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## **Plenary Session**

### **High-Rise Buildings**

#### **Keynote Lectures**

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## Architecture and Urban Responsibility in High-Rise Design

### Jun MITSUI

Cesar Pelli & Assoc., Japan  
Jun Mitsui & Assoc., Architects  
Tokyo, Japan



Jun Mitsui, born 1955 received his Bachelor of Science degree from University of Tokyo in 1978 and Master of Architecture from Yale University in 1982 with awards. He is currently heading Cesar Pelli & Assoc., Japan and Jun Mitsui & Assoc. He is also a member of Japan Institute of Architects and American Institute of Architects and is licensed in both countries. He practices in architectural design and urban design.

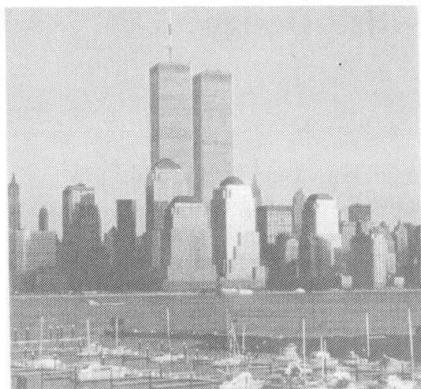
### Summary

High-rise buildings became possible through technological innovations, however at the same time their impact to our living space has been astronomical and changing our look of cities dramatically. Technology should be for the better quality of our life. Therefore as an architect Cesar Pelli has been struggling hard to make this very modern building type as part of our friendly partner. Technology is becoming very internationally recognized and understood however, urban culture of each place is very much attached to the place and strongly connected to the tradition and custom of the district. The job of architect is to negotiate those conflicting phenomena of modern age and create a better cities for people.

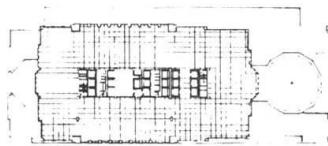
### The Era of High-Rise Building

High-rise Building or so-called Skyscraper is a new invention of the modern society. They became able to exist by the modern technology which did not exist before the modern time. Office space before the skyscrapers were low to mid height office buildings with the light well (exterior courtyard in the middle) in the center.

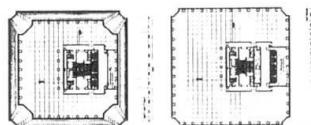
Skyscrapers became possible on a group of technologies, such as fast elevator technology, air conditioning and electrical technology and structural technology. Especially in Japan, compared to other areas of the world, the idea of real skyscraper had to be a very new idea, because of the strong seismic consideration.



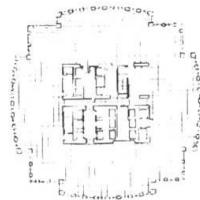
1 Skyline of New York



2 North West Center Plan



3 Mori Building Plan



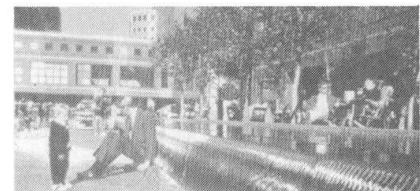
4 NCNB Plan



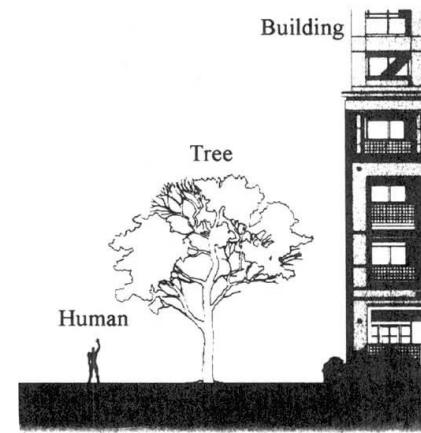
5 Bird's-eye view of Shinjuku



6 Bird's-eye view of Firenze



7 World Financial Center



8 Comparing Scales

At the same time high-rise buildings became also possible by the economical reasons of the land development. One was a great need for white-color work space and the other was a pressure to maximize the limited urban property. As the commercial activities get centralized and very dense in terms of the per square feet value in cities, the pressure to maximize the every inch of the property became very important. At the same time with the development of the hi-speed elevating system, it actually became economically more efficient to do high-rises than doing flat and large floor plate buildings. The leasing depth of the tower high-rises were around 40 ft and it was a comfortable dimension as a office space.

In any case, the idea of skyscraper became a very common idea in the modern world supported both by economy and technology and they are changing the traditional idea of urban space and urban development planning method.

### Urban Impact by High-Rise Buildings

Because of its immense scale and volume as well as the numbers of the people living in the building and the energy consumed there, high-rise buildings have been always controversial issues in our society. Here I would like to focus my attention on the visual impact of the high-rise to the city both as part of our culture and as part of the tools to create comfortable city.

Cities are places for people not for buildings. Therefore the urban space such as street, piazza, plaza and others are so de-

signed that people in there feel comfortable and can enjoy their life in the city. And people has certain scale. Human scale, although they may be slightly different by generations, or country, they are in a certain height range. And trees are also in a certain height ranges too. As a result the scale of the buildings should fit to the scale of people and trees not vice versa.

In the process of urban planning studies for high-rise buildings, incentive method were created to minimize the negative impact of the high-rise buildings. This was to achieve more comfortable open spaces around the building by giving more FAR to the building as a bonus. As Le Corbusier tried in his "La Ville Radieuse" book, towers surrounded by green open space was one of the first try to solve the high-rise building and human scale, in which he tried to solve the scale problem by placing park around the tower. This method however as a result did eliminate the development of urban street space and made the space around the tower very barren. People needed street activities on the street not a very windy open plaza or just trees. From a urban activity (nigiwai) view points, the high-rise shape controlling method should be carefully studied.

Because of its immense volume, the wind moves around the tower sometimes in a very unexpected way and can cause uncomfortable micro-climatic conditions. Wind, after hitting the tower can be a very strong down-draft on the street and the velocity of the wind around the tower could be very annoying and sometimes can become physically very dangerous. The consideration to the micro-climate conditions which will be caused by the towers are a new urban problems and needs careful design responses to solve the problem.

### **Roles of High-Rises in the Urban Space Planning.**

Because of its height, high-rise towers can play important role which mid-rise buildings could not play. One thing which it can achieve is the sense of landmark of the area. Height itself already gives a strong visibility and people get very much inspired by the height. There has been always a desire in people to go higher and taller structure. The KLCC towers which Cesar Pelli



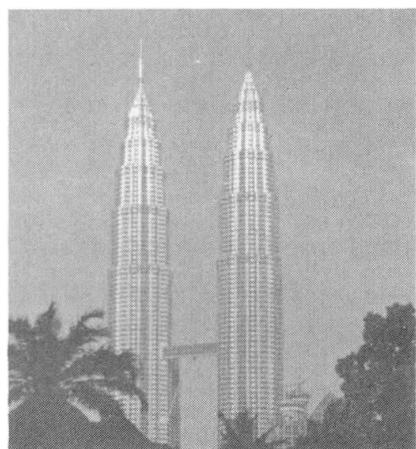
9 A contemporary city for 3 million people.



10 Urban Street Space formed by human scaled building fronts



11 Lack of attention to surrounding space



12 View of KLCC



& Associates (CPA) designed are the highest skyscraper in the world as of 1998 and the fact has been actually very much appreciated as a national pride by Malaysian people.

### **-KLCC Towers Kuala Lumpur, Malaysia-**

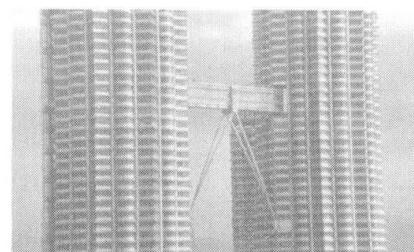
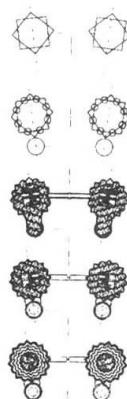
Because of its very visible presence, not only the height but the design of the tower is also very important. In the KLCC tower we tried to achieve cultural metaphor in the tower design. First the floor plan of the tower is the overlap of the two squares rotated by 45 degrees. This combination is the basic set of geometry for Islamic visual culture which does not have icon figure in their life. The pattern with comfortable leasing depth and other mechanical space comfortably planned became a very reasonable floor plans for towers. The floor plans are fine adjusted depend on the floor and created a modern symbol for Kuala Lumpur. This project has two tower in symmetry and 70 meters space in-between. Each tower embodies the modern translation of the Islamic culture and the in-between space implies the gateway to the city.

At the 52nd floor level two towers are connected by the double deck bridge for functional reasons. This large scale design configuration is obviously an urban response by Cesar Pelli, accomplishing its role. At the same time this tower has a huge commercial function base which makes the street life much more active and comfortable. People needs excitements and lots of people on the street to enjoy their life.

High-rise buildings have basically two different appearances in urban-scape. One is the long distance view which could be also called sky-line shape and the other is the base of the tower which defines the street space and very much related to human scale. Although the tower structure may be purer and simpler if it is isolated from the other structure, it is more comfortable for people if it has a smaller scale base attached to the high-rise structure.

At the beginning stage of the high-rise structure history, structural consideration prevailed and essentially decided its form.

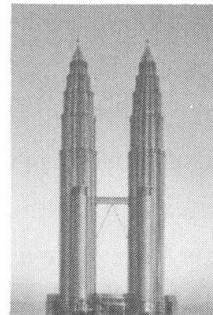
13 Plans of KLCC



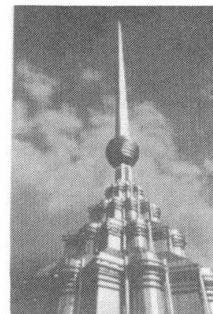
14 Bridge of KLCC



15 Base



16 Full view of KLCC



17 Detail of top

However now we are finding out that the technology and science is for people not just for technology and science and those are tools to achieve thinking of human-being. Even the high-rise buildings should be designed and should reflect the local culture of the place, and then they could be a cultural symbol of the place.

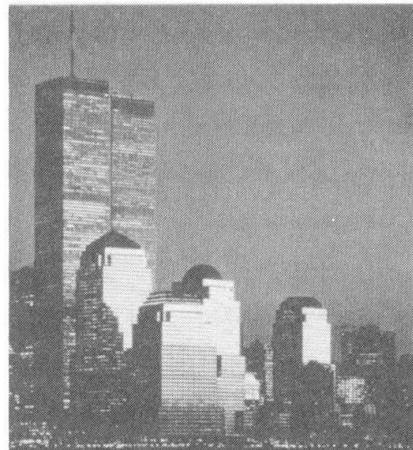
### **-World Financial Center NY, USA-**

High-rise buildings in some cases are designed and planned in groups. When there are so many towers planned in the city, obviously the design and planning coordination of the towers are very important. In the early stage of the high-rise structure, it was not a consideration to make the tower much more sympathetic to the culture of the place. However we are realizing that it is actually very important to design towers carefully in coordination with other developments and urban context because the quality of the urban space will be decided not by a single building but the collection of the buildings in that area. In this project CPA was trying to balance the skyline form which will be created by both World Trade Center and WFC. It was not important to have a stronger presence or distinguished presence than the World Trade Center but to create a better Manhattan skyline and urban space together with the surrounding buildings. The end result, we believe is amazing. The new addition created a much better urban space in New York and added a great life to Manhattan skyline.

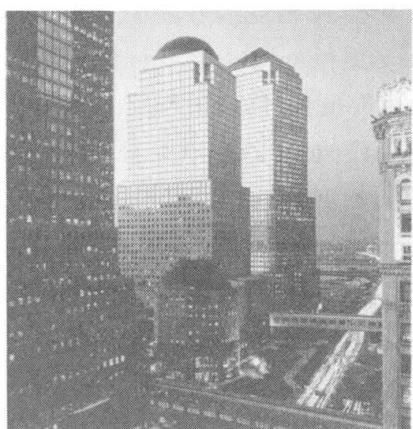
In this project there are four office towers and each has different shape roof as a metaphor to old New York skyscrapers. The floor plate sizes were adjusted so that basic tower floor plate sizes are very similar to World Trade Center. And there are setbacks in tower forms to create a sense of gradual height increase of the towers towards World Trade Center.

By this massing consideration, the World Financial Center and adjacent buildings became very interrelated urban buildings, those are together creating an exciting urban space.

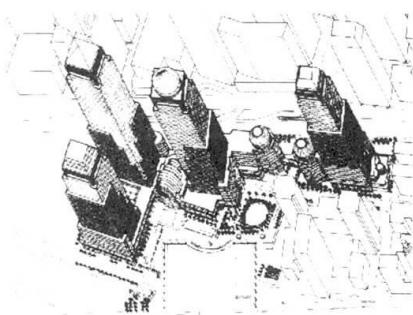
Buildings are so interlaced in the modern cities and collaborating spatial effect of the multiple buildings in the city is becoming



18 View of the World Financial Center



19 View of the World Financial Center



20 Axonometric



21 Base of the World Financial Center



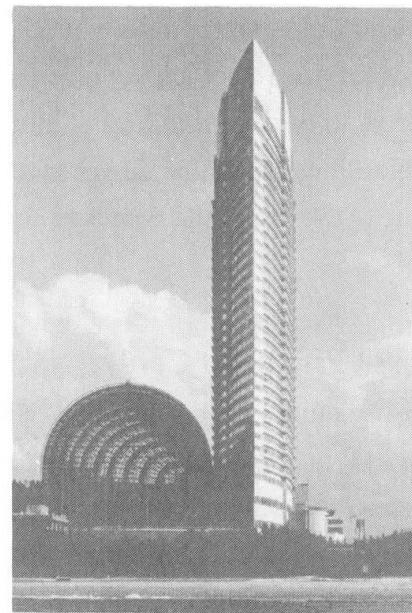
very important especially in the large scale high-rise buildings. As an architect we feel that it is our responsibility to create better city and better buildings for future by adapting the presence of high-rise bldgs. and by adjusting its scale and make it more gentle to people.

### -Sea Hawk Hotel, Fukuoka, Japan-

This project is right on a beautiful bay called Hakata Bay, and next to the huge indoor baseball dome structure called "Fukuoka Dome". When the design started for this hotel, the baseball dome was already designed and our goal was to create a good resort hotel and beautiful skyline for the entire complex including the future Fantasy Dome. Since the massing of the Dome Stadium is so large and chunky that we felt that the design of the hotel high-rise tower should be rather thin in profile and should look visually light. In the end the floor plan of the tower became a ship-like form with the pointed top. This shape also achieved a view to the Hakata Bay from all the guest rooms. We also added a vertical articulation to the tower. Since the structure became so thin, we had to put the seismic mass damper at the top of the tower.

From the bay, the high-rise tower poses a very strong and characteristic presence and it is a very visible landmark of this area. The height of the tower is limited by the airport near-by, however it is the highest structure in that area. When people approach from air or on the sea or by car, the shape of the structure is so designed that from every angle, the structure appears almost as a sculpture and gives a new addition to Fukuoka culture.

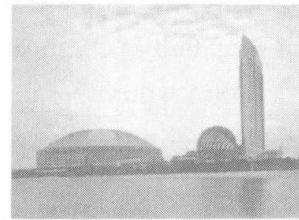
Cesar Pelli & Associates have done many skyscrapers all over the world and what interests us most whenever we design high-rise building is to contribute to creating a comfortable and pleasant living environment through architectural design and urban design. When we design skyscrapers, we see people working there, shopping there and enjoying the buildings and the environment which the skyscrapers creates.



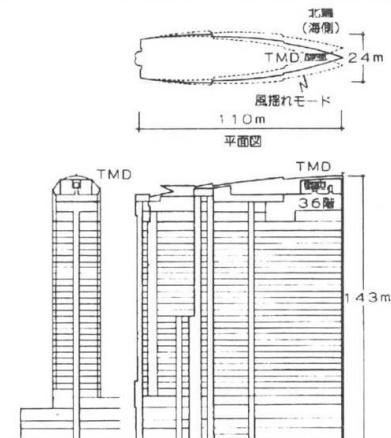
22 View of the Sea Hawk Hotel



23 Plan



24 The view from Hakata Bay



25 Seismic Damper System



26 The base of North

West Tower



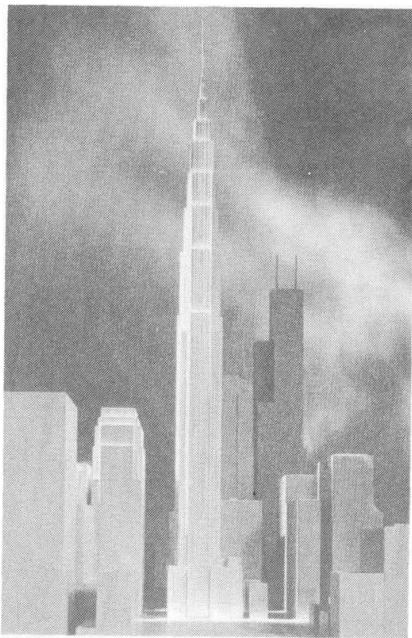
27 ShoppingAcade

in the  
North West Tower

New high-strength steel and high speed computer controlled elevator system will

soon make a kilometer tall high-rise possible. And at that time we will have to

ask ourselves why we are building such a tall tower? Do we really need it for our better life or is it simply for a technological challenge or a desire of human-being to show its pride and achievement. However when economy or technology decides to build the next generation structure, as an architect we are committed to design the new structure to make our city more comfortable and livable space.



29 Miglin Beitler Tower

## Quotation

1. Photo No.1 taken from "The Master Architect's Series-Cesar Pelli," published by Sigma Union, 1993 page 55
2. Photo No.5 taken from "The Development of Complex Renovation," published by Syoukokusya, 1995 page 47
3. Photo No.6 taken from "The Street and Roof of Europe," published by Creo Corporation, 1995 page 103
4. Photo No.7 taken from "The Master Architect's Series-Cesar Pelli," published by Sigma Union, 1993 page 63
5. Photo No.9 taken from "Le Corbusier," published by A.D.A. EDITA, 1975 page 15
6. Photo No.10 taken from "Public Design Dictionary," published by Sngyo Cyosakai , 1991 page 148
7. Photo No.11 taken from "Public Design Dictionary," published by Sngyo Cyosakai , 1991 page 72
8. Photo No.17 taken from "The Master Architect's Series-Cesar Pelli," published by Sigma Union, 1993 page 131
9. Photo No.18 taken from "The Master Architect's Series-Cesar Pelli," published by Sigma Union, 1993 page 54
10. Photo No.21 taken from "The Master Architect's Series-Cesar Pelli," published by Sigma Union, 1993 page 56
11. Photo No.26 taken from "The master Architect's Series-Cesar Pelli," published by Sigma Union, 1993 page 5 0
12. Photo No.27 taken from "The Master Architect's Series-Cesar Pelli," published by Sigma Union, 1993 page 53
13. Photo No.29 taken from " Cesar Pelli,Buildings and Projects" published by Rizzoli inter National Publications,Inc, 1993 page 187

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## Building Where They Said It Couldn't Be Done!

**R. Shankar NAIR**  
Senior Vice President  
Teng & Associates, Inc.  
Chicago, IL, USA



R. Shankar Nair received his Ph.D. in civil engineering from the University of Illinois in 1969. In nearly three decades of practice with engineering and architecture firms in the USA, he developed the structural designs of numerous tall buildings of 30 to 70 stories and many major bridges. He is chairman of the Council on Tall Buildings and Urban Habitat.

### Summary

Construction of tall buildings in the centers of the world's large cities almost invariably involves working within severe site constraints. The constraints can involve all aspects of architectural and engineering design. As illustrated with examples drawn from the author's practice, many different structural engineering concepts are available for overcoming limitations imposed by site conditions. Creating opportunities for development of "impossible" sites through innovative design represents a unique — and uniquely rewarding — challenge to the structural engineer.

### 1. Introduction

Innovations and refinements in the structural analysis and design of tall buildings can make the building structure more efficient by providing the required strength and serviceability at less cost. But important as they are, these improvements in analysis and design (which may save the project owner a few dollars per square meter in construction cost) will rarely have a decisive effect on the economic feasibility of an urban development.

There are situations, however, where the structural engineer's contribution to the success of a project can be decisive. Most often, these situations involve the use of innovative structural engineering to overcome or circumvent constraints imposed by site conditions.

It is the rare tall building these days that can be placed on a "green field" location. Typically, the new urban building project has to conform to constraints imposed by existing conditions at the site. Site conditions can require that a building have a structurally-inefficient shape (e.g., unsymmetric or very slender). And site 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 from the author's practice.



## 2. Types of Structural Transfers

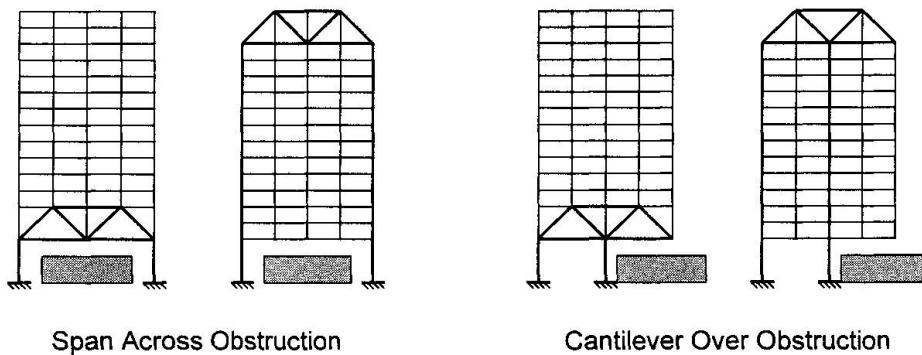
At the most basic level, structural load transfer systems can be classified according to the type of load that is to be transferred — vertical force, horizontal force, or overturning moment. Transfer systems for vertical load and those for horizontal force and overturning moment will be discussed separately.

### 2.1 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 the obstruction, as illustrated in Figure 1. The transfer trusses or girders (trusses shown) used for the span or cantilever could be located near the bottom of the building or at the top (or anywhere in between).

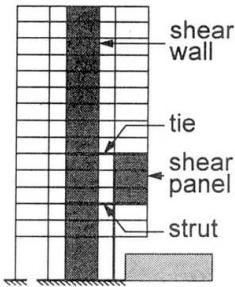
Locating the transfer trusses or girders at the bottom will usually result in lower construction cost. When the transfer elements are at the top, floor loads have to be carried up to the top through hangers and then down to the ground through the support columns. The extra distance through which the loads have to be transmitted will be reflected in increased column and hanger material and cost. Also, the construction sequence can be awkward. Yet another difficulty with the hung-from-above design is proper control of floor elevation, since floor loading simultaneously stretches the hangers and compresses the support columns.

Despite these drawbacks, transfer trusses or girders are sometimes placed at the top, either within the building envelope or exposed above the roof. This is done when transfer components at the lower floors would have an unacceptable effect on the functional or architectural design of the project.



*Fig. 1. Structural transfer concepts for vertical load*

A possible alternative to the transfer cantilever shown in Fig. 1 is the “tied-back shear panel” transfer system shown in Fig. 2. 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. The corresponding moment is restrained by a tension 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.



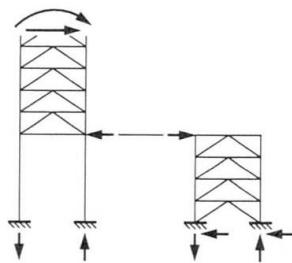
Tied-Back Shear Panel

Fig. 2. Tied-back shear panel transfer concept for vertical load

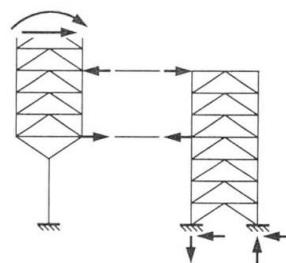
In many situations the shear panel will be less disruptive of the use of the building than conventional cantilever trusses or girders. The drawback is that the moment imposed on the building's lateral load-resisting system can be substantial. (Of course, balanced panels on both sides of the building would avoid this problem.)

## 2.2 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. 3. In the picture on the left, shear alone is transferred, while the moment continues down to the ground. In the picture on the right, both horizontal shear and overturning moment are transferred. (The building's lateral load-resisting system is shown as a truss or braced frame in the illustration; it could be a shear wall or rigid frame instead.)



Transfer of Shear Alone



Transfer of Shear and Moment

Fig. 3. Structural transfer concepts for horizontal shear and overturning moment

Transfer of horizontal shear in a building structure (left side of Fig. 3) 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.

Overturning moment can be transferred from one part of the building to another as a horizontal couple, using floors to transmit horizontal force in one direction at one floor and the opposite direction at another floor (right side of Fig. 3).



### 3. Examples

The use of innovative structural transfer systems will be illustrated with four examples drawn from the author's consulting engineering practice. One of the projects was not actually built; it succumbed to changes in market conditions late in the design process. The other three examples are buildings that have been completed.

In the following discussion of the four projects, there will be some simplification and idealization of actual conditions, for purposes of clarity. Additional information on the three completed buildings can be found in the database of the Council on Tall Buildings and Urban Habitat. (The database is accessible to Council members through the Internet.)

#### 3.1 Morton International Building

The Morton International Building (Reference 1), at 100 North Riverside in Chicago, is a 36-story,  $101,000 \text{ m}^2$  office building. The lower 12 floors, of  $4,300 \text{ m}^2$  each, hold lobbies, parking space for 435 cars, and a  $26,000 \text{ m}^2$  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. 4, the rail tracks cover almost the entire site. The streets in the area are about 10 m above the tracks.

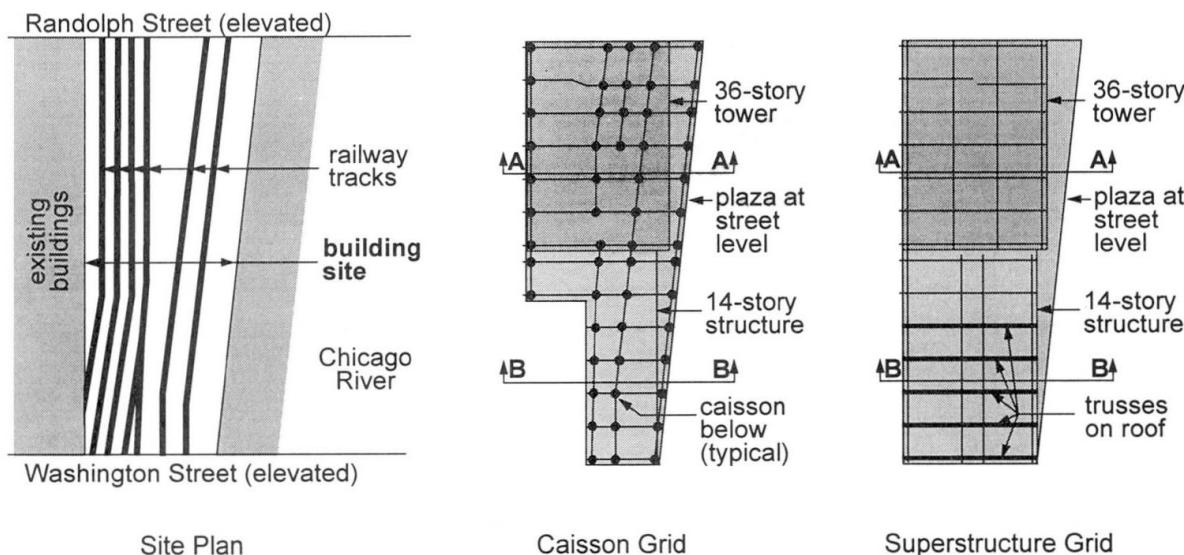


Fig. 4. Schematic layout of Morton International Building

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. 4. The caisson locations did not coincide with column locations in the building above (see superstructure grid in Fig. 4).

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. The columns below the girders are of reinforced concrete (and are, in effect, extensions of the caissons). The building above the girders is framed in steel. Schematic Section A-A in Fig. 5 shows the relationship between building columns, transfer girders and caissons.

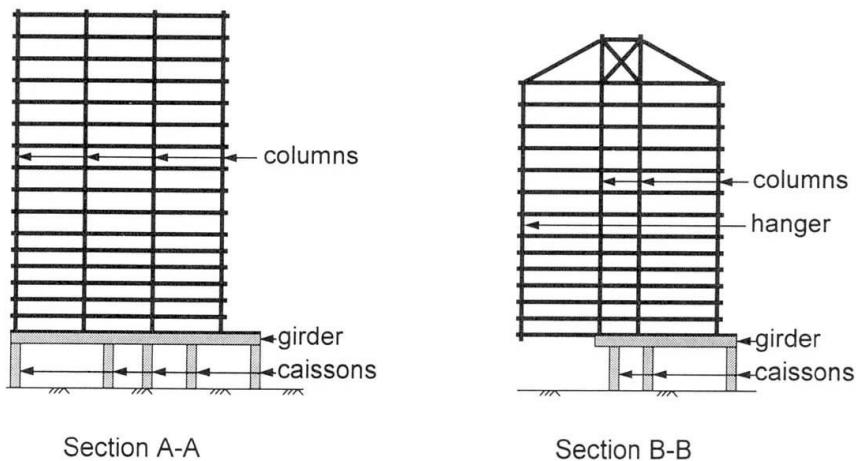


Fig. 5. Schematic sections through Morton International Building  
(see Fig. 4 for location of sections)



Fig. 6. Morton International Building

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 (see caisson grid in Fig. 4). In early planning concepts, this area was left unbuilt. However, it proved to be very important that there be floors above this foundation-



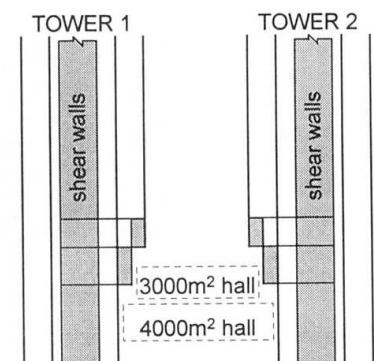
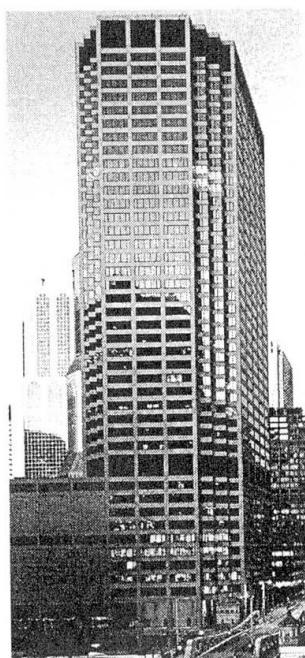
less area. The telephone company demanded full  $4,300 \text{ m}^2$  floors; efficiency of the parking layout also required full floors, without a cut-out in the corner. The solution was to provide a cantilever transfer system to support the part of the building below which there could be no caissons. 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 in Fig. 5 and the photograph in Fig. 6.

The Morton International Building is a good example of the use of an innovative structural transfer system to create an opportunity for development of a site that had previously been judged to be undevelopable. The entire building superstructure, both the 36-story tower and the low-rise portion, is supported on the grid of concrete girders above the railway tracks. The cost of the girder system, distributed over the floor area that it supports, was fairly modest.

The cantilever trusses support only a small fraction of the total floor area in the project. The additional floor area made possible by the cantilevers came at a very high price, if expressed in dollars per square meter of additional space. But this  $$/\text{m}^2$  figure does not tell the whole story. The cantilever system played an important role in the success of the entire project by creating the floor size demanded by a major tenant and by allowing an efficient parking layout.

### 3.2 Chicago Mercantile Exchange Center

The Chicago Mercantile Exchange Center (Reference 2), at 10 and 30 South Wacker Drive in Chicago, includes two 40-story,  $116,000 \text{ m}^2$  office towers and two stacked column-free trading halls, of about  $4,000 \text{ m}^2$  and  $3,000 \text{ m}^2$  respectively. Parking is provided on four floors below street level. The photograph in Fig. 7 shows one of the two towers and part of the structure enclosing the trading halls.



Schematic Elevation

Fig. 7. Chicago Mercantile Exchange Center

Typical floors in the office towers are of just under  $3,000 \text{ m}^2$ , a size considered optimum in the local office leasing market. The challenge to the structural engineer on this project was to accommodate two  $3,000 \text{ m}^2$  office towers and a  $4,000 \text{ m}^2$  column-free trading hall on a site with a total area of under  $8,000 \text{ m}^2$ . The solution was to cantilever each tower about 10 m over the trading hall, as shown in the schematic elevation in Fig. 7.

The building is constructed of reinforced concrete, except that steel framing is used for the long-span floor above the lower trading hall and the roof above the upper trading hall. The lateral load-resisting system is a shear wall core in each tower. The project was completed in two phases: Phase I consisted of one tower and the trading halls; Phase II was the second tower.

Since the office towers overhang the trading halls by 10 m, it was necessary to transfer load out of one row of exterior columns in each tower. Transfer girders or trusses spanning across the halls would have been very expensive because of the long spans involved, and would have been further complicated by the phased construction of the project. Cantilever girders or trusses supported on the first row of interior columns and extending back into the building was another possibility. But this would have resulted in a large amount of wasted space. The cantilevers would have had to extend back into the elevator cores, which would have required a larger back-to-back spacing of elevators and wasted area on all floors in the towers.

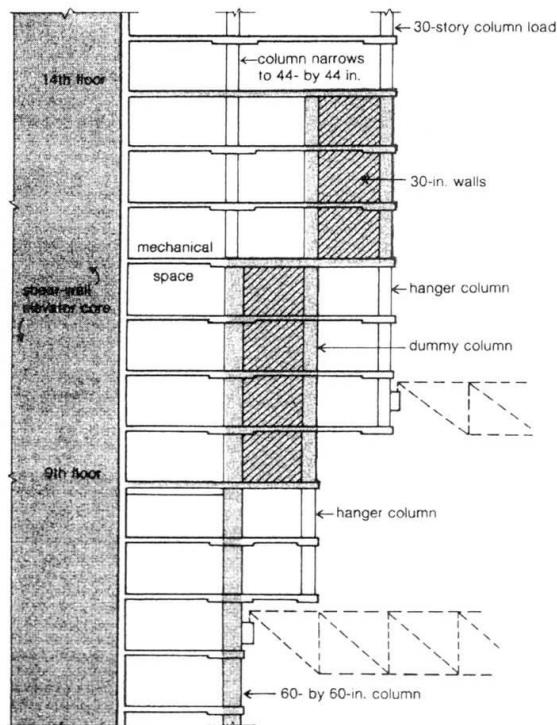


Fig. 8. Shear panel transfer system at Chicago Mercantile Exchange Center

The solution adopted was the tied-back shear panel concept explained in Section 2.1 and shown schematically in Fig. 2. The application of the concept to this project is shown in Fig. 8. The 10-m horizontal transfer is achieved 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.

One of the interesting structural engineering details in the Chicago Mercantile Exchange Center project is that the overturning moments imposed by the transfer system cause lateral deformation of the shear cores. 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.

### 3.3 Unbuilt Mixed-Use Project

This example will deal with a very large mixed-use project that involved extensive transferring of both vertical and lateral load. The project was not built, but the engineering concepts were fully developed (and tested for cost) before work was stopped.

The general layout of the project, simplified and idealized for clarity, is indicated in Fig. 9. 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. The total floor area in the project is about 500,000 m<sup>2</sup>. The project was to be constructed in two phases. The first phase, of about 250,000 m<sup>2</sup>, included the entire basement and podium (including the lower floors of all the office towers), one 40-story office tower and the hotel.

Architectural and engineering design had been completed to the point of receiving a construction manager's Guaranteed Maximum Price for Phase I when the project was stopped because of changes in market conditions.

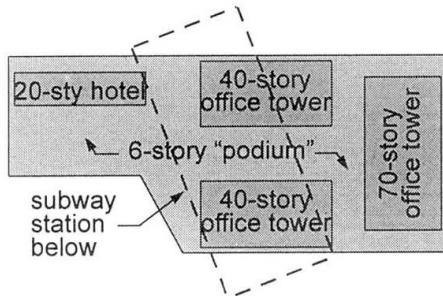


Fig. 9. Overall layout of unbuilt mixed-use project

The most obvious site-related engineering challenge on this project was the presence of a subway station running diagonally across the middle of the property (see Fig. 9). This had discouraged all previous attempts at developing the site, even though it was at a prime location. The top of the concrete roof slab of the subway station structure is about 2 m below the surrounding ground surface.

The solution to the problem posed by the subway was a grid of cast-in-place concrete transfer girders just above the station roof slab. The girders were supported on the station walls, some existing columns within the station where additional capacity was available, and new columns

inserted where possible within the station. The concept is similar to that adopted for the Morton International Building (see Section A-A in Fig. 5), 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 segments, one at each tower, as indicated in Fig. 10. This permitted the four towers to act independently in resisting lateral load, in conformance with conventional practice. But the joints gave rise to certain problems. The most obvious difficulty was that relative movement at the joints could be as much as 200 mm as the towers oscillated out of phase with one another during the design wind event. This was especially problematic in that some of the joints went right through ballrooms and other finished spaces.

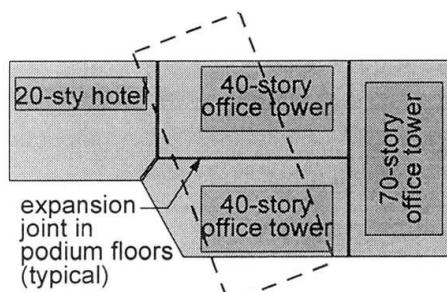
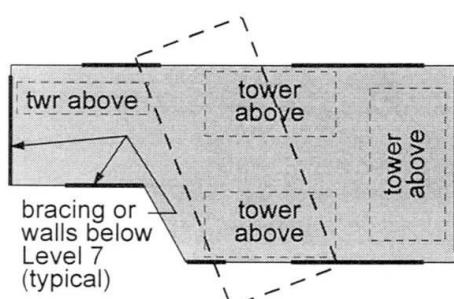


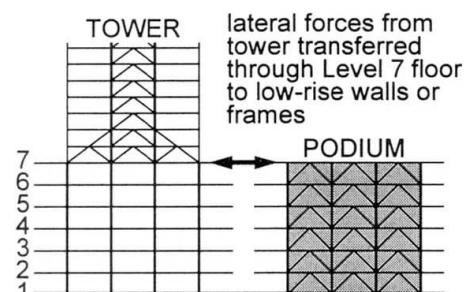
Fig. 10. Conventional expansion joint configuration

The office towers used braced-frame cores with outriggers to "supercolumns" as their lateral load-resisting systems. The initial structural design, again following conventional practice, carried the lateral forces from the towers straight down through the podium floors to the foundation. The problem here was that 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 instead of braced frames, massive steel rigid frames were proposed in the podium floors below the tower cores.

The problems posed by the large movement at expansion joints and the massive (and expensive) rigid frames below the tower cores were eliminated by a redesign that eliminated the expansion joints, causing the entire four-tower project to act as a single structure.



Shear Walls and Bracing in Podium



Lateral Force Transfer Concept

Fig. 11. Design concept with no expansion joints



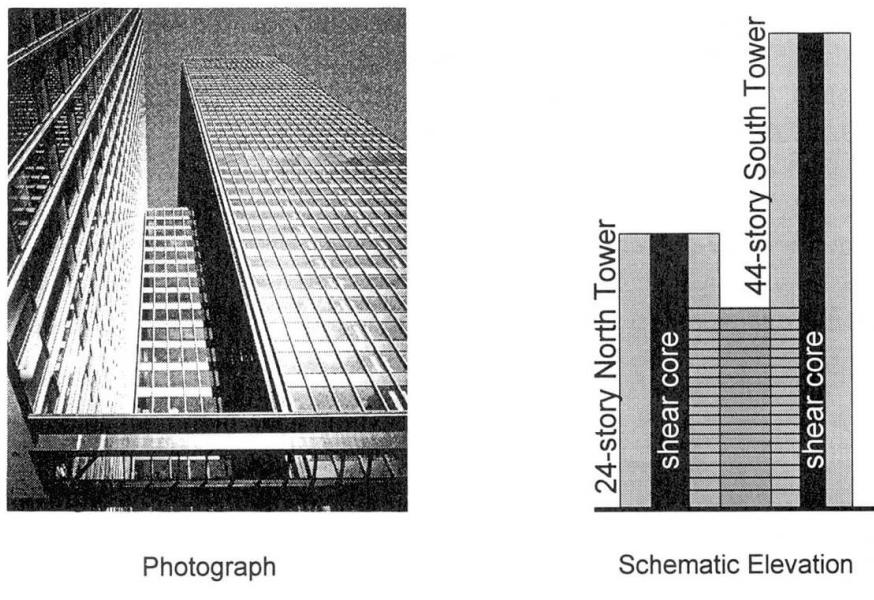
With expansion joints eliminated, a separate bracing system was not needed below each tower in the podium floors. Bracing and walls were provided wherever they would fit conveniently, scattered throughout the project, below Level 7 (at the top of the podium), as shown on the left side of Fig. 11. The Level 7 slab was designed to transfer horizontal shear forces from the tower bracing systems to the podium bracing as shown on the right side of Fig. 11.

The redesign to eliminate the expansion joints and transfer lateral loads as indicated in Fig. 11, together with a few other structural engineering refinements, reduced the estimated cost of this project by \$60 million.

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

Both towers straddle an existing commuter train station, which had to remain open throughout the construction period. A comprehensive grid of concrete girders supports tower columns and shear walls and transfers load to columns between the tracks and on the station platforms. The main subject of this discussion, however, will be not the transfer over the railway station but the linkage between the two towers. (The linked design anticipated some of the concepts proposed for the unbuilt mixed-use project discussed in Section 3.3.)



*Fig. 12. Boulevard Towers*

The 19-story infill between the two towers (see Fig. 12) links the towers structurally. There are no expansion joints between the infill structure and either tower. A joint at the infill 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. If the two towers had been structurally independent, the lateral load-resisting system of the taller tower would have been extremely inefficient and expensive. Linking the towers (see schematic elevation in Fig. 12) 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. 3, except that not all the moment is transferred from the taller to the shorter tower. However, sufficient moment is transferred that the moment in the shear core of the South Tower is greater at the 20th floor (just above the link) than further down in the building. 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.

The project was built in two phases. The shorter North Tower was built first; the taller South Tower was completed four years later. Compared to a design with the towers structurally separated by expansion joints, the linked design resulted in modest additional cost in the shorter tower and major savings in the cost of the taller tower.

#### 4. Conclusions

Innovative structural transfer systems can create opportunities for development where they didn't exist before. This is illustrated by the Morton International Building and the unbuilt mixed-use project discussed in this paper. Existing conditions at the sites of both these projects had defeated all previous attempts at development. At the Chicago Mercantile Exchange Center, an unusual transfer system made it possible to place two office towers and a trading hall where it would otherwise have been economically possible to develop only one tower adjacent to the hall. In all these situations, the purpose of the transfer system was to carry to the ground, along indirect load paths, gravity loads from floors located where they were most useful.

Structural transfer systems can also be used to transfer horizontal shear and overturning moment from one part of a project to another. Transfers of this type can produce major reductions in the cost of the overall development, as illustrated by the unbuilt mixed-use project and the Boulevard Towers buildings. In both these cases, the transfer system integrated into a single structure towers that would, in a conventional design, have behaved as independent structural units.

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



## 5. References

1. "Confident Times Revisited: Morton International Building," by John Morris Dixon, *Progressive Architecture*, July 1991, pp. 94-98.
2. "Unique cantilevers carry 400,000 sq ft of tower," *Architectural Record*, November 1983, pp. 136-139.