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Engineering Design of a Parking Building for Bicycles

Oskar Ostertag*, Peter Janík

Department of Applied Mechanics and Mechanical Engineering, Faculty of Mechanical Engineering, Technical University of Košice, Letná 9, 042 00 Košice, Slovak Republic
*Corresponding author: oskar.ostertag@tuke.sk

Abstract In this paper we present the possibilities of unconventional bicycle parking in a built-up urban area. The unconventional parking solution is represented by a multi-storey parking house. In addition to the proposed construction design, the results of strength calculations of individual elements and nodes of the proposed parking house are presented in the article.

Keywords: *parking building, bikes, stress, strain*

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1. Introduction

Urban, transport, safety and operational criteria of space design for short and long-term bicycle parking, starting and ending with high-capacity garages, form an integral part of the solution to the whole transport infrastructure of the area. The optimal operation of such facilities is subject to the actual development of cycling transport, building the cycling infrastructure, the disposition and the density of the network of cycle routes and their loading. Bicycle parking places demands on the urban area of the municipality. Proper realization of parking spaces for bicycles shall make the streets and squares clear and possible to drive through [1].

The subject of this paper is to highlight the issues related to bicycle parking. The state of covering the possibilities of parking and storing bicycles in public spaces is not sufficient for the needs of securing the property against theft. The created proposal has a capacity of 94 parking spaces for bicycles of different weights and dimensions. Parking space of such capacity belongs among the medium size ones. Parking is fully automated, without the access of people to the interior of the parking house, because of preventing the theft of bicycles. The automation of parking lies in the fact that the bicycle is placed in an entrance grow, where its weight is found out, a camera records its dimensions and within 20 seconds, an automatic lift will place it in a separate predetermined space. After the stated procedure, the owner of the bicycle gets a card with an electronic code of the stored bicycle. The card serves for the takeover of the bicycle. After the payment of the calculated financial charge and the return of the card, the takeover of the bicycle shall take place. This process is also fully automatic.

2. Engineering Design of the Parking House for Bicycles

The proposed parking house is 2.11 m high and covers an area of 8x8 m and offers space for 96 bicycles (Figure 1). The main load-bearing parts have been designed from the beams and bars of square profile with the dimensions of 200x200 mm, with a thickness of 10 mm. In addition to these blanks, bars of rectangular profile with the dimensions of 100x50 mm and with a thickness of 3.2 mm were also used. We used steel with the designation STN EN 17240. It is an austenitic stainless steel, which is the most used kind of stainless steel material with excellent corrosion resistance, cold formability and weldability. Its yield strength R_e is 207 MPa.

Figure 1. The conceptual design of the parking house

3. The Validation of the Design of the Parking House

The rack designed to store the bicycles, can, in terms of load and the structure, be considered to be symmetrical. The base consists of carrier beams of a rectangular profile with the dimensions of 100x50 mm and the thickness of 3.2 mm, on which grooves for the wheels of the bicycle are made. The grooves are 2000 mm long and 100 mm wide. The total weight of the rack is 49.74 kg and it is manufactured of the EN STN 17 420 steel. Figure 2 displays the stated design of the rack shape, Figure 3 shows the direct stress gradient calculated according to von Mises and Figure 4 the gradient of distortions identified by means of FEM.

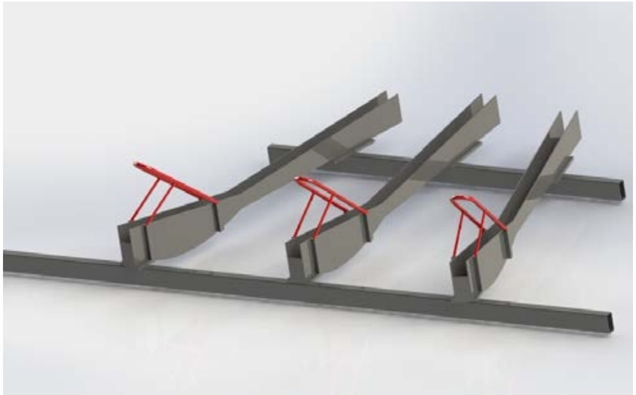

Figure 2. The rack construction

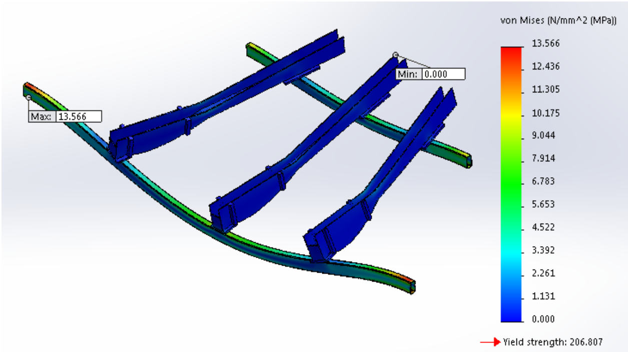

Figure 3. The direct stress gradient of the rack

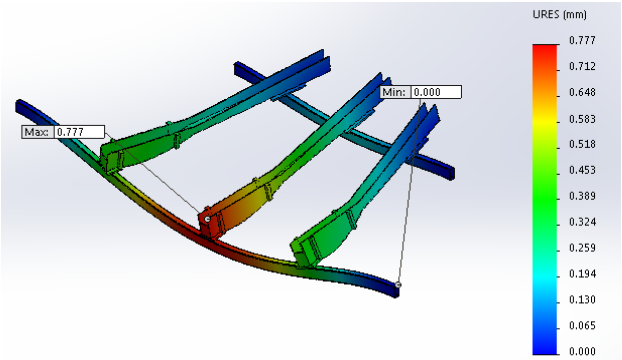

Figure 4. The gradient of distortions of the rack

As part of the total load of the structure of the parking house we considered also the wind and snow (e.g. [2,3]). Load values were determined for the corresponding region according to the relevant tables and standards. The solution reflected the sheath surface and the inclination of the roof of the parking house. In case of wind load we considered the mean wind speed, basic and peak wind pressure and turbulence.

The method of calculating wind load is specified in the European standard [3]. In case of dynamic effects of the load of the entire building or nay part of it by the wind, it is necessary to adapt all the constructional details to the nature of fatigue stress, so as to limit to the maximum the eventual concentration of stress peaks. The occurrence of concentrated high stress is a frequent source of faults which may occur even after several years of use of the building.

The characteristic mean wind speed $v(z)$ in the altitude z above the ground level is given by the equation

$$v(z) = c_r(z) \cdot c_0(z) \cdot v_0, \tag{1}$$

where $c_0(z)$ is the coefficient affected by the surface of the terrain (if $c_0(z) = 1$, then the wind speed is increased by not more than 5%) and v_0 is the basic wind speed.

Terrain roughness coefficient c_r (z) is given by the equation

$$c_r(z) = k_r \ln\left(\frac{z}{z_0}\right), \text{for } z_{\min} \le z \le z_{\max}$$

$$\text{and } c_r(z) = c_r(z_{\min}), \text{ for } z \le z_{\min},$$

where z_0 is the length of the roughness shown in the table of the relevant standard [3],

z_{min} is the minimum altitude given in the table of the standard [3] and z_{max} is 200 m,

k_r is the coefficient of the terrain $k_r = 0.19\left(\frac{z_0}{z_{01}}\right)^{0.07}$ and $z_{01} = 0.05\,\text{m}$.

Peak wind pressure $q(z)$ can be determined as

$$q(z) = (1 + 7D(z))0.5\rho v^2(z), \tag{2}$$

where $0.5\rho v^2$ represents the basic wind pressure, ρ is the air density (generally ρ = 1.25 kg m^{-3}) and $1 + 7D(z)$ is the impact of turbulence.

The turbulence of the wind D (z) is given by the equation

$$D(z) = \frac{k_D}{c_0(z)\ln\frac{z}{z_0}}, \text{namely for } z_{\min} \le z \le z_{\max}, \tag{3}$$

where k_D is the turbulence coefficient (generally equal to 1).

The direct, respectively, indirect wind pressure on the outer surface has a form of

$$w_e = q(z)c_e \tag{4}$$

and on the internal surface has a form of

$$w_i = q(z)c_i, \tag{5}$$

where c_e is the coefficient of the outer surface (depends on the dimensions of the area exposed to the impacts of the wind and, in particular, of the shape of the structure) and c_i is the coefficient of internal pressure. These coefficients are determined according to the standard [3].

When determining the snow load of a construction, it is necessary to consider the various options of pressure distribution which is dependent e.g. on the shape of the roof, thermal characteristics of the roof, the roughness of the surface, the distance to the surrounding buildings, etc.

Snow load on roofs shall be determined as follows:

- for temporary design situations, as is the unlikely occurrence of extraordinary snowfall, unlikely occurrence of snow drifts

$$q_s = \mu_s C_e C_t S_0, \tag{6}$$

- for exceptional design situations, as is the incidence of extraordinary snowfall without exceptional snowdrifts

$$q_s = \mu_s C_e C_t S_1, \tag{7}$$

- for exceptional design situations, as is the incidence of extraordinary snowfall with the occurrence of exceptional snowdrifts

$$q_s = \mu_s S_0, \tag{8}$$

where μ_s is shape coefficient of the snow load, S_0 is the characteristic value of snow load on the ground, S_1 is the proposal value of exceptional load on the ground for the given area, C_e is the coefficient of exposition, C_t is the temperature coefficient.

The C_t temperature coefficient is used to reduce the snow load on the roofs, which involve the melting of snow through high heat transfer. If the heat transfer is greater than 1.0 W/m^2 K, then $C_t < 1$, in other cases $C_t = 1$.

Figure 5 and Figure 6 present the structure deformation of the parking house for two cases of wind load.

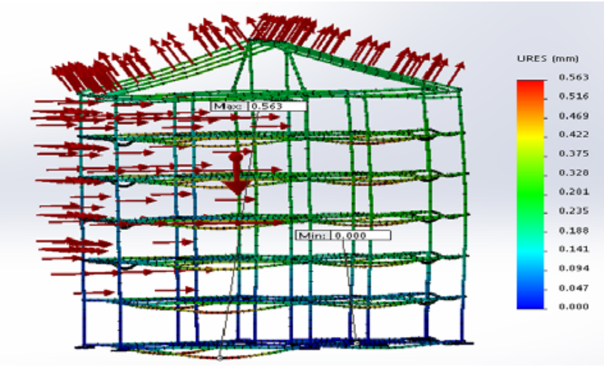

Figure 5. The structure deformation for case I

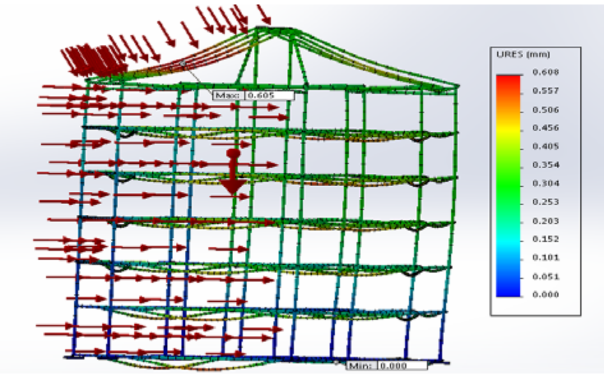

Figure 6. The structure deformation for case II

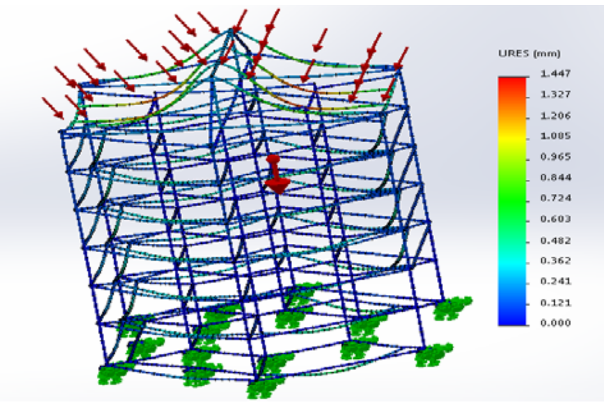

Figure 7. Snow load caused without snowdrift

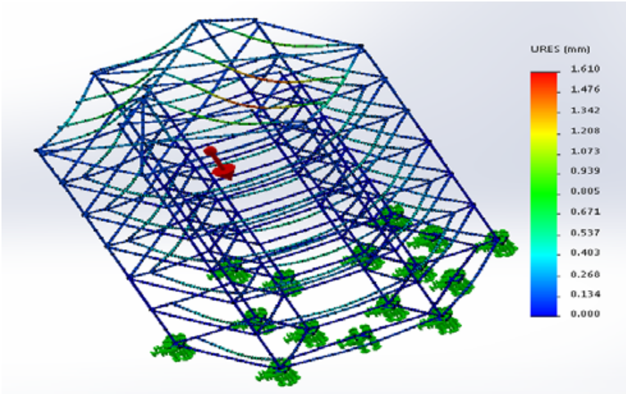

Figure 8. Snow load caused with snowdrift

Figure 7 and Figure 8 display the cases the snow load of the roof caused without and with snowdrifts.

The dynamic response of the construction has been assessed on the basis of the identified natural (eigen) frequencies and the frequencies of the excitation forces. Using the resulting eigenfrequencies, the hazardous operating condition of the construction can be determined (e.g. [4,5]).

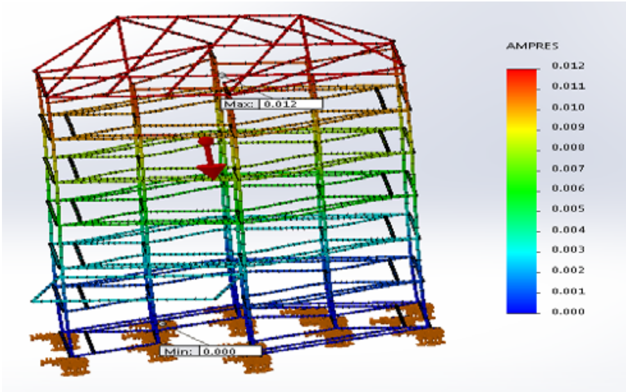

Figure 9. The first eigenmode

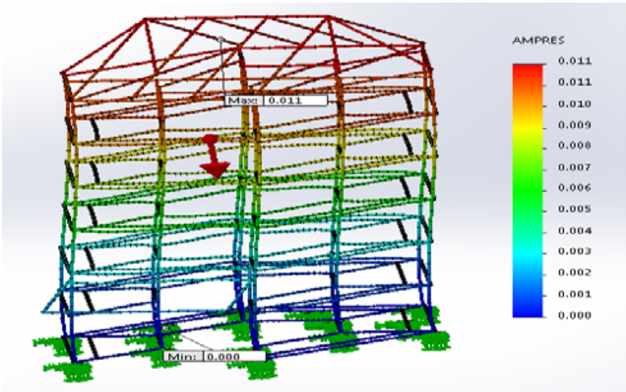

Figure 10. The second eigenmode

In case that the eigenfrequencies comply with the frequencies of the excitation forces, a resonance of the system occurs and that may result in reduced service life, increased noise and damage to structures. Due to the resulting eigenmodes of the vibrations of the excited investigated system, it is possible to determine the points of maximum deformation. Accordingly, it is possible to make structural modifications to eliminate dangerous oscillations. Figure 9 - Figure 13 display the first 5 eigenmodes of the parking house model. The actual calculation of modal parameters by the finite element method is not sufficient to be able to proclaim that the obtained modal parameters are identical to the actual ones. Therefore, it is often necessary to compare the obtained results with the results of experimental modal analysis. This comparison is performed to get more accurate results and eventually modify the calculation model used for further solution (e.g. [6,7,8,9]).

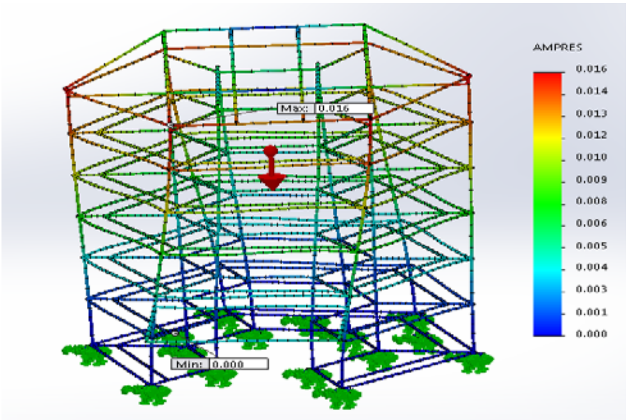

Figure 11. The third eigenmode

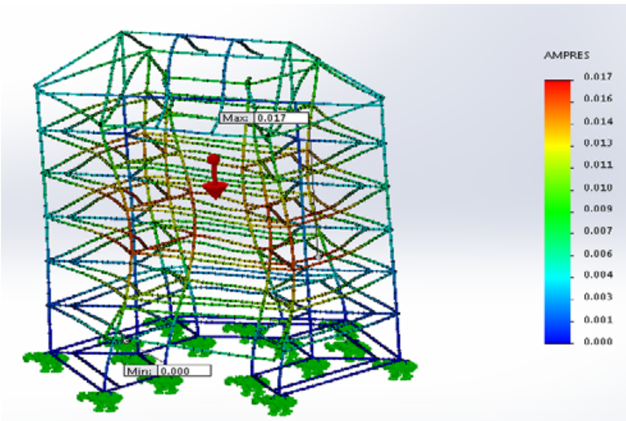

Figure 12. The fourth eigenmode

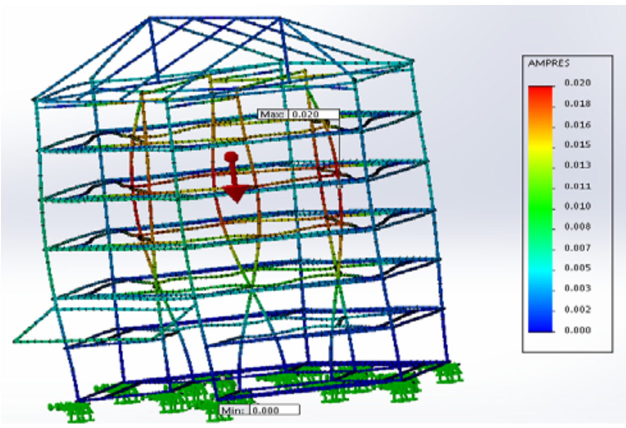

Figure 13. The fifth eigenmode

4. Conclusion

Via our paper we wanted to highlight the possibility of solving the problem of lack of parking spaces for bicycles. The correct realization of parking spaces for bicycles helps to achieve the clearness and driveability of the streets and squares. Bicycle racks do not address this problem. They often present an obstacle on the streets and squares. The cost of installing a single rack with a capacity of 10 bicycles in Slovakia lies in the range from 200 to 2500 euros.

The calculations presented showed the relevant possibility of the realization of the project of a parking house. Stresses in construction elements, as well as their deformation, have shown very little values when compared with the permissible stress, respectively, the required rigidity. In view of these results, it is possible to subject the construction even to significantly higher loads. This design proposal highlights the high safety level of the realized construction.

Acknowledgement

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