Vinay Chandwani, Dr. Vinay Agrawal, Naveen Kumar Gupta / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 2, Issue 4, July-August 2012, pp.556-560

Role of Conceptual Design in High Rise Buildings

Vinay Chandwani*, Dr. Vinay Agrawal, Naveen Kumar Gupta *****
*(Assistant Engineer, Investigation Design & Research Wing, WRD, Government of Rajasthan, Jaipur, India)
** (Assistant Professor, Department of Civil Engineering, Malaviya National Institute of Technology Jaipur, India)
*** (Assistant Engineer, Investigation Design & Research Wing, WRD, Government of Rajasthan, Jaipur, India)

ABSTRACT

With the advent of recent construction technologies, human civilization is striving for cost effective and time saving design solutions. Conceptual design is the first stepping stone and is arguably the most difficult wherein a tentative shape to the final design is given. High-rise buildings being an important financial enterprise as it involves enormous private and public investment and, most importantly, is a large consumer of resources in the form of labor and construction material. In order to maximize the developer's return within the given constraints, the conceptual design and the detailed designs should be done judiciously. Usually a smaller part of the design effort is dedicated to the first phase. However the success of the final design depends predominantly on the conceptual design of the structure based on the opinions, judgments and experience of the designers. The paper focuses on the role of conceptual design in the success of a High Rise building project.

Keywords - Aspect Ratio, Conceptual Design, Exterior Structures, High Rise Building, Interior Structures, Lease Span, Structural System.

1. INTRODUCTION

Tall buildings throughout the world are becoming popular day by day. With the advent of modern day construction technology and computers, the basic aim has been to construct safer buildings keeping in view the overall economics of the project. Earlier the functional use of the tall buildings was limited to commercial office buildings. But nowadays, other uses such as, residential, mixed use and hotel tower developments are rapidly developing. The buildings completed in 2011 have effected significant change in the world's tallest 100 buildings with 17 new buildings added to the list. Perhaps most significantly, for the first time in history, the number of office buildings in the tallest 100 has diminished to 50% mark, as mixed-use buildings continue to increase, jumping from 23 to 31. As recently as the year 2000, 85% of the world's tallest were office buildings, meaning that a 35% change has occurred in over a decade [1].

There has been a regular and significant change in the approach to the design of structures. The most radical change being the conceptual design. This stage of design is quite difficult since it involves various complex factors which are not explicitly defined. At conceptual stage of design process, there is usually very little time to consider all feasible alternatives before decisions have to be made and resources committed [2]. Although, an ideal design is not always achieved using the conceptual design methodology, but it gives an idea to the structural designer to make sensible decisions. The decisions taken at the conceptual stage of design have a long term influence on the performance and economics of the entire project. At conceptual design stage there is a continuous change in the design requirements brought about by the needs and constraints imposed.

Thus conceptual design is the first stage in the structural design, wherein all the relevant data are collected and assessed. Thereafter the objective of the project is decided and finally an initial configuration for major building system is determined. Conceptual design can grasp the overall program of the structure in preliminary design stage, and late-stage can be designed to avoid some unnecessary red-tape operations, but also judge the important basis of computer output reliable or not [3]. Many considerations to geometry, orientation and structural system can be given early in the design process. Tall building design must exploit all of these factors to the fullest extent possible in minimizing the wind loads or alternatively optimizing the design [4].

2. CONCEPTUAL DESIGN TECHNOLOGIES

At conceptual stage, neither there is complete and accurate data nor enough time to design the component again and again with different changing parameters (being at conceptual stage). Improving the quality of conceptual structural design is crucial to the whole design process. At conceptual design stage, human intelligence and past experience coupled with the computation power in the form of decision support system plays an effective and important role. There are many tools available that can be used for conceptual stage designing of high rise building e.g. Soft Computing, Artificial Neural Networks, Decision Support Systems, etc. Expert system technology can assist engineers make the best use of the knowledge available from many sources in the domain to produce appropriate, consistent, safe, and reliable designs [5].

3. HIGH RISE BUILDING

The International Building Code (IBC 2000) and the Building Construction and Safety Code, NFPA 5000TM-2002, define high-rise buildings as buildings 75 feet or greater in height measured from the lowest level of fire department vehicle access to the floor of the highest occupiable story [6]. The overall building cost and the architecture of a High Rise Building depends predominantly on its structural system. Therefore the design concepts for High Rise buildings are entirely different for a low-rise building. The High Rise buildings are dynamically sensitive to lateral loads and hence the structural systems of such buildings are designed to resist the lateral loads, especially wind loads.

High Rise building is conceived as a vertical cantilever, fixed in ground. The structure is required to carry vertical gravity loads, lateral wind and earthquake loads. To counteract these loads the building should have adequate shear and bending resistance along with its vertical load carrying capacity.

All High Rise buildings are considered as composite structures. This is because, steel systems offer speed in construction and less self-weight whereas reinforced concrete systems offer resistance to fire and offer more damping and mass, which in a way is advantageous in combating motion perception by the occupants.

4. HIGH RISE BUILDING STRUCTURAL SYSTEM

Based on the distribution of the components of the primary lateral load-resisting system over the building, the structural system of High Rise buildings can be broadly classified as:

a) Interior Structures
b) Exterior Structures

In Interior structural system, the major part of the lateral load-resisting system is located within the interior of the building. Whereas in Exterior Structural system, the lateral loads resisting system, is located along the building perimeter.

4.1 Interior Structures

The interior structures comprise of moment-resisting frames, shear trusses/shear walls and core-supported outrigger structure. Moment resisting frames consist of horizontal girders and vertical columns rigidly connected in a planar grid form. Such frames resist load primarily through the flexural stiffness of the member. Braced frames use vertical steel trusses to resist the lateral loads primarily through axial stiffness of the members.

Shear walls, which are plane elements, generally start at foundation level and are continuous throughout the building height. They can be considered as vertical cantilevers fixed at the base. Their thickness can be as low as 150 mm, or as high as 400 mm in High Rise buildings. Shear walls are usually provided along both length and width of buildings. Shear walls provide large strength and stiffness to buildings in the direction of their orientation, which significantly reduces lateral sway of the building and thereby reduces damage to structure and its contents.

The Outrigger systems are modified form of braced frame and shear-walled frame systems. It comprises of a central core of either braced frames or shear walls. The core is connected to the external columns through horizontal “outrigger” trusses or girders. Through this arrangement, the overturning moments in the core are reduced and transferred to the outer columns through outrigger connections.

4.2 Exterior Structures

The exterior of the building is vulnerable to lateral forces especially wind loads. Hence it is essential that most of the lateral load resisting system is concentrated along the perimeter of High Rise buildings.

One of the most typical exterior structures is the tube, which consists of a great number of rigid joints, acting along the periphery, creating a large tube. In framed tube system, exterior tube carries all the lateral loading and gravity loading is shared between the tube and the interior columns or walls. The columns are closely packed on the exterior connected by a deep spandrel. In braced tube system instead of using closely spaced perimeter columns, widely spaced columns stiffened by diagonal braces are used. Another structural system can be created by clustering the individual tubes. In Bundled tube systems the tubes are connected together with common interior panels to generate a perforated multicell tube.

The diagrid structural system has been widely used for recent tall buildings due to the structural efficiency and aesthetic potential provided by the unique geometric configuration of the system. Compared with conventional framed tubular structures without diagonals, diagrid structures are more effective in minimizing shear deformation because they carry shear by axial action of the diagonal members, while conventional framed tubular structures carry shear by the bending of the vertical columns [7]. Lateral loads are introduced directly into a diagrid structure and immediately transferred into the system of triangulated elements. This means that a diagrid does not rely on the floor system to transfer any of the lateral forces to the other parts of the structure. Hence, diagrid structures generally do not need high shear rigidity cores because shear can be carried by the diagrids located on the perimeter. The horizontal rings of a diagrid provide much needed buckling bracing to the diagonal members. The rings tie all of the pieces together and create one solid tube. A network of interconnected nodes is formed which gives the triangulated elements another degree of stiffness. Thus diagrid structures provide both bending and shear rigidity. Other types of lateral load resisting exterior structures include space trusses, super frames and exoskeleton. These have been occasionally used for High Rise Buildings.

5. DESIRED STRUCTURAL SYSTEM

The design of tall and slender structures is governed by three factors viz., strength (material capacity), stiffness (drift) and serviceability (motion perception and accelerations), produced by the action of lateral loading, such as wind and earthquake. The overall geometry of a building is of importance as it often dictates which factor governs the overall design. As a building becomes taller and more slender, drift considerations become more and more significant.

The High Rise building is designed predominantly to resist the lateral loads induced by wind and earthquake. As the building height increases the lateral loads induced by wind become predominant. However it should be equally efficient in carrying the vertical loads. High Rise building involves heavy expenditure on material and resources. Hence it would be pertinent to select a structural system at the conceptual stage of design, having strength and stiffness fulfilling the desired purpose. The structural system not only gives aesthetic appeal to the building but also optimizes the interior space planning. The structural system therefore holds the key for optimal design of High Rise buildings for which the following points are to be kept in mind at the conceptual stage of design which have been incorporated in the following sub sections.

5.1 Interior Structures

a) Moment-Resisting Frames perhaps are the most commonly used system in low-to medium-rise buildings. The moment-resisting frame is characterized by linear horizontal and vertical members connected essentially rigidly at their joints. The frame itself has to resist all the actions, vertical as well as horizontal. At the same time, it has to provide the required stiffness to the structure in order to limit deformations within the allowable values. But as the height of the building increases, this structural system cannot mobilize sufficient stiffness under lateral forces and shows shear deformation. Hence this type of structural system remains efficient for 20 to 30 stories. But it is worth noting that this system provides flexible floor planning and faster construction.

b) The Braced Frame offers greater stiffness in comparison to moment-resisting frames. Additional bracing almost eliminates the bending of columns and girders. These systems efficiently resist lateral loads by axial forces in shear truss members. By using this type of system, shallower beams can be used in rigid frames. The system is characterized by linear horizontal, vertical, and diagonal members, connected simply or rigidly at their joints. It is used commonly in conjunction with other systems for taller buildings and as a stand-alone system in low-to medium-rise buildings. It is most applicable for buildings about 50 stories in height.

c) The Shear Wall system offers greater stiffness against lateral loads and can therefore be regarded as a step forward in constructing a stiffer building. The system is characterized by relatively thin, generally (but not always) concrete elements that provide both structural strength and separation between building functions. In high-rise buildings, shear wall systems tend to have a relatively high aspect ratio, that is, their height tends to be large compared to their width. The system, intrinsically more economical than steel bracing, is particularly effective in carrying shear loads down through the taller floors in the areas immediately above grade. The system has the further advantage of having high ductility, a feature of particular importance in areas of high seismicity. But this system offers less flexible interior plan layout due to integration of shear walls. The shear strength of the wall is weaker than its bending strength and therefore prone to brittle shear failure.

d) Shear walls can be combined with Moment Resisting Frames, to offer greater restrain to lateral loads by producing shear wall frame interacting system. Buildings up to 70 stories height can be constructed using this type of structural system. But flexible interior plan layout is restricted due to presence of shear walls.

e) Outriggers play the most significant role in the design of these kinds of structures, since they are the elements that control the drift of the building. The outrigger concept is in wide spread use today in the design of tall buildings. Outrigger systems can lead to very efficient use of structural materials by mobilizing the axial strength and stiffness of exterior columns to resist part of the overturning moment produced by lateral loading. When compared to single-storey outrigger structures, multi-storey outriggers have better lateral resistance and efficiency in the structural behavior [8]. There are, however, some important space planning limitations and certain structural complications associated with the use of outriggers in tall buildings. This system can be used for buildings over 100 stories high.

5.2 Exterior Structures

a) In tubular structural system the entire perimeter of the building is utilized to resist the lateral loads. Hence the interior floor slab is kept relatively free from core bracing and large columns, thus increasing net leasable area of the building. This system can be used for buildings up to 100 stories high.

b) Diagrids are designed in configurations which use every member's full ability to resist compression and tension. Due to this reason, most diagrids have been constructed out of steel but other materials can be used. Buildings which have used steel diagrids have saved an average of 20% in materials when compared to a typical moment frame design. These structural systems are also effective in providing an aesthetic character to the building. This system can be used for buildings up to 100 stories high.

6. ACHIEVING SPACE EFFICIENCY

High-rise buildings are expensive to construct and operate but sometimes produce less usable space. Therefore to optimize the returns from a High Rise building project, space efficiency is required to be thought at the conceptual stage of design. Following points should be kept in view to achieve Space Efficiency:

a) Efficiency of net to gross floor area is the key to balance construction costs and total rental values. This ratio designates space efficiency of floors and higher the ratio, the higher will be the income derived from the building. Generally the floor slab shape is kept simple and regular as it responds well to user requirements in terms of space planning and furnishing. Mostly square and rectangular floor plans are preferable as these work more efficiently.

b) As the height of building increases, core and structural elements tend to expand, to satisfy the requirements of vertical circulation and resistance to lateral loads.

Lease span or the distance between core and exterior wall, increases the space efficiency. The structural system should provide column free spaces, thus maximizing the lease span. Interior structures concentrated at core like moment resisting frames and shear walls, lack maximum space efficiency. Tubular structures enhance the leasable area of the building, by eliminating large columns and core bracings.

c) The service core of the High Rise building comprises all of the vertical circulation elements such as elevators, fire stairs, mechanical shafts, toilets and elevator lobbies. Shear walls that provide lateral stability are also integrated in the core. Layout of the core is critical to the development efficiency and operational effectiveness of a High Rise building, while also playing a significant role in the way the structure copes with lateral loads [9]. In order to achieve maximum space efficiency, the core must be reduced to an acceptable ratio of the gross floor area, keeping in view the fire regulations and effective vertical transportation. Nowadays with changing technology in concrete construction, high strength concrete having compressive strength in excess of 100 MPa can be used to reduce the thickness of service core walls, thus maximizing the useable floor area.

7. OTHER GOVERNING STRUCTURAL FEATURES

7.1 Earthquake Resistant Design

a) Damping in High Rise buildings varies depending on the selection of materials for structural system. Steel systems offer speed in construction and less weight. But its counterpart, reinforced concrete systems offer more damping and mass, which is advantageous in combating motion perception by the occupants. Hence composite structures are being used today, to harness the advantages of both steel and concrete.

b) For High Rise buildings slenderness of the structural system, measured in terms of the aspect ratio is also to be considered at the conceptual stage. The typical value of the aspect ratio for core wall lateral system ranges from 10:1 to 13:1. For lateral systems that engage exterior elements an aspect ratio up to 8:1 is adoptable. However if higher aspect ratios are used, then there is a need for special damping devices to mitigate excessive motion perception.

c) The height of a building in an earthquake is analogous to the length of a cantilever. It is self evident that as the height of the building increases, the earthquake-resisting problem increases exponentially. Height affects the natural vibrating period of the building. The higher the building the longer its period. Hence response spectrum analysis should be performed regardless of the site seismic zone.

d) Earthquake forces are dependent on the distribution of mass and stiffness along the height of the building. Hence it should be ensured while framing the layout of building, that the structural material is distributed efficiently to the lateral system components. Moreover it should be ensured that earthquake forces are brought down to the foundation level through a direct load path.

7.2 Wind Loading

a) The wind loads prove to be the governing factors in the design of High Rise buildings. Drift due to wind loads can produce second-order effects i.e. P-Δ effects and can thus increase the overturning moments. The maximum wind drift criteria of H/500 should be used [10].

b) The effects of the winds can be reduced by aerodynamic shaping of the building as blunt buildings typically invite higher loads and motion. It is also beneficial to orient the weak axis of building away from the dominant wind directions. For this wind-tunnel testing should be done on High Rise building models

8. CONCLUSION

Nowadays High Rise buildings are built in abundance to maximize the land use and investment return. Success of these high investment projects are centered around choosing the appropriate structural system, optimizing the space requirement, earthquake resistant design and design for wind loads. Moreover the complexity of modern high rise buildings has meant that the successful completion of initial design has become more important and therefore choosing the most economic frame has become more difficult. Extremely efficient designs are desirable for economic feasibility therefore highest performing high rise building structural systems are needed by performing optimization of structural parameters in an efficient and structurally rigorous manner. Structural optimization method explores a diverse range of structural topologies and geometries [11]. Such an optimization method at initial stage of design would not only ensure financially beneficial designs but would also reduce the engineer's design burden.

There is often little time for designer to perform the design process, therefore a designer often choose the most obvious structural frame for a building, because to thoroughly investigate all possible schemes there isn't ample time or the resources. Conceptual design stage being iterative can be exploited to the fullest in maximizing the returns from such large investment projects. It gives a structural designer the freedom to choose the best structural system suited to the building and site requirements.

Conceptual stage designing requires sound knowledge, past experience, imaginative power and creativity skill. Thus Architects can give shape to the building to enhance its aesthetic appeal. Different geometry of floor plan can be used and experimented with, to achieve the desired space efficiency. Wind tunnel testing and aerodynamic shape to the building can be given at conceptual stage of design. This in a way optimizes the lateral load resisting structural system. Thus conceptual design presents a number of feasible options to the designer, which incorporates both aspects i.e. limitations and advantages, thereby making it easy for the designer to take sensible decisions at the final stage of design.

REFERENCES

[1] Hollister Nathaniel and Wood Antony, Skyscraper completion reaches new high for the fifth year running, The Indian Concrete Journal, 86(3), 2012, 39-42.
[2] Rafiq M.Y., Mathews J.D. and Bullock G.N., Conceptual Building Design-Evolutionary Approach, Journal of Computing in Civil Engineering, 17(3), 2003, 150-158.
[3] Xue Mingchen and Zhao Yongsheng, The Conceptual Design of High-rise Structures, Journal of Applied Mechanics and Materials, 99-100, 2011, 46-50.
[4] Kumar Suresh K., How to Engineer Tall Buildings to Resist Wind, Civil Engineering and Construction Review, 24(12), 2011, 98-101.
[5] Golabchi M., A Knowledge-Based Expert System for Selection of Appropriate Structural Systems for Large Spans, Asian J.Civ.Engg.(Building and Housing), 9(2), 2008, 179-191.
[6] Notifier's Worldwide Communications Newsletter, Issue 1, 2004.
[7] Moon K. S., Diagrid Structural systems for tall buildings, characteristics and methodology for preliminary design, The Structural Design of Tall and Special Buildings, 16(16), 2007, 205-230.
[8] Gunel Halis M. and Ilgin Emre H., A proposal for the classification of structural systems of tall buildings, Building and Environment, 42, 2007, 2667-2675.
[9] Watts S., Kalita N. and Maclean M., The Economics of Super-Tall Towers, The Structural Design of Tall and Special Buildings, 16, 2003, 457-470.
[10] IS 456:2000, Indian Standard Plain and Reinforced Concrete-Code of Practice (Fourth Revision).
[11] Ballal T., Sher W., and Neale R., Improving the Quality of Conceptual Structural Design: A Neural Network Approach, The Royal Institution of Chartered Surveyors, 2006, ISBN 0-85406-894-5.