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Structural Sustainability Techniques for RC High Rise Buildings

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***Abstract*—**Over the early years of the 21st century, cities throughout the Middle East, particularly in the Gulf region have expanded more rapidly than ever before. Given the presence of a large volume of high-rise buildings allover the region, the local authority aims to set a new standard for sustainable development; with an integrated approach to maintain a balance between economy, quality, environmental protection and safety of life. In the very near future, as mandatory requirements, sustainability will be the criteria that should be included in all building projects. It is well known in the building sustainability topics that structural design engineers do not have a key role in this matter. In addition, the LEED (Leadership in Energy and Environmental Design) has looked almost exclusively on the environmental components and materials specifications. The objective of this paper is to focus and establish groundwork for sustainability techniques and applications related to the RC high-rise buildings design, from the structural point of view. A set of recommendations related to local conditions, structural modeling and analysis is given, and some helpful suggestions for structural design team work are addressed. This paper attempts to help structural engineers in identifying the building sustainability design, in order to meet local needs and achieve alternative solutions at an early stage of project design.

***Keywords*—**Building, Design, High-rise, Middle East, Structural, Sustainability.

I. Introduction

THE map of high-rise buildings around the world has changed over the past five years. The centric of the tallest buildings has shifted from North America through Asia and settled in the Middle East region. Currently, there is no agreed-codified definition or vibration period above which a building may clearly be classified as a tall or ultra-tall building. Practically, the tall structure is defined as those buildings exceeding 30 floors. However, design of flexible buildings is mainly governed by lateral loads generated from wind or earthquakes.

Historically, the seismicity intensity surrounding Middle East region has been accepted as between low to moderate hazards [1], which may corresponded and fall into SDC-Seismic Design Category ‘C’ according to the IBC-International Building Code. On the other side, the wind environment in the Middle East is a complex mix of events. However, and by using ASCE-7 code, a minimum value of 38 m/second basic wind speed “or 45 m/second (~100 mile/hour) to suit some local conditions” could be used. Otherwise, a wind tunnel test should be performed by a wind specialist to characterize the wind design parameters.

Structural design should be in accordance with the requirements of the accepted international codes, client’s trends, and local authority regulations. It should ensure the project is scheduled to meet all safety, serviceability, durability, efficiency and constructability requirements. In such extreme high-riser cases, static and dynamic analyses of buildings require careful structural modeling, wind characteristics, appropriate selection of ground motions, and a through knowledge and familiarity of the analyst with the procedures and computer software employed.

As a result of the decline in the real estate market in the region, some developers today have been completed to a large extent on the organizational restructuring to take advantage of the economic recovery expected in the end as a whole. To accept the new global reality, governments have to develop their regulations to prepare the next phase and future needs. Importantly, some local authorities-governments have already begun to optimize their applications. Sustainability development is one of the most important of these applications.

Upon it, and in accordance with the new challenges, structural design engineers must have an active role in these regulations that have been made for the sustainability of buildings. Presently, a lot of questions are still in the mind of the expert consultants on the sustainability definition and its techniques and applications. However, it is necessary to achieve two basic concepts:

- Assurance of safety, economy and quality (this means for structural engineers: loadings, computer modeling, analysis, design, and structure optimization).
- Reducing the environmental impact (i.e. materials, construction technique, new technology, post operation, management problems and cost).

The objective of this paper is to establish best-practice for structural sustainability techniques such as: analysis methodology, computer modeling, concrete design, sustainability aspects as well as other structural considerations for high-rise concrete buildings. A set of recommendations is given, and some useful suggestions are also provided.

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II. Local Authority Requirements

It is appropriate before start sustainability techniques to recall some of the following local authority requirements:

1) SDC-Seismic Design Category 'C' shall be considered in the seismic calculations and a minimum value of 38 m/sec of basic wind speed for 3 second gust can be used for wind pressure estimation.
2) All buildings shall be designed to limited maximum design drift to a certain value of 1/500 of building heights. Also, the acceptable top floor accelerations due to 10 years wind pressures shall be limited to 0.015 m/sec^2, and torsional velocity shall not exceed 3 milli-rad/seconds.
3) Unless otherwise specified, 50 year design life-span of the building structure shall be adopted. However, important tall buildings would have a longer design life, e.g. 75 or 100 years.
4) Minimum fire rating shall be 2 hours for floors, and 3 hours for transfer slabs, outriggers, and vertical elements.
5) Notional horizontal loads, effective ties, and alternate load path approaches shall be planned and designed in details for robustness strategy. Car park and ground floor columns shall be checked for accidental impact loads.
6) Unless otherwise specified, a 2% critical damping for wind analysis and 5% for seismic design can be used for structural damping.
7) Thermal effects shall be evaluated based on realistic temperature distribution. Seasonal temperature change shall not be less than ±25^o C or in accordance with credible local climate record.
8) Temperature variation ±12^o C can be considered in the raft and basement design.
9) Contractor must ensure that the structures will not move or changing during or after the construction. Long term shortening effects shall be investigated carefully, which might affect cladding and mechanical systems.
10) And finally, improving the concrete structural system, in the front of green building code, durability and sustainability are effectively required to be considered.

III. Third-Party Peer Review and Monitoring

In Middle East developments, it is common practice for a building of significant height to be reviewed in detail by an expert peer review consultant with expertise in tall buildings. Review of design document and components during the design process is one of the best practices to strengthen the design. This third-party external checking is a mandatory requirement in some local areas. Also, to minimize the risk and damage to the properties, appropriate construction monitoring for the project shall be conducted by the designer to ensure that construction is executed in a manner consistent with the design concepts.

IV. Structural Computer Model and Design Considerations

Based on building configurations and material characteristics, applied advanced three-dimensional finite element approach needs a considerable effort for analysis of large-scale buildings. The following points include some guidelines for advanced structural analysis and design considerations of high-rise concrete buildings:

1) Cracked section properties shall be used, by providing crack analysis exercise or by direct application of the stiffness modifiers as recommended in ACI-318.
2) Shrinkage and creep effects shall be investigated to determine their impact on the design of the structural elements. These effects can be catered for by multiplying the value of the modulus of elasticity by a reasonable reduction value.
3) Critical and higher vibration mode effect shall be investigated. A typical combination method is the square root of the sum of the squares (SRSS) if the modal frequencies are not close and un-identical. Other wise the method of complete quadratic combination (CQC) will be a good estimate if frequencies are closely spaced.
4) Coupled flexure-torsion effect, brought by architectural irregularities of plan and elevation, shall be investigated carefully. For an irregular building, having fundamental mode due to torsional vibration, further base shear calculations by restraining freedom of movement for global direction separately may be significant and needed for the sake of comparison.
5) Construction sequences and stage analysis (time-dependent) shall be performed, especially as it relates to serviceability limits.
6) Post-tensioned PT slabs are generally used for typical floors of towers. In this case, PT slabs shall be designed by specialist for gravity loading. The main consultant has to design additional reinforcements required to account for the lateral load effects. These reinforcements shall be provided in addition to reinforcements designed by PT specialist.
7) Lateral and axial long term effects due to elastic, creep and shrinkage shall be investigated and accounted for in the design and construction. If measures to compensate for the effects of differential shortening are taken, the consultant shall include such information on engineering drawings and relevant documents.
8) Vibration and fatigue assessment of the slender spire at the top of the building shall be considered carefully in the detailed design. Tuned mass dampers may be needed for spire structure.
9) Wind noise control study should be investigated and carried out.
10) Deformation compatibility for the structural elements not part of lateral resisting system shall be achieved according to the applicable code requirements.

Based on the considerations above, the building structure model has to run and be designed in conformance with the adopted codes and standards. The performance of the structure shall meet all requirements and limits.

V. Greens and Sustainability

In terms of building the future, the right way, it be must provide a multidisciplinary group of different skills that promotes development in order to put survival in the forefront. Nowadays' the Middle East status is reinforced by excellent channeling and innovations. For general knowledge, high-rise buildings of 40 stories and above are very common in UAE. An impressive number of high-profile professionals as well as technical experts participated in the forum, held in Dubai, on innovations in design and construction; which was hosted by Trakhees - Civil Engineering Division of Ports, Customs and Free Zone Corporation (PCFC) on February 26, 2008. One of the main goals of the forum was to bring attention to greens and sustainable building development practices. Actually, there is no significant difference or more cost in the three major phrases named "green building", "sustainable development", and "high performance buildings", all of which describe the practice of development and building with responsibility towards the environment and community [6]. Sustainability means living within our own resources without environmental damage. Also, sustainability means creating an economic system and better performance with long-term safety. To achieve the full objectives of greens and sustainability, the developers and local governments are well on the way to establish wide range of laws governing the construction of new buildings in the region. Recently many papers focus on the sustainability of buildings from the viewpoint of the energy and environment, while there are not many on the structural engineering role. The main target of this paper is to inform engineers about structural sustainability techniques and applications in concrete buildings. Once again, structural engineers must take a role and educate themselves to enter the circle of sustainability decision makers.

VI. Structural Sustainability

Sustainability is the criteria that should be included in the buildings design. Undoubtedly, the contribution of structural engineers to the sustainability design can not be ignored. The following sustainability techniques can be achieved and suggested as guidance to the structural engineers:

A. Sustainable Techniques for Team Work

In order to gain all of the environmental and economic benefits, prior knowledge and experience of the working team is one of the most important tools needed in the design of high-rise buildings.

1) At the early scheme design stage, and due to a lot of unconventional form of towers and tallest waves over the world, an initial assessment of the structure will be necessary to achieve the required architectural concepts in the shortest time as possible.
2) Careful consideration shall be given to the building orientation and massing.
3) Adopt technical feasibility study with alternative strategies for development, and explore options for its buildability.
4) Develop appropriate structural frameworks for effective control over the re-designed, rework and project management.
5) Principal engineers should educate or have good knowledge of techniques in sustainable design.
6) Avoid the movement of staff during the work stage, especially the core units and key engineers.
7) Think positively and respect the views of other professionals.
8) Coupled lateral-torsional vibration modes are common in irregular tall buildings. In this case, the stability response would be magnified and using uniform shapes will be the simplest way of reducing these higher coupled effects.
9) Minimize any complex and irregularity shape that will impact the lateral deformations due to gravity loads. A uniform form will be integral with the building performance as well as re-use scaffolding approach. Formwork re-use can lead to significant saving in material resources and reduce waste.
10) Structural engineer should make more effort to achieve the most efficient structural design. They must use advanced structural analysis and the most powerful computer programs available today.

B. Sustainable Techniques for Analysis and Design

There are several techniques specifically related to the structural analysis and design, which are effective in helping the achievement of sustainability objectives for high-rise building projects without affecting building performance. The following are a summary of number of these techniques:

1) The analytical finite element computer model is almost overstating the elements weight due to overlap of frame/shell elements, which are connected at centerlines. This weight reduction could be significant in large projects.
2) In general, the structural computer model shall be consistent with the loadings stated in the project design criteria. There is no reasonable reason to add conservative figures into the model.
3) To allow further weight reductions, the live load reduction factors and reduced load factors for strength design, as permitted in the code standards, shall not be ignored.
4) The surrounding buildings influence the distribution of wind pressure and wind load seriously. To obtain the wind load/responses and assess the living comfort and safety of the building, wind-tunnel model test shall be performed for economic design, rather than using the exaggerated static wind loads that are based on design code estimations.
5) Do not ignore the structural components interaction, such as: beam-column continuity interaction; soil-structure model interaction; infilled wall-frame interaction….etc.

This approach can result in economy designs.

6) To minimize shrinkage cracking in a large concrete structure, it is a common practice to adopt stage construction by providing late-cast strips technique.
7) According to marketing price and economy design, alternative solutions should be examined for floor design. Usage Precast hollow-core or/and post-tensioned slabs may reduce the volume, false works and reinforcement quantity; especially for large-area building floor.
8) Accommodating longer spans and simpler solutions would affect the architect's designs and best area uses.
9) Assess the impact of the nonstructural elements on the final building stiffness as well as its contribution in the natural damping and deformation-drift characteristics.
10) Produce preliminary pile tests, where the results will give a good understanding of the soil behavior to provide a more reliable soil-structure interaction model.
11) Temporary works can be used as permanent works; for example the shoring system could be used as external permanent structural skeletons for the basement structures.
12) Optimize the component of concrete mixes. Incorporate amounts of slag or fly ash, as an alternative cement, would be significant.
13) Building Information Modeling (BIM) is the intelligent process of generating and managing building data during its life cycle. The Model encompasses building geometry, spatial relationships, geographic information, quantities and properties of building components. BIM can also be used to explore and manage the construction process, energy optimization, sustainable construction, cost, and facility management.

C. Sustainable Techniques for Foundations

The increasing emphasis on iconic skyline high-rise building projects, coupled with difficult and variable ground conditions, requires innovative foundation solutions. The seismic forces are a function of the overall weight of the building structure. Reducing the weight of the structure can result in lower seismic design forces for the lateral load resisting systems and the foundations carrying them. The following sustainable foundation techniques can be achieved:

1) First, it is important to provide early discussion and collaboration with the architect, to make adjustments to final column and shear wall locations. Also, to minimize the forces that attracted from the lateral events, the center of mass of the building should be near to the center of rigidity.
2) Avoid unforeseen ground conditions that escalate costs.
3) Minimize pile material usage and project time by optimizing foundation design.
4) Material quantities can be minimized through the use of higher-strength materials, 70 MPa for concrete compressive strength is available in most locations.
5) Prevent redesign by carrying out cost-effective site investigations to detect cavities. It can be utilize new QA and QC techniques to prevent the possibility of re-design.
6) Examining methods of temporary excavation support (secant piles and diaphragm walls). Recognizing the temporary walls as a permanent structure.
7) Use grouting blankets and other techniques to ensure sustainability of piles.

D. Sustainable Techniques for Site and Construction

The following techniques related to site can be a very successful strategy in sustainable design as well as quicker and easier construction:

1) The installation of instrumentation to monitor the seismic and wind response of tall buildings is encouraged. These instruments will provide data valuable to the design community to calibrate and further improve design procedures.
2) Light weight partition, such as drywalls and others, will impact the super-imposed loads consideration, and result in gravity and stability building design. Besides, there is a reduction in laboring and constriction period.
3) Compared with the traditional retaining structure, the reinforced soil-cement mixture has more advantages.
4) Develop a sustainable material cut and fill strategy for the development.
5) Avoid the use of non-indigenous species in the civil works. Wherever possible, consultant shall specify locally manufactured materials as a first priority.
6) Achieve and maximize the use of clean and non-destructive construction building technologies, including off-site pre-fabrication.
7) The use of recycled materials, such as concrete aggregates, would be possible for low strength concretes.
8) Develop a management plan to maximize waste reduction, re-use and recycling.

Finally, and looking at the above sustainable technique features, it is clear that long time multilevel design life span by adequate efforts can be made and accordingly a Life Cycle Assessment (LCA) can be undertaken to determine the optimal building system design.

VII. Conclusion

The tall building label is appropriate for the Gulf region. Construction rates in the Middle East region for the last ten years have been incredibly fast, with a unique opportunity to those of modern high-rise buildings. The authority aims, with accreditation, to ensure quality and performance of both design and construction in all projects under its jurisdiction. In the very near future through local regulations, every aspect of the building design will be designed with sustainability as a prime consideration. Many structurally subjects have been highlighted in this paper. This paper outlines the structural techniques which can be used in the sustainability design of high-rise buildings. Of particular note, in this document, the author asked the structural engineers to take the role and be a member of the sustainability decision makers.

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