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REVIEW ARTICLE

Emergence of Earthquake Resistant Buildings: Review of Earthquake Resistant Tall Buildings of India

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ABSTRACT

Earthquakes are a sign that the earth's internal structure is changing. Seismic activity is normal in most parts of the world, but the frequency with which it occurs is determined by the tectonic setup of the region. Past earthquakes have resulted in significant loss of life and property, impacting a country's social and economic conditions. Though an earthquake cannot be prevented, the least that can be done to minimize damage is to make buildings earthquake-resistant. Most countries have required the inclusion of seismic requirements in building design and architecture as our understanding of earthquakes has increased. This paper aims to create a review of some earthquake resistant tall building in various seismic zones in India. This study focuses on what are the different techniques adopted for these tall building to make it earth quake-resistant. This is a research with the approach consists of analysis from various case and literature studies and their comparison with regard to earthquake.

Keywords | Earthquake Resistant Building, Techniques, Seismic Zones

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INTRODUCTION

Earthquake is a tectonic or volcanic phenomena that depicts rock movement which causes the earth to shake or tremble. Earthquakes are one of the most terrifying natural occurrences. Due to its peculiar geophysical factors, India is extremely vulnerable to earthquakes of various magnitudes. Several million earthquakes occur each year all around the planet. Several devastating earthquakes have struck the country in the previous years, causing a considerable amount of fatalities and property damage.

Five earthquakes measuring M8 or more hit various areas of the globe during the last century:

- Uttarkashi (1991) M6.6
- Latur (1993) M6.4
- Jabalpur (1997) M6.0g
- Chamoli (1999) M6.8
- Bhuj (2001) M6.9.

Other earthquakes (Muzaffarabad in 2005 M7.6; Great Sumatra earthquake, 2004 M9.1) that occurred outside Indian territory had a significant impact on the country as well. Table 1 displays the recurrence of earthquakes by area over the last 110 years. (Safety_earthquake@ Nidm.Gov.In, n.d.)

METHOD & MATERIALS

Seismic Zones of India

According to the magnitude of the damage or the frequency at which earthquakes occur, the country has been divided into regions or zones. The seismic coefficient can be used to design buildings in various parts of the nation by referring zoning charts given by National Institute of Disaster Management.

Zone 5

This zone encompasses the areas that are most vulnerable to earthquakes of magnitude MSK IX or greater. The highest amount of seismicity is connected with Zone 5.

Very High Damage Risk Zone is what it's called. Kashmir, the western and central Himalayas, North and Middle Bihar, North-East India, and the Rann of Kutch, as well as the islands of the Andaman and Nicobar group.

Zone 4

Zone 4 is susceptible to MSK VI to MSK IX intensity. The High Damage Risk Zone is what it's called. Zone 4 includes the Indo-Gangetic basin, the country's capital (Delhi), and Jammu & Kashmir. The Patan area (Koyananager) in Maharashtra and the northern section of Bihar, such as Raksaul, near the India-Nepal border, are both in Zone 4.

Zone 3

This zone is vulnerable to MSK VI intensity. This zone includes the Andaman and Nicobar Islands, sections of Kashmir, and the Western Himalayas. The Moderate Damage Risk Zone is the name given to this area.

Zone 2

The Zone of Low Risk of Damage is defined as a zone that is vulnerable to MSK VI or less. The lowest level of seismicity is linked with this zone.

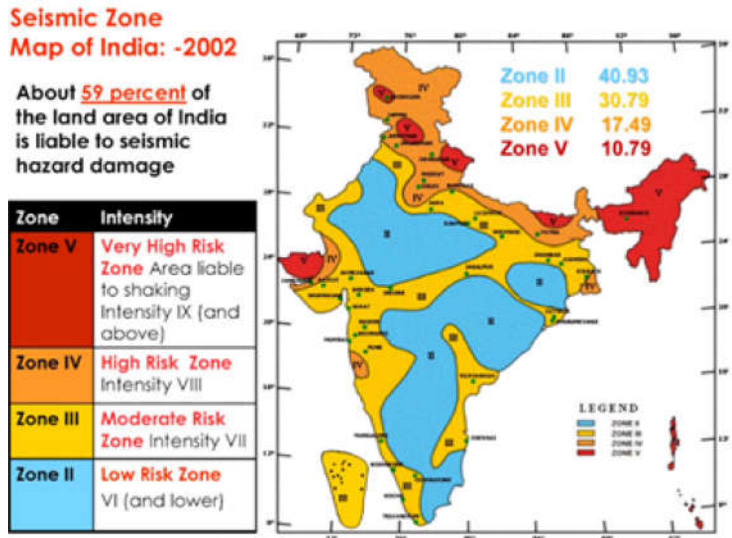

Figure 1 Seismic Zone Map of India - 2002 Source: The Hindu Times

SEISMIC REGION	NO.OF EARTHQUAKES OF MAGNITUDE				RETURN PERIOD
	5-0.5.9	6.0-6.9	7.0-7.9	8.0+	
Kashmir & Western Himalayas	25	7	2	1	2.5-3 yrs.
Central Himalayas	68	28	4	1	1yrs.
North East India	200	128	15	4	<4Months
Indo-Gangetic Basin and Rajasthan	14	6	-	-	5yrs
Cambay and Rann of Kutch	4	4	1	1	20 yrs.
Peninsular India	31	10	-	-	2.5-3 yrs.
Andaman & Nicobar	80	68	1	1	<8 months

Table 1 Regionwise major earthquakes in India

Source: Safety_earthquake @ Nidm.Gov.In, n.d.

METHODOLOGY

This paper showcases idea of earthquake resistant tall buildings by studying some of the earthquake resistant tall buildings of the world. Since these buildings are located outside India; the data has been collected through online articles, journals and other internet sources. The main objective is to study their vertical shaping, plan shaping for wind, foundation treatment, materials used and may more. Study provides an understanding of advancements in the building industry which includes Foundation design, Innovative materials used, vertical shaping of the skyscraper. These tall buildings have incorporated such principles and withstand itself in high intensity earthquakes. This paper analyzes these innovative techniques and their capability to withstand earthquakes.

Limitations

Some of the structures under investigation are approaching completion, so their earthquake resistance cannot be accurately assessed, but the features and techniques are useful for future research. As a result, only qualitative data is available for such structures.

Seismic Codes of India

India is among the nation's greatest catastrophe countries, having been hit by practically every natural and man-made calamity.

Around 85% of the region is exposed to one or more disasters, and approximately 57 percent of the country, along with the capital, is positioned as a high earthquake zone. Technological intervention in buildings and infrastructure to makes them more resilient to natural disasters.

IS codes are intended to serve as a guideline for the construction and repair of buildings that are subject to seismic forces. (Safety_earthquake @ Nidm.Gov.In, n.d.).

Earthquake Resistance Construction

Earthquake-resistant construction refers to the design of a structure or building that can withstand the rapid ground shaking that happens during earthquakes, decreasing structural damage as well as human deaths and injuries. Appropriate construction procedures are required to ensure that correct design objectives for earthquake resistance are accomplished. Because construction methods vary so widely over the world.

The design of a building and the construction procedures utilised to construct that building are fundamentally different. Advanced earthquake-resistant designs can only be successful if suitable construction procedures are applied in the site selection, base, structural members, and link joints. Structures and structural elements designed to withstand earthquakes frequently have ductility (the ability to bend without breaking).

Behaviour of Tall Buildings to Ground Motion

During earthquakes, ground vibrations induce inertia forces at mass locations in the house. These forces pass to the base via the roof and walls. The main focus is on ensuring that these requirements are met. Without causing significant damage or failure, the powers hit the ground.

The roof, wall, and foundation are the three components of a masonry building. The walls are the most resistant to earthquake damage caused by horizontal forces. When pushed horizontally at the top in a direction perpendicular to its plane (the poor direction), a wall topples quickly, but when pushed along its length, it provides much more resistance (termed strong direction).

Source: architizer.com

CASE STUDIES

Spire Edge, Manesar

- Architects: T.R. Hamzah & Yeang Sdn Bhd
- Project: Spire Edge
- Location: Manesar, India
- Client: A.N Buildwell Pvt. Ltd
- Nos. of Floors: 20 floors + Roof Garden
- Site Area: 4,765 sq.m
- Proposed Development: Commercial and Offices
- Project Architect: Glen Pang
- Design Architect: Khairi Ismail

(Elements & Criteria, n.d.)

Winner of numerous awards Spire Edge is a Leed Platinum and Leed Gold Mainstream Green office complex designed to provide a financially stable, socially lively, and environmentally restorative work environment for IT/Ites organizations seeking development, expansion, or consolidation.

Design Strategies

Source: architizer.com

The green Design Strategies of the building areas are as follows:

- Continuous Landscape Ramp
- Rainwater Harvesting/Recycling
- Roof Gardens
- Climate Responsive Façade
- Pocket Park
- Sun Shading Strategy
- Eco cell
- Earthquake resistant

Architectural features that make it earthquake Resistant

- Rubber shock absorbers to absorb earth tremors.
- Foundations sunk into bedrock avoiding clay.
- Computer controlled weights on roof to reduce movement.
- Automatic window shutters to prevent falling glass.
- Fire resistant building materials.
- Roads to provide quick access for emergency services.
- Steel frames that can sway during earth movements

Chandrodaya Mandir, Vrindavan, Mathura

The world's tallest temple skyscraper, Vrindavan Chandrodaya Mandir, is currently under construction (2016).

The Hindu temple will be built in the Mathura area of Uttar Pradesh, India, and would have a footprint of roughly 5 acres and a height of 213 meters (700 ft).

It is being erected at a cost of Rs. 300 crore (US$45


Source: www.designingbuildings.co.uk/

Source: http://hindupad.com

million) by ISKCON Bangalore, making it one of the most expensive temples ever built.

The building will be cutting-edge and earthquake-resistant.

It is being designed by Thornton Tomasetti, who has created some of the world's highest structures, including the Petronas and Shanghai Towers.

The project is projected to cost around Rs. 800 crore, with a total of 50 crore spent on piling work. Vrindavan Chandrodaya Mandir, as the world's highest religious monument, demands a large number of construction materials.

It will have 32,516 m2 (350,000 sf) of glazing, 127,426 m3 (4.5 million c.f) of concrete, 17.2 million kg (19,000 tons) of reinforcing steel, and 5.8 million kg (6400 kg) of structural steel, and will be supported by more than 500 piles with a diameter of 1 m (3 ft) and a depth of 55 m (180 ft). Under the Leadership in Energy and Environmental Design (LEED) standard, the project team is aiming for a Gold rating.

The project team is seeking a Gold rating under the

Leadership in Energy and Environmental Design (LEED) program.

The Indian Institute of Technology (IIT) Roorkee is also doing a seismic study of the site to guarantee that the building design is designed to withstand the projected amount of seismic activity. The temple is currently intended to withstand a seismic event nearly twice as powerful as the area's largest known earthquake, which struck in 1803 and measured 6.8 on the Richter scale.

RWDI, a Canadian consulting engineering firm, is one of the project's other consultants, having completed wind-tunnel design with a wind-load goal of 226 km/hr (140 mph),

Tata Consulting Engineers, based in India, built the queue systems to hold 35,000 people on a typical day. (These systems should be able to hold 250,000 people on a festival day.)

Aecom, an American corporation, will install and design a fire and life safety system, overseen by Sunil Shahani, who has worked on similar projects before.

Earthquake Resisting Techniques In High Rise Buildings

Building damage can be avoided or minimized by taking a few precautions during construction. Buildings' earthquake protection can be improved by good design and construction. Many high-rise buildings incorporate earthquake-resistant features such as shear walls, moment-resistant frames, or new strategies such as base isolation or energy dissipation systems to avoid or minimize damages and casualties.

Techniques Used

A. Shear walls
B. Base isolation
C. Energy dissipation methods
D. Addition of Composite with concrete
E. Addition of any above methods

A. Shear walls

Shear wall is a type of wall seen in structures that extends from the bottom to the top of the structure at various points in the plan, preferably along the periphery. Shear walls are employed in structures to resist seismic and wind forces acting in a lateral direction on the structure.

B. Base isolation

The devices that are positioned between the foundation and the superstructure are known as isolators. Base isolators function similarly to automobile suspensions in that they shield passengers from shock. One of the best tools for controlling vibration or shaking of buildings in an earthquake is base isolation.

As an effective technique, the base isolation system

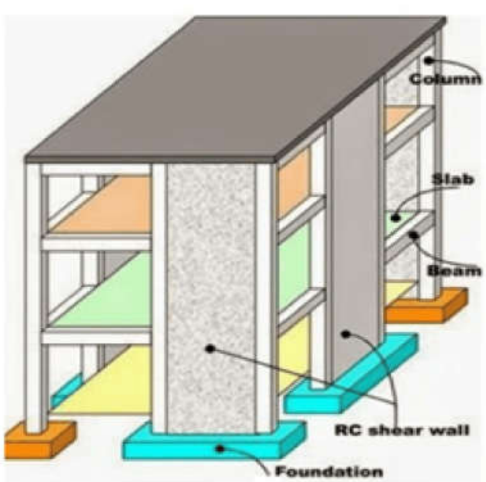

Fig. 6 Shear Wall Design to EC2 Source: civildigital.com

Fig. 7 Elastomeric bearing (Mahadik & Bhagat, 2020)

Figure 8 Low friction bearing (Mahadik & Bhagat, 2020)

is employed to improve earthquake resistance. It is one of the most effective ways to reduce the rigidity of a structure so that it can withstand earthquake forces.

Bearings used in stiffness reduction

C. Energy Dissipation System

The use of energy dissipation devices known as dampers is another method of seismic strengthening. In this strategy, structures are outfitted with additional devices known as seismic dampers, which have a high dampening capacity and can significantly reduce seismic energy entering buildings while minimizing structural damage.

This system consists primary structure and secondary structure. Structure is pre strengthened with secondary structures called as seismic dissipaters.

D. Addition of Composite to Concrete

Another way for strengthening seismic resilience of structures is to use composite materials. These composite materials are used to improve the structural behaviour of concrete in structural members. Composites are made up of two or more components that are mixed together to create a new substance that is superior to the original.

Review of Tall Buildings Earthquake Techniques:

Earthquake-resistant or aseismic systems are designed to shield buildings from earthquakes to some degree or another. While no structure can be fully earthquake-proof, earthquake-resistant architecture aims to build structures that perform better than their traditional counterparts during seismic activity.

Building codes state that earthquake-resistant buildings must be able to withstand the largest earthquake with a reasonable chance of occurring at their site. This means that the loss of life should be reduced for rare earthquakes by avoiding building collapse, while the loss of functionality should be limited for more common ones. To avoid being destroyed by earthquakes, ancient architects had no choice but to design their landmark structures to last, often by making them overly rigid and solid.

Abeno Harukas, Japan

Abeno Harukas is a steel-structured multi-functional skyscraper tower stands on the west side of Osaka Abenobashi Station in Abeno ward.

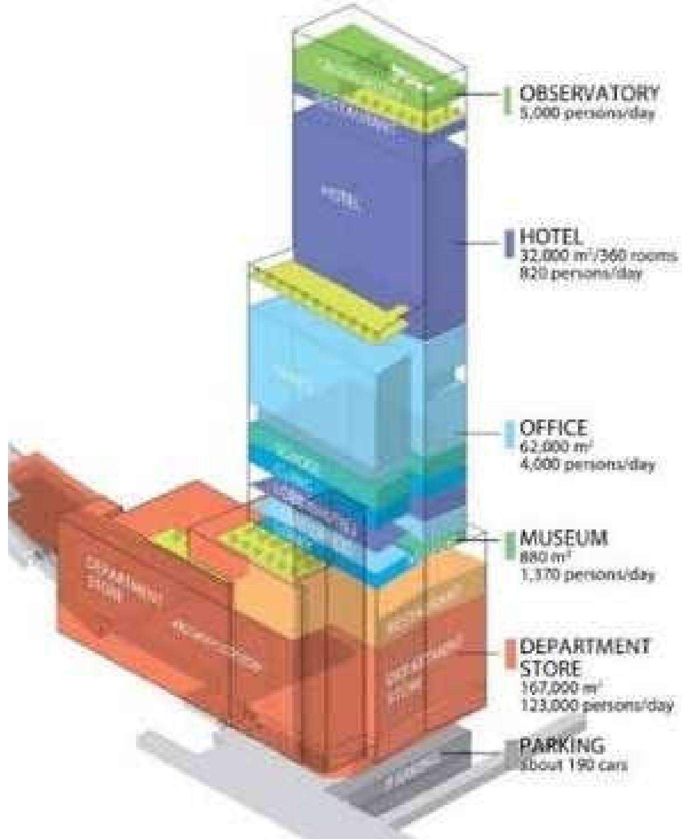

Fig. 9 Vertical Zoning of Abeno Harukas, Japan. (Mahadik & Bhagat, 2020)

The structure stands 300 meters tall, with 60 storeys above ground and 5 floors below. It is Japan's tallest skyscraper and the third tallest structure in the world, after Tokyo Sky tree and Tokyo Tower.

Takenaka Corporation, an architectural firm, designed the tower. The superstructure is made up of three blocks, each with a north side setback.

The bottom building has the Kintetsu Department Store, which has a platform on the second level for the Kintetsu Railway, the middle block houses offices and an Art Museum on the 16th floor, and the upper block houses a hotel with an observation deck on floors 58-60.

The building's foundation is a piled raft foundation, which comprises of a raft foundation with a bottom depth of 30.5 meters below ground level and cast-in-place concrete piles placed in a dense gravel layer below a depth of 70 meters.

Techniques To Achieve Seismic Design Concepts

High-capacity piled raft foundation with soil-cement continuous wall construction

Because Harukas is a reconstructed structure over the city's central terminal station, it occupies nearly the entire site. Many constraints apply to the foundation structure, which necessitates excellent efficiency.As a result, for this building, a piled raft foundation consisting of piles and bottom plate, both of which bear the building weight, is employed, with an inverted placement method employing basement columns. As a result, the superstructure is built up to the 50th floor level before the bottom plate is installed. Accordingly, the piles bear approximately 90% of the column axial stress, while the bottom plate bears the remainder.

High-strength CFT columns

Because HARUKAS was built in such a small location on the site, it was essential to keep the column sections as small as possible. In order to assure the safety of the columns that bear significant axial forces, concrete filled steel tube ("CFT") columns consisting of high-strength concrete and high-strength steels were utilized in this structure.

New Joint System

To achieve the self-filling property of high-strength concrete, this structure uses a unique joint system consisting of an exterior diaphragm and aluminum spray jointing.

Rotational Friction Dampers

In the void of a low-rise department store, rotational friction dampers and oil dampers are installed to absorb the seismic energy that will be input into the building and help lessen seismic responses.

Corrugated steel plate walls

In the middle gap of the office area, corrugated steel plate walls are erected in the longitudinal direction of the building. A corrugated steel plate wall is an earthquake-resistant structure made up of a steel plate that is corrugated in the height direction and surrounded by flanged steel plates that are integrated with their frame.

Core Truss Dampers

The core truss dampers are positioned in the hotel's central void so as not to interfere with ventilation and to reduce the high-rise component's deformation.

Taipei 101 Taiwan

Taipei 101, located in Xinyi District, Taipei, Taiwan, is one of the world's tallest buildings. The 1,667-foot tower has a tuned mass damper to prevent damage in the event of a natural disaster such as a typhoon or earthquake. Near the top of the structure, steel cables suspend a massive mass that acts like a pendulum, swinging back and forth in the opposite direction of the building to dissipate steam. One of the world's largest tuned mass dampers is the gold ball, which weighs 730 tonnes and hangs from the Taipei 101.

Foundation

Soft soil in the form of clay and stiff colluvial soil is present just below the site of Taipei which has low load bearing capacity.

Soft rock in the form of sand stone is present beneath 40-60m; hence it is required matt foundation with bored piles. The tower required a 21 m deep basement

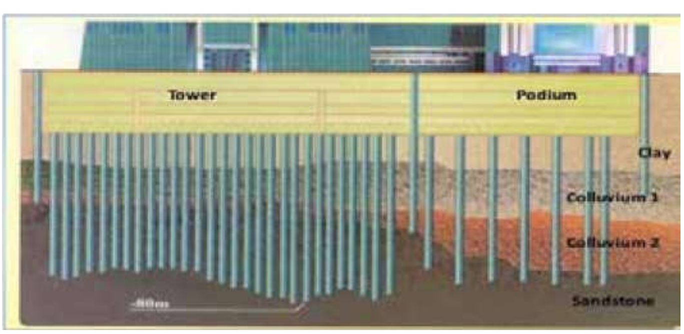

Figure 10: Spacing of Piles below Podium and Tower, Taipei 101

Source: structures-explained.com

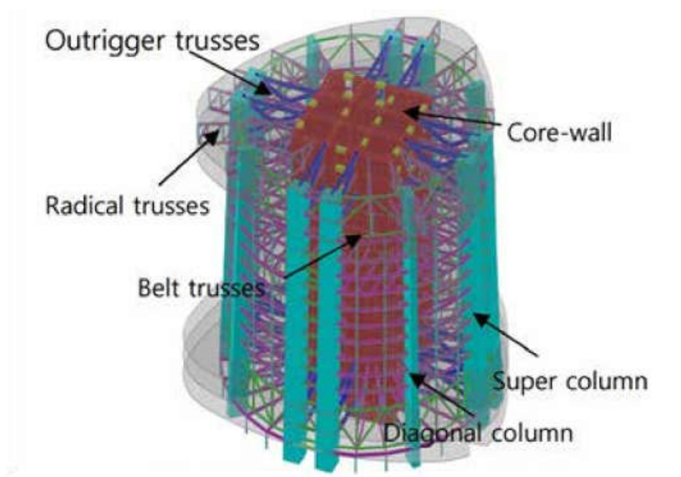

Fig. 11: Outrigger trusses with central braced core, Taipei 101

Source: http://faculty.arch.tamu.edu/

Water table at a site is 2m below ground which would create huge uplift forces on the foundation of the building. hence slurry walls were constructed to lay the foundation below the tower.

Foundation Depth 80m.

These walls surround both the tower and the podium and are 1.2 m thick and up to 47m below the ground. Main foundation of the tower consists of 380 piles of 1.5 m dia. And 167 piles for podium area. They were spaced 4m apart in the staggered rows for tower portion. A concrete raft thickness 3-4.7 m capped the piles and transferred the load from columns and walls above. Use of steel in the superstructure minimized the building weight which reduce the cost of foundation.

Superstructure

The building is 508 m above ground and resembles ancient pagodas. it takes inspiration from bamboo

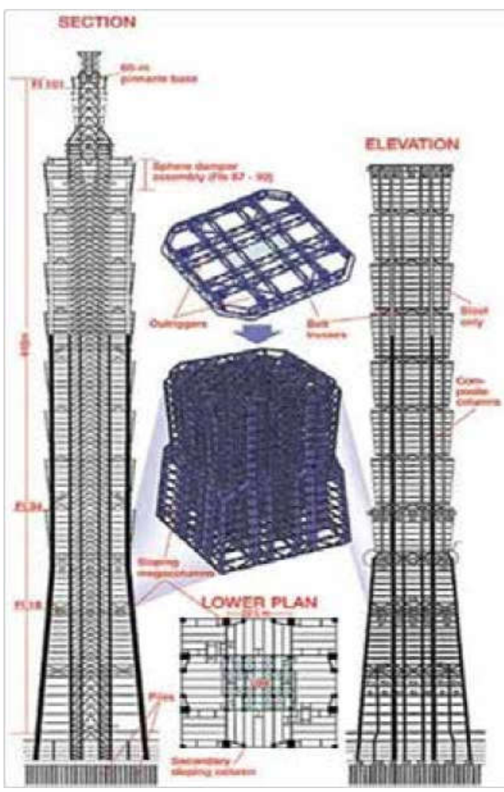

Figure 12: Seismic Design Components, Taipei 101, Taiwan www.ctbuh.org/papers

which is flexible and light yet strong. The bamboo has joints at intermediate locations which are mimicked by the building in the form of out riggers and belt trusses at every 8 floors. this separates the building into 8 identical modules.

At the top of 8th module sits on 9th module which has a smaller footprint. This module supports a spire and contains equipment and a observation deck. Below the 8th repetitive modules, a 25-story base shaped as a truncated pyramid is present. This base provides as an improved overturning resistance and lateral stiffness compared to a straight block. The story height of each floor is 4.2 m and retail floors below are 6.3 m. The floor is composite steel and concrete typically 135mm thick.

Tapai 101 is built in a high typhoon zone which experiences winds of 156km/hour with 100 year return period.

The building is impacted by alternating cross wind forces due to vortex shedding which means wind passing the building separated from the sites producing alternating whirlpools. These winds can also damage façade and partitions.

Sawtooth or double notch corners were provided which reduced the wind forces by up to 40%. The building has a square core made up og 16 box columns in four lines which are generally fully braced by moment frames between floors. The braced core is encased in concrete wall from foundation to the 8th level.

The core box columns were filled with concrete of strength 69Mpa till level 62, The building has 8 super columns or mega columns which are steel boxes filled with high strength concrete. they are present on the perimeter of the building to on each face. these super columns built up to the level 90 of tower. They were filled with concrete of Strength

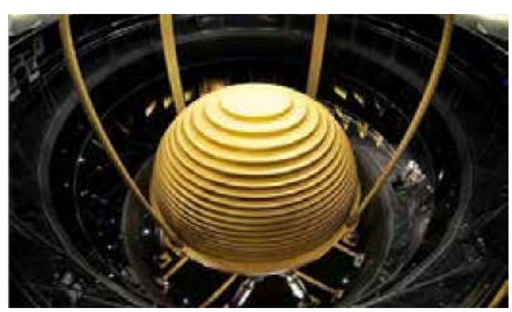

Figure 13 Mechanism of Damping, Taipei 101
Source: www.ctbuh.org/papers

69 Mpa from bottom of the basement till level 62, these columns control drift as large portions of drift is created at lower stories due overturning rotations.

The building was design to be stiff for resisting the wind forces first and then checked for seismic ductility and seismic strength.

The steel framing used in the building is a special moment resisting frame also known as SMRF Steel moment frames along sloping face of the building works in the braced core and out riggers to counter seismic forces.

MASS Dampers

At the top of the building between 86 and 92th floor is a huge pendulum which is called a tune massed damper or just TMD.

This pendulum counters the wind force and reduces sway of the building in typhoons. This damper uses building motion to push and pull giant shock absorbers to convert motion to heat by forcing fluid through small internal openings.

RESULT & DISCUSSION

The components that are placed in a structure to improve its seismic resistance are referred to as earthquake resisting elements, and the procedures used to apply these elements are referred to as techniques.

Even if structures are planned and detailed according to code, there is still the chance of damage or failure in the event of a significant earthquake. Building performance can be improved by incorporating earthquake-resistant materials and strategies.

As per analysis from the above case studies it is concluded that various techniques are used in Indian tall buildings as well as tall buildings in other countries, the major difference is the variation in seismic zones, accordingly, the design concepts were used and also techniques were used. So, the major thing is that there is a smaller number of a tall building are in India, so for future trend architects or engineers refers following techniques which were concluded from the above analysis that is Flexible foundation, Damping, Shield building from vibrations, Reinforce the structure by using shear walls, cross braces, diaphragms.

As a developing country, India has a limited number of tall buildings, according to the case study analysis. There is a lack of understanding about how to use earthquake-resistant materials and construction procedures.

As a result, it is critical to spread information on earthquake-resistant structures, technologies, and materials. To achieve this, we must introduce such basic programs at the elementary school level to raise awareness about earthquake-resistant structures, as well as higher-level awareness programs for people working in the construction industry such as architects, contractors, civil engineers, and structural engineers, to ensure that they will incorporate this knowledge into their upcoming projects.

CONCLUSION

In the past 50 years, India had faced six massive earthquakes which killed over 23,000 people and wreaked havoc. India has the world's second-largest population and, the second-largest number of buildings. However, few people realize that India also boasts of highest number of earthquake-prone structures. As everyone knows, earthquakes don't really kill people; nevertheless, falling buildings do, making India the world's most susceptible country. All structures in India are designed to the lowest seismic category-D, which means that after an earthquake, the building will be inoperable and will have to be abandoned. People who want better protection should have their structures designed in the same way that Japan does. Making India the world's most susceptible country. So, guidelines should be strictly followed in the construction. IJFMP

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