AN APPLIED RESEARCH OF SEISMIC AND VIBRATION RESISTANCE OF THE EQUIPMENT WITH ASSESSMENT OF SEISMIC AND VIBRATION EFFECTS

Juraj Úradníček
Slovak University of Technology in Bratislava, Faculty of Mechanical Engineering, Slovakia.
Andrea Horniaková
VUJE, a.s. - Research Institute of the Nuclear Power Plant in Trnava, Slovakia.
Miloš Musil
Slovak University of Technology in Bratislava, Faculty of Mechanical Engineering, Slovakia.
Jozef Keníž
VUJE, a.s. - Research Institute of the Nuclear Power Plant in Trnava, Slovakia.

Summary
The article elaborates on the applied research into seismic and vibration resistance of the nuclear facility installations. It deals with verification the equipment behaviour at seismic event while focusing on the representative type components being tested on a single-axis seismic shaker, further compared and evaluated with the results attained through calculating the virtual models. The work concludes with a concise assessment of the seismic and vibration effects.

PACS no. 43.40.+s

1. Introduction

Seismic event - earthquake, is an activity (shaking, vibration) in the period of time, either caused by natural phenomenon or induced by human activity and equipment operation impacting on the locality and surroundings.
The two types of seismic event are recognized:

- NATURAL - earthquakes, a short time event, in the range of several kilometres, frequency ranging 0,5–33 Hz, commonly resulting from plate tectonics or volcanic activity.
- INDUCED - related to human activity, e.g.: explosions, mining, transportation, machine operation, etc. It can be steady character, ranging few metres, with frequency of 2–100 Hz.

Nuclear facility accommodates huge amount of installations. The systems, structures and components deployed in the facility can be divided as follows:

- tough
- flexible
- vessels (empty, filled with fluid)

Seismic and vibration resistance can be assessed using different methodology:

- EXPERIMENTAL METHOD - most frequently applied with the primary aim to verify the equipment operability. This method is often required to validate the results of analytical method; or, if analytical method ends up with unsatisfactory results. Tested sample is a representative of the type product. The tested sample shall be exposed to the conditions that approximate the real operation as much as possible.
- ANALYTICAL calculating method – (finite element analysis) FEA is usually applied for the equipment of enormous size, or, if the equipment/construction involve a simple mechanisms; often used when designing new prototypes.

Based on the above principles, the research of seismic and vibration resistance of the equipment to assess the seismic and vibration effects, i.e. the construction has been tested for dynamic and modal properties, comparing the results of calculating FEA and experimental model. [1]

2. Comparison of the calculating model FEA of tested construction with the experimental model, accounting the dynamic and modal properties

2.1 Analysing the subject matter

The tested equipment consists of two parallel plates mutually joined by four circular beams – Figure 1. The equipment material is structural steel 11 373, calculated elastic modulus E=2.15 GPa, density ρ=7850 kg/m3. [2]

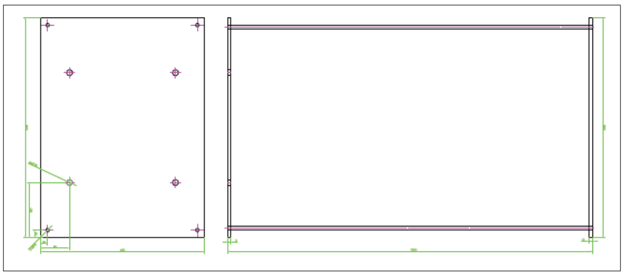

Figure 1. Tested equipment

Experimental testing of the equipment has been carried out on a vibration single-axis shaker. Tested equipment was excited following the document "Requirements on evaluation of seismic resistance of structures, systems and components of Mochovce NPP" - PNM34080183, directed in axis X.
Modal shape excitation: 1-100 Hz
Seismic excitation: Spectra for EMO34 CS 806/1,2; level +9.6 m, damping 1 % Table I.
The scheme of acceleration sensors position and excitation direction shows Figure 2. [2]

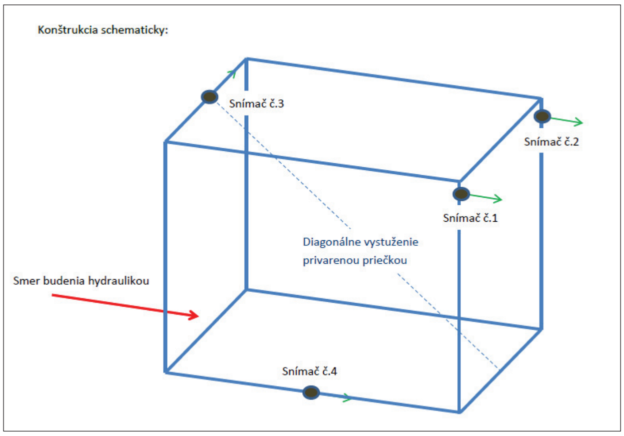

Figure 2. Deploy of acceleration sensors

Table I. Spectra for EMO34 CS 806/1,2; level +9.6 m, damping 1 %

Frequency [Hz]	Acceleration at damping 1 % [m/s ^{2}]
0.09	0.20295
0.26	1.4685
3.37	21.6414
4.22	21.6414
4.53	27.3339
7.79	27.33555
7.88	23.9415
8.81	23.9415
9	20.3082
10.67	32.4027
11	37.8807
16.08	37.88235
17.86	36.5211
19.67	14.64705
22.25	10.2135
28.24	6.6066
32.35	6.3921

Time and frequency response of both, experimental and calculating model of the tested equipment is being analysed through the article, while the input signal is the acceleration measured by sensor no 4; and, the output is the signal of acceleration measured by the sensor no 1. [2]

2.2 Analysis procedure

Finite element analysis by ANSYS software was applied for numerical simulation. Created FEA model of the equipment shows Figure 1.

Figure 3. FEA model of the tested construction

A comprehensive analysis of modal shapes has been applied to examine modal properties of the calculating model. FEA model response to excitation as well has been analysed in time period using transient analysis, due to anticipated effects of nonlinearities caused by large deformation and twisting of the construction.

Filtered acceleration signal measured by sensor 4 was considered an excitation signal to verify the calculating model of the construction, see Figure 2. The signal was filtered by “low pass” filter of grade 4 (Figure 4.), which helped to clear out the amplitudes above 10 Hz.

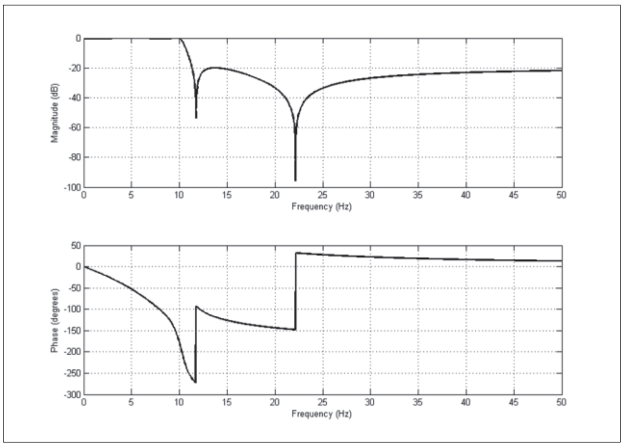

Figure 4. Frequency characteristics of the used filter of input signal

Frequency and time course of filtered and non-filtered input signal shows Figure 5. and Figure 6.

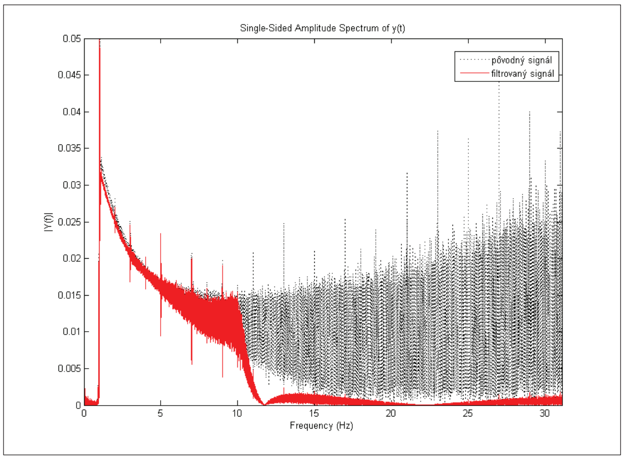

Figure 5. Amplitude of accelerations excitation signal

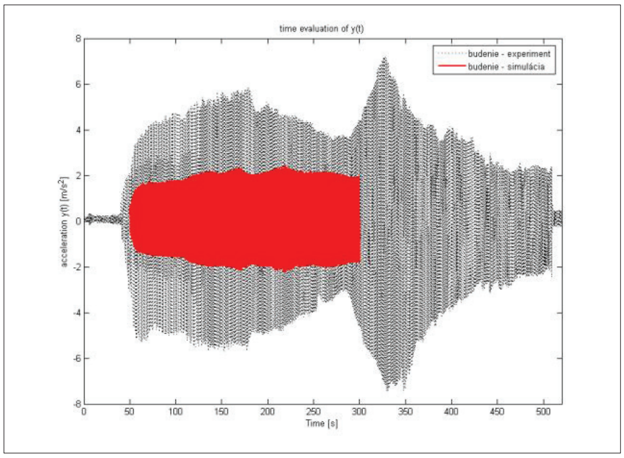

Figure 6. Time course of acceleration excitation signal

Time course in Figure 6 displays shorter simulation interval compared to the experiment. The simulation signal involves amplitudes with frequency range 1 - 10 Hz (chirp signal), whatever higher frequency was not accounted through the simulation.

2.3 Analysis findings

2.3.1 Modal analysis

To study modal shapes and construction frequencies, a comprehensive modal analysis was applied. Figure 7 shows the first and second calculated modal shapes.

Figure 7. The two initial calculated modal shapes of the construction

Table II. Design angular frequencies of the construction

ω_1 [rad/s]	ω_2 [rad/s]
2,567	2,583

2.3.2 Transient analysis

The results of both linear and nonlinear transient analysis have been compared, to study the effects of nonlinearities on the system response. Large deformations and twisting of the system was considered through non-linear transient analysis. Comparison of the two analyses results shows Figure 8.

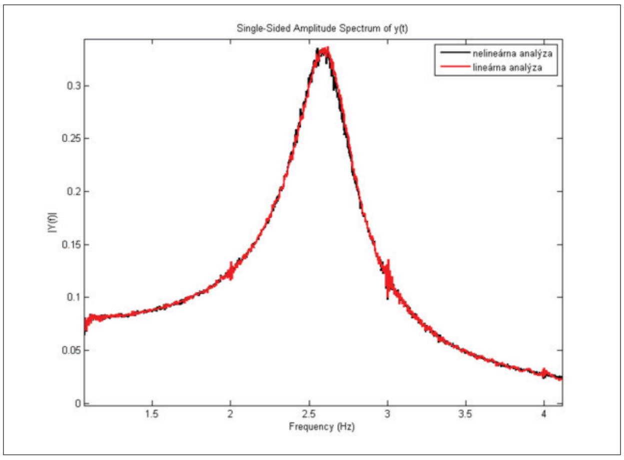

Figure 8. Linear and non-linear transient analysis results achieved within frequency zone

Figure 8 proves that whether geometric non-linearities accounted or not, the results are virtually alike.

2.4 Results analysis

Figure 9 presents a comparison of amplitude spectrum of accelerations measured by sensor 1 (Figure 2, Figure 3)

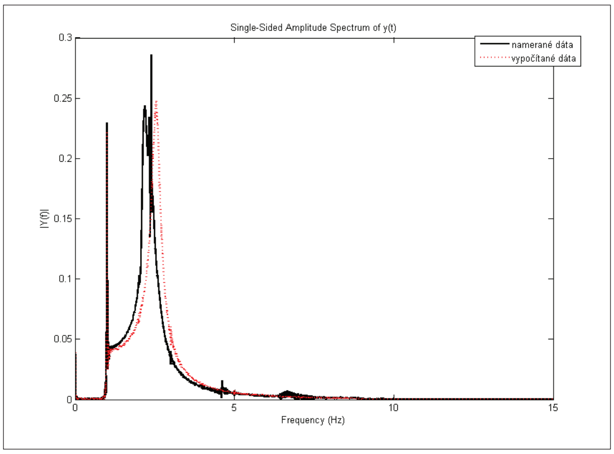

Figure 9. Amplitude spectra of acceleration detected by sensor 1, experiment vs. calculation

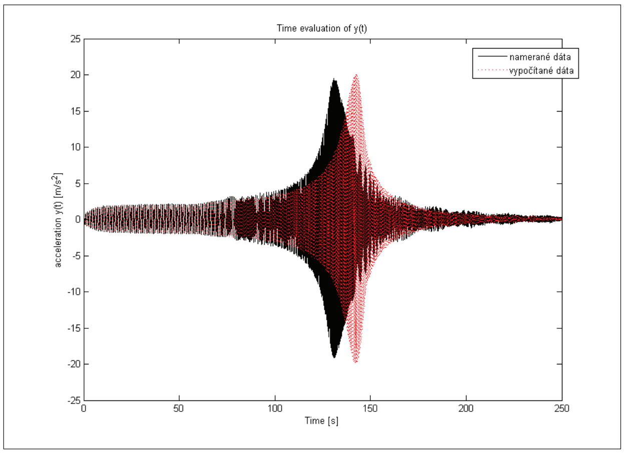

Figure 10. Time course of accelerations detected by sensor 1, experiment vs. calculation

Figure 10 presents a comparison of acceleration courses by sensor 1 detected through the experiment and calculated by the model.

3. Conclusions

Dynamic characteristic of the tested construction have been analysed in the article. It has manifested one predominant modal shape of the construction created in the direction of excitation at self-frequency of 2.3 Hz measured experimentally. FEA model of the tested construction subject to a comprehensive modal analysis evidenced self-frequency of 2.58 Hz; while the transient analysis demonstrated 2.55 Hz frequency. Deviations of measured and calculated self-frequencies do not exceed 10 %. The results of comparison the linear and non-linear transient analysis proved no significant effect of non-linearities. Experimental construction proves to be less tough compared to calculating model. It could be caused by slightly unequal modelling of the construction fixing to the shaker, or by dissimilar material and geometry of the construction to its experimental model.

Acknowledgement

The present work was initiated within the R&D program, in particular the project “Safety Enhancement of Nuclear Installations at Seismic Event” (ITMS: 26220220171), funded in association with European Regional Development Fund.

References

[1] Horniaková, Andrea: Posúdenie seizmickej odolnosti zariadení analytickou a experimentálnou metódou. In: MG SNUS 2014 : zborník príspevkov z odbornej konferencie Mladej generácie Slovenskej nukleárnej spoločnosti. Častá-Papiernička, 25.4. 2014. - Trnava : Slovenská nukleárna spoločnosť, 2014. - ISBN 978-80-971498-2-6. - [8] s.

[2] Keniz, J, Horniakova, A. and Musil, M. Laboratory of seismic and vibration tests, assessment of seismic devices resistibility by analytical and experimental method. Noise and vibration in practice. Peer-reviewed Proceedings. Vol. 19, Bratislava 2014, p, 93-7.