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Vibration Structure System: A Building Technology for Resisting Dangers

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Abstract: *The Vibration structure engineering has accomplished significant progress during the last decades. At present, there is an appropriate understanding of vibration ground motions and vibration response of structures. Natural and manmade hazards such as earthquakes, hurricanes, and explosions can cause structural damages or exacerbate existing damage. The main objective of this study is to analyze the vibration structure system as a way to resist different dangers. By mean that must be discerning what's best way to reinforce the buildings so that they suffer the least damage possible. The paper therefore defines the meaning of this system clarifying what building may face of possible dangers. This study tries to give indications of how to make a building ready to resist natural hazards in seismic zones. Through analyzing two different case studies, it can be figured out how this structural system works. From the important conclusions, the vertical resisting system with triangulations has the greatest influence on performance. Clearly, the design of these buildings must working hand by hand architects and engineers. Without the collaboration of design and proper execution the results can be reached catastrophic.*

Keywords: *architecture, vibration structure system, danger, resistance*

1. Introduction

In the last three decades, there has been an intense research activity focused on design of systems able to mitigate the vibrations in engineering structures such as buildings, towers and bridges. Vibrations caused by seismic motions, strong winds and heavy traffic may not only be uncomfortable for people but dangerous if these compromise the stability of the structure and the safety of its occupants. Structures progressive deterioration due to ageing under effects of environmental conditions has become a worldwide concern. In order to make structures safer against these phenomena, researchers have taken advantage of the fact that structure can be designed to resist any kind of vibration. A system characterized by adaptability and multifunction. [1] This study presents the role of vibration structural system examining the resistance of buildings against natural hazard. The purpose is to explain why vibration structure systems became a needed solution. The problem statement is that the geometry of the building is rather complex as the floor plans are changing along the height of the building, resulting in a more complex structure than the design codes normally assume and therefore the guidelines they provide may not give correct estimates of dynamic properties and response characteristics for the building. The existence of such problems makes vibration structure system may be exposed to problems that still remaining to be solved. A list of the main problems is outlined next:

- **Seismic motions:** It is not possible to predict when an earthquake is going to take place, neither its magnitude not duration. Unknown disturbances are of major concern because they can excite the structure at its natural frequencies and as a consequence the structure may be severely damaged or even collapse.
- **Uncertain parameters**: Executing large-scale structures often leads to errors due to the neglect of nonlinearities and different ranges of dynamics.
- **Asymmetric structures and Coupling**: The asymmetric distribution of stiffness or mass can make a seismic load cause torsional and lateral motions of the structure to be strongly coupled. [2]

The aim of this paper is to understand the dynamic properties and behavior of vibration structure system, recognizing the developed strategies in order to effectively deal with the complexity of hysteretic nonlinearities, parametric uncertainties, measurement limitations and unknown disturbances, and consequently to achieve the robust performance. It hypothesizes that techniques of vibration structure system can be a new building technology protecting buildings from the mentioned problems. Following a scientific methodology, the paper starts with defining the meaning of vibration structure outlining indications of how to make a building ready to resist natural hazards in seismic zones. In the next part, two different case studies will be analyzed to figure out how this structure system works.

2. Purpose of Vibration Structure System

Vibration structure is a structure that designed to withstand natural hazards especially earthquakes and strong winds. The goal of vibration-resistant construction is to erect structures that fare better during seismic activity than their conventional counterparts. According to building codes, earthquake-resistant structures are intended to withstand the largest earthquake of a certain probability that is likely to occur at their location. This means the loss of life should be minimized by preventing collapse of the buildings for rare earthquakes while the loss of functionality should be limited for more frequent ones. The movements of the earth's surface causing an earthquake are not a risk, except in rare cases, but its consequences affect us, causing disasters: falling buildings, city fire, landslides or tsunamis. Considerations for multi-hazard engineering emerged at the beginning of the twenty-first century when terrorism concerns raised the importance of designing buildings against blast loads as well as other natural hazards. Though the risk of blast loads for a typical structure is still relatively minor, the events of September 11, 2011 spurred interest in the field. Since loading from multiple hazards can result in conflicts in load demands on the structure, considerations for each of the differing loads must be considered. With regards to the architectural elements in a building, an example of conflicting demands would be the drop ceilings that are common in office buildings. The suspension of the ceiling tiles may be beneficial in terms of reducing seismic loads, but they become safety risks when blast pressures lift the tiles which then fall on the building's occupants. [3]

3. Architecture against Natural Hazards

Any building should be designed resisting any possible natural hazard through an appropriate structural configuration, with appropriately sized components, materials, and proportions to withstand action forces caused by frequent vibration. Even when a building designed and constructed to meet all safety requirements, there is always a possibility of a danger even stronger than they have been provided and must be resisted by building without damage occurring. For this reason there are no entirely danger resistant buildings. [4] The guideline addressed seismic resistance includes:

- Use regular building shapes without changes in geometry or stiffness, and/or seismic isolation of sections.
- Limit the inclusion of large openings in diaphragms and shear walls.
- Avoid placing large loads at higher building levels.
- Use diagonal or chevron bracing.

According to Civil Engineering, there are principles guaranteeing that buildings can resist natural hazards safer as follows:

- Regular shape: Geometry of the building must be simple in plan and elevation. Complex shapes, irregular or asymmetrical cause confusing behavior when the building is rocked by an earthquake. Irregular geometry bring on the structure undergoes torsion or attempt to turn in a disorderly manner. The lack of uniformity makes it easier in some corners are presented intense concentrations of power that can be hard to resist.
- Lightweight: The more lightly the building the less force you have to bear when an earthquake occurs. Big masses or weights move more severely when they are shaken by an earthquake and, therefore, the demand of the force actuating on components of the building will be greater.
- High rigidity: It is desirable that the structure will deform slightly as it moves against the action of an earthquake. A flexible or flimsy to deform excessively brings on damages that occur in walls or partitions non-structural architectural finishes and facilities that are often fragile items that do not support further distortions.

- Good stability: The buildings must be firm and maintain balance when they are subjected to the vibrations of an earthquake. Unsound and unstable structures can tip or slide in case of a poor foundation.
- Appropriate structure: To support a natural hazard a building structure must be strong, symmetrical, uniform, continuous or connected. Sudden changes in its dimensions, its rigidity, lack of continuity, structural configuration disorderly or excessive overhangs facilitate the concentration of harmful forces, torques and strains that can cause serious damage or collapse of the building.

Structures are seismic resistant when if the design provides: reinforcement of the concrete foundation, reinforcement through external auxiliary structures, using tensioned reinforced elements, reducing the weight of the slab, increasing the number of vertical supports, and replacement of rails and vertical element and metal reinforcements.[5]

4. Methods of Vibration Structure System

There are two methods of Vibration Structure System as follows:

4.1.1. Traditional Method

Vibration reduction in structures and components has been a topic of longstanding interest in the field of vibration engineering. Traditionally, problems relating to this topic were tackled by four principal methods, namely:(i) vibration isolation, (ii) use of vibration absorbers, (iii) introduction of damping, and (iv) active vibration control. Without knowing the innermost characteristics of a structural system, these methods have been rigorously explored in recent decades and effectively used in dealing with some practical vibration reduction problems based on a much simplified mathematical model of the system.

4.1.2. Modern Method

Local Structural modification is a new structural analysis technique that has been gaining more attention in recent years. This technique involves determining the changes to the dynamic properties of a linear elastic structural system that arise due to the redistribution of the mass, stiffness and damping of the system. The re-distribution can be realized by local modification of physical or geometrical parameters of the system, such as local thickness, width or Elastic modulus. The emergence of this technique has benefited from well-developed theories of Finite Element Analysis (FEA) and Experimental Modal Analysis (EMA). [6]

Since 1970s, architecture has passed the Age of High Technology. New structural components and materials entered the field of construction. Architects such as Norman Foster, Nicholas Grimshaw, and Santiago Calatrava invented new building technologies employing the modern method of vibration structure system. Based on the preceding, the paper can reach criteria of designing buildings using vibration structure system.

5. Design Criteria by Vibration Structure System

The shown table represents the design criteria that will be used in analyzing the following case studies.

TABLE I: Design criteria used to analyze the “Vibration Structure System”

Method	Techniques	Structure System	Materials
Traditional	Low	Appropriate or not	- Reinforced concrete - Pre-stressed concrete - Steel - Masonry - Reinforced masonry
Modern	High		

After analyzing the case study, the used design criteria will be highlighted in this table.

6. Experiencing two case studies

In order to examine the vibration structure techniques, the paper will analyse two case studies as follows:

6.1. The Millennium Tower, Tokyo, Japan, 2000 - (Non-built Project)

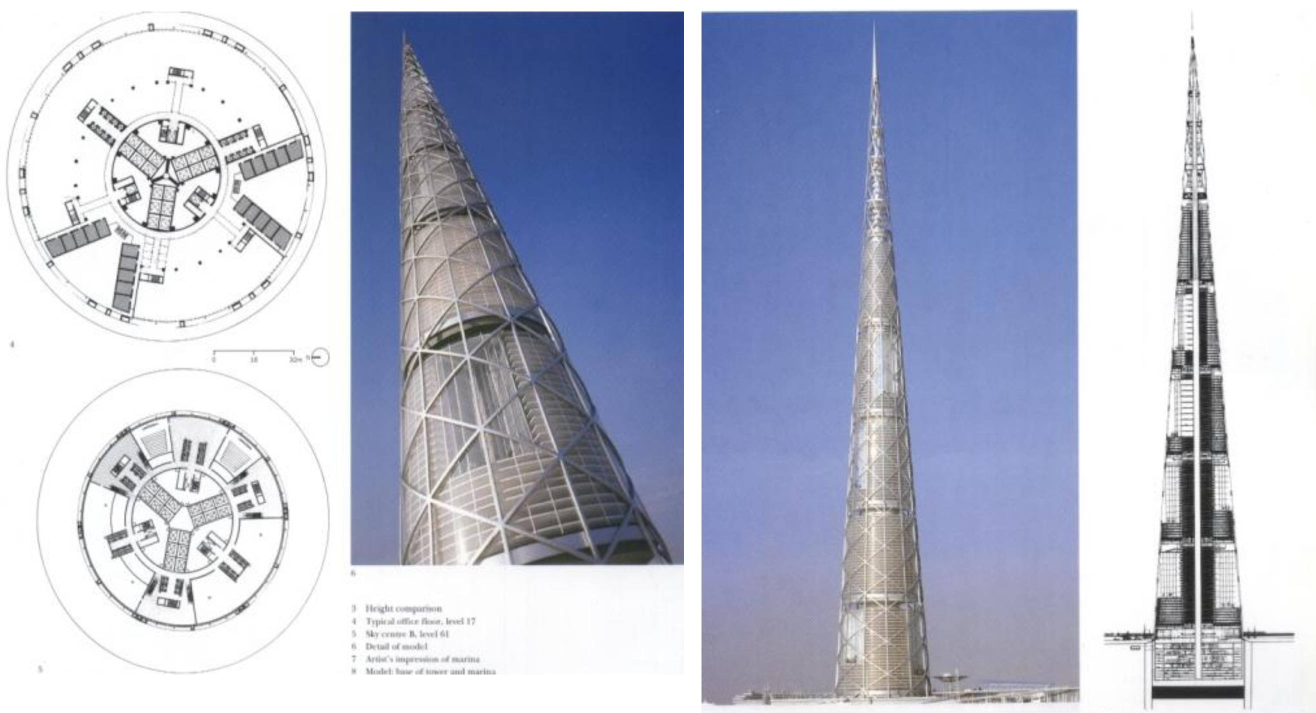
Dynamic behavior of this building can be analyzed through the following points:

6.1.1. The Building

Japan decided to enter the race of the highest tower in the world. In 1989, a design competition was held to design a tower on Tokyo bay that approximately equal one mile height, 170 storyes, accommodated by 60.000 inhabitants. It was intended to include residential, entertainment, and administrative activities. According to the chosen site located in a seismic zone of earthquake and volcanoes, the design condition was to produce a proposal that resists these natural hazards. The British architect Sir Norman Foster won this competition. He produced a unique tower structurally.

6.1.2. Building Construction

The form is looked like a needle pointed up. The tower is structurally based on a single steel core. This core is intended to be raised up and surrounded by circular reinforced concrete slabs to be the floors of the building. 1/3 of the total height is supposed to be pile foundations beneath water fixed hardly in the bottom of the bay. The architect suggests that, through steel hooks, cables can be fixed from the highest and lowest points of the core. These cables will be tensile members tighten the circular slabs in a dynamic balance. This new system Foster called it; vibration structure system with a modern method. To keep slabs in balance, they must be in a continuous state of vibration. Under any circumstances, this vibrating tower is able to resist dangers of natural hazards due to its flexible ability to move within natural cracks and strong winds without breaking slabs or even the main structural core. [7]



Figs. 1-5 The Millennium Tower, designed by Sir. Norman Foster
Plans, section, and the 3d model represent the tower's form

TABLE II: Design criteria used to analyze the “Millennium Tower”

Method	Techniques	Structure System	Materials
Traditional	Low	**A Core + Circular Slabs + Tensile Cables (Compression + Tension)**	- Reinforced concrete - Prestressed concrete - **Steel** - Masonry - Reinforced masonry
Modern	**High**		

6.2. The Dome of Sony Center, Berlin, Germany, 2000

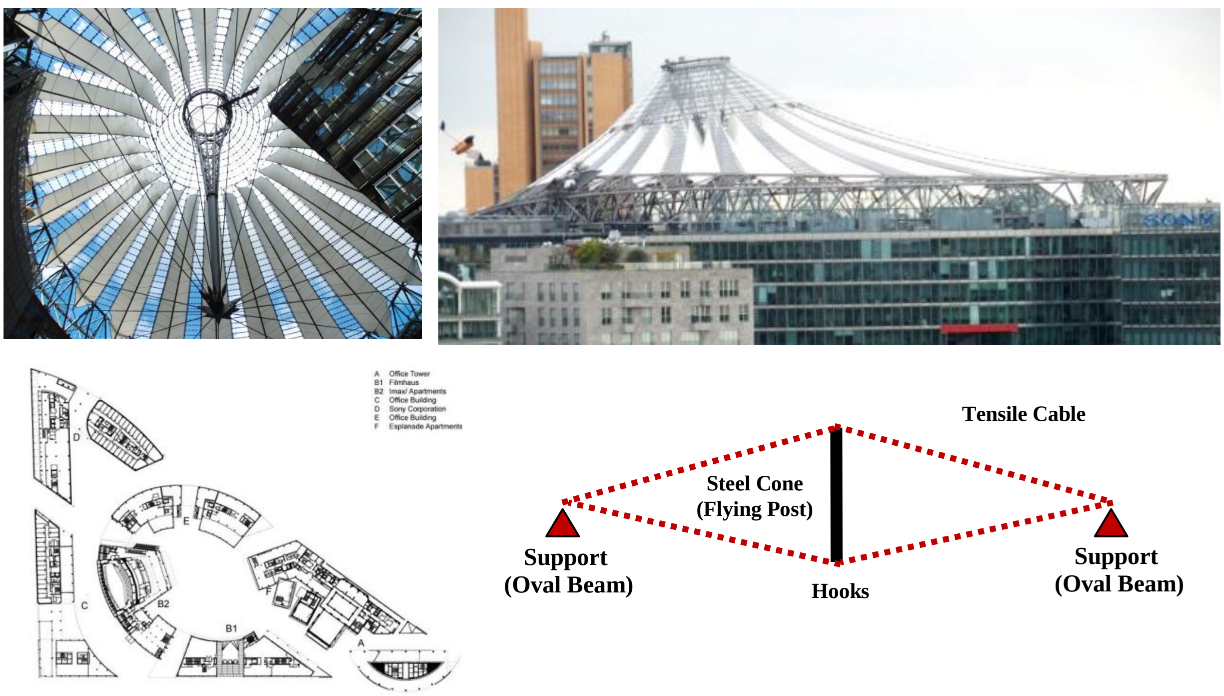
Dynamic behavior of this building can be analyzed through the following points:

6.2.1. The Building

In the heart of Berlin, a multifunction complex was designed, 2000, to be an attraction point for tourism and entertainment. It is Sony Center. This complex included a central court open to the sky. This court is an oval not a circle. A design competition was held to design a special dome covering this court to protect users from rain and other environmental issues. The German-American architect Helmut Jahn won the first price according to his powerful proposal. Diameter of Jahn's dome equals 102 meters and the height of its peak equals 60 meters from the lower level.

6.2.2. Building Construction

Jahn's dome is structurally based on steel oval beam. 50% of its surface is covered by glass panels, while the other 50% is covered by white kinetic sails made of Teflon sheets. It results a semitransparent dome not opaque due to this property of the Teflon sheets. The question is how this dome became balanced without any posts or columns? The answer is: The architect invented a new vibration structure system. This dome is suspended by tensile wires. Through a flying vertical post, Jahn suspended wires starting from hooks fixed in the bottom of the post, connecting with the oval beam, reaching to the peak of the post, and ending with other side of hooks. Tens of wires were used to tighten the dome's surface which let it erected in dynamic balance. Sensors of solar cells are distributed over the Teflon sails. They determine the power of natural light. Through these sensors, each Teflon sail can move revolving around its axis. If sunlight is strong and direct the sails move to close, and vice versa. [8]



Figs. 6-9: Dome of Sony Center designed by Helmut Jahn
Elevation, interior, plan, and sketch represents the Vibration Structure System idea

TABLE III: Design criteria used to analyze the "Dome of Sony Center"

Method	Techniques	Structure System	Materials
Traditional	Low	**An oval beam + A Post + Tensile Wires (Compression + Tension)**	- Reinforced concrete - Prestressed concrete **- Steel, Glass, & Teflon**
Modern	**High**		- Masonry - Reinforced masonry

7. Comparison Between the Case Studies

The shown table rephrase the vibration structure techniques that were used in the two previous case studies.

TABLE IV: Comparison between the two case studies

The Project		Millennium Tower	Dome of Sony Center
Photo of the project			
Location		Tokyo, Japan	Berlin, Germany
Date		2000	2000
The Architect		Sir. Norman Foster	Helmut Jahn
Built/Non Built		Not-Built	Built
Design Criteria	Method	Modern	Modern
	Technique	High	High
	Structural System	A Core + Circular Slabs + Tensile Cables (Compression + Tension)	An oval beam + A Post + Tensile Wires (Compression + Tension)
	Materials	Steel	Steel + Glass + Teflon
	State of Balance	Dynamic Balance	Dynamic Balance
Function		Saving from seismic actions (earthquakes, tsunamis)	Saving from environmental actions (rain, wind, snow, and strong rays of sunlight)

From this comparison, it can be figured out that architecture of the present era provides new solutions for resisting dangers. Vibration Structure System became an outside of the box solution to fight natural or artificial hazards.

8. Conclusions

The paper can set a group of conclusions as follows:

- Steel became the material of the present and future ages. Since using it at the beginning of the twentieth century, it has become the cornerstone in the architectural industry. Architects and structural engineers employ it to produce new inventions.
- Methods of Vibration Structure System can be functioned in saving and preserving the cultural heritage that day by day became more vulnerable to dangers.
- The modification having a great impact on the behavior of the base structure.
- The influence of the many parameters involved in the formulation needs to be explored. The number of sensors, their location, the properties and geometry of the local model are subjects of interest for further research.
- The establishment of this knowledge base advances the field of multi-hazard design.
- The vertical resisting system with triangulations has the greatest influence on performance. Clearly, the design of these buildings must working hand by hand architects and engineers. Without the collaboration of design and proper execution the results can be reached catastrophic.

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