

BRACING SYSTEMS

For low-rise buildings the most common structural solution is obtained by integrating two different load resisting systems in the same structure:

Semi-rigid or pinned frames, which resist vertical actions only.

Steel bracings or concrete walls and cores, which resist horizontal actions.

For high-rise buildings (up to 120 stories), different structural systems are used according to the height range:

1. Up to 30 stories, concrete wall or core systems.
2. From 30 to 60 stories, frame systems.
3. Above 60 stories, tube systems.

For 'braced' steel frames, different types of bracing can be used according to the structural and functional requirements.

Appropriate calculation models for multi-storey buildings can be used for pin-ended structures and truss bracings.

For seismic resistant steel structures, an excellent performance in terms of strength and ductility can be obtained.

The design requirements in such cases correspond to three given limit states: serviceability, resistance to damage, and prevention of collapse.

The innovative structural system of the John Hancock Center consists of a bearing structure around the perimeter which behaves as a framed and diagonal tube.

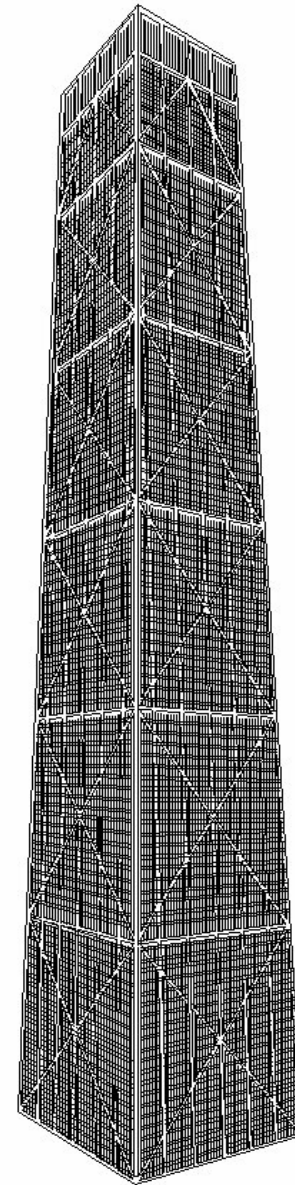


Figure 2 John Hancock Centre, Chicago

The twin towers had a square plan and their structural system was a 'tube in tube' system, because it was made of an external skin with very close steel columns (framed tube) and an internal core where all vertical facilities were concentrated (stairs, elevators and so on).

This concept allowed the building to reach 104 stories and 411 meters of height

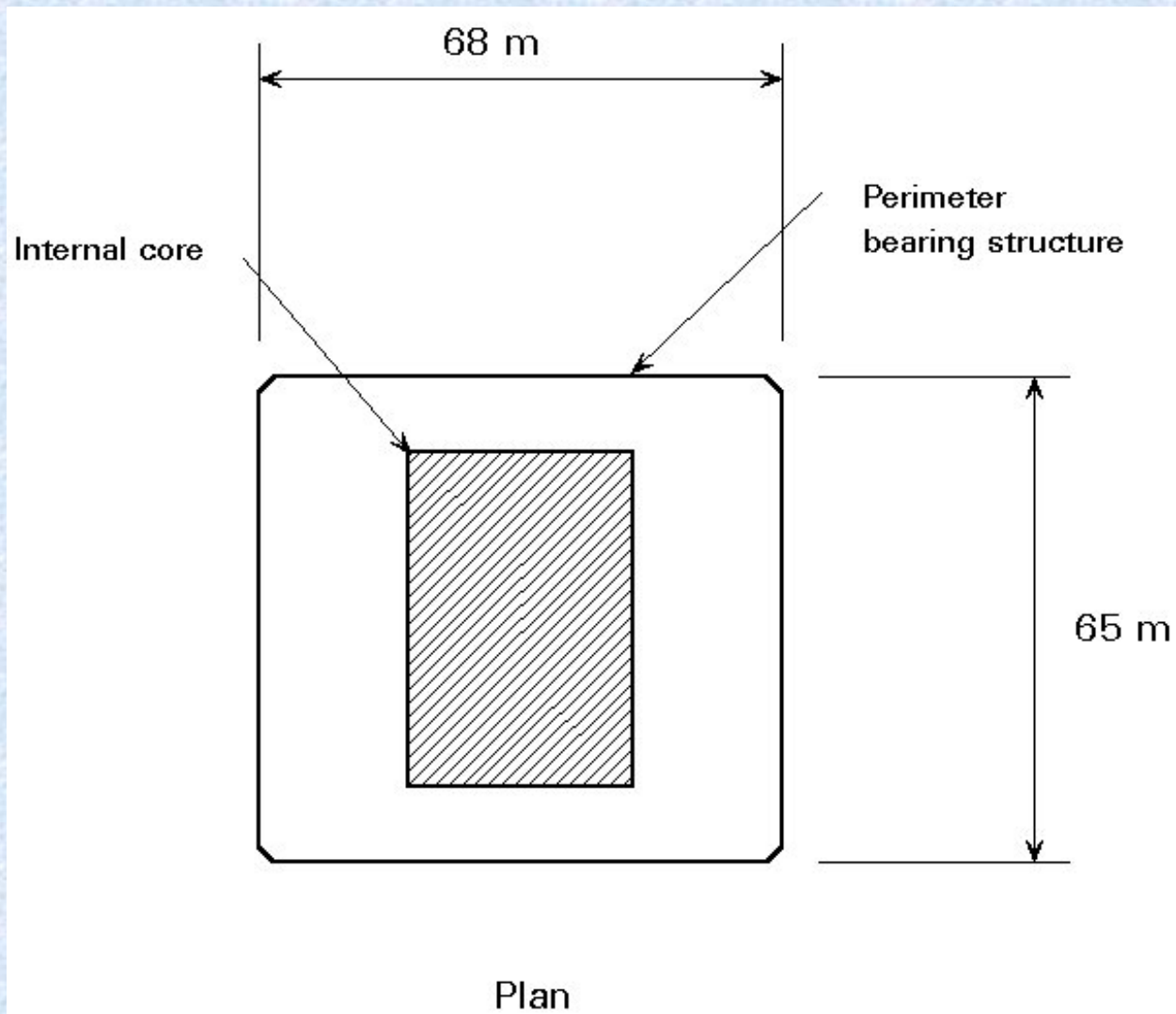


Figure 3 World Trade Centre, New York

The structural system of 'Sears Tower' in Chicago consists of an external framed tube located on the perimeter together with three horizontal trusses, which act as ring belts.

A feature of the building is the reduction of its plan area with the height, which transforms the base square into a quasi-rhombic shape, a cross shape and finally a rectangular shape at the top of the building.

The variation of the resisting cross-section makes this structure similar to a big cantilever with variable section.

It is interesting to observe that the perimeter structure is made of completely prefabricated elements of three spans and two stories in height which characterize the facade (Figure 4b).

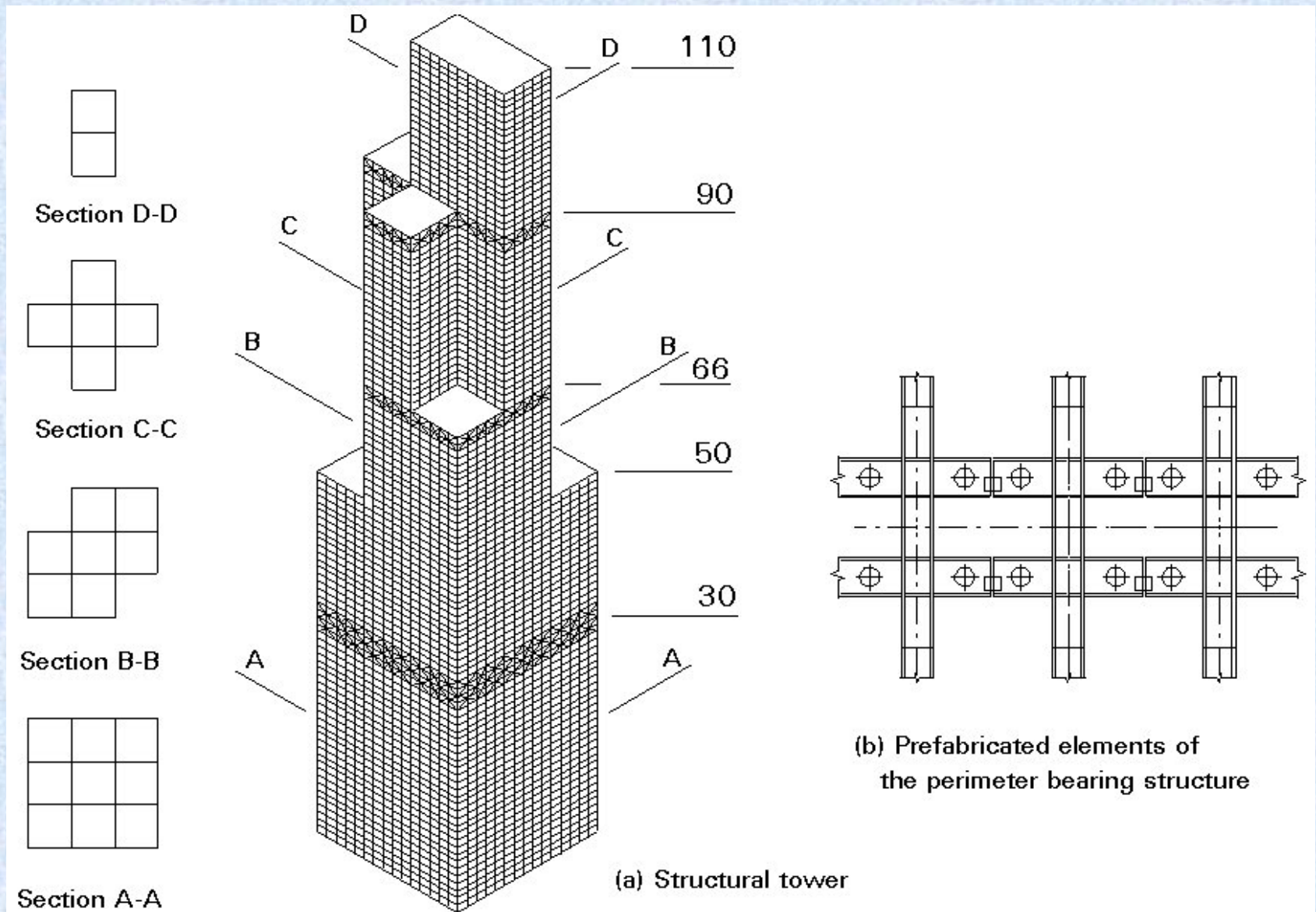


Figure 4 Sears Tower

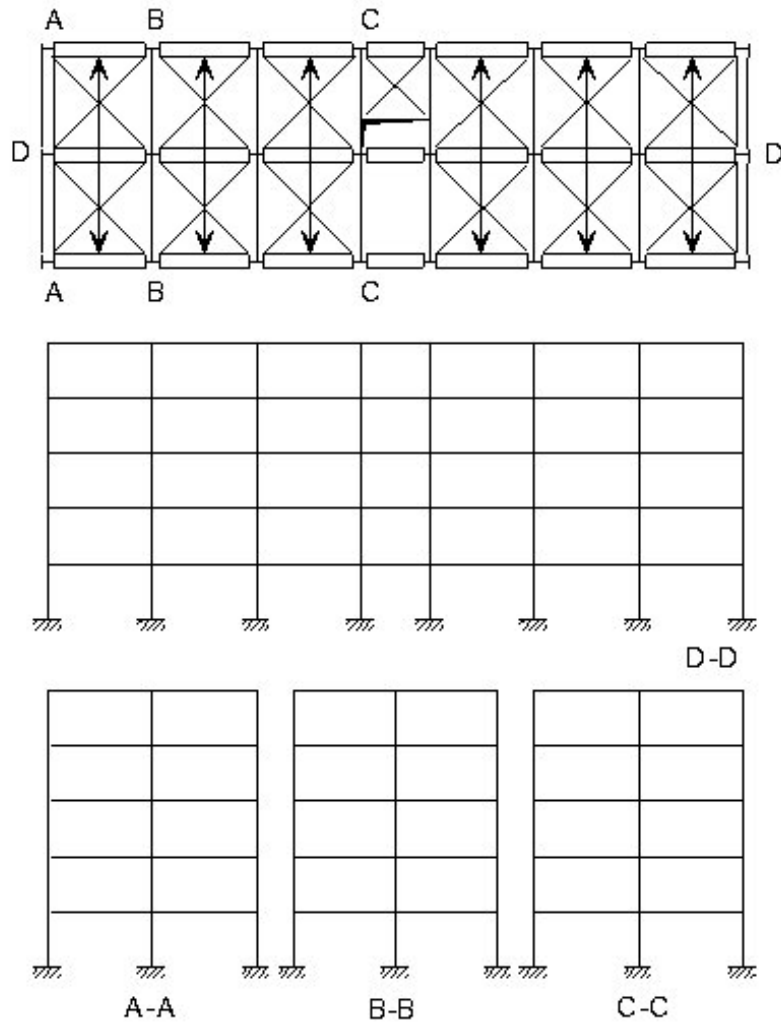
THE MAIN FEATURES OF LOW-RISE STEEL BUILDINGS

The simplest way to resist both vertical and horizontal loads is to use moment resisting frames (cases 1 and 5 of Figure 5), with floor structures oriented in transverse and longitudinal directions.

This solution is not the most economical, because it requires beams and columns with different cross-sections at the various levels.

In addition, it is susceptible to too large sway deflections when the no. of stories is greater than 4 or 5.

① Longitudinal rigid frames
Floors arranged transversely



② Longitudinal frames with braced cantilevers
Floors arranged transversely

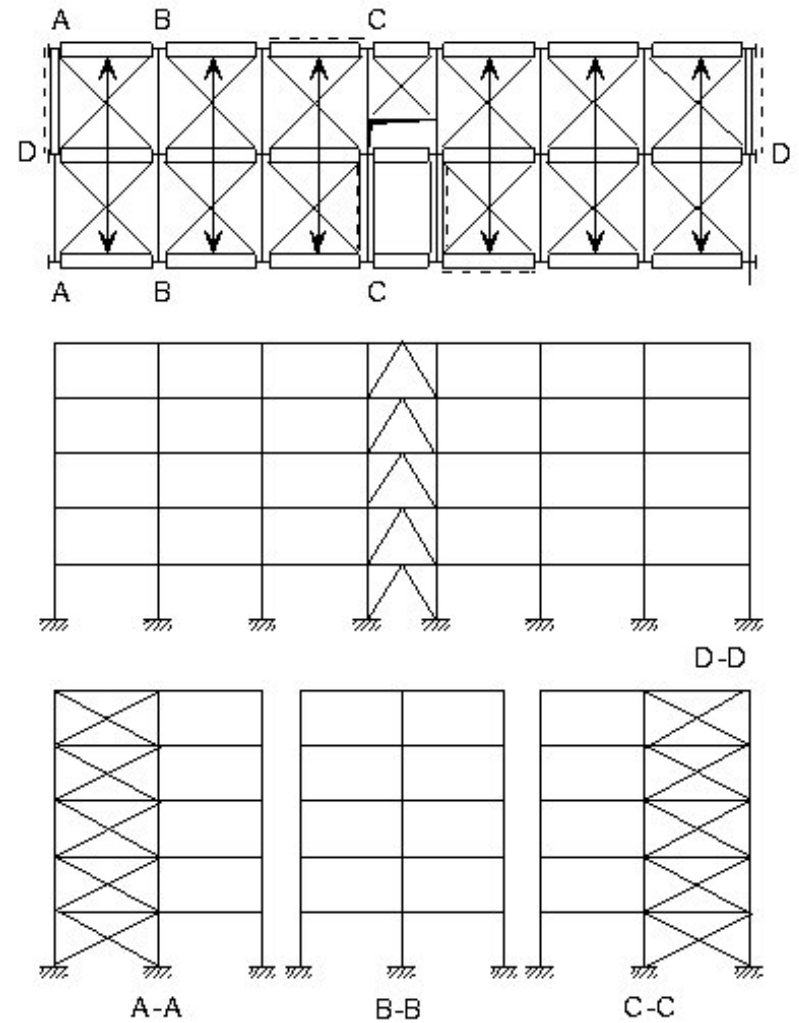
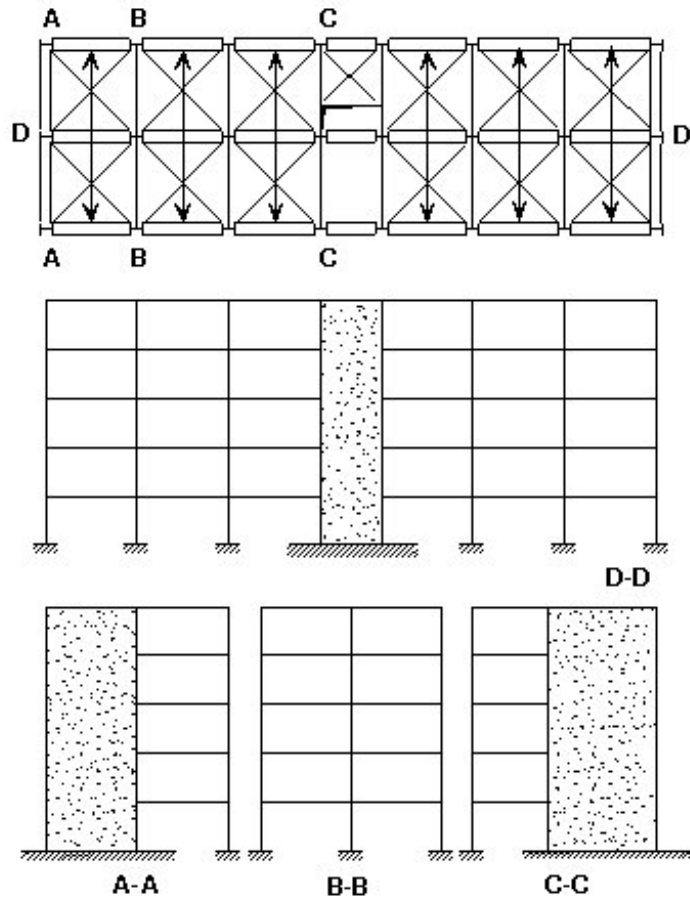


Figure 5 Structural systems for low-rise steel buildings

- ③ Longitudinal frames with concrete walls or core
 Floors arranged transversely



- ④ Longitudinal frames with bracing as ① ② & ③
 Floors arranged longitudinally

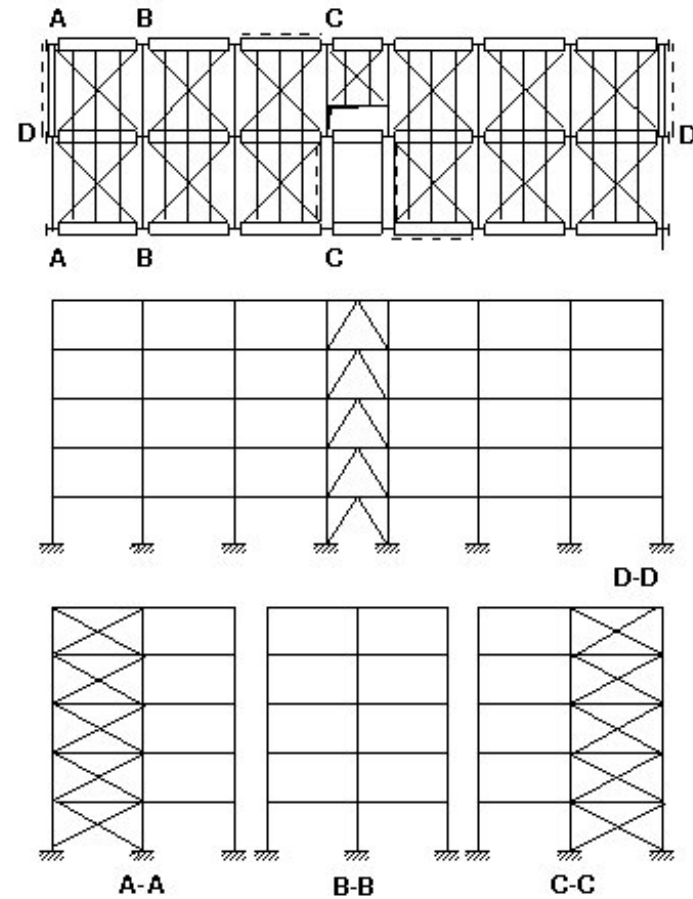
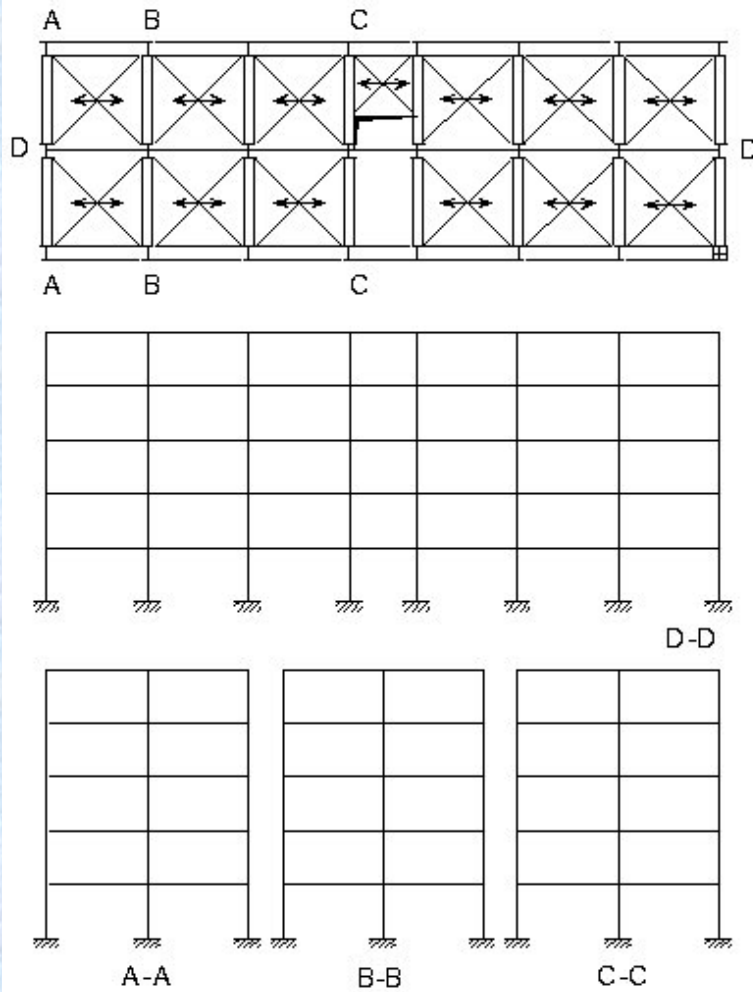


Figure 5 Structural systems for low-rise steel buildings (cont.)

⑤ Transverse rigid frames
Floors arranged longitudinally



⑥ Transverse frames with braced cantilevers
Floors arranged longitudinally

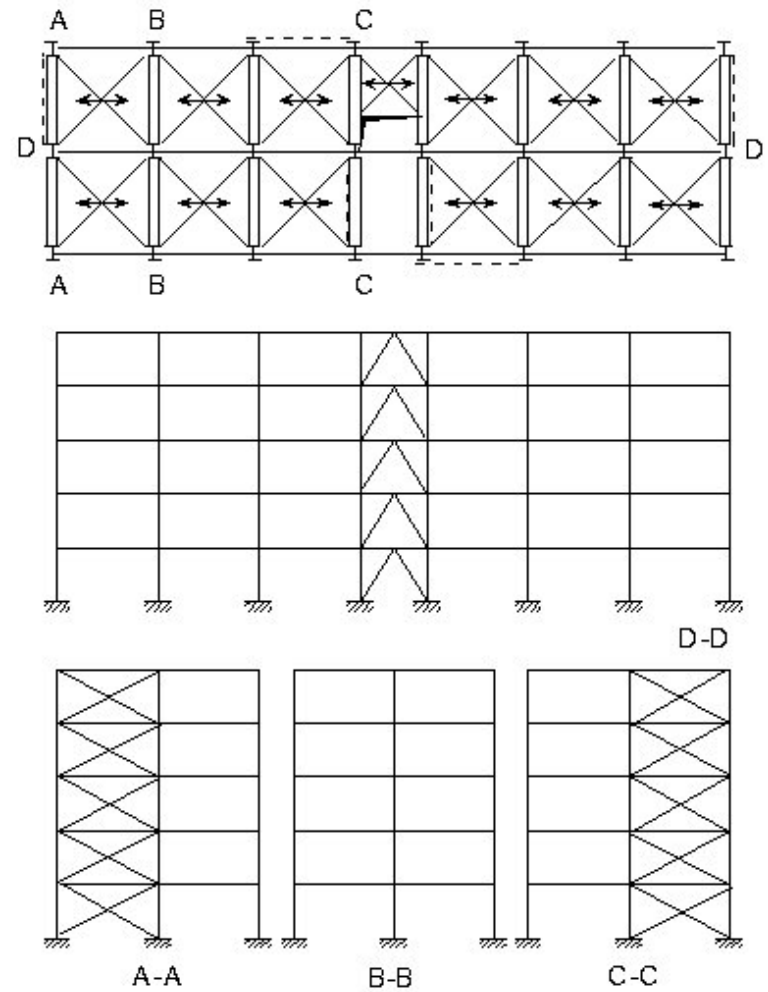
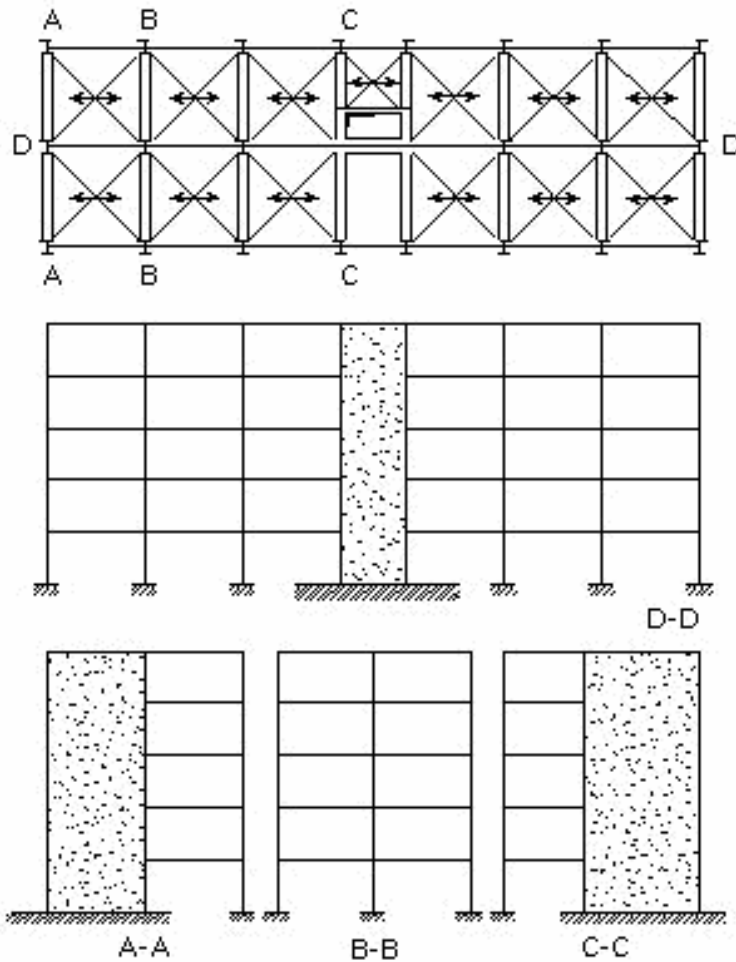


Figure 5 Structural systems for low-rise steel buildings (cont.)

⑦ Transverse frames with concrete walls or cores
Floors arranged longitudinally



⑧ Longitudinal frames with bracing as ⑥ or ⑦
Floors arranged transversely

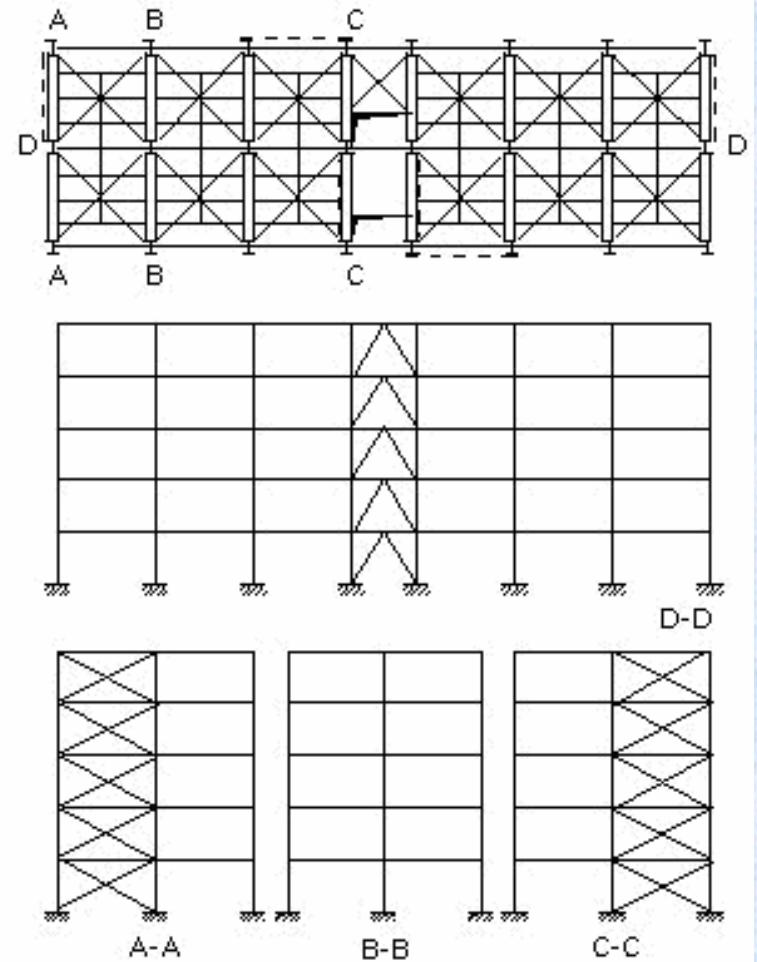


Figure 5 Structural systems for low-rise steel buildings (cont.)

A better solution is obtained by the use of two different structural systems in the same building (cases 2, 3, 4, 6, 7, 8 of Figure 5), i.e.:-

- a) semi-rigid or pinned frames, which resist vertical actions only.
- b) steel bracings or concrete walls and cores, which resist horizontal actions.

Both systems are connected together by means of floor structures, which provide a rigid diaphragm at each storey level. The main advantage of this solution is to unify the shapes of all beams independently of the floor level.

The first example of the use of the 'fourth dimensions of steel construction' was the IBM Building in Pittsburgh, built in 1965 with three different kinds of steel for the bars of the external lattice bracing, (Figure 6).

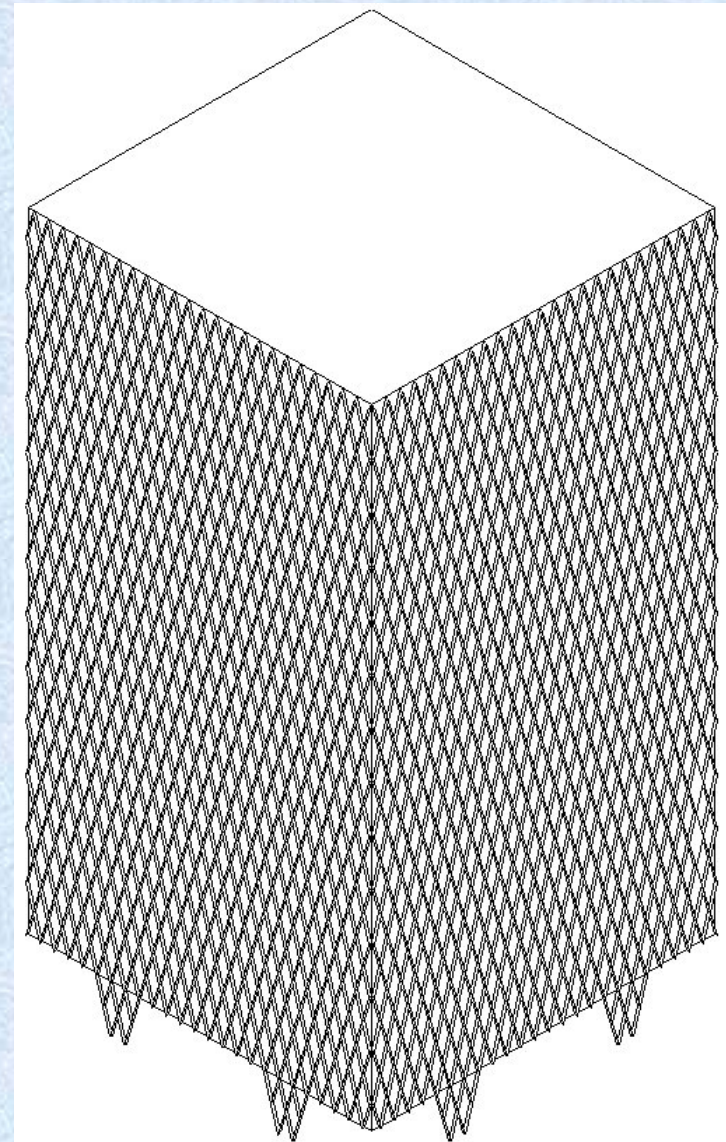


Figure 6 IBM building, Pittsburgh

STRUCTURAL SYSTEMS FOR HIGH-RISE BUILDINGS

The structural system of a high-rise building must resist both gravity and lateral loads.

As the height of the building increases, the lateral loads gradually dominate the structural design.

Figure 7 compares some steel structural systems on the basis of the structural efficiency, which is measured by the weight of the building.

Framed tube structures could be conveniently used in high-rise buildings up to 20 stories.

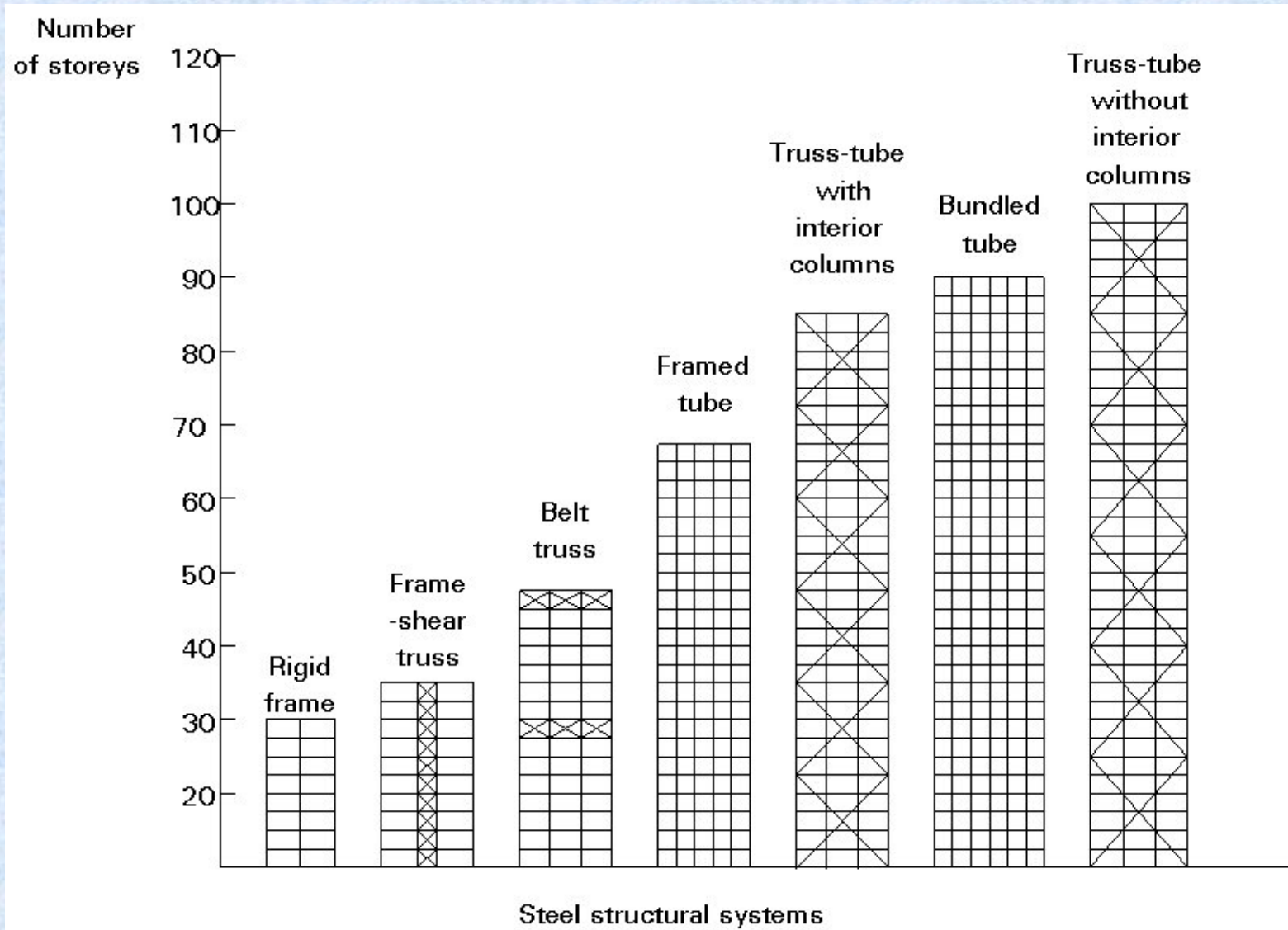


Figure 7 Steel structural systems and the number of storeys

Lateral loads due to wind and earthquake produce lateral accelerations.

As people normally perceive these accelerations during service conditions, stiffness rather than strength tends to become the dominant factor in buildings of great height.

The serviceability limit state can, therefore, be more important than the ultimate limit state.

Four overall groupings of structural systems may be identified.

They are:

- a. Bearing wall system
- b. Core system
- c. Frame system
- d. Tube system.

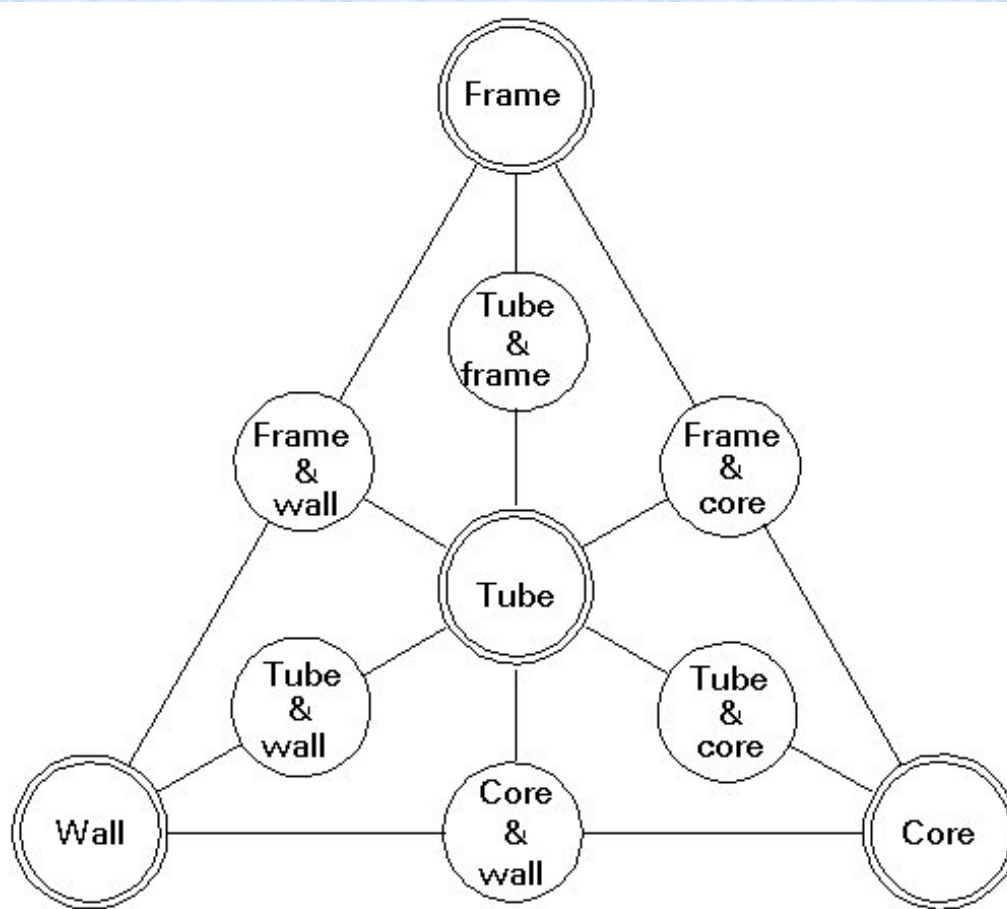


Figure 8 Classification of structural systems of multi-storey buildings [Drosdov, Lishak-1978]

The idea that steel components can be assembled in various forms to constitute an overall 3-D system which can efficiently resist wind forces as a total system began to emerge in the 1960's.

The main proponent of this design trend was Fazlur Khan who systematically pursued a logical evolution of high-rise systems based on the premise that different height ranges demand a new composition of steel framing.

Many systems were devised, such as Truss-Frame Interacting Systems, Tubular Systems, Bundled Tubular Systems, Mixed Systems, etc.

A trend in the last decade has been to design buildings that are shaped both in plan and profile in a variety of ways to respond to urban grid and subjective aesthetic criteria.

A brief discussion of the generic high-rise steel systems is given below followed by some consideration of the design of ultra high-rise systems.

The system descriptions are conceptual in nature.

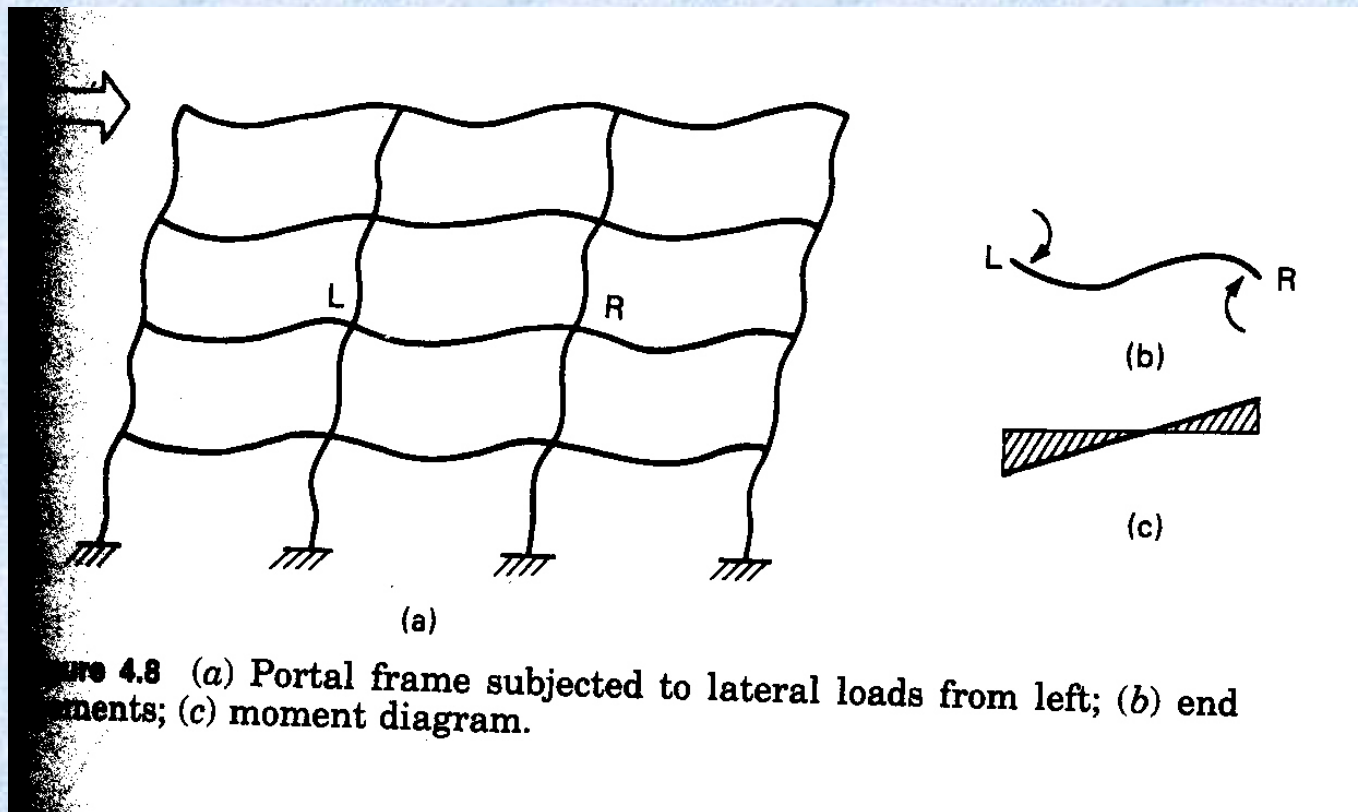
The height ranges (number of stories) referred to in this Lecture for the various framing options relate to American practice and American site dimensions.

As slenderness is a significant parameter, the width of the building should be taken into account in assessing the suitability of a particular bracing option for a building of a given height.

The steel systems developed between 1960 to 1975, fit a logical evolutionary pattern with one development leading to another, each new system being a link in the process.

Although the primary motivation for these developments was structural efficiency, the systems offered great opportunities for Structuralist facade architecture.

The windward moment acts in a direction opposite to the gravity moment, while the leeward moment acts in the same sense as the gravity moments.



Braced Frames

Pure rigid frame systems are not sufficient for buildings higher than about 30 stories because the shear racking component of deflection produced by the bending of columns and girders causes the building drift to be too large.

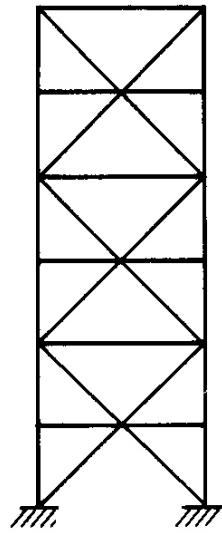
The efficiency is improved by adding truss members such as diagonals between the floor systems.

Bracing types available for incorporation into the structural system range from a concentric simple K or X brace between two columns to knee bracing and eccentric bracing with complicated geometry requiring computer solutions.

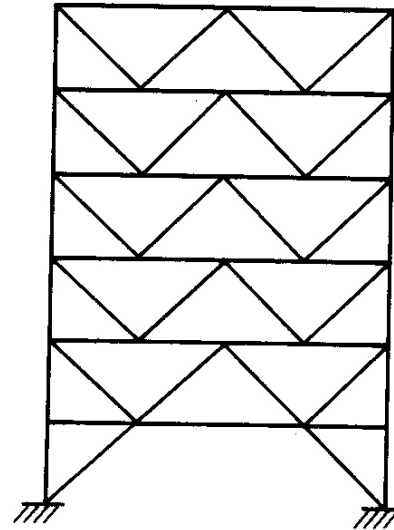
In an eccentric bracing system the connection of the diagonal brace is deliberately offset from the connection between the beam and the vertical column.



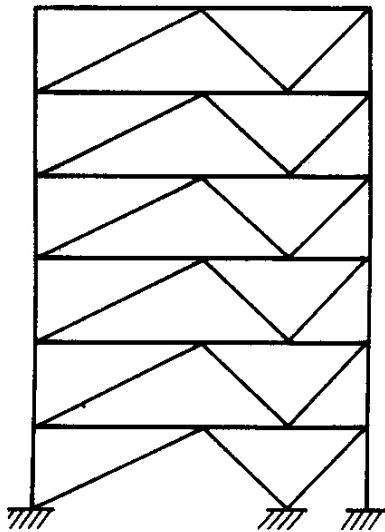
Figure 4.16 Inverted K bracing with double-angle connections.



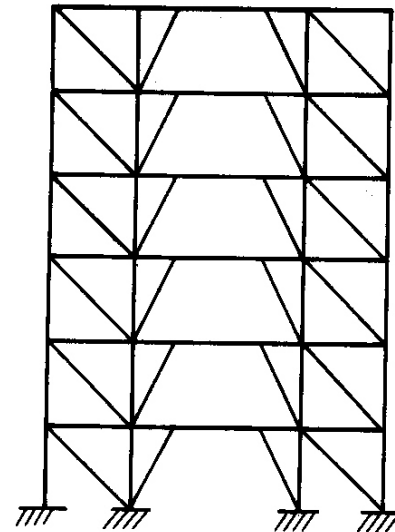
(a)



(b)



(c)



(d)

Figure 4.17 Common types of braced frames.

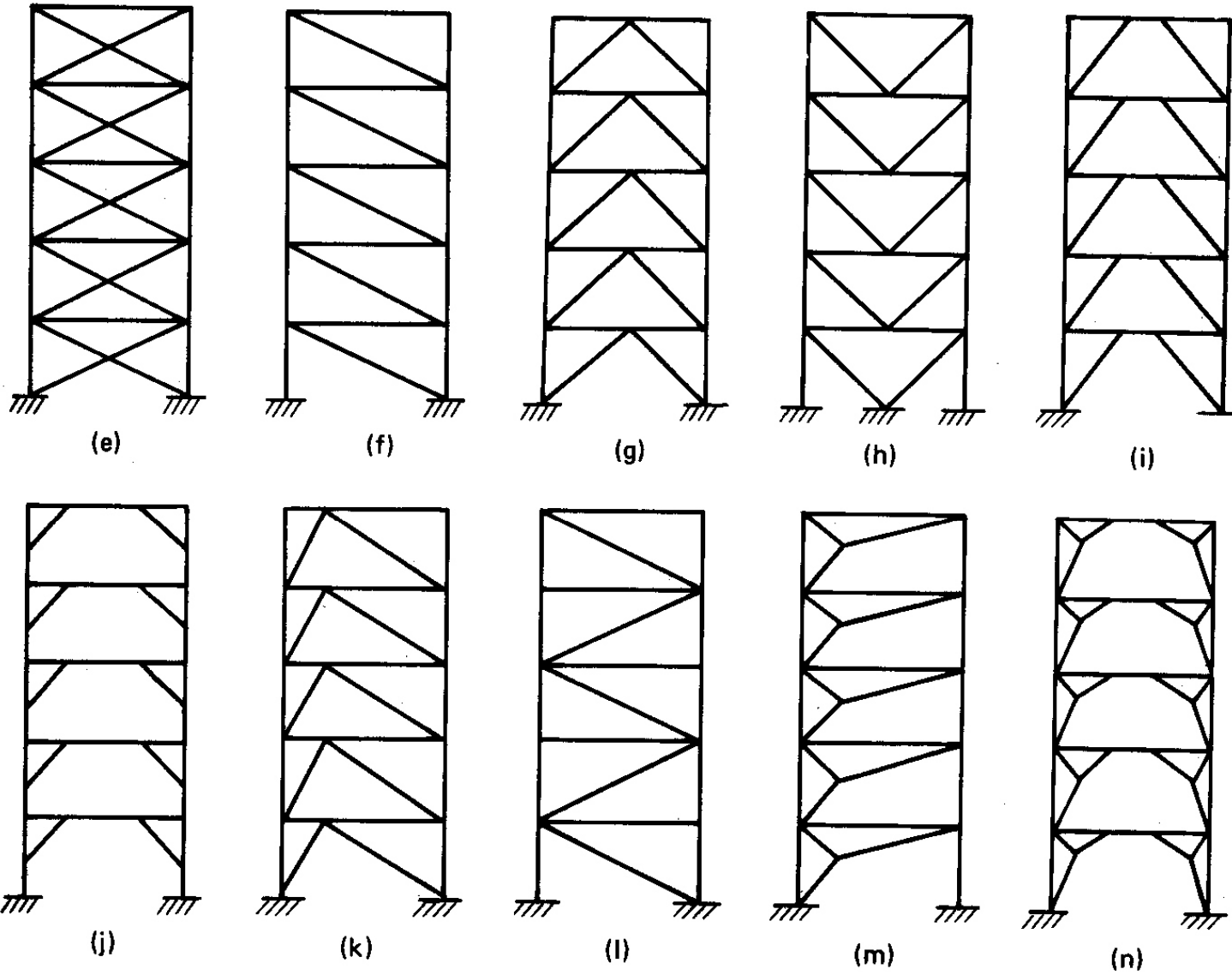


Figure 4.17 (Continued)

Staggered Truss System

Using staggered trusses, as shown in the next slide, the required flexibility in unit layouts is achieved by arranging the trusses in a staggered plan at alternate floors.

The floor system acts as a diaphragm transferring lateral loads in the short direction to the trusses.

Lateral loads are resisted by truss diagonals and are transferred into only the direct / axial loads in the columns (without moments).

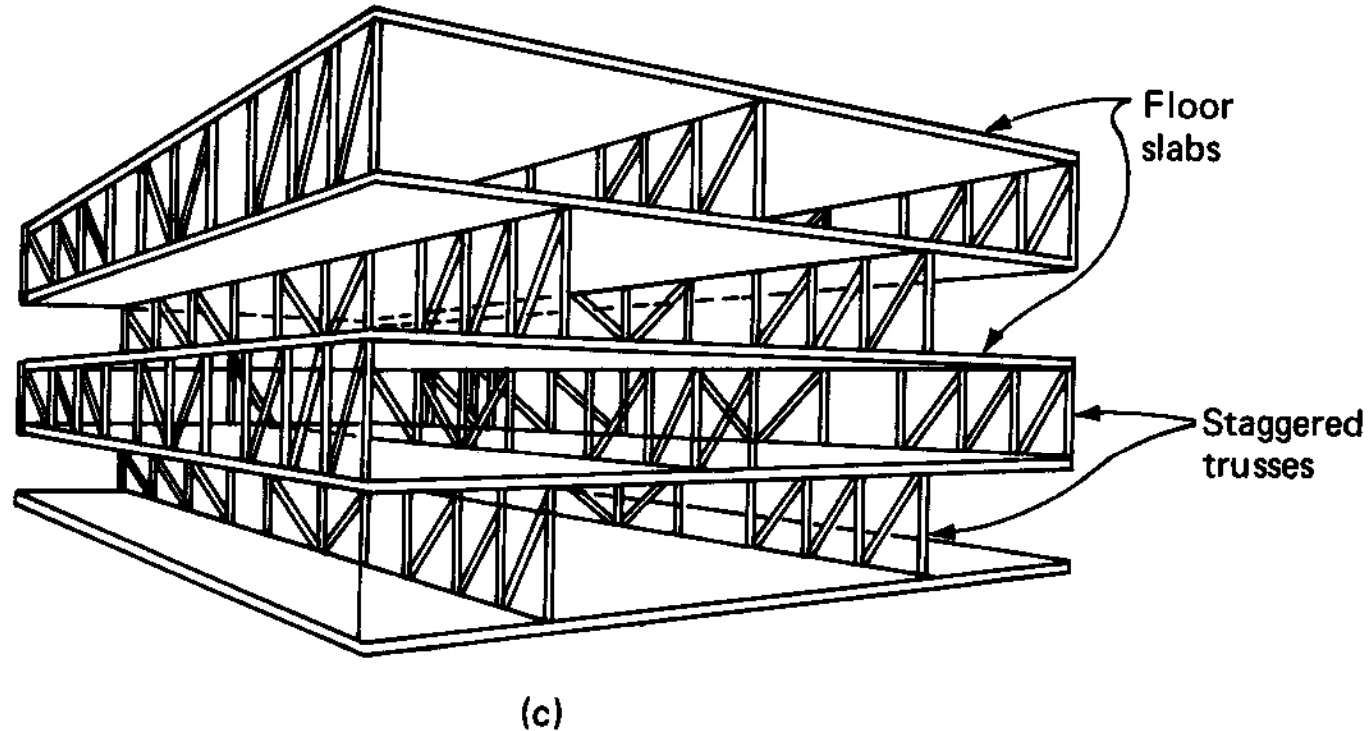


Figure 4.18 Staggered truss system. (a) Hotel plan showing layout of guest rooms; (b) arrangement of staggered trusses; (c) perspective view of truss arrangement.

Shear Frame Systems

Shear frames or Vierendeel frames, in which beams and columns are rigidly connected to provide moment resistance at joints, are placed in two orthogonal directions to resist wind forces in each direction.

The efficiency of development of lateral stiffness is dependent on bay span, number of bays in the frame, number of frames and the available depth in the floors for the frame girders.

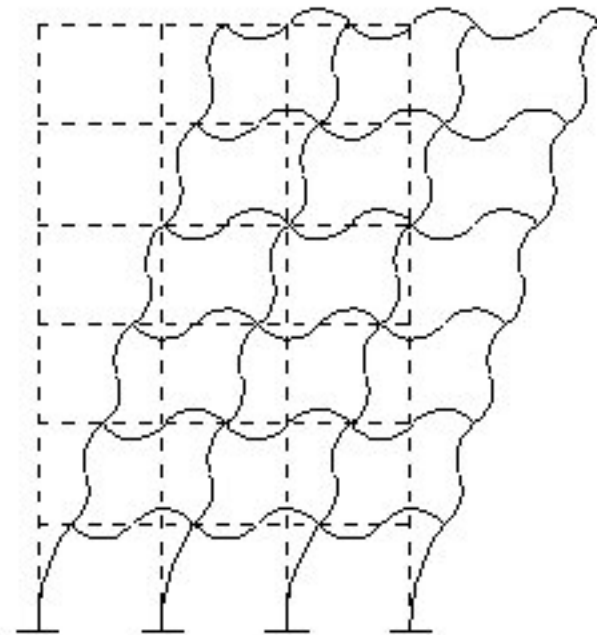
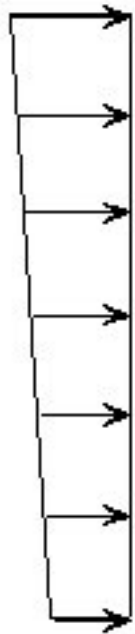
Bay dimensions in the range of 6m to 9m are commonly used.

In these shear frames; the predominant contribution to sway deflection under wind load comes from the bending of beams and columns due to the wind shear and to a smaller extent, from column shortening or the cantilever component (Figure 2).

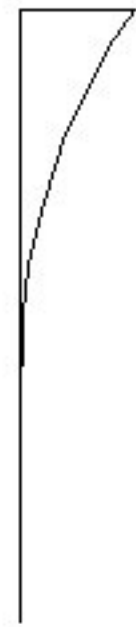
The design of these frames is controlled therefore by the bending stiffnesses of individual members.

The deeper the member, the more efficiently the bending stiffness can be developed.

Wind pressure



Shear sway
(80-90%)



Column shortening component
(20-10%)

(a)

(b)

Figure 2 Frame sway

In current practice, buildings with pure shear frames are generally restricted to only a few stories in height, since other more efficient forms are available.

However, the uncluttered rectilinear Vierendeel form may still be preferred in cases where other forms involving diagonals or trusses may interfere with architecture and space planning.

The basic inefficiency in shear frame buildings arises from the need for moment-connected rigid joints which are expensive to fabricate, in addition to the steel quantities involved.

Shear Truss and Frame System

Shear trusses can be provided in the vertical direction, if the organization of the core permits such an arrangement.

In general, building core elements including elevator banks are centralized and will permit core trusses connecting columns in at least one direction.

These trusses combined with perimeter shear frames produce a Shear Truss and Frame System (Figure 3).

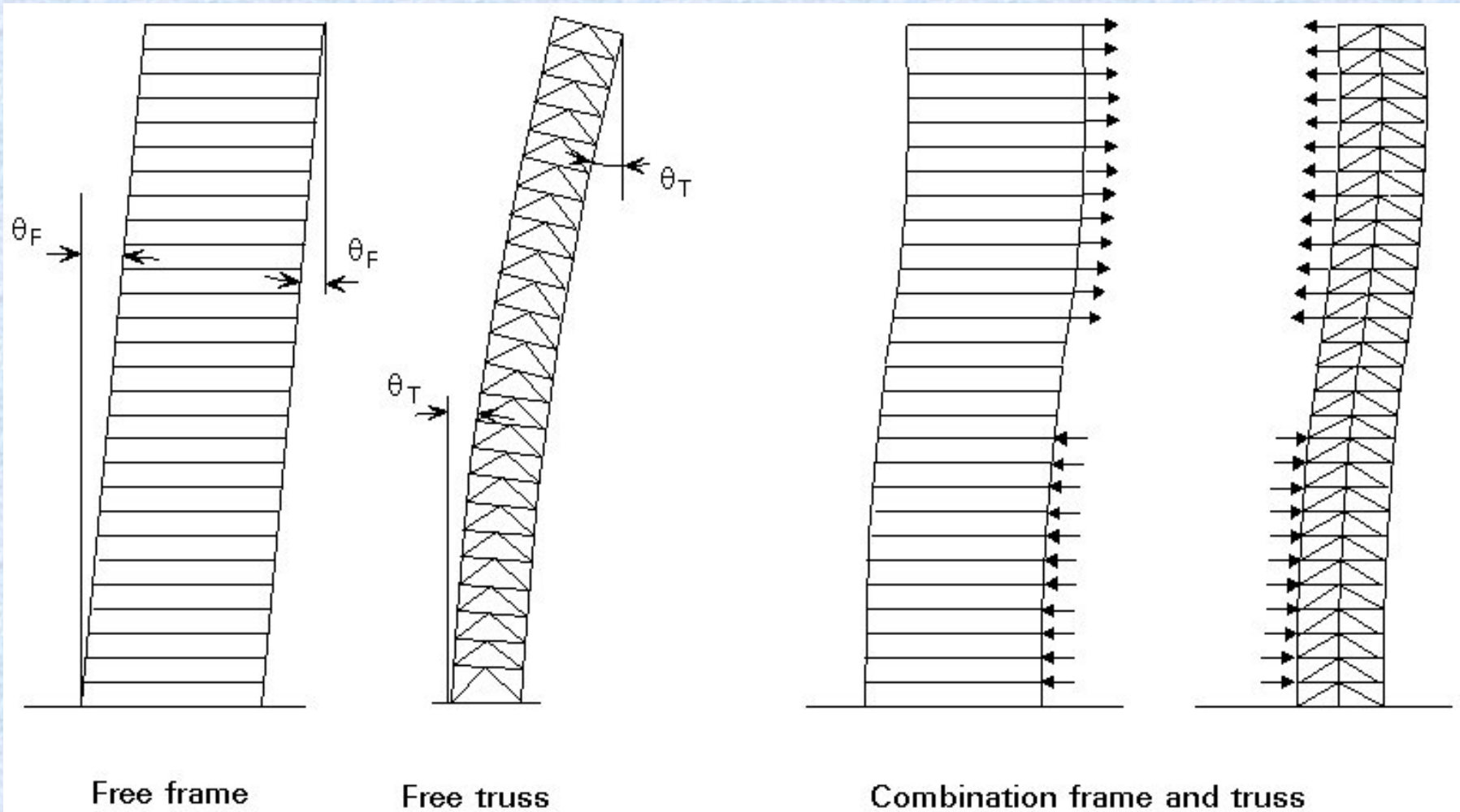


Figure 3 Frame-shear truss interaction

There may be other interior frames which participate as well.

This type of interacting system has a wide range of application in structures from 10 to 40 stories.

Particular coordination with respect to providing access into the core needs then to be considered.

The combination of the Shear Frame and vertical braces produces interaction of two modes of behavior, that of a Shear Frame and a Cantilever (Figure 3).

This combination produces desirable results in the stiffness efficiency of the overall system.

Vertical trusses resist wind forces as a cantilever and therefore provide lateral stiffness more efficiently than shear frames.

However, the depth available to the truss (dependent on the planning of the core area) determines the overall effectiveness of the system.

For the truss bracing K-forms, X-forms or single brace forms can be used.

The K-form is common since the bracings do not participate extensively in carrying gravity load, and can be designed for axial forces due to wind without gravity axial forces.

In the X and single brace forms, gravity axial forces may dominate in the design of braces.

In general, Shear Truss and Frame Systems produce the most economical steel structural system for buildings up to 30 stories in height.

Frames, Vertical Trusses, Belt and Outrigger Trusses

The exterior fascia shear frames and the vertical trusses in the core can be tied together by a system of outrigger and belt trusses which are provided at plant room levels, where the trusses will not interfere with the interior space planning.

The primary result of the outrigger trusses is the development of axial forces in the exterior columns due to wind action.

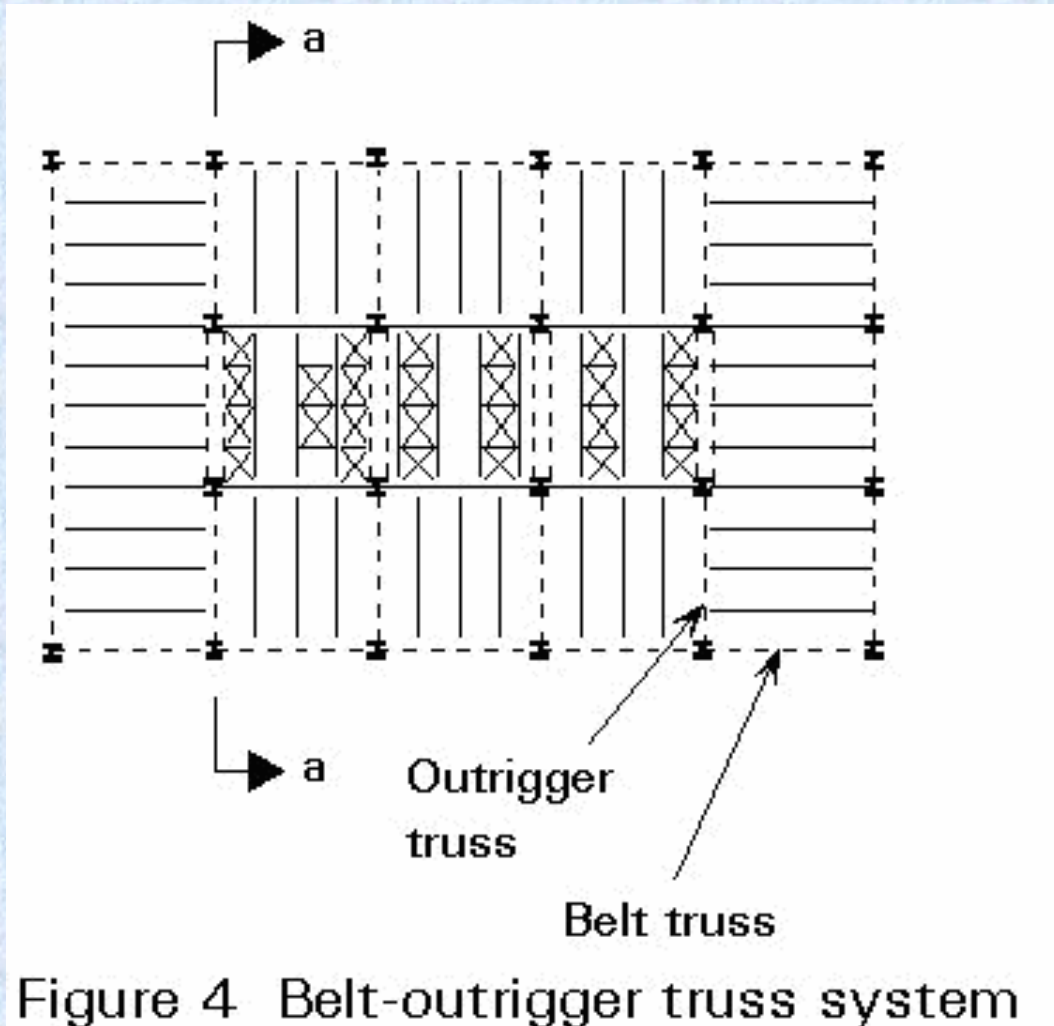
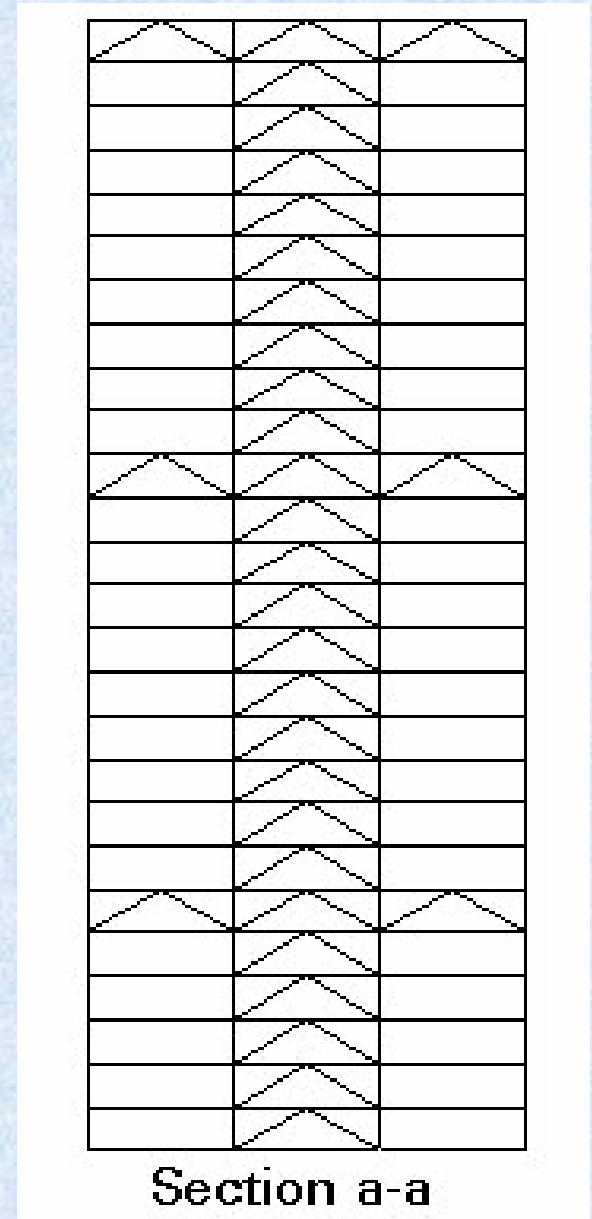


Figure 4 Belt-outrigger truss system



Section a-a

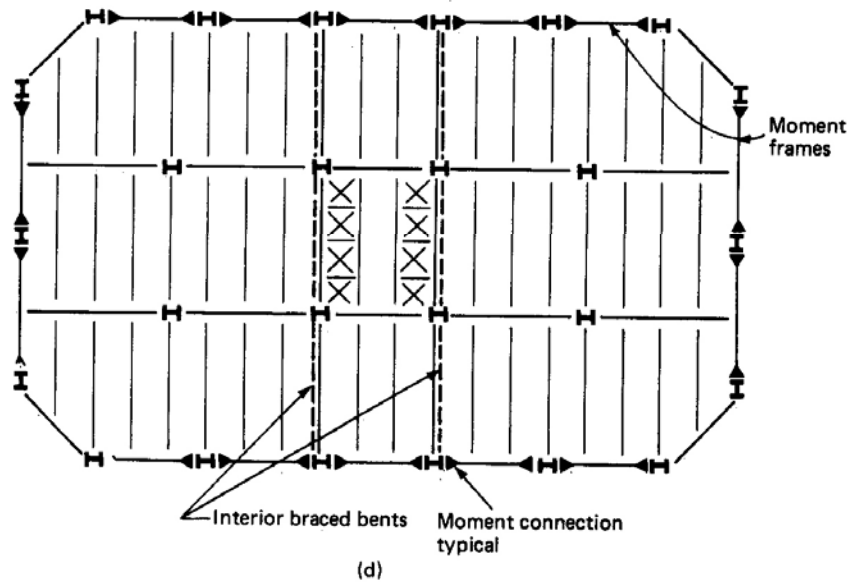
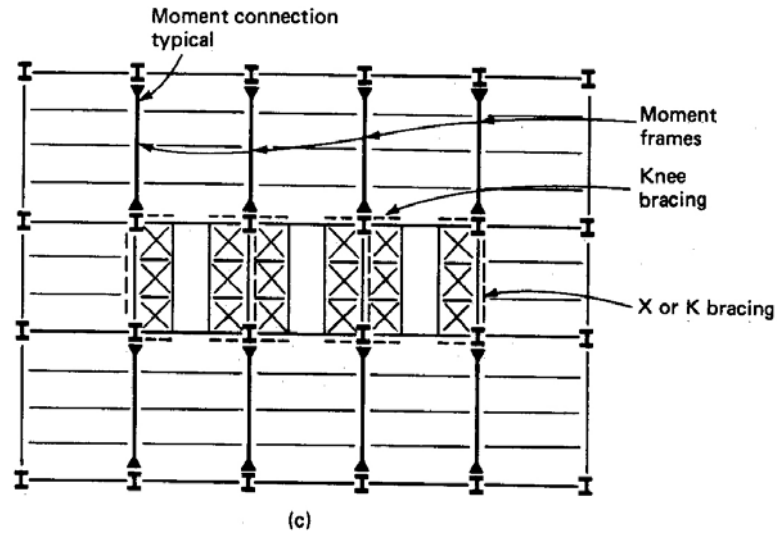


Figure 4.24 (Continued) (c) Braced core and interior frames; (d) full-width interior bracing and exterior frames.

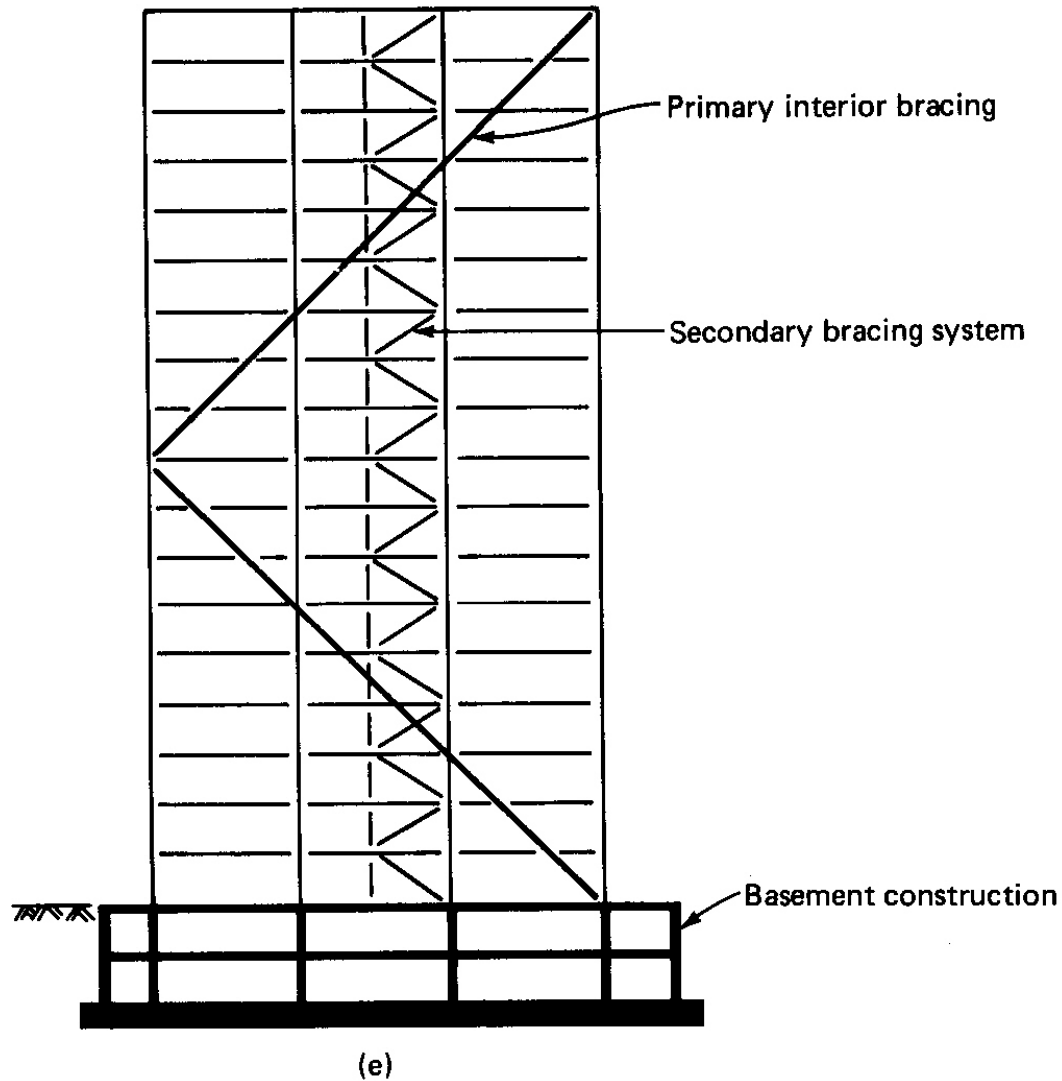


Figure 4.24 (Continued) (e) Transverse cross section showing primary interior bracing, secondary bracing, and basement construction.

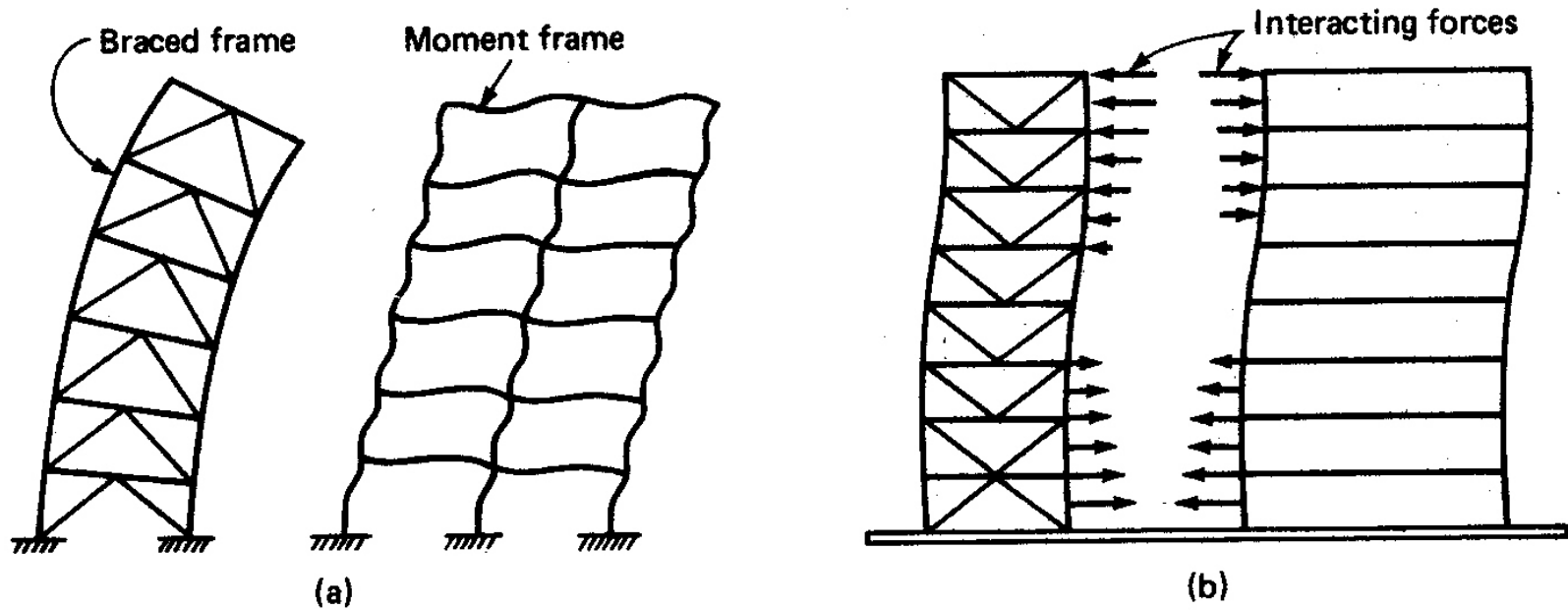


Figure 4.25 Interaction between braced and unbraced frames. (a) Characteristic deformation shapes; (b) variation of shear forces resulting from interaction.

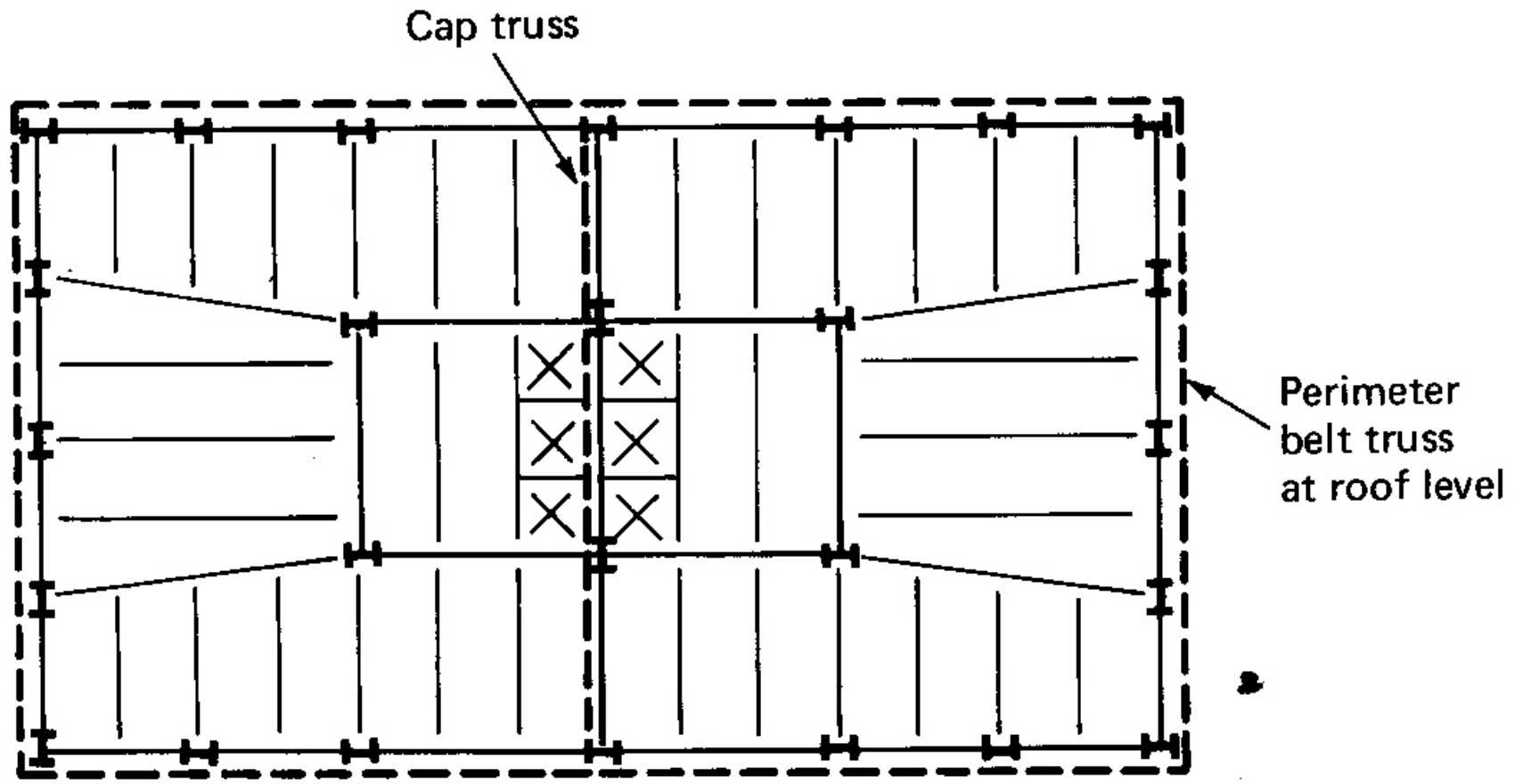


Figure 4.26 Building floor plan showing cap and belt trusses.

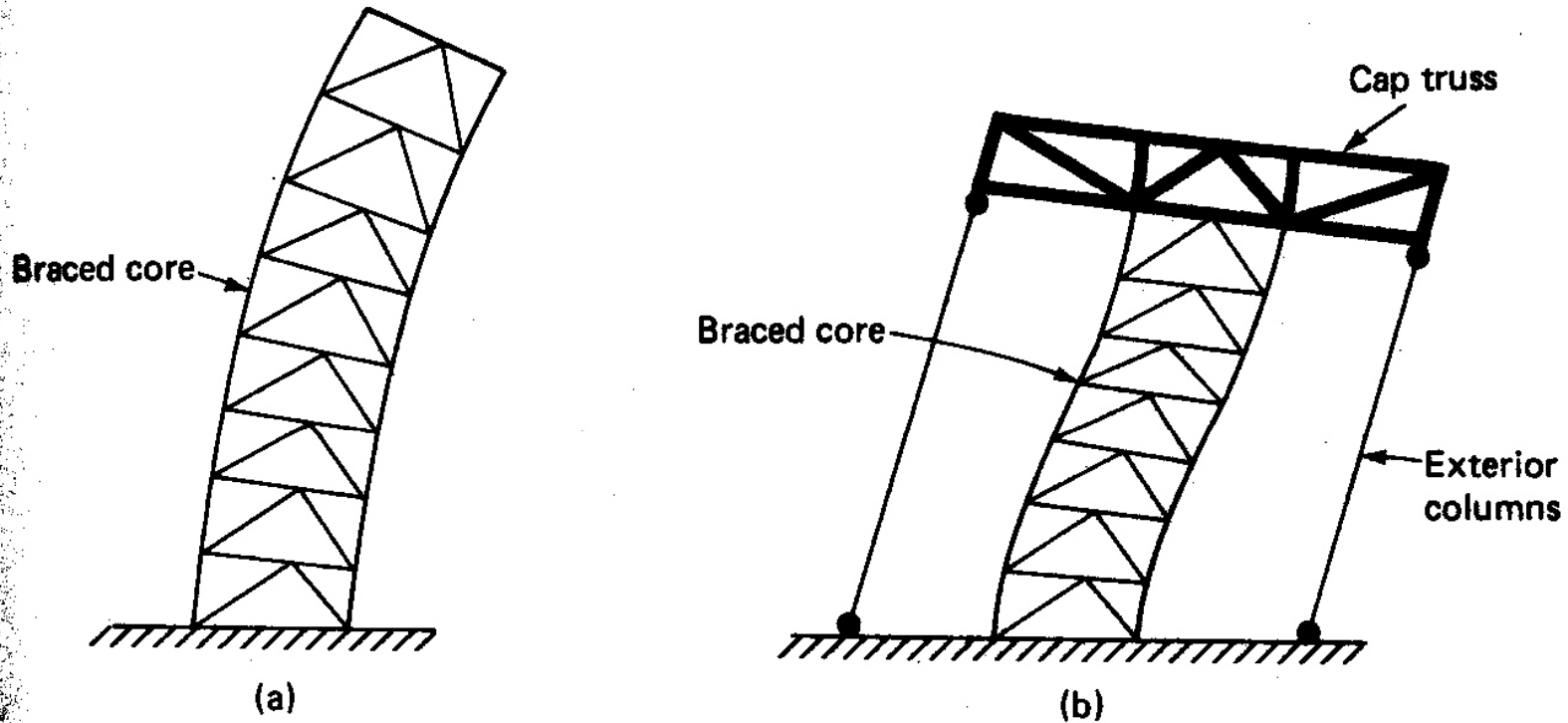


Figure 4.27 (a) Cantilever deflection of core; (b) reversed curvature induced by cap and belt trusses.

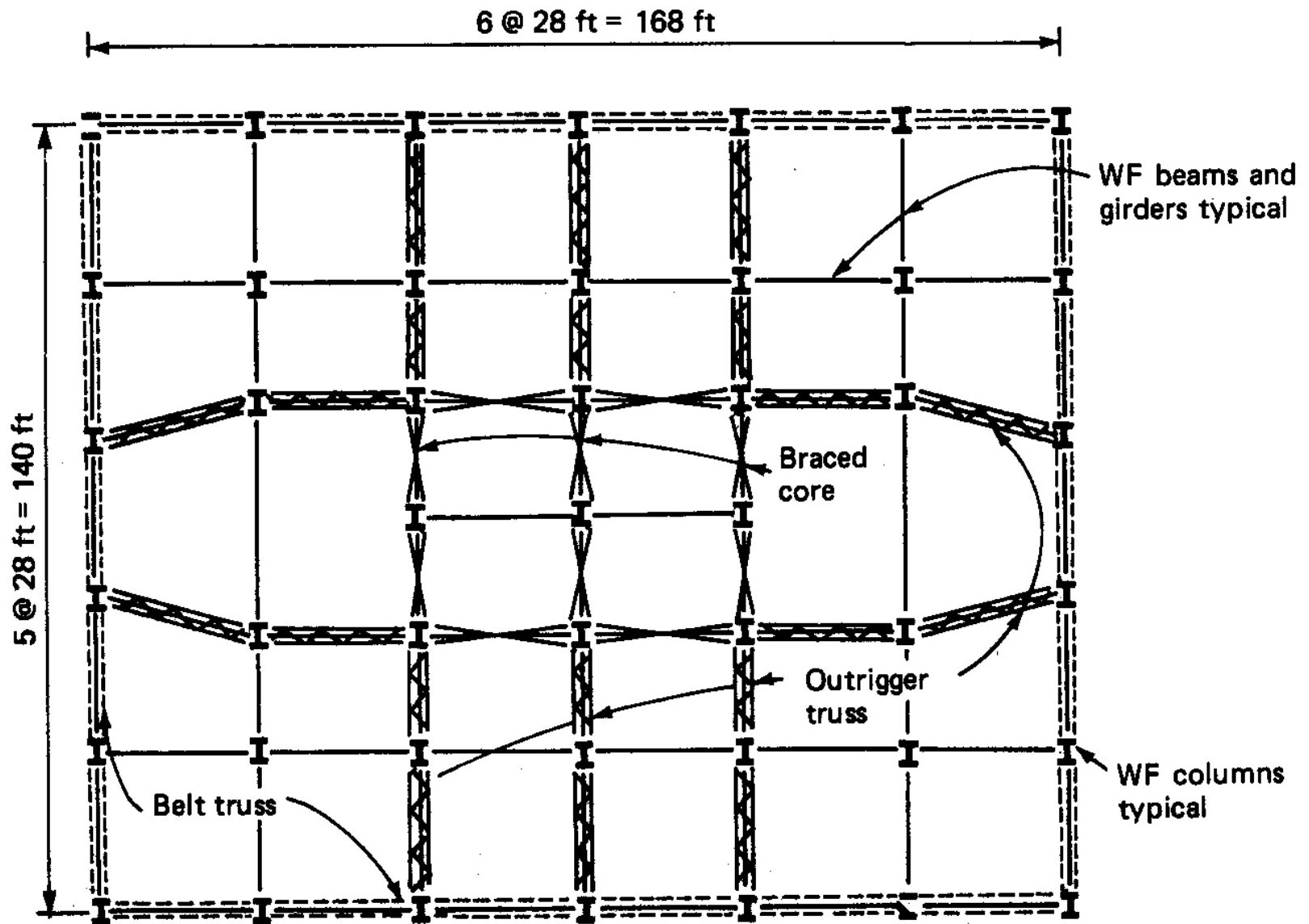


Figure 4.28 Belt truss structure framing plan.

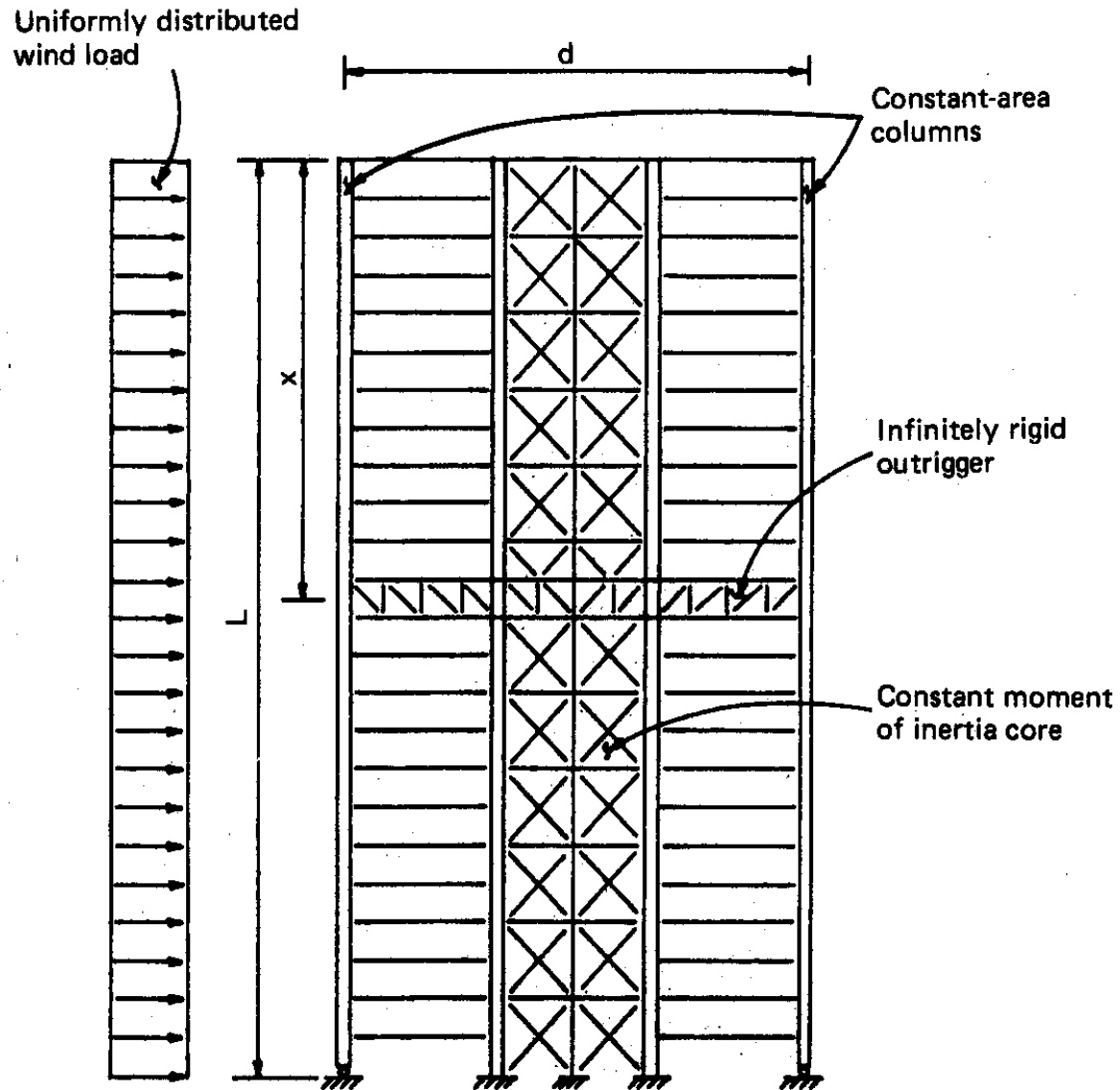


Figure 4.29 Simplified analytical model for single-outrigger system.

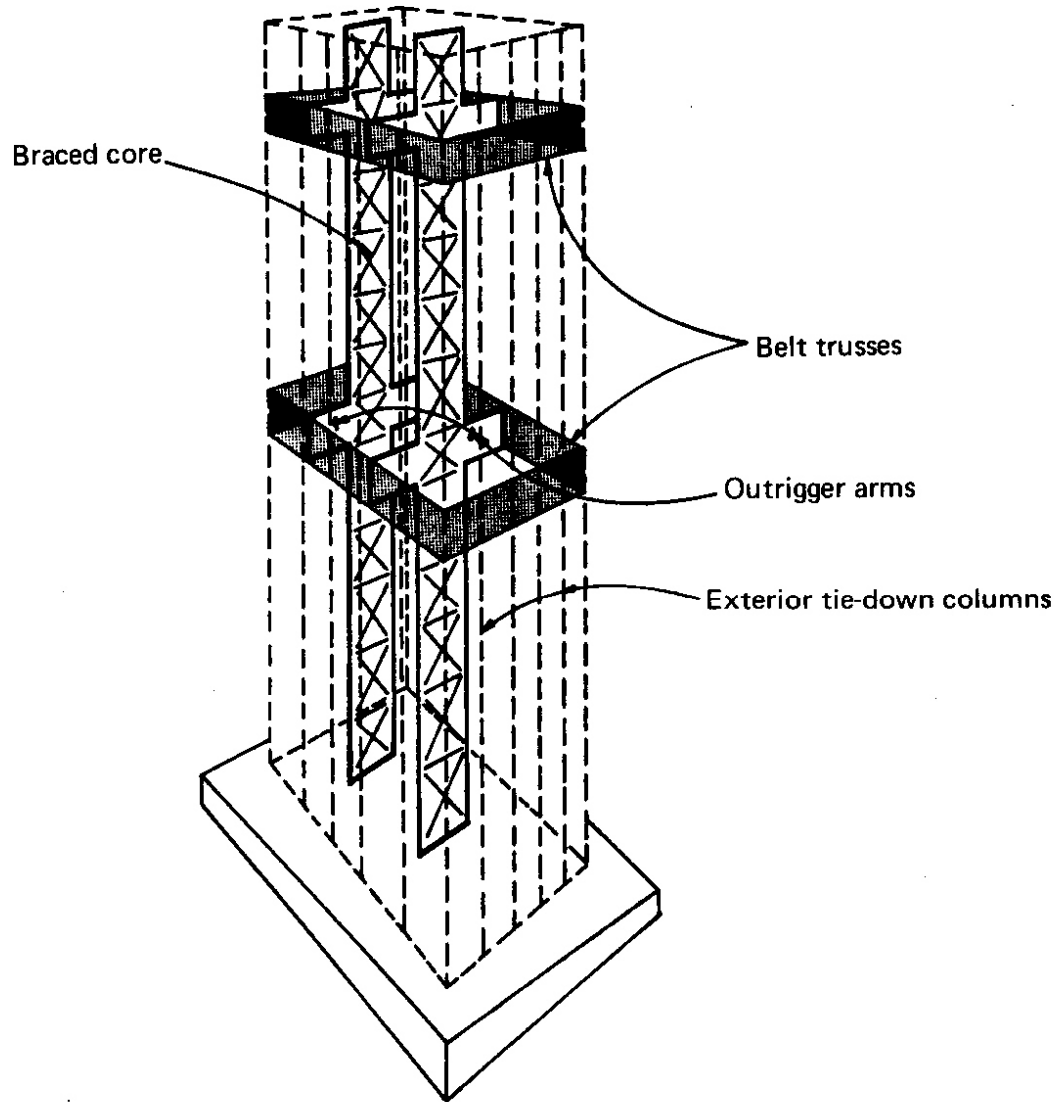


Figure 4.31 Schematic elevation of two outrigger and belt truss system.

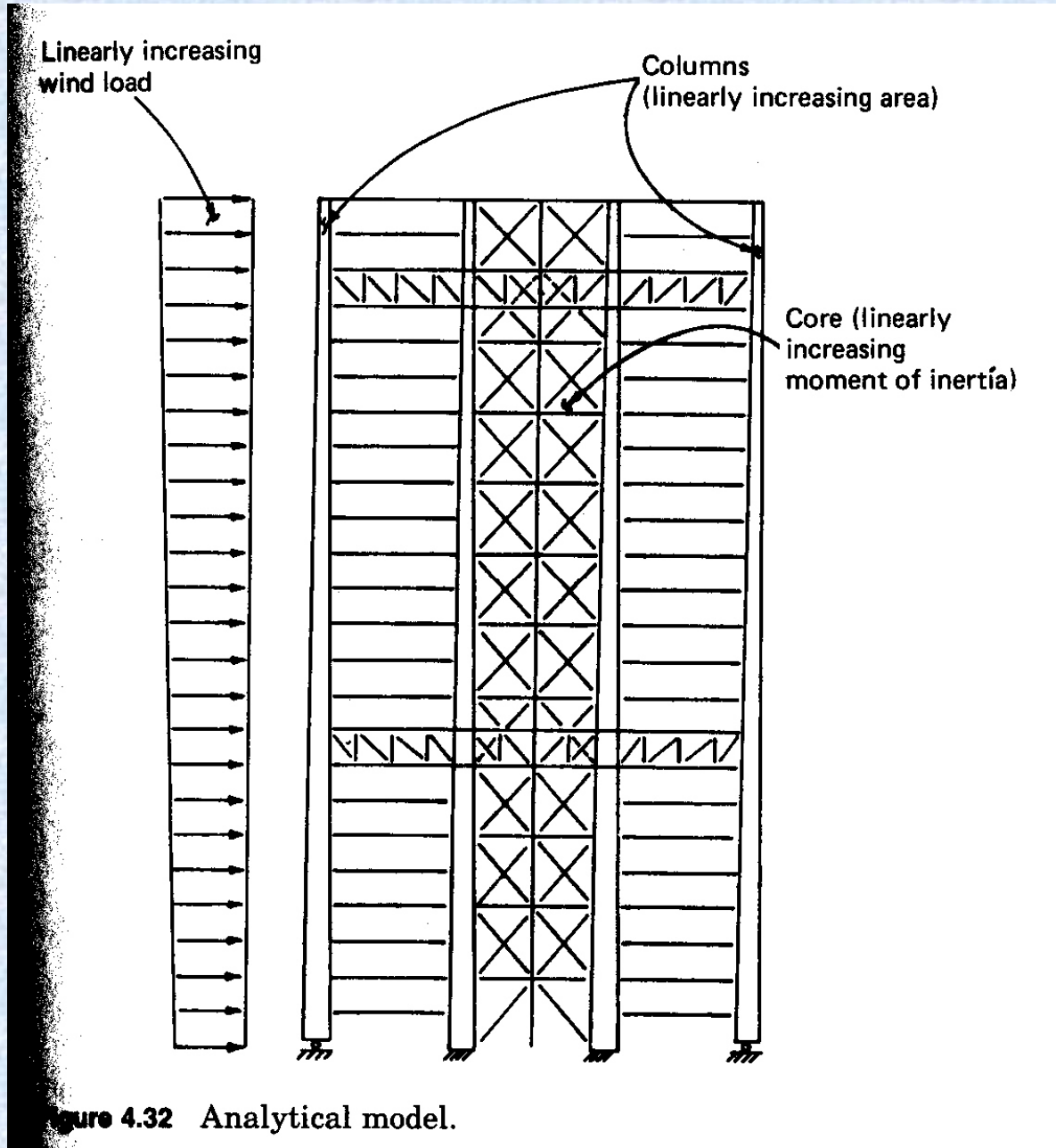
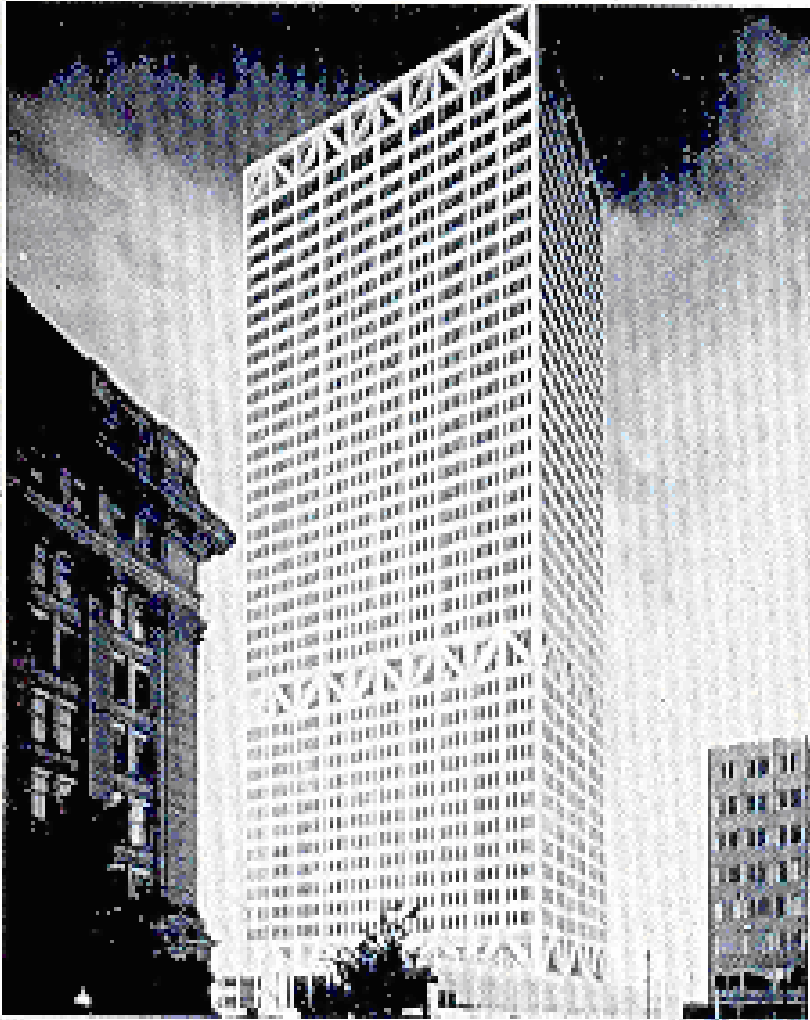
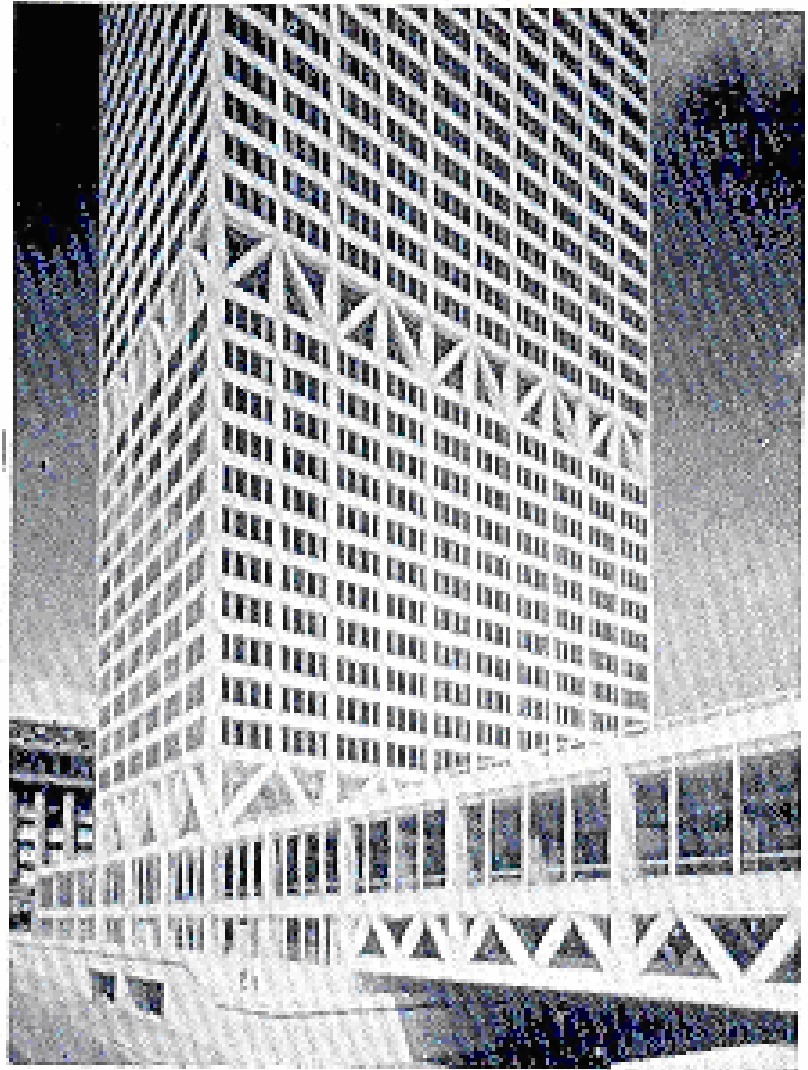


Figure 4.32 Analytical model.



(a)



(b)

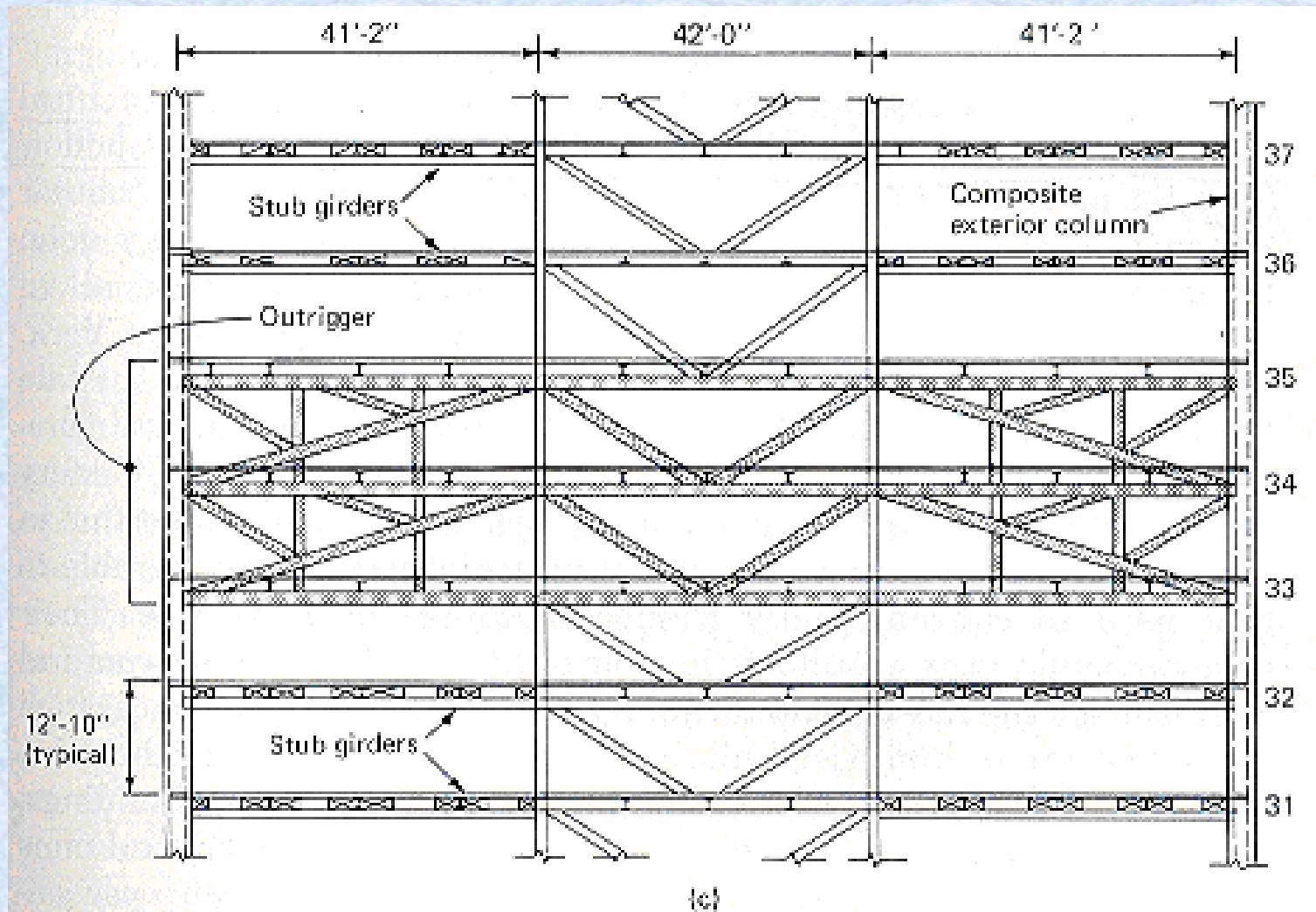


Figure 4.35 (a and b) Photographs of First Wisconsin Center, Milwaukee. A system of outriggers and belt trusses interacting with moment frames constitutes the lateral bracing system (Architect/Engineer, Skidmore, Owings & Merrill, Chicago); (c) schematic framing elevation of outrigger truss for One Houston Center project (Structural engineers, Walter P. Moore and Associates).

Outrigger trusses run parallel to the direction of lateral force.

Belt trusses run perpendicular to the direction of the lateral force, along the perimeter of the building.

This behavior significantly improves the lateral stiffness under wind forces.

The use of belt trusses on the facades, at the same level and perpendicular to the outrigger trusses, further enhances participation of exterior frames in the cantilever behavior.

The belt trusses transform the two-dimensional frame system into a three-dimensional frame system which resists wind action.

The building sway under wind is significantly reduced by the introduction of these trusses.

A review of the deflection curve indicates two stiffening effects: one related to the participation of the external columns in a total-building-width cantilever mode; the other related to the stiffening of the facade frame by the belt trusses.

Improvements in overall stiffness of up to 25% can result as compared to the Shear Truss and Frame System without such outrigger-belt trusses.

The effectiveness of the system depends on the number of trussed levels and the depth of the truss at each level.

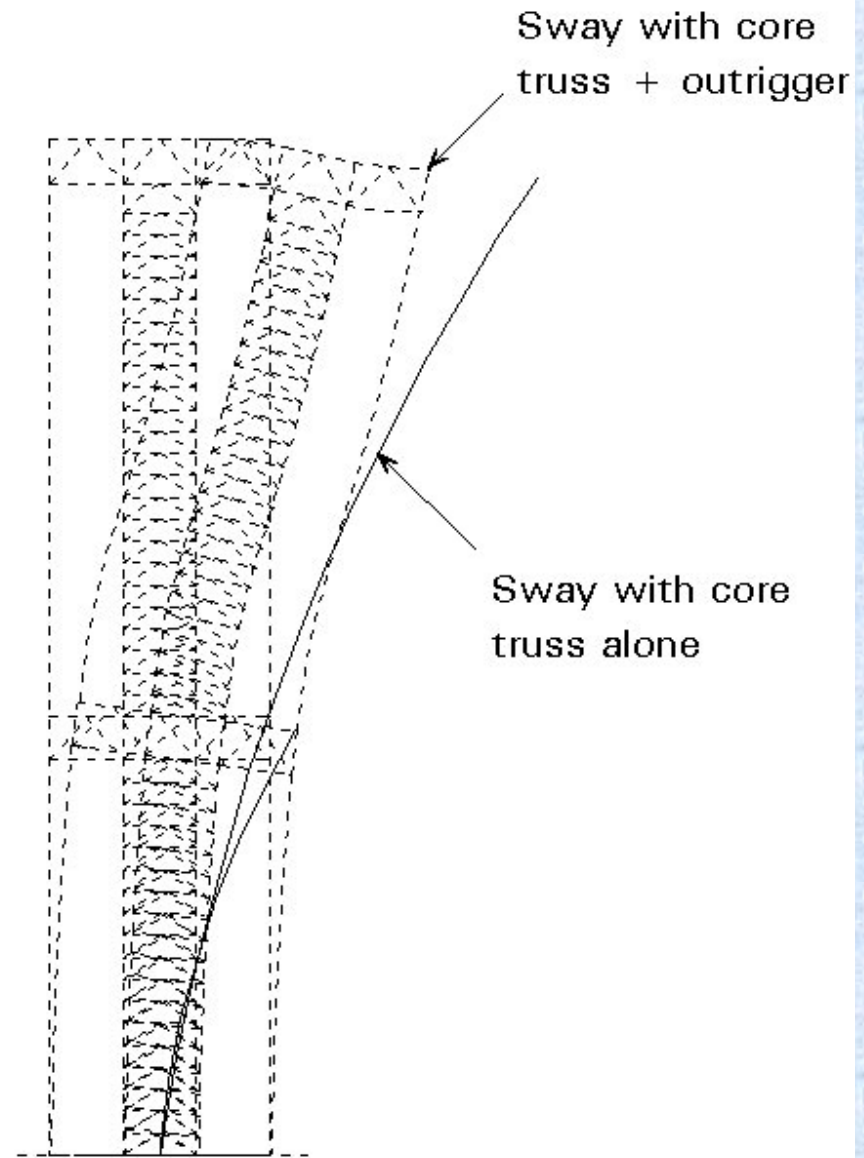


Figure 5 Improvement in overall stiffeners due to outrigger-bolt trusses

The Framed Tube

If the facade shear frame is made stronger by closer spacing of columns and larger member proportions and if such frames are continuous at corners, the overall frame is transformed into a cantilever Framed Tube fixed at the ground.

When such frames are provided on all four faces of a tower, one obtains a hollow tubular configuration.

This 'silo' form containing small window perforations is most efficient in resisting wind forces.

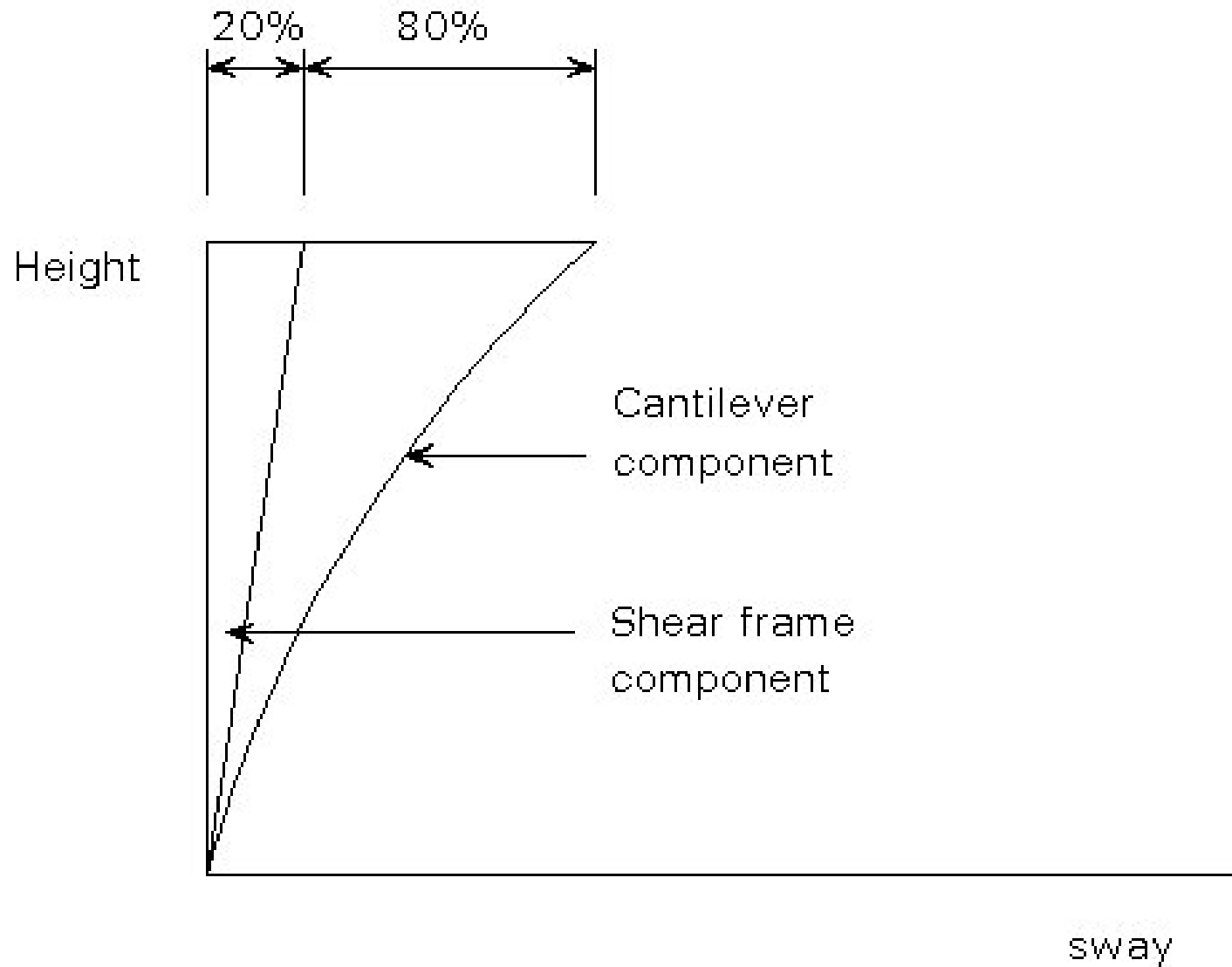


Figure 6a Framed tube : lateral sway

Figure 6b shows the distribution of column axial forces due to cantilever action.

The more the distribution is similar to that of a fully rigid box with uniform axial stress on the flanges and triangular distribution on the webs, the more efficient the system will be as a cantilever.

The Framed Tube system was first introduced in the mid-1960's in reinforced concrete.

The dense grid exterior structure was readily formed, creating the appearance of a punched tube.

This system was adopted later for steel buildings.

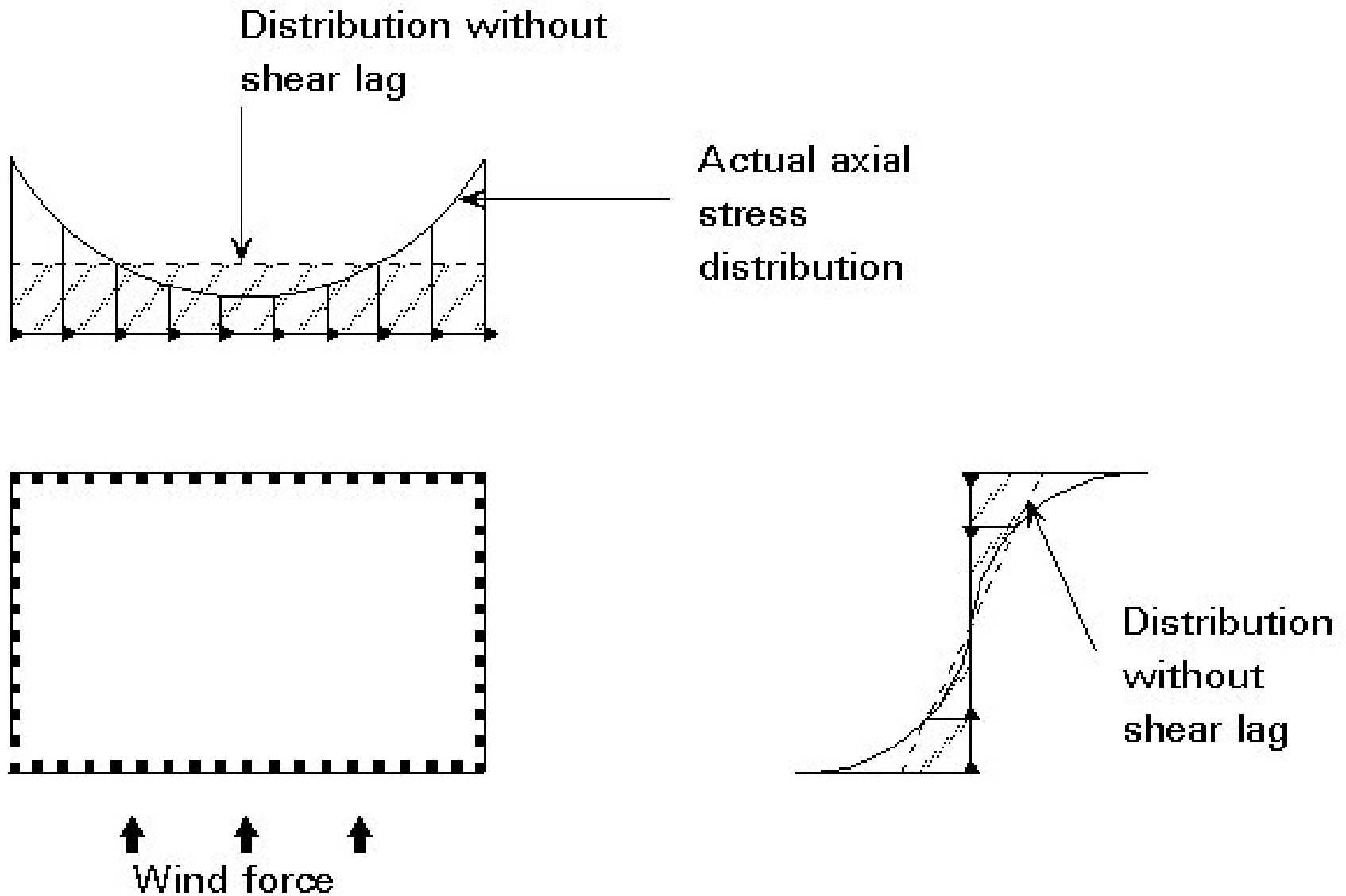


Figure 6b Framed tube : Axial load distribution

In structural steel, the joints need to be welded for rigidity and the members built-up for larger widths.

The use of a prefabricated Framed Tube "Tree" element (Figure 7) where all welding can be done in the shop in a horizontal position has made the steel Framed Tube more practical and efficient.

The "Trees" are then erected by bolting at mid-span of the beams. Considerable speed of construction of the order of 3 to 4 stories per week can result if "Trees" are used.

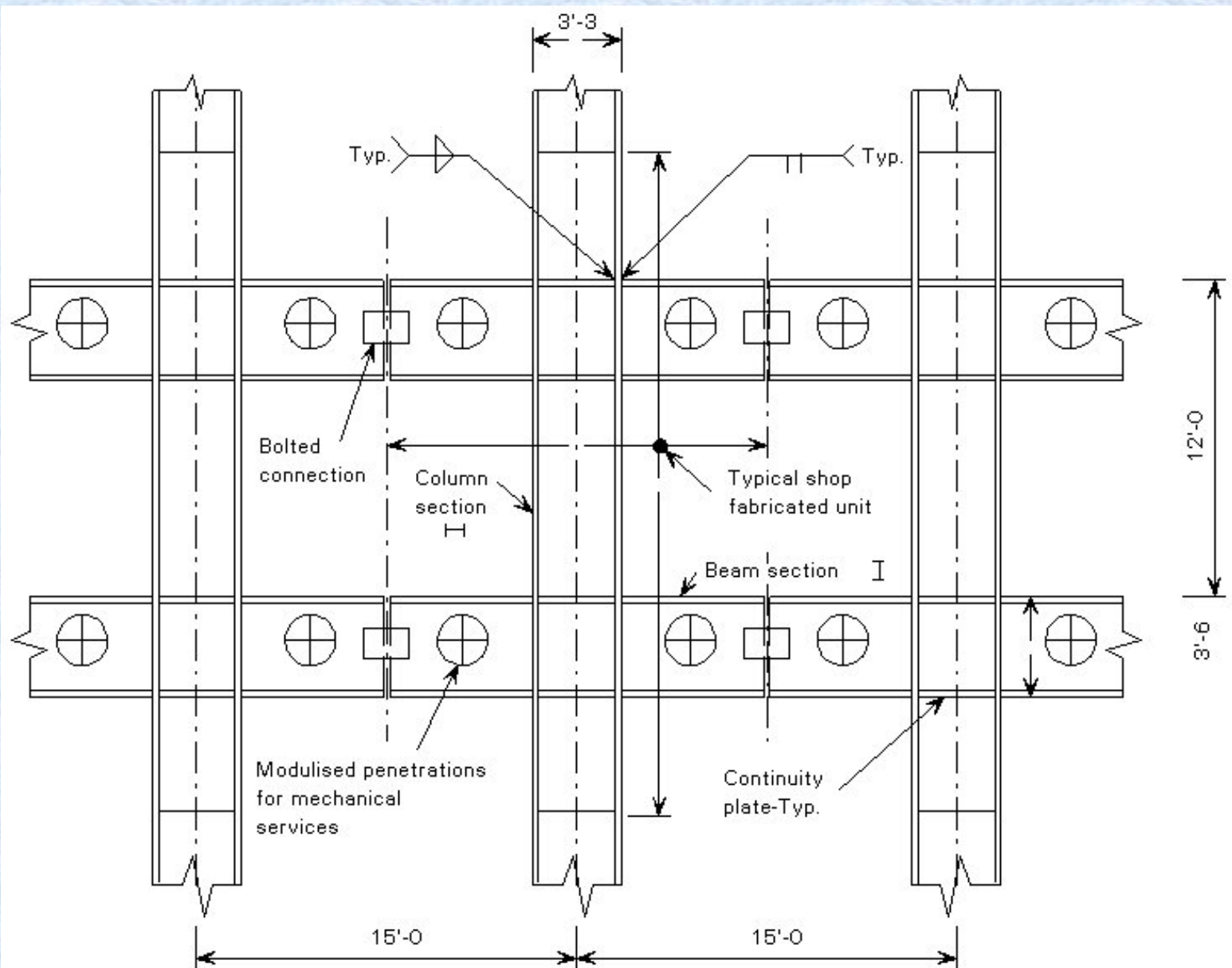


Figure 7 Tree fabrication unit

Steel Framed Tube buildings involve column spacings of 3m to 5m on the exterior which can be transferred or transitioned into wider spacings, if required, at the lower stories to integrate street level activities.

Such tubular systems have been used extensively for structures of 30 to 110 stories in height.

An outstanding example was the World Trade Centre in New York.

Tubular systems are generally adaptable to prismatic vertical profiles.

For varying vertical profiles and buildings involving significant fascia offsets, the discontinuity required in the tubular frame to achieve the shape introduces serious disadvantages.

The system can however, be readily adapted to a variety of non-rectilinear plan forms.

Figure 8 shows a particular plan configuration that has been used as a Framed Tube.

Provided the proportionality of the elements of the tubes is maintained, any closed overall form can be used as a Tubular system.

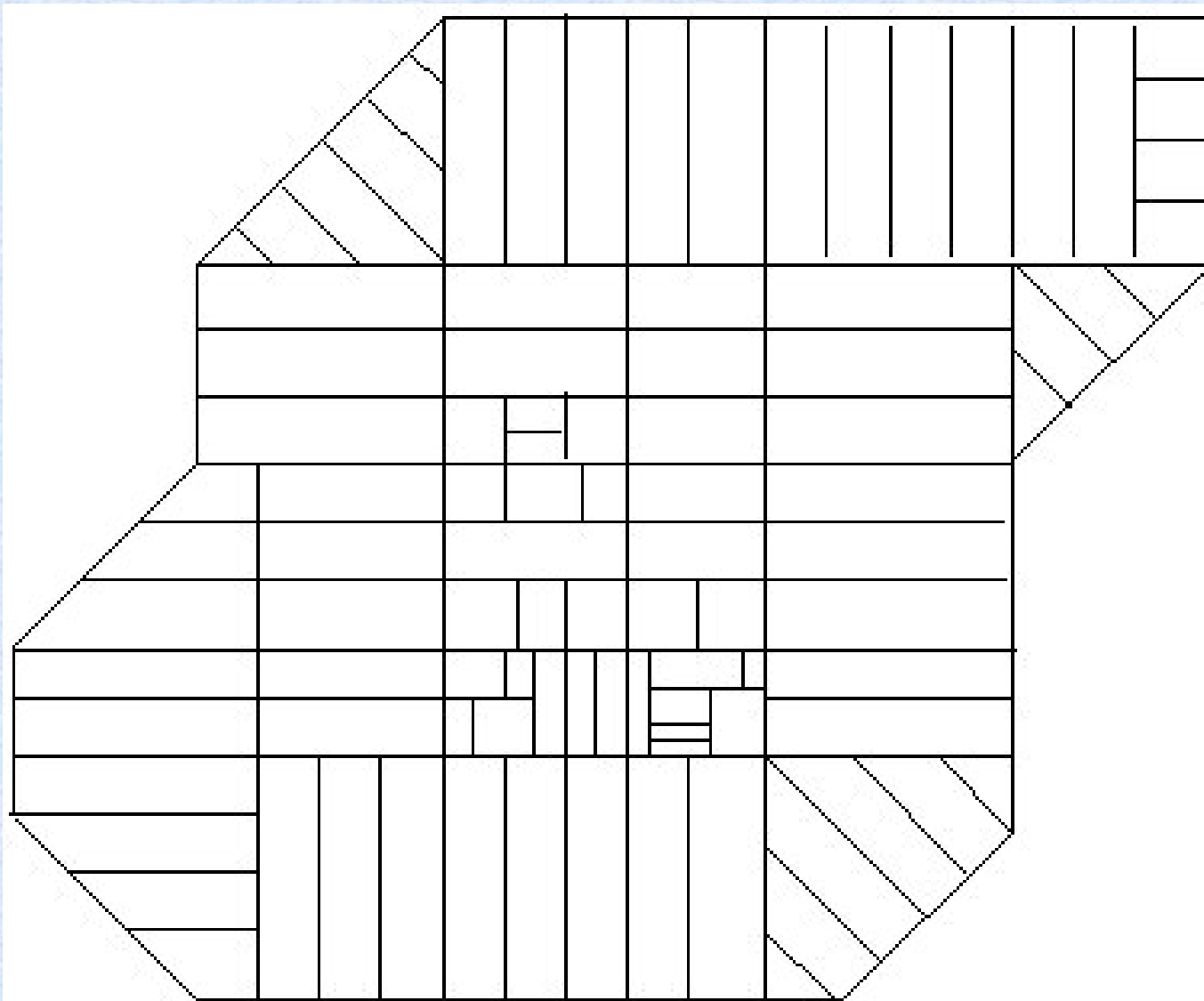


Figure 8 Free-form shape

The Diagonalized Tube

The most efficient structure acting as a cantilever is the exterior Diagonalized system.

This system was first introduced in the John Hancock Centre in Chicago, a multi-use, 100-storey structure (Figure 9a).

The system is essentially a Trussed Tube with the fascia diagonals not only acting as a truss in the plane, but also interacting with the trusses on the perpendicular facades to develop the tube action.

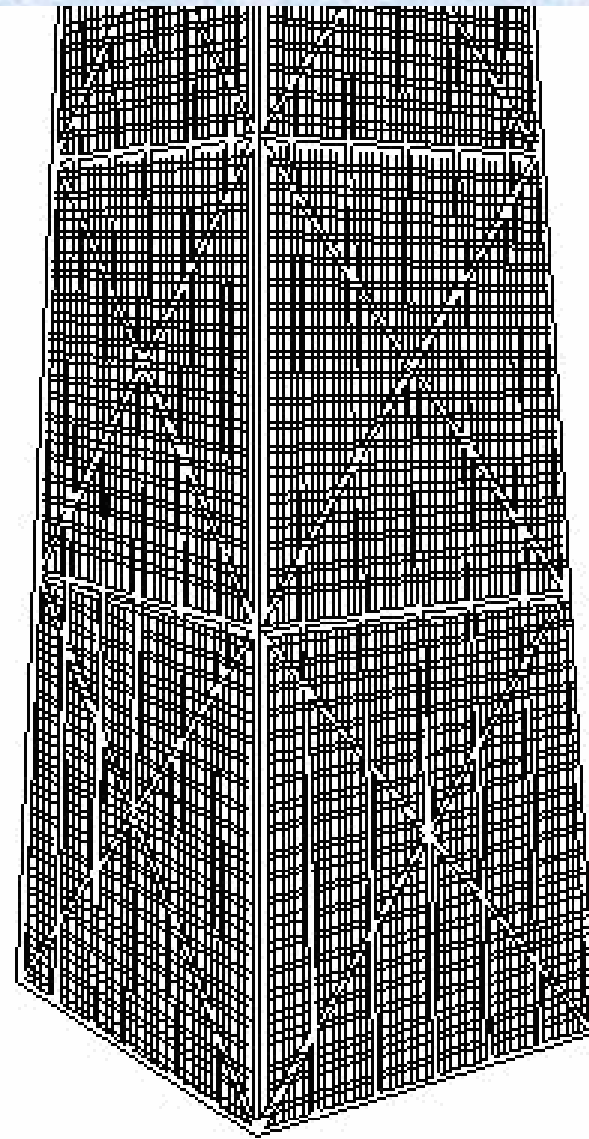


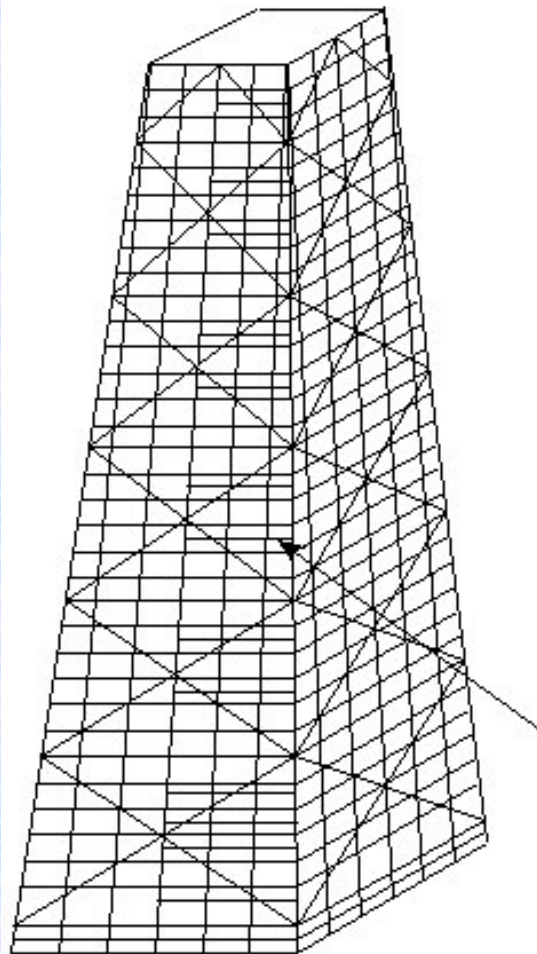
Figure 9a John Hancock Centre, Chicago

A principal advantage of the Trussed Tube is that it eliminates the need for the closely spaced columns of a framed tube.

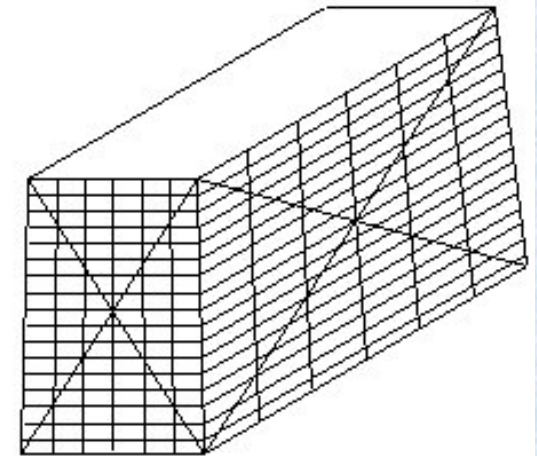
In the John Hancock Centre, the column spacing on the broad face is 12.2m and on the short face, 7.62m.

Another advantage of this Tube is that the interior is free from structure for resisting wind action.

The design of most members is controlled by gravity forces rather than wind forces.



Column axial stress
under wind only
(one quarter shown)



Base tier module

Figure 9b Diagonallized tube

Simpler fabrication and erection techniques resulted from shop fabrication of joints and field bolting.

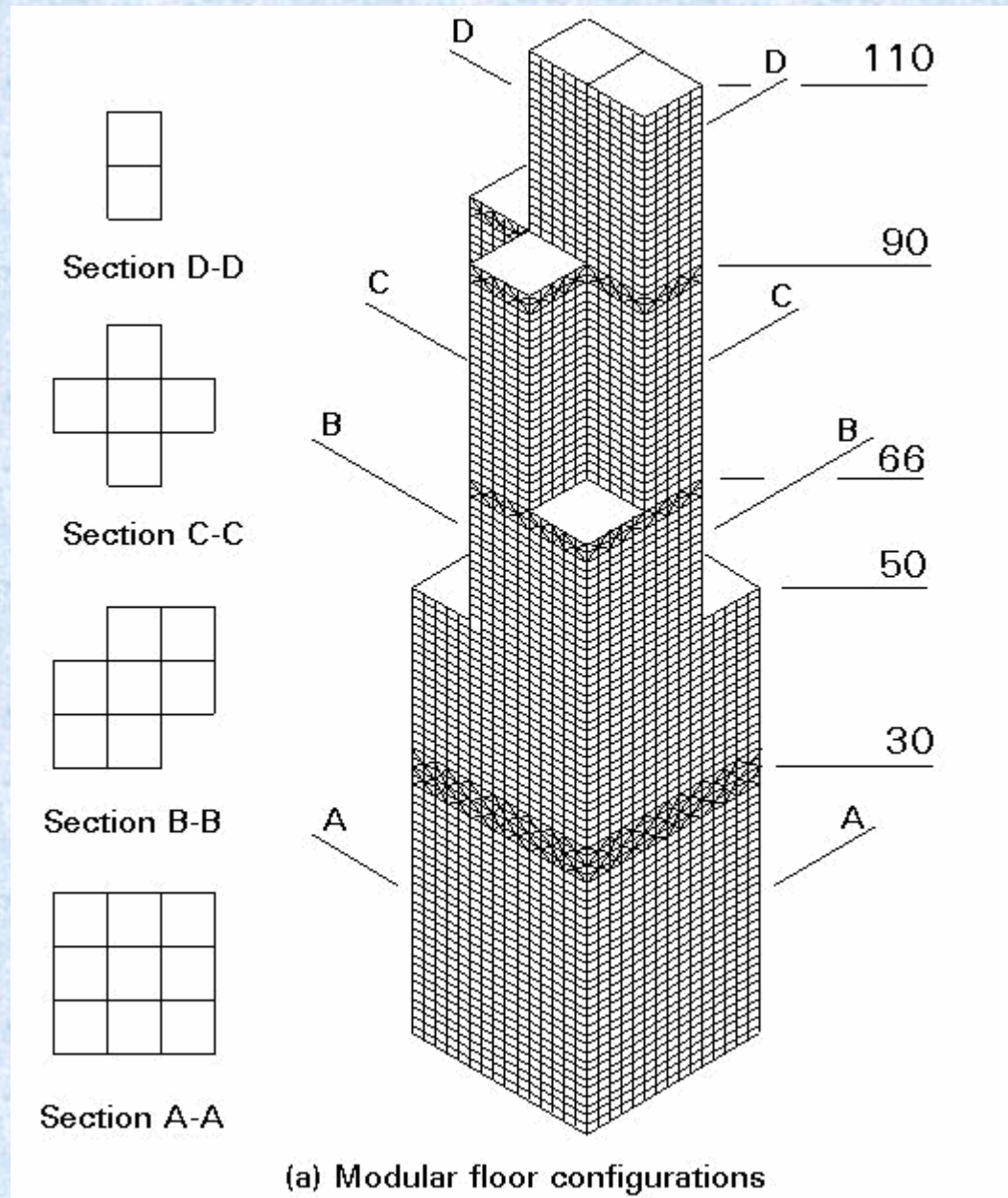
The clear disciplined structure set the basis for the overall exterior architecture of this building.

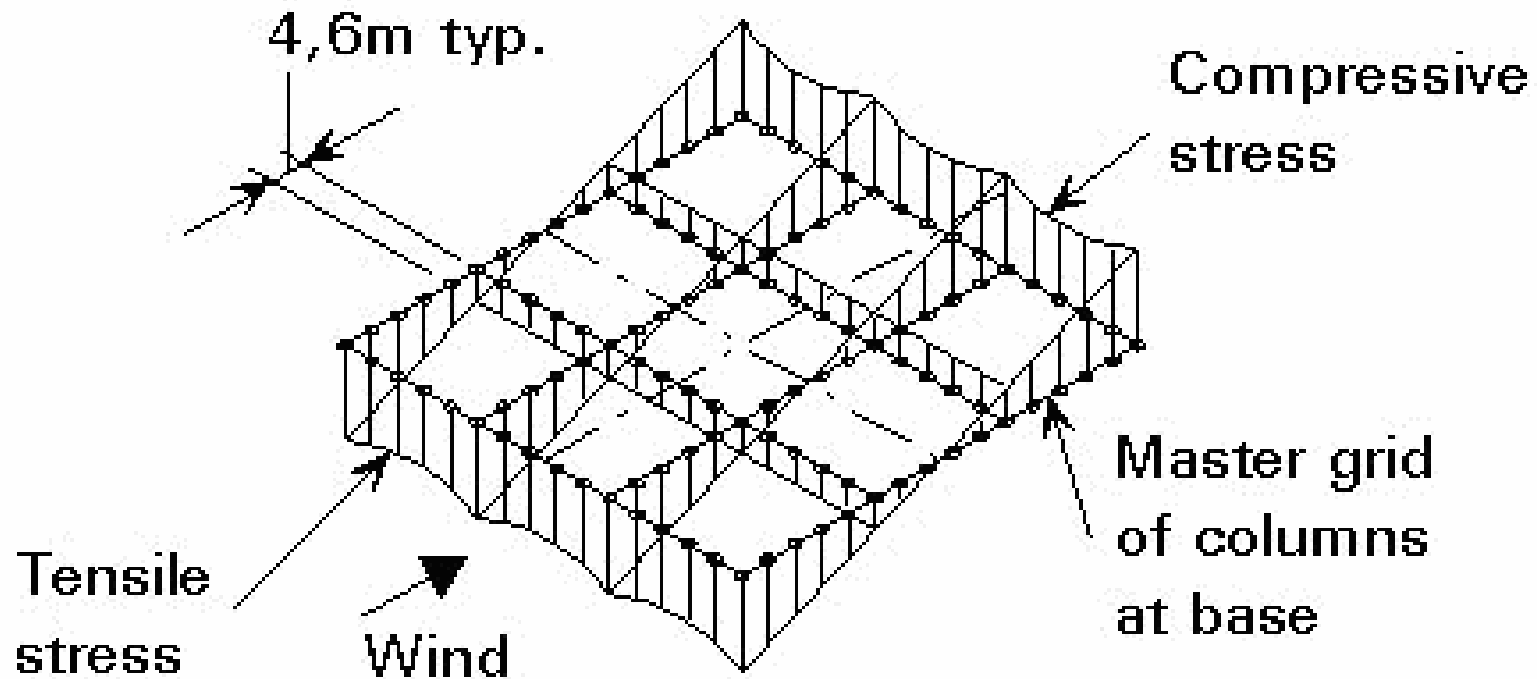
Bundled Tube or Modular Tube System

The need for vertical modulation in a logical fashion has created a variation of the tubular structure based on clustering or bundling of smaller sized tubes, each of which rises to a different height.

This variation is clarified by the bundled tube system of the Sears Tower in Chicago, Figure 10.

In the Sears Tower, the Bundled Tube is composed of 22.86 m square modules, and nine modules are lumped together to form the total system.





(b) Shear lag behaviour

Figure 10 Sears Tower, Chicago, Illinois

The walls of the tube are formed by columns at 4.57m centers and deep frame beams at each floor.

The introduction of Framed Tube lines on the interior greatly reduced the influence of the "shear lag" effect that is present in exterior tubes of large side dimensions.

The modularity and the conceptual basis of the Bundled Tube have a broad application.

The cells or tubes can be arranged in a variety of ways to create different massing. It can be applied to 30 stories as well as to ultra-tall structures.

The shape of each tube itself can be changed to any other closed clustered shape.

Triangular and hexagonal units have been used in some existing applications.

A significant advantage of the Bundled Tube system is the enormous torsional resistance which is helpful in absorbing torsional lateral forces due to asymmetry.

The torsional loads may be generated both by wind and seismic forces.

Apart from meeting wind deflection and stress criteria, the detailing of members and connections for ductility and an appropriate sequence of plastic hinge formation is required.

Higher tubular efficiencies result from deeper beam members.

However, this advantage has to be balanced with the strong-column, weak-beam principle to assure plastic hinges in the beam element.

Other items include panel zone areas which need to be reinforced with doubler plates.

Mixed Steel-Concrete Systems

Mixed Steel-Concrete systems are now a well established new system that can be used as readily as either steel or concrete systems for high-rise buildings.

Such mixed systems which involve reinforced concrete and structural steel components in forms that are generally applicable, such as the Composite Tubular system, and Concrete Core Braced systems, have been widely used.

Shear wall elements and/or punched wall or framed-tube elements with monolithically cast beam-column joints are of higher strength concrete.

Concrete has extended the application to structures of 50 to 80 stories in height.

Concrete strengths of 40 MPa to 55 MPa are commonly used, but in some cases, strengths up to 95 MPa have been used.

The floor framing is of steel in mixed systems, which is advantageous because of the ability to span longer distances with lighter members. Thus larger column-free spaces are possible.

1. Composite tube systems

Structural steel floor framing and other interior steel columns complete the system of the first Canadian Centre in Calgary, Canada, as shown in Figure 12. The Tube system on the exterior is a combination of Framed Tube of beams and columns with solid walls at the corners.

The structural concept is based on a tube-in-tube concept involving an exterior reinforced concrete framed-tube and an interior shear wall core tube.

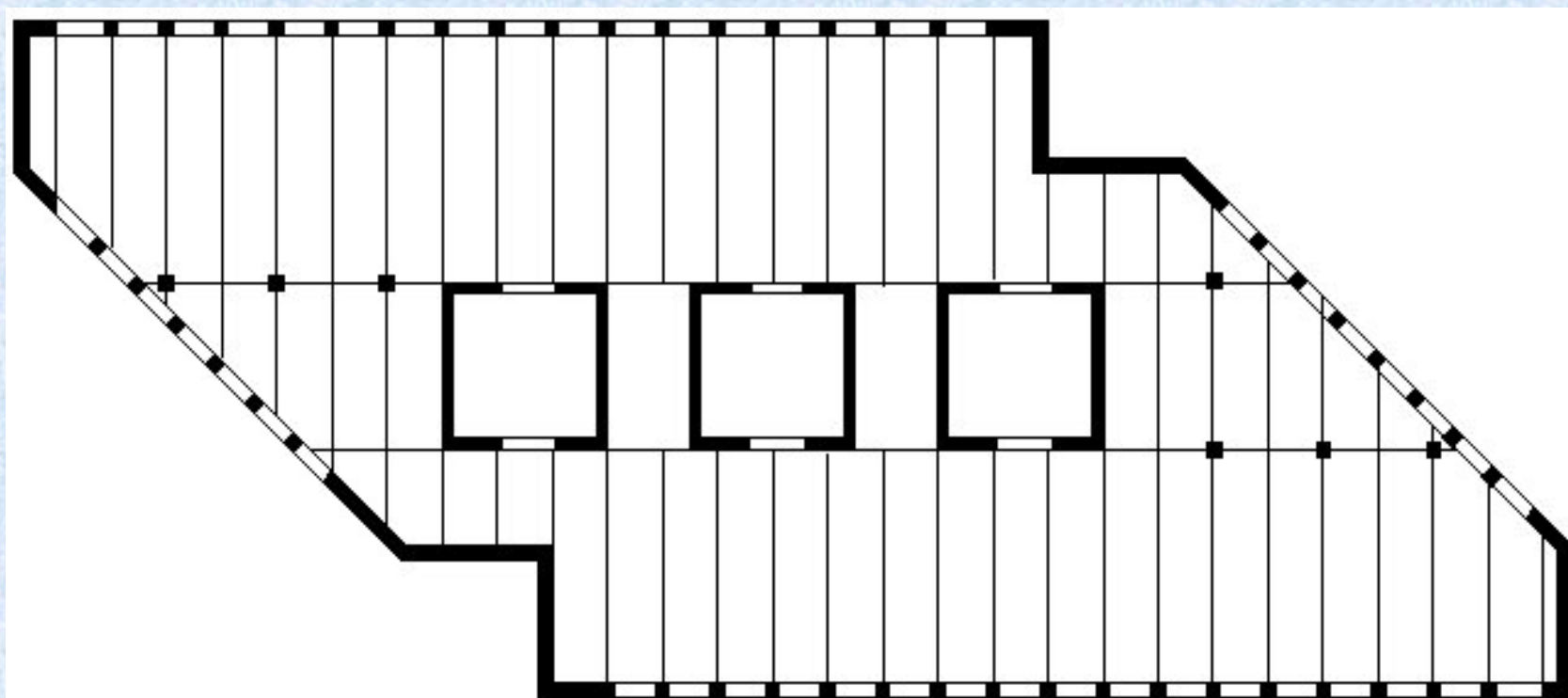


Figure 12 Composite tube

2. Core braced systems

In contrast to exterior Tubular systems, Core Braced Systems resist wind forces by shear walls in the core.

Core walls for wind resistance have been utilized quite extensively in concrete buildings.

The closed tube shape is then in the interior with access penetrations into the core.

This type of core element can be used in a steel frame to form the Core Braced Steel system.

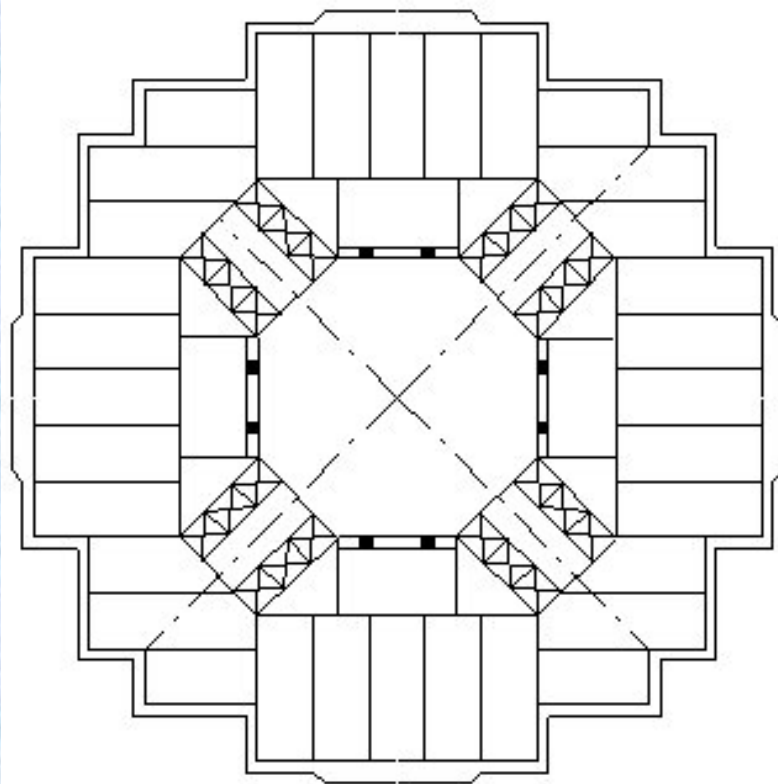
Since all wind forces are resisted by the concrete core, the steel components need only be connected non-rigidly to resist gravity forces.

Figures 13a and 13b show an arrangement of cores for a 75-storey structure which required considerable flexibility in exterior shaping with offsets and setbacks.

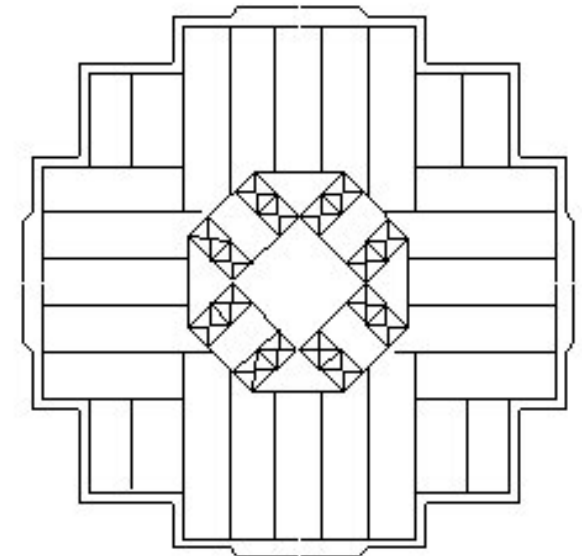
A lighter, non-rigid structure in steel on the exterior allowed this flexibility.

The Core Wall Tube system was planned with four inter-connected pods encasing an atrium in the lower part and an octagonal shaped core in the upper parts.

This simple arrangement of walls and cores allowed maximum efficiency of the wall system for the structure and maximum flexibility for exterior architecture.



(a) Lower floors



(b) Upper floors

Figure 13 Arrangement of cores for the scheme design of a 75-storey building

ULTRA HIGH-RISE STRUCTURES

1. Superframe or Megaframe

Superframes or Megaframes assume the form of a portal which is provided on the exterior of a building.

The frames resist all wind forces as an exterior tubular structure.

The portal frame of the Superframe is composed of vertical legs in each corner of the building which are linked by horizontal elements at about every 12 to 14 floors.

Since the vertical elements are concentrated in the corner areas of the building, maximum efficiency is obtained for resisting wind forces.

The vertical legs and the horizontal links are themselves frames with large dimensions in the plane of the frame.

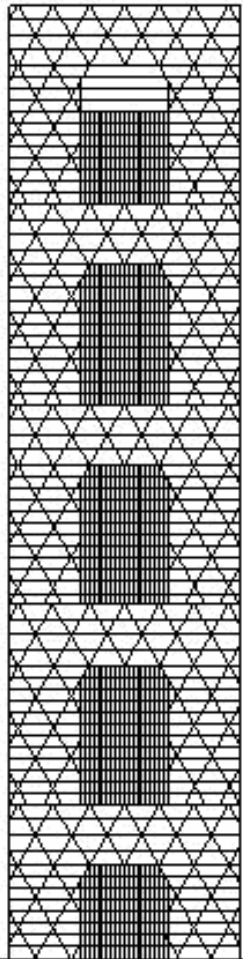
Inherent in the concept of a Superframe is the ability of the system to accommodate varieties of spaces suitable for multiple functions.

Ultra high-rise Megastructures will need to further the idea of flexible space or modular spaces, where each space can be planned efficiently for its own use and inserted into a Megaframe.

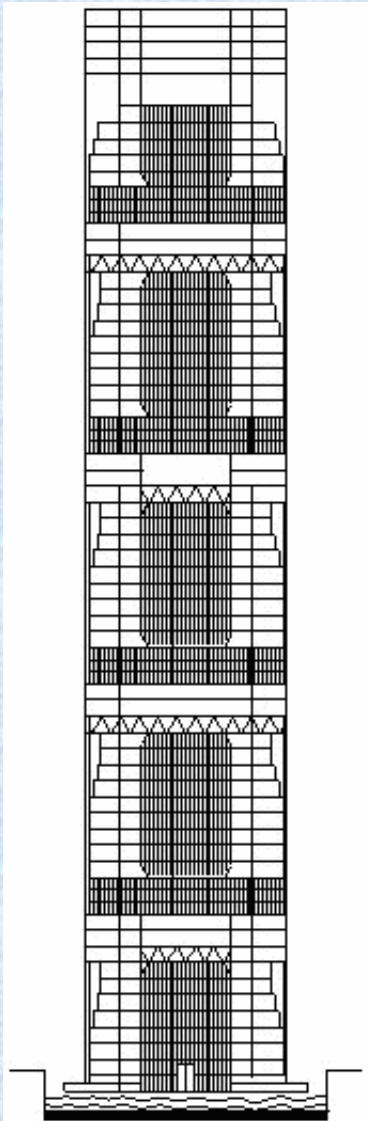
Superframes allow this modularization of space to occur with maximum freedom from structural encumbrance.

Portal apertures on the exterior wall allow freedom of expression for each unit and also provide access for daylight.

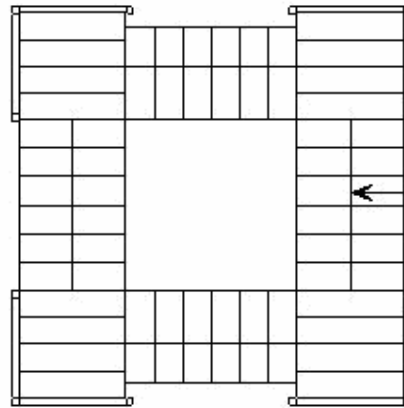
Figure 14b indicates an arrangement of interior spaces with an atrium in each space module.



(a) Houston proposal



(b) Superframe



(c) Plan of Houston building

Figure 14 Superframes

The net effect of this combination would be to produce an equivalent cantilever structure as effective as a Tubular system.

An appropriate diagonalization of structure is represented by an overall modularized diagrid frame, in which the structural members within the portals are removed (Figure 14a).

Figure 14a also shows the adoption of the Superframe concept to an 80-storey structure in its simplest rectilinear form.

Figure 15 shows a study of a Superframe concept applied to a 170-storey, 655m tall tower involving 706.000 sq. meters of floor space.

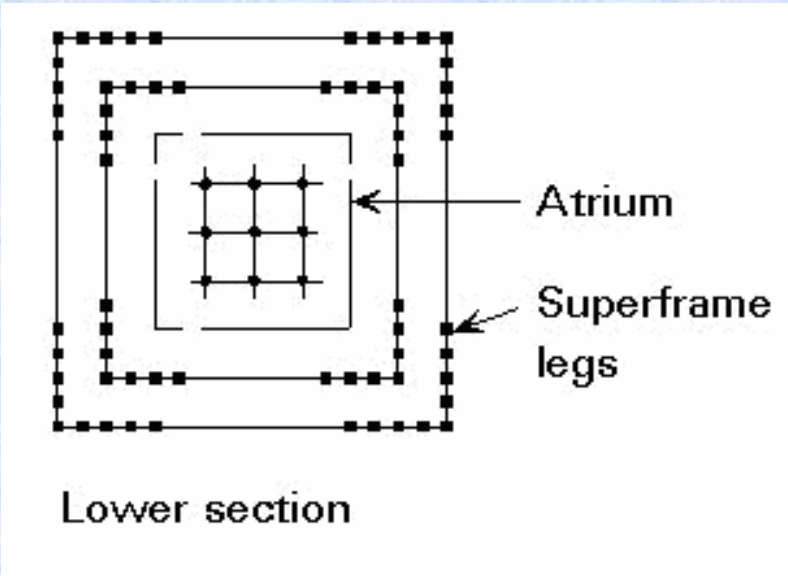
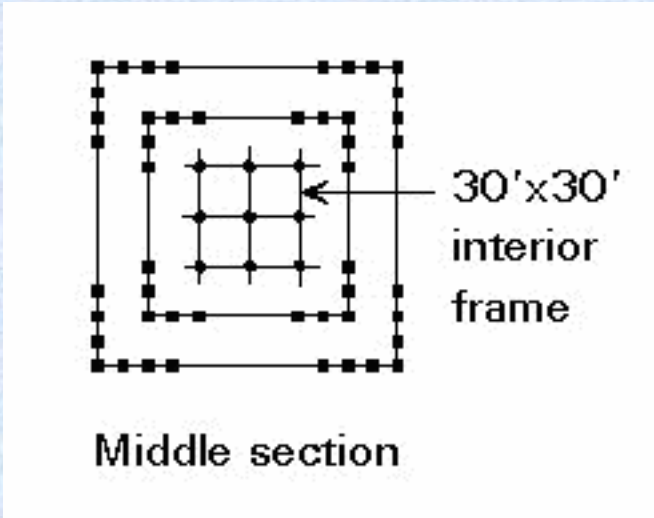
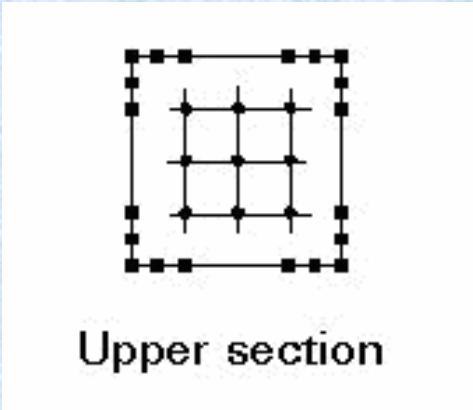
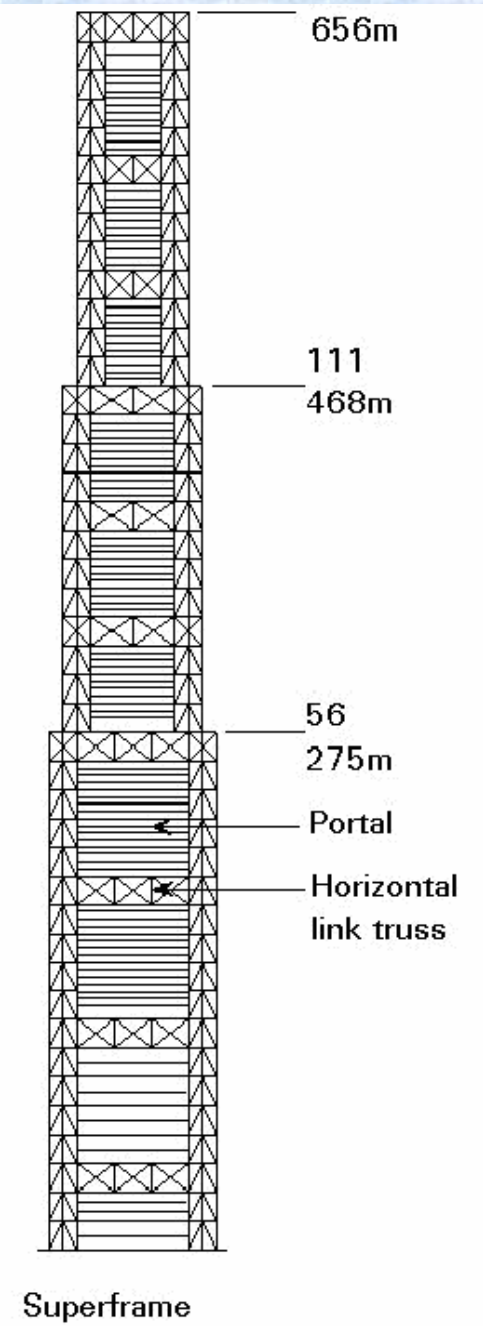


Figure 15 Superframe structure, Chicago (proposal) : Frame details

The structural efficiency is obtained from the concentration of material close to the corners.

Each of these vertical legs is required to be stiff in its own plane.

The legs then take the form of a diagonalized truss chord.

The corner truss legs need strong horizontal connections at frequent modular intervals to make them function together like an equivalent cantilever.

The horizontal members, therefore, will need to be equally stiff, and are diagonalized as well.

The multiple functions involved are indicated in Figure 16a.

The tower form, step-tapered from 88m x 88m at the base to 44m x 44m at the top denotes the functional needs of space.

The effectiveness was confirmed by wind tunnel testing.

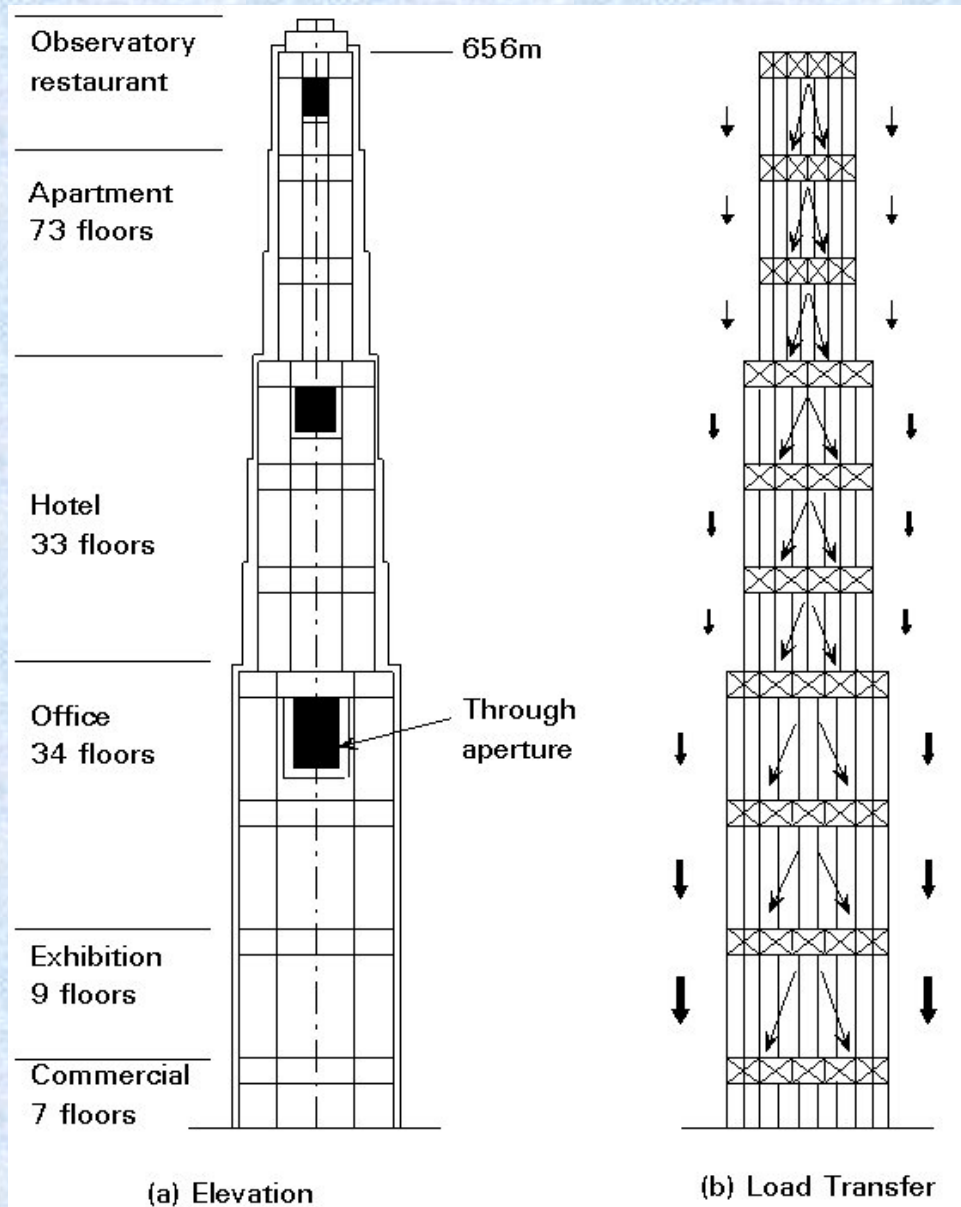


Figure 16 Superframe structure, Chicago, (proposal) : details

The equivalent dampening effect of this aerodynamic shaping illustrates the need for such design coordination in supertall structures.

The significant aspects of this structural design were:

- i. Telescoping of the Superframes allowed an orderly transition of the structure and the needed lateral stiffness.

ii. The aerodynamic behavior was greatly assisted by the apertures which reduced the cross-wind accelerations and forces due to vortex shedding by as much as 25%.

The overall tapered form assisted as well in reducing the wind 'sail' area gradually toward the top.

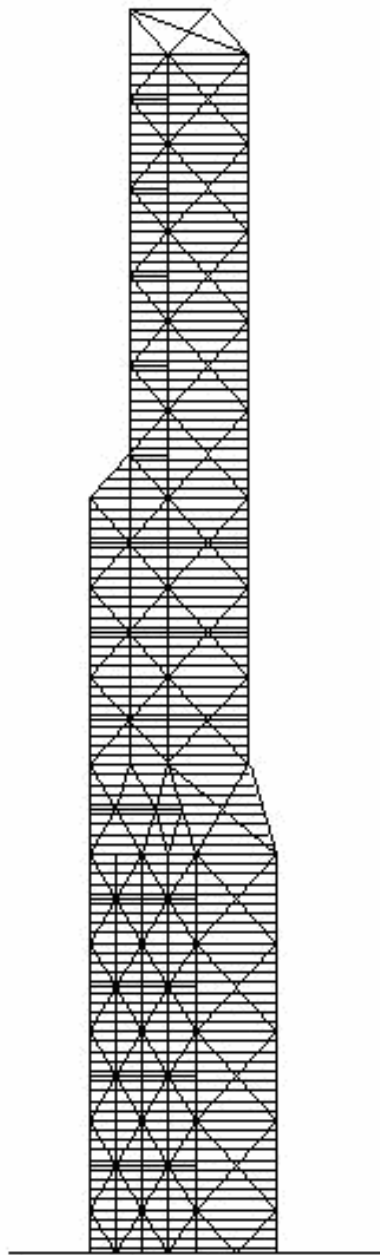
iii. The structural system efficiency was enhanced by the sequential load transfer from the interior to the exterior, as shown in Figure 16, so that all gravity loads were carried by the Superframes.

2. Super-Trussed Tubes

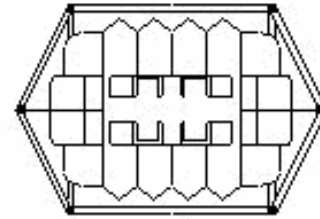
The general concept of the exterior Trussed Tube can be extended to ultra high-rise structures involving multiple functions.

Figure 17 shows a 135-storey exterior Trussed Tube, which was submitted for a project competition in New York.

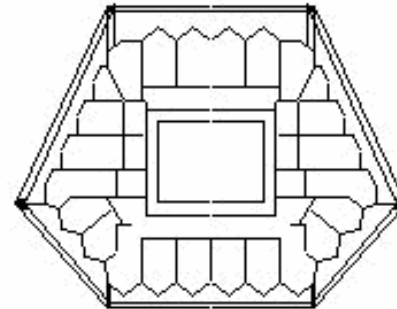
This slender form, having an aspect ratio of 10 to 1, involved approximately 185.908 sq. meters of floor space.



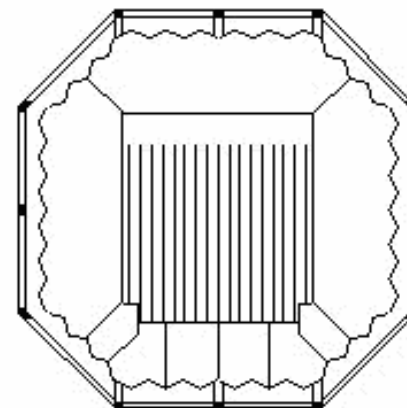
Elevation



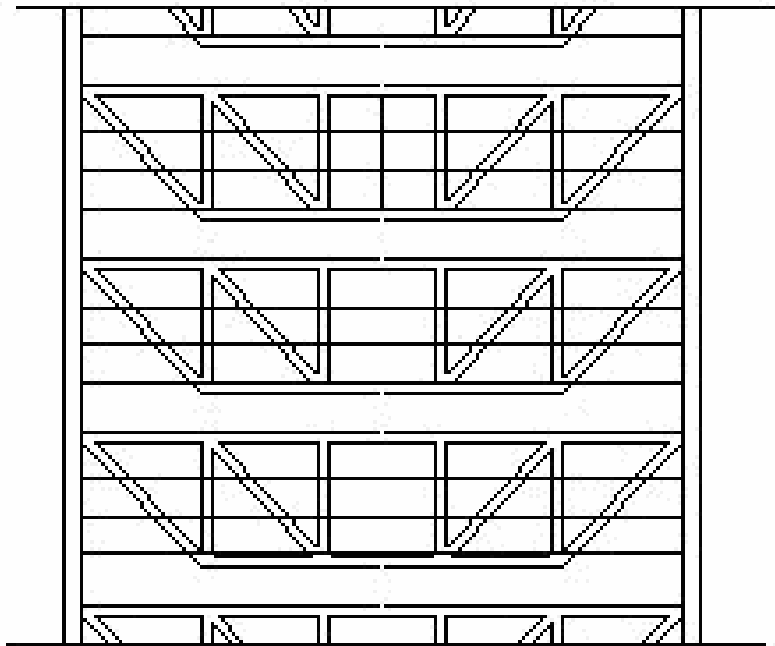
Typical apartment plan



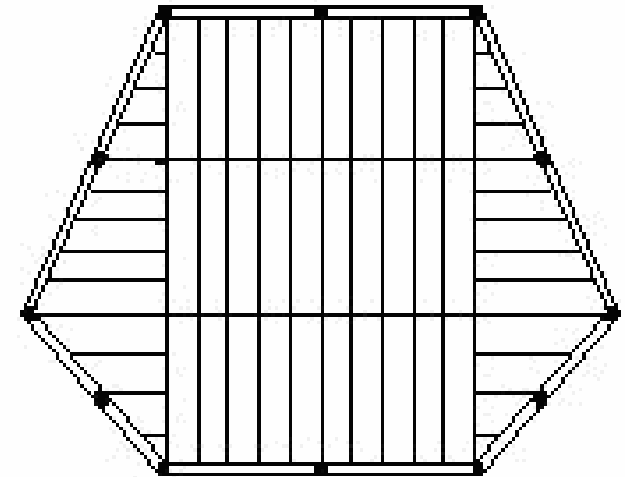
Typical apartment hotel plan



Hotel skylobby plan



Transfer trusses



Truss plan

Figure 17 Transfer trusses

The arrangement of multiple functional spaces is indicated in the plans.

The horizontal and vertical facets of the shape were modulized so that a triangular shaped framing could be used without discontinuities.

This framing resulted from the concept of a tetrahedrally framed solid form where all the non-essential elements were eliminated to create the tube and the external shaping of it.

This is another form of aerodynamic shaping to mitigate wind effects.

The internal structure is supported on 3-storey tension truss elements which span across the tube thereby eliminating the need for internal columns.

This arrangement allowed the use of gravity steel in the development of lateral stiffness and wind load resistance.

It also made it possible to deal with the effects of temperature contraction of the exposed, but clad exterior columns.