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The Earthquake Proof 'Tokyo Sky-Tree'- Bringing New Possibilities for Modern Architecture

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ABSTRACT
The pagodas have always fascinated the people who see them. Not only are they interesting, but they also represent the essence of science and architecture which was used in the olden days. Thus, bringing new possibilities for modern architecture. The world's tallest tower and Japan's biggest new landmark, The Tokyo Sky-tree is one among them which remains unaffected when the earthquake strikes. In our paper, we are going to review the construction technologies used in building this massive tower and compare it to the traditional Chinese pagodas.
Key-terms: seismic forces, micro-motion array observation, oil damper

I. INTRODUCTION

Any country that borders the Pacific Ocean is under the pressure of most active source of volcanic activity and tectonic movement. The land often rubs against the undersea floor, and so the vibrations cause the plates of the earth to be softer and more loose, which results in the area around these countries to be prone to the plates of earth buckling, therefore resulting in a higher chance of earthquakes.
Japan, one among the world's mostly densely populated countries, is located between the Sea of Japan and the Pacific Ocean. It has been a hot spot for seismic activity and in 2011 experienced the strongest ever earthquake which was followed by a Tsunami causing a lot of infrastructural damage. Even after experiencing such violent earthquakes, there is no record of a pagoda being knocked over.

II. WHY CAN'T EARTH QUAKES KNOCK THEM DOWN?

The answer to this question can be obtained by studying the structure of the Pagoda. The raw material used to build this magnificent structure is wood. When wood is subjected to force it does not break easily. It bends and when the force is removed the wood returns to its original shape. Because it is flexible, it can absorb seismic stress. All the pieces of wood are joined by inserting carved thinner and narrower ends into slots. When the earth quake occurs, these joints twist and rub against each other. A Pagoda is made up of almost thousand such joints making the structure flexible practically.This prevents the seismic energy from traveling up the tower.

Pagodas are layered boxed structures. Each later allows certain amount of gentle swaying. When the bottom most mater swayed to the right, the one above it swayed to the left, the one above that swayed to the right , and so on.

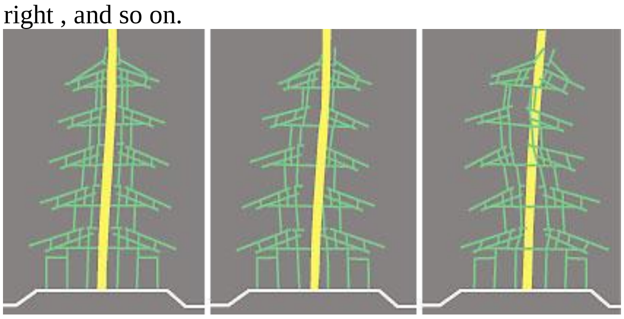


Fig 2.1 Movement in a Pagoda when earthquake hits.

There is a thick central pillar in a pagoda running from top to bottom which is called as the shinbashira. This central pillar keeps the box layers form sliding off to the side.

III. TOKYO SKY-TREE : OUTLINE

The Tokyo Sky Tree, world's largest tower boasting a height of 634m, is a television transmitter and observation tower. The construction of this massive tower started in July 2008 and it took about 3 years to complete the project. The design and construction administration was under the guidance of Nikken Sekkei Ltd. and the builder was Obayashi Corporation.

The previous Tokyo Tower was tall enough in 1958, but as time commenced the tower's height proved insufficient for coverage to the area - hence the need for the Tokyo Sky tree.

The tower was designed to assure much more safety that the usual buildings against unpredictable earthquakes and storms.

3.2THE FIRST TEST:

The company floated a radiosonde balloon at first to gather extensive wind data used to determine the lateral wind forces that the building would have to withstand and disturbance conditions at such an altitude.

Meanwhile, thousands of feet below, the company undertook a "micro-motion array observation" granting insight in the minutest detail of the make-up of the earth to a depth of 3 km (1.9 miles) underground. This level of detail allows much more accurate computer simulation of building sway in earthquake conditions.

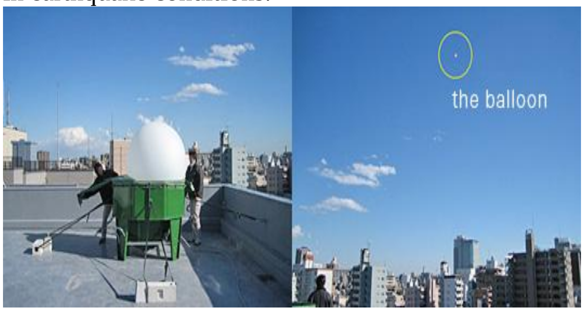


Fig 3.1 Balloon Test

3.3STRUCTURAL TECHNOLOGY OF THE SKY-TREE

The cross-section shape of the tower varies as it moves upward. (shown in fig 3.)The lowest section of the tower is an equilateral triangle. This shape is gradually rounded and becomes a perfect circle at about 300m of height. The change from the triangle to the circle also entailed “warp” and “camber” which are traditional shapes in Japanese culture. The ridge line of the triangle has a “warp” typically seen in Japanese swords and the transition section in which the triangle changes to a circle has the “camber” seen in the gently expanded columns of the temple architecture.

The tower has three legs, under each leg is bunch of 50m deep walled pipes. Forming a triangle between the three clusters are three longer, 35m deep piled walls. The usage of wall- shaped piles increased the useful frictional resistance with the ground. Another set of piles are inserted at the center of the triangle.

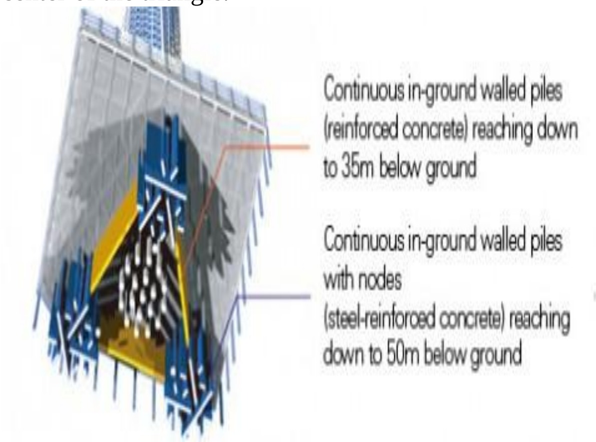
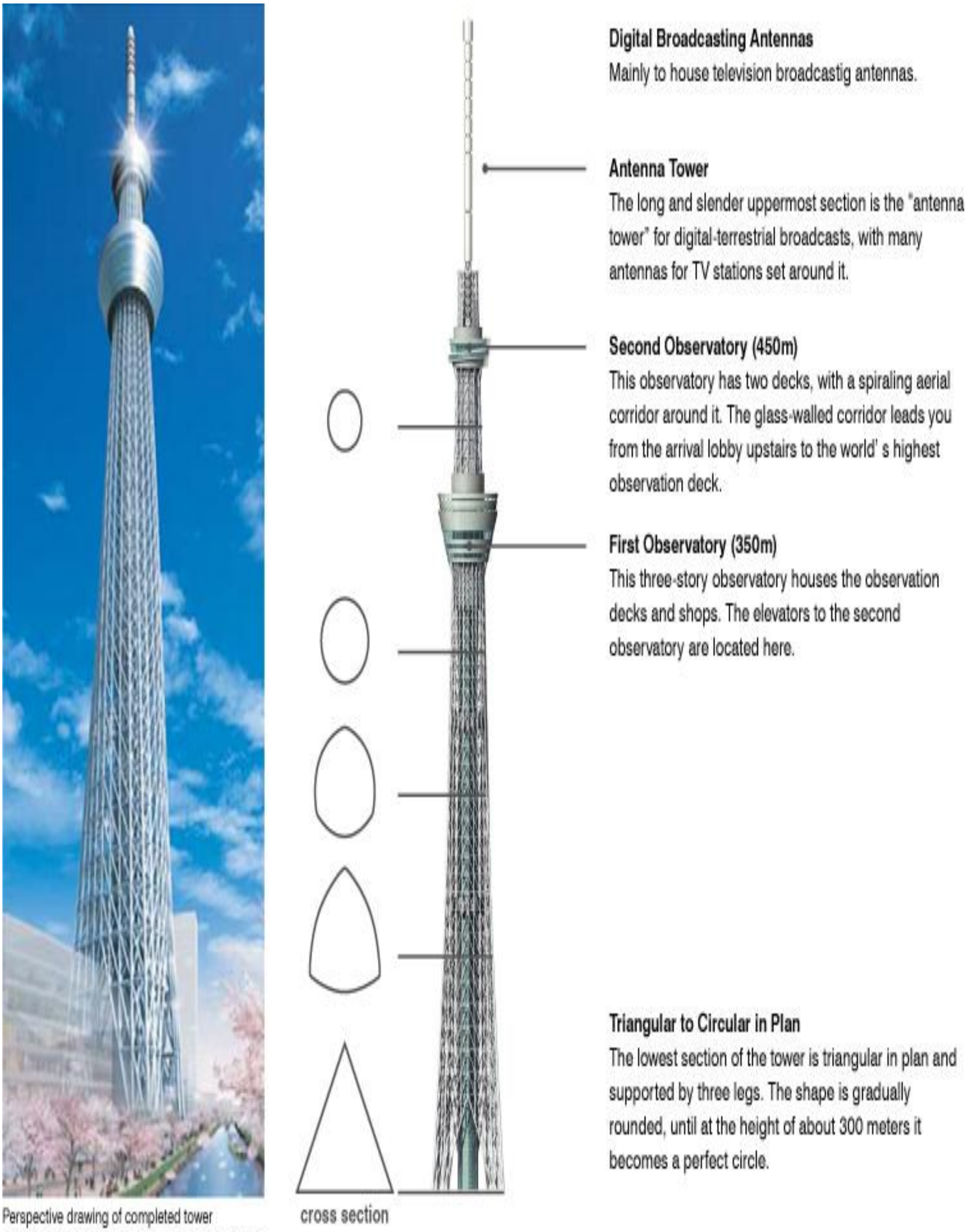


Fig 3.2 Underground fixtures

Extremely strong steel tubes are inserted at the tower’s base which have a diameter of 2.3 m (7.5 ft) and a thickness of 10 cm (3.9 in). These are arranged in an array of triangular trusses which, unusually for a building, employ branch joints more common on marine structures such as oil rigs.



Perspective drawing of completed tower
Provided by Tobe Railway Co., Ltd. & Tobu Tower Sky Tree Co., Ltd.

Fig 3.3 Cross-section shapes

To control vibration, Nikken Sekkei took inspiration from the Pagodas. The central column (or shimbashira) does not physically support any of the pagoda's stories but instead acts as a counterweight about which the rest of the building's structure can vibrate. Nikken Sekkei brought the concept of center column vibration control, with the core column and surrounding steel frame connected by a flexible oil damper.

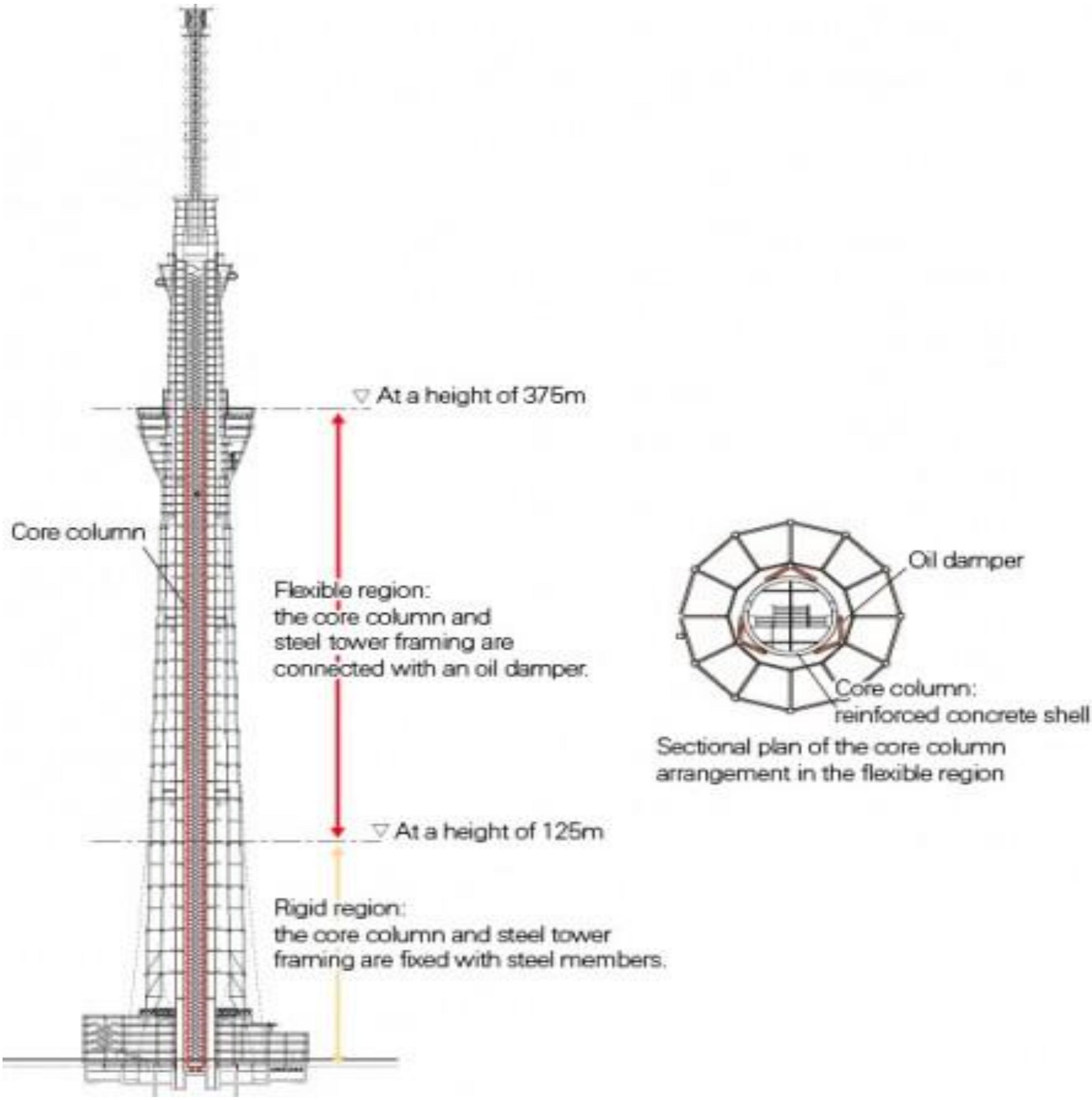


Fig 3.4 Structure of tower and position of oil damper

Oil dampers are anti-seismic devices that exploit the resistance of hydraulic fluid passing through a valve in a cylinder to generate the damping resistance force required.Dampers consist of a pressure tube, a piston rod with a special piston system and the damping medium oil. The piston rod is located within the oil-filled pressure tube with its special seal and guiding system which hermetically seals the inner compartment of the hydraulic damper against the atmosphere - also under extreme environmental conditions. The damping oil is pressed through the damping bores in the piston system through the movement of the piston rod.The damping forces are therefore also dependent on the piston speed.

Since the damping borings can be closed respectively on both sides by valve washers, it is possible to regulate the damping forces in the direction of extension and compression largely independent of one another. The damping force on compression determines the hardness of a shock absorber on retraction. The damping force on extension regulates the extension speed.
There are two types of oil dampers.

Linear Type:
An oil damper that is equipped with a sole pressure regulating valve and delivers damping force as represented by the F = CV straight line.

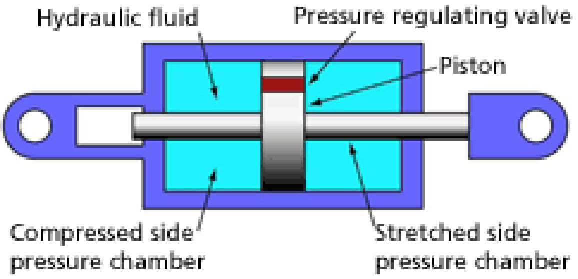


Fig 3.5 (a) Linear Oil damper

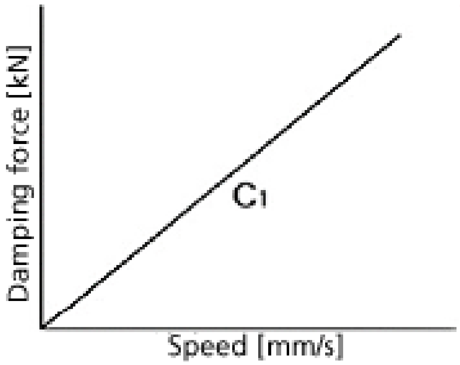


Fig 3.5 (b) Graph of linear damper (damping force vs speed)

Bilinear type:
An oil damper that is equipped with a pressure regulating valve and relief valve and delivers a damping force that increases in proportion to speed until the given speed is reached and at a lower rate after the given speed is exceeded.

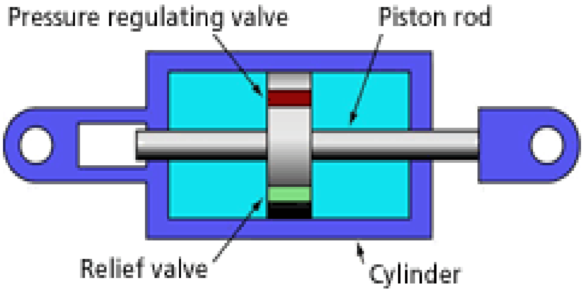


Fig 3.6 (a) Bilinear damper

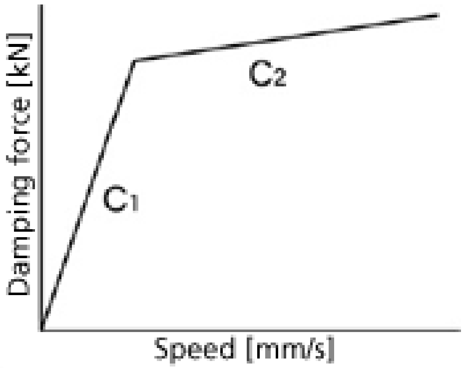


Fig 3.6 Graph of Bilinear damper (damping force vs speed)

IV. CONCLUSION

There are many interesting architectural techniques hidden in traditional monuments which can be incorporated in modern architecture, which lead to construction of such massive undestroyable structures.

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