

The Levitating Ring Restaurant Tower

Jacob Bloch¹⁾, *Yossi Amir²⁾ and Guy Austern³⁾

¹⁾ *Department of Civil Engineering, Ariel University, Ariel, Israel*

²⁾ *Faculty of Architecture, Technion, Israel Institution of Technology, Haifa, Israel*

³⁾ *Faculty of Architecture, Technion, Israel Institution of Technology, Haifa, Israel*

²⁾ yossi@n-t-a-arch.com

ABSTRACT

The Levitating Ring Restaurant Tower is an architectural engineering innovation which enables the construction of a tower in which a slender mast ($D=5m$) and a system of pre-stressed cables (bundles of wires), reciprocally work together to ensure the stability of the entire tower system which rises to the height of 600 meters (higher configurations may also be designed). The structure includes a levitating ring restaurant, which takes part in ensuring the tower's stability.

While this remarkable height is in fact 10% greater than that of Toronto CN TOWER, the total mass of the structure is approximately only 1/6 of its Toronto predecessor. The capacity of the restaurant located in the tower's levitating ring (approx. 1800) is four and a half times greater than that of the CN TOWER with all the tables offering first-row window views.

The proposed structure is unique, as its only compressed elements are the central mast and the ring, while all the others are tension elements (the buckling preventing elements included). These facts also influence the price of the tower to be much less than that of similar towers.

Comparison with more high towers, as well as selected detail of the connectors and a possible method of construction will be described below.

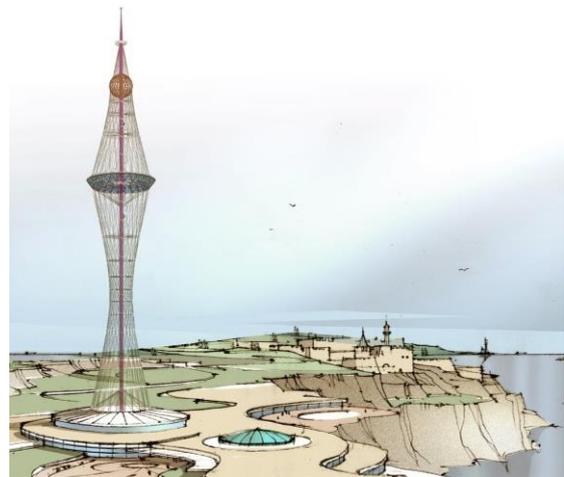


Fig. 1: The Levitating Ring Tower

¹⁾ Professor

²⁾ Senior Lecturer

³⁾ Architect, PhD. Candidate

1. INTRODUCTION

The earliest and most familiar of the self-supporting high towers erected is of course the Eiffel tower in Paris. It was built as a linear steel pyramidal structure, 324 meters in height in the beginning of the 19th century, and was the highest man made structure for over a century. In 1973, work started on the Toronto CN Tower, a self-supporting concrete structure, rising to the height of 553 meters, which was completed after 3 years and held the title of the world's tallest structure for several decades ("CN Tower" 2015). In 2009, the Canton tower was completed in Guangzhou, China, it also held the title of the world's tallest structure until its Japanese rival reached its full height ("Canton Tower" 2015). In 2011 the Tokyo Skytree tower was completed, combining a concrete core with a 3-dimensional steel frame system which surrounds it. The Skytree tower rises to 634 meters and it is currently the world's highest structure of its kind ("Tokyo Skytree" 2015).

Many of these structures are almost devoid of function, mainly housing scenic restaurants usually referred to as "360 degree" restaurants, which are placed in the higher floors of the tower. As indicated by their name, the seating in these restaurants rotates slowly around the tower's core, providing guests with a full panoramic view of the surroundings. Since these restaurants are usually shaped like a saucer suspended from the tower, the most popular seating is always at the circumference of the saucer, and is thus limited in number even if the restaurant has several levels. The CN tower restaurant, for example, has only 400 of these types of seats, according to its official website.

2. THE TOWER AND ITS ADVANTAGES

The structure presented in the following section is the work of Architect Yossi Amir, it is protected by a registered U.S patent (Amir 2015) and is pending in several other significant countries. In 2012 Professor Jacob Bloch joined the design team and conducted a preliminary structural feasibility analysis on the design, which is presented below, the main points of this analysis are:

- The structural system of this tower is more efficient in relation to the systems of other existing self-supporting towers, as will be shown in the later parts of this document.
- Additional efficiency is achieved by the fact that the structural elements of the tower also serve other purposes. The most prominent example being the ring restaurant which is situated within one of the compressed rings described below. The spatial structure of the ring, as well as its large diameter (82 meters), enable situating a significant amount of restaurant seats in attractive window facing areas, in the outer, inner and underlying areas of the ring.
- Different details of the tower, such as the cable connectors presented below, are designed to shorten and simplify the construction process as well as to provide structural support. This fact should decrease the cost of the construction process considerably. A clear example of this is the "cable intersection connector" shown below, this connector enables the use of large spans of continuous cables which have benefits for both the structure and the construction sequence.

- The structural system of the tower is designed so that after the lower part of the structure is complete, it can **serve as the basis for the construction for the upper segment**. This fact contributes to the efficiency and cost effectiveness of the construction process, as can be seen in the chapter describing it.

The instance of the tower shown in this document is 601 meters in height, and can seat 1800 people in four window facing lanes. As a part of the preliminary design studies, the options for designing a higher tower with increased seating capacity were considered and found possible, yet the maximum economically feasible height this type of structure can reach was not yet arrived at. In case the overall dimensions are altered, the dimensions of the other features of this construction will have to be re-evaluated.

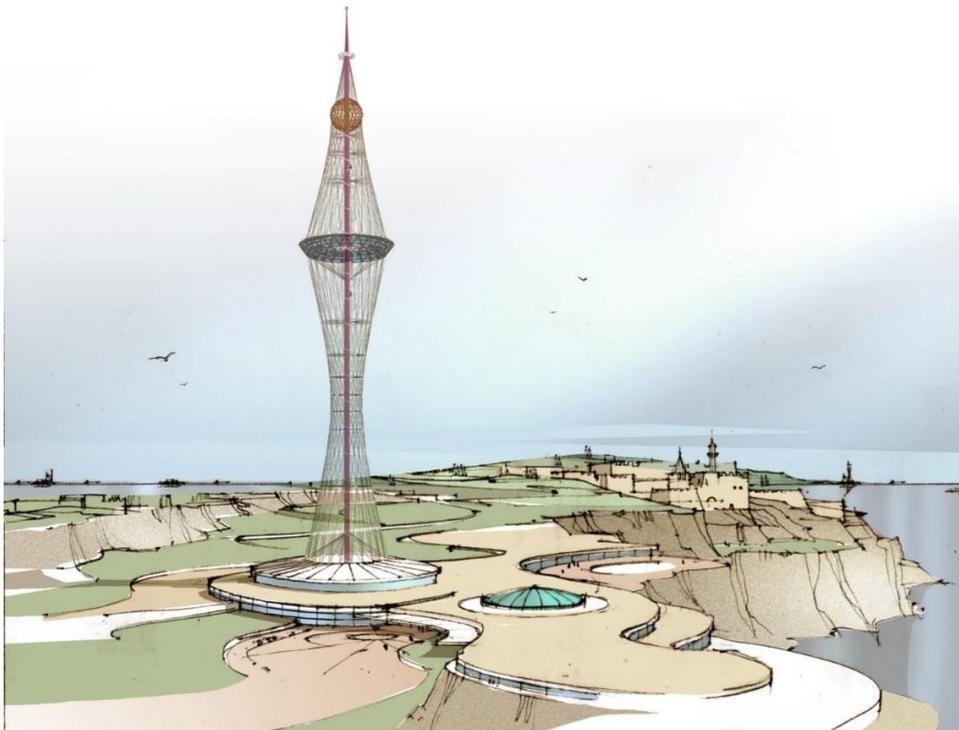


Fig. 2: General View

3. DESCRIPTION OF THE TOWER

The main structural features of the tower include:

- An upright steel structure central core.
- Two peripheral systems of pre-tensioned cables, which surround the entire height of the structure.
- A radial cable system connecting the peripheral system and the core.
- Cable intersection connectors which tie together the different cable systems.

- Compression rings which also serve as functional spaces.

3.1 Description of the structural features

The central core A slender steel construction made of tubular sections strengthened by exterior ribs. The ribs serve as a basis for climbing and anchoring the construction cranes during the construction, and once the tower is completed will serve as the tracks for the elevators. The core is planned to resist compression forces.

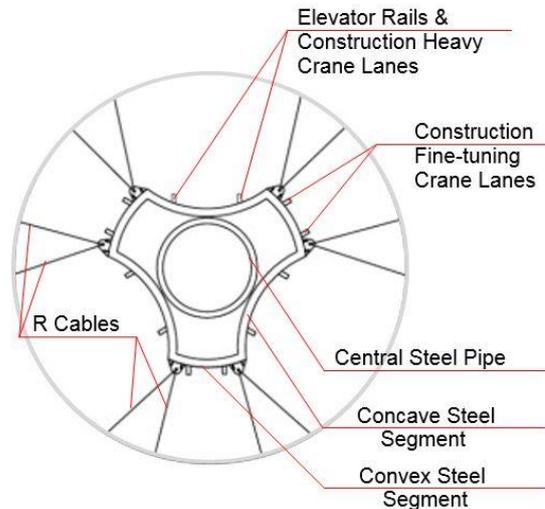


Fig. 3: Central Core Section

Pre-tensioned Peripheral Cable System Is comprised of 2 main cable subsystems:

- A-Left and A-Right (2X24 cables): peripheral pre-tensioned linear cables that span from the base ring to the restaurant ring. The A-right system passes to the right of the core while the A-Left system is mirrored across a vertical plane to pass to the left of the core. Together these systems define spatial rhombuses which form a paraboloid envelope.
- P-Cable system (24 cables): Spanning between the base ring and the restaurant ring, these cables connect the junctions formed of the intersections of the A-Left and A-Right systems, forming paraboloids in plane with the central core.

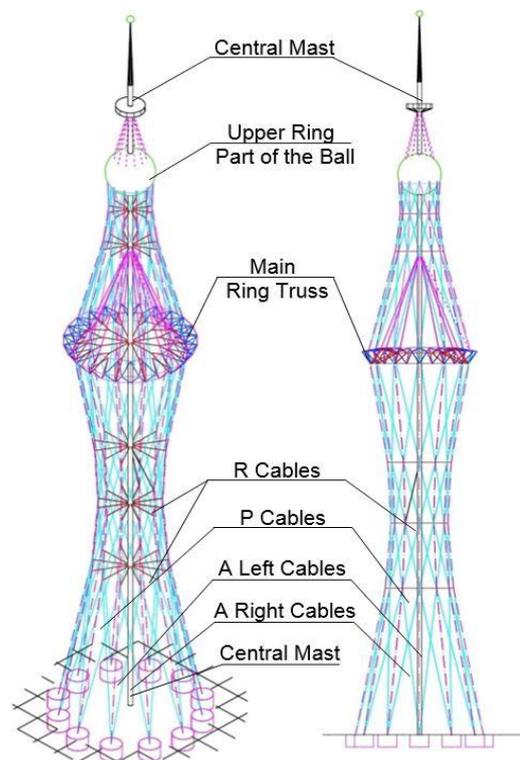


Fig. 4: Isometric and Front View

Compression Ring System Three compression rings, consisting of:

- Lower ring: With the same diameter as the projection of the cables on the ground plan - 100 meters, this ring serves as part of the foundation of the building.
- Central ring: A spatial torus shaped truss with a triangular cross section. The triangles are oriented with the peak towards the ground and have a height of 11 meters. The diameter of the entire torus - calculated by the circle which connects the centers of the triangles, is 82 meters.

- Upper Ring: In the shape of a 15 meter radius ring, as a part of a sphere.

Radial Cable System – R

- Pre-tensioned radial R-cables spanning the intersections between the A system cables and the core on a roughly horizontal plane.
- The lower set is comprised of 8 X 24 cables and the upper set is comprised of 3 X 24 cables.
- The Radial Cable system functions as buckling support for the central core, which is compressed due to the weight of the structure and the stresses introduced by the peripheral pre-tensioned cables.

Cable Intersection Connectors As can be observed in the schematic diagram in figure 5, the typical cable connectors link the different continuous peripheral longitudinal cable systems: A-right, A-left and P-cable, to the core with the radial R-cable that starts at the connector. All the connectors of a specific level are self-similar, yet in the different levels, the connectors are adjusted to accommodate different cable angles.

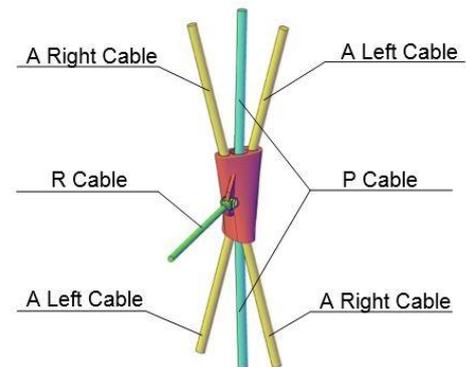


Fig. 5: Cable Intersection Connector

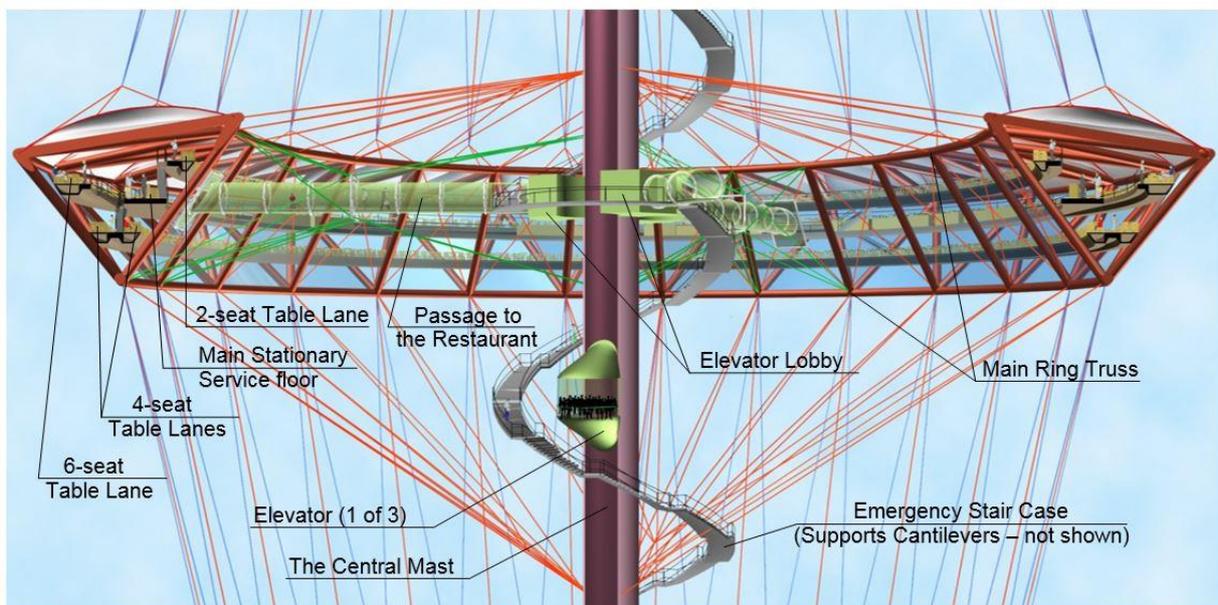


Fig. 6: Restaurant Ring Truss Isometric Section

3.2 Description of the “Levitating Ring Restaurant”

The restaurant is located within the central, torus shaped compression ring whose dimensions are described above. In addition to minimal diagonal members, the sides of the torus are clad with transparent elements in order for all the diners to experience the surrounding scenery as well as the “interior” scenery, in which one can also see the other side of the ring structure and the central core. Both sides share the views down towards the tower base as well as upwards to the sky.

On the top level of the restaurant, a revolving track houses tables for two people with views towards the interior facing down (colored in light pink in figure 7). In the middle level, a revolving track with six seat tables faces the exterior view (colored in blue). On the bottom level, two layers of tracks with four seat tables (colored in purple), half facing inwards and half facing to the outside. In fact, from all the restaurant space each visitor is exposed to all the surrounding view: outside, inside and down, as well as to the continuation of the ring restaurant structure itself.

The access to this restaurant is via three transparent elevators which travel along tracks inset into the central core. These elevators reach the lobby of the tower, which also includes the different necessary services.

Between the elevator lobby and the interior space of the restaurant (colored in green), three transparent radial passageways connect to a fixed circular platform which serves as an orientation point for the guests, enabling them to choose their preferred seats, meal type, dishes etc.

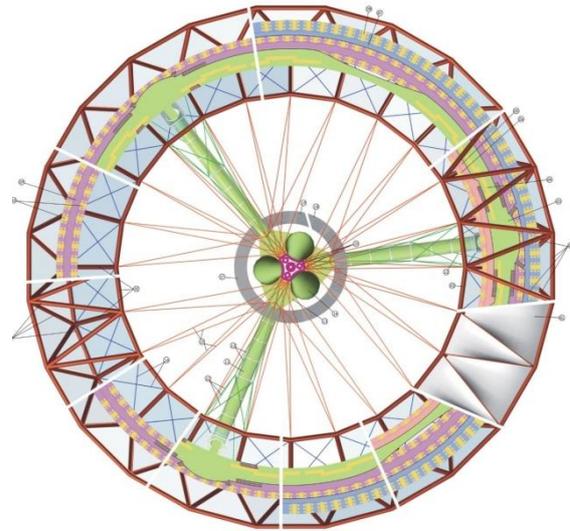


Fig. 7: Restaurant Ring's Layers Plan

4. FINDINGS OF THE PRELIMINARY STRUCTURAL ANALYSIS

- a) A preliminary structural design of a 600m high Tower for Tourism and Entertainment, based on the initial architectural design, was executed in order to investigate its feasibility.
- b) The dimensions of its main elements for the preliminary analysis are as follows:
 - i) A central column in a pipe shape 5m diameter and 100 mm wall thickness.
 - ii) The restaurant in a shape of a torus 80m diameter at its center and 12m high.
 - iii) A ball at the top 30m diameter
 - iv) A set of 72 tie rods from the foundations to the restaurant, 150mm diameter.
 - v) A set of 72 tie rods from the restaurant to the top level, 100mm diameter.
- c) The actual characteristic of the main elements will be probably as follows:

- i) The central column will be constructed with steel plates 100 mm of thickness in the shape as designed in the architectural design.
 - ii) The tie rods will be constructed as a bundle of parallel wires as used on suspension bridges or a bundle of parallel strands as used on cable stayed bridges.
- d) Some of the results of the calculations are as follows:
- i) Central column: bending moment 200,000 kn meter, vertical force, due to weight and pretension of tie rods 430,000 kn.
 - ii) Tie rods at the lower part 12,500 kn tension.
 - iii) Tie rods at the upper part 500 kn tension.
- e) Total weight of the steel structure is estimated to be 20,000 ton.
- f) It is difficult to estimate the cost of the structure, but it will be much higher than a conventional one, constructed of ordinary steel or concrete elements, due to difficulties in handling and connecting very heavy elements of great thickness of the central column and the construction of the tie rods in situ, as well as the height of it.
- g) However, due to its unique structural system it will be, for sure, much less expensive than any other tower built till now.

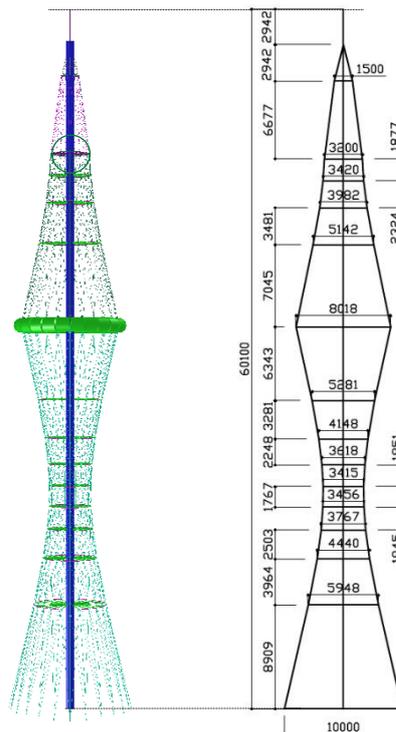


Fig. 8: Preliminary Structural Analysis Scheme and Dimensions

5. COMPARISON TO OTHER SELF-SUPPORTING TOWERS

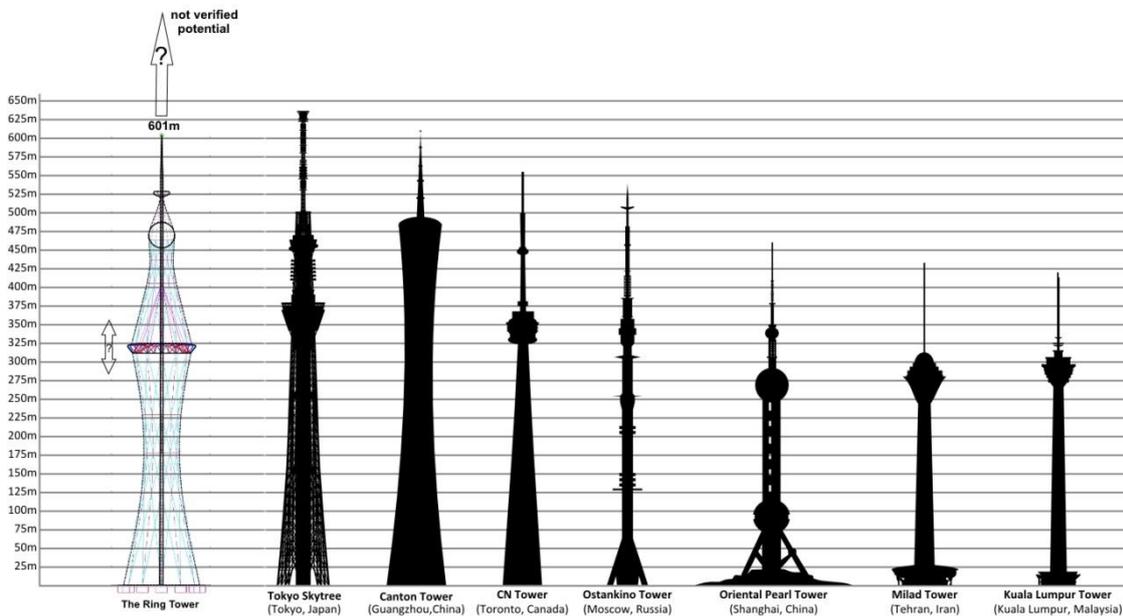


Fig. 9: Comparison to the Tallest Towers in the World (taken from Wikipedia content)

In many buildings, the architectural vision tends to conflict with the structural and site management requirements. In this structure we propose a “Unified design” approach similar to that suggested by ARUP Associates in their book bearing the same title (Arup Associates 2008). In this approach the architectural and structural requirements serve each other and the construction process is taken into consideration and influences overall design process. This process improves the overall performance of the structure and limits the adverse effects structural and construction considerations typically have on the final outcome.

The “Unified Design” process enables a significant reduction in the size of the structural elements, which in turn reduces both the wind loads and the structural loads in a process of optimization. As a result, the Tower's mass greatly decreases, improving its earthquake performance and reducing its material quantities and costs, in comparison to similar structures. Additionally, this process will decrease the construction time, further reducing the overall cost of the tower.

It is well known, that tensile elements are much lighter than compressed ones. Thus, as the characteristic features of the proposed structure consist mostly of tensile elements (the buckling preventing elements are also in tension) and its only compressed elements are the central mast and the rings, its mass approaches minimum.

6. PROJECTED TOWER CONSTRUCTION SEQUENCE

In the first stage of the sequence, the foundation is poured and a “half module” core segment attached. A second, “full module” of the core is now welded to the top of the initial module (see Fig. 10). Later, a “sleeve” module is lifted into position and welded to both the foundation and the core segments. The connections between the “sleeve” segments always occur adjacent to the mid-point of a core segment, ensuring structural stability (see Fig. 11). The cranes are now attached to the main tracks located on the sleeves and use the sleeve openings as additional support (see Fig. 12). In the next step of the process the structure is continued up to height where three temporary exterior supports become necessary for maintaining the stability of the structure. These supports will accompany the construction process until the tower is stabilized (see Fig. 13).

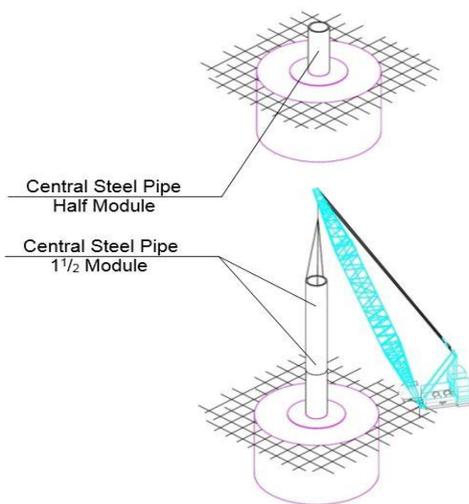


Fig. 10: Construction Stage A

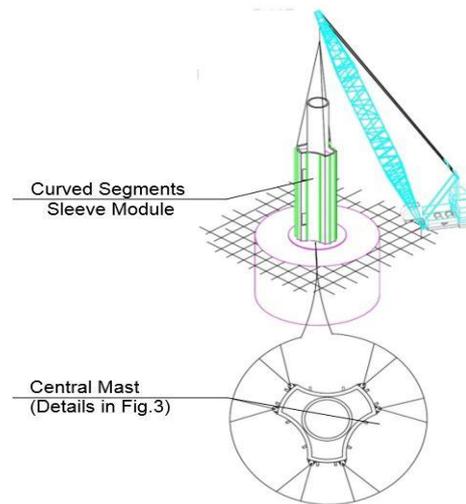


Fig. 11: Construction Stage B

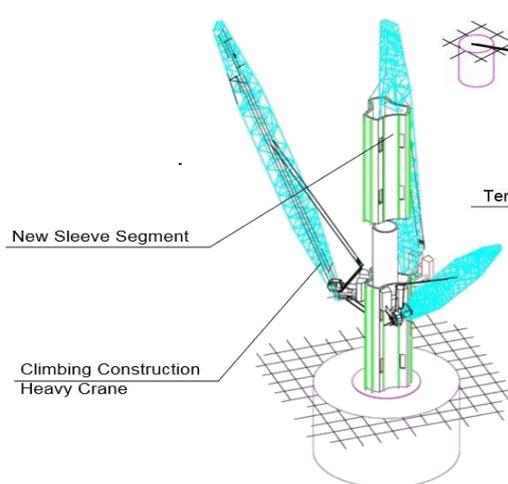


Fig. 12: Construction Stage C

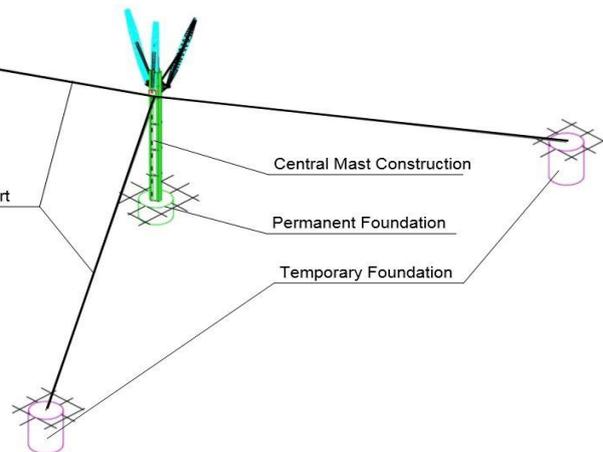


Fig. 13: Construction Stage D

The central core is constructed vertically until it reaches a height from which the levitating restaurant can be suspended, stabilized by temporary support cables. Once the correct height is achieved the three parts of the ring truss are lifted into position using the cranes (see Fig. 14), the Levitating Ring truss is attached to the central core and balanced using radial cables (see Fig. 15). Concurrently, the A-Left cables are laid out on the ground and the connectors are attached to them. After the foundations for the cables are all in place, the A-Left system is lifted into place and fixed to the central ring (see Fig. 16).

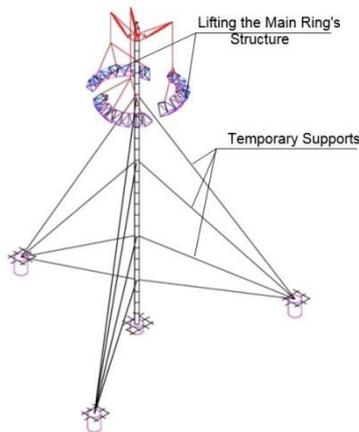


Fig. 14: Construction Stage E

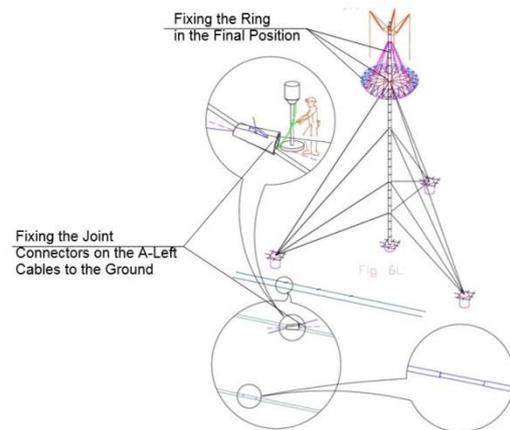


Fig. 15: Construction Stage F

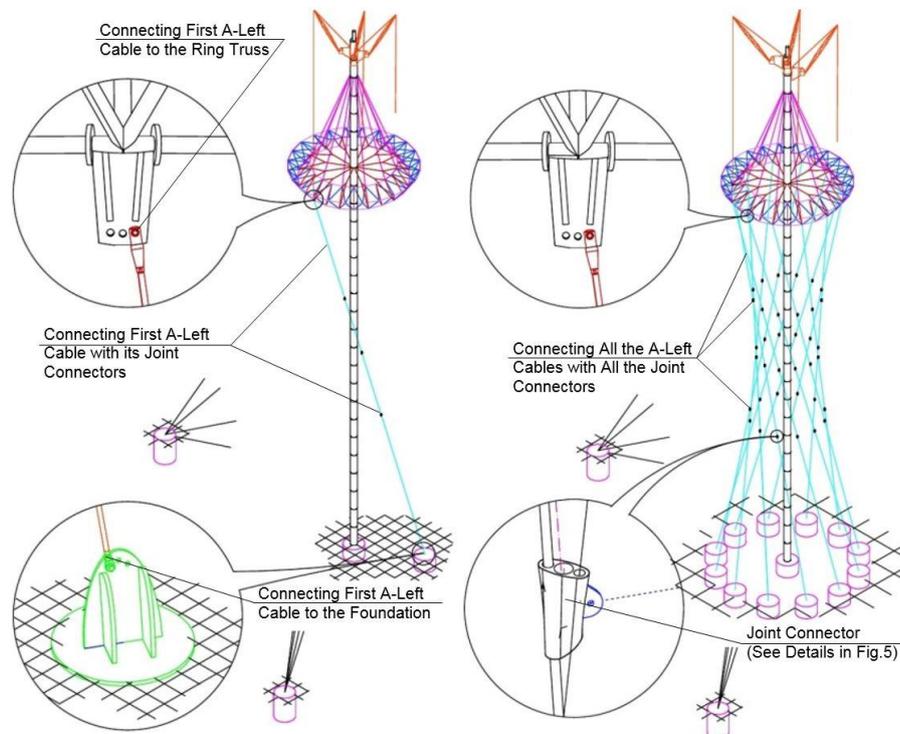


Fig. 16: Construction Stage G

In the next step of the process, a guide thread is inserted through the connectors, attached to the end of an A-Right cable and pulled back up until the cable can be connected to the lower part of the “Levitating Ring” (see Fig. 17). Thus all the A-Right system is threaded, attached to the base and pulled up to the central ring.

The P-system is similarly connected using guide threads passing through the connectors, after which the cables can be pulled into place and fixed to the top and bottom (see Fig. 18).

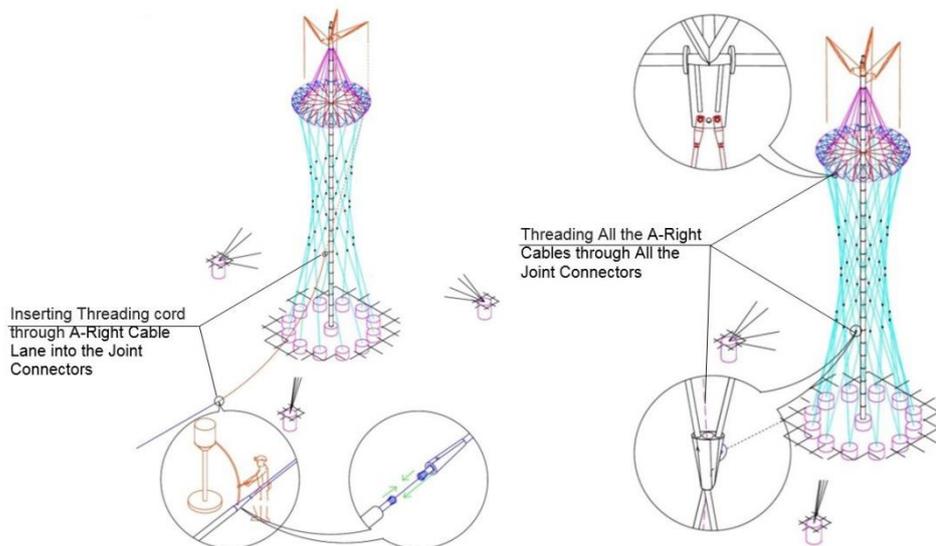


Fig. 17: Construction Stage H

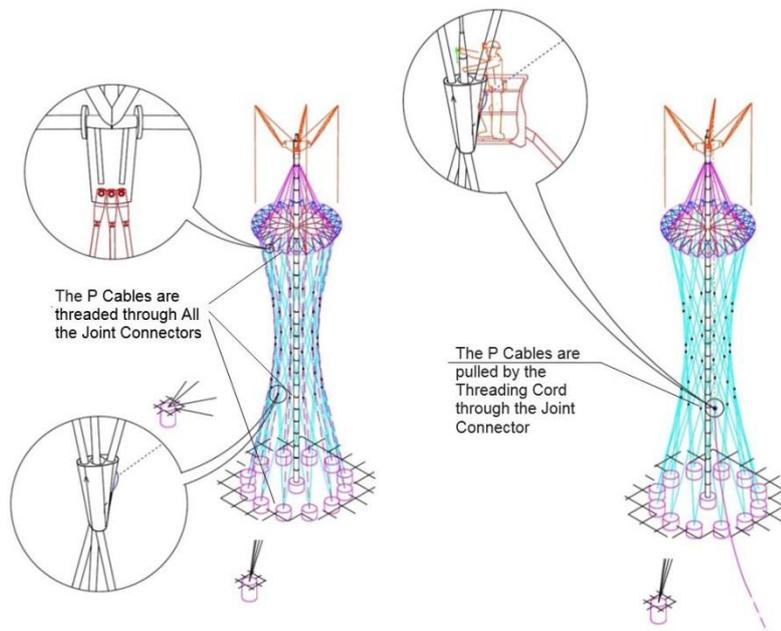


Fig. 18: Construction Stage I

In the final step of this part of the process, the Radial tension rod system R - spans between all the cable connectors and the central core. The rods are attached one level at a time (creating roughly horizontal layers) until all the system is in place.

Now the peripheral systems A + P can be pre-tensioned downwards. This will create pre-tension in the radial system R, as well. After the tensioning stage, the system is stable and the temporary supports can be dismantled. The next level of the tower (between the ring and the sphere) can now be constructed in a similar fashion and the rest of the fittings can be installed.

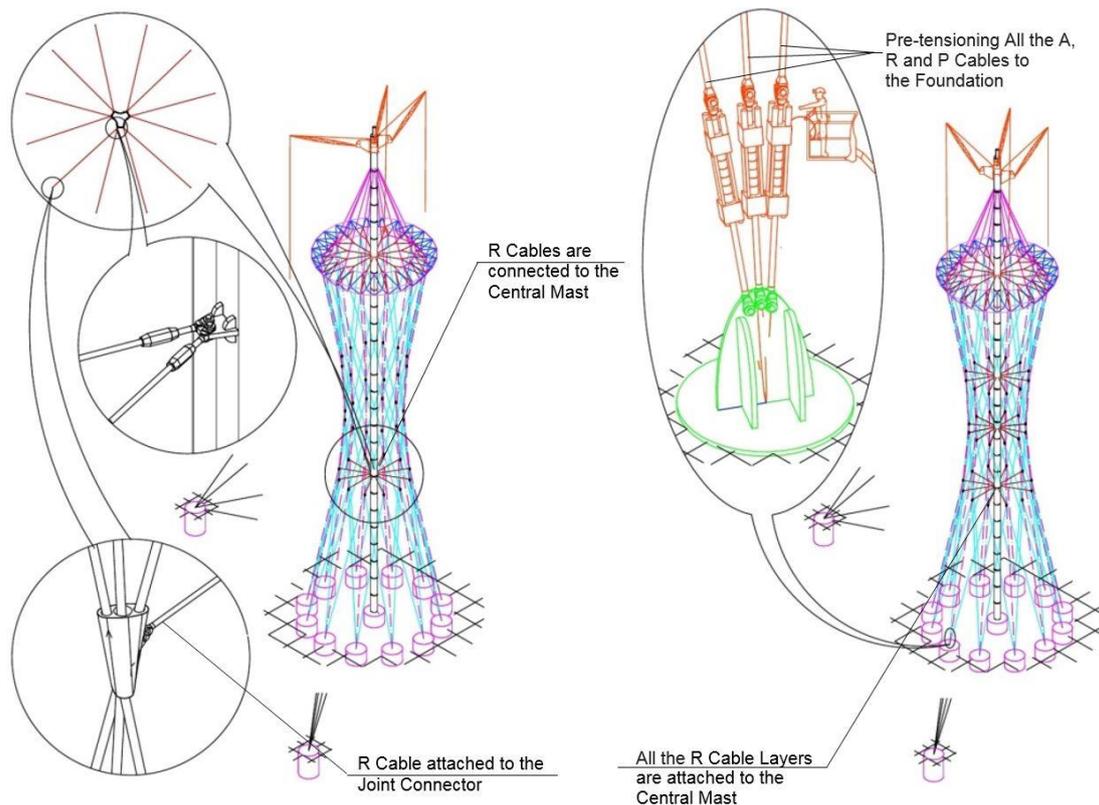


Fig. 19: Construction Stage J

7. CONCLUSION

The Levitating Ring Tower is a communication and tourism structure which uses three pre-tensioned cable systems to provide structural bracing against horizontal forces and to defend the main core against buckling. In this way the Tower can achieve a central core only 5 meters wide. As the height of the tower is 600 meters, this means that the slenderness ratio is an outstanding 1/120, and all the structure mass is only 20,000 tons. All these achievements affect the Tower's earthquake resistance, relatively low cost and "transparent" appearance.

The main ring truss in the higher level of the Tower is a crucial element of the structure, it enables pre-tensioning of the two longitudinal cable systems, while at the same time it provides a space for a unique revolving "360 degree" restaurant. This

restaurant houses seating for 1800 diners, each with panoramic view to the scenery and the Tower structure.

The unique detail of the “Cable Intersection Connectors” allows the creation of stable cable junctions while using continuous longitudinal cables. This system enables the use of a threading technique in the tower’s construction process, greatly increasing its construction rate and hence decreasing its price.

The combination of all these advantages achieves a structure whose mass is 1/6 of the CN-tower, 1/5 of the Canton tower and most likely, much less than the mass of the Skytree Tower (whose envelope is built of compression resistant steel profiles), while being in the same height “league”. The revolutionary structural system of The Levitating Ring Tower represents a “Unified Design” approach typical of groundbreaking projects in this age. It has the potential to turn into an “iconic” building, contributing to the success of its urban environment.

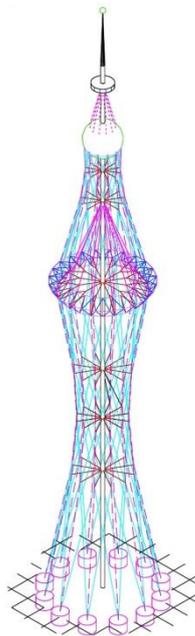


Fig. 20: The Final Construction Stage

REFERENCES

- Amir, Y. (2015), Tower Structure. US 8,973,309 B2.
Arup Associates (2008), Unified Design. Wiley.
Canton Tower (2015), Wikipedia, the free encyclopedia at
<http://en.wikipedia.org/w/index.php?title=Canton_Tower&oldid=660468984>
CN Tower (2015), Wikipedia, the free encyclopedia at
<http://en.wikipedia.org/w/index.php?title=CN_Tower&oldid=664878783>
Tokyo Skytree (2015), Wikipedia, the free encyclopedia at
<http://en.wikipedia.org/w/index.php?title=Tokyo_Skytree&oldid=663669784>