A SEISMIC RESISTANT STRUCTURE – PHILIPPINE ARENA MIRRORS ENDURANCE

The archipelagic nation of 7,641 islands, Philippines has diverse ecologies to cater to the world. Among the nature's bounty, it also houses some of its equally stunning infrastructure; solidifying a unique balance between the two: nature and human creation. The Philippine Arena boasts to be one of the notable structures of the country.

Keeping in mind the extreme high-winds speed, torrential rains and severe earthquakes, the largest indoor entertainment venue in the world is designed to shelter up to 55,000 spectators and 5,000 performers against these elements. The Phillipine Arena is inspired by the traditional Filipino Nipa Hut and the indigenous Narra tree and is a symbol of endurance, strength and indomitable spirit of the Filipino people.

Being situated in the Pacific 'Ring of Fire', the area is distraught with frequent volcanic eruptions and earthquakes of magnitude as high as 8 or more. The Arena is located just 24 km away from the West Valley Fault, a long active fault line that runs through Metro Manila and some provinces in Luzon. This highly engineered structure acts as a respite for the people of the island nation for being one of the best earthquake resistant design.

The domed roof structure which is also the largest non-column area in the world, measured to be around 227 m × 179 m is located in Barangay Duhat, Bocaue, Bulacan, which is north-west side of Manila, capital of Philippines. The arena has total floor area of 99.000 sq. m and it took more than two-year time of labor to build the structure, containing 9,000 tons of steel work. The roof was made as a separate unit to reduce burden on the arena with extra load. The arena is 65 m in height, or about 15 storeys high and founded on pile construction. About a third of the dead load of the building was designed for earthquake loads.

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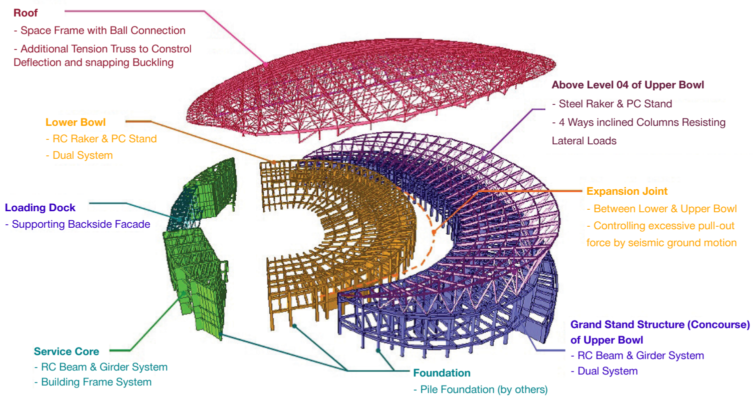
The building was also divided into multiple structures to strengthen the arena's earthquake resistance. It is one of the center piece of the many centennial projects of the Iglesia Ni Cristo (INC) for their centennial celebration on 27th July, 2014.

Populous Architects followed an extensive search throughout Asia to find the most suitable construction company. Buro Happold from Hong Kong was entrusted with the structural and MEP for the project.

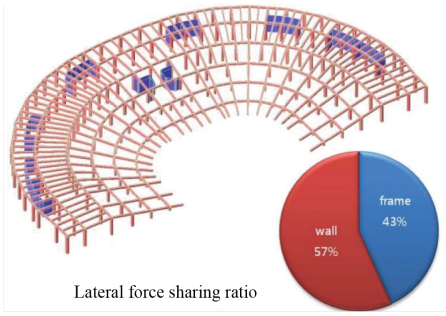
Philippine Arena is divided into four major parts – the roof, upper bowl, lower bowl and service core with loading dock. The roof and the upper bowl are steel structures while the lower bowl and service core are made of reinforced concrete.

Seismic Design

The structural member designs were mainly governed by seismic force. For this reason, it was very important to select proper seismic force resisting system from the onset. Analysis of the structure required a seismic demand corresponding to more than 40%, for the frame and more than 50% for the shear wall.

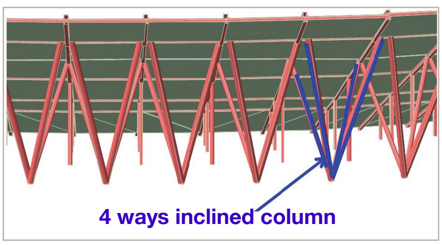


A dual system was selected for lower bowl which meant that 25% of lateral load would be resisted by frames without shear walls and hence, adequate reinforcement was provided in column and girder to ensure ductile behavior of the frame. Precast stand was planned for diaphragm action of bowl structure.



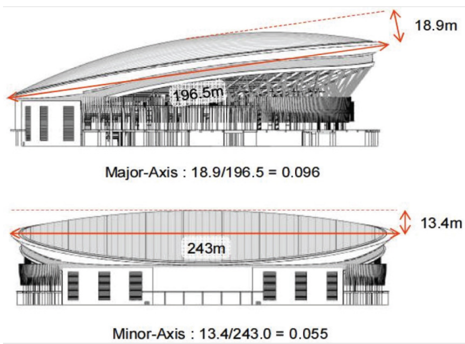
Lateral force sharing ratio of lower bowl.

The shape of structure indicated enough stiffness to exhibit behavior in seismic activity. Push over analysis was performed to estimate the seismic resistance of the structure, which clarified that columns, rakers and girders of upper bowl remained in the elastic range in case of earthquake. The structural elements were designed with amplified seismic force by over strength factor of 2.8 to be safe at the force level with elastic response.



Columns of upper bowl

The seismic behavior of a spatial structure is different from that of general structure since in spatial structure, horizontal seismic force happens to cause vertical vibration which has a significant effect on the overall structure. Hence, static and dynamic analysis (response spectrum analysis and linear time history analysis) were conducted for seismic load. The earthquake wave of linear time history analysis was made by extracting the three artificial seismic loads, using response spectrum of MCE (maximum considered earthquake) level. These earthquakes were scaled down to 2/3 and applied to the structural DBE (design based earthquake) level. When ground acceleration passes the structures, response acceleration may be reduced or amplified according to dynamic characteristics of each structure. Hence, five points of the roof supports were selected from different sub-structure (three points from upper bowl, two points from service core). Then, response acceleration was compared with ground acceleration. As Philippine Arena had short period, the response acceleration was greater than two to four times than ground acceleration itself.



Overall geometry of roof structure

Buro Happold's innovative response to this challenge was to design a foundation and base that is independent from the rest of the arena structure, isolating the building at ground-level to reduce acceleration of forces. The structure and the base are joined by lead bearings, allowing the base to move with the violent quake tremors while the structure remains stable. This incredible piece of engineering has ensured the Philippine Arena is amongst the top five most earthquake resistant structures in the world.

In this case, lead rubber bearing (LRB) was applied as a base isolation system owing its high energy dissipation ability. The lead core inside of the LRB provides the specific behavior which has different stiffness as external force reaches to designated value. From the characteristic of the LRB, displacement caused by normal use can be absorbed while lead core remains in elastic range and against severe lateral loads, it can provide high energy absorption capacity. To confirm effectiveness of the LRB, response acceleration and member forces were compared between two cases, with and without LRB. When the isolators were installed, the response acceleration and member forces were reduced significantly. Thus, the structural design progressed including stiffness of isolators. Moreover, by employing a seismic joint system, the building has strong durability and the ability to withstand earthquakes up to a magnitude of 7.0-7.5.

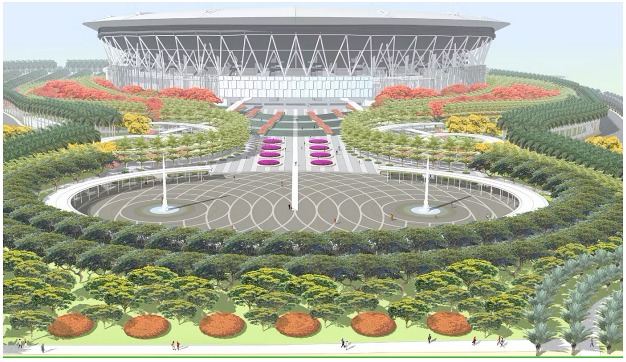
As the 10,000 ton dome structure is one of the greatest load, the Arena was constructed with thick core shear walls using 1,127 tons of steel and 541 major concrete columns. The load support system of the entire structure consists of 55,000 cubic meters of concrete and around 8,000 tons of reinforced steel bars.

Other significant features of the structure, which make it an engineering splendor include:

1. **The Large Dome** – It was designed with utmost safety while creating the most beautiful angles and curves. The arena withstands external forces of heat and wind due to such intricate engineering. The exterior design maximizes aesthetics while the interior of the 4 storey building offers a lavish space for cultural events.
2. **Space Frame** – The Philippine Arena built with the space frame construction method divided the dome ceiling frame into 46 blocks and enabled assembly on the ground prior to installation. This reduced the weight on the steel frames and minimized internal columns to minimize seat loss and dead angles. Not only did this reduce the risk of fall accidents but this also brought down the overall construction time since it was able to avoid the time-consuming welding work at height.
3. **Roof Surface without Connecting Joints** – The surface of the world's largest dome is free from connecting joints and covered with extruded sheets. This technology absorbs thermal expansion caused by higher temperatures and provided much needed relief in the tropic climate of the Philippines.

4. **Sandwich Plate System (SPS)** – Use of lightweight construction materials, specially the ones normally reserved for ships, were used to complete the upper seating area of the Arena. This enabled increased precision and reduced the construction period.

Structure	One of the 5 major earthquake resistant structures consisting of a roof structure, upper bowl, lower bowl and service core with loading dock.
Roof and Upper Bowl	Steel System
Lower Bowl and Service Core	Reinforced Concrete System
Construction Period	2011-2014
Architectural Firm	Populous
Structural Engineer	Buro Happold (Hong Kong)
Main Contractor	Hanwha Engineering and Construction Corp.
Cost	US$ 213 Million



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Research Initiative

SEISMIC PERFORMANCE ASSESSMENT OF NON-STRUCTURAL ELEMENTS IN A BUILDING

The recent earthquakes in India and across the globe have again reminded us about the most unpredictable behavior of the hazard. Over the last 10 years, there has been more than 2500 moderate to severe earthquakes which have been experienced within a distance of 300 km of India (source: earthquakelist.org). As per the Vulnerability Atlas of India, 59% of the land is prone is earthquake hazard and almost 11% is susceptible to severe earthquakes. While the standards for design of earthquake resistant structures have evolved over period of time creating robust guidelines, the same was not observed for non-structural elements (NSE) within a building.

It is important to understand that NSE constitute a major compnent of any builing project. Their contribution to the overall project cost is to the tune of almost 75 to 80% for specific categories of buildings. Failure of non-structural elements have several repercussions. They lead to loss of life, extensive repair cost, create obstacles in the escape routes and jeopardize the safe evacuation of the people and also render the building like hospitals, airports, data centers, etc. non-functional.

The existing Standards in India lacked adequate assessment criteria until the release of National Building Code 2016. Emphasis on the structural stability of non-structural elements is a welcome addition. IS 16700-2017 resonates the requirement. A research project was taken up between **Hilti India Pvt. Ltd. and Earthquake Engineering Department, Indian Institute of Technology (IIT) Roorkee** on "Seismic Performance Assessment of Non-Structural Elements in a Building".

To know more, click here -

https://theseismicacademy.com/research-initiative-detail/seismic-performance-assessment-of-non-structural-elements-in-a-building