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Experimental Procedure to assess Damages of Welded Beams

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This paper presents an experimental procedure to assess damages of welded beams, the weld being transversal to the longitudinal beam axis. It consists of comparing the natural frequencies in intact and damaged state, calculating the frequency shift due to damage and weigh the shifts against patterns derived a priori.

Keywords: *welded structure, damage assessment, experiment, frequency shift*

1. Introduction

Damages can be detected in a structure by involving global methods, most of them based on vibration analysis. These methods are developed for structures with constant cross-section [1]-[3]. Welded structures are more complex, since deviation of thickness and mechanical properties are associated to the weld area [4]. Also, residual stress is usually present in the structure. Therefore, damage detection applied to welded structures needs a specific approach, where mass and mechanical characteristics in the weld area are different comparing with the rest of the structure, thus specially contrived patterns have to be used for the damage location process.

2. Experimental setup

The experimental research was performed on the basis of a test program in order to determine the natural frequencies of a double clamped beam, welded at different distances from one of the fixtures [5]. In a first stage, the presence of a defect in the weld area that crosses the whole width of the beam was assumed as an incomplete filling of the root. Natural frequency measurements were completed on a beam with the dimensions of the cross section 50x5 mm, having a length of 1 mm and manufactured from S235 JR steel, according to SR EN 10025-2.

The test program was conducted according to the following scenario:

a) the natural frequencies were measured for the healthy (without damages) beam (Fig. 1);

b) the beam was cut in two parts and welded on one side, thus realizing the weld defect, incomplete filling of the root (Fig. 2);

c) natural frequencies were measured for weld defects located on the beam in five different positions: 0,5L, 0,4L, 0,3L, 0,2L and 0,1 L.

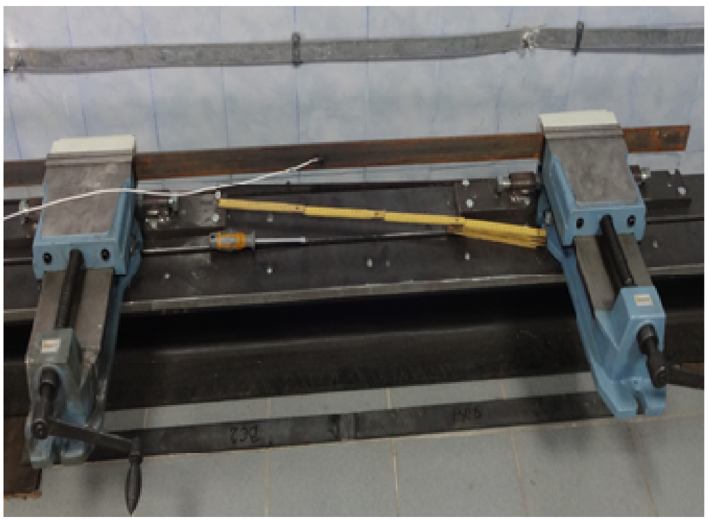

Figure 1. Frequency measurement on the healthy beam

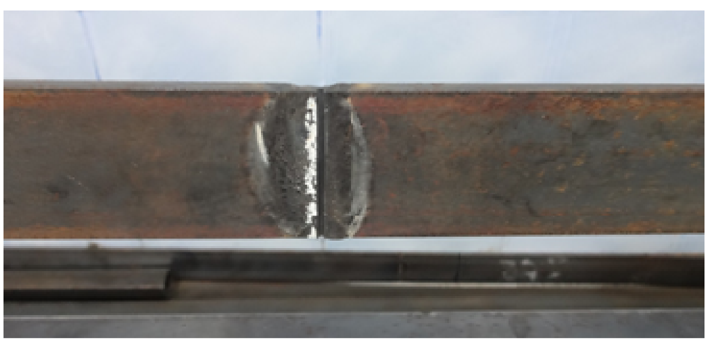

Figure 2. Frequency measurement on the beam with welding defect

The measurement results were centralized, analysed and compared. To detect and locate the defect, a procedure developed within the researches undertaken by the Doctoral School of "Eftimie Murgu" University from Resita, has been used. This process involves measuring the natural frequencies for the first six modes of vibration, based on the change in natural frequencies for the above-mentioned analysis cases.

3. Results and discussion

For each stage of the scenario mentioned in the previous chapter, six sets of measurements were performed and the frequencies of the first six vibration modes were calculated using the arithmetic mean of the measured values.

Table 1 presents the measurement results performed on the healthy beam, and Tabs. 2 - 6 show the values for the welded beam with weld defects at the root, located at 0,5L, 0,4L, 0,3L, 0,2L and 0,1L. The tables also present the computed natural frequencies and the deviations between the average of the measurement results and the computed natural frequencies.

Table 1. Results of frequency measurement on the healthy beam

Measurement no.	Vibration mode					
	1	2	3	4	5	6
1	25,8051	71,8012	141,2341	231,3792	346,8814	486,5207
2	25,8312	71,3548	141,0699	232,4187	347,2230	486,3472
3	25,6631	71,5591	140,8524	232,5084	347,1098	487,3381
4	25,8011	71,6262	140,8869	232,5781	347,2481	487,1086
5	25,3485	71,7908	140,9115	231,9124	346,9198	487,2295
6	25,5981	71,7154	141,2327	232,1171	347,0455	487,3135
Average	25,6245	71,6413	141,0312	232,1523	347,0713	486,9763
Computed	25,6264	71,7545	140,6270	232,5234	347,4483	485,4520
Deviation [%]	0,1878	0,1578	0,2875	0,1596	0,1085	0,3140

Table 2. Frequency measurement results on the beam with defect located at 0,5L

Measurement no.	Vibration mode					
	1	2	3	4	5	6
1	25,5517	70,8814	136,8517	230,1415	341,2854	481,2004
2	25,4184	71,1216	137,2153	230,8873	341,3615	480,6417
3	25,3483	71,0588	137,1018	231,6277	340,8893	481,0051
4	25,4011	71,2863	136,9452	231,2044	341,1544	481,6762
5	25,4394	70,9438	136,8884	230,5117	340,9311	480,7189
6	25,4158	71,2265	137,2001	230,8188	341,2143	481,4415
Average	25,4291	71,0864	137,0338	230,8652	341,1393	481,1140
Computed	25,3363	71,6424	137,5083	232,0063	339,4123	483,6187
Deviation [%]	0,3663	0,7761	0,3451	0,4918	0,5088	0,5179

Table 3. Frequency measurement results on the beam with defect located at 0,4L

Measurement no.	Vibration mode					
	1	2	3	4	5	6
1	25,6123	71,4153	138,0115	226,4471	347,6628	474,0888
2	25,6233	71,6124	138,2544	226,6389	347,4852	473,5642
3	25,7115	71,4552	138,2836	226,6448	348,5011	473,6611
4	25,7105	71,5058	137,9905	226,5899	347,6680	473,6820
5	25,6838	71,3159	138,1146	226,6201	348,2034	473,5155
6	25,6366	71,4442	138,2109	226,6385	347,8004	473,8017
Average	25,663	71,4581	138,1443	226,5966	347,8868	473,7189
Computed	25,4429	70,8485	139,8079	227,3932	346,2526	475,8215
Deviation [%]	0,8651	0,8605	1,1900	0,3503	0,4720	0,4419

Table 4. Frequency measurement results on the beam with defect located at 0,3L

Measurement no.	Vibration mode					
	1	2	3	4	5	6
1	25,8236	69,0113	137,4652	230,8115	341,0224	475,6642
2	25,8644	68,9277	137,6991	230,7254	340,7861	475,8137
3	25,8439	68,9756	137,7028	230,7793	340,7792	475,8811
4	25,7118	68,9524	137,5303	230,7188	340,8433	475,6925
5	25,7593	69,0203	137,7219	230,7647	340,7957	475,7333
6	25,7764	68,9178	137,6463	230,7887	340,7110	475,7748
Average	25,7996	68,9675	137,6276	230,7647	340,8230	475,7599
Computed	25,6883	69,9804	139,3298	231,5617	339,9992	477,5029
Deviation [%]	0,4215	1,4474	1,2217	0,3442	0,2423	0,3650

Table 5. Frequency measurement results on the beam with defect located at 0,2L

Measurement no.	Vibration mode					
	1	2	3	4	5	6
1	26,0046	70,1115	138,2202	226,6671	346,3144	480,3062
2	25,8489	69,8455	138,2814	226,9111	346,3213	480,4617
3	25,8716	70,2489	138,0403	226,8434	346,2865	479,9236
4	25,8435	70,2921	138,1044	226,8088	346,4041	480,2553
5	25,8476	69,9834	138,1867	226,8745	346,3991	480,2831
6	25,8801	70,1815	138,1644	226,8203	346,4263	480,3088
Average	25,8827	70,1105	138,1662	226,8209	346,3586	480,2565
Computed	25,8973	70,5783	137,1589	228,0728	344,8932	483,4015
Deviation [%]	0,0563	0,6628	0,7344	0,5489	0,4249	0,6506

Table 6. Frequency measurement results on the beam with defect located at 0,1L

Measurement no.	Vibration mode					
	1	2	3	4	5	6
1	25,6020	70,8356	137,2116	230,1552	338,4336	470,5581
2	25,5843	70,9771	137,4572	230,2074	338,6184	470,5685
3	25,6119	70,8437	137,4771	229,8399	338,6681	470,6127
4	25,6344	70,9182	137,3985	230,1105	338,2473	470,5899
5	25,5535	70,8644	137,4263	230,1593	338,4441	470,5787
6	25,6028	70,9002	137,2884	230,2007	338,3875	470,5611
Average	25,5982	70,8899	137,3765	230,1122	338,4665	470,5782
Computed	25,9408	71,4722	139,5907	229,2811	340,1749	473,0681
Deviation [%]	1,3209	0,8148	1,5862	0,3625	0,5022	0,5263

In addition, using the computed natural frequency deviation (*Af*) between the average of the measurement results and the computed natural frequencies (*f*), the coefficients for the location of the defects (CFD) have been determined, using the relation:

$$CLD_i = \frac{\left| \dfrac{Af_{i_{HB}} - Af_{i_{BD}}}{f_{i_{HB}}} \right|}{MAX\left(\left| \dfrac{Af_{n_{HB}} - Af_{n_{BD}}}{Af_{n_{BD}}} \right| \right)}, \tag{1}$$

where the used indexes have following meaning: *i* is the number of the vibration mode; *n* is the number of considered vibration modes (*n*=6); HB- healthy beam; BD- beam with welding defect.

Tables 7-11 present the deviations of the natural frequencies and the coefficients for the location of the defects obtained for the healthy beam and for the beam with welding defect respectively. For a better understanding of the obtained results, Figure 3 provide the graphical representations of the coefficients for the location of the defects for the investigated cases.

Table 7. Comparison healthy beam versus beam with defect located at 0,5L

Vibration mode i	Natural frequnecies [Hz]		Deviation A_f [%]	CLD
	HB	BD		
1	25,0762	25,4291	1,4073	1,0000
2	70,6163	71,0864	0,6657	0,4730
3	135,9718	137,0338	0,7810	0,5550
4	230,0702	230,8652	0,3455	0,2455
5	338,3969	341,1393	0,8104	0,5759
6	481,3589	481,1140	0,0509	0,0362

Table 8. Comparison healthy beam versus beam with defect located at 0,4L

Vibration mode i	Natural frequnecies [Hz]		Deviation Af [%]	CLD
	HB	BD		
1	25,0528	25,6630	2,4357	1,0000
2	69,7920	71,4581	2,3872	0,9801
3	139,2007	138,1443	0,7589	0,3116
4	226,4629	226,5966	0,0590	0,0242
5	344,4141	347,8868	1,0083	0,4140
6	475,4514	473,7189	0,3644	0,1496

Table 9. Comparison healthy beam versus beam with defect located at 0,3L

Vibration mode i	Natural frequnecies [Hz]		Deviation A_f [%]	CLD
	HB	BD		
1	25,3119	25,7996	1,9268	1,0000
2	69,3829	68,9675	0,5987	0,3107
3	138,9530	137,6276	0,9538	0,4951
4	229,5995	230,7647	0,5075	0,2634
5	339,3852	340,8230	0,4236	0,2199
6	476,7400	475,7599	0,2056	0,1067

Table 10. Comparison healthy beam versus beam with defect located at 0,2L

Vibration mode i	Natural frequnecies [Hz]		Deviation A_f [%]	CLD
	HB	BD		
1	25,5719	25,8827	1,2154	1,0000
2	69,8334	70,1105	0,3968	0,3265
3	136,9804	138,1662	0,8657	0,7123
4	226,7932	226,8209	0,0122	0,0100
5	343,6050	346,3586	0,8014	0,6594
6	481,9501	480,2565	0,3514	0,2891

Table 11. Comparison healthy beam versus beam with defect located at 0,1L

Vibration mode i	Natural frequnecies [Hz]		Deviation A_f [%]	CLD
	HB	BD		
1	25,8129	25,5982	0,8318	0,6205
2	70,9154	70,8899	0,0360	0,0268
3	139,2429	137,3765	1,3404	1,0000
4	228,8270	230,1122	0,5616	0,4190
5	339,2943	338,4665	0,2440	0,1820
6	472,9038	470,5782	0,4918	0,3669

As it can be observed, the damage location coefficients (CFD) are patterns [6] which allow locating, by means of vibration measurements, the crack on the welded structures, without taking into account its depth [7]. This method has been developed by the Doctoral School of "Eftimie Murgu" University from Resita.

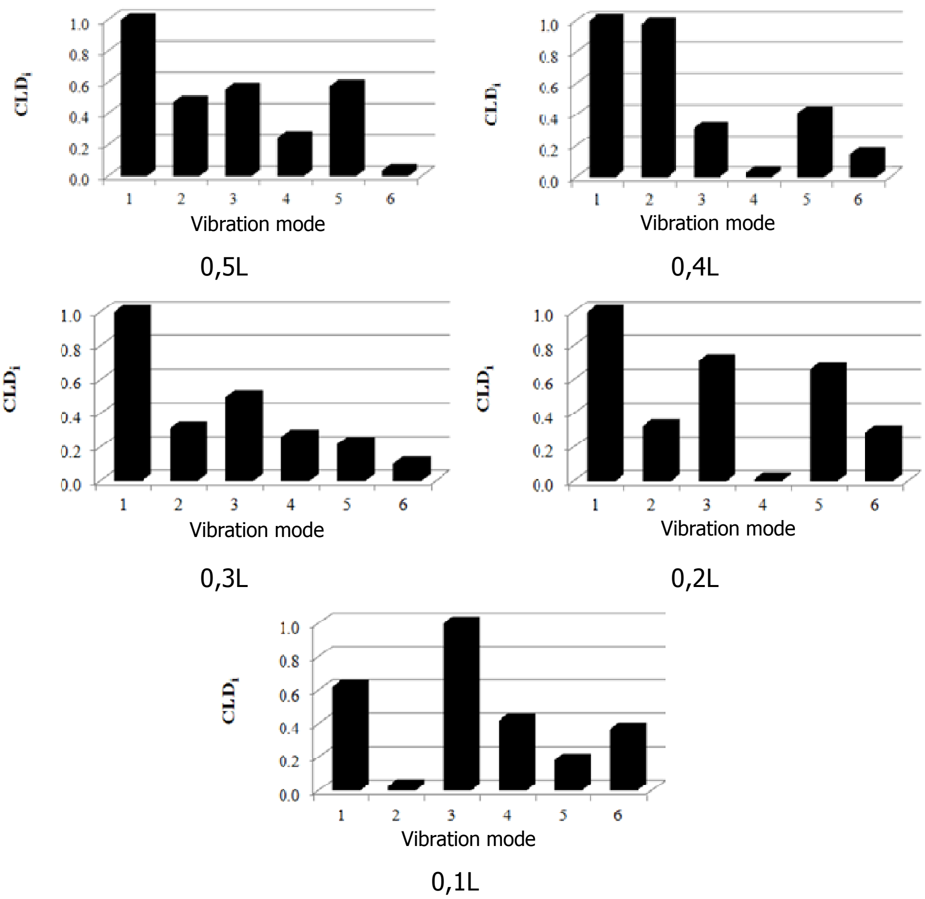

Figure 3. Damage location coefficients for the weld structure with a crack for various positions of the weld

4. Conclusions

It was shown in this study that damage location coefficients specially developed for butt weld joints can be successfully used for damage assessment purposes in the case of welded structures.

These coefficients should consider the rigidity and mass decrease due to damage, but also the mass increase due to the thickness increase in the weld area. This makes damage detection in welded structures more complex and request precise frequency evaluation.

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