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Wind and Architecture: Design to the flow

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Abstract – *Since ancient times, Architecture have always been an environment sensitive field in their design approach which makes it deal with various obstacles present in the nature. The study of local climatic characteristics navigates the building design to a great extent which makes Architecture defining its own styles from one place to other. The hand in hand coordination of design with engineering has helped world witnessing the revolution in building cities across the globe. The approach has also changed from battle to cooperative over a period of time that makes it a more cohesive setting. With the advent of mega structures even engineering and technology are also discovering new horizons of their domain by bringing the reality to the creative ideas of Architects. Wind has been the most important aspects that needs attention while making new age structures of mega million projects reaching sky. The paper discusses various ways the wind and Architecture can together accommodate through proper design approach.*

Key Words: Architecture, Environment, Building design, Engineering, Mega structures, Technology.

1. INTRODUCTION

Wind characteristics change with every region and every season, according to the topography, physiology, geography etc. Every built form acts or reacts to these characteristics in its own unique fashion.

The built form is the result of the plan, the façade and the openings on the façade. A sphere will react to the wind like no cube will, a cube will act in a manner a pyramid never will. Every solid mass (building) either acts as a barrier, or facilitates the air movement in the required direction as per the form.

Though technology has played an important role in serving the Architects to combat these obstacles but sometimes they can be catalyst to the new built form produced.

Objectives:

- To study the various wind conditions and its effect on buildings specially skyscrapers.
- To study and understand the impact of wind on various built forms with different design approach.
- To understand how wind pressure is been tackled in design of buildings across globe.

1.1 Wind Characteristics

The wind pressure and its impact over building keeps on increasing with altitude due to increase in wind velocity. Due to greater viscosity near the ground level, the wind velocity is almost negligible as the retardation effect is greater. With every layer this retardation effect goes down, and the surface friction decreases. After a certain height, this effect becomes non existent, where, the wind velocity is maximum.

2. TYPES OF LOADS

Wind has been an essential part of human life and hence Architecture design too. It serves the purpose of proper ventilation in the built spaces. However we need to understand its basics before applying to the Architecture.

Wind is the term used for Air in Motion and is usually applied to the horizontal motion in the atmosphere. Winds are produced by differences in atmospheric pressure, which are primarily attributed to difference in temperature. When temperatures of adjacent regions become unequal, the warmer and thus lighter winds tends to rise and flow over the colder, heavier winds.

<u>Types of Winds:</u>

- Prevailing winds
- Seasonal winds
- Local winds

All three types of wind mentioned, are equally important for design. However, for calculating wind loads, prevailing and seasonal winds are considered together, while local winds are studied separately.

3. DESIGN APPROACH

The design of building plays an important role in making it wind responsive. Though the wind pressure plays on all built structures but the major impact is seen on high rise or skyscrapers and hence more emphasize is given in engineering them as per wind flow.

Due to lateral nature of wind pressure, the force of wind against tall structures can cause serious damage and some cases displace the top of buildings by considerable distance. However, with the innovations in architectural treatment, increase in strength of materials and advances in the methods of analysis, tall building structures have become more efficient and lighter and consequently more prone to deflect and even sway under wind load.

3.1 Two Methods of Designing the Building:

Though the design of buildings is case specific but there are some specific thumb rules every Architect and engineer need to take care of while designing high rise structure. The two very basic approaches are:

Static Approach

- It assumes the building to be a fixed rigid body in the wind.
- The static methods are appropriate for tall buildings of unexceptional height, slenderness or susceptibility to vibration in the wind.
- It accounts for the effects of gusting and for local extreme pressures over the faces of the buildings.

  Eg: Taipei 101, Taiwan; Empire State Building, New York

Dynamic Approach

- These methods are for exceptionally tall, slender or vibration prone structures.
- These are generally used when the width: height ratio is 1:5 or above.
- The effective wind loading on such buildings may be increased by dynamic interaction between motion of the building and gusting of the wind.

  Eg: Burj Khalifa, Dubai; World Trade Centre, Bahrain

3.2 Wind & Plan Form

The plan form of a building affects the airflow around and through it. It could either aid or hinder the natural flow of wind.

Physical obstacles in the path of airflow create pressure differences. This causes a new airflow pattern. Air tends to flow from high pressure areas. Knowing the direction of air movement, the plan form can be determined also as to create high pressure and low pressure areas. Building openings connecting the high pressure areas to low pressure areas would cause effective natural ventilation.

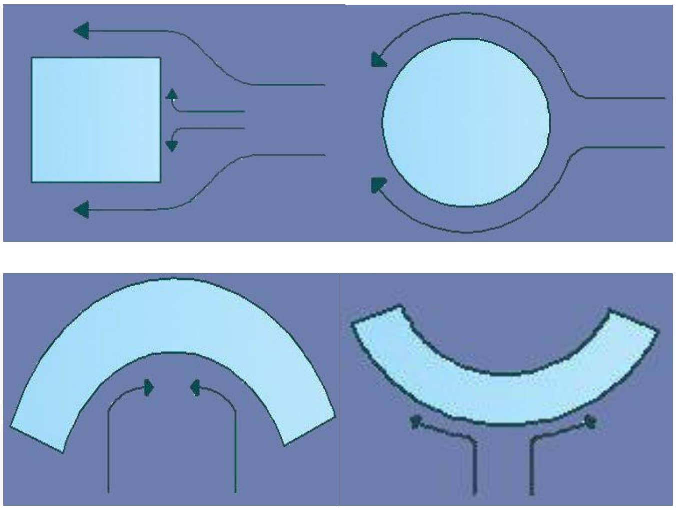

Fig-1: Wind action on various Building Plan forms

3.3 Wind and Built Form

Various aspects of the building form can cause increase or reduction in wind effects. Although it is seldom as critical in building design, streamlining can improve the relative efficiency of the building in wind resistance.

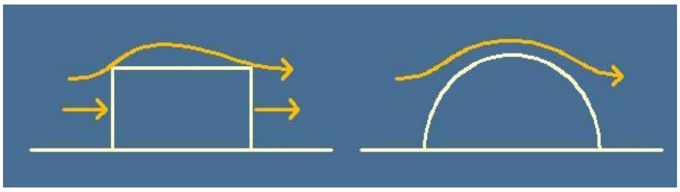

Fig-2: Wind action on Builtforms

Buildings with rounded forms, rather than rectangular forms with flat surfaces, offer less wind resistance.

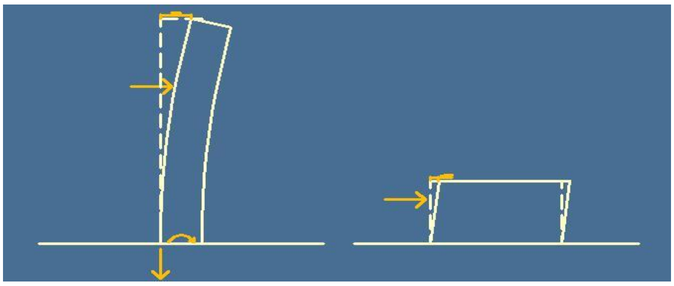

Fig-3: Wind action on different height of buildings

Tall buildings that are short in horizontal dimensions are more critical for overturn and possibly for the total horizontal deflection at their tops.

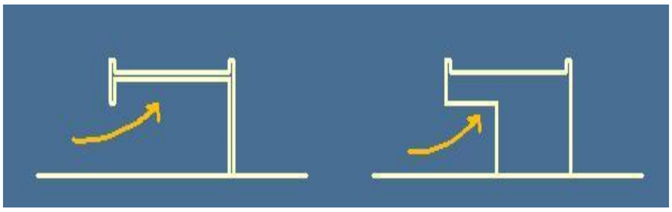

Fig-4: Wind action on Semi-open Builtforms

Open-sided buildings or buildings with forms that cup the wind tend to catch the wind, resulting in more wind force than that assumed for the general design pressures.

3.5 Construction Technology

The construction industry has grown manifolds through inventions and improvisations. The materials strength has been the major boost for construction industry along with the elasticity in building design and flexibility of variety. A major structural element that may be used alone or in combination includes:

- Deep foundations

- A central concrete core (open column) large enough to contain elevator shafts and other mechanical components a steel skeleton

- Non-load-bearing curtain walls

A core is a little more than two, three or four bearing walls placed perpendicular to each other in order to create a closed geometry. Tubes, round or square, can resist torsional loading and are very stiff. A core can be added to the typically parallel alignment of the bearing walls in order to create a lateral load resistance in a direction perpendicular to the bearing walls, to prevent the parallel walls from collapsing.

The core is often placed in a central location. This is for the convenience of building services and for increased structural integrity.

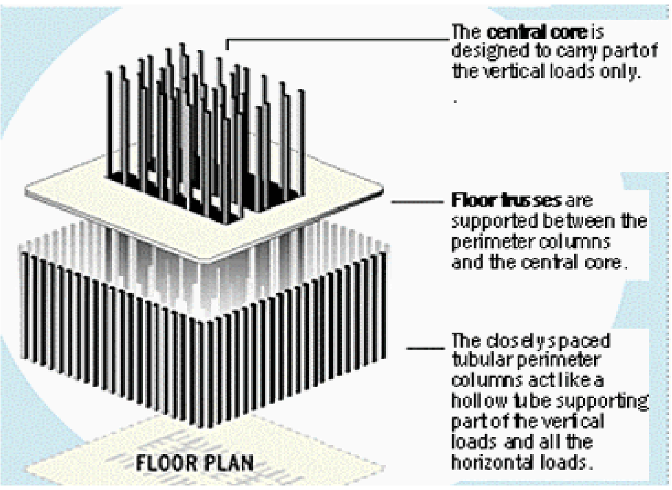

Fig-5: Typical structure of High Rise buildings

Source: Building Structures," 3rd edition

Mass Dampers

Dampers, are nothing but shock absorbers, in high rise buildings that absorb some of the vibrational energy put into a building by wind.

Dampers absorb some of the horizontal forces exerted on tall buildings, minimizing the stress applied to the structure.

- All buildings have various modes, or frequencies it can vibrate at. The frequencies of these modes depend on the height of the building.

- If the building is exposed to vibrations of the same frequency as its lowest (fundamental) mode, maximum destruction will result, compared to the higher modes

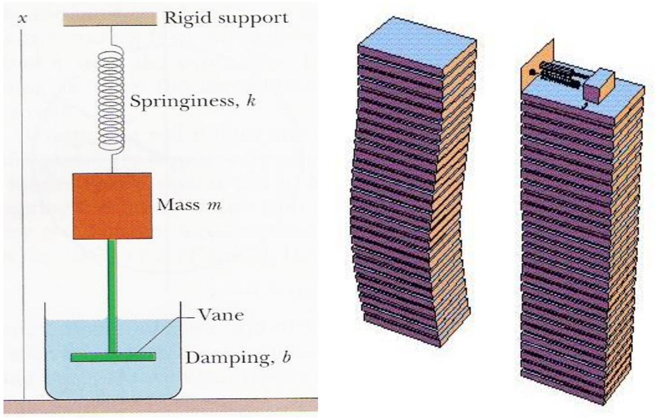

Fig-6: Assembly Mechanism of Mass damper

Source: www.burjkhalifa.ae/en/the-tower/design.aspx

4. CASE STUDIES

4.1 BURJ KHALIFA, Dubai

Architects: Skidmore, Owings and Merrill (S.O.M.)
Facility: Mixed use, basically Residential.
Features: 521 m, desert rose shaped plan.
Size: 37,00,000 m^2

Architecture Design

- The tri-axial 'Y'-shaped plan was advantageous in several ways.

- The shape lent itself beautifully to the 'buttressed' core structural concept.

- Furthermore, by stepping back one wing at each tier of the tower and varying the distance in height between steps, helps to reduce the wind forces on the tower.

- Designers purposely shaped Burj Dubai to reduce wind forces on the tower, keeping the structure simple and to foster constructability. The structural system could be described as a structural core. The result being that the tower is extremely stiff torsionally.

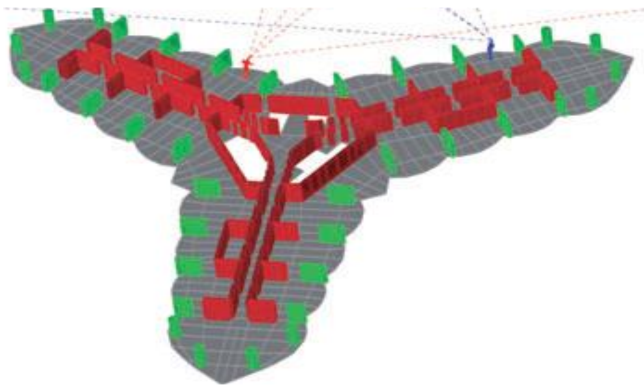

Fig-7: Tri-axial 'Y'-shaped plan of Burj Khalifa

Source: www.burjkhalifa.ae/en/the-tower/design.aspx

Wind Engineering

The building has essentially 6 wind directions. 3 of these are when the wind directly blows into a wing. The other 3 directions are when the wind blows in between two wings.

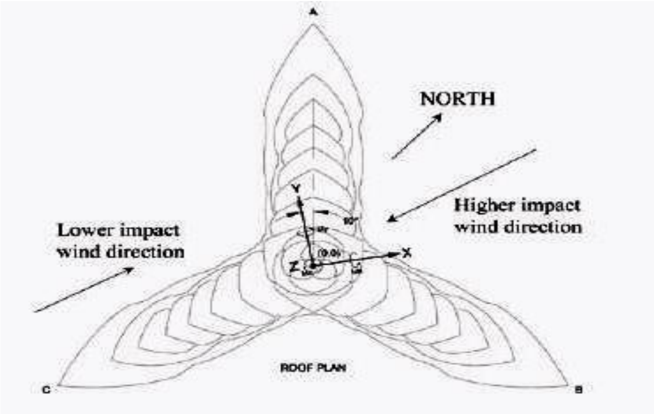

Fig-8: Plan form of Burj Khalifa

Source: www.burjkhalifa.ae/en/the-tower/design.aspx

These wind directions were borne in mind when orienting the tower to the most strong wind directions for Dubai: north west, south and east.

As wind whirls around a tall building it can build into powerful vortices that in turn generate powerful winds on the ground. But the wide base of the Burj Khalifa prevents wind from causing these disturbances.

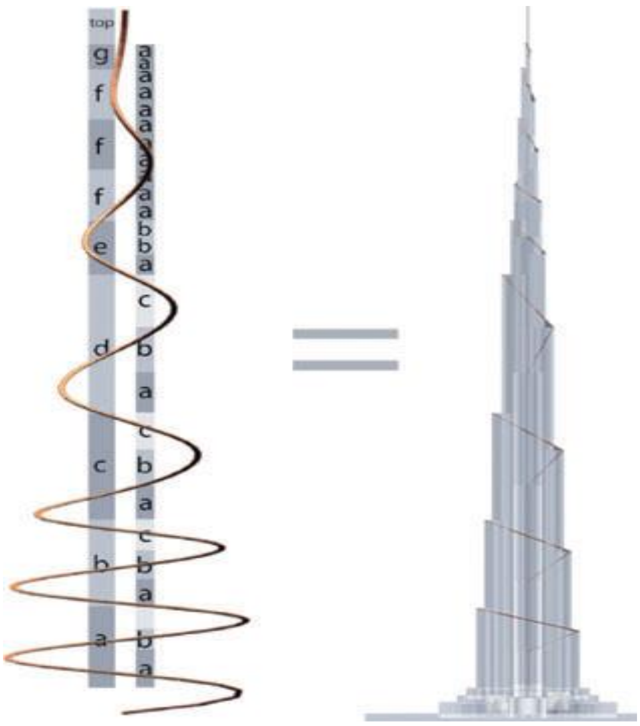

Fig-9: Wind Tornado phenomena in Burj Khalifa

Source: www.burjkhalifa.ae/en/the-tower/design.aspx

Also, varying the plan and cross-section as the tower rises tends to 'confuse the wind'. That is to say, the wind vortexes never become organized because at each new tier the wind encounters a different building shape, allowing for a very economical structure.

Through a combination of re-orienting the tower, adjusting its shape, modifying the structural properties, the construction of Burj Khalifa became possible.

4.2 TAIPEI 101, Taiwan

Architects: C Y Lee & Partners
Facility: Commercial Office tower
Features: 508 m, Square Plan with Static form
Size: 3,57,719 m^2

Architecture Design

The greatest challenge in designing a statement building is not the construction technology involved, but how the building reflects the culture in which it functions. Though it highlights the local elements in its builtform we still need to ponder over this engineering marvel with its innovative approach towards Architecture as well as engineering.

- The spirit of local Architecture style lies in the builform through balance between local culture and internationalism.
- Since it is static builtform which should stand firm against any wind pressure the structure is designed on concept of Mega Column.
- The design ahs also taken care of the fact that it is placed over one of the most challenging geographic condition of typhoons and earthquakes.
- The mass damper placed on top portion to tackle wind impact on high altitude is the highlight.

Structure Highlights

The structure is designed around the concept of Mega Column placed at perimeter holds the tower together against any lateral pressure to the extreme conditions of cyclones as well.

- The tower is built on 380 concrete piles sunk 80m into the ground to hold superstructure firm.
- The structure is reinforced by a Moment Frame System linking the columns on all floors. Massive Steel Outrigger Trusses span between the columns on every eight floors.
- The W-shaped corners minimises the wind load on the structure.

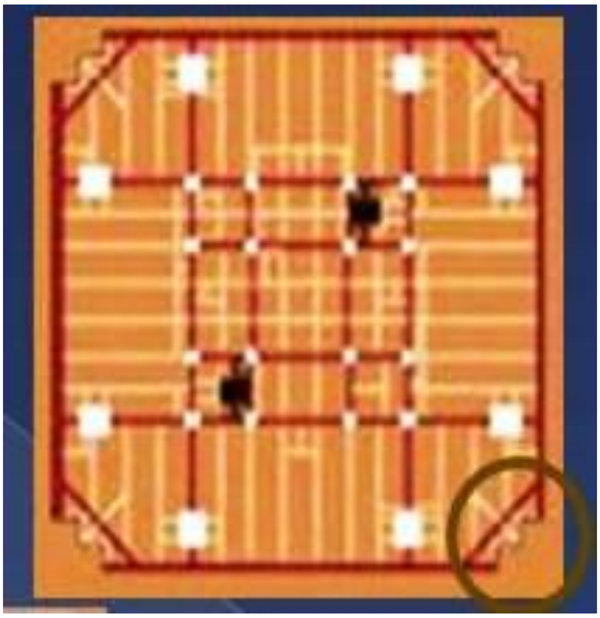

Fig-10: The four W shaped corners for Wind tackle

Source: www.taipei-101.com.tw/en/building.aspx#SCROLL2

Mega Columns

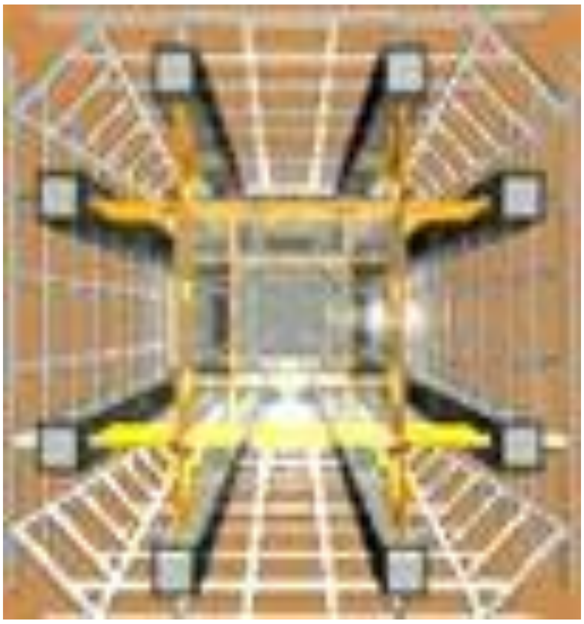

Fig-11: Planform of Taipei 101 structure

Source: www.taipei-101.com.tw/en/building.aspx#SCROLL2

- There are 8 Mega columns placed at the perimeter around which further 36 columns are placed to provide vertical support36 columns provide vertical support.
- Mega columns slope with building profile just after level 26.

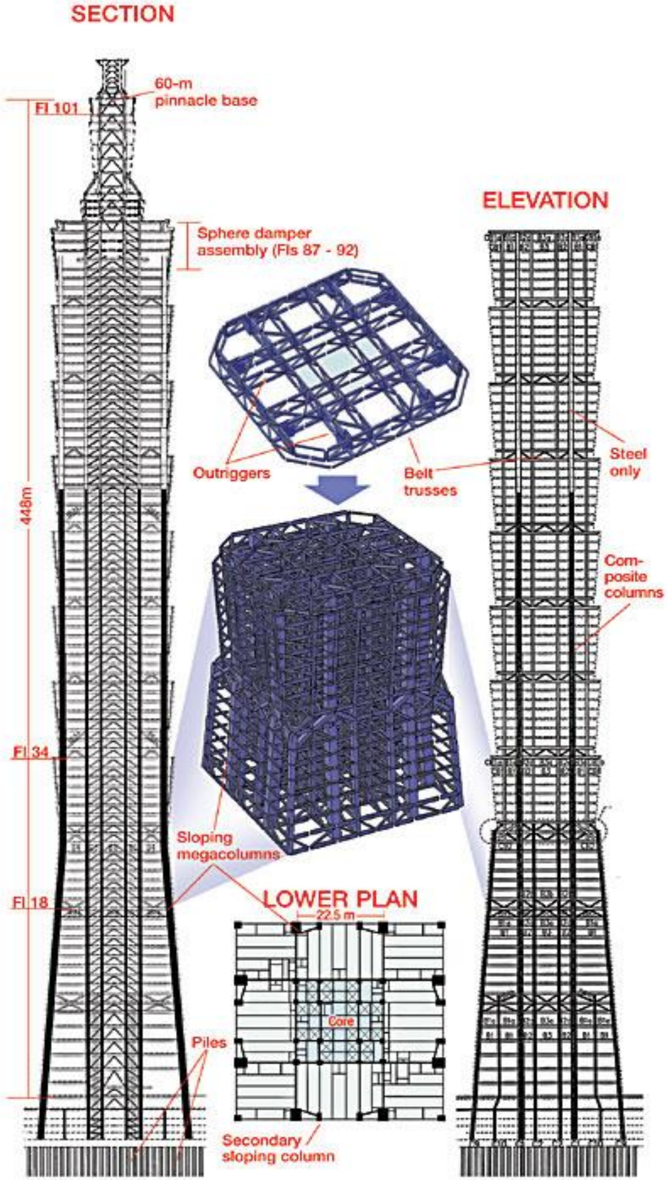

Fig-12: Sectional details of Taipei 101

Source: www.taipei-101.com.tw/en/building.aspx#SCROLL2

- Designed for axial loads up to 38,000 tonnes, main mega columns are made of steel as thick as 8 cm. Along with the core elements.
- Mega columns are filled with 10,000-psi reinforced concrete up to level 62. Additional box columns below floor 26 are also filled.
- Corner columns are tied to the main frame with two-story-deep belt trusses under levels 9, 19 and 27. All other sloping Mega columns are connected to core columns with double-story outriggers at these levels.
- A 660 tonnes of Mass damper is paced at 82nd floor occupying 5 floors with its whole assembly counteract the wind impact on upper portion of building.

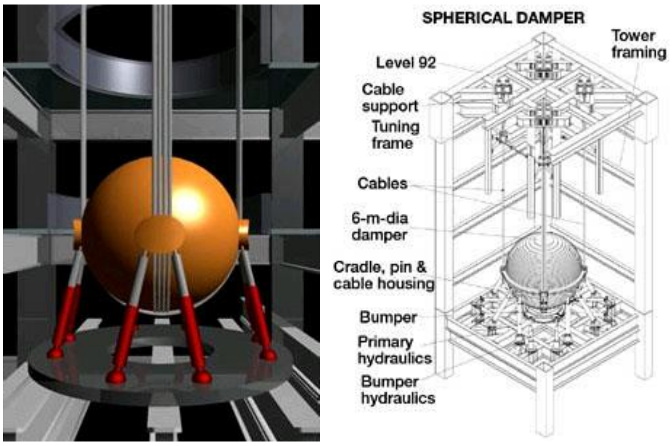

Fig-13: Mass Damper placed inside Taipei 101

Source: www.taipei-101.com.tw/en/building.aspx#SCROLL2

The structural and Architecture innovation in this building has given wings to Architects and engineering to aspire beyond conventional approach towards building construction at such challenging locations.

4.3 Bahrain World Trade Centre

Architects: Atkins
Facility: Commercial Retail+Office Tower
Features: 240m high, Twin towers
Size: 1,20,000 m^2

Fig-14: Twin towers of WTC Bahrain

Source: www.bahrainwtc.com/content/architecture-design-awards

This landmark is one of the most Sustainable Developments in the world, The Bahrain World Trade Centre is a groundbreaking structure for a laundry list of reasons. The most important and unconventional feature of this building is integration of large-scale Wind Turbines. Before this building, this attempt has not been done across the globe.

Architecture Design

- The design is based on Twin towers symmetrical in nature bridged at 3 different floors.
- The Wind turbines at 3 floors have been the most intelligent feature which generate significant amount of power for the building contributing to operation cost.

Fig- 15: Wind Turbines fixed in centre of 3 bridges of WTC

Source: www.bahrainwtc.com/content/architecture-design-awards

- Sustainable features include buffer spaces between the external environment and air conditioned spaces, such as a car park deck above and to the southern side of the mall, which will have the effect of reducing air temperature and reducing conductive solar gain.
- Also incorporated into the design are deep gravel roofs to provide kinetic insulation, a significant proportion of projectile shading to external glass facades, balconies to the sloping elevations with overhangs to provide shading, a high quality solar glass used with low shading co-efficient to minimize solar gains, and low leakage and operable windows to allow mixed-mode operation in winter months.
- Vertically, the sculpting of the towers is also a function of airflow dynamics. As they taper upwards, their aerofoil sections reduce. This effect when combined with the increasing velocity of the onshore breeze at increasing heights, creates a near equal regime of wind velocity on each of the three turbines.

5. CONCLUSION

With the perfect and over the conventional correlation approach between Architecture and Engineering has result in creating the landmark in the world. Its very important to understand phenomena of wind over the building form to counteract the wind pressure on the structure. Further, the design of tall buildings is not limited to wind sensitive design but rather using wind to the advantage of building. With these examples already in place it is believed that Architecture is not limited to designing spaces but go hand in hand with different fields of engineering.

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