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APPLICATION OF GEOMETRY OF WIND FLOW ACROSS SPHERE IN PYLON ALUMINIUM SUBSTRUCTURE ANALYSIS

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The paper focuses on the presented cause of structural analysis of an aluminium substructure for lighting sphere on top of the brand pylon and the effect of such design on the structural stability and stiffness against horizontal loads from wind. This paper reviews the problems, inputs and analysis procedure during the geometric shaping of substructure elements and acrylic coating.

1. Introduction

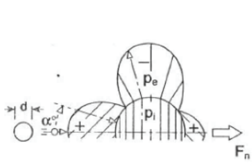
Static Procedure, appropriate for this case, including the design cases of the structure of most low- and medium-rise buildings as well as the cladding of all buildings gave answers about wind flow impact on sphere substructure. The goal was to construct the lighting ball with 3.4m diameter, on the top of brand pylon. Height was 25m from the ground level. The structure to be designed in this case is relatively rigid. Detailed approach to the dynamic properties of the structure and elements is not required and dynamic actions of the wind can be represented by equivalent static loads. The applicable exposure factors and some gust effect factors, and pressure coefficients also, for the Static Procedure are specified in many state code standards, but for this case, it was necessary to obtain all available articles and papers that describe the problem. Figure 1 shows the calculation of total wind force.

TOTAL FORCE $F = C_f \cdot q \cdot C_g \cdot C_e \cdot A$; $A = \frac{\pi d^2}{4}$

for $d\sqrt{qC_e} > 0.8$ and moderately smooth surface

C_f : FORCE COEFFICIENT

$C_f = 0.2$



$p = p_i - p_e$ p_i for closed tanks = working pressure

$p_e = C_p \cdot q \cdot C_g \cdot C_e$

C_p : EXTERNAL PRESS. COEFF. FOR $d\sqrt{qC_e} > 0.8$ and moderately smooth surface

α=	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°
C_p	+1.0	+0.9	+0.5	−0.1	−0.7	−1.1	−1.2	−1.0	−0.6	−0.2	+0.1	+0.3	+0.4

Figure 1 – Calculation of total wind force

2. Load analysis and drag coefficient

In fluid dynamics, the drag coefficient (commonly denoted as: *cd*, *cx* or *cw*) is a dimensionless quantity that is used to quantify the drag or resistance of an object in a fluid environment such as air or water. It is used in the drag equation, where a lower drag coefficient indicates the object will have less aerodynamic or hydrodynamic drag. The drag coefficient is always associated with a particular surface area. The drag coefficient of any object comprises the effects of the two basic contributors to fluid dynamic drag: skin friction and form drag. The drag coefficient of a lifting airfoil or hydrofoil also includes the effects of lift-induced drag. The drag coefficient of a complete structure such as an aircraft also includes the effects of interference drag.

2.1 Definition

The drag coefficient is defined as:

$$c_{\mathrm{d}} = \frac{2F_{\mathrm{d}}}{\rho v^2 A}, \tag{1}$$

where:

F_d is the drag force, which is by definition the force component in the direction of the flow velocity

ρ is the mass density of the fluid

is the speed of the object relative to the fluid and

A is the reference area.

The reference area depends on what type of drag coefficient is being measured. For a sphere reference area is $A = \pi r^2$.

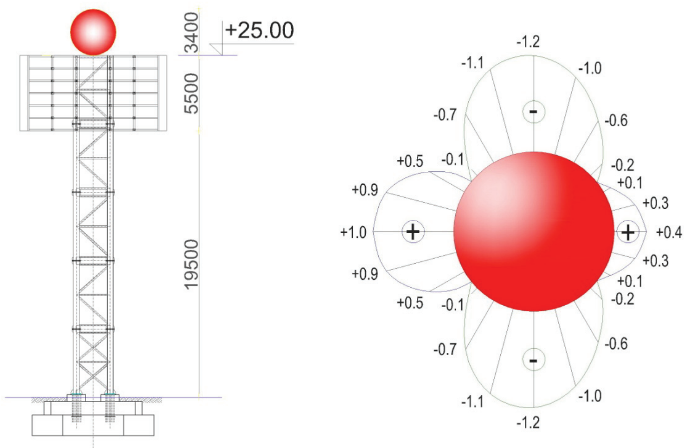


Figure 2 – LEFT: Side view of pylon structure with aluminium sphere on top, RIGHT: Wind force coeff. distribution across sphere

3. Design

Sphere substructure needed to be lighter then 500kg, and because of the sphere and pylon dimensions it was impossible to make it from steel. The only structural material that should response the stiffness and strength conditions, and also be much lighter then 5kN was aluminium AlSiMg 0.5. Figure 3 and Figure 4 shows load values on main structure elements.

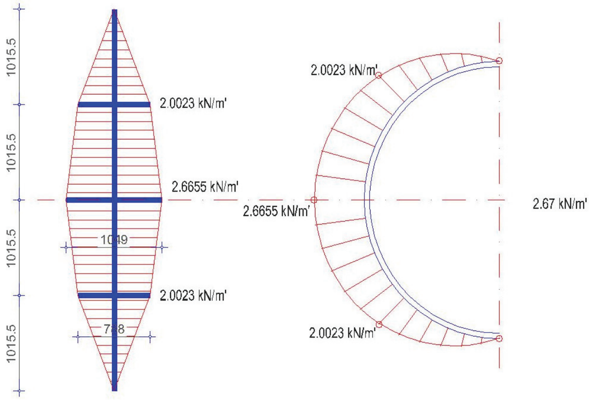


Figure 3 - Nominal wind loads on the one vertical structure element:
LEFT: front view, RIGHT: Side view

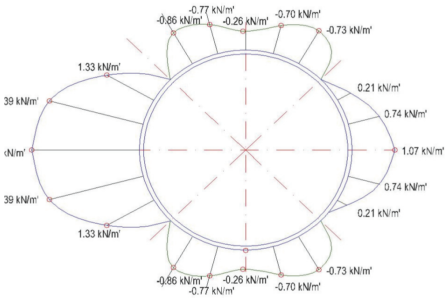


Figure 4 – Calculation values for wind loads on the one vertical structure element: Side view

First analysis results was used to recombine members, add diagonals, remove the "zero-members" and check structure on exploating loads, such as servising LED lights inside the ball and meintenance.

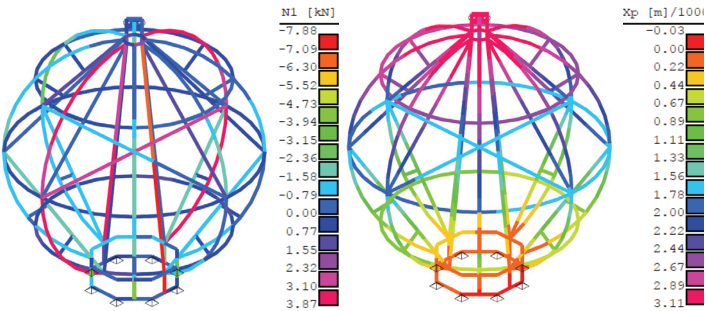
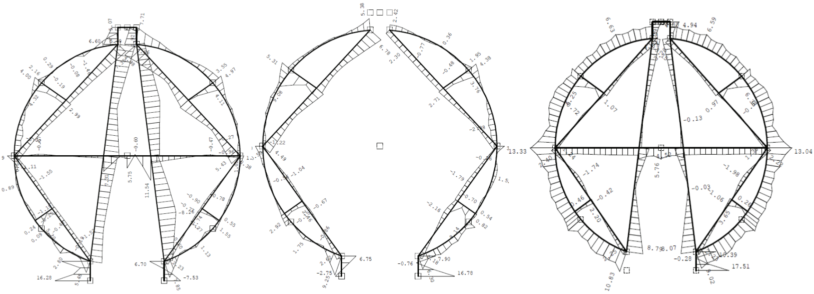


Figure 5 – LEFT: Axial forces in structural members, RIGHT: Deflections from wind impact

4. Limitations and requirements

After that, profiles and cross-sections should be unified, but noticing the construction and coating limitations. Hollow cold-formed profiles with square sections should be capable for welding, but with wall-thickness shouldn't be bigger then 2.5mm. Those limitations become requirements in structural optimization phase.



(1) (2) (3)

Figure 6 – Stress distribution in three main vertical structure planes:
(1) along, (2) 45°degree angle, (3) cross plane

At the end of the analysis and design processes, lightweight optimal aluminium substructure was obtained. Total weight was less then 200kg, and with acrylic coating (Figure 7) and joints together - less than 350kg. This was resulting the chance to optimize the pylon steel structure bellow the height of +25.0m from the ground.

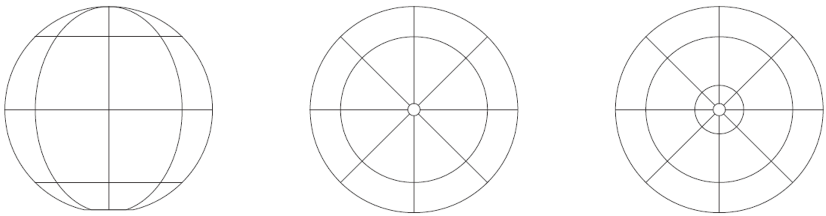


Figure 7 – Acrylic coating: Side view, Top view, Bottom view

Successful completion of design phase launched the construction phase and subjects like making, cutting, shaping, bending, welding processes etc. There was necessary to produce several test samples to be sure that dimensions and fittings can "work" together (Figure 8).

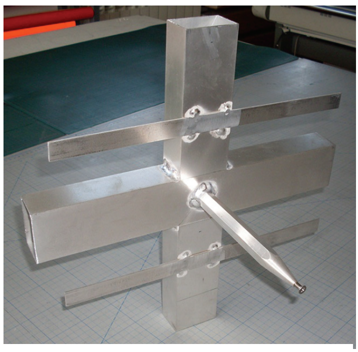


Figure 8 – Joint Test sample

5. Conclusion

Integrated design and analytical approach resulted with an optimal solution of aluminium substructure for quiet large lighting ball, supported on the bottom ring, on the height 25m from the ground, on parking area, in front of the trade center. That means that the sphere has maximum of exposure to wind flow, and geometrical distribution of the loads couldn't be ignored. On the contrary, application of drag coefficients and gust effect in quasi-static formulation gave realistic behavior of calculation model and analysis.

References

1. *Daekun Kwon1, Tracy Kijewski-Correa, Ahsan Kareem* (2006). e-Analysis/Design of Tall Buildings Subjected to Wind Loads
2. ASCE, ASCE 7-98: Minimum Design Loads for Buildings and Other Structures, American Society of Civil Engineers, Reston, VA, (2000).
3. *Bungale S. Taratah* (2008). Wind and Earthquake Resistant Buildings, Marcel Dekker - New York

Аннотация

Статья посвящена структурному анализу алюминиевого основания сферического фонаря на вершине пилона и определению влияния этого фундамента на устойчивость и жёсткость конструкции при действии горизонтальной ветровой нагрузки. Эта статья обобщает проблемы и этапы геометрического формообразования элементов основания и акрилового покрытия.