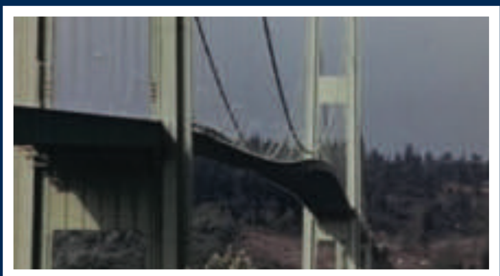
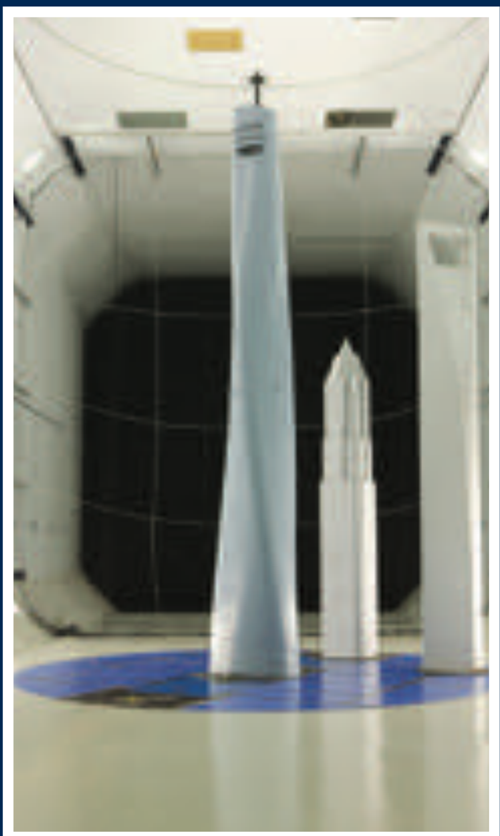
B&SE_Volume 47_Number 4_December 2017

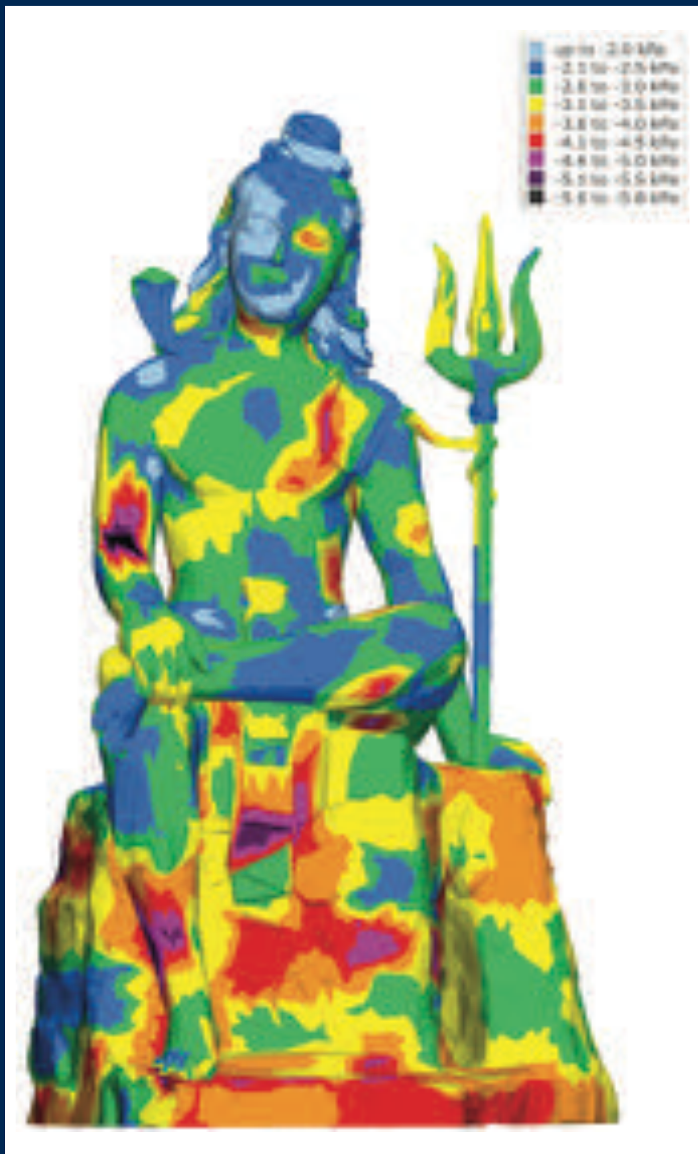
The Bridge & Structural Engineer

ING - IABSE

JOURNAL OF THE INDIAN NATIONAL GROUP OF THE INTERNATIONAL ASSOCIATION FOR BRIDGE & STRUCTURAL ENGINEERING







Wind Sensitive Structures

The Bridge & Structural Engineer
Indian National Group of the International Association for Bridge and Structural Engineering

Contents : Volume 47, Number 4 : December, 2017

Editorial

Special Topic : Wind Sensitive Structures

Paper carried over from September, 2017 Issue:

Panorma

CONTENTS

TALL BUILDING FAÇADE DESIGNS -IMPACT OF WIND AND ASSOCIATED LOADINGS

Rajan GOVIND

Façade Specialist – Director at BES Consultants Pvt. Ltd.,
rajan@besconsultants.net
www.besconsultants.net

Rajan has 22 years of international experience within the facade industry with Structural engineering background. With his wide International and regional experience with on-going leading role on number of projects, he has attained extensive knowledge on façade and construction industry in the region. Known face to regional facade industry, he has attained good reputation with high quality works completed.

Abstract

This paper illustrates and shares author experiences on High rise building façade design challenges specific to wind associated and structural design aspects.

1. Introduction

Building facades are increasingly becoming sophisticated and interesting in order to adapt modern building architecture and challenging requirements. Facades are receiving special attention in the construction industry as it is a specialized construction field which has well adopted latest technologies. Façade designs, constructions, implementations are not set by any limitations or boundaries and thus leave opportunities for designers or owners to make their design ideas a reality. This paper focusses on the façade systems structural engineering aspects of high rise buildings, presented with experiences and actual project details.

2. High Rise Design Challenges

Facades for high rise buildings have specific design. Few major aspects are given in **Table 1**. These challenges are not just limited by engineering and science but many other practical aspects related to fabrication and implementation.

Table 1 : Major Aspectsof Façade Design

Design	Weather	Site
• Structural	• Performances	• Logistics
• Visual architectural	• Durability	• Access
• Performances	• Finishes	• Material handling
• Framing sizes and shapes	• Corrosive environment	• Site testing
• Brackets - adoptability to building structure	• Local conditions	• Limitation due to building form

Design Challenges are illustrated in the graphical image (**Fig. 1**).

Following are some key design principles which shall be focused by façade engineers/designers from engineering point of view.

- Direct load transfer
- Structurally efficient
- Allow movement/rotations
- Ease of fixing
- Simplicity in detailing
- Ability to interface cleanly with main building

2.1 *Structural Design Aspects*

Wind pressures being a prominent design load, which varies from normal to high and extreme pressures, and non-uniform pressures among various elevations, lead to challenges on achieving optimum design balance between practical and technical aspects.

Fig. 1 : Design Challenges

2.2 Building Movements

Following are primary aspects for the façade movements on tall buildings. Refer to **Fig. 2**.

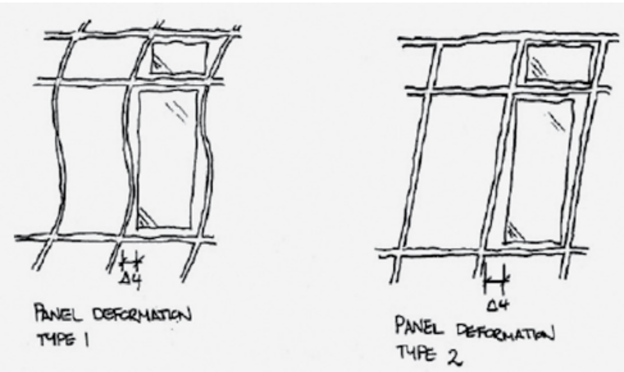


Fig. 2 : Panel Mode of Movement Due to Sway

Sway or Inter-Story Drift: Horizontal or lateral movements at floor level due to wind or seismic movements. This will induce racking and in - planar forces on façade panels.

Fig. 2 shows typical panel deformation mode due to building sway. As a good design guidance, the façade systems are recommended to accommodate H/500 (H-floor height) lateral movement.

Floor movements:

Building floors may have different movement behaviours due to imposed load and other aspects. Hence it is recommended that the façade fixings and floor interfaces are adequately designed to address these movements. Ignoring this key design aspect may have adverse impact such as panel cracking or other failures. **Fig. 3** illustrates a typical floor fixing which has vertical movement allowances.

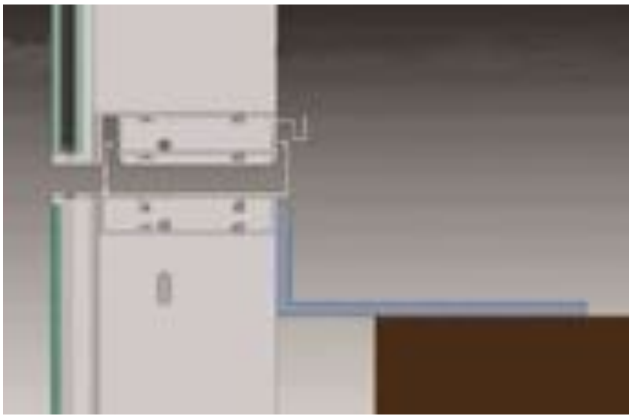


Fig. 3 : Typical Floor Bracket and Curtain Wall Profiles

3. Glazing Systems

There are several ways the systems shall be classified. However, from the construction point of view, following are the widely used glazing systems.

1. Stick Glazing system
2. Semi Unitized or Cassette system
3. Unitized system or panel system

3.1 Stick Glazing System

Fig. 4 Illustrates the basis of the system in which Glass has been supported by Aluminium grid work framing system. Vertical frames (called as "Mullion") span between floors supported by brackets at each floor. Horizontal framing (called as "Transom") connected to verticals is used to glaze the glass units. All materials are delivered as components to the project site and installations are carried sequentially. These types of systems are site fabricated and generally adapted for low rise buildings, small size applications, using standard available designs. This system is adapted for the basic requirements which do not require customized design solutions.

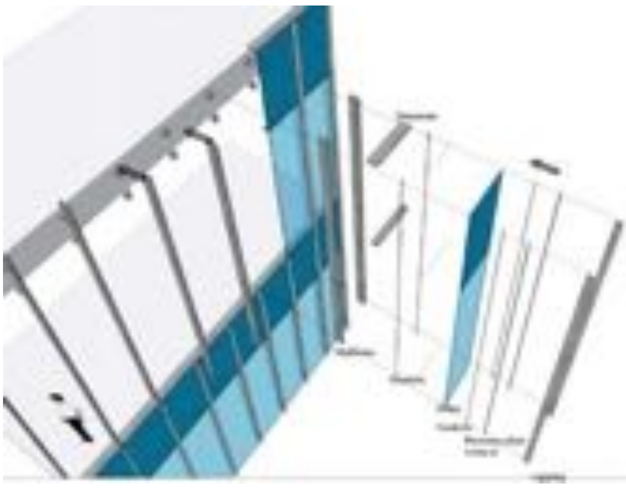


Fig. 4 : Stick Glazing System

3.2 Semi Unitized System

Also known as Cassette system, this is similar to Stick system as defined in sec. 3.1. However, the glass units are glazing with Aluminium sash frames at factory and then delivered to the site. These glazed units are hooked on to the Aluminium grid works erected at the site. Hence this system is partially pre-fabricated and has less site work. All materials are delivered as components to the project site and installations are carried out sequentially. Refer **Fig. 5**.

This system has slightly lesser site work as compared to Stick glazing system. However, the system weather performances rely on site workmanship as it involves the primary sealing between glazing cassettes to be maintained with high integrity, so that no water or air enters the system.

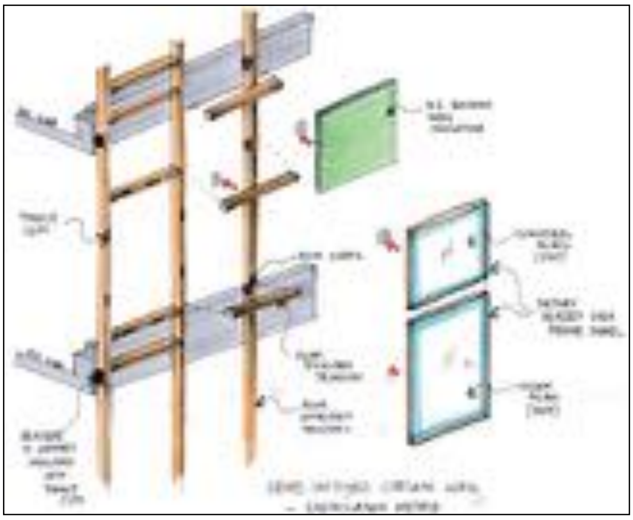


Fig. 5 : Semi Unitized System

3.3 Unitised or Panel Systems

This employs most modern fabrication and construction techniques of pre-fabrication approach. The glazed panels are fully finished at the factory and delivered to the site and ready to be erected in place. This results in very little work at the site and achieves high quality and faster completion. In recent times, most modern buildings globally adapt this approach. These types of systems were implemented internationally and proven to be time tested design solutions without any compromise on quality and time frame. The following sections give a detailed description of this particular façade systems widely adopted for modern high rise/tall building facades. Refer **Fig. 6**.

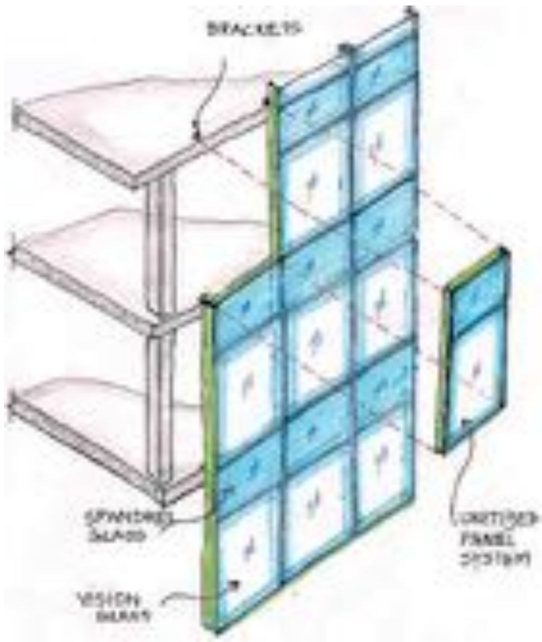


Fig. 6 : Unitized/Panel System

4. High Rise Façade Systems

Facades of tall buildings use Unitised panelised glazing, which follows a pre-fabricated factory finished façade system. **Fig. 7** shows a factory finished glazed panel.

Fig. 7 : High Rise Façade System

- Irrespective of any façade system, following are basic design principles of tall building façade systems.
- Uses Light weight aluminium framing system structurally glazed with glass panels with silicone structural sealant/bonding technique.

- Panels are supported on to building using bracketing and fixing at each floor.
- Systems allow for large movement and building sway.
- Each panel is supported and hung from top, hence allowing large movements and building sway without affecting or breaking glass units.
- Pre-fabricated and pre-finished panels with very less site works.

5. Key Structural Aspects

Critical structural aspects of tall building facades are elaborated in **Table 2**.

Table 2: Key Structural Aspects

Aspect	Critical Impact	How to Address
Wind	Predominant load, overall design controlling	Appropriate Structural design of framing, in fill panels and support systems.
Seismic	Fixing designs and interface with building.	Fixings and connections to allow large movement. Appropriate bracket designs
Movement	Design to address thermal and building movements.	Panel joints and gaskets are designed for large movement and equally without compromise on weather performances

Wind load being a predominant design aspect in the overall designs, following section elaborates this aspect.

6. Wind Loads

Wind load being a predominant design aspect in the overall designs, has impact on the buildings in many ways as elaborated below.

Fig. 8 : Wind Load Design Aspects

Engineer requires good understanding of wind loads and how the building behaves under wind pressures. Appropriate wind pressure derivations and prediction of its effects are fundamental to high rise façade design. These change from building to building, hence engineer's understanding of these aspects is critical.

6.1 Wind Load Calculations

Wind loads are derived in following ways

1. **Code based:** Indian Standard IS 875 Part 3 and NBC 2016, calculated as per recommended methods.
2. **Wind tunnel (laboratory based)** – Physical scaled building model with surrounding terrain were tested in a laboratory setup, and results measured using sensors and instrumentation. The test results are expected to give correct prediction of wind pressures based on actual site conditions considering surroundings.
3. **CFD - (Computer simulations based)-** Computational Fluid Dynamics techniques will help to predict reasonably accurately, the building façade pressures for complex and more detailed localized study otherwise impossible by above methods.

6.2 Wind Patterns – Indian Cities

Images in **Figs. 9 and 10** show the Wind Directional Distribution (for Mumbai region) as per IMD information, wind speed calculated for 50 Years return Period and 10 Years Return Period.

It is noted that the North-West Direction is the most dominant for Mumbai region. Whereas South-West is also critical as highest wind speed is experienced through this direction. It is also important for engineers to consider not just peak wind pressures or 50 years return period. Often for design efficiency several non-critical façade elements are designed for 10 years return wind speed. Hence engineers' understanding of local effects and wind patterns are highly important.

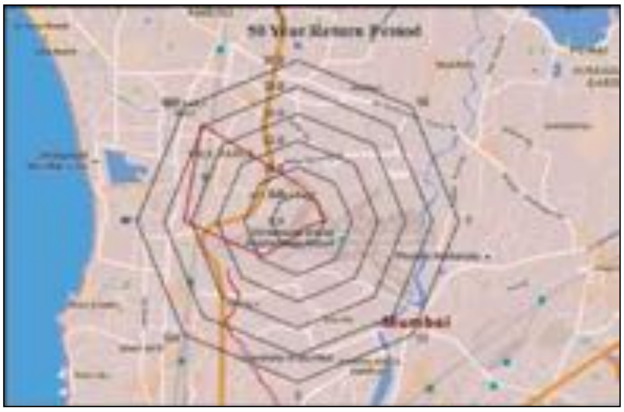


Fig. 9 : 50 Year Return Period

Fig. 10 : 10 Year Return Period

7. Case Study – Mumbai High-Rise

This section illustrates wind load derived from three different approaches as explained above. This has been extracted from an actual high-rise building project completed in recent times. There is no single approach that may yield the best outcome - quite often comparison of different methods will justify the Engineers decisions. Due to complex nature of wind distributions on tall building facades, engineers need to carry out detailed analysis and study of particular locations on micro level. This will avoid any structural failures due to possible underestimation of high local pressures. Hence engineers can't just limit to code based approach for high-rise building facades - a detailed approach through a wind tunnel or CFD based approach will help accurate predictions of wind pressures.

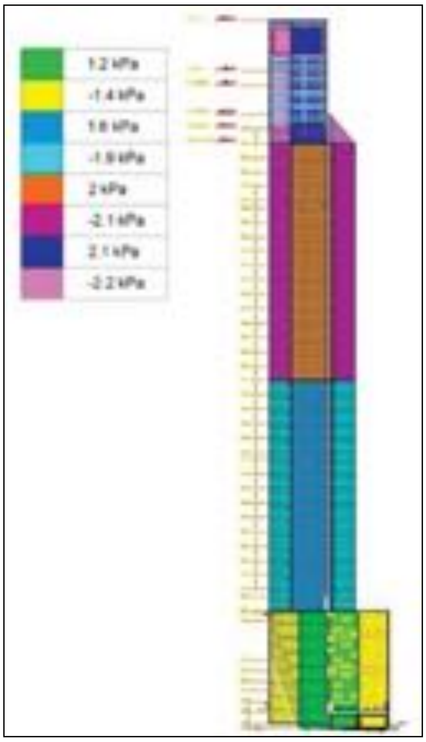


Fig. 11 : Wind Pressure Thro IS Code

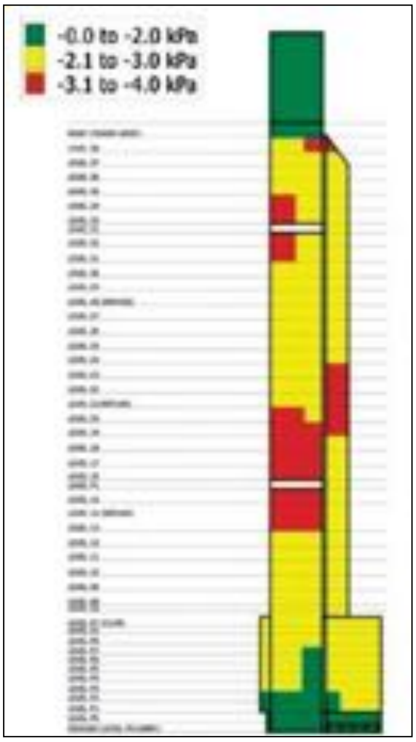


Fig. 12 : Wind Pressure Thro Wind Tunnel

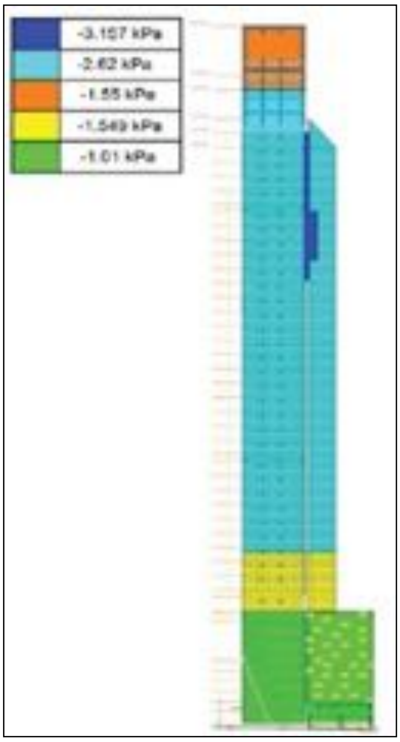


Fig. 13 : Wind Pressure Thro CFD

8. Discussions

Facades for high rise buildings often face several design and implementation challenges; each building may pose specific sets of challenges. Hence engineers and designers should approach these requirements with an innovative and most appropriate approach best suited for that particular building requirements. Following are Author's own assessment and experiences.

9. Engineers Limitations

A typical Building structural engineer may not be aware of several key aspects which impact the designs, such as joints and connection detailing on facades which may have great impact on structural aspects. In the Façade engineering of high-rise building, there are situations wherein framing and fixing sizes are just not controlled by wind loads or structural aspects, but are rather limited by non-engineering challenges like functional, visuals etc,.

Hence the overall quality of structural design and project outcomes are relying on experience of the engineer. **Table 3** elaborates the critical aspects of these points.

Table 3 : Engineers Skills and Quality of Designs

Design Aspects	Design Check	Skills Required	Impact	Design Quality & Relevance
Structural	Basic Design Check	Structural and Façade Engineering	Check adequate for short term performances only	✓
Joints	Secondary Check	Façade Expertise	Check long term performances.	✓
Movements	Secondary check & Building Interface Checks	Façade Expertise & Building Engineering	Check long term performances and potential risk of Large movements	✓✓✓

10. Knowledge and Capability

Availability of local expertise on this domain is limited due to several factors but few key factors are noted below.

- Limited high-rise building designs were taught in the institutions
- Knowledge gap on practical Vs theoretical i.e., Academic learning not as per real world.
- Very less participation or collaboration of private/industry experts with academics/ institutions
- Limited built references and knowledge were not harvested or shared to wider engineer's community

Hence due to several factors, high rise building façade engineering design knowledge and techniques are largely infused from international experts, collaborations etc., Experiences and lessons learned from wider international experts with leading local institutions adopting and learning appropriate and modern engineering designs will help this domain. The capability is improving dramatically with the recent developments of high rise buildings in many regions of the country, with improved availability of quality and experienced engineers and designers for high rise building facades.