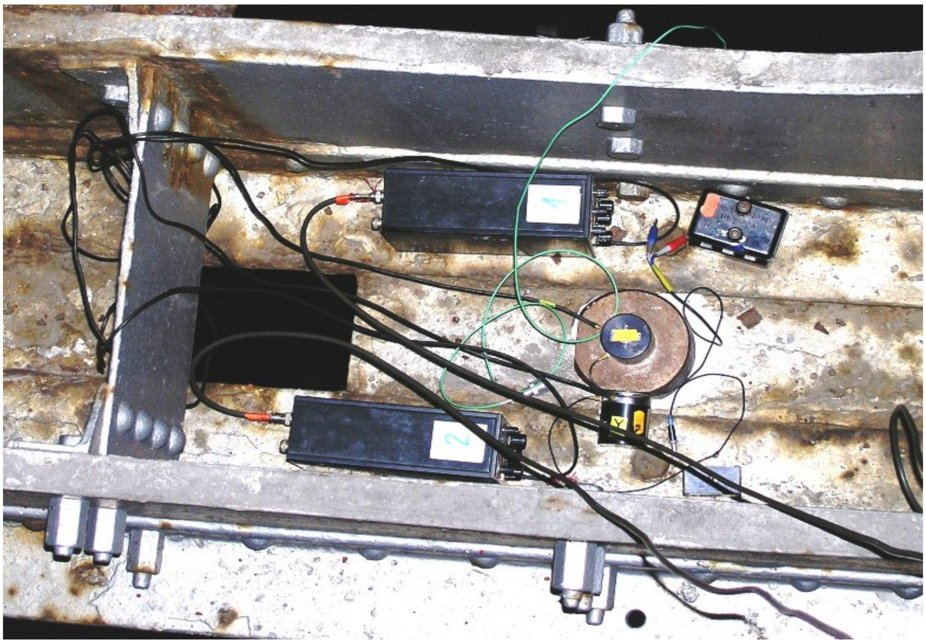


Figure 7 Acceleration sensors with amplifiers – a part of *CBMS*

Table 1 Calculated and measured natural frequencies

NATURAL FREQUENCIES OF THE BRIDGE (Hz)				
Natural mode	Numerical calculation *)		Experimental analyses **)	Vibration direction
	Model 1	Model 2	2 – 3 Span	
1	0,993	0,844	-	HORIZONTAL
2	1,200	1,024	-	HORIZONTAL
3	1,204	1,027	-	HORIZONTAL
4	1,589	1,298	-	VERTICAL
5	2,104	1,788	1,53	HORIZONTAL
6	2,199	1,801	1,85 (1,82)	VERTICAL
7	2,501	2,049	1,93 (1,95)	VERTICAL
8	2,514	2,129	~ 1,78 (1,79)	HORIZONTAL
9	2,531	2,152	~ 1,78 (1,79)	HORIZONTAL
10	2,767	2,291	2,55 (2,58)	TORSION
11	2,934	2,681	~ 2,95	TORSION
12	2,937	2,693	~ 2,97	TORSION
13	3,091	2,977	~ 3,00	AXIAL
14	3,154	2,994	2,58	HORIZONTAL
15	3,754	3,551	2,97	HORIZONTAL
16	3,772	3,568	3,42 (3,44)	HORIZONTAL

As an example, *Fig. 8* shows a part of the spectral analysis procedure results of the dynamic vertical components structure vibration from the bridge *DLT*. *Fig. 8* also shows corresponding cross – spectral density $G_{xy}(f)$, *Fig. 8(c),* with its phase spectrum $\theta_{xy}(f)$, *Fig. 8(d)*, coherence function $\gamma_{xy}^{2}(f)$, *Fig. 8(e)* and gain factor $|H(f)|$, *Fig. 8(f)*.

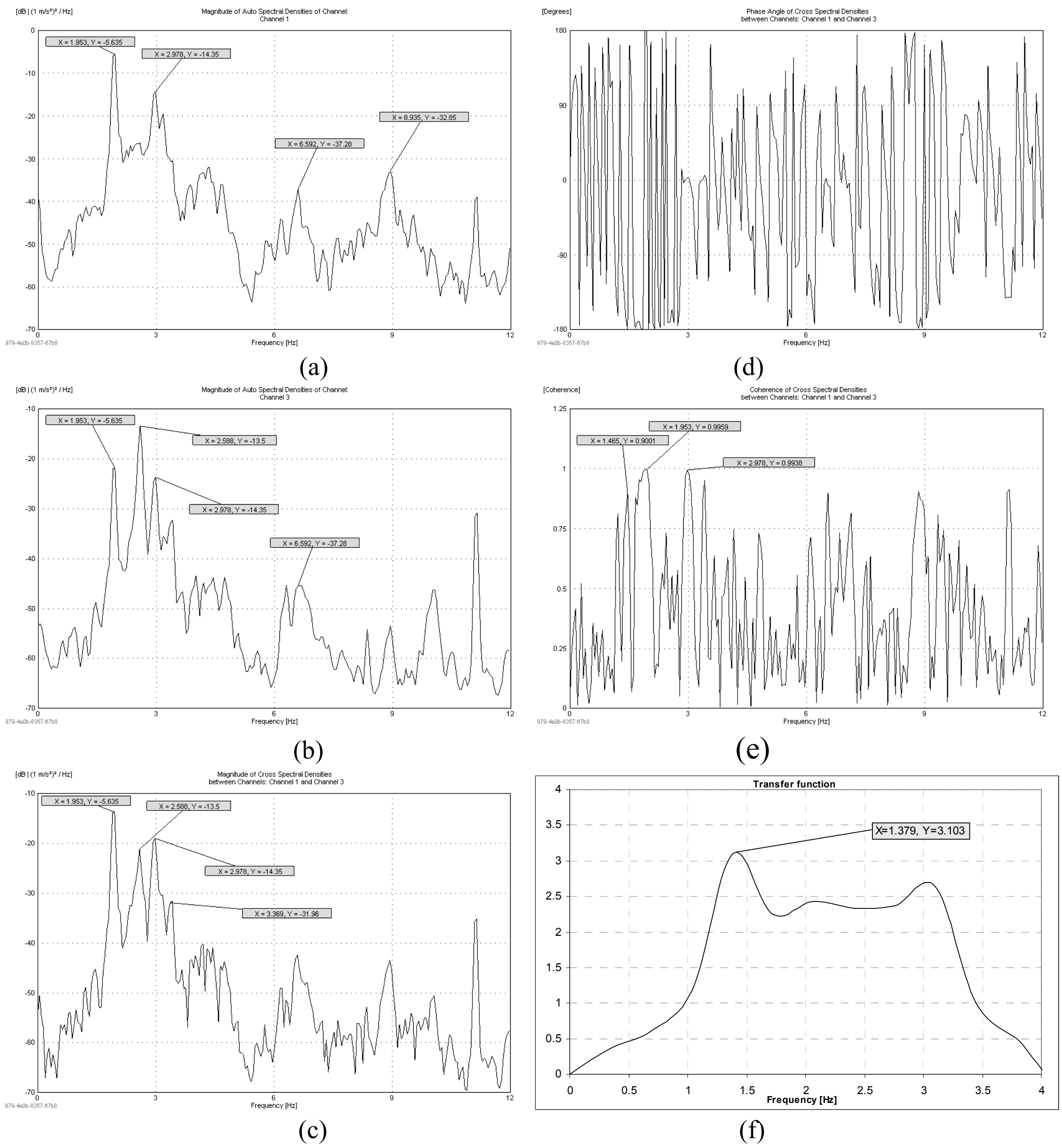


Figure 8 Spectral analysis procedure functions

5. Conclusion

Theoretical and experimental investigation of the *Old Bridge* over the *Danube in Bratislava* is described in the paper. The following conclusions can be drawn:

- The predicted dynamic behavior of the bridge by a simplified *FEM* analysis calculation was compared to the measured one. Despite both the complex structural layout of the bridge *(Fig. 1)* and simplifying assumptions of the model *(Fig. 4)*, results showed good agreement for all identified frequencies in the basic frequency range 0 – 4,5 Hz.
- The bridge dynamic loading test results proof of the truss main beams continuousness (2, 3 and 4 spans) which is in good agreement with adopted computational model and applied input bridge parameters.
- It seems the numerical model is affected by bridge steel structure joints mass, corrosion grade and geometrical stiffness; if such effects are neglected in the *FEM* analysis, the

resulting theoretical and experimental dynamic properties can be different, mainly during modal identification procedures.

- There were performed calculations of the natural frequencies with several combinations of the input parameters (with and without corrosion effect, lower and higher joint mass estimation, *etc*.) in the numerical analysis. The computational model with acceptation of the 96% cross section area (4% corrosion loss) and including the steel structure higher joints mass effect yield very close natural frequencies values in comparison with experimental ones.
- This computational model will be applied for the bridge fatigue and seismic analysis before starting a decision making process regarding to the bridge strengthening or general reconstruction.

6. Acknowledgement

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