Transilvania University of Brasov
FACULTY OF MECHANICAL ENGINEERING

The 7th International Conference on
Computational Mechanics and Virtual Engineering
COMEC 2017
Brasov, ROMANIA, 16-17 November 2017

COMPARISON OF COMPUTED EIGENFREQUENCIES WITH EXPERIMENTAL RESULTS FOR CORRODED CANTILEVER BEAMS

Stanciu E. [1], **Korka Z.I.** [1], **Praisach Z.I.** [1], **Gillich G.R.**[1], **Niţescu C.** [1]
[1] University "Eftimie Murgu", Resita, ROMANIA, e.stanciu@wksimonsfeld.com, z.korka@uem.ro, zpraisah@yahoo.com, gr.gillich@uem.ro, codnit07@yahoo.de

Abstract: *The paper presents a comparison of modal analysis results obtained via the finite element method and experiments. To have a clear image about the convergence of the results, four beams in intact state respectively with several corrosion scenarios are taken into consideration. To get accurate results from the experimental modal analysis we employed an advanced non-contact excitation and signal post-processing method. We found out that the results obtained by the two methods fit for all sixteen analyzed cases, which proves their robustness and availability.*
Keywords: *cantilever beam, corrosion, modal analysis, eigenfrequency*

1. INTRODUCTION

Corrosion is a natural deterioration process of materials due to their interaction with the environment where they are exposed [1]. Even if the term of corrosion is generally associated with metals, it is also used to describe the degradation process of concrete, wood or plastics. As corrosion is frequently causing material and structural damage, the interest in studying the phenomenon has increased in the last decades. Furthermore, the effects of corrosion have a significant impact on the environment where the structures are operating, causing high operating and maintenance costs [2].
Therefore, in order to minimize the economic and environmental impacts of corrosion, it is necessary that the structures subject to this phenomenon have to be inspected and controlled periodically [3],[4]. As in case of large structures, located in places where the visual inspection is difficult to be done, or for corrosion occurred inside the materials, where the traditional inspections are irrelevant, vibration-based methods are required for the detection of corrosion [5].
In previous researches [6]-[9] we have developed a very accurate algorithm for the extraction of frequencies from vibration signals of plates and beams with transversal cracks, in order to compare the damage signature with an existing database containing damage location indexes.
The aim of this research was to find out if the eigenfrequency changes of beams having different stages of corrosion can be found out precisely if involving the finite element method (FEM) and an experimental method designed with a non-contact excitation and an advanced signal processing algorithm lead to convergent results.

2. MODAL ANALYSIS USING THE FINITE ELEMENT METHOD FOR A CORRODED CANTILEVER BEAM

The beam subjected to analysis in this research is a prismatic one, fixed at the left ends and free at the opposite end, having the geometrical, physical and mechanical parameters shown in Table 1.

Table 1: Geometrical, physical and mechanical parameters of the investigated beam

Length L [mm]	Width B [mm]	Thickness H[mm]	Mass density ρ [kg/m3]	Young modulus E [N/m2]	Poisson ratio υ [-]
1000	50	5	7850	$2 \cdot 10^{11}$	0,3

The uniform corrosion is placed iteratively in four characteristic positions on the beam, has different extension surfaces, respective depths (corrosion severity levels). Corrosion was simulated as an asymmetrically loss of material on one of the beam faces, between the limits l_1 and l_2, as schematically presented in Figure 1. In the healthy state, the beam has a moment of inertia I and a cross- sectional area A, while at the corroded areas, the beam has a reduced moment of inertia I_C, which depends on the level of corrosion. In the research, the corrosion was considered uniform, without effect on the Young modulus E.

Besides the four healthy beams, following damage scenarios with the corrosion damage placed between the limits l_1 and l_2, were considered:

- beam B1, with corrosion damage located between the limits l_1= 100 mm and l_2= 150 mm;
- beam B2, with corrosion damage located between the limits l_1= 300 mm and l_2= 400 mm;
- beam B3, with corrosion damage located between the limits l_1= 600 mm and l_2= 650 mm;
- beam B4, with corrosion damage located between the limits l_1= 900 mm and l_2= 950 mm.

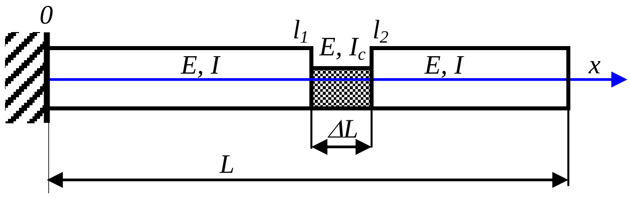

Figure 1: Model of clamped beam for describing the corrosion location, extension and severity level

For each of the upper mentioned corroded beams, three levels of corrosion severity where considered: 10%, 20% and 30%, which were materialized by reducing the beam thickness with 0,5 mm, 1 mm, and 1,5 mm, respectively.

Table 2: Eigenfrequencies of beam B1 obtained by FEM modal analysis

Level of corrosion severity	**Vibration mode**					
	1	**2**	**3**	**4**	**5**	**6**
	Natural frequencies [Hz]					
0%	4,0900	25,6273	71,7567	140,6316	232,5272	347,4627
10%	3,9875	25,4715	71,7924	140,6329	231,6318	344,9875
20%	3,8410	25,2580	71,8059	140,5214	230,2289	341,6133
30%	3,6326	24,9742	71,7855	140,2566	228,2341	337,4156

Table 3: Eigenfrequencies of beam B2 obtained by FEM modal analysis

Level of corrosion severity	**Vibration mode**					
	1	**2**	**3**	**4**	**5**	**6**
	Eigenfrequencies [Hz]					
0%	4,0900	25,6273	71,7567	140,6316	232,5272	347,4627
10%	4,0094	25,4307	70,6731	140,2743	229,0940	342,7974
20%	3,8907	25,1123	69,2473	139,6600	225,0829	337,8073
30%	3,7145	24,6402	67,5054	137,2941	220,6993	332,5348

Table 4: Eigenfrequencies of beam B3 obtained by FEM modal analysis

Level of corrosion severity	**Vibration mode**					
	1	**2**	**3**	**4**	**5**	**6**
	Eigenfrequencies [Hz]					
0%	4,0900	25,6273	71,7567	140,6316	232,5272	347,4627
10%	4,0933	25,2992	71,0170	140,5204	229,9650	346,1009
20%	4,0928	24,7850	69,9363	140,3401	226,4554	344,2683
30%	4,0855	23,9871	68,4275	140,0564	221,9536	341,9256

Table 5: Eigenfrequencies of beam B4 obtained by FEM modal analysis

Level of corrosion severity	**Vibration mode**					
	1	**2**	**3**	**4**	**5**	**6**
	Eigenfrequencies [Hz]					
0%	4,0900	25,6273	71,7567	140,6316	232,5272	347,4627
10%	4,1233	25,7330	71,8295	140,3407	231,3100	344,6758
20%	4,1575	25,8415	71,8698	139,8166	229,3213	340,0364

30%	4,1924	25,9515	71,8452	138,8621	225,9649	332,9087

The FEM modal analysis was performed by means of the *ANSYS* simulation software, using hexahedral elements with a maximum edge dimension of 2 mm. The computed eigenfrequencies for the first six vibration modes of the beams B1, B2, B3 and B4, having different levels of corrosion severity (0%- healthy beam, without corrosion), are sown in Tables 2 to 5.

3. EXPERIMENTAL MODAL ANALYSIS

To perform the experimental modal analysis we used a special designed test stand. The stand shown in Figure 2 mainly consists of a base frame (1) on which, a 20 mm thick table (2) with T-channel was mounted. For a proper fixing of the analyzed beam, an universal vice (3) used on machine tools and fixed on the table by “T”- channel screws (4), was utilized. For avoiding any undesirable influences on the measurement of the beams natural frequencies, rubber mats (5) were used for isolating the stand from the ground.
For simulating of the corrosion of the beams B1-B4, with different levels of severity, 12 beams were machined between the limits l_1 and l_2 (see figure 1) on depths of 0,5 mm,. 1 mm, and 1,5 mm respectively.
Sound pressure produced by a signal generator and transmitted via an amplifier by a low-frequency loudspeaker (6) was used for exciting the beams. Vibration signals were acquired by a system consisting of a Kistler 8772 accelerometer a chassis NI CDAQ-9172 and an acquisition module NI 9234. For a fine processing of the vibration signal and an accurate identification of the frequencies, a special algorithm described in [10] was designed using LabView software.

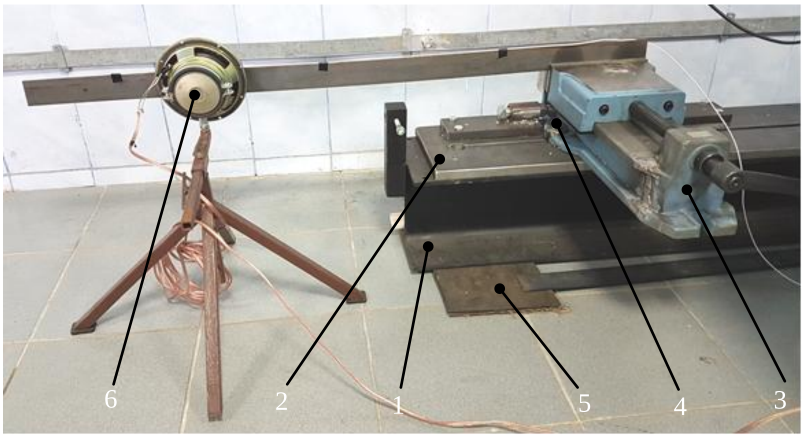

Figure 2: General view of the test stand

For each analyzed case, sets of five measurements were performed and the arithmetic mean of the measured values for the first six vibration modes was computed. The results are shown in Tables 6 to 9. Evaluating the sets of measurement, a very good repeatability was found, which confirms that the chosen excitation method was suitable for the purpose of the experiment.

Table 6: Experimentally measured eigenfrequencies on beam B1

Level of corrosion severity	Vibration mode					
	1	2	3	4	5	6
	Eigenfrequencies [Hz]					
0%	4,0970	25,9531	72,0343	141,0708	233,4162	348,8815
10%	3,9940	25,8370	72,0985	141,0570	232,5910	346,4460
20%	3,8599	25,6475	72,1395	141,2090	230,6080	342,0944
30%	3,6239	25,1033	72,0798	140,1000	227,6490	337,5400

Table 7: Experimentally measured eigenfrequencies on beam B2

Level of corrosion severity	Vibration mode					
	1	2	3	4	5	6
	Eigenfrequencies [Hz]					
0%	4,0440	25,4727	72,5060	143,2311	235,1570	350,7516
10%	3,9661	25,2611	71,3439	142,6392	231,5180	346,0870
20%	3,8617	24,9598	69,9739	141,9065	227,5700	341,2060

30%	3,6805	24,6380	68,0254	139,9126	223,2002	335,8406

Table 8: Experimentally measured eigenfrequencies on beam B3

Level of corrosion severity	**Vibration mode**					
	1	**2**	**3**	**4**	**5**	**6**
	Eigenfrequencies [Hz]					
0%	4,0624	25,8239	73,0958	142,9460	236,6008	353,5772
10%	4,0683	25,5269	72,3050	142,8286	233,9971	352,0016
20%	4,0780	24,9721	71,3083	142,6600	230,1244	350,5000
30%	4,0509	24,1561	70,0260	142,3420	225,4910	348,2590

Table 9: Experimentally measured eigenfrequencies on beam B4

Level of corrosion severity	**Vibration mode**					
	1	**2**	**3**	**4**	**5**	**6**
	Eigenfrequencies [Hz]					
0%	4,0613	26,0757	72,0175	141,2410	234,0644	348,7590
10%	4,1040	26,1661	72,0245	140,9740	233,0630	346,2990
20%	4,1369	26,1991	72,1717	140,5332	230,7148	341,3264
30%	4,1749	26,4080	72,0770	139,9840	227,1652	334,2660

4. COMPARISON OF RESULTS AND DISCUSSION

Comparing the eigenfrequencies achieved by means of the FEM (shown in Tables 2-5) with those obtained by experimentally measurement (shown in Tables 6-9), one can easily observe that they are very close. In fact, the relative differences does not exceed 2,5%. This confirms, on one hand, that the model proposed for the FEM analysis simulates very well the real phenomenon, when the corrosion may be placed in differing positions on the beam, can have diverse extension surfaces, or various depths. On the other hand, the research validates the proposed method of measuring the natural frequencies as being very precise. The precision of the frequency measurement method is also reinforced by the fact that, in order to simulate the various degrees of corrosion (10%, 20% and 30%), the bars were dismounted and mounted again, for several times, in the vice of the test stand.

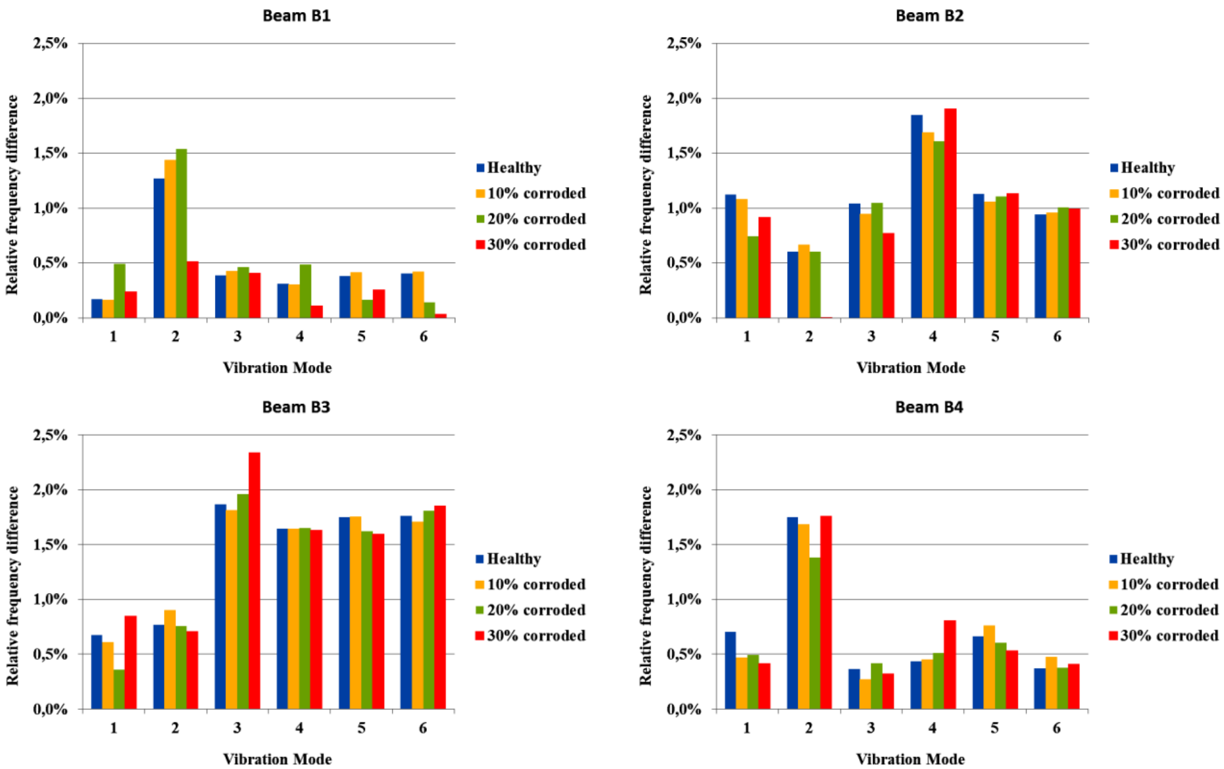

Figure 3: Relative frequency differences between FEM and experimental modal analysis

To better understand the differences between the results of the FEM and that of the experimental modal analysis, Figure 3 shows the variation patterns of the relative frequency differences at all four levels of corrosion severity. The frequency differences have been calculated using the following relation:

$$RFD_i = \frac{\left| f_{Exp-i} - f_{FEM-i} \right|}{f_{FEM-i}} \cdot 100 \qquad [\%] \qquad (1)$$

where we denoted:

RFD_i [%] – the Relative frequency difference between FEM and measurement results, for the *i* vibration mode;

f_{Exp-i} [Hz] - the frequency of the *i* vibration mode, obtained by experimental modal analysis;

f_{FEM-i} [Hz] - the frequency of the *i* vibration mode, obtained by FEM modal analysis.

The relative frequency differences are small and comparatively distributed for one beam. So for beam B1 the difference level is around 0,5%, for beam B2 it is around 1%, for beam B3 it is around 1,5% and for beam B4 it is again around 0,5%. This makes us considering that the geometry and/or mechanical properties were not the same for all beams, even if these belong to the same lot number.

5. CONCLUSION

The study presented in this paper proves that small frequency changes occurring due to uniform corrosion can be assessed both by modal analysis performed via FEM as well as involving experimental techniques. Moreover, concordance of the results obtained by the two methods was achieved. In the majority of the analyzed cases the differences do not exceed 1%, the upper limit being 2.5%.

ACKNOWLEDGMENTS

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/132395.

REFERENCES

[1] Schweitzer P.A., Fundamentals of Corrosion: Mechanisms, Causes, and Preventive Methods, Taylor& Francis Group, New York, 2010.

[2] Korka Z.I., Precision Coatings, in: Gupta K. (eds), Micro and Precision Manufacturing. Engineering Materials, Springer Cham, 2018.

[3] Papavinasam S., Corrosion management, in: El- Sherik A.M. (eds.), Trends in Oil and Gas Corrosion Research and Technologies, Elsevier, 2017.

[4] Ortega N.F., Robles S.I., Assessment of Residual Life of concrete structures affected by reinforcement corrosion, HBRC Journal, Volume 12, Issue 2, pp. 114-122, 2016.

[5] Cox W.M., A Strategic Approach to Corrosion Monitoring and Corrosion Management, Procedia Engineering, Vol. 86, pp. 567-575, 2014.

[6] Gillich G.R., Praisach Z.I., Iancu V., Furdui H., Negru I., Natural Frequency Changes due to Severe Corrosion in Metallic Structures, Strojniški vestnik - Journal of Mechanical Engineering 61 (12), pp. 721-730, 2015.

[7] Gillich G.R., Praisach Z.I., Furdui H., Ntakpe J.L., Minda A.A., Evaluation of loss of mass due to corrosion using vibration-based methods, Applied Mechanics and Materials 658, pp. 77-82, 2014.

[8] Tufoi M., Gillich G.R., Mituletu I.C., Iancu V., Location of the corrosion damage in rectangular plates, Journal of Physics: Conference Series 628 (1), 012005, 2015.

[9] Gillich G.R., Praisach Z.I., Wahab M.A., Gillich N., Mituletu I.C., Nitescu C., Free vibration of a perfectly clamped-free beam with stepwise eccentric distributed masses, Shock and Vibration, Article ID 2086274, 10 pages, 2016.

[10] Gillich G.R., Mituletu I.C., Praisach Z.I., Negru I., Tufoi M., Method to Enhance the Frequency Readability for Detecting Incipient Structural Damage, Iranian Journal of Science and Technology, Transactions of Mechanical Engineering, Vol. 41, No. 3, pp. 233-242, 2017.