# Structural and Load Analysis of the Belgian Atomic Tower

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**Abstract.** In order to study the service life of the building and its variable factors, the material composition of the building is analyzed with the example of the Atomic Tower in Belgium. At the same time, in order to study the variable load factors on the building more carefully, the transfer of load on the atomic tower is first analyzed, and then the analysis of wind load, snow load, geometry and dead weight on the Atomic Tower in Belgium is analyzed. In addition, in order to ensure the accuracy of the experiment, the phenomenon that the experiment may fail is analyzed. lognormal distribution is used to show the experimental process. Finally, it is concluded that snow load and wind load are the main variables affecting the stability of the Atomic Tower in Belgium. Moreover, the influence of materials may reduce the limit that the building can withstand due to oxidative corrosion, leading to instability.

**Keywords:** Atomic Tower in Belgium; structural analysis; load analysis.

## 1. Introduction

One of the most recognizable structures in the world is the Eiffel Tower, located in Paris, France. A local and even national landmark, it was constructed in 1889 to commemorate the 100th anniversary of the French Revolution's victory [1]. Its bottom is distributed 128 meters on each side, and the four giant angled inclined piers on the long base are well-known in this brief introduction. However, there is also a new problem that arises, which is the lifespan. And now people are more concerned about how long the Eiffel Tower can last, as different building structures and materials mean different lifespans. For example, the main structural material of the Al Tower is steel, which will lead to oxidation and shorten its lifespan. If it is too light, it will cause insufficient elasticity and easy bending. The higher the building, the higher the wind speed at high altitudes, and the higher the wind loads. The maintenance of the Eiffel Tower is also very difficult. Starting from 1968, the painting project of the Eiffel Tower began a new phase. Repair the rusted area with raw linen oil red lead paint. The topcoat adopts a mixture of dry oil (92 94%) and alkyd resin (6-8%) as the base material.

The material of the building determines the life of the building and the stability of the entire structure. If the entire building is made of iron, it will face long-term oxidation. Iron is a reactive metallic element that reacts with oxygen, carbon dioxide, and water vapor in the air to form a mixture of iron oxide, iron hydroxide, and carbonate iron. The volume of the rust body is about 8 times the original volume, loose and porous, which is very conducive to continuous further rust. The connected iron parts rust and are corroded, and the stress area continues to decrease. Over time, they are unable to bear the connection force, causing components and furniture to fall off. The steel bars of concrete are exposed to rust, causing cracks due to the volume expansion of rust. The concrete falls off and further deteriorates, causing the concrete components to gradually lose their load-bearing capacity.

The impact of loads on buildings is also crucial, for example, the impact of wind loads on buildings is to cause lateral deformation and vibration when the wind is strong, mainly affecting high-rise buildings. Primarily made up of fundamental wind pressure, wind load form coefficient, wind vibration coefficient, and wind pressure height variation coefficient. These coefficients depend on the location's wind speed, the height and design of the buildings, and the degree of regional roughness.

## 2. Structural Analysis of the Belgian Atomic Tower

The same situation happened in the Belgian Atomic Tower, which is located in the city park of Elmendo in the northwest suburb of Brussels. It was designed by the famous Belgian engineer Andrew Watercairn for the Brussels International Exposition in 1958. Its design idea is to integrate the metal iron molecules α. The model of the cubic crystal structure of iron is magnified 165 billion times. The Brussels Atomic Tower has now become the most representative Belgian landmark with a structure very similar to the Eiffel Tower. The 9 balls are connected by thick steel pipes, with a total weight of 2200 tons. Its 9 balls represent 9 iron atoms and symbolize the 9 provinces of Belgium. It is composed of both aluminum and iron. Such materials are prone to oxidation and reduce the service life of steel. Of course, there are also many other variable factors that can cause deviations in the entire building. Therefore, analyzing variables such as structure and materials can better analyze the lifespan of the entire building and provide solutions.

The Belgian Atomic Tower is composed of 9 large aluminum balls with a diameter of 18 meters, each representing an atom. The balls are connected by hollow steel pipes, each of which is approximately 29 meters long. The total weight of 9 round balls and steel frame structure is 2200 tons, and the highest ball is 102 meters above the ground. Each ball surface is welded with 5800 triangular arc aluminum sheets. The structure consists of 9 balls connected to form a cube, with 8 balls located at the 8 corners of the cube and connected by steel columns. One corner of the cube is consolidated with the ground, and the other three balls in the lower half are connected to the ground through steel columns, thereby supporting the entire structure. Connections among elements and the external supports: The structure is connected to the ground through three steel columns, which provide restraint in the x and y directions and provide restraining bending moments. The dead load is mainly its own weight, which is 2400 kN. Because the weight of the ball is much greater than that of the rod, it can be approximately. Assuming 2400 kN is evenly distributed among 8 balls, the live load it is subjected to can be ignored. The additional load is snow, as indicated in Fig. 1.

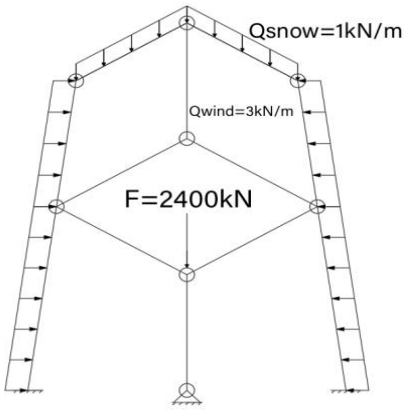



**Fig. 1.** Structure of the Belgian Atomic Tower.

### 2.1. Potential hazards of the material

Iron rust will reduce its strength, plasticity, toughness and other mechanical properties, and will also destroy the iron geometry and shorten the service life. In addition to its chemical activity, iron is susceptible to rusting, which also has a lot to do with environmental factors. When oxygen from the air is dissolved in water, oxygen combines with iron in the presence of water to create rust of iron oxide. Rust is easy to fall off, and if the rust is not removed, it is especially easy to absorb moisture, and the iron will rust faster.

In order to facilitate subsequent calculations and simplified the Belgian Atomic Tower into a similar planar structure. By consulting relevant information on the atomic tower, the length of the bars and the angle between the balls and the bars are calculated, as shown in Fig. 2. After finding connections among elements and the external supports, the dead loads, live loads and additional loads, and draw the free-body diagrams of components are identified. The structure is connected to the

ground through three steel columns, which provide restraint in the x and y directions and provide restraining bending moments.

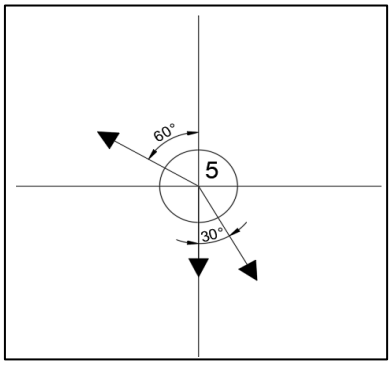



**Fig. 2.** The angle between the balls and the bars.

### 2.2. Loads on structure

Live loads that fluctuate in value during the course of the design reference period and whose values are not insignificant in comparison to the average value, such as crane loads, wind loads, snow loads, floor live loads, roof live loads, and ash accumulation loads. Live loads, often referred to as changeable loads, are the use or occupancy loads as well as naturally occurring natural loads brought on by people, objects, and moving vehicles. Examples include live loads on industrial and civil building floors, loads on the roof and on the roof area, loads on vehicles and cranes, and loads caused by the wind, snow, ice, and waves. Particularly on inadvertent loads (special loads or accidental impacts), which may or may not happen during the design reference period, are significant and last for a little time when they do. For instance, exploding force, impact force, and avalanche from a typhoon.

Under the same horizontal load, the existing vertical load of the pile top is conducive to reducing the horizontal displacement of the pile body and weakening the bending moment of the pile body caused by the horizontal load. In the horizontal loading process, the main area of pile soil action is the middle and upper part of the soil around the pile, and the application of vertical load on the top of the pile will mobilize the soil on the side of the pile to form a larger soil disturbance zone [2].

## 3. Transfer of Loads among Elements

Load transmission model for vertically loaded bored piles in areas of reclamation that contain gravel. The measurement of pile-side friction resistance exertion, which is directly related to the shear behavior of the pile-gravel contact, is the main objective. It is believed that the surface profiles of concrete piles and crushed stone particles are, respectively, circular curves and wavy curves. The macro and micro geometric relationship between the pile surface and the gravel particles serves as the foundation for calculations of shear displacement and shear expansion. Each finite element model's analysis error, when compared to the findings of the static load test, is often less than 15%. The prestressed hollow-core slab bridge has an increase in cracking load, through-joint load, and ultimate load of 50.0%, 91.7%, and 66.7%, respectively, over the conventional hollow-core slab bridge [3]. Empirical elastoplastic equation is used to calculate the shear stress at the pile-crushed stone interface surface. Additionally, a straightforward slip line field is created to pinpoint crucial shear displacements. The load-displacement curve of vertically loaded bored hole piles in the reclaimed gravel area was derived by using the finite difference equation. The performance of the suggested method is confirmed, and the findings are shown to be reasonable. The model prediction results are compared with the field observation and particle flow numerical simulation results. Additionally, parametric tests are conducted, and the findings demonstrate that the pile can bear higher loads when the particle diameter is similar to the pile's rough surface, and that an increase in wave angle and relative friction coefficient can help to improve bearing capacity [4].

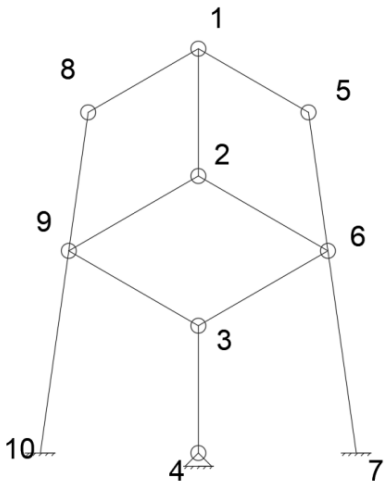



**Fig. 3.** The ballpoint numbers.

Step1: load transfer to the bend: The load is transfer directly to this red bead and the ballpoint passes through the column to the three ballpoint below and the three columns bears the load.

Step2: the top three ballpoint continue to transfer the load down, and these four beads carry the force of the top three pillars.

For No.2 and No.3 ballpoint: bears part of the load carry by ballpoint 1, but there is no pillar under it so it can only be transferred to two pillars No.9 and No.6 should bear the load passed down by No.8 and No.5 and share it with No.2. But finally share part of the load with No.3 to achieve stability.

Step 3: the load is transfer from these two black pillars to the found atomic, and the middle one is transfer from the pillar to the bottom bead by the ballpoint touching the grand.

### 3.1. Wind loads variability

Based on the Augmented Discrete Kalman Filter (ADKF), the wind load and wind response inversion methods are established, namely the ADKF virtual displacement method and the ADKF linear displacement method. Firstly, the structural dynamic equation is transformed into the form of state-space equation, and the wind load time history is assumed to be a random process, and the Kalman filter equation for inverting wind load and wind response is derived, and the acceleration and displacement response are fused to improve the inversion accuracy by expanding the observation equation [5].

Wind loads are formed by air movement, and the effect on buildings is irregular wind loads, which are actually random variable live loads, but different from general live loads. Basic wind pressure, geography, the roughness of the ground, height above the ground, and the size of the building are all related to wind load. In addition to wind noise, wind has an impact on buildings, although wind loads have the biggest impact on horizontal displacement. Supertall buildings are primarily controlled by wind loads, which manifest as downwind, crosswind, and torsional wind loads, which cause the structure to shake in three directions as the air passes through the towering structure. The frame structure has the advantages of large overall rigidity, strong ability to resist deformation, can improve the seismic resistance of the building, and is conducive to dividing the internal space of the building [6]. The probability density function is as follows:

$$f(x) = \frac{1}{x\sigma_1\sqrt{2\pi}} e^{-\frac{(\ln x-\mu_1)^2}{2\sigma_1^2}} \tag{1}$$

Where μ is the mean of the deflection, σ is the standard deviation of the deflection, and $\mu_3$=3, $\sigma_3$=0.6. Assuming the deflection of the bars follows a normal distribution, the probability density function (PDF) is shown in Fig.4.

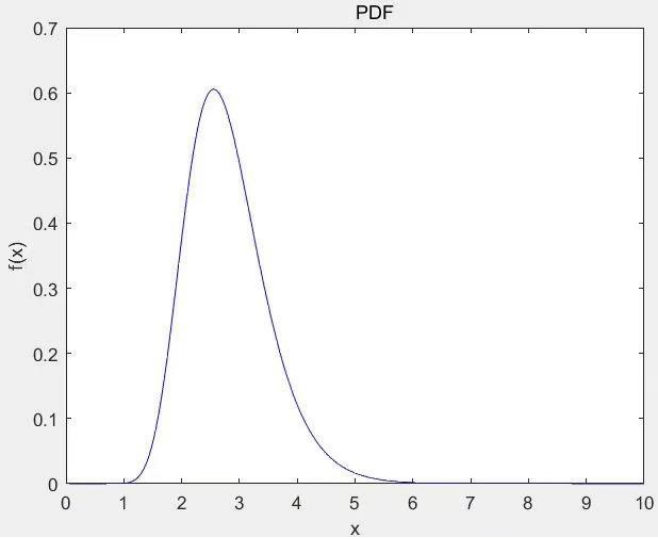



**Fig. 4.** Lognormal distribution of wind load.

### 3.2. Snow loads variability

Compared with the uniform distribution of snow loads, the solar greenhouse arch is more sensitive to non-uniform distribution of snow loads, and the ultimate bearing capacity under non-uniform distribution of snow loads is about 28% under uniform distribution of snow loads [7]. For high and low cross roofs, due to the drifting effect of wind on the snow, the snow of the higher roof will be blown down on the lower roof, forming a locally large drifting load on the low roof. For multi-span slope roofs and curved roofs, wind action not only reduces the total roof area snow, but also causes unbalanced snow load on the roof. The influence of roof slope on snow cover Roof snow load is closely related to roof slope, and generally decreases with the increase of slope, mainly due to the action of wind and snow slippage. The impact of snow cover on roof temperature. Long-span structures, like Single Layer Diamatic Space Frame Domes, are particularly vulnerable to earthquake damage when exposed to non-symmetric snow loads. This lightweight frame structure's structural system and geometry, when combined with the non-symmetrical loading conditions, may cause structural members to become unstable [8]. Assumming that snow load follows a lognormal distribution $\mu_2$=1 and $\sigma_2$=0.25, the probability density function (PDF) is shown in Fig.5.

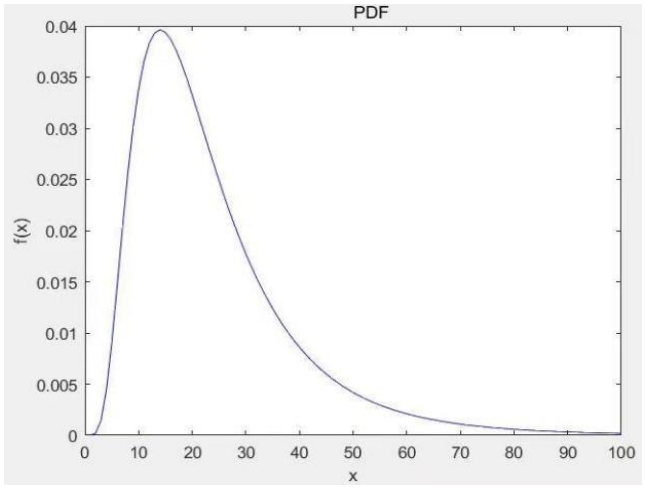



**Fig. 5.** Lognormal distribution of snow load.

### 3.3. Geometry Variability

Geometry is the foundation of the architectural design process, and has been intertwined with architecture since its inception, architecture is closely related to ancient geometry, so the space and shape of buildings appear in different geometric forms [9].

Geometry affects the media of architectural design, but also affects the results of architectural design, based on the context of architectural history, to analyze the interaction and change of architectural expression methods and architectural thinking activities, pointing out that the mature computer technology will inevitably lead to a new style in architectural history, and at the same time expounding the geometric characteristics of architecture and establishing geometric architectural views

Where μ is the mean of the deflection, and σ is the standard deviation of the deflection. Assuming $\mu_1$=0.07, $\sigma_1$=0.001. The probability density function graph is shown in Fig. 6.

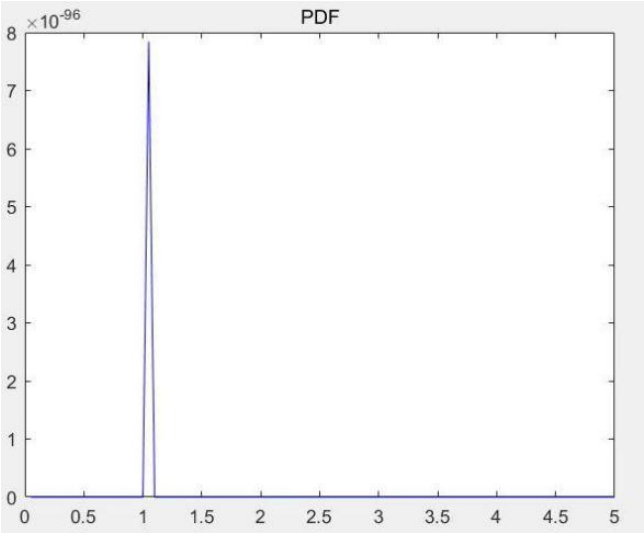



**Fig. 6.** Lognormal distribution of geometry

The linear strain value of the material is 0.002. Based on a given tensile strength of 50 MPa, the modulus of elasticity can be calculated using the following formula:

$$E=\sigma/\varepsilon \quad (2)$$

Where: E is the modulus of elasticity (in Pascal, Pa or megapascal, MPa), σ indicates the stress, i.e. tensile strength in Pascal, Pa or megapascal, MPa, and ε indicates strain (unitless).

Substituting the given tensile strength and linear strain into the equation, the elastic modulus of the material can be calculated: E = 50 MPa / 0.002 = 25,000 MPa. Therefore, under this assumption, the elastic modulus of the material is 25,000 MPa.

### 3.4. Dead Weight Load

Consistent load (permanent load), whose value is consistent over time. Or loads with very little variance in comparison to the average. For instance, the weight of the structure, ground pressure, settlement of the prestressed foundation, shrinkage of the concrete, welding deformation, etc. A load that is applied to an engineering structure that doesn't change (or whose change is minimal in comparison to the average) is known as a constant load, sometimes known as a permanent load. Such as the structure's own weight, added permanent load-bearing, the weight of decorative and non-load-bearing structural elements, soil pressure. Because a structure experiences consistent load over the course of its existence, long-term consequences must be taken into account while building the structure. The standard value of the bulk density of the material, sometimes referred to as the nominal value, and the geometric dimensions of the structure are the two main factors that define the structures self-weight. For example Splitting of robot models; Robot module stiffness identification; robot stiffness modeling; modeling of elastic deformation brought on by outside forces, as well as modeling of self-weight; Modeling of total elastic deformation of robots [7].

Heavy structural elements including foundations, walls (columns), beams, and plates make up the structure of the house. They must first support their continuous weight, which is themselves. The ground, roof, and ceiling also, plastering layer on the wall, doors and windows are all loads. Adjust

the connection state of the steel beam and the support so that the steel beam and the support are in the first connection state, and configure the first load to be borne by the steel beam in the first connection state, wherein the first load is part of the total load; The steel beam and the support are adjusted from the first connection state to the second connection state, and the second load to be borne by the steel beam in the second connection state is configured, where the second load is the total load minus the remaining load of the first load [10].

## 4. Probability of Failure

Structural performance function is Z for structure performance function C for structure resistance. D for load effects.

$$Z=C-D \tag{3}$$

If Z >0: structure reliable, Z<0: structure failed Z=0: structure in limit state.

Assuming the cross-section of the load is circular, and the diameter d is random variable, d-lognormal (0.07, 0.001), lognormal here takes 2 attributes: (mean, standard deviation). Each member needs to consider its own weight, snow load, and wind load. For example, when calculate whether the R of rod 1-8 under snow load is greater than 0 from the perspective of bending moment, from the graph can obtain D=56800qwind.

The structure is considered a series system, which means that the failure of any one member will lead to the failure of the entire structure. Only when the corresponding shear force and bending moment of the member under three different loads do not exceed the maximum value in certain sampling, can this sampling be considered successful.

After the experimental data, the results of the experiment were very unstable at the beginning. However, the instability also decreased as the number of tests increased, and the probability of failure of the experiment gradually stabilized between 0.3-0.4 after 9000 experiments, as shown in Fig. 7.

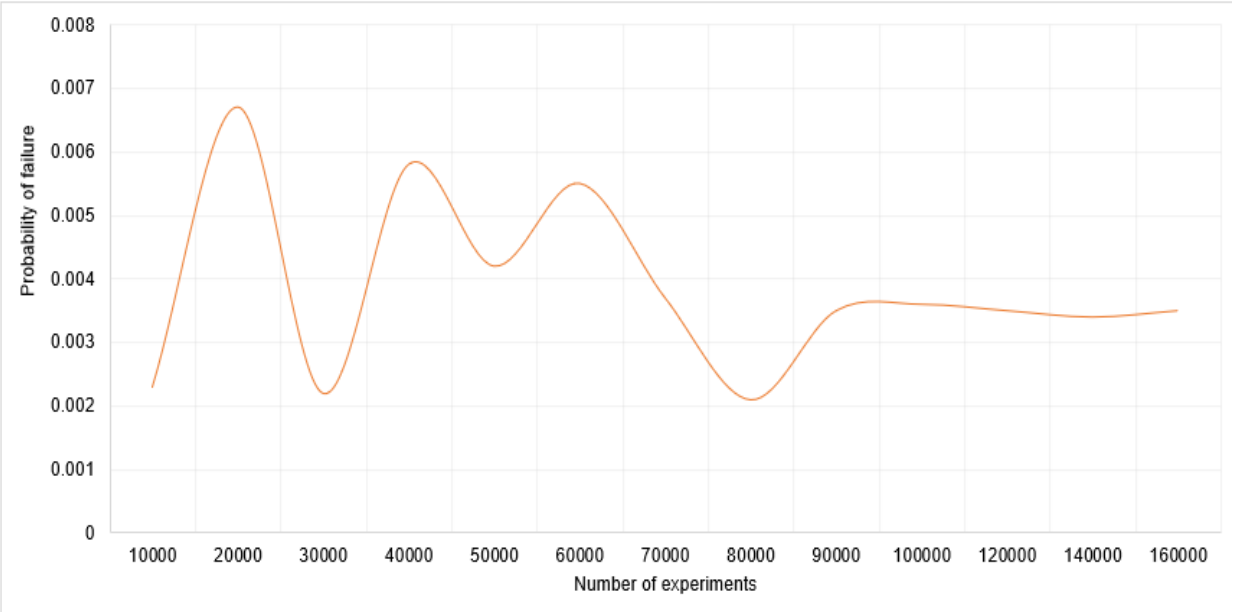



**Fig. 7.** Probability of failure.

## 5. Conclusions

The research shows that the failure of the atomic tower is different between the wind loads, snow loads, and geometry and self-weight. The higher the height of the atomic tower, the more wind there will be in the upper part of the atomic tower. In other words, in other words, the highest level of wind and load is at the height of the tower. If the critical point is reached, the wind load squeezes the sides

of the atomic tower, which can be extremely dangerous. The effect of snow load is due to the difference in snow, and the increase of snow load in the atomic tower when it is elevated in October is studied. According to the elasticity of the building, when the elasticity is less than or equal to 1, the whole building will be particularly serious. However, the elasticity of the atomic tower is not less than or equal to 1, indicating that the structure of the atomic tower is very stable and almost not affected by the elasticity. The factors that influence their weight are not very large. The only possible effect on body weight is the average, while the effect of material corrosion increases the weight of the entire building. There is also a material factor, because the main building material of the atomic tower is carbon steel, which can be oxidized over time, resulting in structural instability. If the maintenance treatment may be tilted in the way it is built, then the second one above may reduce the weight. Third, because the corrosion of the material may withstand the pressure of the load, such as the failure of severe conditions like typhoons and heavy snow, which will cause the collapse of the atomic tower.

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