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"The Bow": Unique Diagrid Structural System for a Sustainable Tall Building

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Barry Charnish

Joining Yolles in 1974, Barry's career progression as an engineer has increased to include technical and business development roles within the company. As Principal Engineer, his responsibilities include working on many projects of varying size while maintaining responsibilities for conceptual design, construction drawings, specification production, and site reviews.

Barry's area of expertise includes structural steel, reinforced and post tensioned concrete, as well as hybrid high-rise structures in Canada, the United States of America, China, and Germany. Other projects include cultural arts centers across North America, hotel and residential structures, casinos, churches, and sports and community centers.

Committee work includes the NCARB preparation for the Architect's exams; the associate professional to the Canadian Institute of Steel Construction, as well as the technical committee for the development of CSA Standard S16 01 Design of Structural Steel for Buildings; CEO Quality Assurance Standards for Engineering Practice in Ontario; and professional advisor in bringing high performance concrete in Toronto.

Terry McDonnell

Terry McDonnell joined Halcrow Yolles in 2007 as a Principal to provide leadership within the growing United States practice. Prior to joining Halcrow Yolles, Terry focused on high performance architectural design and complex engineering systems. His portfolio includes the structural design and project management of a variety of building types including high rise, stadiums and arenas, entertainment, cultural, commercial, and residential.

His strong leadership and past experience with complex construction sites enables him to produce value-driven solutions that meet complex and diverse building systems. In addition to intricate structural design, Terry also specializes in earthquake engineering, renovation and re-use of existing buildings, life cycle design, and emergency stabilization."

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Abstract

The new 59 story “Bow” project for EnCana Corporation will be the tallest building in Calgary and Western Canada at nearly 247 meters (or 810 feet) high. The building is one of the largest commercial office developments in Canada with 180,000 square meters (or 2 million square feet) of total floor space. The Owner, Developer, Tenant, and Design team for the “Bow” project all wanted a distinctive tower design which catered to people, both occupants and the surrounding Calgary residents. An additional goal was to create a city center that offered a progressive and sustainable office environment. The end result is estimated will reduce energy consumption significantly when compared to a conventional office tower.

The lateral support system consists of a perimeter trussed tube made of diagonal grids (or a “diagrid”) which consists of six story high diagonals along the curved north and south elevations. The inward curving southern exterior of the building allows for many of the sustainable design features, including a double glazed atrium and sky gardens located on floors 12, 18, and 24. This paper describes the structural design considerations of the lateral system, some construction methods, and the unique sustainable features incorporated into the building.

Keywords: Diagrid, lateral design, high rise, construction logistics, heat atrium

Introduction

“The Bow” or EnCana Tower derives its name from the Bow River running near to the project location. In addition, the tower is shaped like a bow in plan. This bow shape was designed primarily to maximize perimeter office space, while also taking into account wind direction and floor layout for energy consumption. This resulted in a typical floor area on the order of 35,000 square feet, which reportedly gives the most people views of the Bow River Valley, the Bow River, and the Rocky Mountains to the floor occupants. The entire two million square feet of building space includes such amenities as indoor sky gardens, complementary retail businesses, and vibrant cultural venues.

The project also creates a public outdoor space in the center of Calgary, which was well received by the City of Calgary Building Department. The design process began in January of 2006, and construction on the tower started in the summer of 2007. The building is scheduled to be fully occupied by the end of 2010.

Other building characteristics include the following:

- 247 meters high (810 feet) with 59 stories.
- Tallest building in Calgary.
- 2nd largest building in Canada.
- Occupied solely by the EnCana Corporation.
- Total area of 180,000 square meters or 2 million square feet
- A two level retail lobby space.
- Pedestrian bridge connections to the City of Calgary enclosed PATH system.
- A five level below grade parking facility.

Figure 1. Rendered image of the “Bow” Project, Calgary (Courtesy of Foster + Partners, 2006)

“The Bow” project team consists of the following major contributors, as well as many others:

- Building Owner - H&R REIT through Center Street Trust
- Building Developer - Matthews Developments Alberta
- Building Tenant - EnCana Corporation
- Design Architect - Foster + Partners
- Executive Architect - Zeidler Partnership Architects
- Structural Engineer - Halcrow Yolles
- MEP Services Engineer - Cosentini Associates
- Constructor - Ledcor Construction Limited
- Structural Steel Trade - Supreme Walters Joint Venture

Structural Systems Description

As mentioned previously, the bow shaped EnCana Tower is composed of a unique diagrid lateral system and a composite gravity system that must blend peacefully into sustainable features such as the southern elevation full building height atrium space, three separate sky gardens, and elegantly address the beneficial curvature of the building exterior.

The following sections of this paper will address the gravity system design, the lateral system design, construction issues, and the major sustainability aspects of the project.

Gravity System

The building floor framing consists of structural steel beams with concrete on steel deck, or composite slabs. The gravity columns of the tower were structural steel.

Prior to the construction of "The Bow", most commercial high rise construction in Calgary utilized reinforced concrete or post tensioned concrete floor framing systems. These alternate concrete framing systems were considered, but ultimately were rejected due to undesirable effects these systems placed upon column size, construction time, and the aesthetic goals of the project.

The floor framing accommodated mechanical and electrical systems by utilizing a raised floor horizontal plenum. This system permits even distribution of air and heat transfer in between the raised floor and structural floor without concern for interferences. The structural depth needed only consider this raised floor, and the depth of overhead lighting and fire protection. This enabled the overall floor to floor height to be kept to a minimum, and lower than normal for composite floor system construction.

Lateral System

A number of lateral options were considered during the design phase of "The Bow" project. These systems included reinforced concrete core wall, structural steel shear wall, a hybrid system of core and outriggers, mega-diagonals through the tower interior, a rigid frame perimeter tube of closely spaced columns, and the chosen perimeter trussed tube in a "diagrid" form. The "diagrid" option was ultimately chosen for providing an important and unique architectural expression for the building, and because this system eliminated the need for an interior concrete shear wall, thus maximizing interior space.

This diagrid system consists of a perimeter diagonal grid which is composed of six story high diagonal elements across the north and south elevations of the bow shaped building. The "diagrids" are linked to each other through rigid link beams (or fingers) at each tip of the bow.

The "diagrid" perimeter framing lead to unique circumstances of building stability and diaphragm design as well challenging resolution of forces through the system. Both "diagrids" are curved to match the bow shape of the building. The north elevation "diagrid" is expressed along the glazed perimeter of the building. The southern diagrid is offset from the building floor diaphragms by a full height exposed atrium or plenum. This open atrium allows for some unique energy savings that will be discussed within the Sustainability section of this paper. This southern "diagrid" has limited tie back bracing frames to the overall building at levels 24, 42, and 54. These tie backs act in a sense as stabilizing outriggers and connect into the interior of the building at vertical braced frames surrounding the outlying stair towers.

The "diagrid" system takes advantage of the structural efficiencies of its natural curved form to reduce the overall required steel quantity when compared to a building with a conventional braced core or rigid frame perimeter tube structure.

The perimeter diagonals of the "diagrid" form equilateral triangles which are the primary elements for the gravity as well as wind and seismic load resisting systems. The "diagrid" node placement occurs every six floors up the face of the building. This triangular uniformity enables repetition of the perimeter glazing units.

With respect to the lateral system, this perimeter "diagrid" system with limited interior bracing towers saves approximately 20 percent of the structural steel weight when compared to a conventional moment-frame structure.

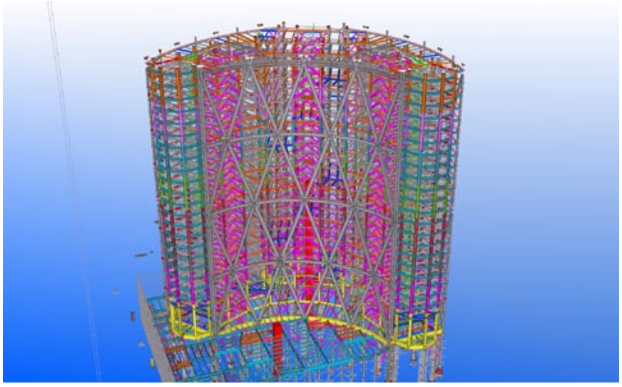

Figure 2: X steel model of lower elevation of the structure (Courtesy of Walters Inc., 2006)

The "diagrid" takes two unique forms, one on each elevation. On the north elevation of the building, the "diagrid" is generally hidden behind the exterior cladding of the building and is hidden by drywall construction within the office space. At the atrium screen wall that is offset from the building diaphragm is exposed to view from the interior office and garden floor areas.

Steel pipe sections (with and without infill concrete), steel box built up sections, steel plate rectangular sections, and built up steel plate triangular sections were all considered possible shapes for the "diagrid" framing. Ultimately, built up triangular plate sections were selected for design.

The fabrication and erection of the "diagrid" system had fewer complexities that a fully moment connected frame. This was due to well selected node points that enabled repetition of the components and connections. However, the exposure of the "diagrid" and its curved shape required a higher level of tolerance control within the fabrication process.

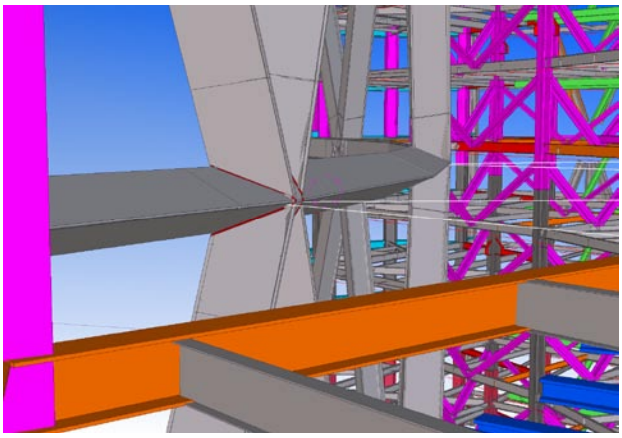

Figure 3: X Steel Model of a node detail within the atrium plenum (Courtesy of Walters Inc., 2006)

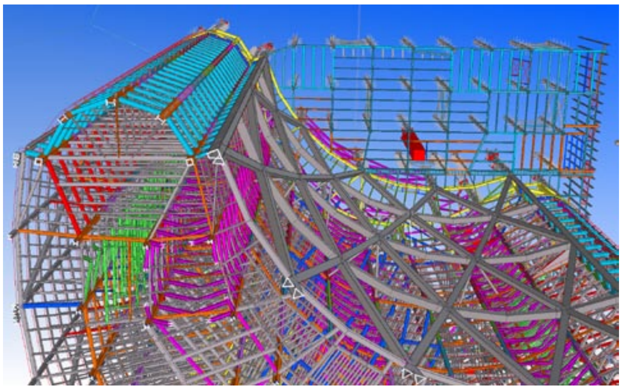

Figure 4: X Steel model of the curved offset atrium wall (Courtesy of Walters Inc., 2006)

Some other considerations of the lateral "diagrid" frame included moment transfer concerns on the triangular members during the building drift analysis. The solution was to consider moment amplification of the wind induced loads between the floors, and tie the diagrid into the two small bracing towers at discrete points so that these forces could be reduced.

Similar analysis of the offset atrium screen wall required special consideration of the unsupported length of the diagonal members. Fortunately the curved profile of the atrium screen reduces the effect of the un-braced system between the floors at this location.

Construction Items

The design and construction schedule requirements of the project were extremely aggressive, and required unique ways to think about constructability. The excavation and shoring of the basement area was released early in the design process to facilitate excavation of the over 20,000 square meters or 200,000 square feet in site preparation. This vast amount of excavation takes up time that the tower construction did not have. Therefore, it was evident that the tower work could not wait for the completion of the below grade parking garage. To solve the problem, the foundation columns were chosen to be constructed out of large pipe columns filled with high strength concrete and be installed directly to the deep foundations free-standing up to grade. A combination of temporary bracing and permanent bracing was designed to resist wind and construction related lateral forces. These pipe columns were filled with 85 MPa (12,000 psi) concrete.

The early start of the vertical steel erection enabled the tower floors to begin construction prior to the lower level slab and diaphragm completion. The tower steel was limited to topping out at approximately the 30th floor prior to completion of the lower level framing because of concerns about lateral wind load transfer into the main foundations.

This approach is sometimes called, "up-down construction". To achieve this construction approach the lowest lift of columns were augmented with tie-down anchors into a raft design for the lower level floors. The bracing located within the basement area was reinforced to support the building until such time as the permanent below grade shear walls and the ground floor diaphragm could be constructed. In some cases this temporary bracing was embedded within the final shear wall construction.

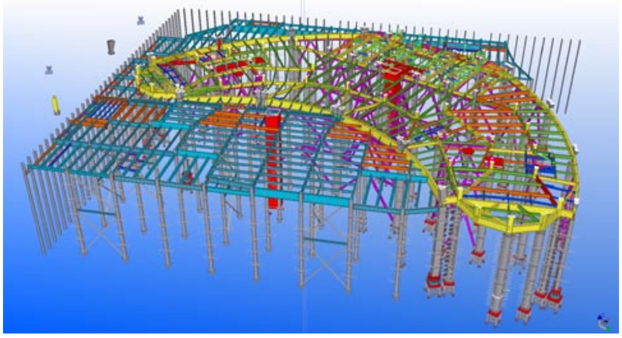

Figure 5: X Steel model of the ground floor framing and sub-grade vertical steel (Courtesy of Walters Inc., 2006)

A construction erection scheme was also implemented which advanced the construction of the office portion of the tower prior to the erection of the southern elevation atrium screen wall. This base structure could be used to fine tune the erection of the building. Unlike conventional structures with a reinforced concrete or structural steel core, the perimeter system of the “diagrid” did not have the advantage of a strong, central, erection base to which the perimeter framing could be anchored and adjusted. Also, the erection of the atrium screen wall would take longer than the erection of the office portion due to the lead time required for obtaining the node connections, and the fact that the atrium wall was offset approximately 10.2 meters from the edge of slab of the building, thus making work on both portions at the same time very difficult for the contractor. Therefore, only the north “diagrid” and the interior stair frames provided lateral stability for the building during construction. To augment the lack of bracing in the temporary condition, some temporary bracing was located adjacent to the rigid finger links at the ends of the bow.

This temporary bracing was designed to be removed and re-installed in the construction of the building, with the anticipation that it would be used three times through the tower height.

To achieve the erection of the atrium screen wall at a later date, temporary frames were constructed to span the atrium plenum at various levels as a means of stabilizing the entire wall. Similarly these temporary frames were removed and re-used as construction of the atrium wall progressed up the height of the building. Generally the atrium wall erection was approximately six stories behind the office construction. This delay in the atrium wall erection avoided some of the dead load creep from the office areas that could happen with a structure of this nature.

Considerations on the field connectivity of the “diagrid” node covered many aspects including; aesthetics, interface of mechanical electrical and plumbing disciplines, the field connection aspects of the structural steel, the shipping weight of the node, the fire protection of the connection, and the interface with the cladding. While bolted connections were preferred from a cost point of view, it was determined that the size and nature of the connections forces would require an unacceptable large connections from an aesthetic point of view. A compromise included detailing welded nodal connection for the first 24 floors (where the connections are most visible) and bolted connections above the 24th floor where the connection is least visible.

Sustainable Issues

A great deal of thought and design effort was placed on creating a progressive sustainable building within Canada. Basic consideration was given to create a space that paid tribute to nature. A public space at the base of the structure was created to invite interaction among city residents. Multi-story sky gardens were incorporated into the building at three separate levels to provide added green space. In addition, the overall building height was limited by the City of Calgary to prevent shadowing on the Bow River.

The design of the tower itself pushed sustainable ideas even further. Using the curving bow shape, wind loads were able to be reduced when compared to a rectangular building, thus reducing the required amount of structural steel. Extensive studies were also done to position the building in order to maximize sunlight within the office space. These studies partially helped determine the crescent like bow shape with the interior curvature facing southward. Using this interior curvature like a bowl that captures sunlight gave rise to the full height atrium space along the southern elevation. This atrium, or plenum type buffer zone, is designed to absorb the heat from daily sunlight and use it to partially warm the building much longer than conventional buildings.

The overall result is an estimated energy reduction of approximately 30% when compared to a conventional office tower. (Senay, 2006) At the same time the entire building benefits from more natural light, better quality space due to the sky gardens, and ultimately more enjoyment for people everyday.

Conclusion

“The Bow” project in Calgary succeeded in providing a unique environment for all people within and around the building. The tenant of the building, EnCana, will enjoy monetary savings for years to come because of the implementation of heat and light design efficiency features. The lateral structural system, despite unique design and construction challenges, achieved its aesthetic goals and will become a distinct architectural feature for the City of Calgary.

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