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STRUCTURAL DESIGN OF A BILLBOARD SUPPORTING STRUCTURE

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Abstract: *This paper aims to evaluate the stresses and displacements of a three sided unipole billboard using the finite element analysis software ANSYS Workbench and various design codes. The main loads that act on this type of structure are its dead load, wind and snow which they are going to be multiplied by a number of factors and grouped together for the FEA simulation. The structures stability was analyzed with the Eigenvalue Buckling module of ANSYS Workbench. The seismic load was determined using the acceleration spectrum (acceleration vs frequency graph) specified in the Romanian design code for Galati county area. The objective of this study is to check if the von Mises stresses which resulted from the FEA analysis are within the limit yield strength of the material that was selected for the structure.*
Keywords: *ANSYS Workbench, wind load, seismic load, dead load, yield strength*

1. INTRODUCTION

Advertising panels are usually large structures that are placed to draw attention to a commercial good or to indicate locations of interest and are usually found in areas with heavy traffic or pedestrian traffic. The billboard format that will be analyzed in this paper is 8.3 x 2.2 m called Super 8. A Super 8 type panel will be found on a major highway or on the outskirts of a city. Advertising panels can also be used to reduce exposure to wind, rain or snow for sensitive equipment such as a telecommunications antenna or a public lighting fixture that can be located inside the structure. Part of the disaster cases involving billboards are due to very strong winds or tornadoes. In Europe between 1800 and 2014,a total of 9563 tornadoes were recorded, of which 74.7% of the tornadoes were classified as F0, [1] (low wind intensity tornadoes, between 104 km / h and 136 km / h for 3 seconds [2]), and in Romania, between 1990 and 2013, a total of 89 tornadoes were registered according to the following article [2]. But on continents such as North America, especially the central part, there were registered over 1253 tornadoes annually during the period 1991-2010 with an annual average of 37.5 tornadoes with intensity of F3-F5 [3] (violent wind intensity tornadoes, between 218 km/h and 321 km/h for 3 seconds [2]). Compared to much more affected areas, Romania is still experiencing disasters even with the low number of tornadoes recorded due to incorrect estimates of location or design.

2. GEOMETRY DESCRIPTION

The 3D CAD model of the structure was created with Design Modeler of ANSYS Workbench [4] using a variety of commands: Extrude, Point, Line from Points, Surface from Edges. The geometrical elements that shape the structure are: Points, Lines and Surfaces.

Table 1: Overall dimensions [5]

	Height [mm]	Length [mm]	Thickness[mm]
Column	14	ø800	8/7/6/5/5
Panels	2200	8300	2

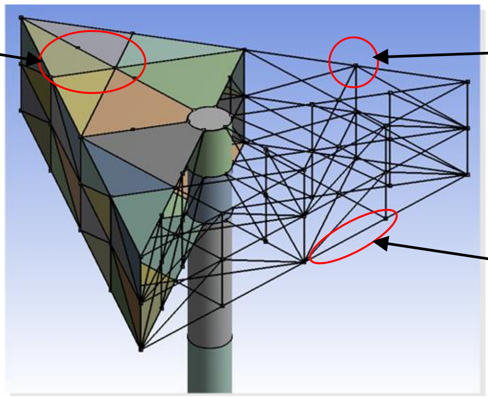

Figure 1: Inside view

The beam structure is generated out of line elements and it will be assigned with two types of profiles,I profiles[5] and a square tubular profiles[6].

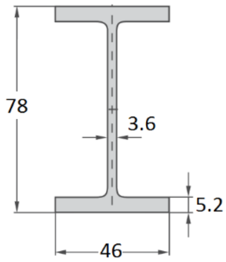

Figure 2: IPE80 [mm][5]

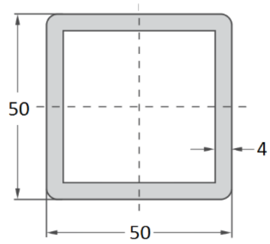

Figure 3: 50x50 [mm][6]

The material used for the analysis was S275 chosen from the designers' guide [7] with the following material properties:

Table 2: Properties of the material [7]

Yield strength [MPa]	Young's modulus [MPa]	Poisson's ratio
275	$2.1 \cdot 10^5$	0.3

3. GROUPING EFFECT OF LOADS

3.1. Wind load

The wind pressure that acts on the structure was determined with Fluid Flow CFX module. The wind speed that was loaded in the CFX simulation was calculated using the Romanian design code [8].
The structure was analyzed in three separate cases: Case 1, when the wind acts in front of the structure, Case 2 when it acts on the back and Case 3 on the side of the structure.

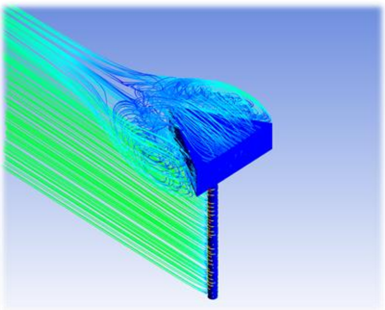

Figure 4: Front wind vectors

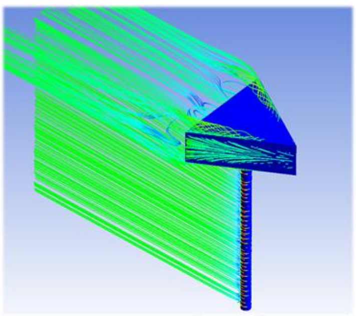

Figure 5: Back wind vectors

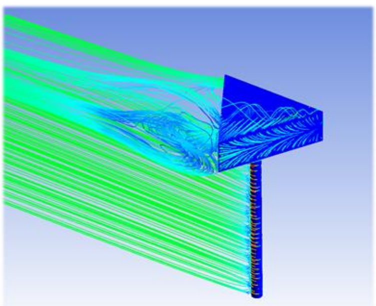

Figure 6: Side wind vectors

The reference value of wind speed v_b is worked out from the dynamic wind pressure q_b, which is specified in the reference values map for wind pressure.

$$q_b = \frac{1}{2} \cdot \rho \cdot v_b^2 \quad (1)$$

The reference wind speed value is:

$v_b = 30.983\ m/s$

The peak value of the wind speed $v_p(z)$ was calculated further using the reference wind speed value:

$v_p(z) = 40.478\ m/s$

The peak value of the wind speed is used in CFX simulation to evaluate the pressure on the structure.

3.2. Snow load

The snow load was calculated for the persistent / transient design situation according to the coefficients from the design code[8]:

$$s = \gamma_{ls} \cdot \mu_i \cdot C_e \cdot C_t \cdot s_k \quad (2)$$

Where:

- $\gamma_{ls} = 1$ is the factor of exposure for the action of the snow.
- $\mu_i = 0.8$ is the shape coefficient of snow load.
- $C_e = 0.8$ is the location exposure coefficient of the structure.
- $C_t = 1$ is the thermal coefficient.
- $s_k = 2.5\ kN/m^2$ is the snow load characteristic value on the ground.

The snow load for the persistent / transient design situation is:

$s = 1.6\ kN/m^2$

3.3. Factors of grouping effect of loads

The factors of grouping effect of loads:dead load,wind and snow are calculated with the following equation from the design code[8]:

$$1.35 \sum_{j=1}^{n} G_{kj} + 1.5V_k + (1.5 \cdot 0.7)Z_k \quad (3)$$

- G_{kj} is the value of permanent loads on the structure.
- Z_k is the value of snow load on the structure.
- V_k is the value of wind load on the structure.

The primary load that act on the structure is the wind load.

The dead load value resulted from the ANSYS software is multiplied by a factor of 1.35.

$9.8066 \cdot 1.35 = 13.243\ m/s^2$

The value calculated for the snow load is multiplied by $(1.5 \cdot 0.7)$.

$1600 \cdot (1.5 \cdot 0.7) = 1680$ Pa

The value for pressure resulted from the Fluid Flow CFX analysis is multiplied by a factor of 1.5.

$1072 \cdot 1.5 = 1608$ Pa

Values multiplied by the factors of grouping effects are then loaded in the FEA simulation to evaluate the static results.

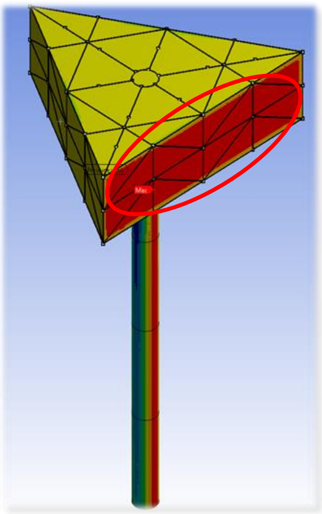

Figure 7: Wind load

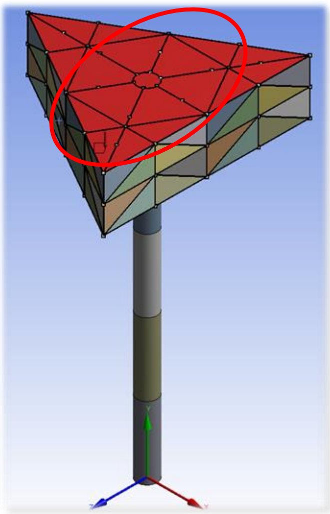

Figure 8: Snow load

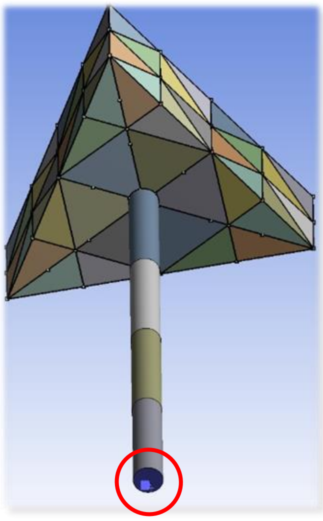

Figure 9: Fixed Support

4. VIBRATION

4.1. Free vibration of the structure

The free vibration of the structure was calculated with the Modal module of ANSYS Workbench. The software was set to solve for the first 12 frequency modes.

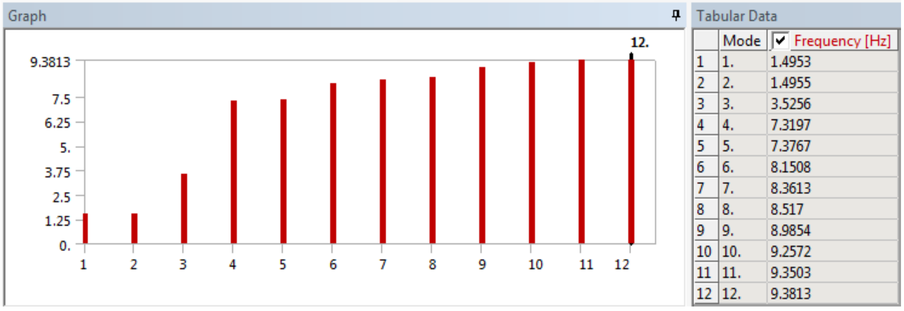

Figure 10: Frequency modes

The mass participation factors of the analysis are 0.870473 for X direction and 0.872151 for Z direction. The seismic load will act on X and Z direction, Y direction is of little significance in this analysis.

4.2. Variation of acceleration vs frequency graph

The acceleration vs frequency graph is calculated using the seismic design code [9].

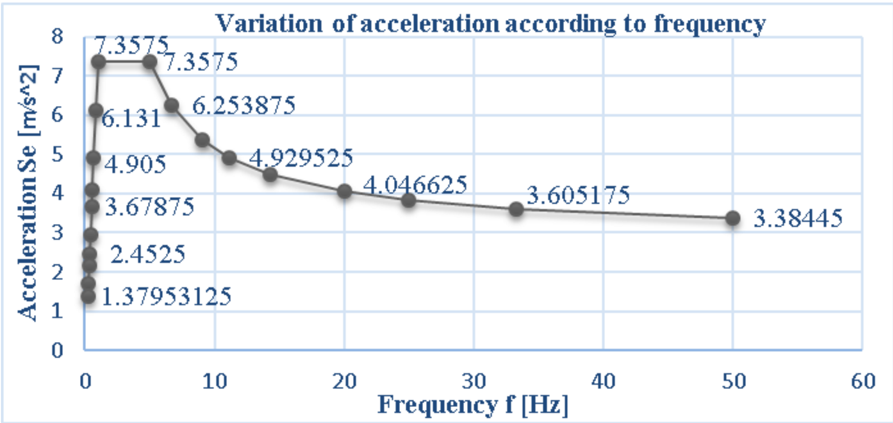

Figure 11: Variation of acceleration vs frequency

The graph was calculated with the elastic response spectrum of absolute acceleration for the horizontal components of the terrain $S_e(T)$ in $\mathrm{m/s^2}$.

$$S_e(T) = a_g \cdot \beta(T) \tag{4}$$

- a_g is the value of terrain acceleration selected for the region.
- $\beta(T)$ is the normalized elastic response spectrum of acceleration for the fraction of critical damping $\xi = 0.05$.

The variation of acceleration vs frequency values have been uploaded to Response Spectrum module in ANSYS to calculate the stresses and displacements of the structure.

5. BUCKLING ANALYSIS

The buckling modes of the structure have been determined using the Eigenvalue Buckling module of ANSYS Workbench[4]. The first 10 buckling modes are calculated for each of the three load cases.

Table 3: Buckling modes

Buckling mode	Case 1	Case 2	Case 3

1.	4.1022	5.0867	3.5846
2.	4.4174	5.6225	3.7679
3.	4.5073	5.8035	3.9678
4.	4.896	6.5039	4.7195
5.	6.4262	9.3023	5.3087
6.	6.8757	10.22	5.966
7.	7.0595	11.095	6.1607
8.	7.6519	12.433	6.1737
9.	8.9483	12.873	6.3954
10.	9.2309	15.628	6.5472

The structure will not buckle if the first buckling mode is greater than 1.Case 3 in which the wind acts on the side of the structure is most likely to buckle first.

6. CONCLUSION

6.1. Grouping effect of loads results (static results)

The maximum equivalent stresses are found at the base of the column for all three cases. The first case when the wind acts on the front of the structure is the most unfavorable of the three cases analyzed.

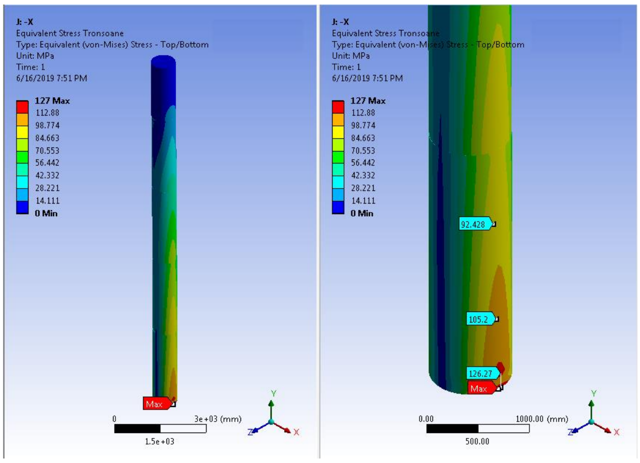

Figure 12: Case 1 equivalent von mises stresses

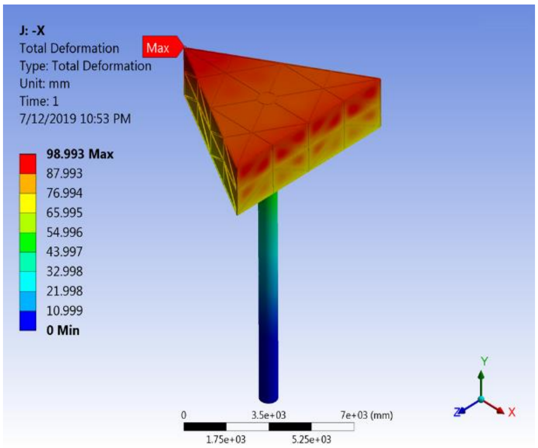

Figure 13: Case 1 maximum displacement

Table 4: Static load results

Case	Max Equivalent Stress [MPa]	Maximum Displacement [mm]
Case 1	127	90.983
Case 2	73.333	56.102
Case 3	106.05	87.665

6.2. Seismic results

The maximum equivalent stress between all of the load cases are within 1≅2[MPa] of each other, and the maximum displacement of the structure has the same value for all three cases.

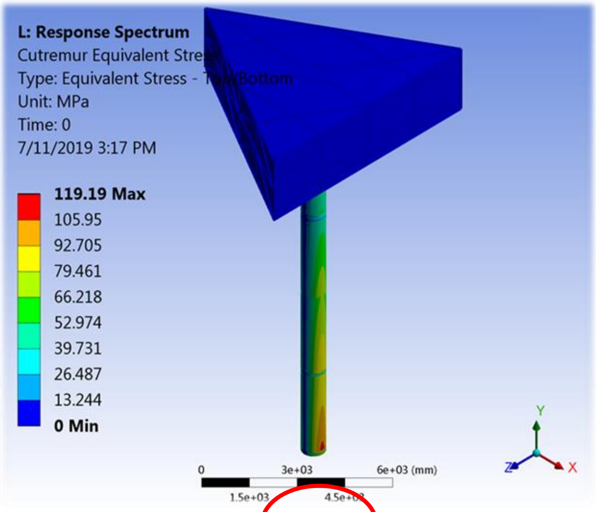

Figure 14: Case 1 maximum stress

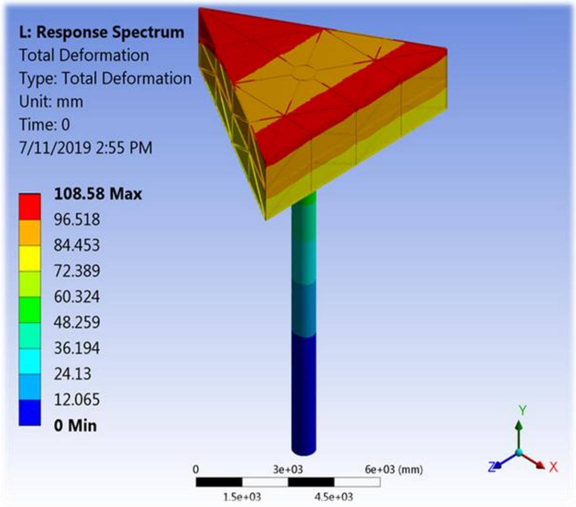

Figure 15: Case 1 maximum displacement

Table 5: Seismic results

Case	Max Equivalent Stress [MPa]	Maximum Displacement [mm]
Case 1	119.19	108
Case 2	117.81	
Case 3	118.08	

To verify if the structure withstands the combination of static and seismic loads, the equivalent maximum stress of static and seismic load are summed and the sum is compared to the yield strength of the structures material. The sum of the stresses is valid only because both von mises stresses are found in the same geometrical location(base of the structure).

Table 6: Seismic + static load stresses

Case	Max Equivalent Stress [MPa]	Material yield strength [MPa]
Case 1	246.19	**< 275**
Case 2	191.143	
Case 3	224.13	

The first case has the largest surface area which the wind acts on and for this reason it is the most unfavourable case out of the three cases. Therefore case 2 when the wind acts on the back of the structure experienceses the least equivalent stress due to small surface area. In conclusion the maximum equivalent stresses for all three cases are below the material yield strength which proves the structure won't collapse in the event of an earthquake excitation, wind or snow load.

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