Steel truss outrigger systems are an efficient structural response to increased urbanization and the resulting bigger (and hopefully better) buildings.

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RIGGED FOR THE FUTURE

BY JOE DARDIS

THE EFFECTS OF URBANIZATION have given rise to new, more robust skylines across the country.

In the first decade of the 21st century, urban population growth outpaced overall national growth by 2.4%, according to the U.S. Census Bureau. How are cities accommodating this higher population density? By building bigger. Since 2002, square footage per project has increased by more than 90%, which translates to taller buildings and larger floorplates.

As high-rises and other urban buildings continue to grow in height and exterior surface area, demands on their lateral systems are increasing significantly. One method for meeting these demands is to incorporate a steel truss outrigger system, which is highly effective in reducing drift, faster to erect than core-only solutions and adjustable in terms of height. While this approach isn't new, today's higher-strength materials and fabrication and erection technologies make it a more efficient option than ever.

In a steel truss outrigger system, the trusses extend from a steel braced frame core to columns located typically at the exterior of a building. The axial strength and stiffness of the exterior columns are mobilized by the truss, which restrains rotation of the core and converts part of the moment in the core into a vertical couple at the columns. In other words, when the core tries to bend, the truss(es) act as lever arms that directly transfer axial forces into the perimeter columns. The columns then act as struts to resist the lateral deflection of the core.

Following this design philosophy, the increased stiffness provided by the outrigger system will result in a drastic reduction of lateral deflection (drift)—a reduction that can pay huge dividends. As buildings get taller, the sizes of the lateral members must increase, primarily to control drift. Since the outrigger system is so effective in drift reduction, the designer gains the ability to reduce tonnage in the lateral columns and braces throughout the height of the building, while only adding comparatively less tonnage in the trusses.

Location, Location, Location

The terms *hat* and *belt truss* are typically used to describe outrigger trusses at certain heights of a building. A hat truss is typically placed at the highest level, while a belt truss (typically used as a "virtual outrigger") is typically placed anywhere from one-third to two-thirds of the way up the building height; sometimes, hat trusses may be combined with one or multiple belt trusses in taller buildings. Additionally, the height of the trusses can be single-story or extend to multiple levels, depending on bay geometry, floor height and whatever makes the most sense in order to fully engage the outriggers.

In determining where in the building to place the hat and belt trusses, the design team has the opportunity to be creative and experimental. For starters, hat and belt trusses aren't necessarily both required for an optimized design. One hat truss or one belt truss, a combination of the two or multiple belt trusses at different heights are all possible solutions. Building height, geometry, magnitude of lateral loading and architectural layout should all be considered in order to locate and maximize the effectiveness of the outrigger trusses and provide architectural freedom of expression.

The magnitude of the overall drift reduction will be a function of the number of trusses, truss depth and their location(s) in plan and height. Generally, when using a hat truss only, overall drift can be reduced by about 50%. If a single truss is used at around halfway up the building, overall drift reduction increases to roughly 60%. Additional trusses will result in additional reductions in drift, with the percentage of reduction decreasing by around half of the reduction provided by the previous truss. When trying to determine the optimal height placement of an n-truss building, a good rule-of-thumb calculation is to place trusses at the $1/(n+1)$, $2/(n+1)$, up to the $n/(n+1)$ height location. It is good practice to first determine what your drift is without the outrigger trusses and then determine the fractional amount of drift that needs to be decreased. Trusses can be

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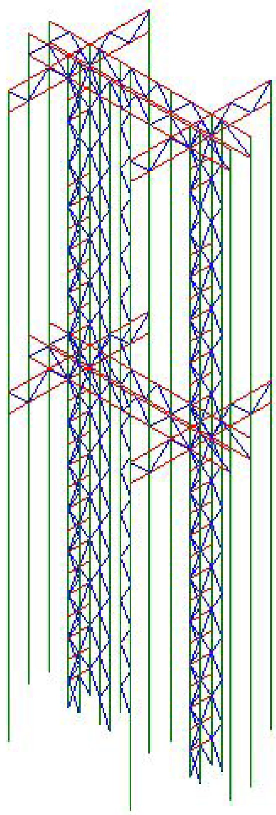

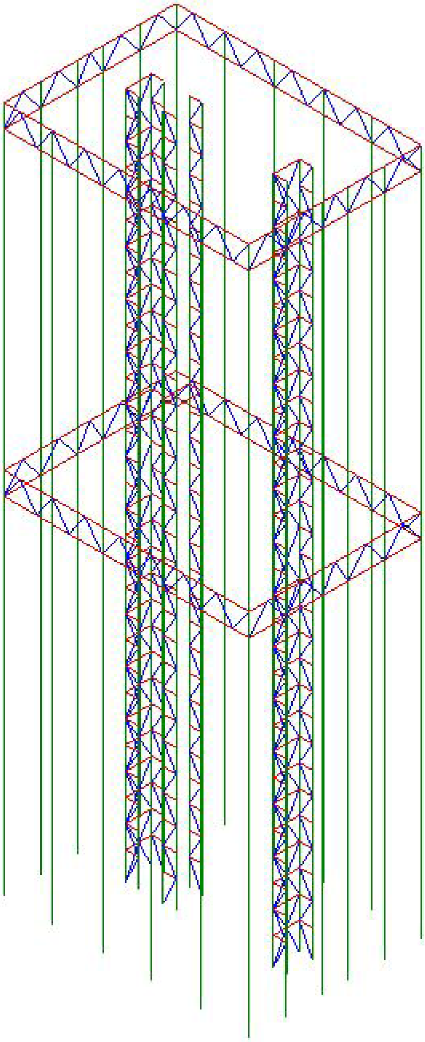

▲ A conventional outrigger system.

➤ A virtual outrigger system incorporating a hat truss and a belt truss.

added incrementally until the drift requirement is satisfied, at which point the designer can go back and start reducing member sizes outside of the truss zone. Additionally, virtual work optimization techniques are often useful in guiding the engineer on how to most efficiently distribute loads and optimize member sizes.

One common practice is to locate the outrigger trusses at the mechanical level(s) of the building. As mechanical levels typically don't require the unobstructed space that an office or apartment floor plan would, trusses can span across the entire floor plate without disruption. In addition, mechanical levels are often double-height spaces and therefore can accommodate a deeper truss. Another alternative is to align corridor walls with the trusses. Early coordination between the architect, engineer and other relevant parties can allow the design team to align door openings under braces. The trusses can be hidden from view and still provide total functionality to the space. Regardless of the approach taken, early collaboration will surely provide for a more optimized and economical solution.

Don't like that? Try this!

Steel is adaptable, and in the absence of a mechanical level or an ideal layout for a conventional outrigger system, a virtual outrigger can be a great solution. In a virtual outrigger system, the trusses are not directly connected to the core, yet the same concept of moment transfer from the core to elements outboard of the core still applies. Floor diaphragms are used to transfer moment in the form of a horizontal couple from the core to the trusses. The trusses then convert the horizontal couple into a vertical couple in columns outboard of the core.

With a steel braced frame core, transfer of forces between the core and the floors can be achieved through shear studs on horizontal frame members. As many modern-day buildings use slimmer floor slabs that may not be as stiff, the designer may also want to consider using horizontal bracing beneath the floor to transfer the load. This would prevent stiffening of the slab at particular levels and irregularity in floor construction.

Virtual outriggers also have greater flexibility in location. Since a conventional outrigger is typically located at a mechanical level, it is not necessarily in a position to completely opti-

Courtesy of Gerard Nieblas

Wilshire Grand, L.A.'s tallest building, incorporates an outrigger system using a belt truss (though not a braced core). You can read about the project in "West Coast Boast" in the February issue, available at **www.modernsteel.com**.

mize its stiffening potential. A virtual outrigger is typically not subject to these same constraints and therefore can be placed at the height of maximum effectiveness. Since a virtual outrigger does not typically produce as large of a stiffness increase as a conventional outrigger does, maximizing location effectiveness can help offset this.

But wait, there's more!

A steel core and outrigger system can do more than just increase stiffness and reduce drift. There are some great secondary benefits as well. In a core-only tower, the relatively short distance between resisting elements results in low torsional-stiffness. (If your building model animation has ever looked like it is taking an aerobics class when subjected to wind load, then you may be familiar with this problem.) Incorporating an outrigger system, particularly at the perimeter, can provide a significant increase in torsional stiffness and reduce some of that twisting and turning.

Outriggers can also be helpful when progressive collapse needs to be considered for a project. If there is a need to analyze the effect of the sudden loss of a local member, outriggers can provide alternate load paths. In cases where perimeter columns are engaged by belt trusses, loads from floors above a failed perimeter column could be supported by the upper column, acting in tension, and then be transferred through upper belt trusses to adjacent columns. In another case, loads from floors above a failed core column could be shared by perimeter members through outriggers.

Finally, big steel outriggers look cool! Designing an outrigger system at a building's perimeter has been used as a form of artistic expression by many architects. If you have big muscles, why not show them off?

The high-rises of today and tomorrow will require increasingly stronger bracing, and steel truss outriggers are a great option. Knowing the advantages of these systems and how to get the most out of them will ensure that the sky is the limit on your next project. ■

Thinking about an Outrigger?

Do you want to learn more about steel braced frame core and outrigger systems, or are you considering one for your next project? Contact AISC's Steel Solutions Center. We'll be happy to provide you with any information and even help you develop a conceptual design. We can also put you in touch with an AISC member fabricator or erector for any cost-, schedule- or erection-related inquiries. You can reach us at **solutions@aisc.org** or 866.ASK.AISC.