Journal of Engineering Science and Technology
Vol. 16, No. 4 (2021) 2845 - 2851

WIND LOAD ON TEMPORARY AIR RIB INFLATED PNEUMATIC BUILDING STRUCTURE

SALMON PRIAJI MARTANA

Department of Architecture Engineering, Universitas Komputer Indonesia,
Jalan Dipati Ukur 112-114 Bandung 40132, Jawa Barat, Indonesia,
E-mail: ketuapt@unikom.ac.id

Abstract

This study aims to provide an example of calculating the wind load in an air rib inflated structure. The method used was an architectural simulation in which building criteria were created and then realized in a CAD-generated iconic model. The building is divided into several segments, analysed mathematically using a calculation method adapted from conventional rigid structure calculations. The lift and drag force results obtained in this study can be used to determine how the air-inflated rib structure builds up against these forces so that each rib element remains anchored on the ground when facing the external forces. To tackle the lift up force is then the next issue of finding the correct foundation in a specific surface material to bind the structure to the ground. This study's calculation model is expected to open the possibilities to develop safer air rib inflated structure application to stand the strong wind.

Keywords: Air rib structure, Air inflated structure, Pneumatic architecture, Pneumatic structure.

1. Introduction

A pneumatic structure - either air-inflated or air-supported - is a thin membrane structure stabilized by the internal pressure of the liquid or gas contained within [1]. The word pneumatic comes from the Greek word pneuma, which means, "to breathe with air." The pneumatic structure's peculiarity is that it makes the available air in abundance around as an integrated structural element.

Air rib structure is one form of pneumatic structure; a curved balloon tube made rigid with internal air pressure at a certain level [2]. These tubes will form a temporary shelter when lined up in large numbers at a tight distance, that can be used for various purposes from covering living space to something more utilitarian means [3, 4]. For instance, it can be used as a temporary shelter for refugees, where the cases are very common in Indonesia lately, both refugees who come from abroad [5] or refugees of local natural disasters [6].

So far, the development towards multiple rows of this type of structure to utilize people needs has not been done much while the possibility is wide open since production can be done domestically. All that has to be concerned with is the wind load, the main "enemy" of this lightweight structure. The wind force creates a different approach in structural consideration. In light structures such as rib air-inflated structure, the force that must be accommodated beside the shear force is lift force - unlike in conventional buildings, that main force is mainly directed downward. Thus, the foundation must be the one that can resist lifting forces, either with its load or with the ability to hold on to the ground. This study's main problem is that it is not very clear how to calculate wind loads on air rib inflated pneumatic structure, which stands in a row. Calculations involving tensile loads require a different approach from conventional construction in general.

This research aims to simulate mathematical calculations, which will then map the loads that occur in the building, converting them into load-bearing structures that can be used to determine the structural system and type of foundation when the building is erected with various models.

2. Air Inflated Structure

One of the advantages of the air-inflated pneumatic structure system is –unlike the air-supported structure- the air pressure in the system is only given to the structure, not to the public space, so that building users are not doing their activities under constant air pressure [7]. This system is freer to use as a space cover [8] because it does not require an airlock and other equipment to keep this structure standing. In this case, the ease of evacuation when something happens to the building becomes easier and faster. Moreover, if needed, the building can use such fire-resistant materials [9]. High-pressure pneumatic systems (air-inflated structures) such as the rib system in this study are often categorized as a tube structure because they are generally in the form of a tube [10]. It supported many functions but generally represented conventional building structures such as beams, arch, grid, or even shell.

Because of this classification, these high-pressure pneumatic structures are more often classified into rigid structures. Schodek [11] bases the types of high-pressure pneumatic structures, dividing them into two categories:

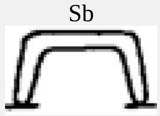
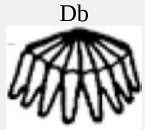
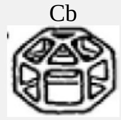
- Pneumatic dual-wall structures (air mattress). It consists of parallel membranes joined together.

- Rib structure (inflated tube), consisting of a row of inflated tubes. These tubes can be assembled to be roof coverings; some are used as frames for other roof coverings. The air pressure in this type of structure serves two purposes: To give shape to the structure and compensate for external loads.

Compared with other transverse load-bearing structures (concrete, steel), high-pressure pneumatic structures have lower efficiency. Therefore, the use is often for specific reasons such as ease of installation process, the lightweight aspect, and ease of transport of the small -after deflating- volume.

Based on the element pattern and the connection system, Herzog [12] created a matrix that helps the designer select the category of structural forms, as shown in Table 1. The choice of shape used in this study is the Da section; Discontinuous arched.

Table. 1. Element pattern and connection system of air inflated structure [12].

	S **Single**	**D** **Discontinue**	**C** **Continue**
s **straight**	Ss 	Ds 	Cs 
b **buckled**	Sb 	Db 	Cb 
a **arched**	Sa 	Da 	Ca 

3. Results and Discussion

The case study reviewed is a multi-purpose shelter building that can be used as a stage for temporary shelter for refugees or similar functions, spanning 16 m to 20 m. unlimited coverage area can be added if there are demands by attaching additional components in the longitudinal direction. However, in this study, the coverage area was limited to 18×9 m.

The building criteria include; the ease and speed of field erection, the ability to span large areas, quick assemble, lightweight, ease of transportation, resistance to external force, and is its safety for building users.

In this case, the structural shape is an arch tube with both ends resting on the ground. For this kind of structure, the price is considerably low, very fast to build, and the weight is very light, helping to facilitate the transportation process. This form is a very simple one but quite effective in overcoming normal external forces in the distribution of loads, especially wind forces, greatly affecting the structure due to its weight. The United States Air Force has extensively used these structural systems as a temporary aircraft hangar in recent years [1]. However, all these advantages are also major drawbacks when facing an unpredicted wind force. Particular dynamic external load like storm winds will be more easily to lift these structures up and uproot them from the ground because of their lightweight [13]. Accidents caused by a lack of understanding of the air rib structure's wind load calculation also occur. Therefore, it is essential to understand the specific wind load calculations for the air inflated rib structure, as explained in this building below.

Each tube's sections are made of 1.6 m in diameter with different segment heights (radii of curvature) to anticipate the pressure of wind loads and facilitate the function and activities to be accommodated. For more details, the shape and size of these segments are shown in Fig. 1.

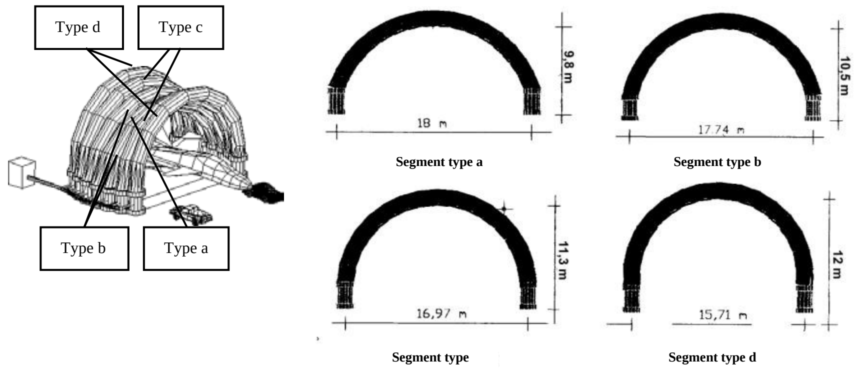


Fig. 1. The shape and size of the building segments.

Since the air-inflated pneumatic system has an air pressure that is up to 100 to 1000 times higher than that of the air-supported system, the membrane base material and the coating used are also different to make impermeable fabric supporting strength [14].

To form this tube segment, a fiberglass fabric with Teflon is used as a layer. The Teflon material is incombustible, so it is safer against fire hazards [9], more durable, and does not require cleaning because it is not stuck with dust, making it suitable for dismantling and moving in high frequency. Material technical data; weight 0.54 kg/m^2, thickness 0.97 mm and maximum tensile strength of 715 kp/5 cm [12].

With the above data, calculation of the own weight of the membrane in each segment are as follows:

i. Segment type a 144 m^2×0.54 kg/m^2 = 78 kg
ii. Segment type b 127 m^2×0.54 kg/m^2 = 67 kg
iii. Segment type c 133 m^2×0.54 kg/m^2 = 72 kg
iv. Segment type d 158 m^2×0.54 kg/m^2 = 85 kg

As seen in Fig. 2, the building use two segments of type b, c and d while the type a segment is placed in the middle. All the membrane own weight for this 160 m^2 building = 78 kg + (2×67 kg) + (2×72 kg) + (2×85 kg) = 526 kg.

Because this side is divided into several segments, the wind calculation is also carried out per segment. For this reason, the following will review the wind load starting from the wind load that occurs in segment types a to d.

The design wind speed is determined from empirical observations of the area to be built. Usually set per period, between 1 and 50 years [11]. The wind speed for coastal areas is generally higher than in urban areas; it can reach 53 m/s. To review the wind speed influencing this building, the calculation used the highest wind speed data ever recorded in the city of Bandung within the last ten years, as Fig. 2 tells, multiplied by a safety factor of 8, equals 126 km/h.

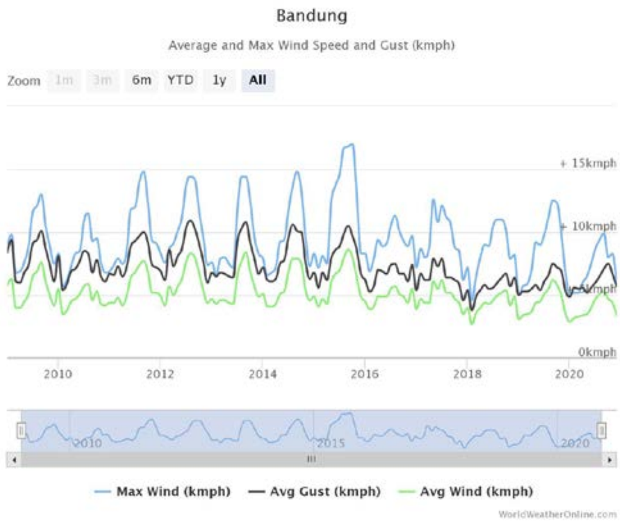


Fig. 2. Wind speed of Bandung, the last 10 years. (Source: WorldWeatherOnline.com)

The first wind static pressure calculation is carried out on the type a segment, using the following equation [12]:

$$q = \frac{Ve^2}{16} \sqrt[4]{\frac{h}{10}} \qquad (1)$$

Ve = wind speed (defined as 35 m/s), *h* = height of the building.

$$q = \frac{1225}{16} \times 0.92 = 70.43 \text{ kg/m}^2 \qquad (2)$$

For a half-cylindrical building, the drag coefficient = 1.4 times the building height divided by the stretch's width, while the lift coefficient = -0.7 minus the building height divided by the width of the stretch.

From this formula, it is obtained that C*lift* = -0.7-(7.3/18) = -1.11 and C*drag* =1.4×(7.3/18) = 0.57

The reactive force of the structure against the wind forces (lift) and shear (drag) that occurs in this segment is calculated using the following equation [11]

$$F = Cn.q.A \qquad (3)$$

Cn = coefficient of drag or lift.

A = the projected area of the building's cross-section against the wind direction

$$F_{lift} = -1.11 \times 70.77 \times 11.68 = -917.52 \text{ kg.} \quad (4)$$

$$F_{drag} = 0.57 \times 70.77 \times 11.68 = 471.16 \text{ kg.} \quad (5)$$

Similarly, calculations are also carried out on the other three segments separately. The result is as shown in Table 2.

Table 2. The calculations on segments b, c, and d.

SEGMENT TYPE "b"

$q = \frac{1225}{16} \times 0.95 = 72.41$ kg/m^2

C_l = -0.7 - (8/17.74) = -1.15

C_d = 1.4×(8/17.74) = 0.63

F_{lift} = -1.15×72.41×12.8 = -1065.9 kg.

F_{drag}= 0.63×72.41×12.8 = 583.91 kg.

SEGMENT TYPE "c"

$q = \frac{1225}{16} \times 0.97 = 74.15$ kg/m^2

C_l = -0.7- (8.8/16.97) = -1.22

C_d = 1.4×(8.8/16.97) = 0.73

F_{lift} = -1.2×74.15×14.08 = -1273.72 kg.

F_{drag}= 0.73×74.15×14.08 = 762.19 kg.

SEGMENT TYPE "d"

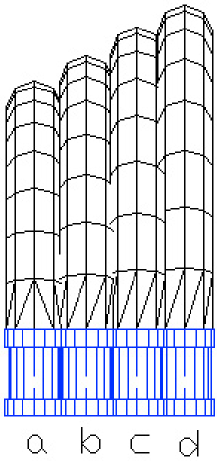
$q = \frac{1225}{16} \times 0.99 = 75.59$ kg/m^2

C_l = -0.7-(9.5/15.71) = -1.30

C_d = 1.4×(9.5/15.71) = 0.85

F_{lift} = -1.3×75.59 ×15.2 = -1493.66 kg.

F_{drag}= 0.85×75.59×15.2 = 976.62 kg.



The result made it possible to see that the segment bearing the largest wind force is the segment type d, with a shear force of 977 kg and a lifting force of 1494 kg.

Assuming that the four types of segments above are exposed by the same wind, the next load calculation will be based on the segment experiencing the greatest force and load, in this case, segment type d. Segment type d is the segment with the widest span, although it is also the shortest from the ground level compared to segments a, b and c. In other words, the segment with the largest cross-section facing the wind direction will face the greatest shear load and lift as well.

This rib segment can be likened to a portal system in a rigid structure supported at two locations, at the ends of the structure.

That way, the shear and lift loads on each pedestal are half of the numbers indicated. Each pedestal bears 488.5 kg of shear and 747 kg of lift.

With the structure simplicity, only the two loads have a significant effect so that the next step in the form of determining the right foundation or pedestal is carried out based on the figures above. The next adjustment will be determined from the type of soil and the type of foundation selected. However, in the ideal windless conditions, the rib component can stand freely without any actual connection to the pedestal.

4. Conclusion

It is concluded that the wind load on a high-pressure pneumatic system can be calculated simply by modelling this lightweight membrane structure to be like any other rigid structure. The stiffness is obtained through the amount of air volume pumped into the structure. The calculation of the wind pressure on the building directly produces an overview of the load that occurs on each of the structural supports. Therefore, the shape and type of the foundation can be directly determined in the next process.

References

1. Purwanto, L.M.F. (2000). Perkembangan struktur pneumatik memperkaya disain arsitektur. *Dimensi Arsitektur*, 28(1), 31-36.
2. Kromoser, B.; and Huber, P. (2016). Pneumatic formwork systems in structural engineering. *Advances in Materials Science and Engineering*, 2016(6), 1-13.
3. Abidin, S.Z.; Nasihien, R.D.; and Budiyanto, H. (2017). Air inflated greenhouse as urban farming facilities: architectural overview. *International Journal of Transportation and Infrastructure (IJTI)*, 1(1), 1-8.
4. Roehman, F. (2019). Rencana strategi bendung karet berisi air sebagai inovasi tepat guna dalam penanggulangan banjir dan rob. *Jurnal Neo Teknika*, 5(1), 8-14.
5. Sihombing, H.; and Farabi, N. (2019). Kebijakan Indonesia dalam perlindungan pencari suaka dan pengungsi pasca kebijakan turn back the boat pemerintahan Tony Abbott. *Journal of International Relations*, 5(4), 599-608.
6. Nuriskha, S.; Utami, A.K.F.; Suharyanto.; and Kurniani, D. (2019). Perencanaan peningkatan flood shelter di daerah aliran sungai beringin, semarang. *Jurnal Karya Teknik Sipil*, 3(1), 177-186.
7. Tarczewski, R. (2000). Self-erecting pneumatic structures. *WIT Transactions on the Built Environment*. Madrid, Spain, 47, 59-64.
8. Budiyanto, H.; Winansih, E.; Setiawan A.B. and Iqbal, M. (2019). Penerapan struktur pneumatic berupa atap panggung tiup dengan energi fotovoltaik. *Jurnal Arsitektur Mintakat*, 20(2), 67-78.
9. Zhang, L.; and Zhu, G.Q. (2014). Structural stability analysis of pneumatic membrane architecture under influence of internal fire. *Procedia Engineering*, 71, 629-636.
10. Poinet, P.; Baharlou, E.; Schwinn, T.; and Menges, A. (2016). Adaptive pneumatic shell structures-feedback-driven robotic stiffening of inflated extensible membranes and further rigidification for architectural applications. *Smart and Responsive Design*, 1, 549-558.
11. Schodek, D. (1991). *Struktur*. Bandung: Eresco.
12. Herzog, T. (1977). *Pneumatic structures a handbook for the architect and engineer*. London: Lockwood Staples.
13. Sukawi. (2011). Struktur membran dalam bangunan bentang lebar. *Jurnal Jurusan Arsitektur*, 11(1), 23-28.
14. Pauletti, R.M.D.O. (2010). Some issues on the design and analysis of pneumatic structures. *International Journal of Structural Engineering*, 1(3-4), 217-240.