Council on Tall Buildings and Urban Habitat Korea

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

International Journal of High-Rise Buildings
March 2022, Vol 11, No 1, 31-39
https://doi.org/10.21022/IJHRB.2022.11.1.31

Shenzhen Rural Commercial Bank Headquarters: an Iconic Tower Defined by the Integration of Architecture, Structure and Sustainability Goals

Charles Besjak† **and Alexandra Thewis**

SKIDMORE, OWINGS & MERRILL

Abstract The seamless integration of the architecture and structure of a tall building plays a key role in establishing a recognizable and iconic design. The structural system developed for Shenzhen Rural Commercial Bank Headquarters (SRCBH) utilizes enhanced structural innovations unique to the tower's geometry to improve structural and sustainability performance. SRCBH utilizes a steel diagrid system pulled outside of the enclosure line with diaphragm forces resolved primarily by corner diagonal beams. During the design process the structural systems underwent performance based design and optimization for wind and seismic loading. Resiliency was prioritized for structural design as well as fire resistance. More closely integrating the structure of a building with its architecture and sustainability goals can lead to unique and innovative towers with a timeless expression.

Keywords Tall Buildings, Resilience, Sustainability, Innovation, Integration

†Corresponding author:
Charles Besjak
Tel: (212) 298-9431
E-mail:
CHARLES.BESJAK@SOM.COM

1. Introduction

The seamless integration of the architecture and structure of a tall building plays a key role in establishing a recognizable and iconic structure. The structural system developed for Shenzhen Rural Commercial Bank Headquarters (SRCBH) utilizes enhanced structural innovations unique to the tower's geometry to improve the structural and sustainability performance. Employee health and wellness was central to the design. Utilizing natural ventilation via operable louvres on each floor, solar-responsive shading and other technology, allows the building to take advantage of natural daylight and fresh air. SRCBH utilizes a steel diagrid system pulled outside of the enclosure line with diaphragm forces resolved primarily by corner diagonal beams. The building presented new structural challenges and spurred varying types of analysis and studies, some of which are presented in the following sections.

2. Creating an Iconic Form

Structural form expressed in architecture has often been a defining characteristic of Skidmore, Owings & Merrill's (SOM) most recognizable projects, SRCBH is a prime example of our integrated practice working together to develop geometries and systems that enhance the architectural functions and form while improving the building's structural performance and enhancing the sustainability approach.

2.1. Adapted Diagrid

The SRCBH project consists of a high rise office tower and an adjacent low rise pavilion building. The 34-story tower is 164 m tall (150 m to the roof level) with a plan dimension of 45 m× 45 m. The design incorporates a tightly-spaced external diagrid pulled outside the enclosure line that serves two primary purposes; to provide an exterior shading system for the building and its occupants, and to create an entirely column free floor plan that allows for increased efficiency of office layouts. Early studies were performed varying the density of the diagrid, the final geometry being chosen as advantageous to both the desire to shade the facade as well as maintaining reasonable structural member sizes.

The exterior diagrid system is modified slightly from a conventional diagrid configuration in order to achieve the



Figure 1. Photograph of Shenzhen Rural Commercial Bank Headquarters, Photo: © Seth Powers

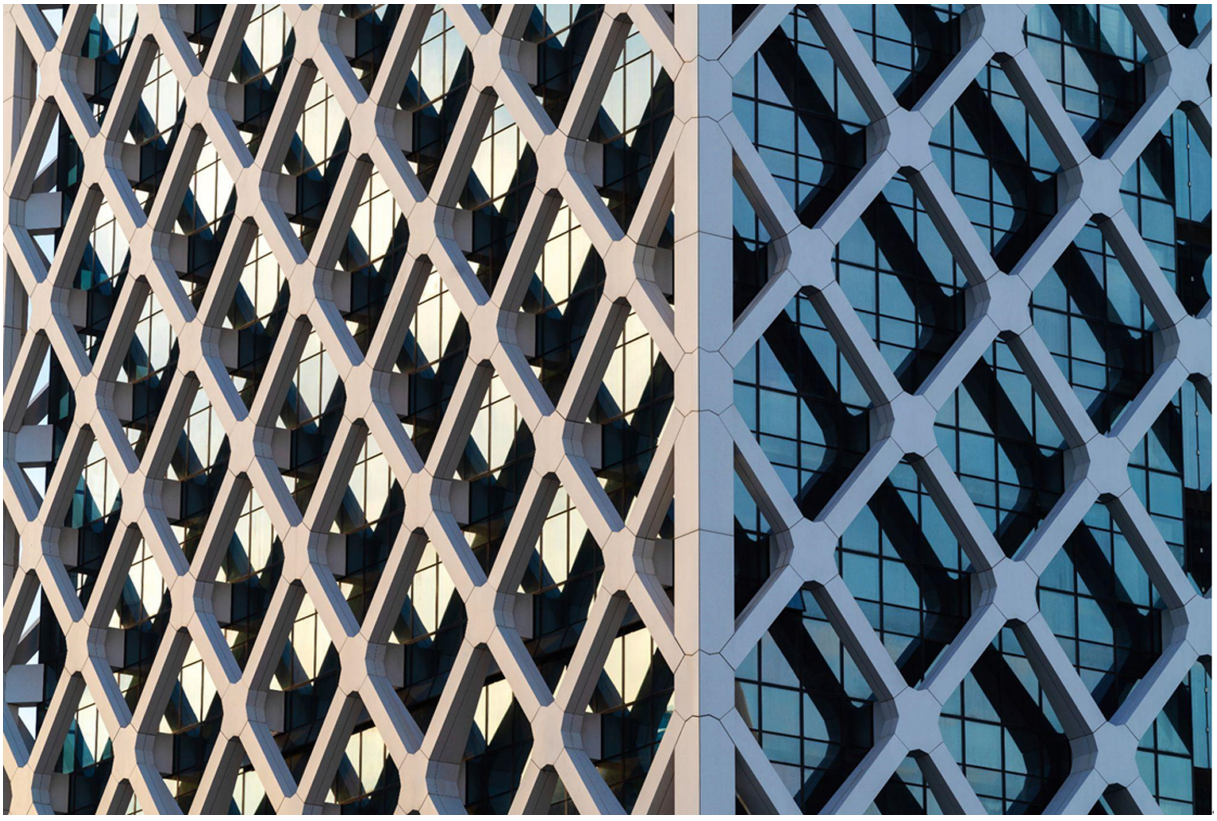


Figure 2. Photograph of Shenzhen Rural Commercial Bank Headquarters Exterior Diagrid, Photo: © Seth Powers

overall design goals of the project. In lieu of the horizontal members that resolve the thrust of the diagonal members of the diagrid, horizontal trusses in the floor plane resolve the thrust inside of the enclosure line to diagonal corner beams which allow the diamond diagrid shape to be emphasized. The diagrid is resolved at the building's corners with a vertical corner column; leaving only four vertical columns present in the tower.

The diagrid opens up at the base of the tower and a triple height-lobby enclosed with a glass cable wall creates a more seamless integration between the indoor and outdoor spaces. The nodal geometry in the SRCBH tower represents the simplest solution, a result of the rectangular building plan and consistent diagrid dimensions. This configuration is beneficial for simplicity of construction as the built up steel node geometry is repeated and angles remain consistent throughout. Diagrid member sizes are optimized and reduced in size throughout the height of the tower, while the cladding dimension surrounding the diagrid remains consistent throughout.

2.2. Sustainability through Structural Design

The tower's facade is defined by an external diagrid structure that enables a column-free floor space within, which doubles as a distinctive design feature as well as a solar shading system, contributing to energy and environmental savings. Solar gain is thereby reduced by approximately 34 percent and dramatically reduces glare in the office spaces within. The resulting interior space is defined only by a simple perimeter glass wall with an automated solar control blind to preserve optimal daylight levels.

By orienting the atrium to the east and west, the amount of occupied floor area experiencing low angle sun is further reduced. This positioning improves comfort and lowers cooling loads. The atrium can also be utilized as a "lung" for the building; a dilating air shaft that naturally ventilates the tower on days with good external air quality.

The East and West atria are integral parts of the building's high-performance design strategy. Using the natural forces of the tower, the atria drives return air upwards from each floor to the mechanical floors for filtering and recirculation. This system naturally and efficiently moves air throughout the building.

3. Structural Systems

3.1. Overall Structural System

The structural system consists of a diamond diagrid - braced megaframe with reinforced concrete core walls. Diagrid members, vertical columns and diagrid node bracing members are steel built-up box sections. Typical composite steel floor framing supporting truss deck span between core and diagrid. A reinforced concrete flat slab is used at all below grade levels. An embedded steel tie member at the ground level resolves the thrust of the diagrid members at the base. The structure at ground level supporting the plaza is a reinforced concrete beam with slab construction and a mat foundation on piles supports the tower.

3.2. Resolving Diagrid Forces

The cladding and the structural slab edges are offset inside of the diagrid system. Bracing of the diagrid system is provided by diagonal beams from the corner columns

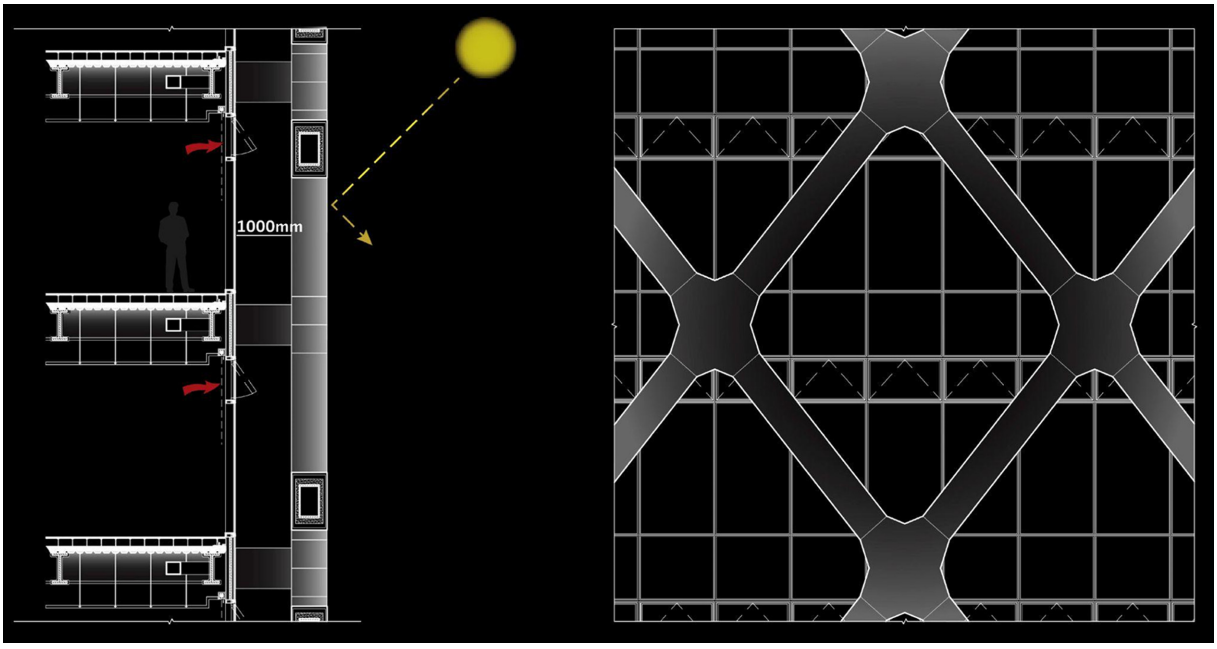


Figure 3. Structural Solar Shading, Image: © SOM

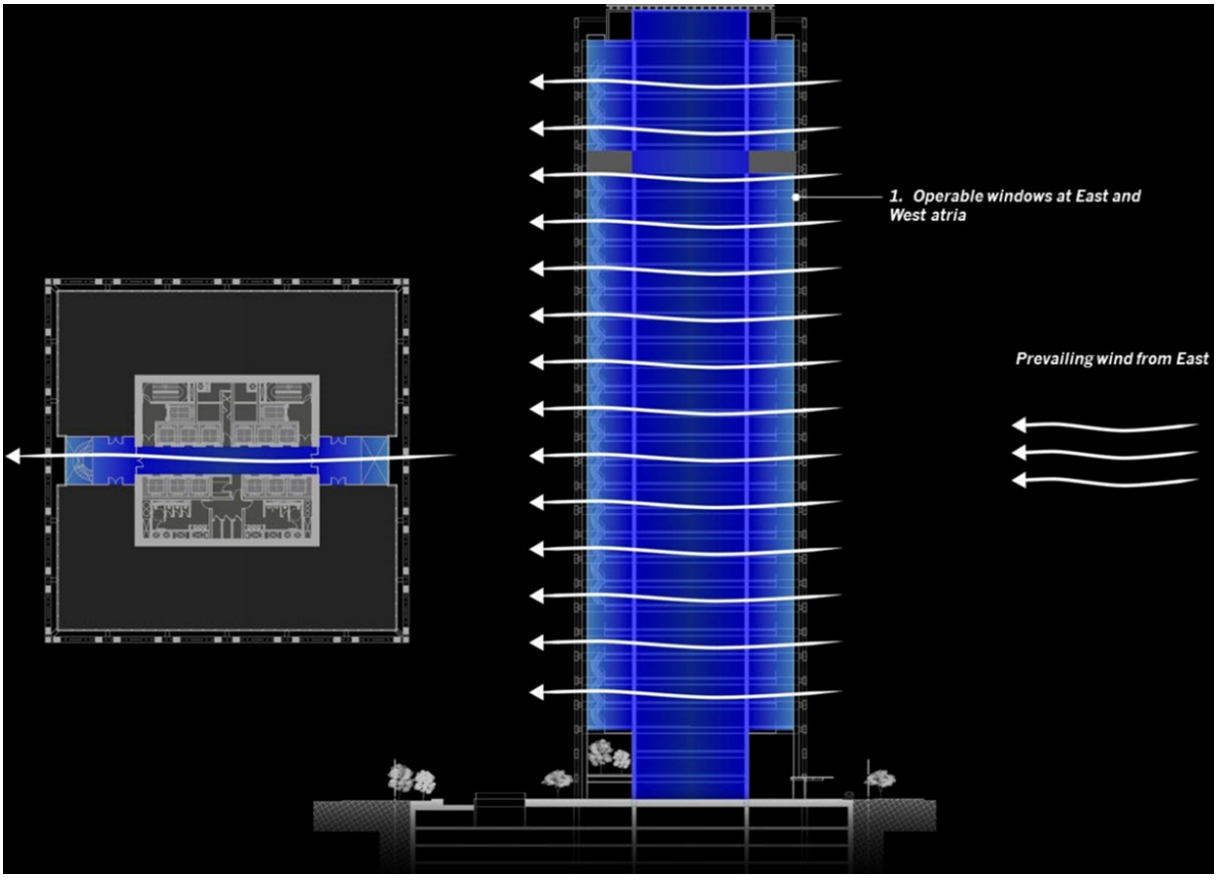


Figure 4. Fresh air flow at atria, Photo: © SOM

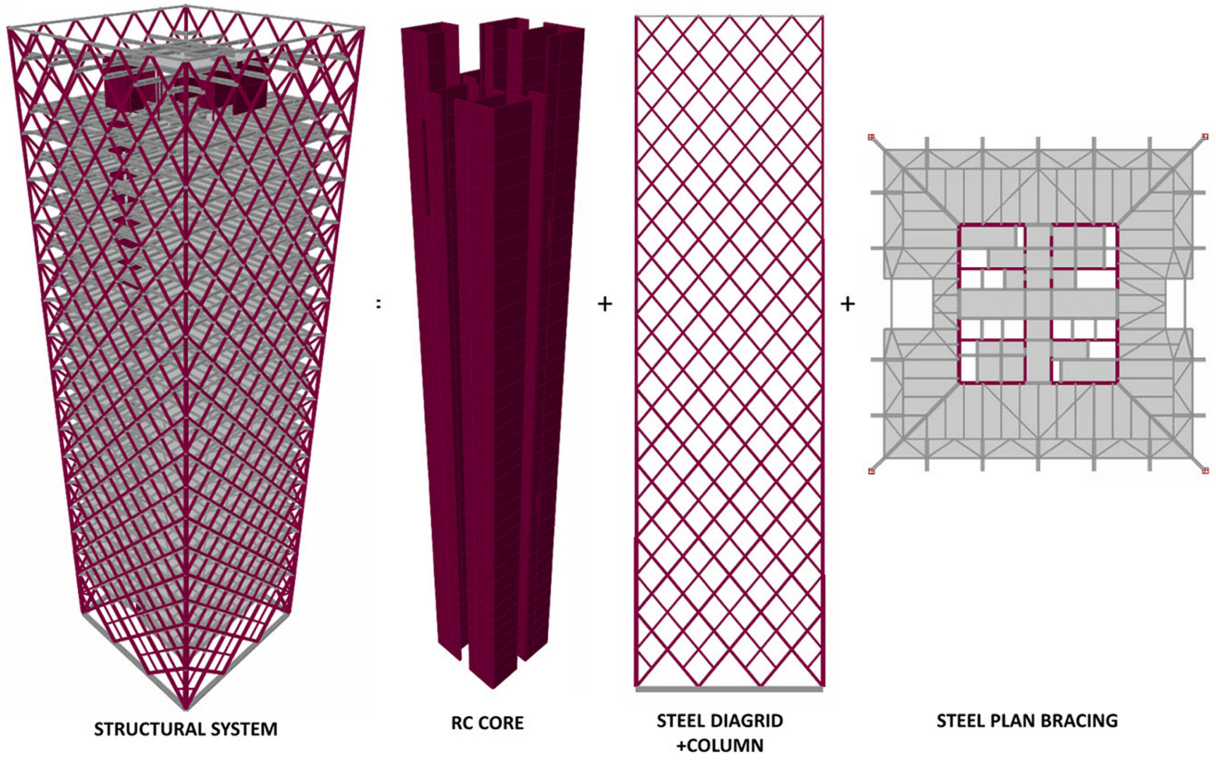


Figure 5. Structural System of Rural Bank, Photo: © SOM

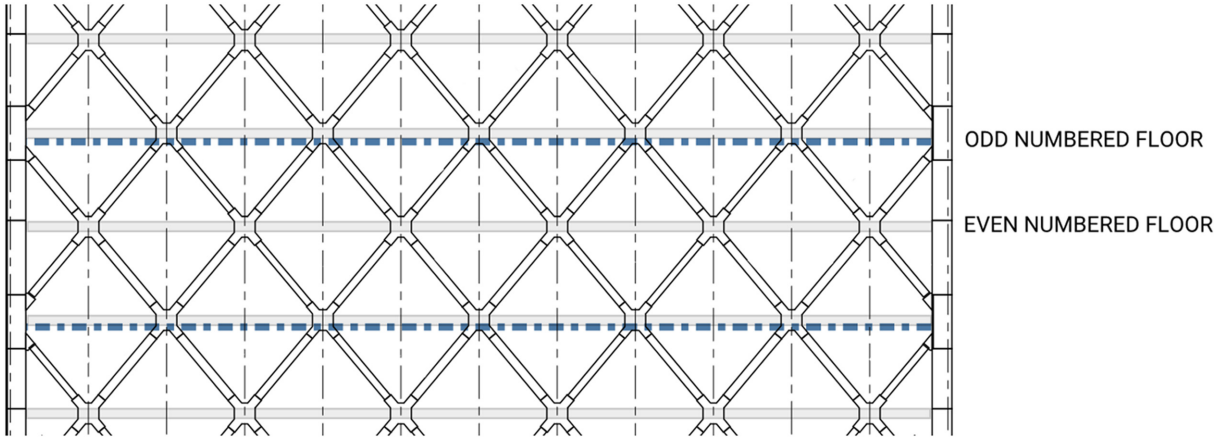


Figure 6. Partial Diagrid Elevation, Photo: © SOM

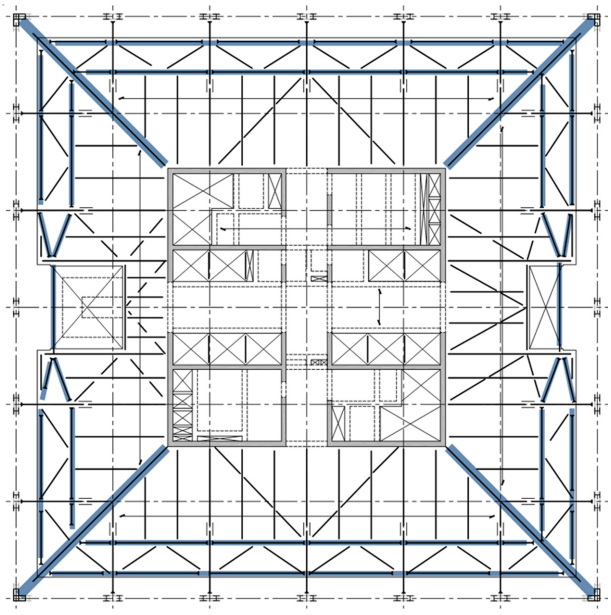


Figure 7. Odd Numbered Floor Structural Framing Plan, Photo: © SOM

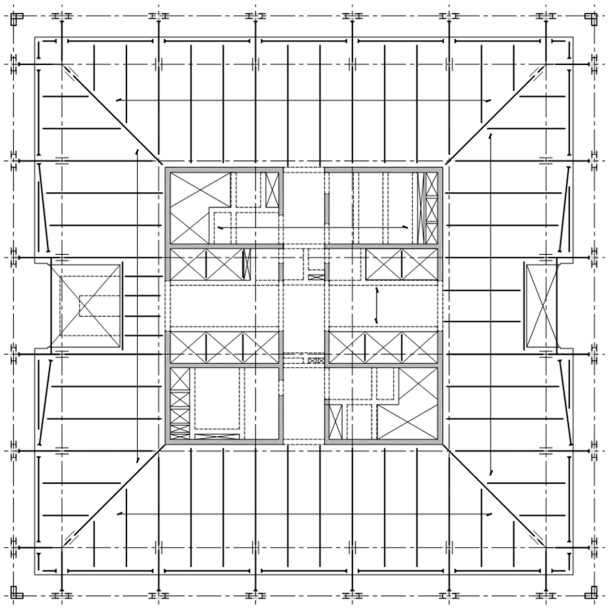


Figure 8. Even Numbered Floor Structural Framing Plan, Photo: © SOM

to the core at odd numbered floors and by box beams at every floor that extend from diaphragm trusses in the floor system to the diagrid nodes. At odd numbered floors, the perimeter spandrel beam, diaphragm trusses and the corner diagonal beams resolve the hoop tension forces and diaphragm forces to the corner diagrid.

Shenzhen is located in a zone of fairly high wind load and moderate seismic activity (Seismic Intensity Degree 7, Design Group I). The diagrid system and the members connecting it to the floor diaphragm system are designed to resist forces that result from the differential thermal movements between the core and the perimeter in addition to the forces from gravity, wind and seismic loads. Since the system is highly redundant, in order to encapsulate the potential forces in the members, four computer analysis models with varying degrees of member fixity between core and perimeter as well as varying diaphragm stiffnesses were analyzed. Each member was then designed for the maximum forces that resulted from any of the models. All analysis models were analyzed with load combinations that include a 20 degree C temperature differential between the interior structure and the exterior structure. The forces that result from staged construction analysis were also considered and included in the member design.

3.3 Connection Analysis

The geometry of the diagrid connections warranted that a 3-D finite element analysis be conducted at the critical atypical connections to verify that the stresses at the connection flowed without exceeding the limits of the material. Stiffeners and transition plates within the connection are included in the model as well. The



Figure 9. Relationship of diagrid, curtain wall and column free interior space, Photo: © SOM

performance of the connections are verified for wind and seismic loads as well as checked to remain non-yielding during a rare earthquake. The 3-D models were also used as a tool to verify plate geometry and member size transitions. An example of the critical node at the first level above the lobby is shown in Figure 11.

4. Resilience and Special Studies

4.1. Disproportionate Collapse

A number of studies were performed to ensure the prevention of progressive collapse. The diagrid is a redundant system with a significant capability to redistribute loads around an individual member. To verify this performance, selected diagrid members are removed and the remaining members checked for the progressive collapse load combinations. Additionally, an individual floor diagonal that ties the corner node to the core is assumed to be damaged or otherwise ineffective and the floor diaphragm truss system is designed for the progressive collapse load combination forces resulting from this situation.

In the case where member removal is not possible elements are designed as protected elements with 80 kN/m^2 load applied laterally to the projected area of the members, this includes corner columns, ground level ties and primary diagrid members. Primary diagrid members are those that form the primary gravity load path such as the diagrid member connecting to the corner node at the first floor above the lobby. Unbalanced gravity load cases and their impact on diagrid forces were also studied.

4.2. Performance-Based Design and Strengthening

Extreme seismic events generally cause structures to respond beyond the linear range. Therefore to accurately assess the behavior of buildings under these effects, it is important to consider the nonlinear behavior of the

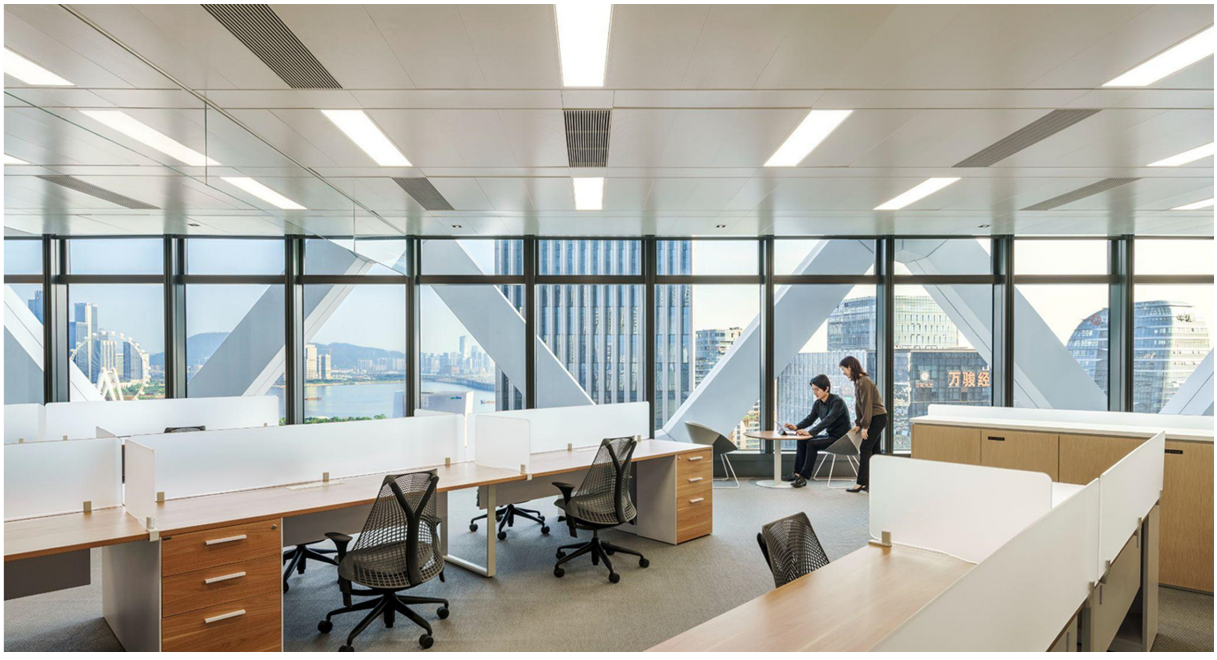


Figure 10. Photograph of column free interior space, Photo: © Seth Powers

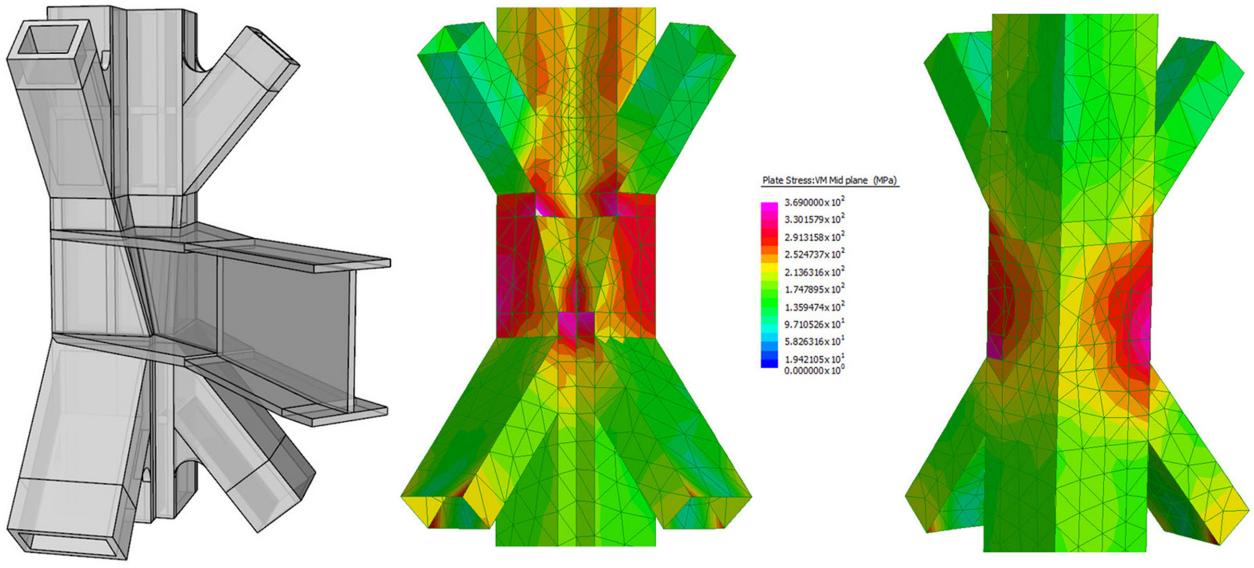


Figure 11. 3-D node model and FEM stress plot of diagrid connection, Photo: © SOM

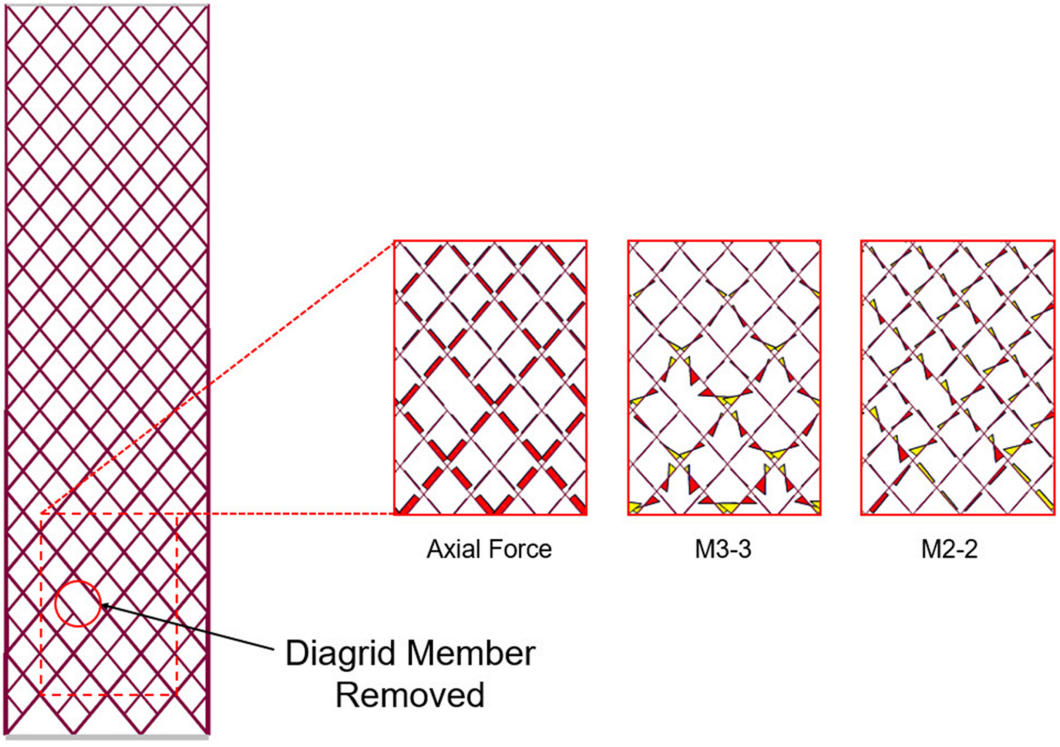


Figure 12. Diagrid member removal force distribution, Photo: © SOM

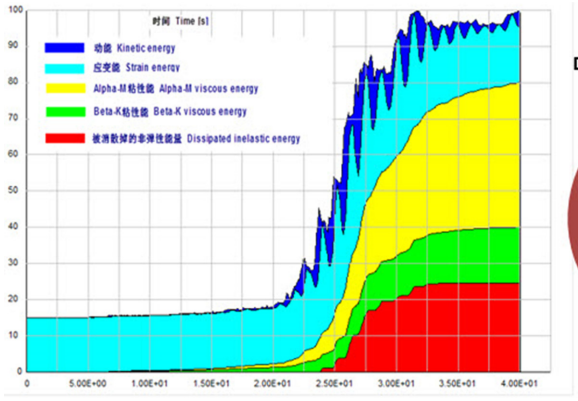
structure and its components. Nonlinear analysis was conducted using the PERFORM-3D software to evaluate the inelastic response of the building and assess its performance during rare earthquakes. The analysis demonstrated that about 96 percent of the energy dissipation during a rare earthquake occurs in the link beams of the core, which is determined to be a stable and safe energy dissipating mechanism. It was also verified that under a rare earthquake, the diagrid members have enough axial compression, axial tension and shear capacity to not yield.

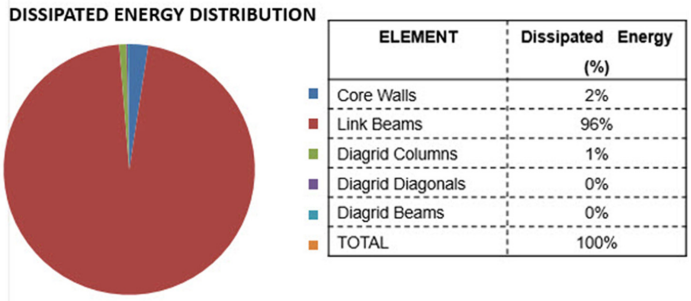
4.3. Fire and Thermal

The SRCBH diagrid members are encased in approximately 70 mm of concrete as well as cladding to provide both corrosion and fire protection to the exterior steel.



Figure 13. Primary and secondary Rural Bank diagrid members at the lobby, Photo: © Seth Powers





ELEMENT	Dissipated Energy (%)
Core Walls	2%
Link Beams	96%
Diagrid Columns	1%
Diagrid Diagonals	0%
Diagrid Beams	0%
TOTAL	100%

Figure 14. Energy distribution of the building at each time step under a rare earthquake time-history and energy element distribution, Photo: © SOM Energy distribution of the building at each time step under a rare earthquake time-history and energy element distribution, Photo: © SOM

The concrete also works to supply thermal lag to the steel members which reduces the thermal expansion and contraction which impart internal stresses into the steel members. Extensive thermal modeling of the overall building as well as the diagrid member cross section was carried out to determine the maximum temperature differentials across the steel section throughout all times of year. The steel temperatures found during the detailed thermal analysis were included in the member design checks and checks for differential movements.

4.4. Construction Sequence Analysis

A detailed construction sequence analysis was carried out on the tower. The ETABS sequenced construction tool was used to create a construction sequence with reasonable construction assumptions to develop a realistic sequence. Two stories and their corresponding dead load are added at each stage. The axial loads in the corner columns and diagrid members resulting from the staged analysis were used in the design of the columns and diagrid members.

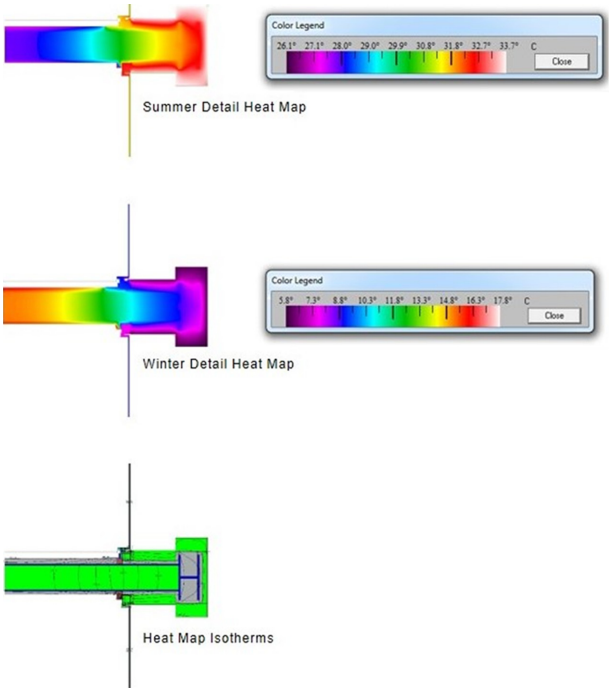


Figure 15. Temperature gradient through members at exterior wall, Photo: © SOM



Figure 16. Construction Photo of Rural Commercial Bank, Photo: © SOM



Figure 17. Photo of Shenzhen Rural Commercial Bank, Photo: © Seth Powers

5. Conclusion

The team reimagined this project as an opportunity to develop several next-generation sustainability technologies, and an update to one of SOM's core structural design legacies - the external diagrid. The building defines a world-class benchmark for sustainable design utilizing naturally ventilated atria and a column-free externalized structure.

In the wake of a pandemic, natural ventilation in contemporary buildings is needed in order to better promote the to promote health and wellbeing of occupants. This project advances the structural skillset available to modern structures moving forward. The ability to integrate these features with nature to a higher degree will set the tone for future projects. More closely integrating the structure of a building with its architecture and sustainability goals can lead to unique and innovative towers with timeless expression.