Diagrid on Display

Federal Center South Building 1202

By Daniel Riemann, P.E. and Jason Black, P.E., S.E.

Federal Center South Building 1202, the new headquarters for the United States Army Corps of Engineers in Seattle, Washington. Courtesy of Benjamin Benschneider.

This is the second article highlighting the innovative design features of Federal Center South Building 1202. "A Worthy Wager: The Innovative Use of Composite Concrete & Timber Floors on Federal Center South" was featured in the April 2013 edition of STRUCTURE.

The recently completed Federal Center South Building 1202, serving as the Seattle District Headquarters for the United States Army Corps of Engineers (USACE), is a state-of-the-art office building resulting from architectural, structural, and construction innovation and collaboration.

One of the key features that makes Building 1202 so innovative is the use of a diagrid system at the exterior wall of the structure. While the diagrid is a system used in many new buildings around the world, its use in Building 1202 represents a clever solution to meeting the specific requirements of this design-build project. Utilizing this unique structural system strengthens the building while reducing material costs and shortening the construction schedule. Building 1202 was planned, designed, and constructed in less than two and a half years, and stayed within the original $65 million construction budget.

In addition to being an effective solution to progressive collapse requirements, the diagrid played an important role during the competition phase of the design-build project and it was a significant part of the architectural expression and story of the building.

Canted building ends. Courtesy of Benjamin Benschneider.

Diagrid Defined

A diagrid system consists of sloping columns (diagonals) and spandrel beams (horizontals). The diagrid system for Building 1202 utilizes a 3-story module (full building height) with bolted connections between spandrels and diagonals. Effectively, the diagrid system is a multi-story truss with pin connections. This system creates an efficient and inherently redundant structure by carrying gravity loads to the foundation through multiple load paths.

Progressive Collapse Requirements

As a U.S. General Services Administration (GSA) project, one of the primary requirements for Federal Center South Building 1202 was that the structure be designed to resist progressive collapse in the event of a terrorist attack. Progressive collapse is the uninhibited spread of an initial local failure to other elements of the structure, eventually resulting in the collapse of the entire structure or a disproportionately large part of it. Examples of progressive collapse include the collapse of the Alfred P. Murrah Federal Building in Oklahoma City, when localized structural damage caused by an explosion spread throughout the gravity load carrying system, eventually resulting in the collapse of a large portion of the building.

Building 1202 is designed to the requirements outlined in UFC 4-023-03, *Design of Buildings to Resist Progressive Collapse*. The goal of this design document is to limit the number of casualties by ensuring that buildings have adequate inherent redundancy to

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Method	Description
Tie Force	Structural elements are designed and detailed as catenary elements to transfer loads through tension to undamaged portions of the structure.
Alternate Path	Structural elements are designed and detailed to bridge over compromised portions of the structure.
Enhanced Resistance	Shear and flexural capacity of exterior structural elements are increased to minimize the extent of initial damage.

resist catastrophic damage due to unforeseeable events. The requirements for progressive collapse design provided in UFC 4-023-03 apply only to buildings which are three stories or taller. This three story requirement is based on a maximum casualty threshold set by the UFC and not the mechanics of progressive collapse.

The level of progressive collapse design is based on the Occupancy Category (OC) and building function. Similar to the OC determined using the IBC, greater risk is associated with loss of structures of higher OC. This OC dictates which method of progressive collapse resistance is to be used in design. The three methods of progressive collapse resistance prescribed in UFC 4-023-03 are the Tie Force Method, Alternate Path Method, and Enhanced Resistance Method (see *Table*).

Traditionally, requirements for progressive collapse resistance have been met by utilizing moment frames or tie beams at the exterior of the building, or by increasing member sizes to provide enhanced resistance. However, for Building 1202, a diagrid was chosen as the primary collapse prevention system. The diagrid is supplemented by moment frames at the canted building ends.

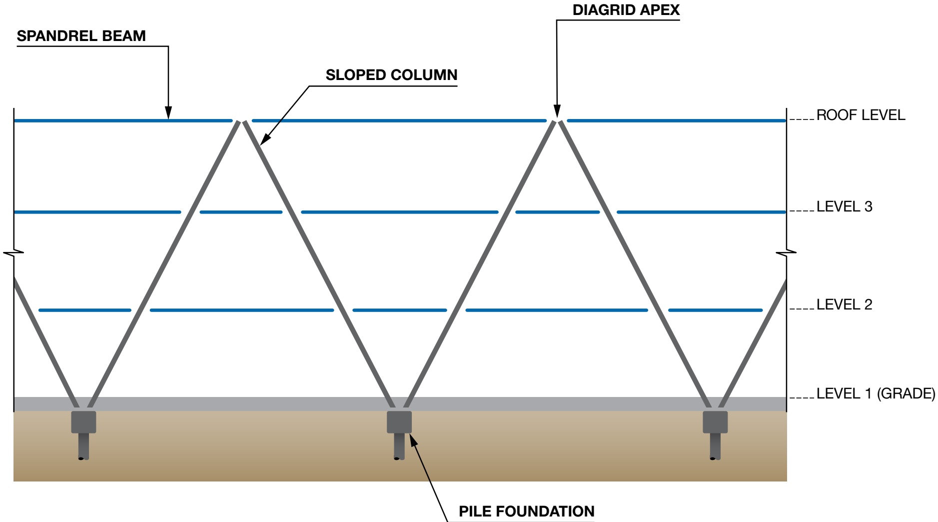
The diagrid system is an optimal solution for meeting collapse prevention requirements because it is essentially a multi-level truss, with the diagonal columns acting as the web members and the horizontal spandrels at each floor acting as the truss chords. The 3-story diagrid module used for Building 1202 creates a 3-story truss. Should any of the diagonal columns become damaged during an attack, the remaining portions of this truss can span over areas of localized structural damage.

Typical bolted connection.

Diagrid Use as Potential Lateral Force Resistance System

The sloped columns of the diagrid are representative of braces in a braced frame. For this reason, the diagrid system was initially explored for use as the lateral system of the building. However, there are drawbacks when utilizing the diagrid as the lateral system. A braced frame is designed to yield and dissipate energy during a seismic event. As the primary gravity load carrying system for the exterior of the building, the sloped columns could not be allowed to yield during a seismic event. Accordingly, the building code requires that systems acting as both the primary gravity and lateral force resisting systems be designed to remain elastic during a seismic event. Therefore, the response modification factor, R, is required to be in the range of 1.0 to 1.5 to achieve essentially elastic behavior.

At the schematic stage, the diagrid for Building 1202 was analyzed and designed for seismic forces associated with this level of elasticity. For an R of 1.0, member sizes were reasonable, only slightly larger than those required for collapse prevention, and maximum drifts were within the code requirements. However, the number of bolts required for connections increased significantly when design overstrength factors were considered. Using bolted connections as much as possible was preferred by the contractor in order to maintain a rapid fabrication schedule and save costs associated with full penetration welds. The labor costs associated with the increased number of bolts that were required to allow the diagrid system to also meet the lateral system requirements effectively mitigated the cost advantage of having a dual system. Ultimately the decision was made to rely on concrete shearwalls at the stair cores as the lateral system for the building, thereby allowing both the lateral and gravity systems to be optimized both in terms of performance and cost.



Diagrid system.

Diagrid erection.

Construction Savings

At the onset of the project, the team developed a progressive collapse resistance scheme utilizing moment frames, to compare to the diagrid scheme. This moment frame option consisted of 3-story moment frames at the building perimeter on a 22-foot bay module. From early studies, it was clear that the diagrid scheme provided the greater savings potential for the project in terms of foundations, materials, and fabrication.

Foundations

Building 1202 is located adjacent to the Duwamish River on extremely poor soils, requiring that the building be supported on driven steel pipe piles. These piles typically extend 150 to 170 feet below grade to reach a competent bearing layer. In the moment frame scheme, a single pile is required at each moment frame column, or every 22 feet. In contrast, the diagrid system utilizes a 44-foot bay module, meaning that pairs of sloped diagonal columns meet grade every 44-feet. Therefore, the moment frame scheme would have required twice as many piles at the perimeter of the building.

Material Savings

The diagrid system results in approximately 30% savings in steel tonnage as compared to a moment frame system. This savings is manifested largely in the spandrels, which become primarily tension/compression members when the diagonal columns become compromised. The spandrel beams in a traditional moment frame system need to resist much larger flexural demands in order to span over damaged columns, requiring larger, heavier spandrel sections.

Erection and Fabrication

Recognizing the old "time is money" axiom, KPFF worked with Sellen Construction to propose a simple "tilt-up" method for erecting the diagrids. In this sequence, pairs of sloped columns were fitted up while on the ground and welded together at the apex to form a triangular assembly, which was then tilted in to place. The horizontal spandrels were then flown in and bolted in to place. This sequence allowed the diagrids, and therefore the entire steel skeleton, to be erected in a relatively short amount of time.

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Project Team

Owner: General Services Administration (GSA)
Tenant: United States Army Corps of Engineers (USACE) Seattle District
Structural & Civil Engineer: KPFF Consulting Engineers
Contractor: Sellen Construction
Architect: ZGF Architects, LLP
Funding: American Recovery and Reinvestment Act (ARRA)

When compared to a moment frame, a diagrid system requires far fewer welded connections. For Building 1202, there are 19 apex connections where field welding is needed. Bolted connections are used at all other spandrel to diagonal column connections. By comparison, the moment frame scheme studied by the team would have required a total of 108 full penetration welds at all connections between spandrels and columns – more than five times as required for the diagrid system.

Architectural Expression

One of the key early design decisions by the project team was to have the structure of the building exposed to the western river-facing view as much as possible, to reiterate the Corps' mission statement of "Building Strong". The diagrid, by its very nature as a strong diagonal element that contrasts with the orthogonal lines of floors, walls, and windows, is a key element of this expression. The design team moduled the building so that the diagrid naturally ended with a backslope on the southwest corner and an outslope on the northwest corner as a counterpoint. These canted ends of the buildings create light filled office and conference room spaces with sweeping views of the Duwamish River. The diagrid is painted white throughout in order to assist in diffusing both natural and artificial light inside the building, but also to be prominently visible through the exterior glazing. The stainless steel skin of the building is peeled back at the main entry to fully expose the diagrid, creating a formal entry portal.

Conference room at canted end. Courtesy of Benjamin Benschneider.

The diagrid scheme also allowed the building's unique *Oxbow* form to be achieved, which drew inspiration from the historic meandering path of the Duwamish River adjacent to the site. Smooth transitions through the curved portions of the building are facilitated with the diagrid by utilizing a tangential variation at each floor line. This allows the exterior skin to easily transition through the corners of the U-shape, resulting in a smoother appearance. Although the use of sloping columns results in a small loss of floor area directly under the column, the diagrid creates unique and dynamic interior spaces.

Summary

The diagrid represents an effective solution to progressive collapse requirements and helps create an iconic identity for Building 1202. The success of this design-build project is a tribute to the early-on collaboration between the architect, engineer, and contractor.▪

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