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STRAIN-STRESS ANALYSIS OF THE PHOTOVOLTAIC POWER PLANT CONSTRUCTION

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Summary: *The paper presents the results of the analysis of the optimization of the photovoltaic power plant construction with regard to its weight (maximum weight of the plant construction – without photovoltaic panels – must not exceed 50 t) while ensuring that the construction is safe against the plasticity of the construction and the loss of buckling stability of steel rods.*

1. Introduction

Photovoltaic power plants represent an alternative and environment friendly source of electric power. Their contribution to the protection of climate and environment is not insignificant. Conversion of solar energy to electricity is environmentally pure, as it does not product any toxic waste, gas, fly ash or noise. One kilowatt of installed power capacity of photovoltaic system saves approximately 850 kg of CO_2 emissions a year (http://www.fotovoltaicke-elektrarny.cz/).

Photovoltaic (PV) power plant is designed to convert solar energy directly to electric power via a photovoltaic process during which the contact between solar irradiation and the surface of light-sensitive photovoltaic cell induces the emission of electrons. The obtained direct current can be used to recharge accumulators, power electrical appliances or, when converted to alternating current, supply public distribution network.

One square meter of the territory of the Czech Republic receives 950 - 1100 kWh of solar energy on average (Fig. 1 - http://re.jrc.ec.europa.eu/pvgis/). For example, a total average irradiance period in Prague is ca 1550 hours a year. Considering the efficiency of photovoltaic panels and other necessary devices, 85 - 100 kWh of electric energy can be produced per 1 m^2 and year. Photovoltaic panel with the area of 1m^2 and rated output of 100 W can produce 100 kWh of electricity a year. Under the climatic conditions of the Czech Republic, conventional fixed-mount system of 1kWp panel can produce ca 1MWh a year. The efficiency of tracking systems that actively follow the sun during the day is higher by 37%.

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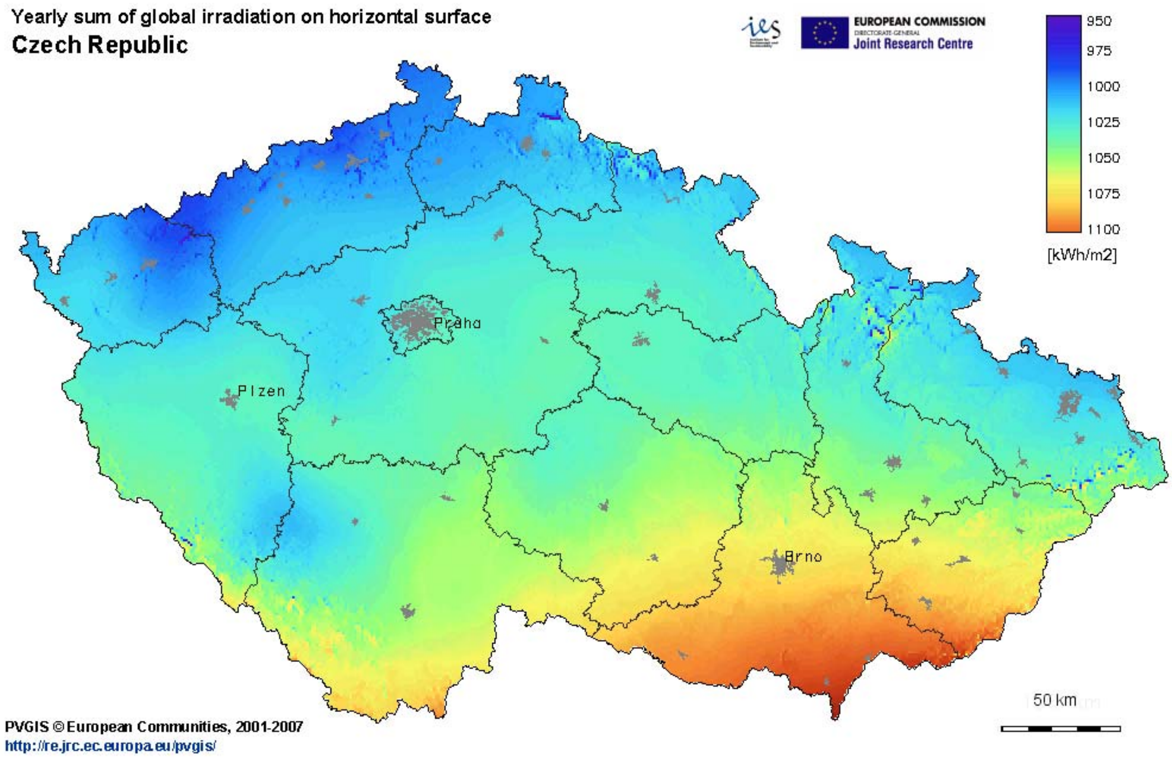


Fig. 1: Distribution of incident solar energy in the Czech Republic

2. Problem situation

Besides its geographical location, the output of photovoltaic plant depends also on the area of photovoltaic panels. Therefore, the presented power plant should use tracking system (following the sun) and have two boards, each 36 m long and 10 m wide (Fig. 2). Operational angle of the plant is defined by α angle ranging from 26^o to 70^o from the horizontal plane.

The photovoltaic panels are mounted to two lattice boards fixed in bearings of rotary stands in order to provide horizontal axis rotation. The stands are mounted to a substructure (Fig. 2a) ensuring vertical axis rotation of the whole construction. Combination of horizontal and vertical rotation makes it possible to follow the sun and enhance the power plant output.

The aim of the analysis is to optimize the power plant construction with regard to its weight (maximum weight of the plant construction – without photovoltaic panels – must not exceed 50 t) while ensuring that the construction is safe against plasticity of the construction and the loss of buckling stability of steel rods. The power plant construction can consist of standardized profiles only that will be connected by welds or bolts. Therefore, conventional optimization in FEM system ANSYS cannot be performed, as the dimensions of cross sections of individual rods are not continuous, but discrete, and depend on the data defined by applicable standards. The construction was optimized "manually": In the places with high safety against expected limit states, the dimensions of cross sections were reduced (or the shape of cross sections was modified) and, conversely, in the places with low safety against the limit states, the cross section dimensions were increased globally (i.e. the whole rod was scaled up) or locally (additional profile was added to a given part of the rod).

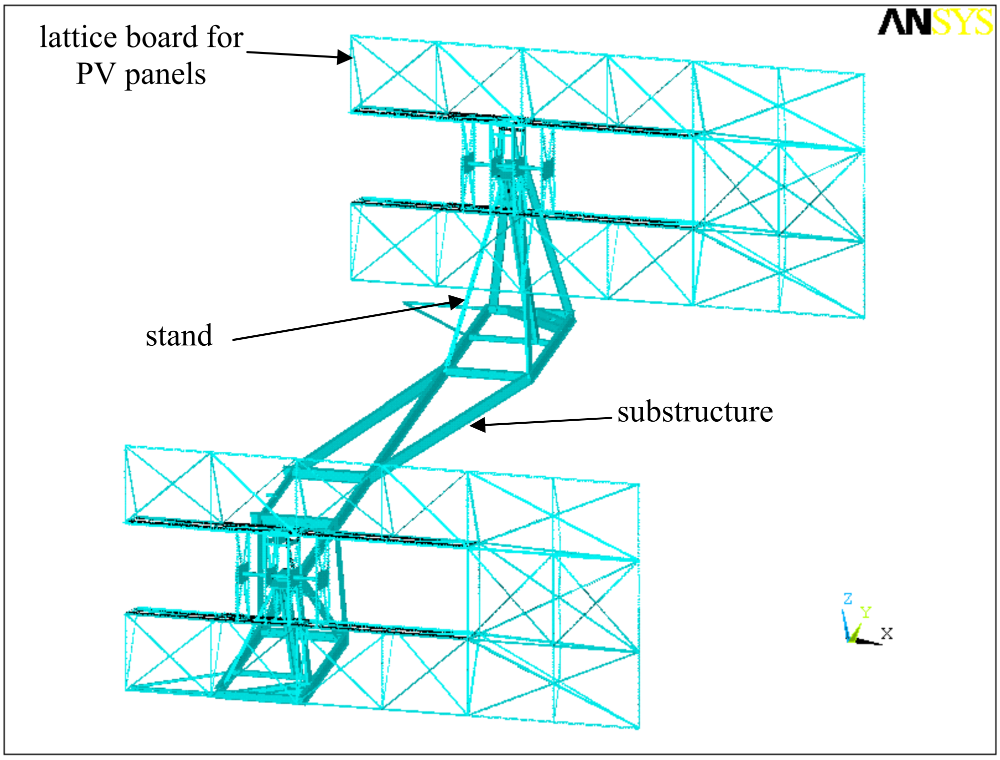


Fig. 2a: Design of the construction without PV panels (half model)

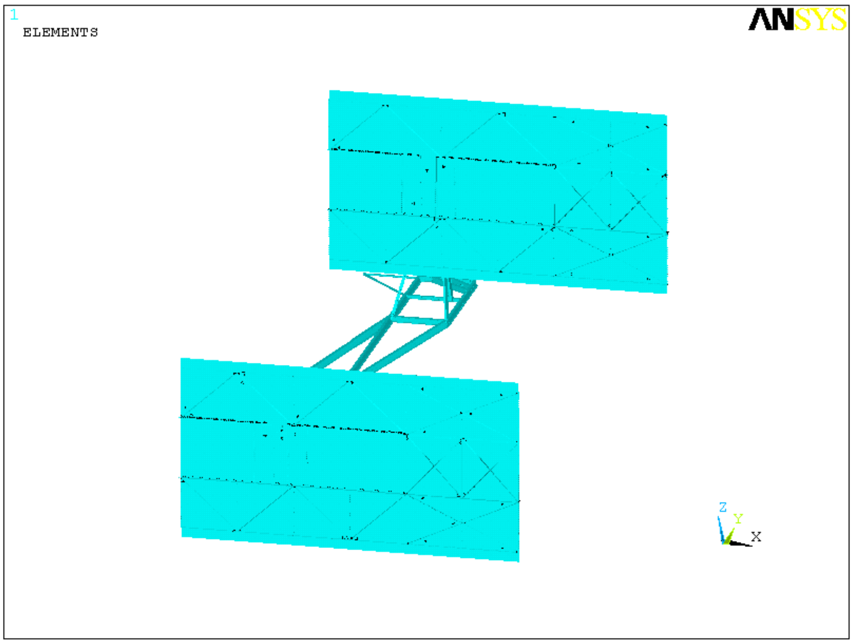


Fig. 2b: Design of the construction with PV panels

3. Computational modeling input data

Geometry of the analyzed system is demonstrated in Fig. 2. The whole construction is loaded by its own weight, the weight of photovoltaic panels including mounting construction

(15 kg/m^2) and the force load that models the action of wind (according to the manufacturer, maximum load of panels exerted by the wind is 130 km/h, i.e. 815 Pa). As soon as the wind speed exceeds the maximum speed limit, the construction will be reclined to the horizontal position ($\alpha = 0°$ - Fig. 3a).

The connections with the basic body are located in the wheels ensuring vertical axis rotation and in the vertical axis. Modeling was based on the symmetry of the construction, as we modeled the load exerted by the wind that does not act the construction obliquely (Fig. 4). Four variants with different inclination of panels (angle α - Fig. 3) were used during modeling. For each variant, wind blowing from the front (in the direction of incident sunlight, Fig. 3c) or from behind (Fig. 3d) was taken into account.

The construction is made of structural steel which is considered as a linear and elastic material ($E = 2.1\ 10^5$ MPa, $\mu = 0.3$, $\rho = 7850$ kg.m^{-3}).

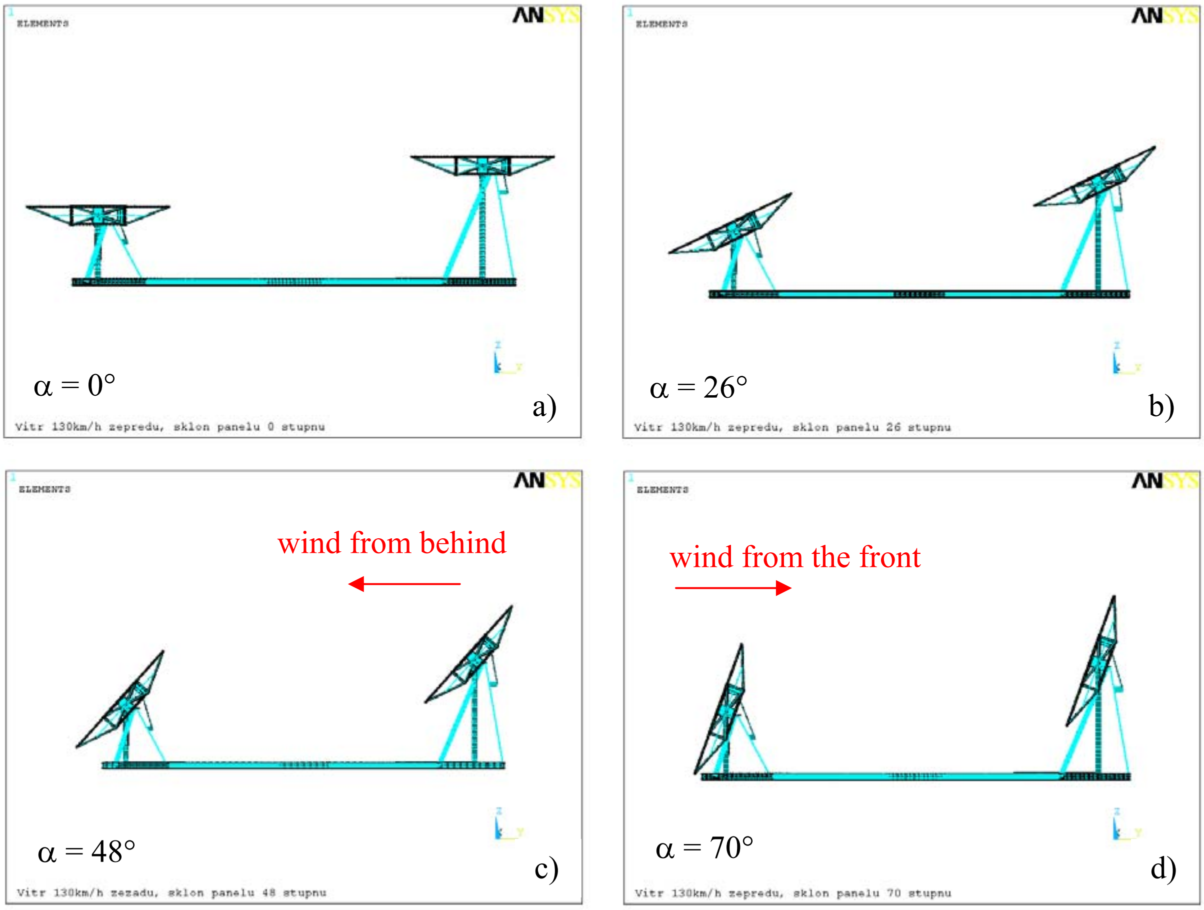


Fig. 3: States of the construction load

4. Results of computational modeling

As the power plant construction is designed to allow rotation of panels around the horizontal axis, the intensity of the load exerted by the wind depends on the effective area of the panel (i.e. angle α). Therefore, four variants were analyzed as illustrated in Fig. 3.

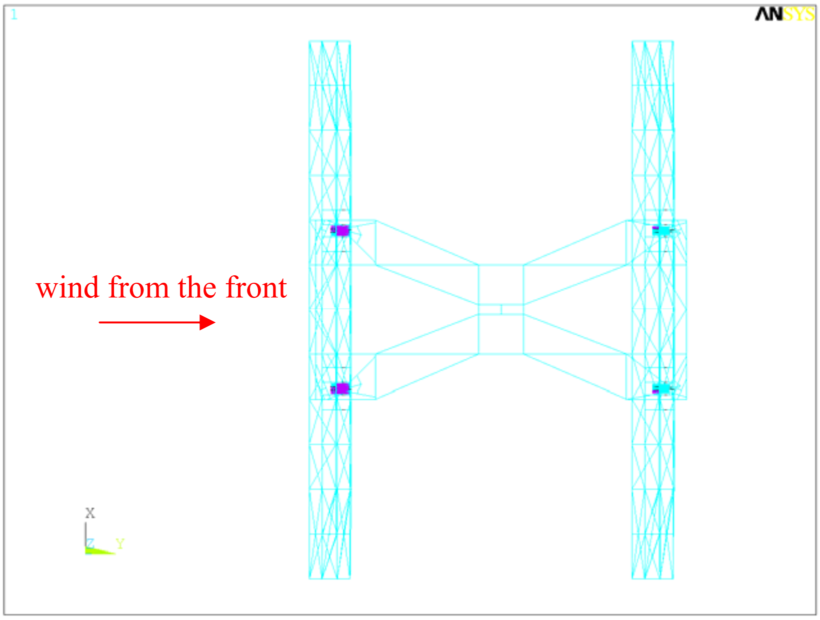


Fig. 4: Direction of the modelled loading of the wind

Coefficient of the safety against limit state of elasticity is evaluated based on isosurfaces of equivalent stresses according the HMH theory of plasticity in MPa. The overall strain of the whole construction (total shift of each node [mm]) corresponding to such load are for each load state demonstrated in Figs. 5 – 9. As far as the strain of the system is concerned, combination of deflection of boards and bending of stands is the crucial factor.

Tab. 1: Results of computational modeling – stress and strain

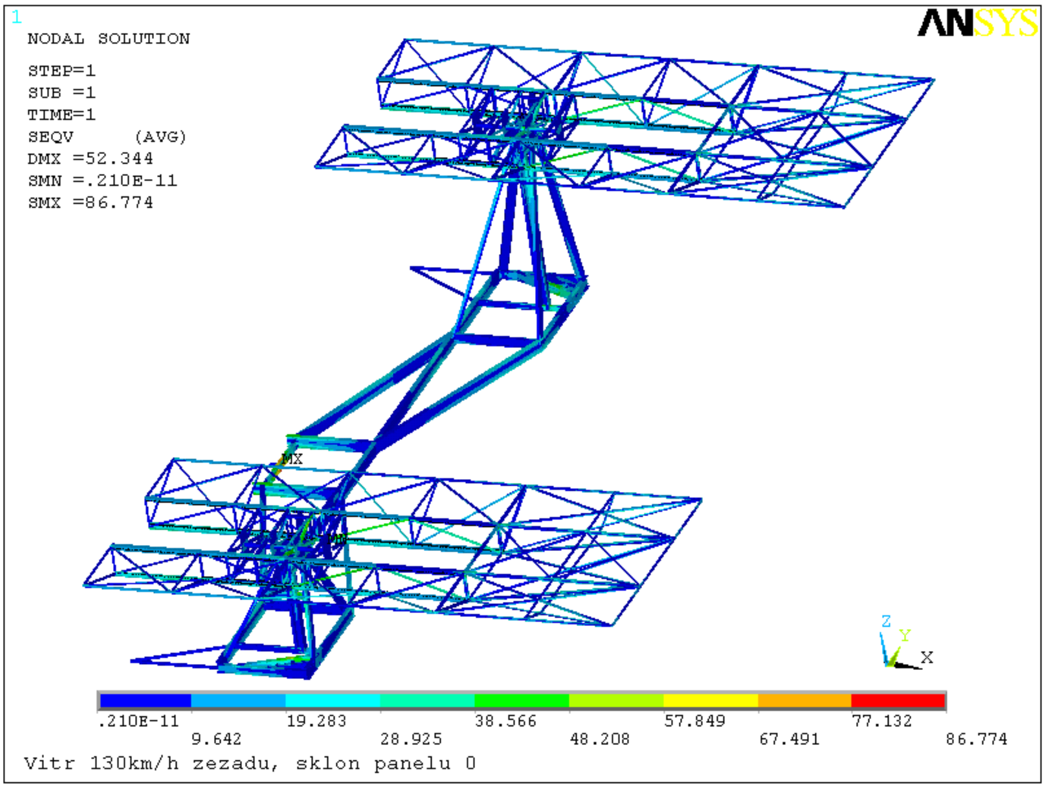
Load state identification	Maximum equivalent stress according to HMH [MPa]	Maximum total shift of the construction [mm]	The result is demonstrated in Fig. no.
α = 0°	86.8	52.3	5
α = 26° – wind from the front	96	62	6
α = 26° – wind from behind	84.6	34	7
α = 48° – wind from the front	150	98	
α = 48° – wind from behind	107	85.6	
α = 70° – wind from the front	193.5	141.8	8
α = 70° – wind from behind	187.4	185.3	9

Maximum equivalent stress increases with growing angle α. It has been found that when the wind blows from the front (i.e. in the direction from the sun), maximum equivalent stresses are higher as compared with the load exerted by the wind blowing from behind. Overall summary of maximum values for individual load states are demonstrated in Tab. 1 or Fig. 10.

The value of collapsing load associated with the loss of stability was determined by linear problem-solving method. Based on linear elastic model, the method estimates theoretical collapsing load at which the stability is lost. The results of the computation are eigenvalues – factors of resistance against the loss of stability – that express the relation between collapsing load and the entered computational load. The analysis indicates that the coefficient of safety against limit state of buckling stability (LSBS) (for a given wind direction) decreases with increasing angle α (see Fig. 13) – similarly to the control of limit state of elasticity. The loss of stability for the construction inclined at α = 70 ° is demonstrated in Fig. 10 and Fig. 11. Summarized results are stated in Tab. 2.

Tab 2: Results of computational modeling – safety against buckling

Load state identification	Eigenvalue representing the safety against buckling (LSBS) [-]	The result is demonstrated in Fig. no.
α = 0°	4.73	
α = 26° – wind from the front	3.01	
α = 26° – wind from behind	6.84	
α = 48° – wind from the front	2.01	
α = 48° – wind from behind	2.51	
α = 70° – wind from the front	1.62	11
α = 70° – wind from behind	1.50	



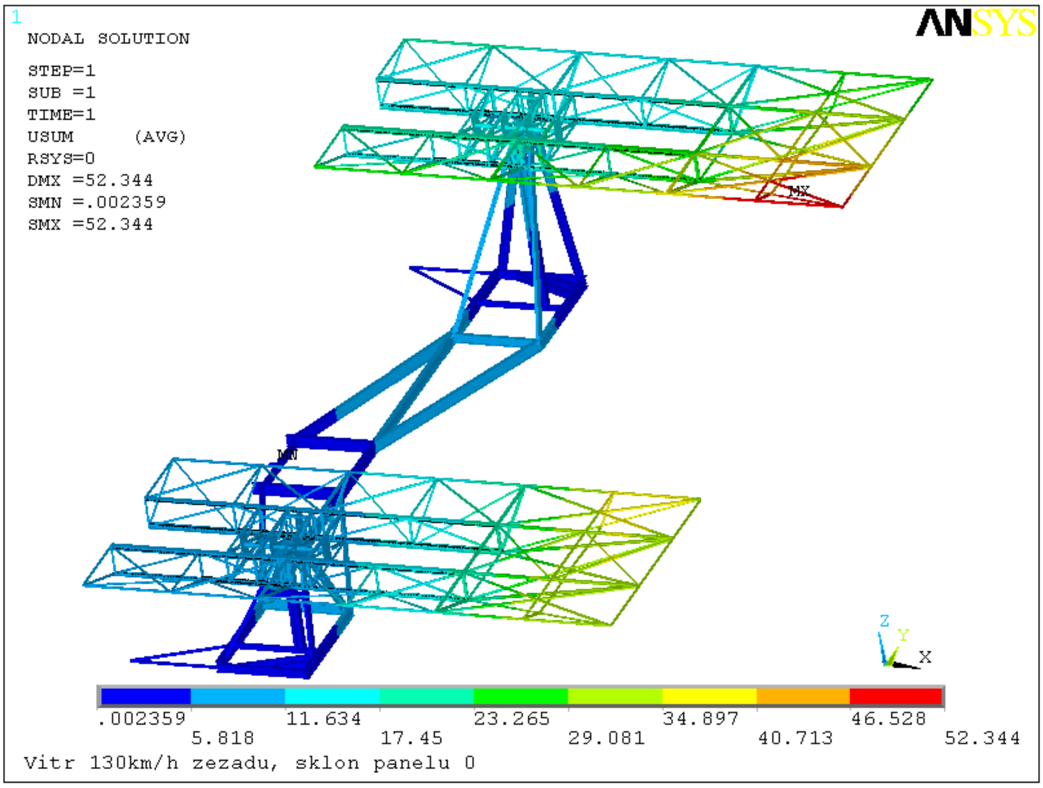
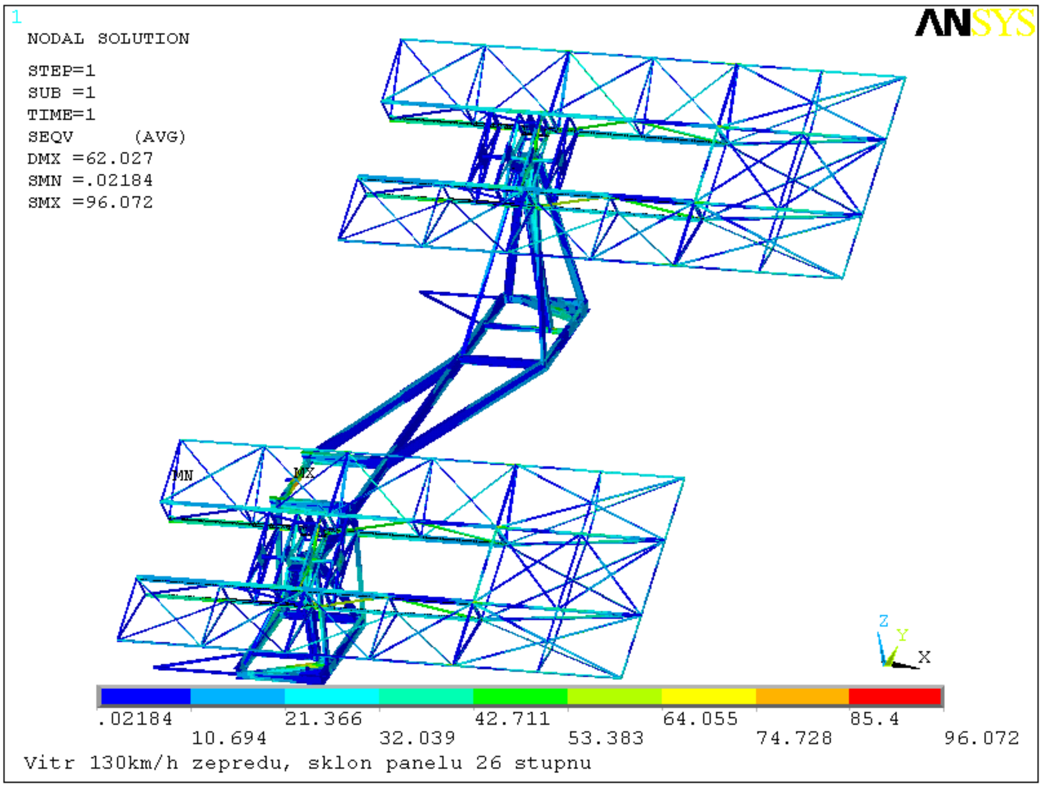


Fig. 5: Equivalent stress HMH and total deformation of the system for $\alpha = 0°$



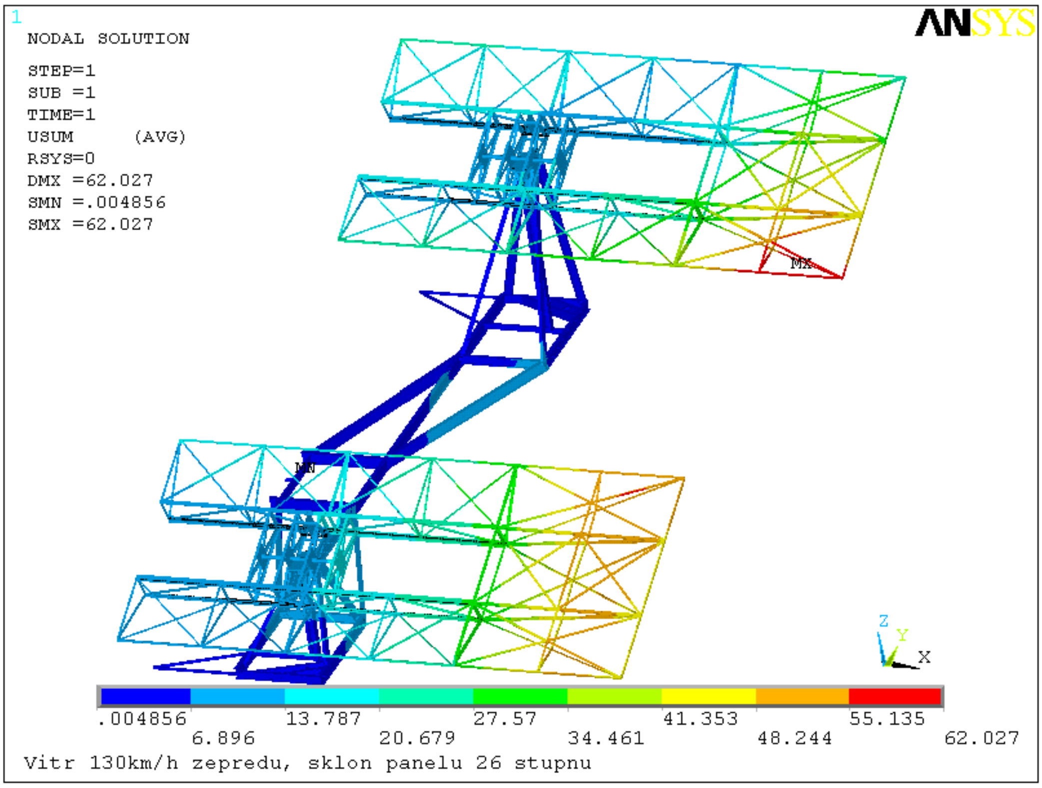
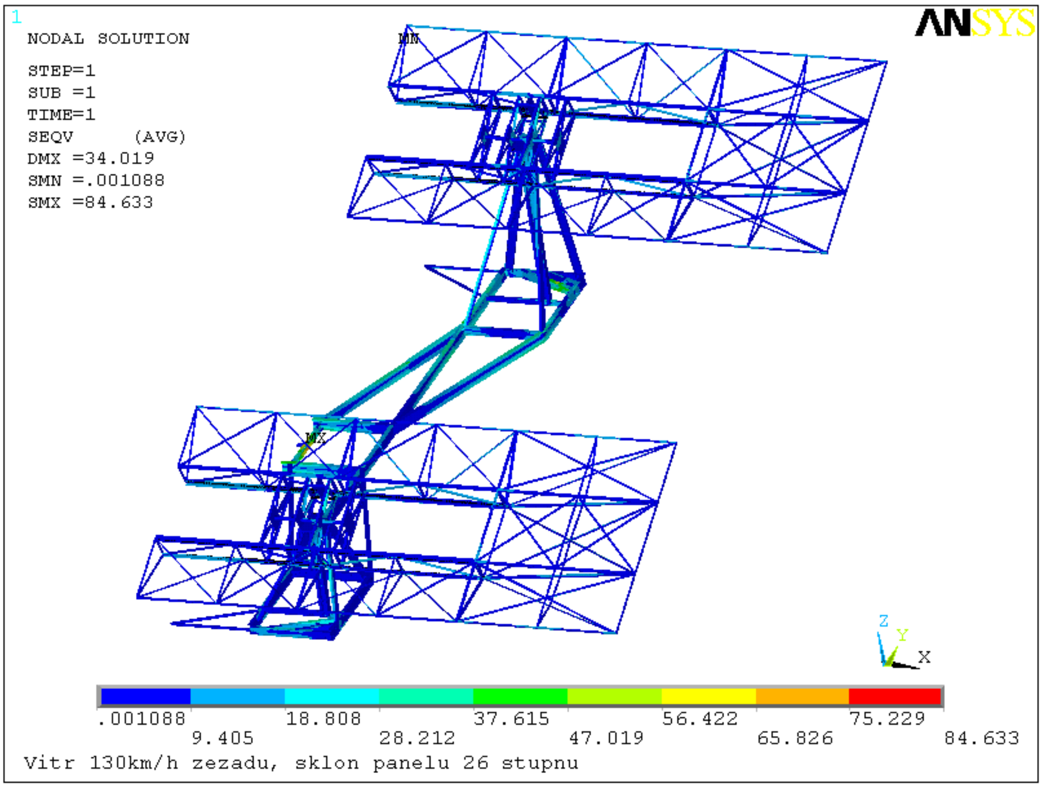


Fig. 6: Equivalent stress HMH and total deformation of the system for $\alpha = 26°$, wind acts from the front



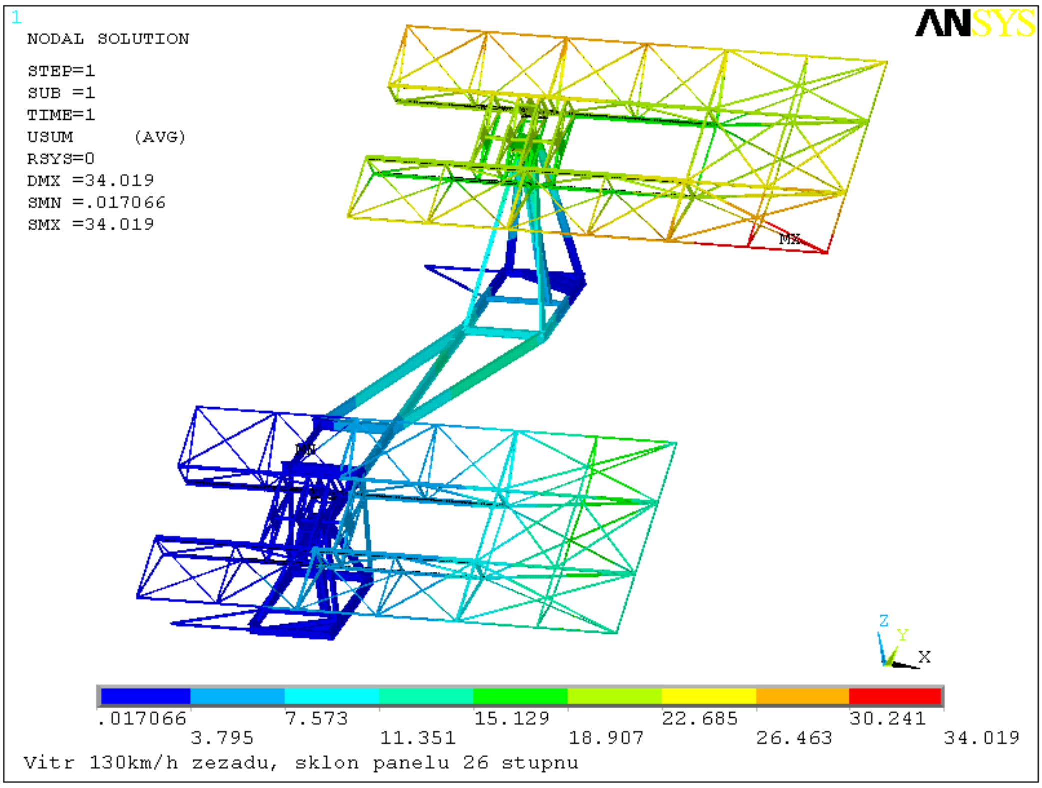
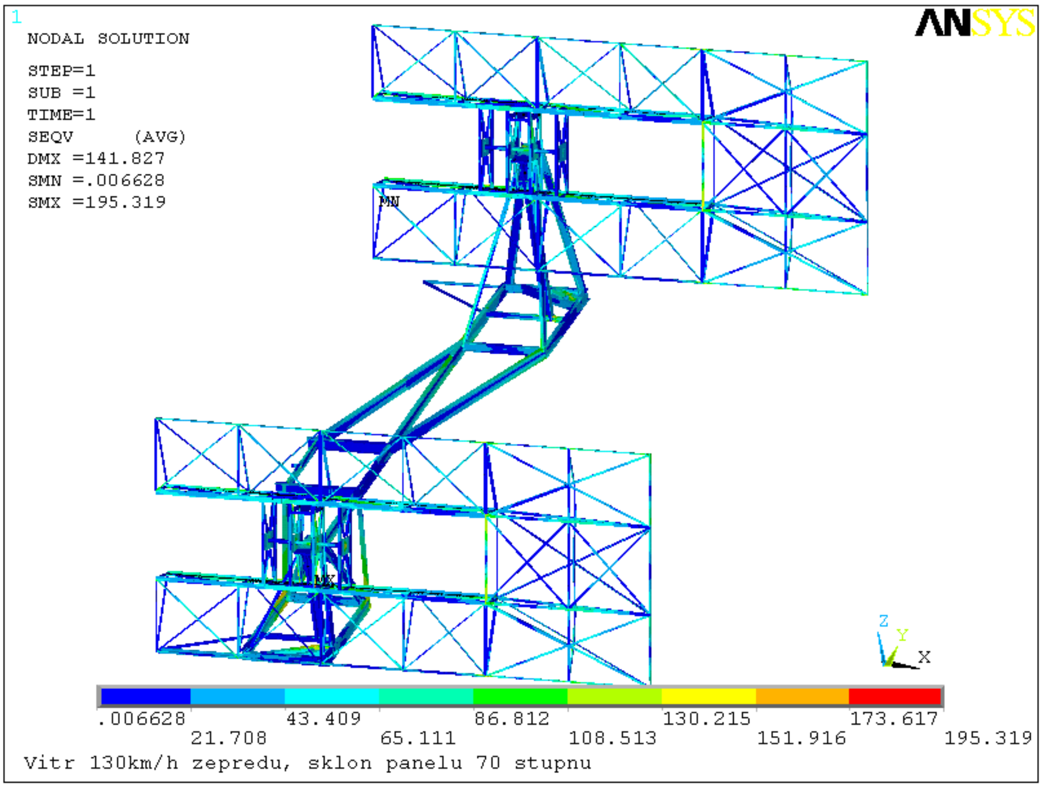


Fig. 7: Equivalent stress HMH and total deformation of the system for $\alpha = 26°$, wind acts from behind



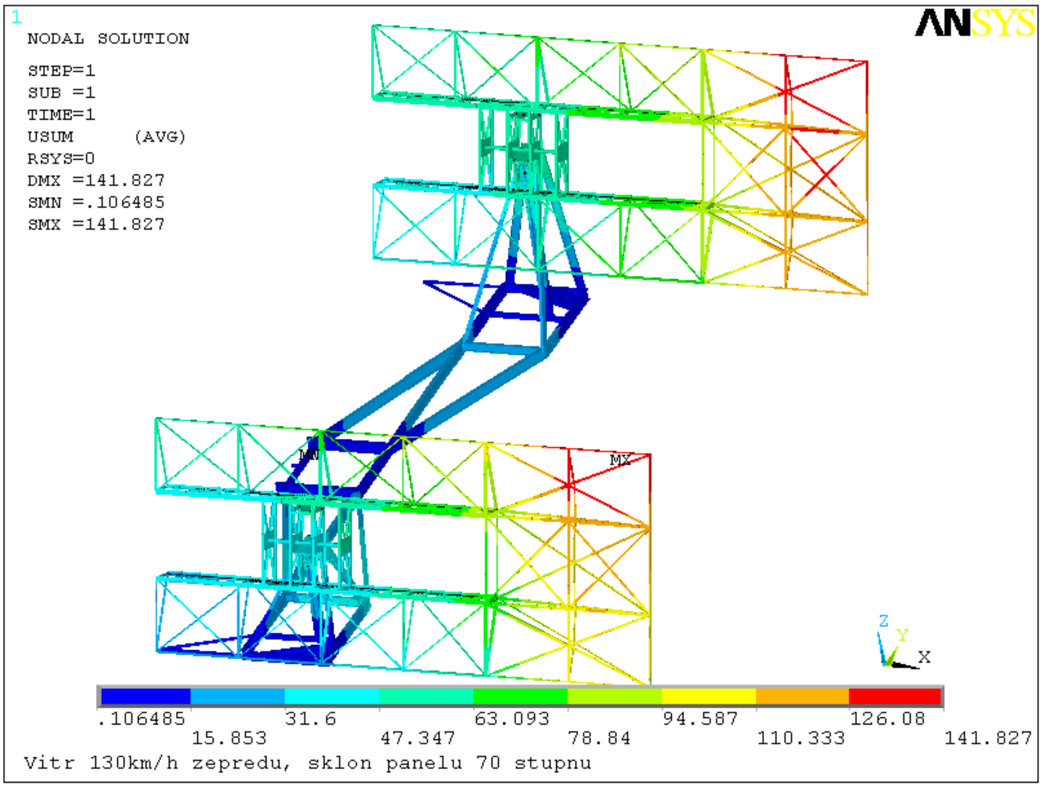
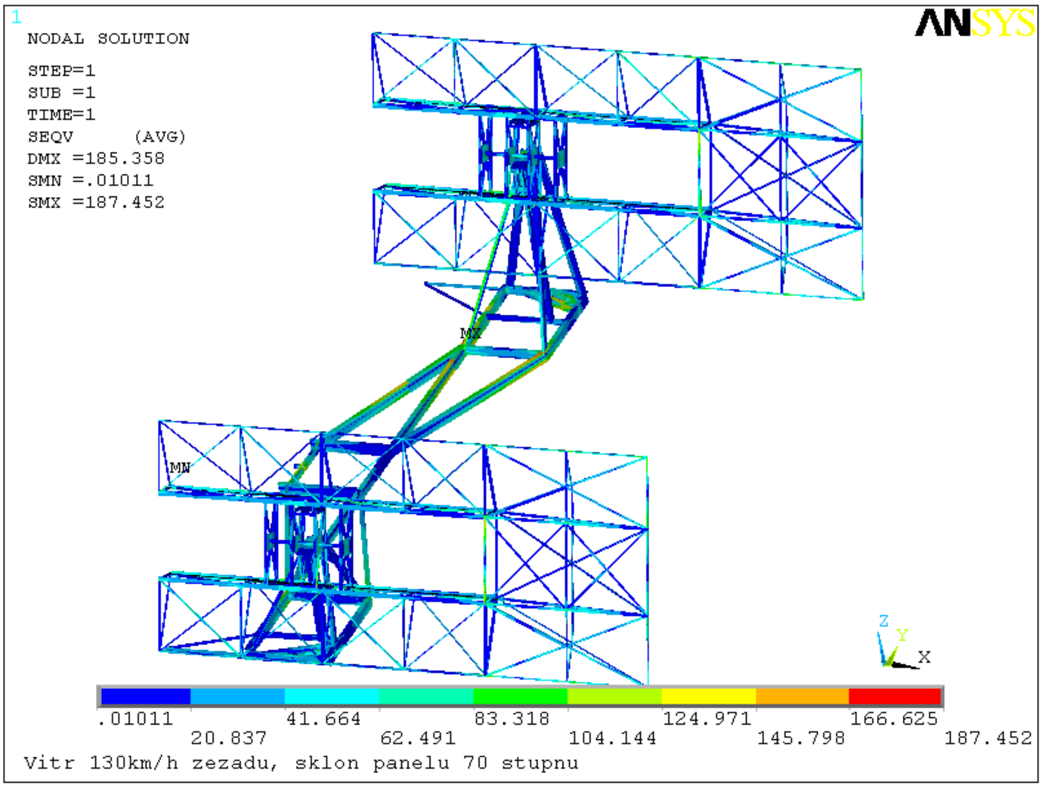


Fig. 8: Equivalent stress HMH and total deformation of the system for α = 70°, wind acts from the front



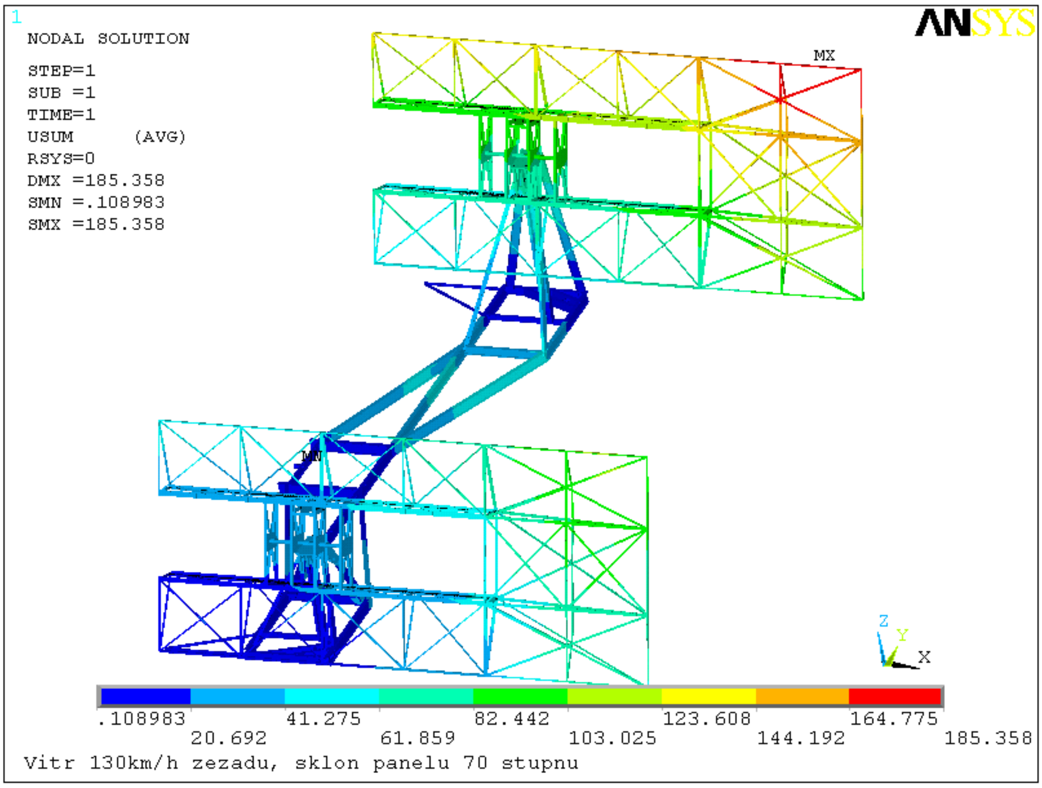


Fig. 9: Equivalent stress HMH and total deformation of the system for $\alpha = 70°$, wind acts from behind

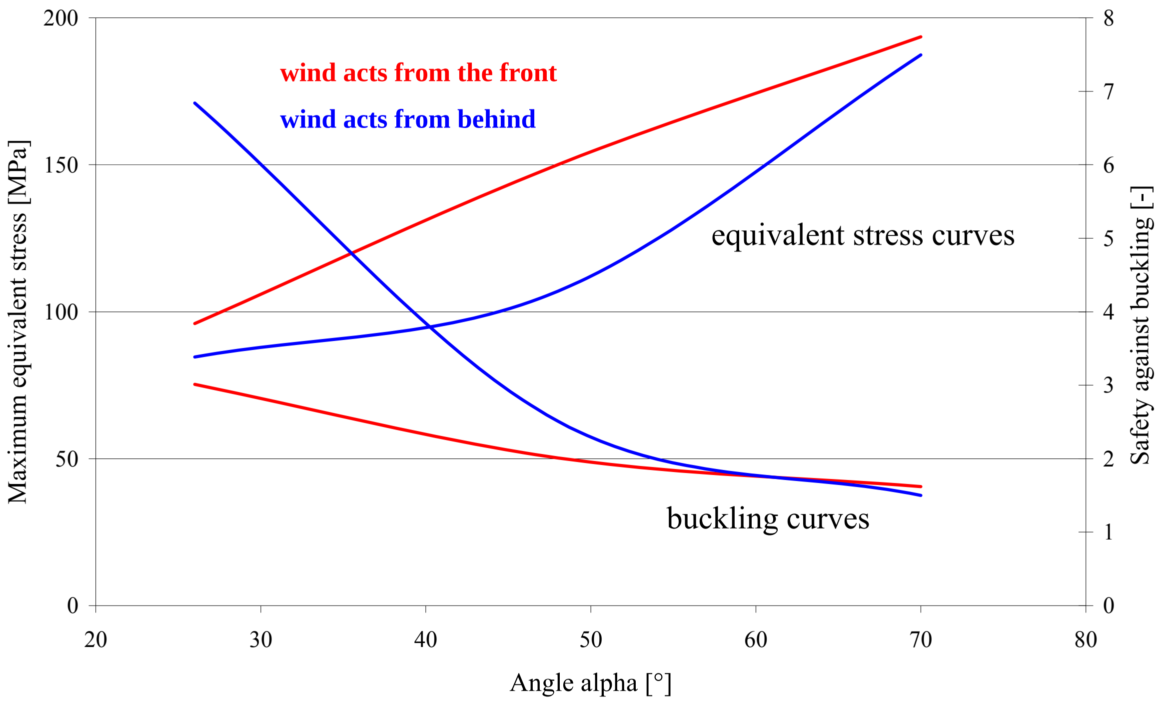


Fig. 10: Influence of the maximun equivalents stress and buckling safety on the angle α

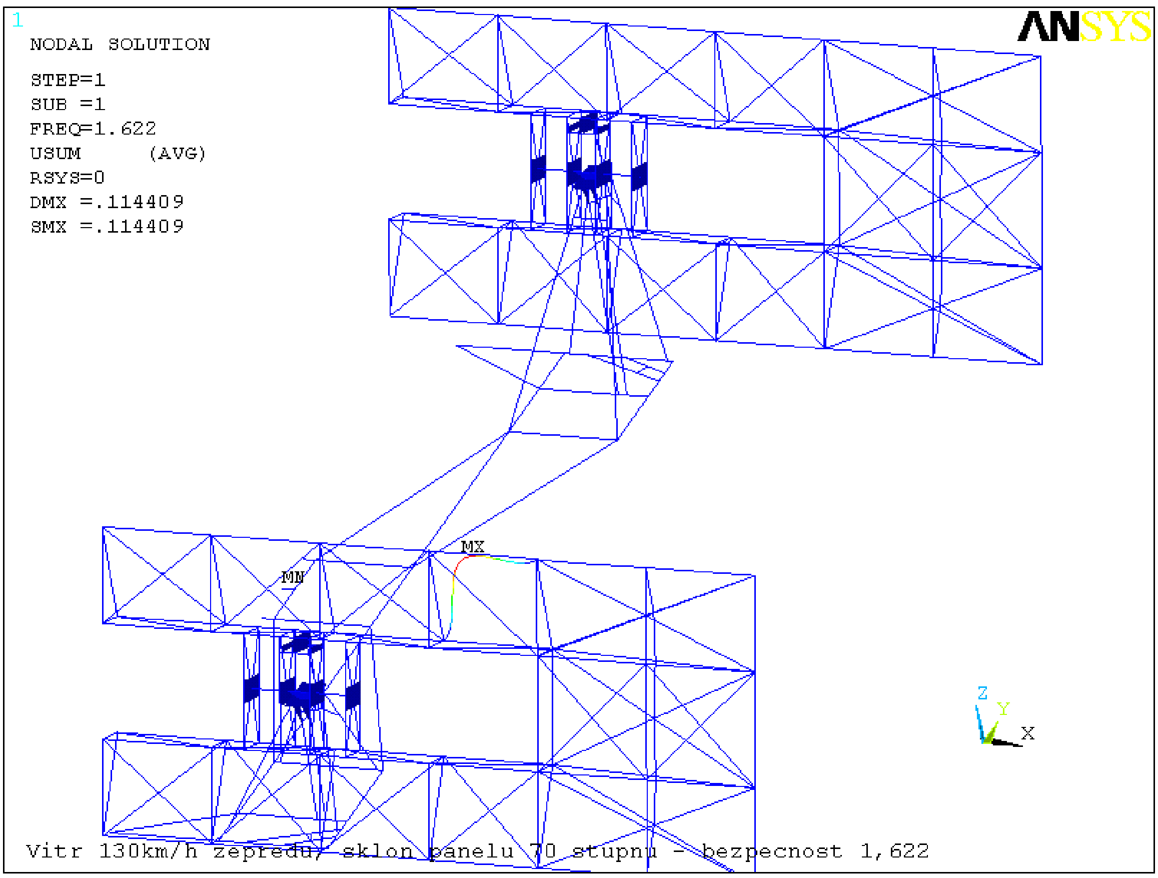


Fig. 11: The rod losing buckling stability for of the system with α = 70°, wind acts from the front

5. Conclusion

The aim of this study was to design and control the photovoltaic power plant. Total weight of profiles used to build the designed construction was 50 t.

Considering the evaluated limit states (limit state of elasticity and limit state of buckling stability of rods), the most adverse inclination of the lattice board equipped with panels is $\alpha = 70°$ which is the maximum vertical inclination of the board. As computational modeling worked only with static action of wind, which does not correspond with reality, the panels must be reclined to horizontal position as soon as wind speed reaches 75 km/h (computational wind speed was 130 km/h).

Acknowledgments

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