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Structural Flex: How One Girder Does the Heavy Lifting

A cantilevering transfer girder helps the corner of Houston Methodist Hospital's new Centennial Tower float over the ambulance drive and critical underground utilities.

By Yavor Cekov, PE, Kara Hartleib, PE, and Andrew Zucker, PE

Centennial Tower, Houston Methodist Hospital's new patient bed tower, is currently under construction in the Texas Medical Center. It is slated to partially open in early 2027 and to be fully operational in early 2028. The tower is a 26-story, 420-foot-tall, pan-formed concrete moment frame with concrete shear walls as its primary lateral system. The structure also includes two basement levels, three mezzanine levels, and multiple rooftop penthouses. Page, now Stantec, led the design team, with Walter P Moore serving as structural engineer of record, and Vaughn Construction as the general contractor.

Challenges and Solutions

One significant structural design challenge for this project was the need for the northwest corner to be free of both a ground-level column and a below-grade foundation element (Fig. 1). This corner of the building houses a vehicular drive and emergency vehicle parking, as well as sidewalks and landscaping. Further complicating matters, an existing underground utility line in this vicinity must remain operational; it could not be disturbed. To properly accommodate the architectural vision for the ground floor and existing conditions, the column supporting the northwest corner of the building's upper floors needed to be transferred. This condition made for a long cantilevering section at the perimeter and an even greater cantilever length where upper floors slightly overhang lower floors (Fig. 2).

Headspace requirements below the first elevated floor over the drive,

Project Team

Owner: Houston Methodist Hospital, Houston, Texas
Structural Engineer: Walter P Moore & Associates, Houston, Texas
Architect: Page, now Stantec, Houston, Texas
General Contractor: Vaughn Construction, Houston, Texas
Concrete Supplier: Keystone Concrete, Houston, Texas
Post-Tensioning Supplier: Suncoast Post-Tension, Houston, Texas

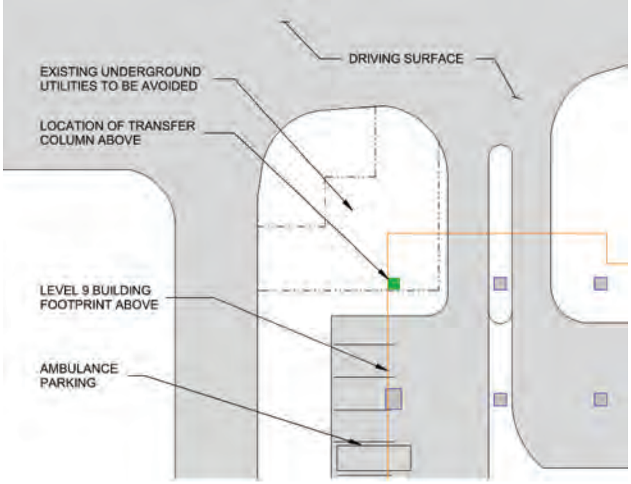


Fig. 1. A column-free northwest corner was needed to accommodate the drive and ambulance parking, and to avoid the underground utilities.

Fig. 2. The northwest corner of Centennial Tower cantilevers over 50 feet. (Photo courtesy of Vaughn Construction.)

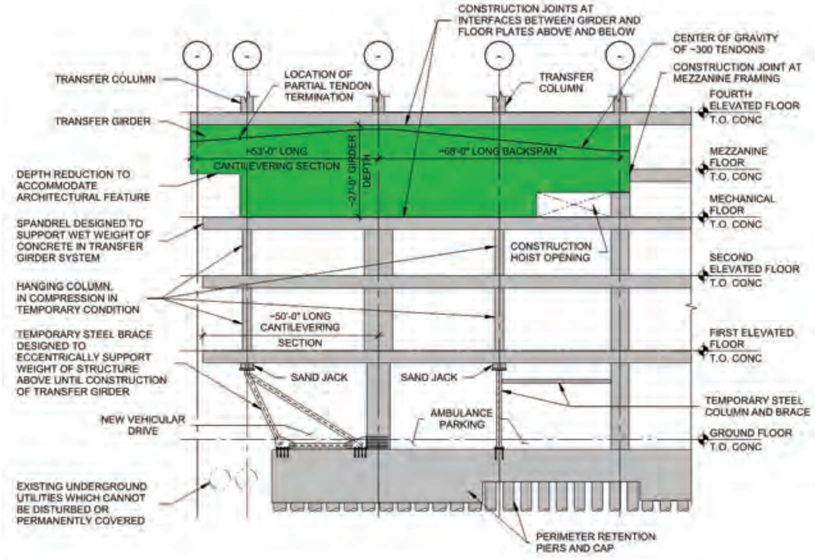


Fig. 3. The perimeter frame along the west side includes an upper level transfer girder.

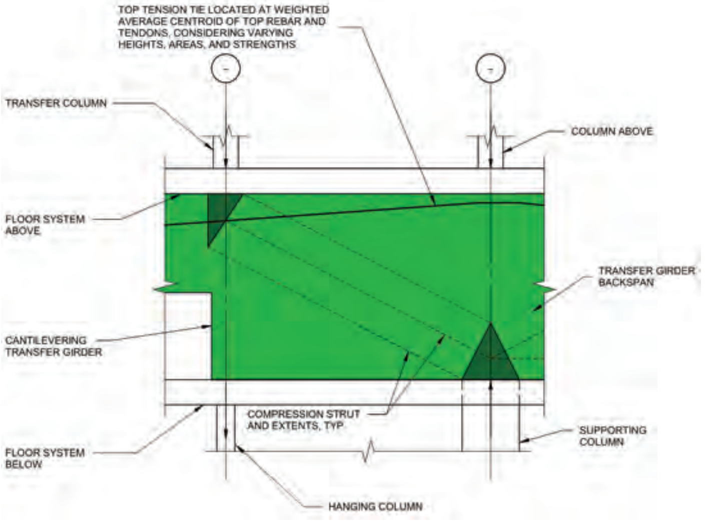


Fig. 4. Portions of the cantilevering transfer girder were checked using strut-and-tie modeling.

coupled with the needed transfer girder depth, prevented the use of a traditionally located transfer girder at the level directly above the drive. However, a mechanical floor a few levels higher in the building quickly proved to be a suitable location for the deep transfer girder (Fig. 3). Plans for the upper mechanical space already included a tall story height to fit equipment, and windows or vents were not needed along the west edge, making it the perfect home for a 27-foot deep, 53-foot long cantilevering transfer girder, with a correspondingly massive 68-foot long backspan that supports a transfer column of its own. Transferring the column at the backspan was also needed programmatically, and it provided a very helpful natural balance to the load on the cantilevering end, reducing uplift in the backspan.

Additional geometric challenges included a depth reduction at the end of the cantilever to accommodate a cladding setback, as well as a depth reduction in the backspan to allow an opening for construction access at an exterior hoist. The depth reduction for the cladding setback is fortunately well located with respect to maximum expected shears and moments (or, from an alternative perspective, locations of struts and ties). The location of the access opening had some flexibility, so the design and construction teams were able to coordinate a similarly favorable spot for it in the backspan.

Analysis, Design, and Detailing

The transfer girder system, which was initially sized using the analysis and design software ADAPT-PT, is composed of normal-weight concrete with a specified compressive strength of 8,000 psi. It is post-tensioned to reduce congestion and help control deflections at the cantilevering end. Although allowed to enter the transition region between uncracked and cracked behavior, i.e., "Class T" per ACI 318-14, the tendon force and profile still provide enough lift to greatly reduce net deflections. Discontinuity (D-) regions were checked outside of ADAPT-PT for deep beam behavior using a strut-and-tie model that includes the effects of the tendons and the mild reinforcing working in parallel. The tendons drape, whereas the top reinforcing extends horizontally at a constant elevation along the top of the girder (Fig. 4). Additionally, prescriptive deep beam requirements of ACI 318 were followed.

Approximately three hundred 0.6-inch diameter, 270 ksi, ASTM A416, low-relaxation post-tensioning tendons replace what would have been a much greater area of rebar had the girder been only mildly reinforced, greatly enhancing the constructability of the system (Figs. 5 and 6). Initially, 0.5-inch diameter tendons were specified. The team at Suncoast Post-Tension suggested the 0.6-inch substitution, which reduced the total number of tendons by approximately 30 percent. This greatly helped to

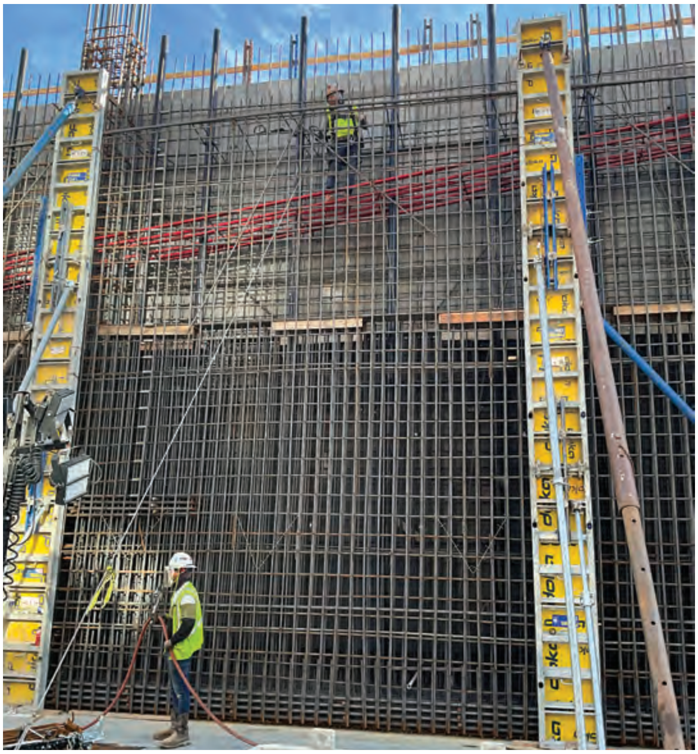


Fig. 5. Walter P Moore worked closely with Suncoast Post-Tension to determine the exact tendon layout.

Fig. 6. Careful coordination and placement of rebar and tendons helped mitigate congestion. (Photo courtesy of Vaughn Construction.)

Fig. 7. Temporary supports were required during construction. (Photo courtesy of Vaughn Construction.)

manage congestion, especially at anchorages, even in spite of the fact that required anchorage hardware for 0.6-inch tendons is larger than that for 0.5-inch tendons.

At the controlling location (the cantilever's first supporting column), well over half the flexural capacity is provided by the tendons. About one-third of the tendons terminate at the depth reduction in the cantilever to avoid overstressing the reduced-depth section. Tendons were stressed from both directions and anchored in multiple layers in order to fit all anchor plates. Five layers of #11 mild reinforcing rebar lie along the top of the transfer system at the controlling location, and face bars are tightly spaced in accordance with deep beam requirements. To reduce congestion, Walter P Moore set the tendon drape such that it falls completely within the outer rebar cage, below the top layers of rebar. Additionally, continuous rebar was spliced using couplers, and the construction team chose to replace hooks at ends of rebar with terminators.

Construction Sequencing

The transfer girder's location higher up in the building means it not only has transfer columns posting down to it, but also columns below that hang from it. As a result, special consideration of the construction sequence was warranted for the lower (hanging) floors.

The hanging columns experienced temporary compression while supporting the weight of the partial structure above until the transfer girder was ready to do the work. Walter P Moore analyzed and incorporated this action into the design via staged construction cases using the structural engineering software ETABS.

The staged construction analysis also yielded the expected system deflections at various steps in the process. Vaughn Construction monitored as-built deflections throughout the construction process, which were compared to predicted deflections to ensure the structure was behaving as expected. The observed deflections tracked the predicted deflections reasonably well, especially in early stages. As construction progressed, observed deflections were smaller than predicted, likely because assumptions made in design tend to be conservative.

Temporary steel shoring and bracing was provided from the foundation level to the first elevated floor directly below the hanging columns (Fig. 7). In the backspan location, the temporary support could be placed vertically and was therefore essentially a steel column. However, at the cantilever end the temporary support had to slope to bridge the gap between the foundation location and the location of the transfer column above. As a result, it was more complex with multiple components (basically a leaning steel column with a neighboring tension diagonal to stabilize it and a horizontal strut between them just above the foundation). These temporary supports had to be kept in place until the tendons in the transfer girder had been stressed and its concrete reached an acceptable percentage of its specified strength (Fig. 8).

The tendons were stressed all in one stage not only to avoid periodically circling back to restress, which could have been difficult as construction of the surrounding intermediate mezzanine level progressed, but also to provide a sizeable lift to the transfer girder prior to removal of the temporary support. Transfer girder bottom reinforcing was sized to handle the single-stage stressing.

The project team engaged Walter P Moore's construction engineering group to design sand jacks that sat atop the temporary steel supports and enabled a slow transfer of load to the transfer girder system above, thereby simplifying removal of the temporary supports. However, the stressing of the tendons actually lifted the cantilevering end enough to almost fully relieve the load in the temporary steel support below it even before any sand was released from the sand jack.

Additional Considerations

Because the transfer system is post-tensioned, the full height between the floor systems above and below was poured continuously without any horizontal construction joints (Fig. 9). A horizontal construction joint within a post-tensioned member, especially a joint with tendons sloping through it, could cause unwanted shears and possibly some degree of slip at the joint. Walter P Moore designed the spandrel beam within the floor system below the transfer girder to support the wet weight of concrete

Fig. 8. The temporary supports were removed once the upper level transfer girder was ready to support the load.

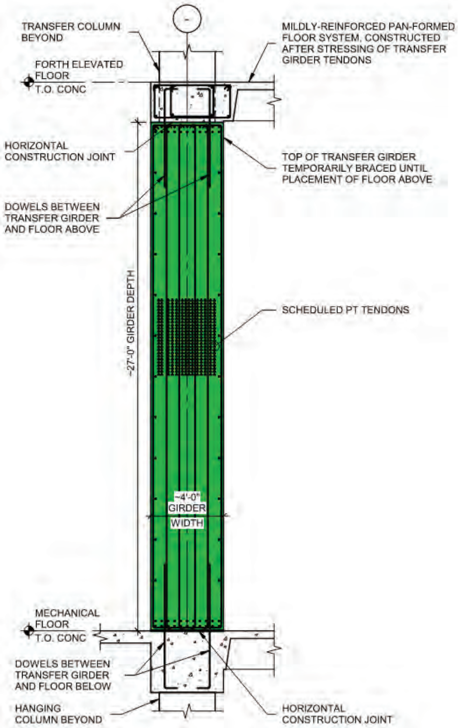
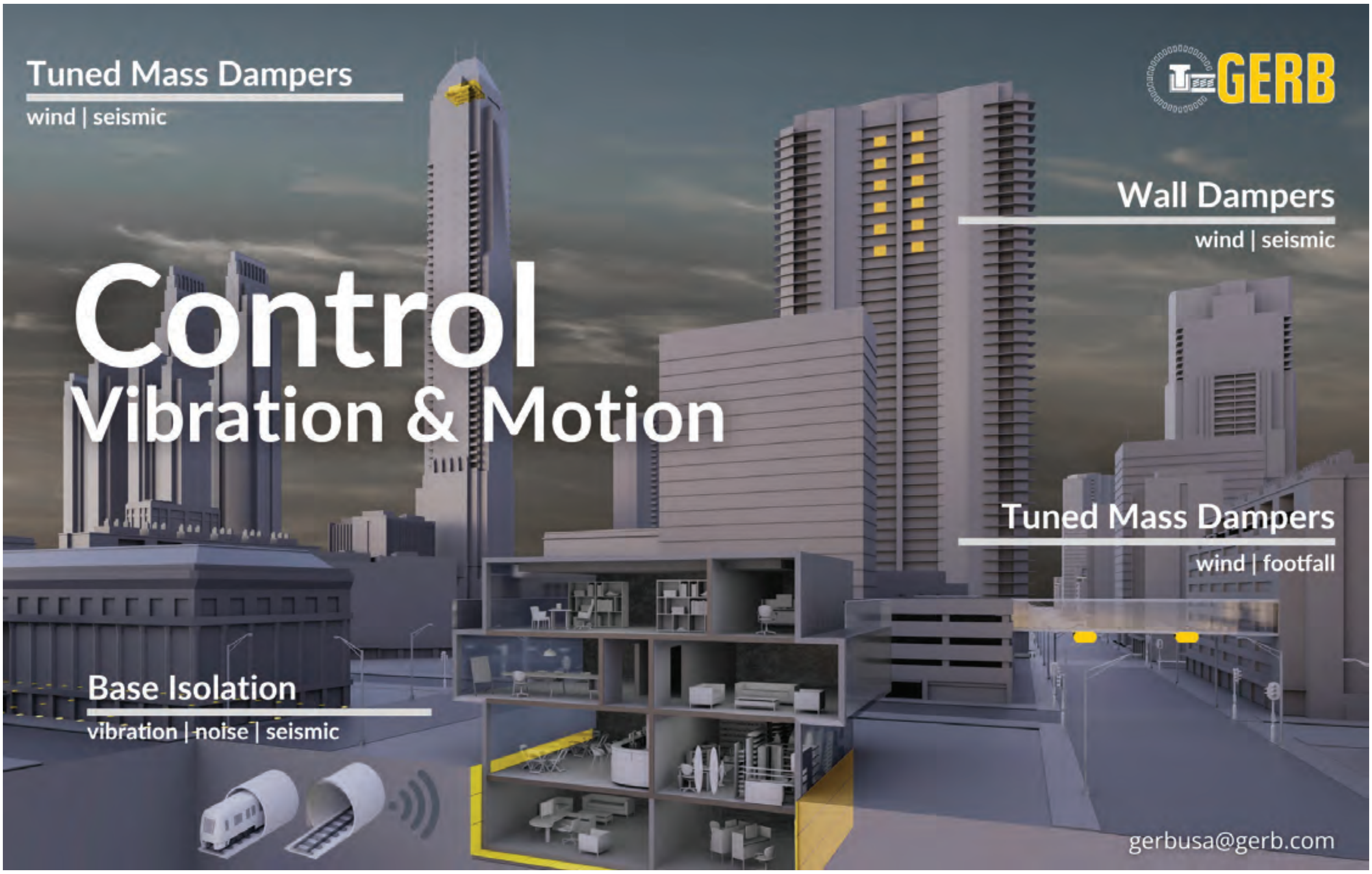


Fig. 9. The cantilevering transfer girder is sandwiched between two floor plates.



of the transfer girder, which amounted to about 16 kips per linear foot, along with its formwork.

Considering both the cantilever and the backspan, the transfer girder system contains approximately 400 cubic yards of concrete. Such a large volume of concrete qualified as a mass concrete pour, and therefore measures were taken to ensure quality of concrete. Keystone construction created two mock up samples of concrete using the intended concrete mix. The concrete temperature was measured during hydration at several points along the depth of the mock up and temperature curve was created based on these measurements.

With the nearly 4-foot thick transfer girder system sandwiched between two floor plates, it could easily act as a massive shear wall inserted for one story within the building mid-height, causing detrimental shear reversals in the shear walls and large associated forces in the connecting diaphragms. From a lateral system standpoint, the transfer girder would ideally be isolated from the floor systems above and below it. However, some connection is needed for lateral and torsional stability of the transfer girder system itself. Also, from a constructability standpoint, it is easiest to pour the girder directly over the floor plate below and to pour the floor plate above directly onto the girder. Detailing the interfaces between the transfer girder and floor plates had to be done in such a way as to balance these conflicting concerns. The approach taken was to avoid complete isolation, but to provide light dowels at the interfaces to limit the amount of lateral shear flowing into and out of the transfer system from the diaphragms through shear friction.

Results and Outcomes

This unique transfer girder addressed the operational and architectural desire for a column-free corner at the ground floor while maintaining adequate headroom at the floor above, constraints that prevented a conventional load path. The transfer girder size, reinforcing, and location, and the associated constructability issues, created challenges for the design and construction teams alike. The successful outcome was made possible only through teamwork and careful coordination among all parties involved. ▪

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