International Journal of High-Rise Buildings
September 2020, Vol 9, No 3, 283-300
https://doi.org/10.21022/IJHRB.2020.9.3.283

International Journal of
High-Rise Buildings
www.ctbuh-korea.org/ijhrb/index.php

The Structural Engineering Design And Construction Of The Tallest Building In Europe Lakhta Center, St. Petersburg. Russia

Ahmad Abdelrazaq[1], Vladimir Travush, PhD[2], Alexey Shakhvorostov, PhD[3] Alexander Timofeevich[3], Mikhail Desyatkin[3], and Hyungil Jung[4]

[1]*Executive Vice President, Samsung C&T, Republic of Korea*
[2]*Executive GP, Moscow, Russia*
[3]*Partners Inforceproject, Russia*
[4]*Deputy General Manager Samsung C&T, Republic of Korea*

Abstract

The Lakhta Center is a Multifunction Complex Development (MFCD) consisting of 1) an 86 story office tower rising 462 m above the ground to provide high-end offices for Gazprom Neft and Gazprom Group affiliates 2) a Multi-Function Building (MFB) that includes, a scientific/educational center, a sport center, a children's technopark, a planetarium, a multi-transformable hall, an exhibition center, shops, restaurants, and other public facilities 3) a Stylobate 4) "The Arch, which forms the main entrance to the tower, restaurants, and cafes 5) underground parking and 6) a wide range of large public plazas. While each of the MFCD buildings is technically challenging in its own right, the focus of the paper is to present the development and integration of the structural and foundation systems of the bowed, tapered, and twisted shape of the tower into the fabric of the tallest Tower in Europe.

Keywords: Super Tall Tower, Composite Structural system, Composite floor framing design, floating raft on reinforced soil structure, Composite Outrigger Core wall Connection with externally stiffened floor diaphragm

1. Introduction

The Lakhta Center (LC), situated in the Primorsky district at the outskirts of Saint Petersburg, is developed and implemented as a business center and a pilot of integrated sustainable development, with the public and city's interest at heart. LC is strategically located to have the connectivity and access to all public infrastructure and to serve as a catalyst to the development of a 21st-century new landmark and iconic business center that is well suited to expand and complement the existing historic and world heritage Central Business District (CBD). This in turn will bring significant economic benefits to the city such as attracting global corporations, adding revenue and creating new jobs. With careful planning, the new CBD has the potential to become one of the most sustainable and iconic cities in the Northern Hemisphere, as seen in Figure 1.

The Lakhta Center is a Multifunction Complex Development (MFCD) consisting of: 1) an 86 story office tower rising 462 m above the ground to provide high-end offices for Gazprom Neft and Gazprom Group affiliates 2) a Multi-Function Building (MFB) that includes, a scientific/educational center, a sport center, a children's technopark, a planetarium, a multi-transformable hall, an exhibition center, shops, restaurants, and other public facilities 3) a Stylobate 4) "The Arch that forms the main Tower entrance and houses restaurants and cafes 5) underground parking and 6) a wide range of large public plazas. While each of the MFCD buildings is geometrically and technically challenging in its own right, the focus of this paper is to present the development and integration of the structural and foundation systems into the architectural fabric of the tallest building in Russia and Europe.

2. The Complex Geometry of the Tower

The geometry of the Tower was influenced by the Swedish town of Niyen and Niyenscans Fortress as shown in Figure 2. The exterior geometry of the tower is sculpted around a central circular core wall with 5 equal extrusions/petals that rotate 90 degrees from the base to the top of the spire and bows/tapers relative to the tower geometric center. The overall dimension of the tower is approximately 65 m at the base, 67.3 m at level 17, 27.8 m at level 86, and diminishes at the tower pinnacle at

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†Corresponding author: Ahmad Abdelrazaq
Tel: +86-21-2145-5190(Direct)
E-mail: a.abdelrazaq@samsung.com

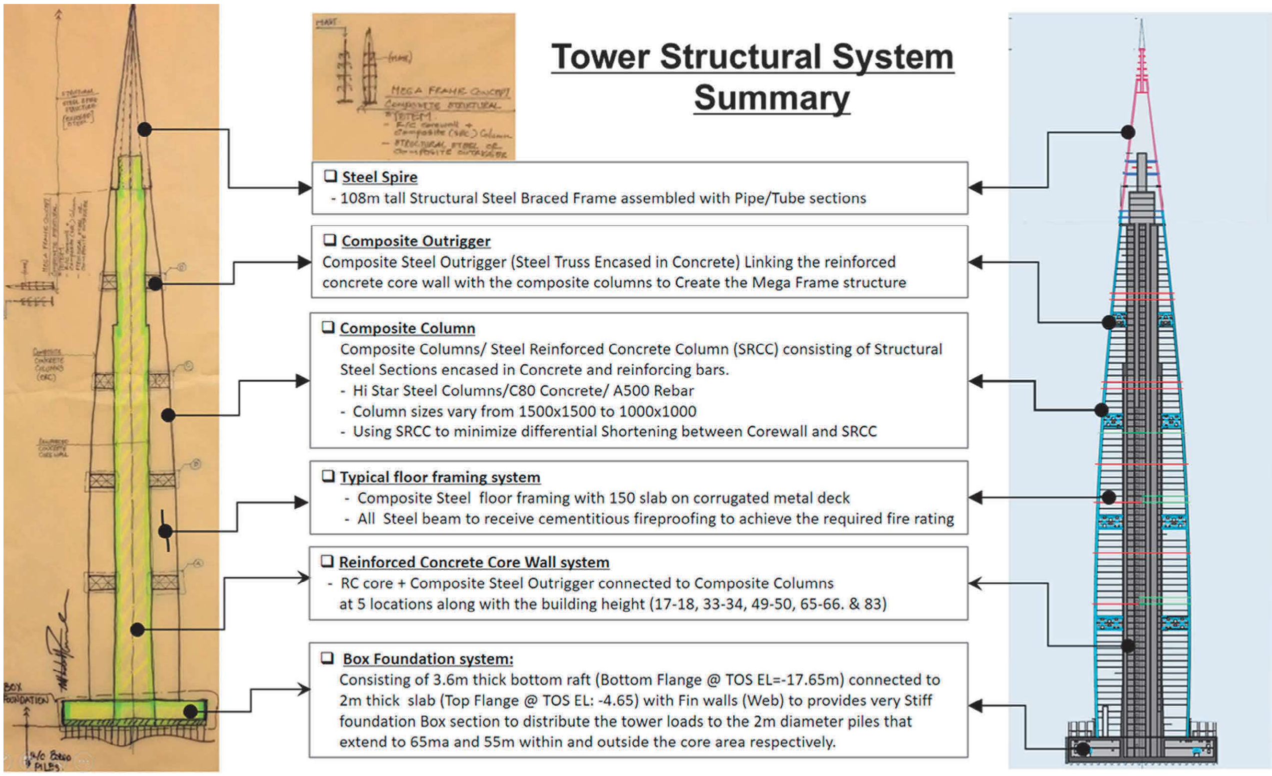
462 m. The exterior structural skeleton is developed to weave into the ever-changing crystalline form of the architectural fabric as shown in Figure 2.

The center core wall dimensions are optimized to house the vertical transportation systems, stairs, mechanical shafts, elevator lobbies, and other technical facilities. The core wall is 26.1 m in diameter between levels 1 to 58, 21.4 m in diameter from level 59-80, and 16 m in diameter from level 81 to 88. The exterior composite steel columns follow the exterior geometry of the tower by twisting at 0.89 per floor, tapering and bowing from level 1 to the tip of the pinnacle as depicted in Figure 2. The structural steel braced frame provides stability and lateral load resistance to the spire. The main steel pipe columns of the spire are founded at the exterior composite columns at level 83 which then taper to a single central ring (as shown in Figure 2) that supports the single pipe pinnacle at 462 m.

3. Design Description of the Structural System of the Tower and Super-structure System Selection

The crystalline and complex geometry of the tower resulted in significant changes to the floor plate shape and floor area. This resulted in significant structural challenges that required simplifications and innovations in selecting structural systems that:

1. integrates the exterior structural frame into the crystalline architecture fabric
2. maximizes the exterior views and minimizes the number of exterior columns
3. continuous throughout the building height without transfers
4. integrates all vertical elements into the stability and lateral resisting system to maximize its resistance to wind, seismic, stability, etc. and maximizes the overall bending stiffness of the building
5. considers constructability and avoids complex detailing when designing for construction
6. provides a robust and redundant structural system in case of accidental events of loads.
7. minimizes effects of differential column shortening between center reinforced concrete core wall and the exterior columns
8. resolves biaxial design forces that are generated at the exterior columns due to change in building geometry (rotation, tapering) without additional cost or complex detailing
9. addresses wind effects and provides for wind engineering treatment to reduce wind loads and wind excitation due to the dynamic wind effects. Variation in building geometry at every floor, because of floor rotation, tapering, variation at edge conditions, and open/meshed/vented façade at the spire (above level 88), has resulted in favorable wind responses that are well within the internationally accepted



Tower Structural System Summary

☐ **Steel Spire**
- 108m tall Structural Steel Braced Frame assembled with Pipe/Tube sections

☐ **Composite Outrigger**
Composite Steel Outrigger (Steel Truss Encased in Concrete) Linking the reinforced concrete core wall with the composite columns to Create the Mega Frame structure

☐ **Composite Column**
Composite Columns/ Steel Reinforced Concrete Column (SRCC) consisting of Structural Steel Sections encased in Concrete and reinforcing bars.
- Hi Star Steel Columns/C80 Concrete/ A500 Rebar
- Column sizes vary from 1500x1500 to 1000x1000
- Using SRCC to minimize differential Shortening between Corewall and SRCC

☐ **Typical floor framing system**
- Composite Steel floor framing with 150 slab on corrugated metal deck
- All Steel beam to receive cementitious fireproofing to achieve the required fire rating

☐ **Reinforced Concrete Core Wall system**
- RC core + Composite Steel Outrigger connected to Composite Columns at 5 locations along with the building height (17-18, 33-34, 49-50, 65-66. & 83)

☐ **Box Foundation system:**
Consisting of 3.6m thick bottom raft (Bottom Flange @ TOS EL=-17.65m) connected to 2m thick slab (Top Flange @ TOS EL: -4.65) with Fin walls (Web) to provides very Stiff foundation Box section to distribute the tower loads to the 2m diameter piles that extend to 65ma and 55m within and outside the core area respectively.

Figure 3. Tower superstructure and summary and description of the foundation system.

the constructability aspect of the columns to achieve a typical 3-4 working day floor construction cycle 2) integrate with and follow the architectural form, and 3) simplify the composite steel floor framing connection to the SRCC. The SRCC consists of centrally located HL 920-Histar high strength steel that is encased in high-performance concrete (B80). These are designed as concrete columns with the highest steel allowed by the Russian Standards. Since the Russian Standards do not have provision for composite column design, the building authorities and experts required special technical documentation and tests to allow their use in building construction. Figure 8 depicts a summary of the sectional details of the composite columns along with construction photos.

Following the architectural form, the SRCC are segmented into two-story modules, rotated every two floors at odd floors and detailed to transfer both the composite steel girder gravity loads and the biaxial lateral loads generated due to change in column geometry. Figure 6 provides a summary of the cumulative and floor-by-floor torsional loads generated from column rotation and inclination. These lateral forces are transferred from the steel-to-steel connection to the floor slabs through a shear stud and finally to the reinforced concrete core through a 150 mm solid reinforced concrete ring slab surrounding the core wall.

The SRCC sections are also optimized to minimize the differential shortening between the center reinforced concrete core wall and the SRCC in order to 1) reduce its impact on the outrigger design maintain floor levelness, and 3) minimize the impact of non-structural components. The actual building survey has shown that the differential shortening between the center core wall and SRCC is similar to the ones predicted from the 3-dimensional

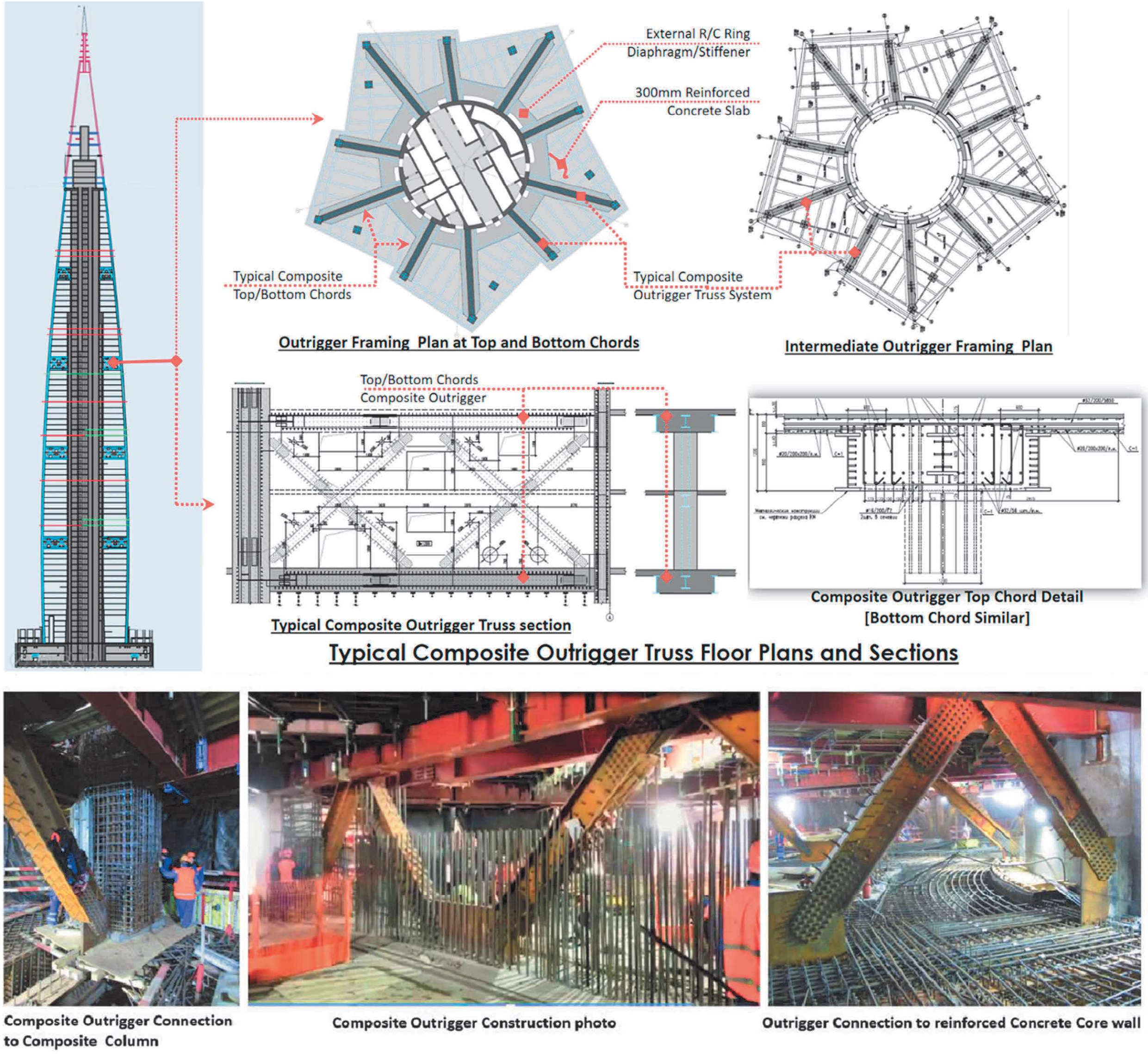


Figure 10. Typical composite outrigger plans, Sections, details, and construction photos.

finite element analysis. This allowed the possibility of connecting the outrigger to the exterior SRCC without time delay.

3.5 Composite Outrigger

As described above, the Mega-Frame structure of the tower, which consists of the center reinforced concrete core wall system, is connected to the exterior composite columns with 4-equally spaced two-story composite outriggers at the mechanical levels (levels 17-18, 33-34, 49-50, 65-66) and secondary outrigger, at level 80, as shown in Figures 9 and 10. The core wall is rigidly connected to the composite steel outrigger system by an externally stiffened plate diaphragm at the top and bottom chords of the outriggers.

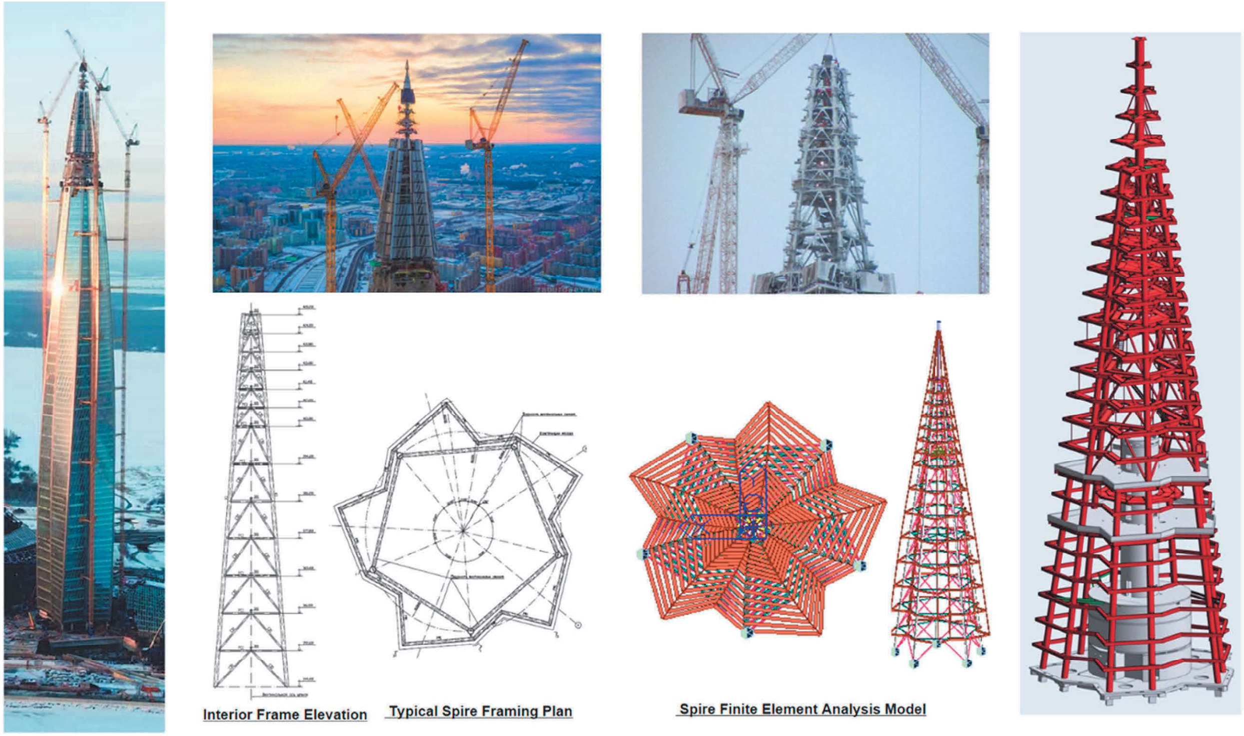
This type of outrigger system has reduced the overall bending moment in the core wall, due to wind and lateral loads, by more than 50%, but increased the exterior columns wind and lateral loads by approximately 20-30%. The design of the composite columns was mostly dominated by gravity load requirements and not significantly affected by wind or lateral loads, which demonstrate the efficacy of the Mega-Frame system.

The composite outriggers are provided to not only maximize the Mega-Frame stiffness but to also provide redundancy and alternate load path to the exterior columns. The composite outrigger system is comprised of 1) structural steel diagonals that carry 100% of the shear, in addition to the concrete sectional capacity 2) Composite top and bottom chords that are cast monolithically with the 300mmm thick reinforced concrete slab to maximize the bending stiffness of the outriggers, and 3) externally stiffened reinforced concrete ring plate diaphragm to transfer the outrigger horizontal forces to the center core wall. This composite outrigger system is a new, unique, and innovative concept that is not only structurally efficient but has significantly improved the overall constructability aspects of the tower by avoiding the detailing complexities associated with traditional outrigger construction methods. Moreover, this outrigger system also helped to skip the outrigger construction from the critical path, which resulted in significant savings in time.

A 3-dimensional finite element analysis is developed to verify the outrigger horizontal design forces that dissipate into the center core wall through the externally stiffened reinforced concrete ring plate.

3.6. STructural Steel Spire

The lateral load resting system of the spire is founded at level 83 and is comprised of a 5-sided braced frame structure that tapers from +344.4 m (level 83) to +428 m. To simplify the spire construction, the spire structure is divided into: 1) an interior braced frame consisting of 5-steel pipe columns that linearly taper to a single structural steel ring at +428 m; the structural steel ring also provides support to the single pipe pinnacle and 2) the primary meshed façade framing system which consists of built-up rectangular steel tube sections that follow the architectural



building maintenance system at level 87, and the telescoping platforms at level 88

Figure 11. Structural steel spire structural concept and construction photos.