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Investigations On the Optimization of the Geometric Shapes of Skyscrapers Applications through numerical simulations in the context of Tirana

Aleksander BUDINI[1]; Nikolla VESHO[2]; Valerio PERNA[3]; Olgert GJUZI[4]

[1] Structural Engineer - Freelance, TIRANA, Albania

[2] Lecturer at Department of Civil Engineering, POLIS University, TIRANA, Albania

[3] Head of Innovation Factory, POLIS University, TIRANA, Albania

[4] Institute of Geosciences, Energy, Water and Environment, TIRANA, Albania

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ABSTRACT

This research presents studies and comparisons on geometric shapes in a skyscraper design. To provide useful information for estimating the geometric shape when designing a skyscraper and to reach useful conclusions. Although for many experts who are not involved in the field of construction can manage the geometric shape of a skyscraper as an iconic shape or a shape which shows the modern architecture and often associate it with its aesthetic side, but this is only one of the conditions of which in terms of importance is not ranked first, as this is mainly related to the solutions made by architects to reduce the force of the wind which affects the structure. To show the impact that geometric shapes on a skyscraper, different models of geometric shapes and comparisons between them will be shown. This comparison consists of numerous simulations in the wind parameters and deriving conclusions with reactive parameters of the structure such as: surface wind pressures and tubular pressures that occur at the rear of the structure. After the development of the method we are able to derive an optimal geometry to achieve a reduction in a high percentage of wind. Early stage design allows us to later give us the parameters and structural performance that engineers seek to achieve. In addition to the reduction of wind force that most high structures have the main problem as they are constantly under this atmospheric pressure, in Albanian case for this regions should be considered another problem related to the seismic factor. In this paper we will try to reach a compromise between the geometric shape which should be as aerodynamic as possible, but also to satisfy the conditions and rules given in Eurocodes, in which it is required that the geometric shapes of the structures be regular in plan and height in order to avoid seismic problems. Based on the latest earthquake that occurred on November 21st 2019 in Albania, which showed some important failure mechanisms of structures by non-compliance with the rules set regarding the seismic configuration and more. The compromise reached between the factors of Wind, Seismic, Exploitation, and Aesthetics would be the ideal geometric shape and the solution of many problems encountered in the high structures called skyscrapers through BIM tools.

Keywords : Geometric Shapes, Skyscrapers, Wind Tunnel, Seismic Simulations, Design optimization, BIM

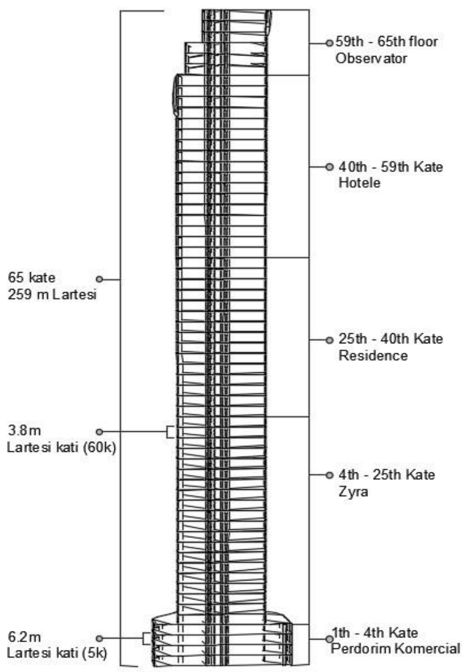
I. INTRODUCTION

The Case Study is a concept form in which after a study in which it is required to achieve aerodynamic geometric shapes but also functional or usable as much as possible, as the more aerodynamic the geometric shapes are, the more their usage space is reduced. In the proposed model it is a semi-elliptical shape on its three sides and with a RC core[ ] system configured in such a way that the seismic stresses are evenly distributed and the RC walls work as well as possible by the shear forces. The height at which the structure is conceived is 259m high, consisting of 65 floors which will be used for commercial use, offices, residences, hotels, observatory. Diving depth to ensure the required insertion is 30.6 m. The groundwater level is generally 2.0-2.7 m below the ground surface. Caisson foundations with a RC plate foundation with 3m thickness and piles with 45m length.

A triangular exterior façade encloses the entire structure, which follows a regular arched shape along its entire height, but the placement of an exterior arched steel element which has a wind deflection function but also an aesthetic that makes this structure iconic and gives it its unique and illuminating character.

The structural layouts of the typical floors in each area are shown in Figure 2. The steel-concrete superstructure resists lateral loads with a central hexagonal concrete wall connected to the mega-frame giving the structure the best possible performance.

A conceptual structure with a height which if we look at the parameters of a skyscraper would be included in the category "Super Tall" height which in Albania still does not have one, where currently "Down Town One" has reached a minimum height of 140m which takes the name Skyscraper



a) Section cut and Function Indicator

b) 3D Model in Perspective

Figure 1. The Sky Tower proposed model (Source: author)

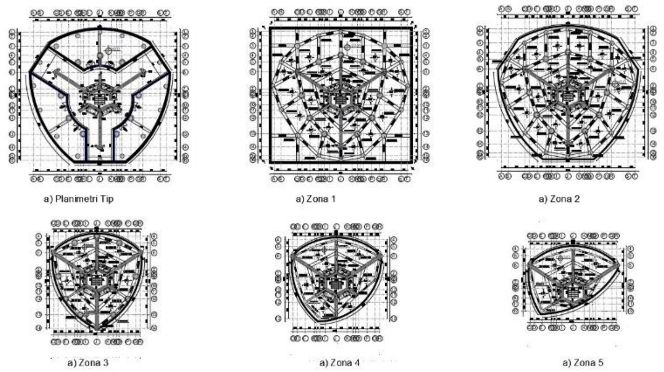


Figure 2. Proposed Structural and architectural plans (Source: author)

To investigate the reaction of the SKY TOWER project, the conceptual model in the design phase is required to be applied in "real scale model" simulation of the wind tunnel, as well as real-scale seismic simulation with the most unfavorable situation and combination.

To accurately determine the structural displacements, drifts and other parameters, to analyze in real scale the eddy effect that occurs behind the structure and to accurately calculate the displacement that this structure undergoes with the most unfavorable maximum combination and application of wind speed. Also doing simulations in computational programs to analyze reactions, diagrams, ground parameters and temperature analysis.

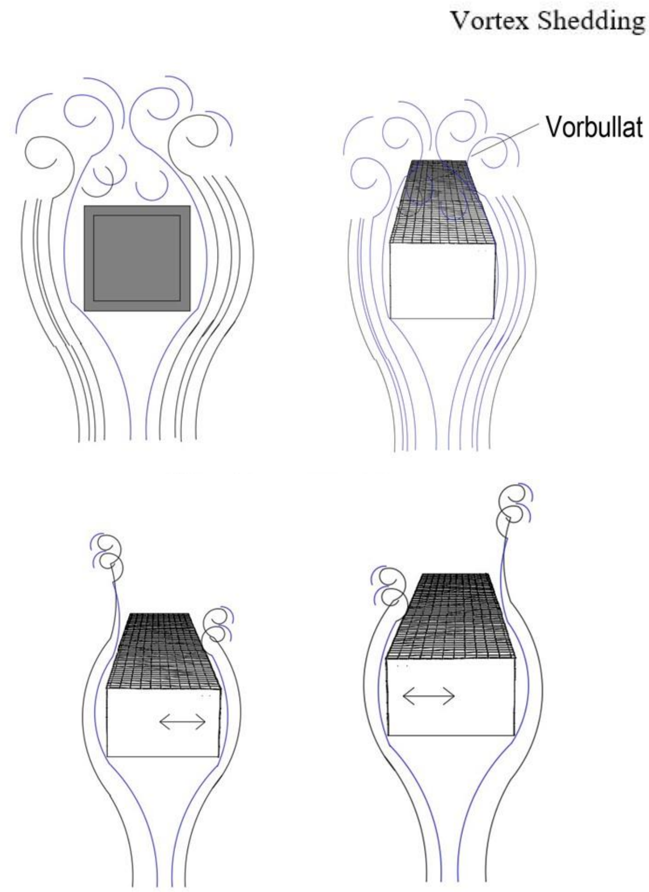


Figure 3. Effect of creating Wind vortices on the structure (Source: Simiu and Scanlan, 1996).

2. Theoretical analysis, Wind Effects on High Structures

When the wind speed increases or when a marked change occurs, then the movement becomes turbulent and the wind current lines cease to move in parallel. See in Figure 3.

Laminar current is characterized by a low average velocity which moves in one direction and has a minimal mixing between wind vectors. As the speed increases, there is an explosion of vector motion, and this is the beginning of the transition from laminar to turbulent mode. If the speed continues and increases, it passes to the phase where it is called turbulent movement of the wind current. Turbulent current is characterized by chaotic motion and consists of rotational motion in areas called vortices.

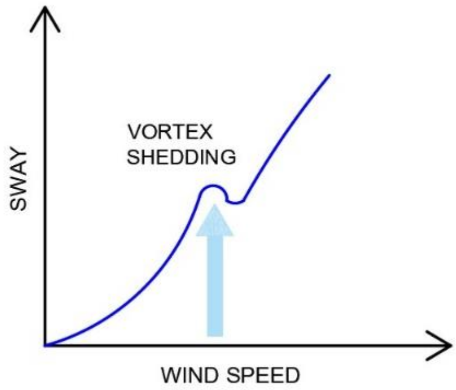


Figure 4. The wind power curve (Source: Taranath, 2012)

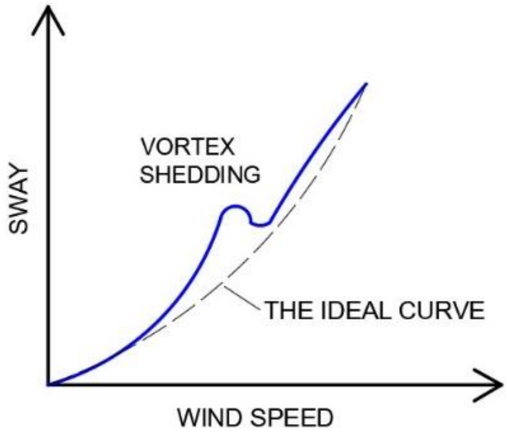


Figure 5. The difference between the vortex shedding curve and the ideal one (Source: Taranath, 2012)

If the velocity in the laminar current is recorded at a point we will get data that show that there is no random fluctuation of velocity therefore the laminar currents are regular and easy to analyze. For turbulent flow we will take data that are more complicated and we can say that it is composed of a constant velocity component and an oscillation component, the larger the oscillation component the more turbulent the air flow becomes. Because it is of a chaotic nature and to analyze turbulent currents is complex and to predict which of the currents would be dominant. To determine this one will need to use a parameter called the Reynolds number in 1883.

$$Re = þ*u*l / \mu$$

Bernoulli Effect – The air masses will have a more reduced pressure when the speed increases showed in Figure 6

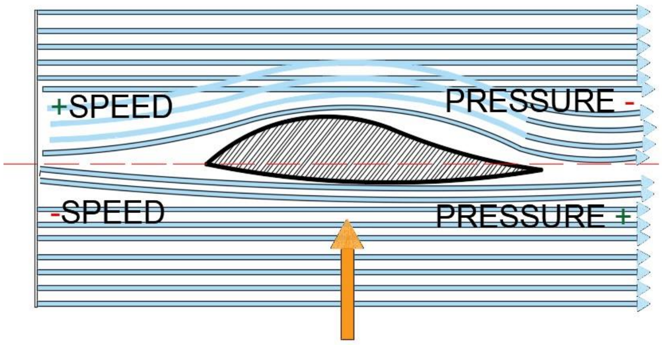


Figure 6. Bernoulli Effect (Source: Taranath 2012)

When the wind speed increases also the intensity of the movement from behind, and in turn increases. Every object has its natural frequency, and when it is related to the frequency of the vortex, a curve is created in the period of oscillation which violates the structural integrity. Figure 4.

The ideal curve needed in a skyscraper is what architects seek to achieve, and for this there are many solutions that are offered by designing geometric shapes in plan and verticality such as to achieve a constant curve in the velocity-oscillation ratio. Figure 5.

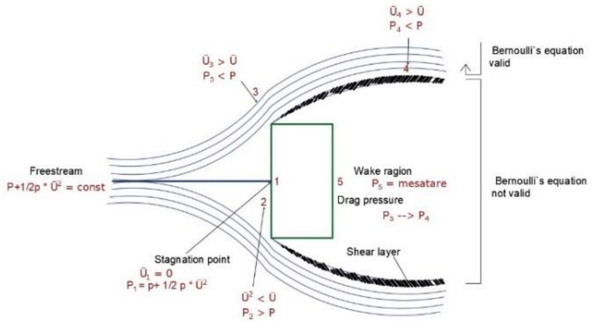


Figure 7. Divide the current into a quadrangular geometric shape (Source: Aynsley et al, 1977).

When the fluid particles near the surface are slowed down by inertial forces, the flow current separates and the upstream stream overcomes the viscous cohesive forces by holding the flow lines together, causing the flow surface to bounce back to form a scattering vortex. from the surface and form a free shear layer (Aynsley et al., 1977). (Simiu and Scanlan, 1996). This usually occurs in the corners or corners of it sharper or smoother, the current characteristics depend on the Reynolds number. Reynold number is the ratio of inertial forces to flowing viscous forces. (Holmes, 2007).

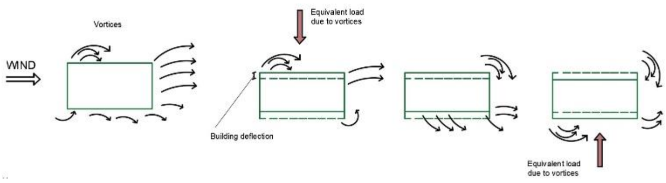


Figure 8. Vortex Shedding and Lift Force (Source: Taranath, 2012)

$$S = \frac{n_s D}{V_h}$$

Equation.5 Strouhal Number (Source: Kaneko Sh. 2008)

Where ns- vortex frequency, D- normal dimension of body in current, Vh- current velocity in height h, Strouhal number is not a constant but varies according to Wind speed and body shape and for cylindrical and arched shapes others are measured by Reyolds number to a limit of up to 0.21 (Holmes, 2007).

If the frequency of the vortex propagation increases to a limit at which it reaches 10% of the natural frequency of the building then we say that the structure passes into resonance.

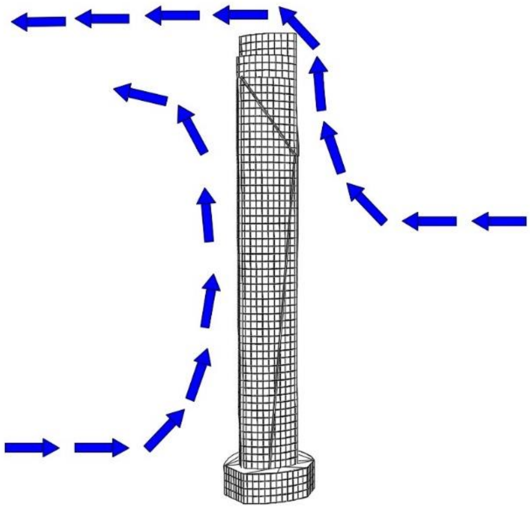


Figure 9. Downwind Eddy (Cochran and ASCE. Committee on Structural Wind, 2012)

3. Simulations in CFD and ETABs software

After the analysis as above, in the simulations made in the wind calculation programs and seismic calculation give us the parameters which satisfy the conditions and rules. The computer calculation analysis has been carefully processed respecting the Euro - Code and taking as a calculation model the most unfavorable cases that can occur to a high structure in a seismic area

Figure 10. Modal, 1st period captured (Source: author)

From the simulation in ETABS where the seismic force is mainly interpreted and applying the most unfavorable combinations the 1st modal period results T1 = 5.8sec. This shows that the structure has a good configuration in plan, uniform distribution of masses and a favorable dimensioning of the structural elements. So, we can conclude that the seismic aspects, this structural configuration reacts satisfactorily.

From the simulation in the dynamic calculation program Auto desk CFD 2021 which is the program that enables us to create the wind tunnel of the calculation. According to the studies of the maximum wind speed in the city of Tirana, it is judged that the wind simulation for the structure in the study is done with a speed of 31m / s. After applying the wind force, the results of the wind pressure are presented below

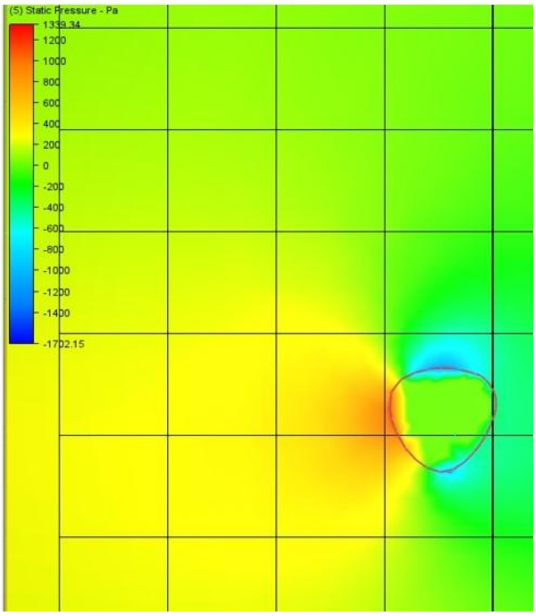


Figure 11. Wind pressure in structure (Source: author)

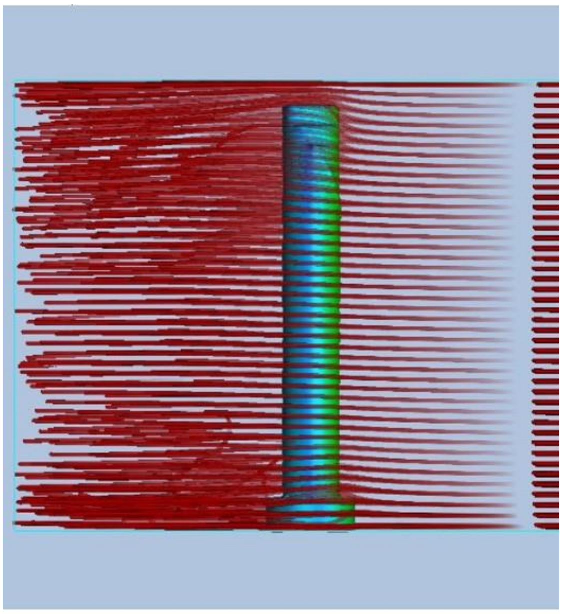


Figure 12. Wind pressure in structure (Source: author)

Comparison of Results between the 2 models, The proposed one versus the rectangular one

After analyzing the two different geometric shapes below we will compare the wind pressures on the surface of the skyscraper according to the directions x1-1, x2-2 and y1-1, y2-2.

Obviously below is the comparison between different shapes, first one is the classic rectangle and the other shape which is an aerodynamic shape that slides the wind force easily and reduces to a high% the Wind, which contributes to the safety of the structure and the cost of building materials, mainly glass facade.

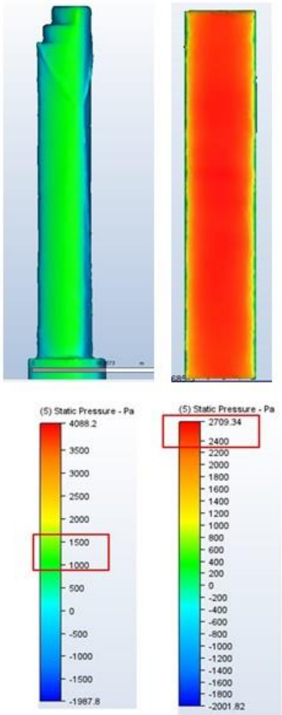


Figure 13. Comparison of wind pressures direction X1-1 (Source: author)

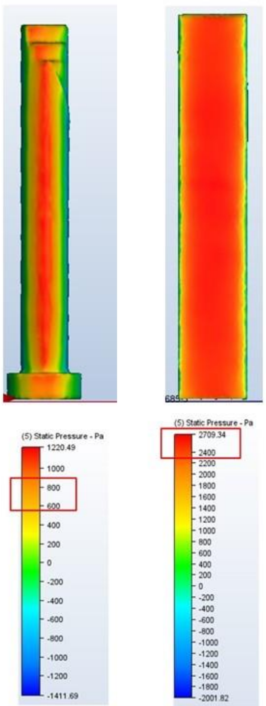


Figure 14. Comparison of wind pressures direction Y1-1 (Source: author)

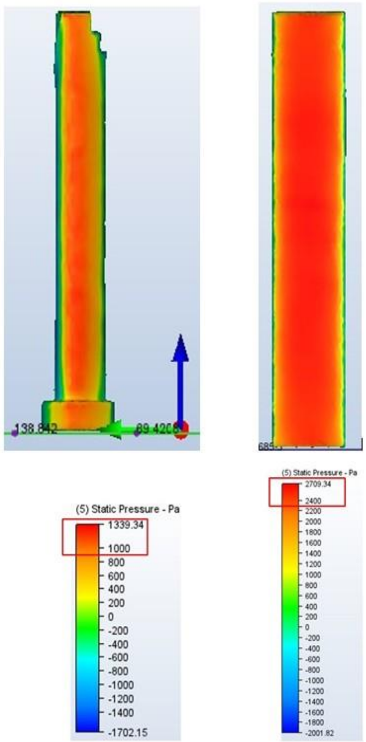


Figure 15. Comparison of wind pressures direction X2-2 (Source: author)

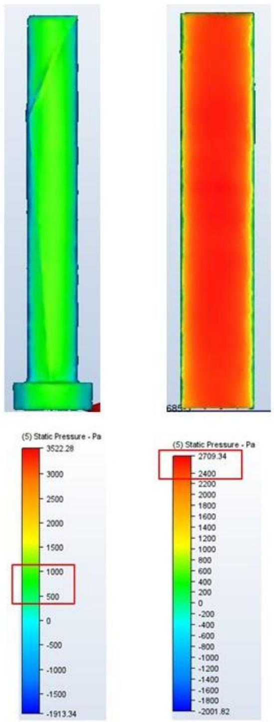
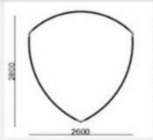
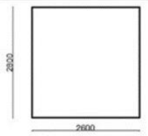


Figure 16. Comparison of wind pressures direction Y2-2 (Source: author)

Table.01. Summary table of comparison of basic parameters (Source: author)

Geometric Shape	Direction X1	Direction Y1	Direction X2	Direction Y2
	F_{max} = 1.5 kN/m²	F_{max} = 1.2 kN/m²	F_{max} =0.8 kN/m²	F_{max} = 1 kN/m²
	F_{max} = 2.7 kN/m²	F_{max} = 2.5 kN/m²	F_{max} = 2.7 kN/m²	F_{max} = 2.5 kN/m²
Wind Force Reduced	57.1%	70.2%	91.8%	85.7%

In the table above are compared according to 4-directions, two different geometric shapes, with equal object height and the same wind speed. From this equal comparison we understand that the role of the geometric shape in a skyscraper plays an important role in avoiding wind forces in the structure. It also plays an important role in the economic cost of a skyscraper, most of all in saving the facade of the building which is constantly under wind pressure.

The pressure which is taken into consideration is that in the most unfavorable case as in figure 15 in which the reduction of the Wind reaches the mass of 57.1% compared to the form with right angles.

In the table above we can use it as a guide in the field of architecture to see and compare possible models that an architect is designing a skyscraper. From this comparison we understand how important it is to choose the geometric shape and behind the geometric shapes is hidden a solution which is in harmony with natural science, which if we study nature we will understand that behind every shape is hidden a law of nature.

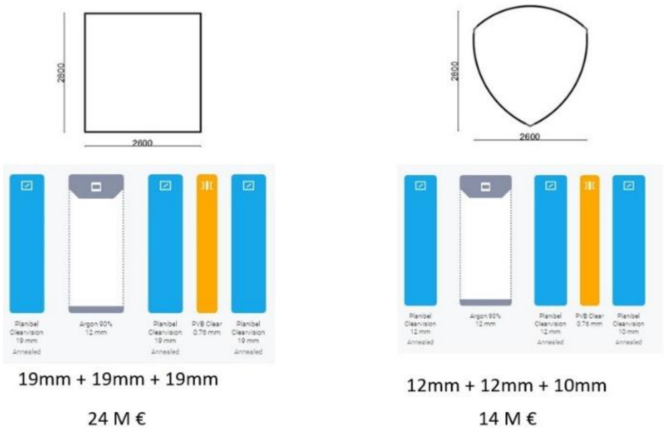


Figure 17. Glass layer and Thickness for each model (Source: author)

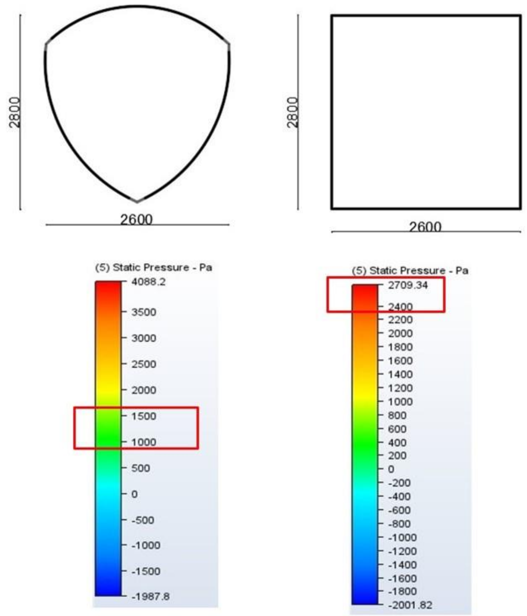


Figure 18. Comparison of wind pressures
The most unfavorable case (Source: author)

After the conclusions as above in table.01 where the performance of two different geometric shapes is clearly seen, according to the most unfavorable case, a technical-economic calculation is made. From the technical-economic analysis the first thing we do are the calculations on the facade of the structure, finding the thickness of the facade glass and the layers of glass needed to withstand the loads as above in figure 17. From the facade calculations it is concluded that the thickness of glass to withstand the loads is needed. In the verifications made SLS and ULS where the required performance is achieved we see that in two geometric shapes it is preferred to keep 3 layers of glass 1 outer and 2 inner and the thicknesses respectively as in Figure 17. From an economic analysis of the cost of the facade it can be seen that there is significantly an economic cost saved in the optimal geometric shape, but even more in the structure.

II. CONCLUSIONS

The conclusion reached while studying geometric shapes in a skyscraper is what we expected. In which the topic of the study is confirmed, which supports the idea that the role of designing the geometric shape in plan and verticality, manages to reduce to a high percentage the reduction of wind force in the structure. This reduction of wind force makes the structural situation easier for an engineer and gives the structure a higher security, but also the economic benefit is high. The one in which most skyscrapers face a problem is the glass facade, which is constantly under wind pressures and requires the use of high-strength glass or the addition of steel contractions as a support for the facade. By reducing the wind force this translates to the facade a glass quality with less resistance and reduction of steel contractions all this at a lower cost, one which can be avoided.

From the study conducted and the conclusion as above, a set of recommendation is reached as follows.

III. RECOMMENDATIONS

Before designing a grille after studying the area in which it will be located and after a good study of the design code in a certain location, it is recommended that the geometric shape in the plan of the building should be as aerodynamic as possible which contributes in reducing wind force.

Since in the design of a skyscraper, in addition to the geometric shape in plan and verticality, the geometric shape should be designed so that the wind pressures are distributed as evenly as possible because their uneven distribution brings great attractive and pressing stresses. must move with the geometric flow so that the pressures are distributed, without compromising the design codes and its security.

Based on the structure, its geometric perimeter should be large due to the large moments that accumulate based on the structure and wind pressures.

To increase the height of the structure to reduce the geometric section.

The use of arched shapes along the whole structure or in its corners.

To avoid as much as possible inappropriate classical designs of structures.

From the performed simulations, the applications would be recommended for tower facades as much as possible the metal joints and contractions, which significantly reduces the vibration and perform as a vibration absorber against the displacements of the building by wind force.

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