WSP Uses Bentley's Structural Software to Optimize Unique Geometric Design of The Shard at London Bridge Quarter

RAM® Software Enables Design Time and Construction Cost Savings for The Shard

Project Summary

Organization:
WSP

Solution:
Buildings

Location:
London Bridge Quarter, London, United Kingdom

Project Objectives:

- Maximize use of space in 1.2-million-square-foot skyscraper, the tallest in Western Europe
- Minimize construction cost for client
- Optimize safety of 1,016-foot pyramid that has 72 habitable floors
- Achieve zero-waste requirements and "Excellent" BREEAM rating

Products used:
RAM® Structural System
RAM® Concept

Fast Facts

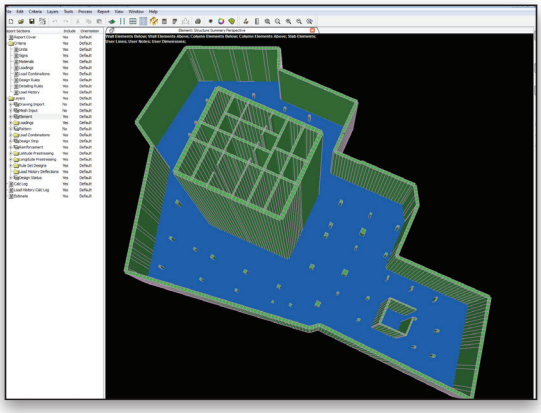
- WSP won the contract in 2004 for structural design by first providing value engineering services for existing schema
- Bentley products enabled engineers to optimize the structural design and achieve project goals
- The Shard utilizes a unique hybrid framing system: post-tensioned levels over steel-framed levels

ROI

- User-friendly, collaborative structural software achieved streamlined workflows, avoided duplication in manual tasks, and improved data and design quality
- Construction cost savings included 50 percent reduction in steelwork frame tonnage

Complex Structure Presents Multiple Design Challenges

Soaring 95 stories above the South Bank of the Thames, The Shard at London Bridge Quarter is the tallest building in Western Europe. As its name suggests, the building is comprised of multiple glass shards that merge to form an elongated pyramid, creating a complex structural form with many design challenges. The skyscraper was also designed for sustainability, using recycled construction materials and targeting an "Excellent" BREEAM rating. The developer, Sellar Property Group chose WSP, a global design, engineering, and management consultancy to deliver a technical solution for The Shard that was financially viable. Using Bentley's RAM® structural analysis and design software products, WSP reduced steelwork frame tonnage from 200 kilograms per square meter to 100 kilograms per square meter – just one instance of the value engineering achieved.



Analysis and design of The Shard's raft foundation in RAM Concept.

The slender, 1,016-foot pyramid is a multi-use, vertical city with commercial offices, international restaurants, a five-star Shangri-La hotel, exclusive residences, and public viewing attraction – The View from The Shard – offering 360-degree, 40-mile views. With a location adjacent to the London Bridge multi-transit station, which averages more than 54 million commuters per year, developer Irvine Sellar conceived The Shard as a way to advance the British government's push for high-density development at transit nodes. The Sellar Property Group retained Italian architect Renzo Piano Building Workshop to design the 1.2-million-square-foot skyscraper as an "expression of the energy" of central London.

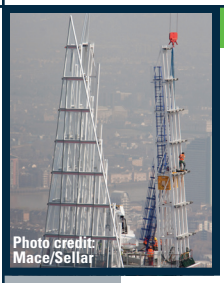
Design of the $729 million (shell and core) skyscraper began in 2000 by Renzo Piano for the Sellar Property Group. WSP, which has a strong history of structural design work on signature skyscrapers such as the 1,776-foot Freedom Tower in New York City, was retained initially in 2003 for peer review and value engineering for a schema developed by another engineer. "We basically won the confidence of Sellar when we did that review," said WSP technical director and Shard chief project engineer Rodolfo Giannini. "We were able to demonstrate to the client that we could save on the structural costs, and they employed us as structural engineer." WSP used Bentley's RAM structural analysis and design software products to meet design goals for maximum space, minimum construction cost, and optimum safety on this project.

Design Challenges Include Mixed-use Occupancy and Non-repeating Geometry

The multi-use nature of The Shard posed one of the greater challenges for the design teams. While the space within high-rise buildings typically serves one primary function, The Shard's 72 habitable floors form a diverse vertical city.

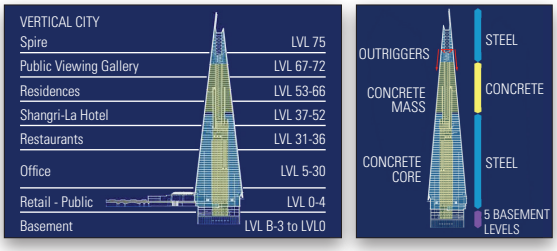
The architect's plan designated floors 4 through 28 for offices, 31 through 33 for restaurants, 34 through 52 for a 200-room hotel, 53 through 65 for residences, and 68 through 72 for a viewing gallery. WSP's challenge was to reconcile the need for entirely different floor framing systems necessary for the residential and office floors.

The non-repetitive nature of the floor plan geometry posed another serious challenge for WSP's designers. While many high-rise buildings derive their exterior geometry from a mathematical equation, or vary in an easily predictable manner along the height, this was not the case with this project. Rather, The Shard is comprised of an array of glass shards that merge to form an elongated pyramid, with little vertical geometric continuity. "Each floor plan is different, but in a different way," explained Giannini. "This kind of random



WSP capitalized on RAM's steel beam auto-design capabilities to reduce the steel tonnage to half of what it was in the original schema.

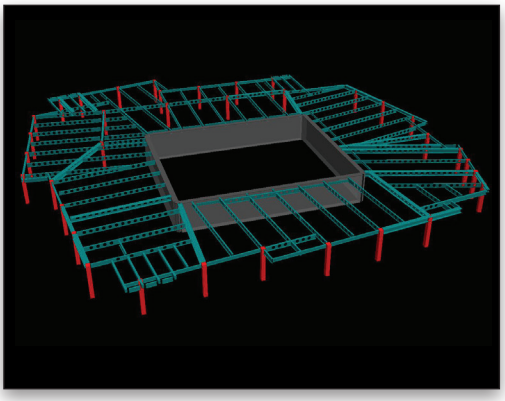
geometry was the most challenging aspect because it dictated where everything else was placed: where columns needed to be discontinued and where transfer conditions were needed."



WSP's drawings of The Shard's basic uses and materials in different portions of the skyscraper.

Structural Design Goals Achieved Using Hybrid Framing Systems

To meet the design goals for this radical structural form, WSP devised a hybrid approach that stacked a series of different floor framing systems on top of each other. Composite steel floors were used for the office floors and the public spaces at the lowest levels of the hotel, while post-tensioned concrete floors were used for the hotel guest rooms and residences. Finally, a steelwork spire with a public viewing gallery comprised the highest extent of the structure. The design provided a high-level of structural robustness, with a number of safety-related innovations, including state-of-the-art blast protection and structural fire engineering design. The unusual layering of concrete levels on top of steel levels also had beneficial dynamic effects on the structure. Due to the additional mass and stiffness of the concrete-framed levels, the expected lateral acceleration due to wind significantly reduced sway at residential levels.



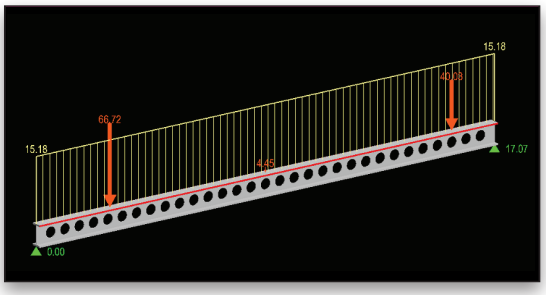
Design of level 21 steel framing system in RAM Structural System.

WSP also achieved goals beyond the design of the fundamental structural system, including exceptional environmental credentials. Using sustainable materials and meeting zero waste requirements, there was no overdesign allowed. WSP worked together with the wider design team, including associate architect Adamson Associates and mechanical, electrical, and plumbing (MEP) engineer Arup, to achieve maximum floor area and minimum structure. As one example of this, the schema done by the original engineer had 200 kilograms per square meter of steelwork frame. WSP reduced this by half to 100 kilograms per square meter through multiple design iterations and optimizations. Sustainability was also addressed in this area by using steel with a recycled content of approximately 55%.

Bentley's RAM Software Enables Design Optimization

Choosing the right structural design software for this highly complex job was simple for WSP. "When we have a steel frame, we use Bentley's RAM Structural System by default," Giannini said. "When we have a reinforced or post-tensioned concrete frame, we use RAM Concept. This software is our natural choice as it automates our most time-consuming design tasks and produces the most efficient designs.

The Shard commercial office space floors required a distribution zone below the ceiling for services, as well as open floor space. The ideal material for this requirement was composite steel beams supporting a concrete slab. WSP used RAM Structural System to design the composite steel floor framing for the offices and portion of the hotel between levels 3 and 40, reducing the steel tonnage to half of what it was in the original schema. RAM's steel beam auto-design capabilities and third-party cellular beam plug-in allowed WSP to evaluate various framing alternatives and identify the superior option. The software's characteristic method of distributing gravity loads over the entire structure with utmost precision, followed by member optimization to an exhaustive list of strength, serviceability, and code requirements, resulted in a design in which each element supported the exact load assigned to it, without any excess material.



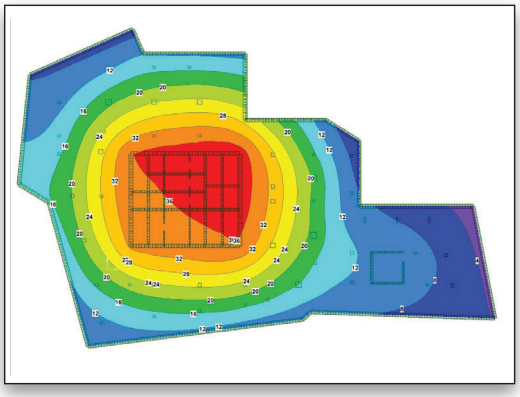
WSP's use of RAM's cellular beam design feature greatly reduced The Shard's steel tonnage.

That's where RAM Structural System is helpful, because it performs the optimization process that would take ages for us to do by hand, beam by beam," Giannini said. "Changes could be accommodated and the floor redesigned and accuracies checked in a matter of minutes, not hours or days."

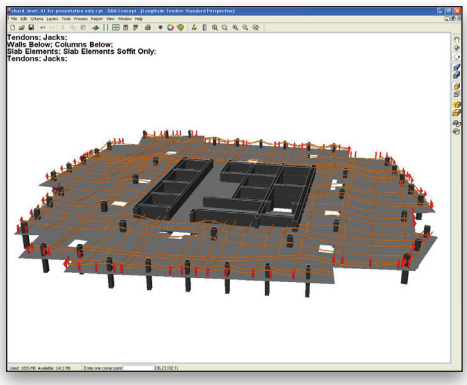
Bentley's RAM Concept was also used in multiple capacities on The Shard project. The entire building is founded on a concrete raft supported by 50-meter deep piles. RAM Concept's mats module was used to assess the stability of the raft system under the loads

"When we have a steel frame, we use Bentley RAM Structural System by default. When we have a reinforced or post-tensioned concrete frame, we use RAM Concept. These are our natural choices because we know that they do the job."

— Rodolfo Giannini, technical director, WSP



RAM Concept color-coded plot of vertical raft deformation.



RAM Concept view of tendon system at level 41.

introduced by the superstructure, determine the required thickness of the mat, and identify the required steel reinforcing. RAM Concept's post-tension design capabilities were used not only in selecting the post-tensioning configuration and conventional reinforcing, but also in determining at which level the transition from a steel-framed floor to a post-tensioned floor should occur. With consideration of the building's tapered geometry, WSP determined that level 41 was the optimum location to switch from steel to post-tensioned floors. RAM Concept calculations showed that beginning with level 41, the 200 millimeter slab could span from the perimeter columns to the center core for the desired open floor plan without requiring intermediate columns.

Achieving the optimal design solution required multiple iterations of the structural models – a process that was simplified through the use of Bentley software. "Every model that we did, we did at least 10 times, and not because we were inefficient," Giannini said. Changes came from multiple sources due to the complexity of the project. WSP dealt with changes from the architect, client, services engineer, and even changes in the predicted structural loads. Design wind loads were revised after wind tunnel test results warranted changes to the design wind forces, which resulted in adjustments to the structural system for lateral stability.

ROI Achieved Through Bentley's RAM Software

Bentley software, namely RAM Structural System and RAM Concept, are embedded in WSP's way of working. "We know exactly what to do with those two software programs," Giannini said. "As soon as there is a new building, a new project, we know 'this part is with RAM Concept, that part is with RAM Structural System.' Every engineer in the company knows how to use these two software applications, and how to push them to their limits to achieve efficiency in our design. That is where we get the value from them."

WSP cites the user-friendliness of RAM Structural System and RAM Concept as the primary appeal of the software to their organization. On The Shard project, where the design phase lasted nearly five years, engineers came and went. Because of RAM software's ease of use, new engineers were able to immediately start where the previous engineers had left off, ready to collaborate with the rest of the team. Bentley's comprehensive software also streamlined workflows, avoided duplication in manual tasks, and improved data and design quality.

The Shard construction rises above London.

The Shard atop London Bridge Quarter.

Given The Shard's unique blend of irregular geometry, multi-use occupancies, and dual materials, optimization of the structural design using the RAM product line produced valuable savings. Construction of The Shard commenced in 2009. The skyscraper was formally inaugurated on July 5, 2012, and is scheduled to officially open to the public in February 2013.

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