Project Title:	VB-9
Report:	Finite element analysis and verification against wind pressure
Client:	GENERAC MOBILE PRODUCTS Srl
Date:	07/12/2016

Dipartimento di Ingegneria Civile e Architettura – Università di Pavia
Via Ferrata, 1 – 27100 Pavia
Tel +39 0382 985450 – Fax +39 0382 985589

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1. INTRODUCTION AND WIND ACTION MODELING

This report is concerned with the finite element analysis and the verification against the wind action of the VB-9 by Generac Mobile Products srl. For the geometric and physical properties of the structure reference is made to the drawing *Layout VB-9* made available by Generac Mobile Products srl. As to the wind action, and more generally to the adopted design rules, the *Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions* have been adopted (*EC1* for brevity sake hereinafter). The fundamental value of the basic wind velocity (Eq. 4.1, *EC1*) was indicated by Generac Mobile Products srl:

$$v_{b,0} = \mathbf{110} \text{ km/h } = \mathbf{30.56} \text{ m/s.}$$

The basic wind velocity writes

$$v_b = c_{dir} \cdot c_{season} \cdot v_{b,0} = v_{b,0},$$

since $c_{dir} = c_{season} = 1$ have been assumed following *EC1*. The mean wind velocity at a height z may then be computed as (Eq. 4.3, *EC1*)

$$v_m(z) = c_r(z) \cdot c_0(z) \cdot v_b,$$

where the orography factor is chosen to be $c_0(z) = 1$ according to *EC1*. As to the roughness factor $c_r(z)$, Equation 4.4 in *EC1* reads

$$c_r(z) = \begin{cases} k_r \ln \dfrac{z}{z_0} & z_{min} \le z \le z_{max} \\ c_r(z_{min}) & z < z_{min} \end{cases}.$$

The quantities z_0 and z_{min} are given in Table 1,

Terrain category		z_0 m	z_{min} m
0	Sea or coastal area exposed to the open sea	0,003	1
I	Lakes or flat and horizontal area with negligible vegetation and without obstacles	0,01	1
II	Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	0,05	2
III	Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)	0,3	5
IV	Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m	1,0	10
NOTE: The terrain categories are illustrated in A.1.			

Table 1 – Terrain categories and terrain parameters (Table 4.1 in EC1)

where the terrain factor depending on the roughness length z_0 is calculated using

$$k_r = 0.19\left(\frac{z_0}{z_{0,II}}\right)^{0,07},$$

and $z_{0,II} = 0,05$ m. The terrain category III is assumed in the calculations to follow, i.e.

$$z_0 = 0.3 \text{ m}, \; z_{min} = 5 \text{ m}.$$

The wind turbulence intensity $l_v(z)$ reads (Eq. 4.7 *EC1*)

$$l_v(z) = \begin{cases} \dfrac{k_I}{c_o(z)\cdot ln\left(z/z_0\right)} & z_{min} \le z \le z_{max} \\ l_v\left(z_{min}\right) & z < z_{min} \end{cases},$$

where $k_I = 1.$ Eventually, the <u>peak velocity pressure</u> may be computed as (Eq. 4.8 *EC1*)

$$q_p(z) = [1 + 7l_v(z)]\frac{1}{2}\rho v_m^2(z) \text{ [Pa]},$$

where $\rho = 1.25$ kg/m^3 is the air density. Relevant values are shown in Figure 1 and Table 2.

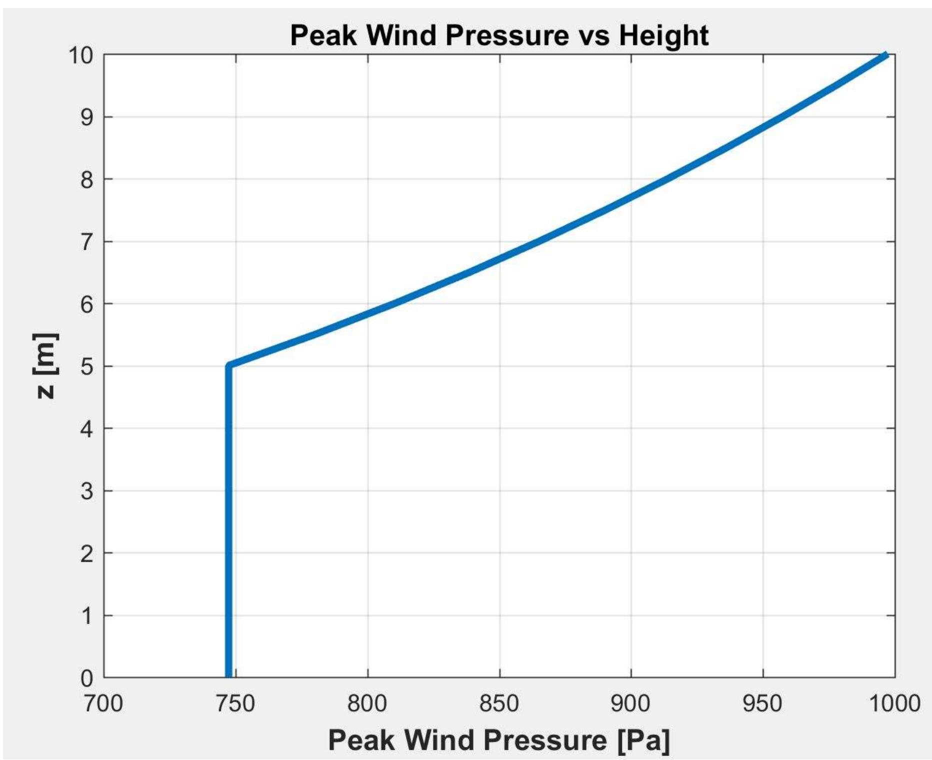

Figure 1 – Peak wind pressure vs Height

Height [m] vs Peak wind pressure [Pa]	
0	747.42
5.00	747.42
5.50	780.24
6.00	810.64
6.50	838.96
7.00	865.49
7.50	890.46
8.00	914.05
8.50	936.42
9.00	957.69
9.50	977.97
10.00	997.36

Table 2 – Peak wind pressure vs height

2. THE FINITE ELEMENT MODEL

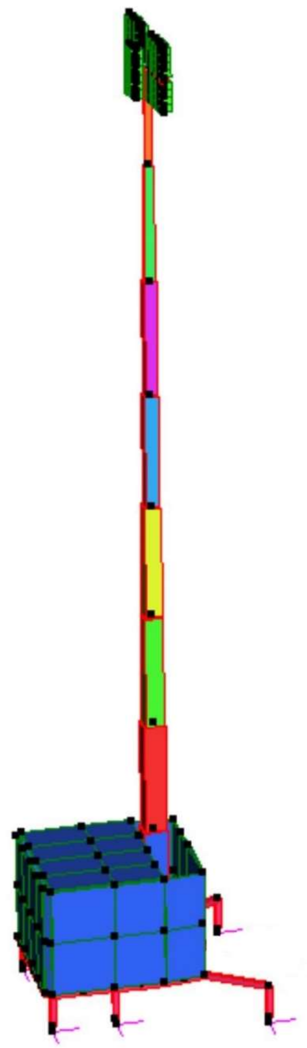

Figure 2 – A 3D view of the finite element model

The main feature of the 3D finite element model, see Figure 2, are as follows:

- Beam elements are used to model the deployable structure on which lamps are mounted;
- Beam elements are used to model the deployable supports as well as the wheel supports;
- Plate elements are used to model lamps themselves as well as the structural basis structure. Lamps and basis structure self-weight are applied to the structure as given external loads as indicated by Generac Mobile Products srl, see Figure 3.

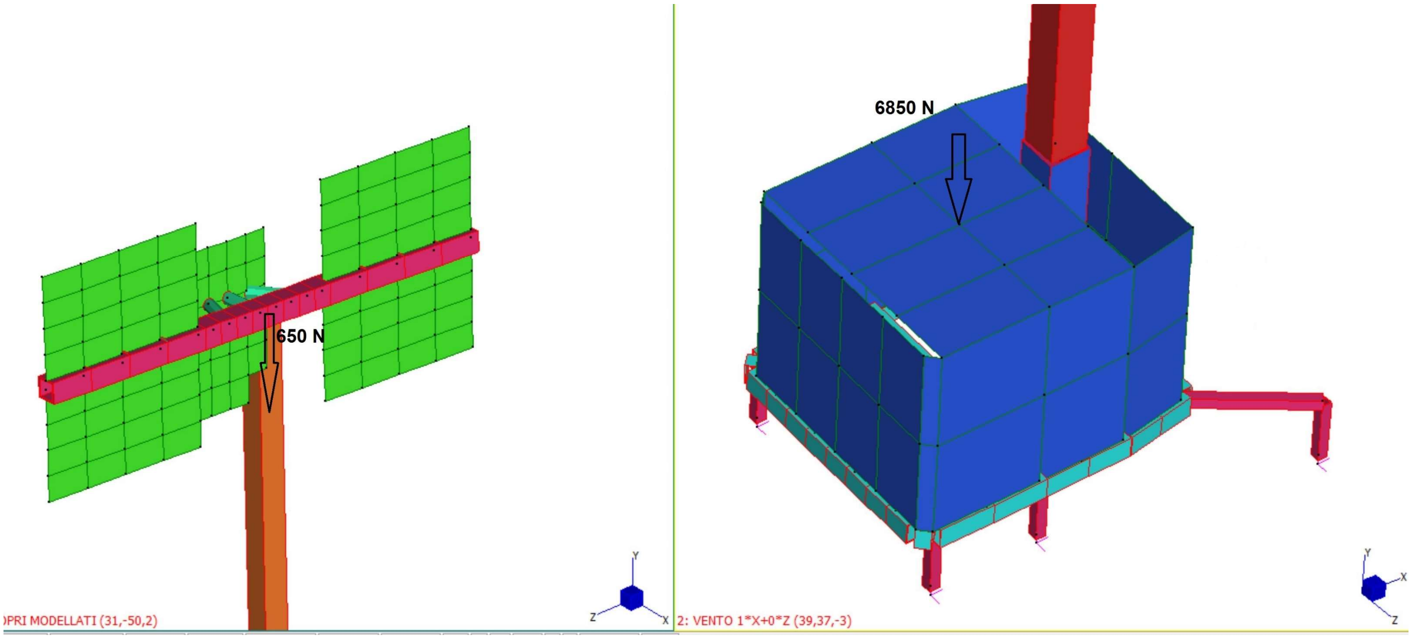

Figure 3 – Concentrated self-weight loads

- Nonlinear constraints with friction are adopted as to the connections to the ground of the lateral stabilizers and the wheels. As a matter of fact, the real structure is acted upon by no ideal horizontal constraints against the wind action but the friction due to the supports, that include the bases of the deployable arms, the wheels and the base. An elastic-plastic 2D friction model with friction coefficient $f = 0.5$ is used in the computations.

Notice that the front wheel was not explicitly modeled since its mechanical resistance do not seem to be adequate to participate the overall resisting mechanism of the supports.

An incremental nonlinear analysis is then performed wherein vertical loads (basically self-weights) act with full intensity since the first iteration whereas the wind load is increased in a stepwise fashion until the final design value is reached. In what follows the overall wind load has been applied in ten steps of equal intensity.

3. NUMERICAL RESULTS AND VERIFICATIONS

3.1 *Displacement response*

The maximum displacement on top of the resisting structure is found to be $u_{max,x} = 82.28$ mm. Upon normalizing to the global height of the structure, $H = 8318$ mm, the displacement-to-height ratio is found to be

$$\frac{u_{max,x}}{H} = \frac{82.28}{8318} = 9.89 \times 10^{-3}.$$

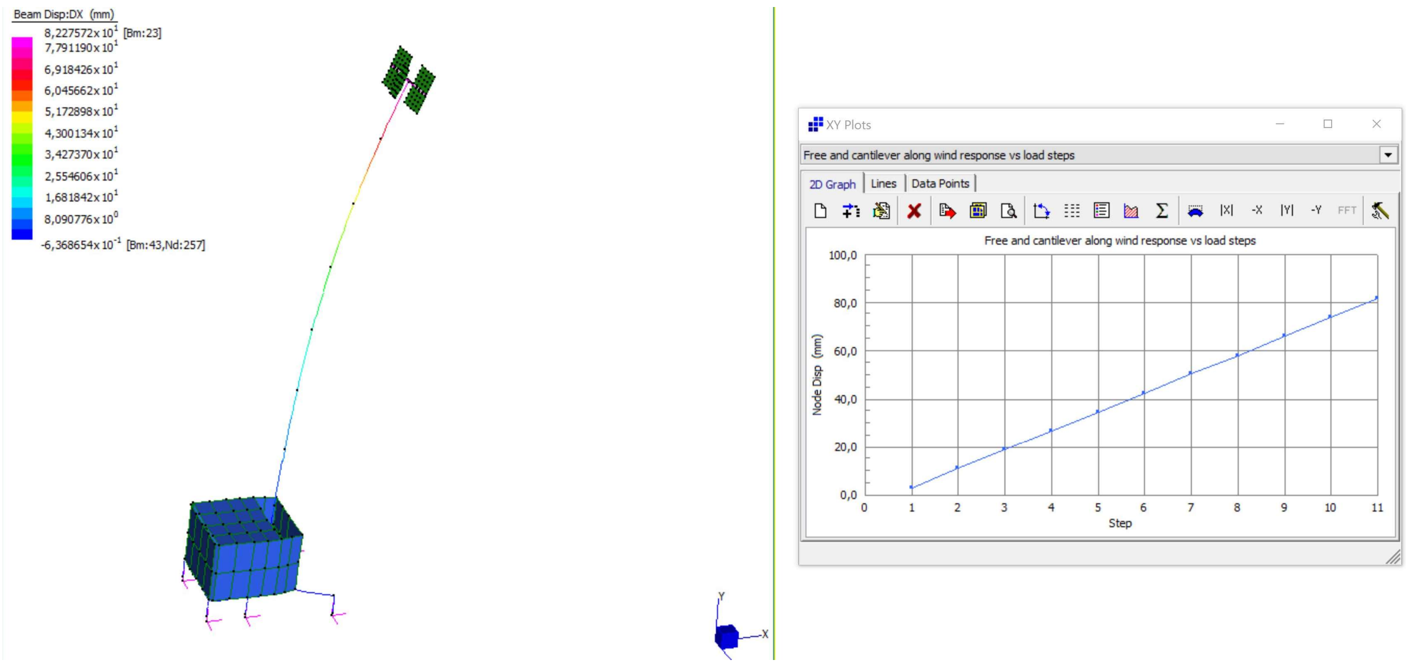

Figure 4 – Along wind displacement response. (Left) Magnified deformed shape – (Left) Free end displacement vs load steps

The displacement-to-height ratio is smaller than one per cent that should be considered an acceptable value.

3.2 *Stress analysis and strength of materials*

The stress map along the cantilever structure supporting the lamp is shown in Figure 5 below.

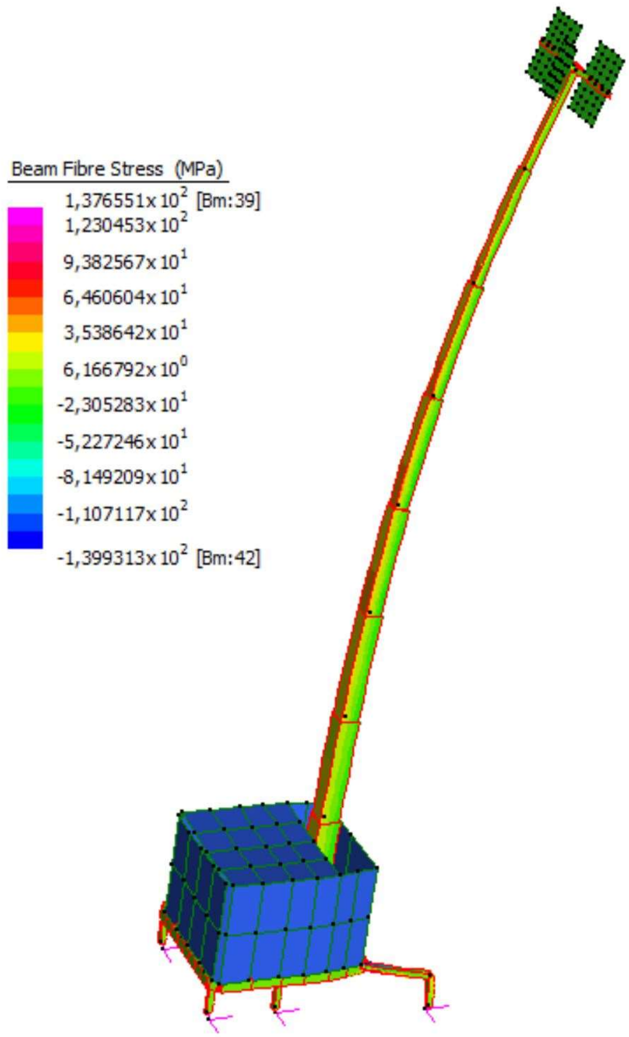

Figure 5 – Stress variation along the cantilever structure (full wind action)

The maximum stress value is found to be $\sigma_{max} = \mathbf{137.66}$ MPa that is smaller than the steel yield stress. Also this verification should therefore be considered positive.

3.3 *Support reactions mechanism to resist the wind pressure load*

Figure 6 shows the support vertical reactions for full wind pressure load. All supports reactions point upward thus ensuring that the reacting system is capable to successfully resist the overall wind action. Reaction values are reported in Table 3.

Left reactions [kN]	Wheel reactions [kN]	Right reactions [kN]
0.461	2.309	4.05

Table 3 – Magnitude of vertical support reactions at full wind action

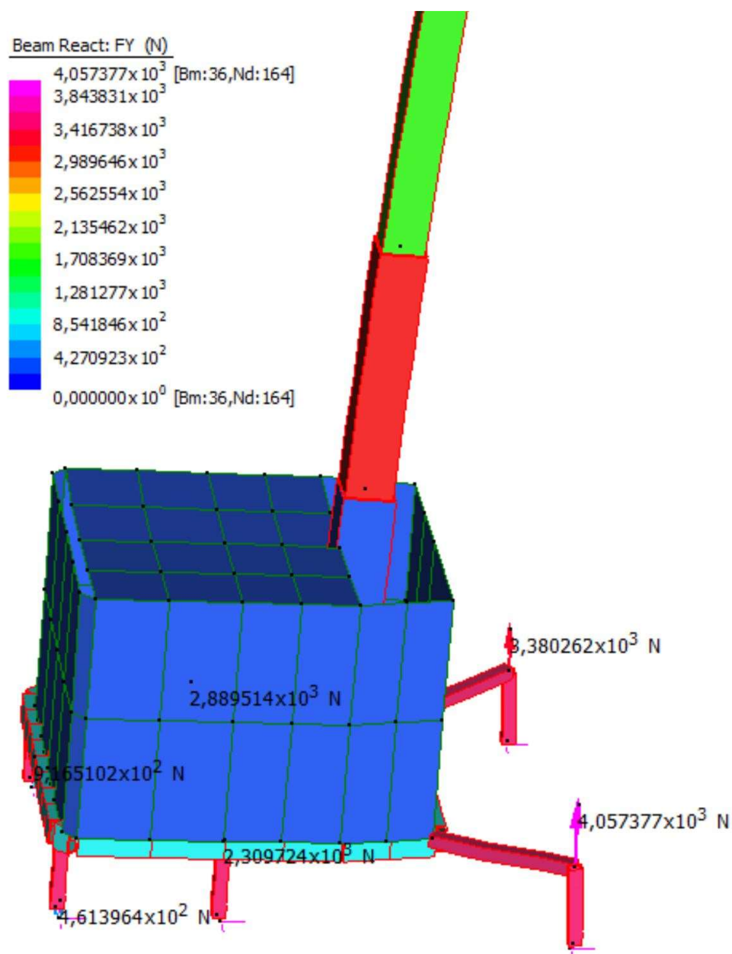

Figure 6 – Support vertical reactions. 100% of the wind pressure

To gain further insight into the resisting mechanism to the wind load, the evolution of the vertical reactions of left (stabilizer), wheel (nearly at the centroid) and right (stabilizer) base supports should be further investigated. The overall scenario is as follows:

- Left supports experience a progressive download due to the wind action, see Figure 7. Left support reaction initial-to-final ratio is nearly one fifth, i.e. left supports are subjected to a progressive download that, however, does not cause such reactions to vanish;
- Wheel reactions undergo a similar diminishing variation, but at a lower rate than left supports as shown in Figure 8. As expected, though, the decreasing rate is small since the wheel axis is located in the vicinity of the base structure centroid where the vertical self-weight is applied;
- Finally, as expected, right support reactions are monotonically increasing with load steps, see Figure 9.

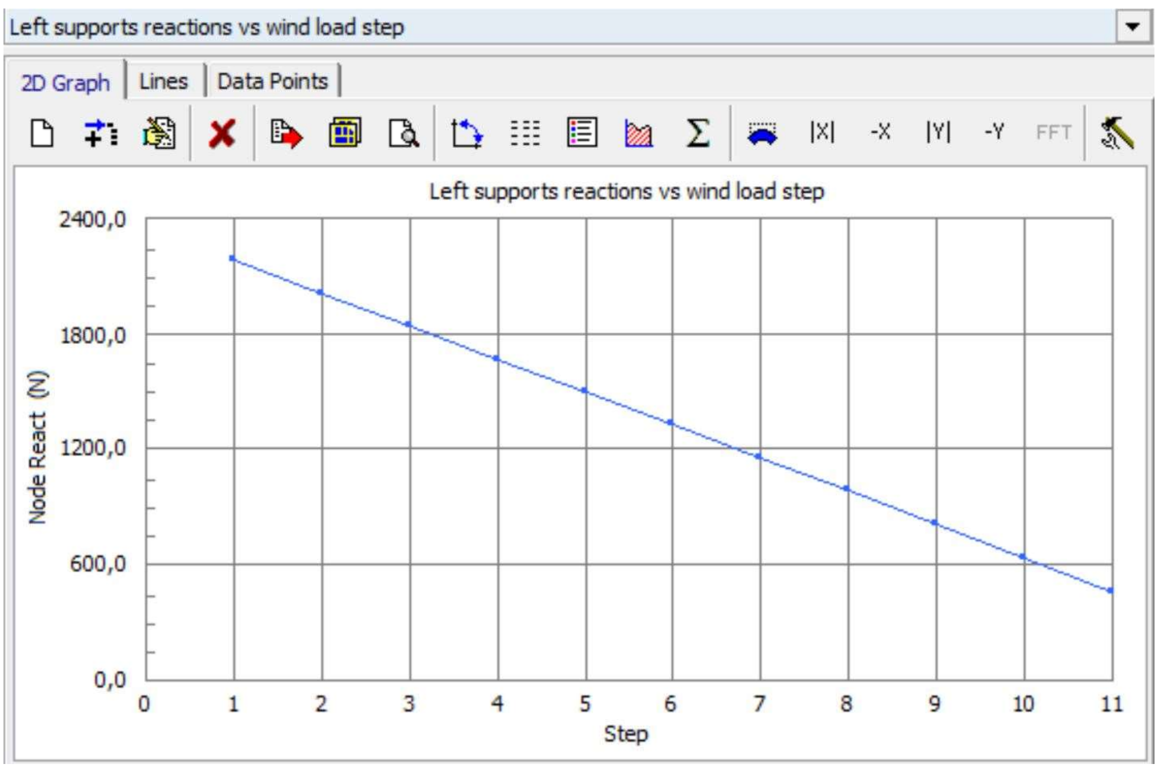

Figure 7 – Left support reactions vs wind load intensity

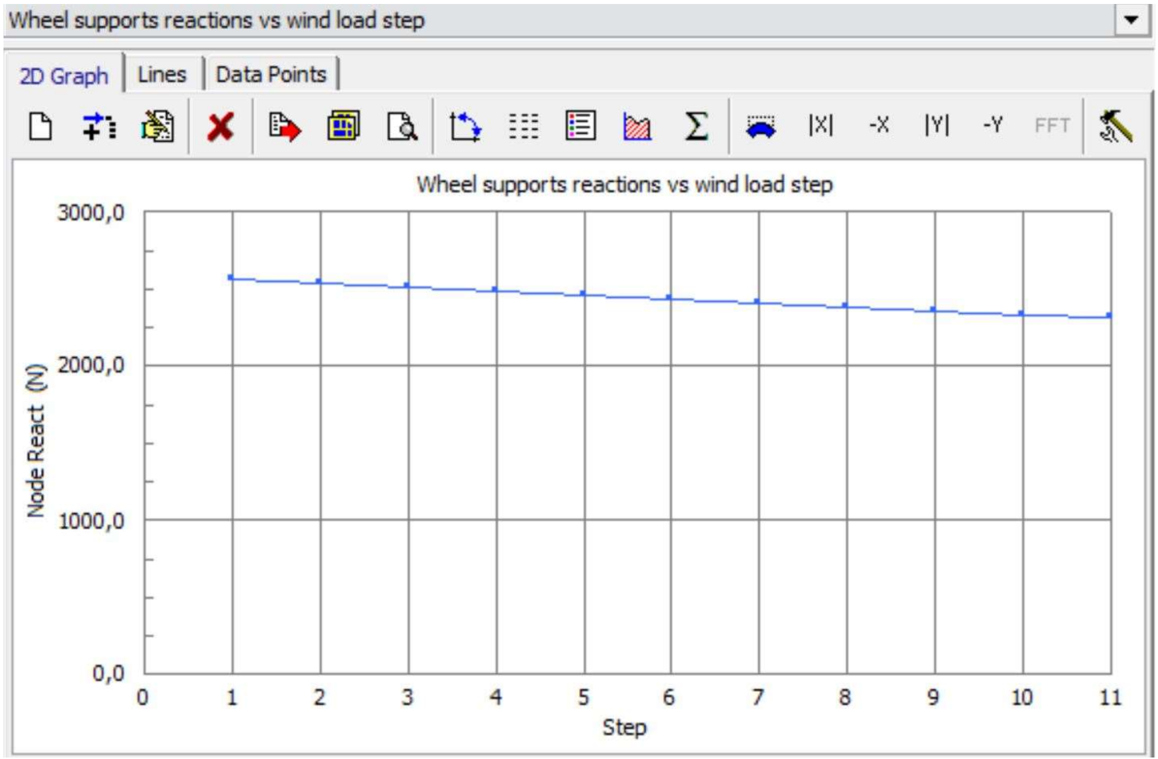

Figure 8 – Wheel support reactions vs wind load intensity

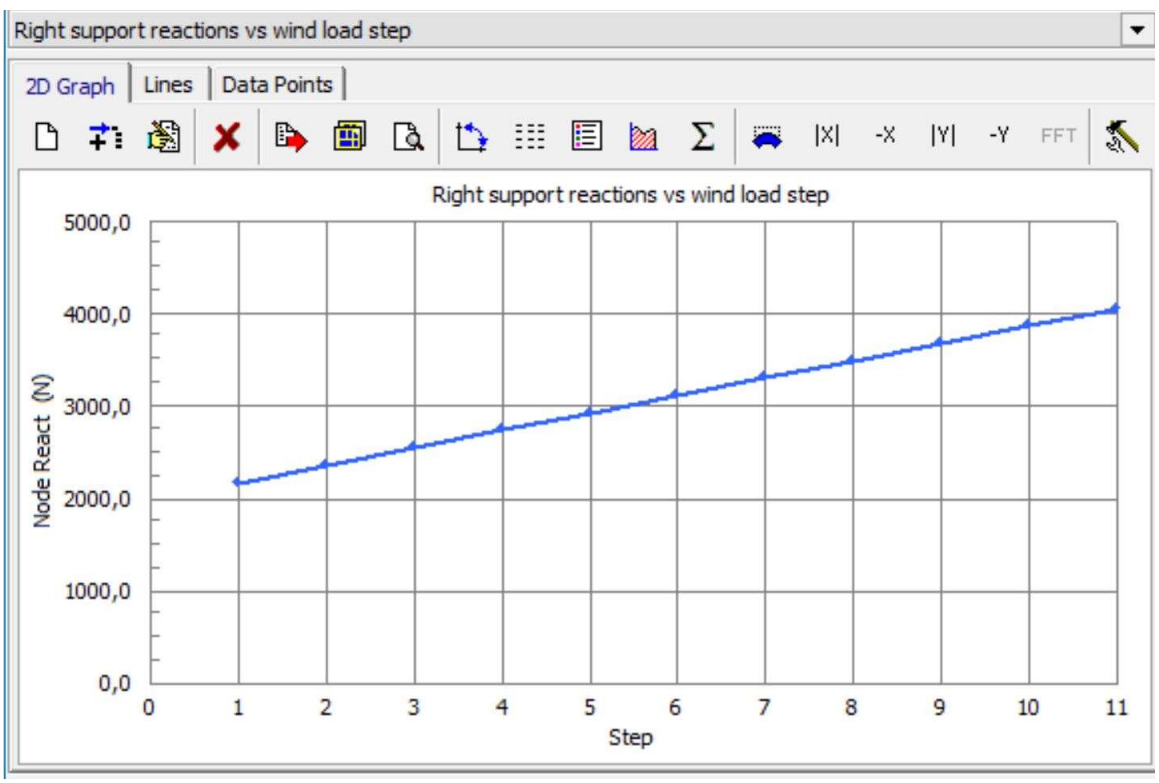

Figure 9 – Right support reactions vs wind load intensity

4. CONCLUSIONS

The following conclusions may eventually be drawn:

The structure named VB-9 is adequate to resist the design wind load indicated by Generac Mobile Products srl ($v_{b,0} = \mathbf{110}$ km/h $= \mathbf{30.56}$ m/s).

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Prof. Ing. Paolo Venini

Dipartimento di Ingegneria Civile e Architettura

Università di Pavia