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Author:	Shankar Nair, Teng & Associates
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# Building Where They Said It Couldn't Be Done

R. Shankar Nair

Teng & Associates, Inc., Chicago, USA

## Abstract

Construction of tall buildings and other major structures in large cities often involves working within severe site-specific limitations that can give structural engineers an opportunity to make a decisive contribution to the economic feasibility of such projects. They may conceive innovative transfer systems, as illustrated by several unusual load-transfer challenges and solutions from the author's practice experience. Examples include: a building supported on a grid of girders above an active rail yard and suspended, in part, from cantilever trusses on the roof; twin towers cantilevered 10 meters over a trading hall using a shear-panel transfer system; tall buildings linked structurally to act as a single unit, resulting in major cost savings; a subway station built under a multi-level parking garage using a method that reduced cost and permitted the garage to remain in service throughout construction.

## Introduction

Construction of tall buildings and other major structures in large cities almost invariably involves working within severe site constraints. These can involve all aspects of architectural and engineering design. As will be illustrated with examples drawn from the author's practice in Chicago, creating opportunities for the development of "impossible" sites through innovative design represents a unique – and uniquely rewarding – challenge to the structural engineer.

Site conditions can result in a building having a structurally inefficient and irregular shape (e.g., it may have to be very slender). Such conditions can create a situation where there is no clear and direct path along which to transmit structural loads into the ground from floors located where they are functionally most desirable. It is the latter situation that is the primary subject of this paper. Some of the main classes of solutions to the problem of transferring structural loads to the ground along indirect paths will be outlined. This will be followed by a discussion of a few unusual load-transfer challenges and solutions drawn from the author's practice.



*Morton International Building*

## Types of Structural Transfers

At the most basic level, structural load transfer systems can be classified according to the type of load that is to be transferred – vertical, horizontal, or overturning.

### Transfer of Vertical Load

When the direct downward transfer of vertical load to the ground is prevented by an obstruction, the solutions include spanning across the obstruction or cantilevering out over it, as illustrated in Figure 1(a). The transfer trusses or girders (trusses shown) could be located near the base of the building or at the top or anywhere in between. Locating the trusses or girders at the base will usually result in a simpler construction sequence and lower cost.

A possible alternative to the transfer cantilever shown in Fig. 1(a) is the tied-back shear panel transfer system shown in Fig. 1(b). In this design, vertical load is shifted laterally by means of a vertical wall panel (or diagonally-braced truss panel) loaded in essentially pure shear. A tie at the top of the panel and a compression strut at the bottom, both connected to the building's main lateral load-resisting system, restrain the corresponding moment.

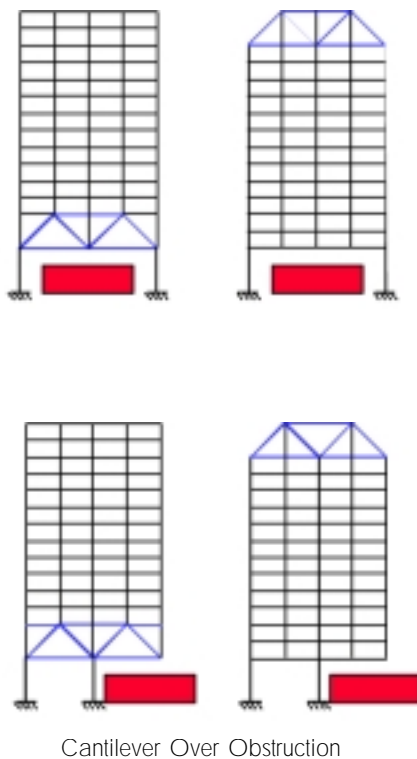


Fig. 1a, Transfer concepts for vertical load

## Transfer of Horizontal Shear and Overturning Moment

Structural design concepts for transfer of horizontal shear and overturning moment from one part of a building structure to another are illustrated in Fig. 1(c). In the illustration on the left, shear alone is transferred, while the moment continues down to the ground. This type of transfer is usually a simple matter. Building floors are typically very stiff and strong in their own plane, and can be designed to transmit large in-plane forces at little additional cost. In the illustration on the right, both horizontal shear and overturning moment are transferred. The moment is transferred as a horizontal couple, using floors to transmit the horizontal forming the couple.

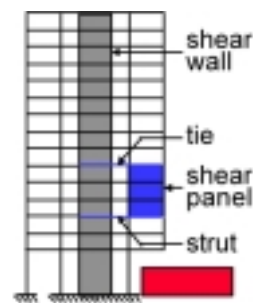


Fig. 1b, Tied-back shear panel transfer concept for vertical load

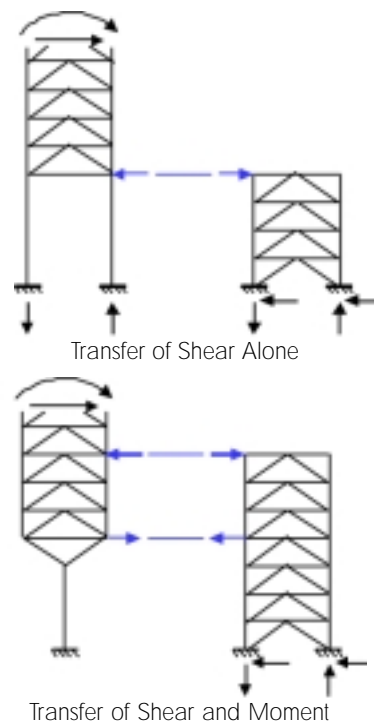


Fig. 1c, Transfer concepts for horizontal shear and overturning moment

## Applications

The use of innovative structural transfer systems will be illustrated with five examples drawn from the author's consulting engineering practice. Four are tall building developments; one is a subway station. One of the projects was not actually built; it succumbed to changes in market conditions late in the design process. The other four examples, all in Chicago, are projects that have been completed. In the following discussion of the five structures, some simplification and idealization of actual conditions will be made for purposes of clarity. The discussion is centered on the transfer systems. (Basic information on the three completed tall buildings can be found in the CTBUH database.)

### Morton International Building

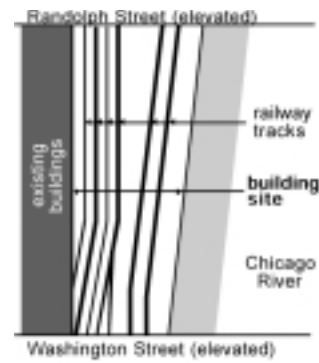
The Morton International Building (Dixon, 1991), at 100 North Riverside in Chicago, is a 36-story, 101,000 m<sup>2</sup> office building. The lower 12 floors, each 4,300 m<sup>2</sup>, hold lobbies, parking space for 435 cars, and a 26,000 m<sup>2</sup> computer center for the local telephone company. The upper floors hold rental office space.

The entire project is above an active rail yard, which had defeated all previous attempts at developing the site, though it is at a prime location on the Chicago River. As shown in the schematic site plan in Fig. 2, the rail tracks cover almost the entire site. The streets in the area are about 10 m above the tracks.

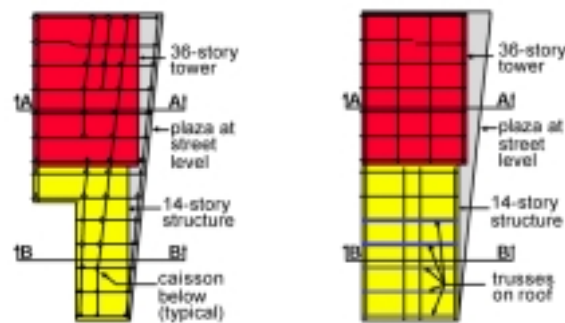
Development of the Morton International site was made possible by a comprehensive transfer system. Foundation caissons (drilled piers) and track-level columns were located where track clearances were adequate, as shown in the caisson grid in Fig. 2. Because of the irregular track layout, the caisson locations could not coincide with column locations in the building above (see superstructure grid in Fig. 2).

A complete grid of concrete transfer girders, about 2.5 m deep and between 1.0 and 2.5 m wide, transfers load from the building columns above to the track-level columns and caissons below. The top of the girder grid is at street level. Schematic Section A-A in Fig. 2 shows the relationship between building columns, transfer girders and caissons.

As shown in the caisson grid in Fig. 2, there was no room for caissons or columns among the tracks in a 20 m x 46 m area at the southwest corner of the site (north is oriented toward the top of the site plan). In early planning concepts, this area was left unbuilt. However, the telephone company demanded full 4,300 m<sup>2</sup> floors; efficiency of the parking layout also required full floors,



Site Plan



Caisson Grid

Superstructure Grid

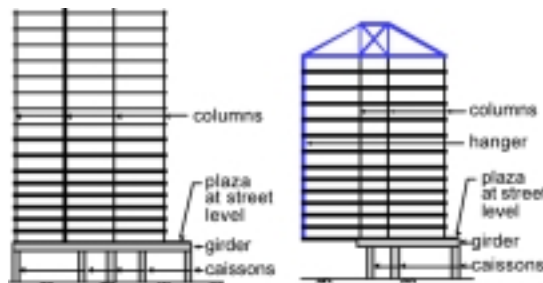


Fig. 2. Morton International Building

without a cut out in the corner. The solution was to provide a cantilever transfer system to support this part of the building. Cantilever trusses at the bottom, just above the tracks, would have been most economical but would have disrupted the parking layout. So the trusses were placed on the roof, where they became part of the architectural expression of the building, as indicated in Section B-B and the photograph in Fig. 2.

## Chicago Mercantile Exchange Center

The Chicago Mercantile Exchange Center (Architectural Record, 1983), at 10 and 30 South Wacker Drive in Chicago, includes two 40-story, 116,000-m<sup>2</sup> office towers and two stacked column-free trading halls, of about 4,000 m<sup>2</sup> and 3,000 m<sup>2</sup>, respectively. The photograph in Fig. 3 shows the two towers and the structure enclosing the trading halls.

Typical floors in the office towers are of just under 3,000 m<sup>2</sup>, an area considered optimum in the local office leasing market. The challenge to the structural engineer on this project was to accommodate two 3,000 m<sup>2</sup> office towers and a 4,000-m<sup>2</sup> column-free trading hall on a site with a total area under 8,000 m<sup>2</sup>. The innovative solution was to cantilever each tower about 10 m over the trading hall, as shown in the schematic elevation in Fig. 3.

The cantilever was achieved using the tied-back shear panel concept, as shown in Fig. 3. The 10-m horizontal transfer was realized in two steps over seven stories (with a total height of 25 m). The shear panels are reinforced concrete walls 760 mm thick. The tension tie at the top and the compression strut at the bottom transfer overturning moment in the form of a horizontal couple to the shear wall core. The moments imposed by the transfer system cause lateral deformation of the shear core. The towers were erected out-of-plumb by up to 100 mm to compensate for this. Subsequent lateral displacements, including long-term effects, brought the towers to a plumb condition.



Chicago Mercantile Exchange Center

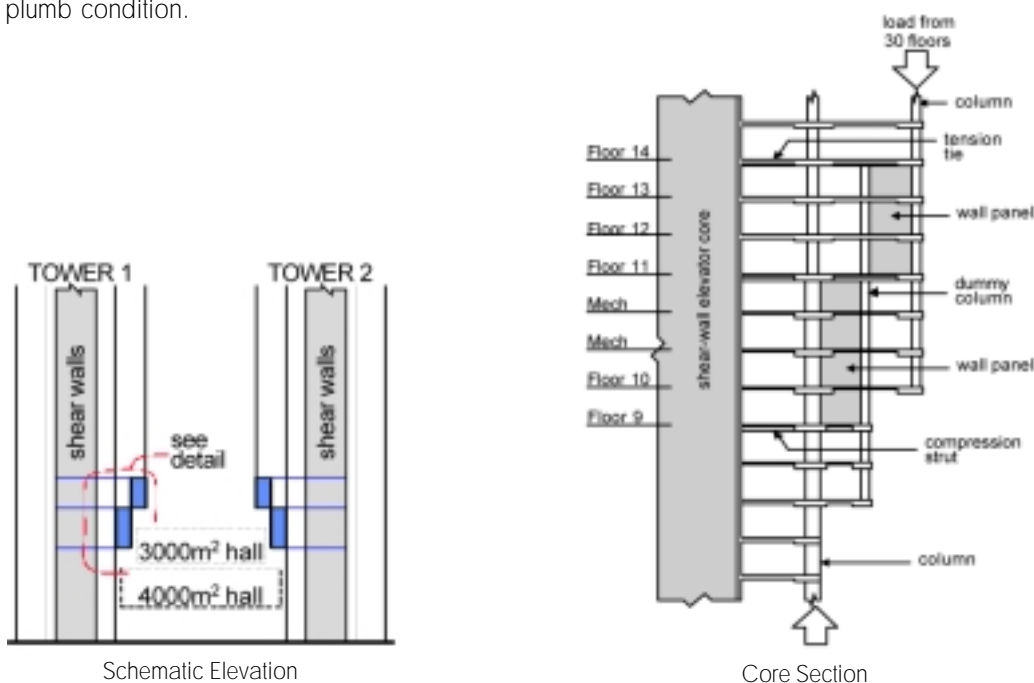


Fig. 3. Chicago Mercantile Exchange Center



## Unbuilt Mixed-Use Project

This example deals with a very large mixed-use project that involved extensive transferring of both vertical and lateral load. The general layout of the project, simplified and idealized for clarity, is indicated in Fig. 4(a). It includes a 70-story office tower, two 40-story office towers and a 20-story hotel, with a common 6-story base or podium holding retail space. Parking is accommodated in several below ground basement levels.

A subway station running diagonally across the middle of the property (Fig. 4) had discouraged all previous attempts at developing the site, even though it was at a prime location. The solution was a grid of cast-in-place concrete transfer girders just above the station roof slab. The concept is similar to that adopted for the Morton International Building (Section A-A in Fig. 2), but without the cantilevers and hangers.

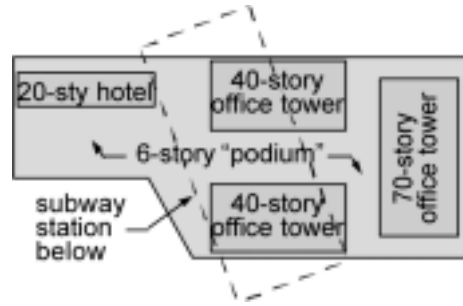
Early designs for the project included expansion joints through the 6-story "podium" structure to separate it into four structurally independent segments, one at each tower, as indicated in Fig. 4(b). The office towers used braced-frame cores with outriggers to supercolumns as their lateral load-resisting systems. The diagonal bracing could not be carried down through the lower six stories since the retail space below the tower cores needed to be open; so massive steel rigid frames were proposed in the podium floors below the cores.

In the final structural concept, as illustrated in Fig. 4(c), the expansion joints were eliminated, causing the entire four-tower project to act as a single structure. Therefore, a separate bracing system was not needed below each tower in the podium floors. Bracing and walls were provided wherever they would fit conveniently, scattered throughout the complex, below Level 7, as shown on the left side of Fig. 4(c). The slab at Level 7 was designed to transfer horizontal shear forces from the tower bracing systems to the podium bracing as shown on the right side of Fig. 4(c).

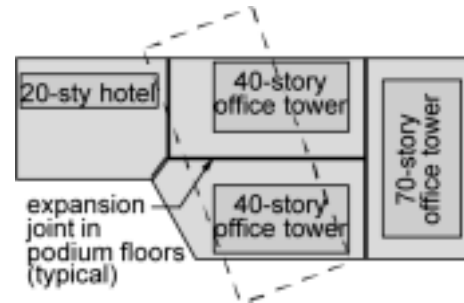
The redesign to eliminate the expansion joints and transfer lateral loads as indicated in Fig. 4(c), together with a few other structural refinements, reduced the estimated cost of this project by \$60 million.

### Boulevard Towers

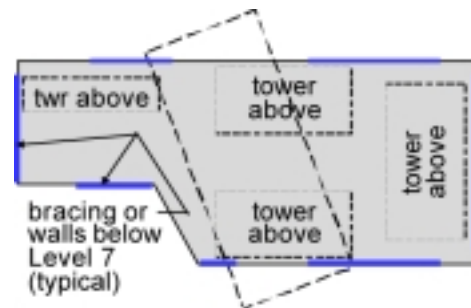
The Boulevard Towers office development, at 205 and 225 North Michigan Avenue in Chicago, consists of a 44-story, 86,000 m<sup>2</sup> South Tower and a 24-story, 82,000 m<sup>2</sup> North Tower. Up to the 19th level, a 30 m wide infill structure spans the 12 m space between the two towers, resulting in floors of over 5,600 m<sup>2</sup> each.



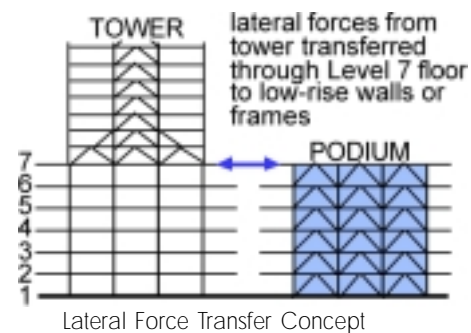
a. Overall Layout of Project



b. Conventional Expansion Joint Configuration



Shear Walls and Bracing in Podium



c. Design Concept with no Expansion Joints

Fig. 4. Unbuilt Mixed-Use Project

The structure is constructed of reinforced concrete, with shear wall cores as the lateral load-resisting system.

The 19-story infill between the two towers (see Fig. 5) links the towers structurally, to make them act as a single unit. This eliminated the need for expansion joints, which would have been subject to very large relative movements – of the order of 300 mm at the 19th floor – which would have been difficult to accommodate in the architectural and functional design of the project.

Moreover, use of the infill floors to link the two towers structurally offered important benefits. The lower North Tower has much larger floors than the taller South Tower. (Typical floor areas are 3,200 m<sup>2</sup> in the North Tower and 2,100 m<sup>2</sup> in the South Tower.) Architectural and space-planning requirements made it possible to have a deep shear core in the stubby North Tower, but only a shallow core in the slender South Tower. Linking the towers (see schematic elevation in Fig. 5) allowed the deeper, stiffer core in the lower building to resist most of the combined lateral loading imposed on the two towers.

The link floors represent a transfer system for both shear and moment, as shown schematically on the right side of Fig. 1(c), except that not all the moment is transferred from the taller to the shorter tower. At the base, the two shear cores share overturning moment roughly in proportion to their stiffness, with the core of the lower building supporting significantly more than half the total.

Compared to a design with the towers separated by expansion joints, the linked design of this project resulted in only a modest additional cost in the shorter tower and major savings in the cost of the taller tower.

#### Subway Station at O'Hare Airport

The extension of a subway line to Chicago's O'Hare Airport required the construction of a new station under an existing six-level concrete parking with structural spans of just under 20 m. To accommodate the station, which had to be column-free, the caissons (drilled piers) supporting two rows of existing garage columns had to be removed. Each pair of these existing columns is picked up by a 2.5 m wide x 3 m deep post-tensioned concrete transfer girder supported on new columns at the edges of the new station. The photograph in Fig. 6 shows the interior of the station; the girders are visible at the top.

The most innovative structural aspect of this project was not the configuration of the finished structure, but rather the sequence of construction and related structural design features. This permitted the entire garage, includ-



*Boulevard Towers*

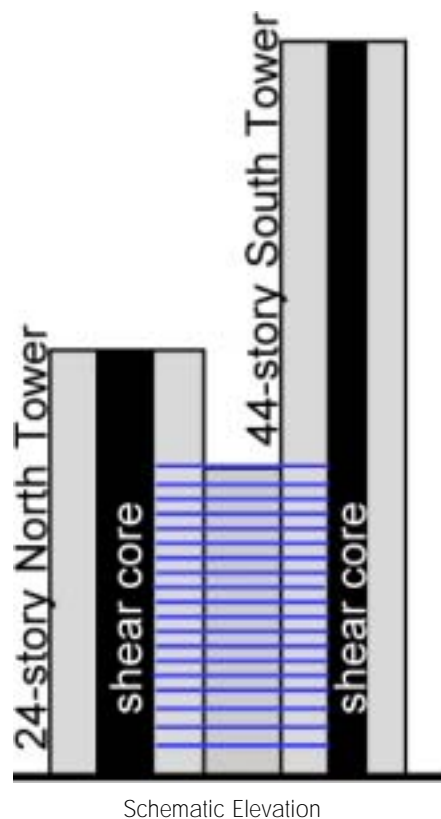


Fig. 5. Boulevard Towers



Fig. 6. Interior of Station

ing areas directly above the station, to remain in service throughout the construction period.

The construction sequence is indicated in Fig. 7. The transfer girders were cast on the ground, before excavation of the space for the subway station (Step 2). This yielded major savings compared to construction on shoring up in the air after excavation. The girders were fastened to the existing caissons and were supported by the caissons during excavation (Step 3) and the construction of new columns (Step 4). Post-tensioning was applied (Step 5) to transfer column reactions from the existing caissons to the new girder and columns. The caissons were then removed (Step 6) and the interior of the station was completed.

## Conclusions

As cities become ever more densely developed, structural engineers will have increasing opportunities to make decisive contributions to the economic feasibility of future projects by conceiving innovative transfer systems using basic concepts of statics.

Innovative structural transfer systems can create opportunities for development where they didn't exist before. The Morton International Building and the Chicago Mercantile Exchange Center illustrate this, as well as the unbuilt mixed-use project discussed in this paper. Combining a transfer system with an innovative construction sequence can offer special cost and functional benefits, as illustrated by the design and construction of the O'Hare Airport subway station.

Besides carrying gravity loads to the ground along indirect paths, structural transfer systems can also be used to transfer lateral loads from one part of a project to another. Transfers of this type can produce major reductions in the cost of the overall development, as illus-

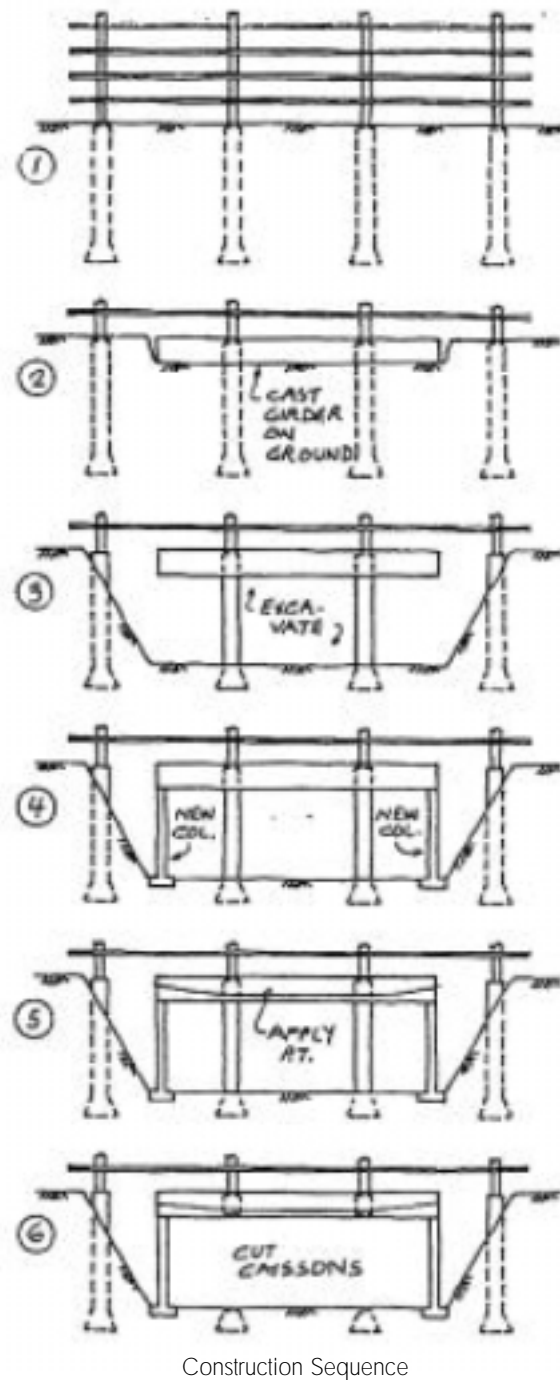


Fig. 7. Subway Station at O'Hare Airport



trated by the unbuilt mixed-use project and the Boulevard Towers buildings, where the transfer systems resulted in the integration of towers into a single structure that would have otherwise behaved as independent structural units.

## References

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