Journal of POLISH CIMAC
Faculty of Ocean Engineering & Ship Technology
GDAŃSK UNIVERSITY OF TECHNOLOGY

STRUCTURAL ANALYSIS OF THE FAN SECTION OF THE AIR HANDLING UNIT ON DYNAMIC LOAD DEFINED BY SEISMIC SPECTRUM

Dariusz Skibicki, Michał Burak, Łukasz Pejkowski, Michał Piotrowski

University of Technology and Life Sciences in Bydgoszcz
Al. prof. S. Kaliskiego 7, 85-796 Bydgoszcz
e-mail: dariusz.skibicki@utp.edu.pl, mibu@utp.edu.pl

1. Introduction

The aim of the research was to obtain stress and displacement maps of the structure of the air handling unit under load caused by the earthquake with spectrum that is characteristic for the area of OLKILUOTO 3. On this basis, the critical points of the structure were identified and the strength of the structure was assessed.

The calculation model of the air handling unit was generally based on the Finite Element Method. Calculations were carried out in LS-DYNA software. A finite element model was created and the results have been developed in the LS-PREPOST software.

Regarding to the standard [1] the seismic effects and the effects of the other actions included in the seismic design situation may be determined on the basis of the linear-elastic behaviour of the structure and the method for determining the seismic effects is the Modal Response Spectrum Analysis.

Thus for the calculation of a response of the structure subjected to input spectrum load, such as the acceleration, Response Spectrum Computation Method implemented in LS-DYNA was used (keyword *FREQUENCY_DOMAIN_RESPONSE_SPECTRUM) [3]. The method is based on results of modal analysis of a structure, e.g. natural frequencies and modal shapes. The method assumes that a maximum structure response is a combination of natural frequencies and mode shapes of the structure using free vibration analysis.

Two methods of combination of modes were used: Square Root of Sum of Squares (SRSS) and the complete quadratic combination (CQC), (parameter MCOMB : EQ.0 for SRSS method, EQ.2 for Complete Quadratic Combination method (CQC) [3]. For models with closely spaced mode shapes, the CQC method is precise whereas faster SRSS method estimates less accurate results [2]. The case which gave greater stress has been selected.

2. Structure modeling

The finite element model of the Air Handling Unit adequately represents the distribution of stiffness and mass so that all significant deformation shapes and inertia forces are properly accounted for under the seismic action considered. The model also accounts for the contribution of joint regions to the deformability of the Unit. Non-structural elements, which may influence the response of the primary seismic structure, are also accounted for.

Parts made of angles, shapes and sections or sheet metal plates were modeled via a shell elements, see Fig. 1, 2. Volumetric parts, such as e.g. a fan, have been modeled by solid elements.

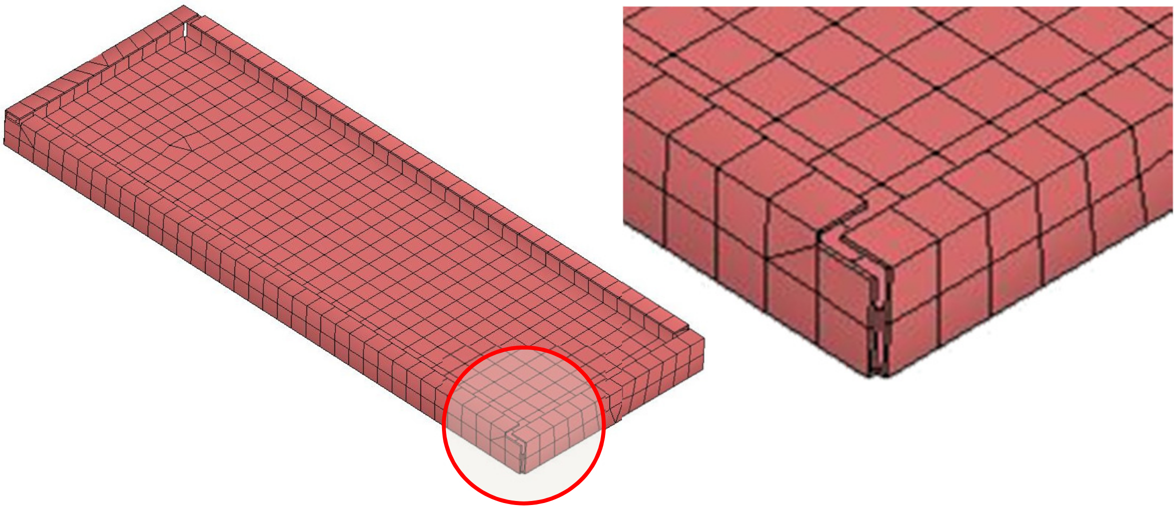

Fig. 1. Membrane type parts

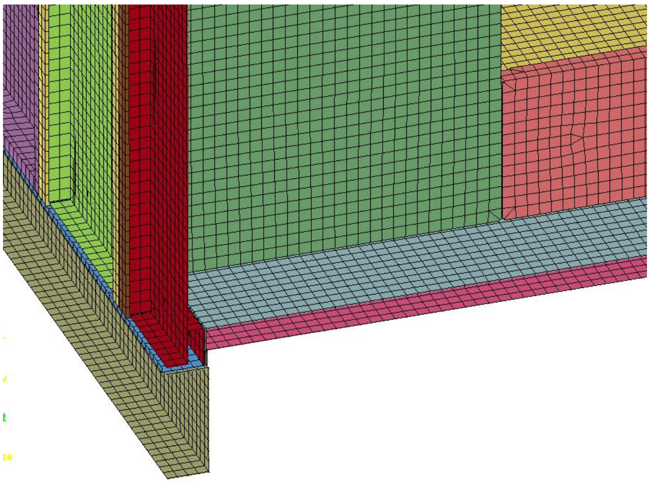

Fig. 2. Part assemblies

Screw connections between sheet metal parts were modelled using solid elements and special kind of part contacts implemented in LS-DYNA by *CONTACT_SPOTWELD command [3], Fig. 3. Welded joints were modelled using a special type of LS-DYNA contact between parts by *CONTACT_TIED_SHELL_EDGE_TO_SURFACE command [3], Fig. 4. Both doors were fitted with rigid connections in places of three hinges and door locks by *CONSTRAINED_NODAL_RIGID_BODY keyword [3]. The structure has been modelled taking into account all geometric interaction between the elements (contacts) using *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE keyword [3].

Total number of parts of the structure is 71, not counting connections of elements (screws) and the fan assembly. The complete finite element model were consisted of 144'016 fully integrated linear assumed strain shell elements and 5'162 constant stress solid elements, Fig. 5.

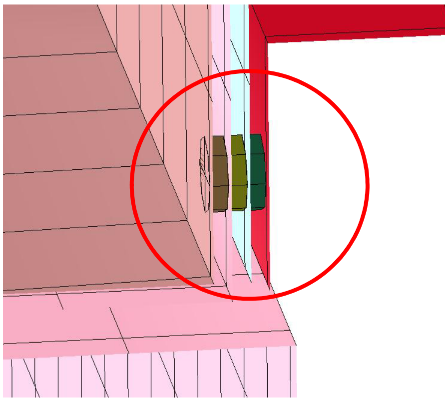

Fig. 3. Screw connection

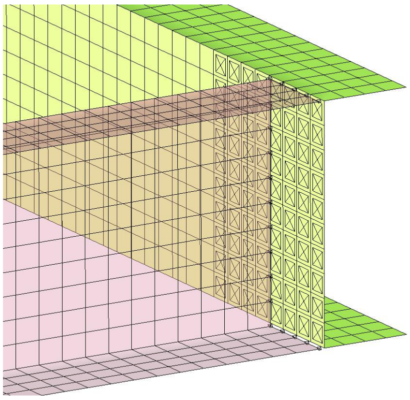

Fig.4. Welding connection

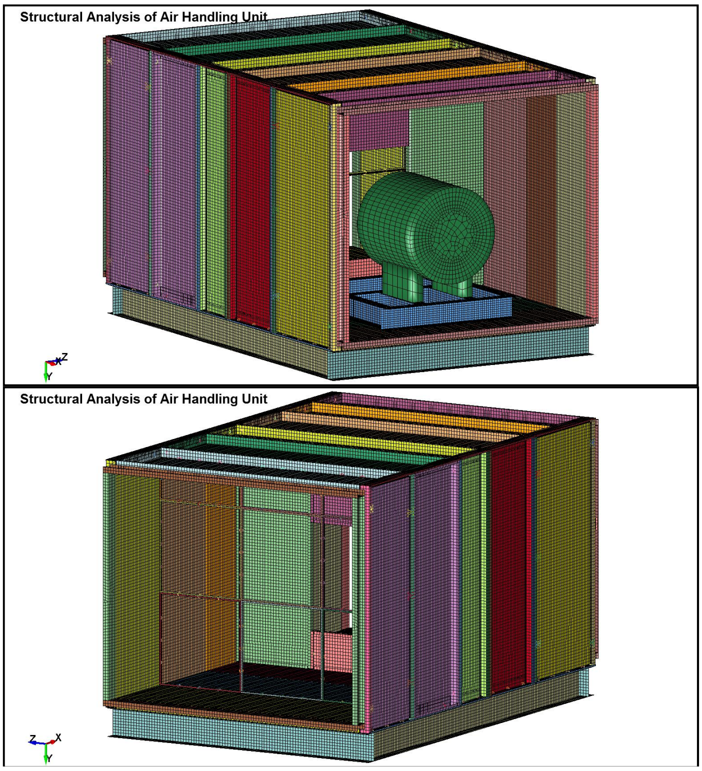

Fig. 5. Complete finite element model of the structure

3. Boundary conditions

Mounting the unit to the ground was modeled by means of withdrawal of all translational and rotational degrees of freedom of nodes lying on the lower surface of the base C-shapes , Fig. 6.
A load in the form of spectrum was applied to the ground in the direction of the smallest stiffness of the air handling unit, i.e. in axis Z. The input spectrum was defined as an acceleration function from frequency, Fig. 7.

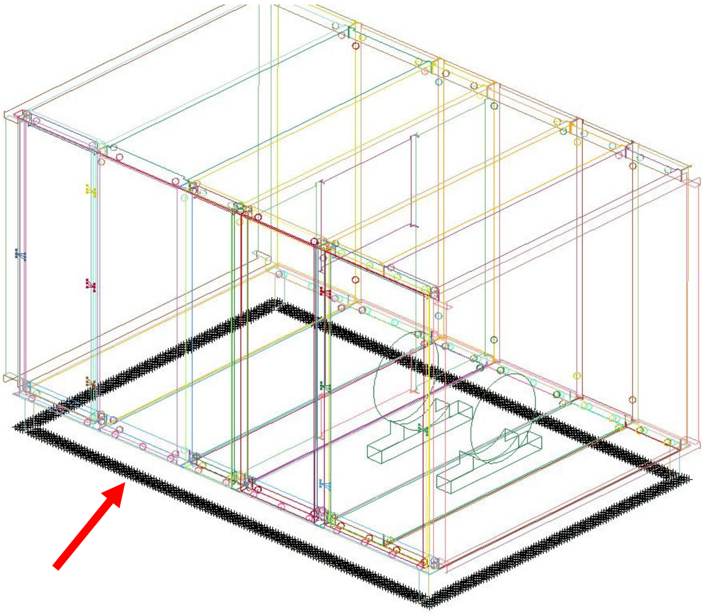

Fig. 6. Boundary conditions

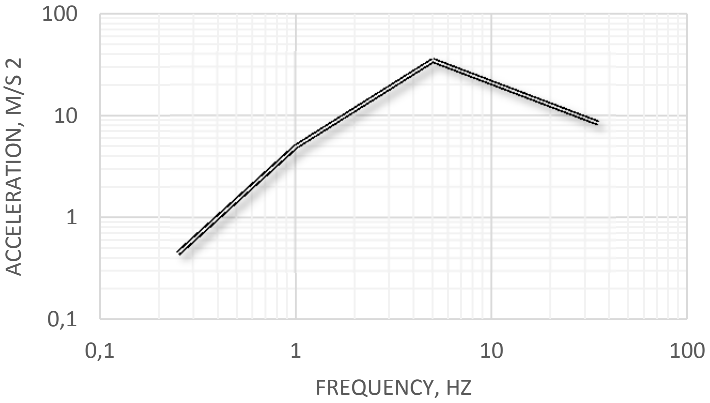

Fig. 7. Input load spectrum

4. Results

4.1. Modal analysis

As a result of modal analysis first 100 frequencies and mode shapes were calculated, Table 1. The examples of the mode shapes (in the form of displacements) are presented at the Fig. 8 – 11.

Table 1. First 100 modal frequencies

Mode	Frequency	Mode	Frequency	Mode	Frequency	Mode	Frequency	Mode	Frequency
1	7.59	21	24.66	41	32.67	61	38.47	81	43.43
2	8.90	22	24.68	42	32.98	62	38.59	82	43.44
3	15.28	23	25.20	43	33.05	63	38.59	83	44.06
4	15.32	24	25.91	44	33.16	64	38.61	84	44.22
5	15.34	25	26.00	45	33.21	65	39.44	85	44.60
6	17.01	26	26.16	46	33.73	66	39.46	86	46.17
7	17.02	27	26.72	47	34.46	67	39.94	87	46.19
8	17.04	28	28.21	48	34.70	68	40.26	88	46.30
9	18.03	29	28.47	49	34.73	69	40.76	89	46.47
10	18.24	30	28.69	50	34.80	70	41.04	90	46.47
11	19.19	31	28.90	51	35.01	71	41.11	91	46.49
12	19.40	32	29.64	52	35.14	72	41.22	92	46.55
13	20.06	33	30.10	53	35.90	73	41.23	93	46.55
14	20.07	34	30.84	54	36.25	74	41.25	94	46.57
15	20.09	35	30.84	55	37.20	75	41.29	95	46.60
16	20.54	36	30.85	56	37.32	76	41.31	96	46.65
17	22.70	37	30.86	57	37.35	77	41.36	97	46.88
18	23.90	38	30.95	58	37.41	78	42.76	98	47.10
19	23.94	39	31.14	59	37.93	79	43.34	99	47.47
20	24.66	40	32.56	60	38.35	80	43.36	100	47.86

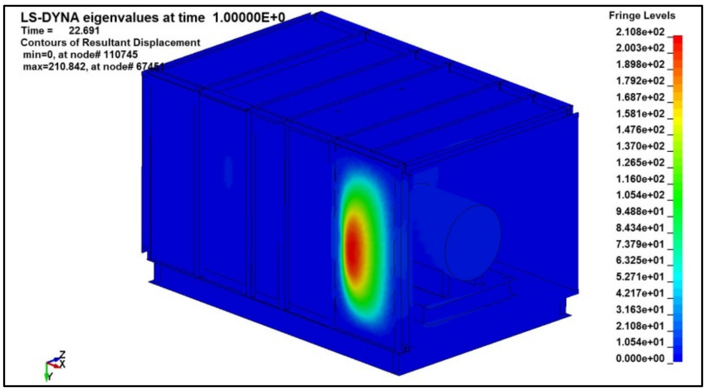

Fig. 8. 10th mode shape

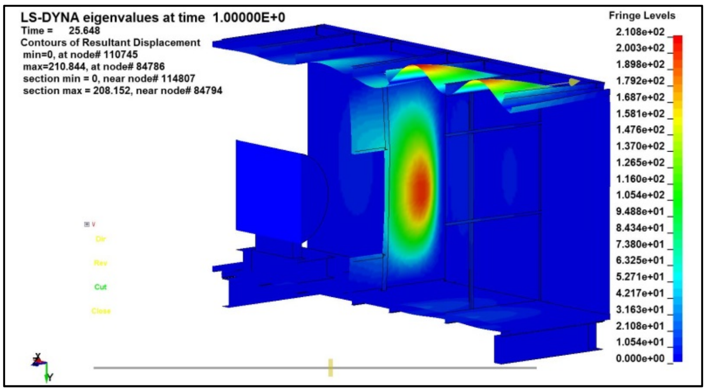

Fig. 9. 11th mode shape

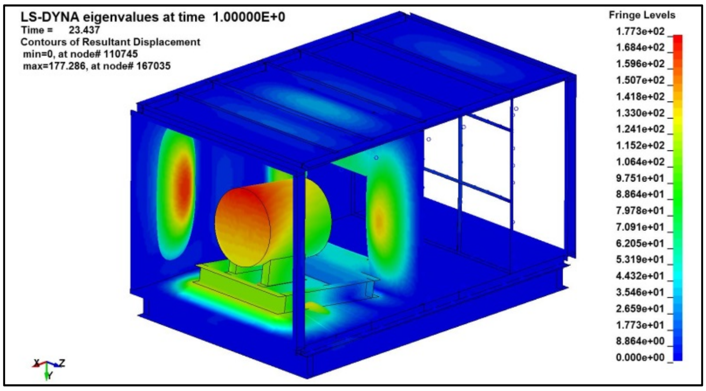

Fig. 10. 13th mode shape

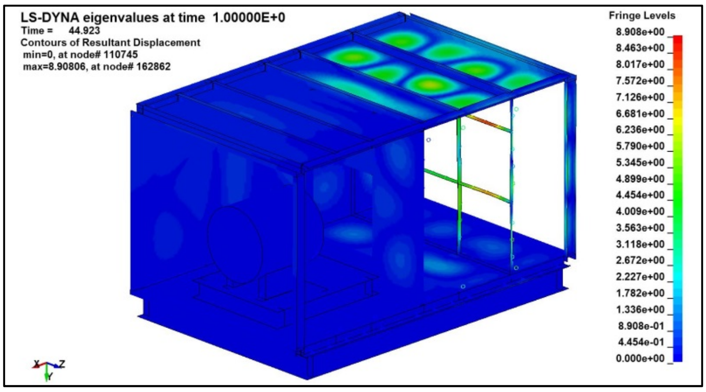

Fig. 11. 82th mode shape

4.2 Response of the structure to the load

The maximum response of the air handling unit subjected to input spectrum load was presented in the form of equivalent stress σ_HMH (Huber-Mises-Hencky) maps (Fig. 12).
To determine the strength of the structure the maximal equivalent stresses σ_HMH were compared with allowable stresses k. Allowable stresses were calculated according to the formula:

$$\sigma_{HMH} \le k = \frac{R_e}{x} \tag{1}$$

where: R_e – yielding stress, x – safety factor.
Calculated allowable stresses for structural wall, frames and screws are presented in the Table 2.

Table 2. Allowable stresses

Component type	**Yielding stress MPa**	**Safety factors**	**Allowable stresses MPa**
walls and frames	**235**	**1.5**	**k1 = 157**
screws	**640**	**1.5**	**k2 = 427**

The stresses in the frames and surfaces of membranes are of the order of several MPa's only, Fig. 12. Stresses in all critical points clearly satisfy the condition of strength, Table 3.

Table 3. Equivalent stresses in membrane parts

Point no.	Equivalent stress MPa	Allowable stresses MPa
61515	14.50	**≤ k1 = 157**
61516	14.48	
61514	11.70	
61517	11.50	

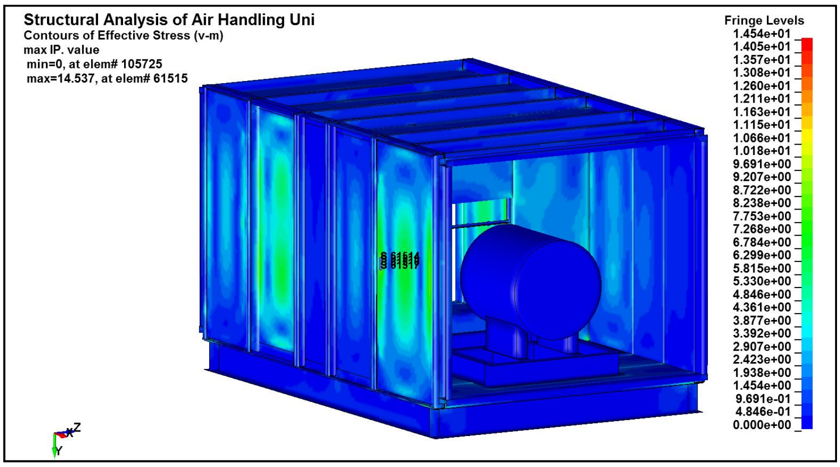

Fig. 12. Equivalent stresses in membrane parts

The highest values of stresses are in the bolts connecting the components. Location of the most loaded screws are shown in Fig. 13. Values of those stresses are given in Table 4.

Table 4. Stresses in the most loaded screws

Screw no.	Stresses MPa	Allowable stresses MPa
290	370.8	**≤ k2 = 427**
262	320.7	
307	319.0	
260	316.9	
139	314.1	
238	295.3	
310	288.2	
308	284.7	
289	272.0	
306	271.8	

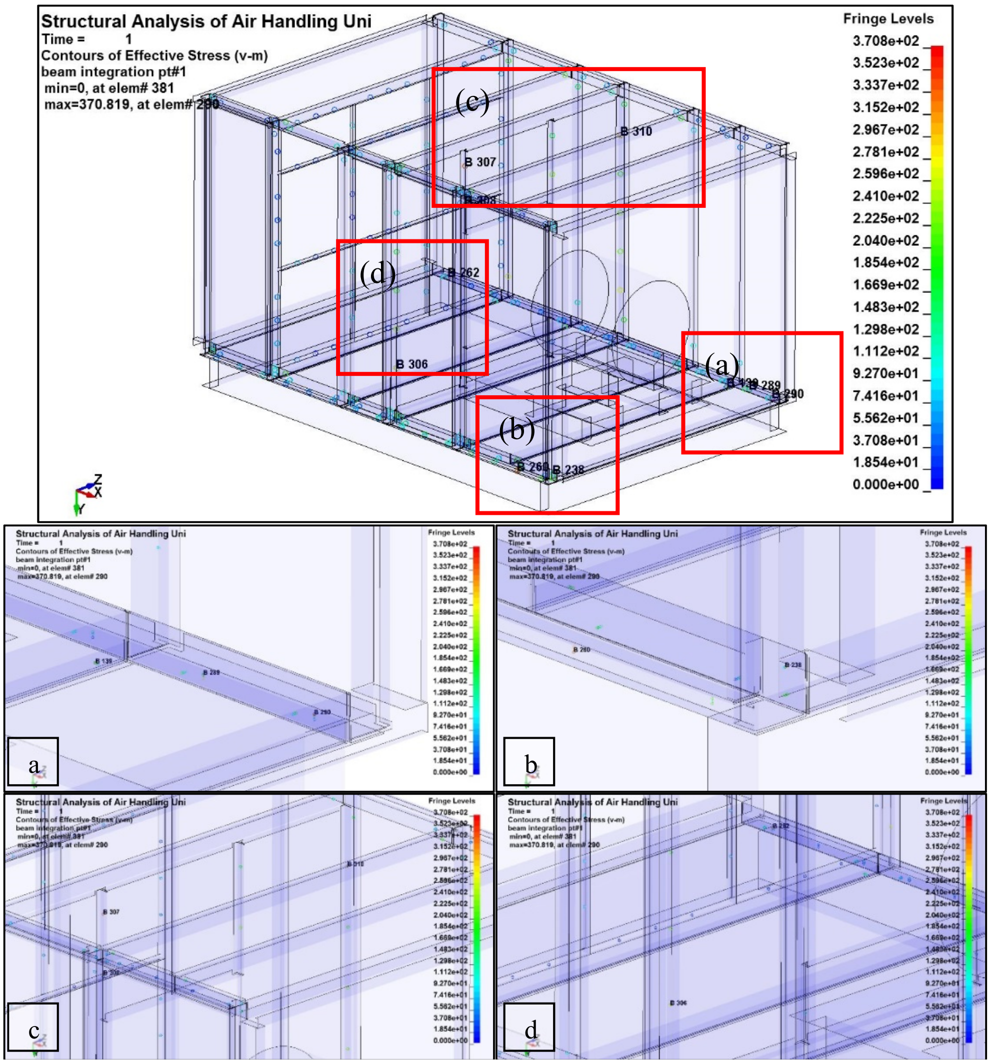

Fig. 13. Location of the most loaded screws

5. Conclusions

5.1. Conclusions about the structural analysis

1) The analysis showed which structural elements are most stressed and which are most deformed under load resulting from the earthquake.
2) Elements which are the most loaded are the screws. Sheet metal plates of the front doors are the parts which are the most deformed.
3) The stresses are in the elastic range and in all critical points satisfy the condition of strength.
4) Deflections of structure are very small and do not pose any threat to the stability of the structure. The strains are in the elastic range.

5.2. Conclusions about the calculation method

1) Since the stress values did not exceed the yield there is no need to use the Time History Method. Selected Response Spectrum Computation Method is entirely sufficient.

References

[1] EN 1998-1:2004 Eurocode 8: *Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings* EN 1998-1:2004 (E)

[2] Bavirisetty, R., Vinayagamoorthy, M., Duan, L., *Dynamic Analysis. Bridge Engineering Handbook*. CRC Press, 2000

[3] LS-DYNA Keyword *User's Manual Volumes I and II*, August 2012, Version 971 R6.1.0, Livermore Software Technology Corporation