The Staggered Truss System—Structural Considerations

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THE STAGGERED TRUSS system is a new concept in structural steel framing for high rise buildings. The system consists of a series of story-high trusses spanning the total width between two rows of exterior columns and arranged in a staggered pattern on adjacent column lines (Fig. 1).

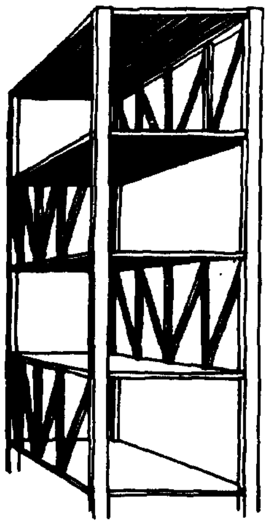

Figure 1

The system was developed to achieve a more efficient structural frame to resist wind loads and at the same time provide versatility of floor layout with large column-free areas.

The concept was developed by a team of architects and engineers from the Departments of Architecture and Civil Engineering at M.I.T. who combined their respective talents to achieve this imaginative and efficient steel framing system. This paper is a summary of the structural steel design considerations contained in that report. [1]

The theory and design requirements for each structural component to resist gravity and wind loads and to maintain stability of the structure will be discussed separately in the following sections.

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THEORY

The basic concept of the staggered truss system is that the total frame behaves as a cantilever beam when subjected to lateral loads. In this context, all columns are placed on the exterior wall of the building and function as the flanges of the beam, while the trusses which span the total transverse width between columns function as the web of the cantilever beam (Fig. 2).

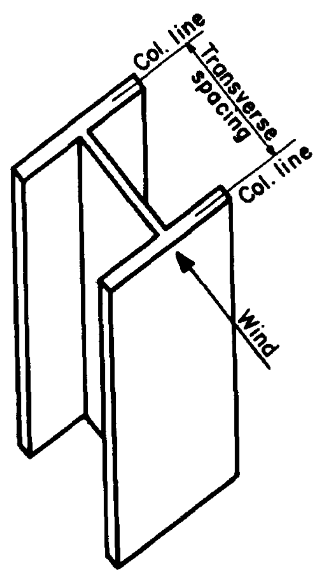

Figure 2

With the columns only on the exterior walls of the building, the usual interior columns are omitted, thus providing a full width of column-free area. The staggered arrangement of the floor-deep trusses placed at alternate levels on adjacent column lines allows an interior floor space of twice the column spacing to be available for freedom of floor arrangements (Fig. 3).

The floor system spans from the top chord of one truss to the bottom chord of the adjacent truss. Therefore, the floor becomes a major component of the structural framing system serving as a diaphragm transferring

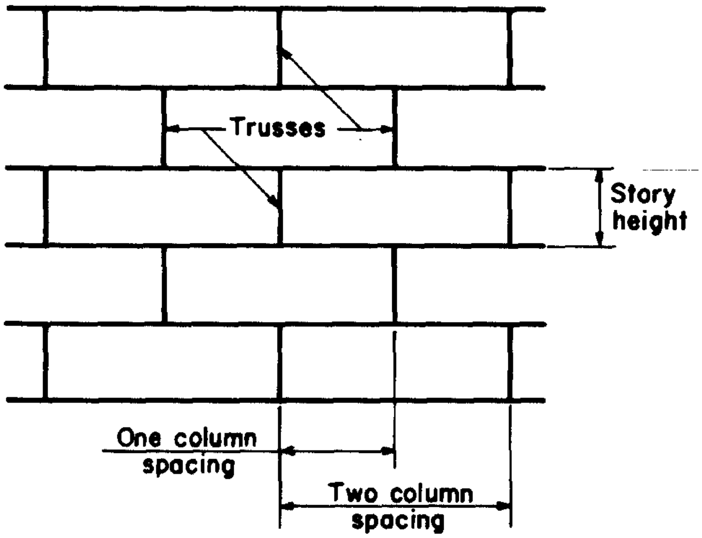

Fig. 3. Longitudinal elevation

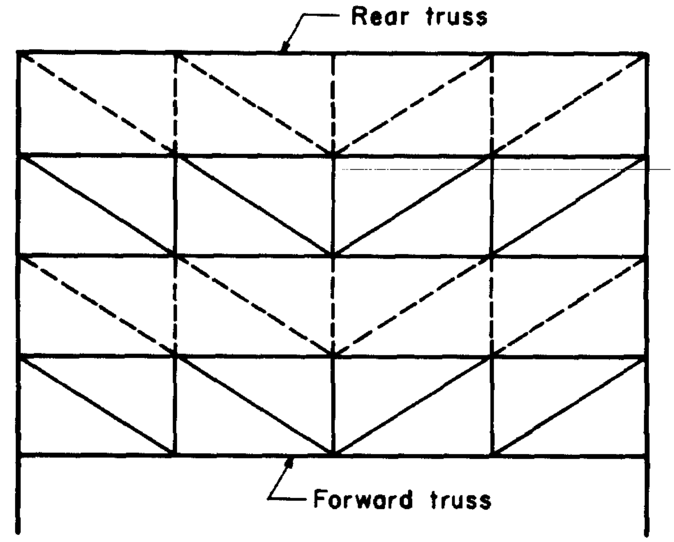

Fig. 4. Double-planar braced frame

the lateral shears from one column line to another, thus enabling the structure to perform as a single braced frame, even though the trusses lie in two parallel planes (Fig. 4).

The cantilever action of the double-planar truss system due to lateral loads minimizes the bending moments in the columns. Therefore, in general, the columns are designed for axial loads only and may be oriented with their webs perpendicular to the trusses (Fig. 5), thus eliminating local bending due to the connection of the truss chord. With the orientation noted, the strong axis of the column cross section becomes available for the portal frame system in the longitudinal direction of the building.

ADVANTAGES

The advantages of the staggered truss system compared with the portal frame system are summarized below:

1. Columns have minimum bending moments due to gravity and wind loads, because of the cantilever action of the double-planar system of framing.
2. Columns are oriented with their strong axis resisting lateral forces in the longitudinal direction of the building.
3. Floor spans may be short bay lengths, while providing two column bay spacings for room arrangements. Thus, floor depths are held to a minimum.
4. Maximum live load reductions may be realized because tributary areas may be adjusted to suit code requirements.
5. Large clear span open areas for parking or concourse are possible at the first floor level, because columns are located only on the exterior faces of the building.
6. Foundations are on column lines only and may consist of two strip footings.
7. Drift is small, because the total frame is acting as a stiff truss with direct axial loads only acting in most structural members. Secondary bending occurs only in the chords of the trusses.
8. High strength steels may be used to advantage, because all truss members and columns are subjected, for all practical purposes, to axial loads only.
9. A lightweight steel structure is achieved by the use o f high strength steels and an efficient framing system.

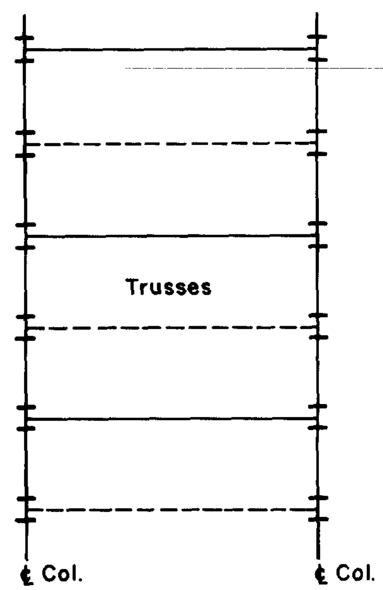

Figure 5

FLOOR SYSTEM

The type of floor to be used in the staggered truss system is usually dictated by the economies of construction in a local area. The major factor to be considered is the shear diaphragm capabilities of strength and stiffness of the floor system in addition to its ability to resist gravity loads. The usual procedure is to determine the floor thickness required for gravity loads and subsequently to verify the in-plane shear capacity and stiffness. Then, if greater diaphragm action is required, the floor may be adjusted accordingly. Thus, many floor systems can be used, such as steel deck with infill, steel joists with sufficient concrete topping, concrete slabs, and concrete planks.

To resist gravity loads, the floor system may be considered to be a series of simple spans or continuous for two column spacings. As a continuous system, the floor members rest on the top chord of one truss and extend to the bottom chords of the two adjacent trusses. The floor reactions to the gravity loads become the applied loads on the top and bottom chords of the floor trusses.

In general, the total lateral load due to wind forces is distributed equally among the trusses at any given floor level. Therefore, each truss must resist the wind load acting on two bays, and the adjacent floor panel must provide sufficient in-plane diaphragm strength and stiffness to transfer these lateral loads to the trusses (Fig. 6). The floor system is acting as a deep beam and must be designed to resist the in-plane shears and deformations and the resulting in-plane bending moments. The longitudinal shear strength must be capable of developing the interaction between floor panels to enable them to act as a single unit.

The in-plane bending moment at the connection of the floor to the truss is determined on the assumption that a point of inflection occurs at the midpoint of the adjacent spans. The

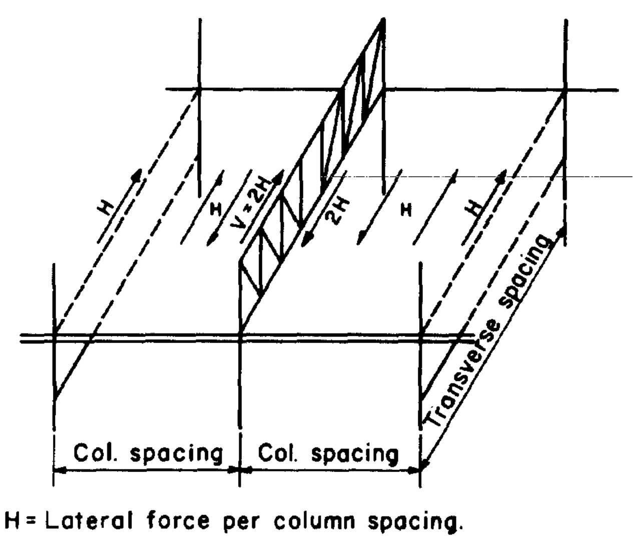

Figure 6

magnitude of the bending moment is calculated by multiplying the in-plane shear force by the distance from the column line to the midpoint of the adjacent span. This is comparable to assuming a fixed end beam with a span equal to twice the column spacing and having a concentrated load applied at the center of the span.

Research at M.I.T. established the fact that the shear distribution along the truss chords in the transverse direction approximates the usual parabola for a rectangular section, with the maximum ordinate equal to 1½ times the average value. Therefore, for a specific building geometry, the shear capacity of the floor system may limit the height of the building.

The connection of the floor system to the chords of the trusses must be capable of transmitting the gravity loads and the in-plane shear loads directly to the chord members. Gravity loads are transmitted by direct bearing contact. The in-plane shears are transferred by shear connections such as direct welding (if a steel deck is used) or by a welded shear plate (if concrete slabs or planks are used). The connection to the chord member is made according to the shear distribution along the truss in the transverse direction of the building.

TRUSSES

The general requirements for the story-deep trusses are to span the total transverse dimension of the building, support the gravity loads directly, and provide the necessary resistance to the lateral loads.

The truss must provide an opening near the center of span to permit a width and height of sufficient proportions to be used as a corridor. The chords of the truss should be kept to a minimum width in order to have a wall of minimum thickness and yet of sufficient width to provide a seat for the floor system.

To be economical for mass production, the trusses throughout the building should be identical in form and type of members, designed so that jigs can accommodate the slight differences in member dimensions.

Current economies in design and fabrication indicate that the Pratt truss with diagonals omitted for passageways is the most efficient type of truss to be used in the staggered truss system. The number of panels in the truss depends upon the depth and span while maintaining the inclination of the diagonals at approximately 45 to 60 degrees.

The Vierendeel truss, by the nature of its design with open panels, appears at first glance to be the most efficient truss to be used in the staggered truss system. However, the designer should evaluate the economics of the various truss systems, for his particular design, before making a final selection.

Gravity loads from the floor system are applied as concentrated loads at panel points of the top and bottom

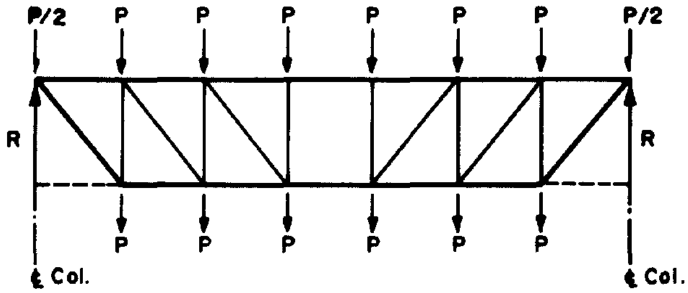

Figure 7

chords. The member sizes are determined on the basis of the usual assumptions for pin-connected trusses simply supported at the ends and adjusted for local bending (Fig. 7).

In order to design the truss members for maximum conditions, symmetrical and unsymmetrical live loading should be investigated. The passageway opening introduces local bending in the chords, due to the shear force acting in the panel. To determine the effect of the panel shear on the design of the chords and web members, the secondary bending effect must be evaluated. The panel shear is proportioned to the top and bottom chords according to their relative bending stiffness and is then transferred to the panel points producing a local shear and bending effect on the chords. Approximate solutions may assume the chord to be continuous over one or several panels, either simply supported or interacting with the web members. Computer solutions for truss analysis are available which will take into account the omission of diagonals and the end fixity of all members.

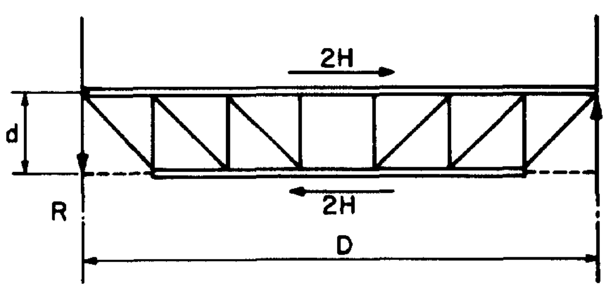

Figure 8

The lateral loads are assumed to be resisted entirely by the diagonals of the trusses and, because the trusses are placed at every other column line, each interior truss must resist the shear force acting on two bays (Fig. 6). Therefore, the wind shears are applied by the floor system to the top chord of the truss and reacted horizontally at the lower chord into the floor system at that level (Fig. 8). The resulting moment is resisted at the column connection at the top chord. These shear loads are considered to act at the panel points of the chords and the analysis and design of the individual

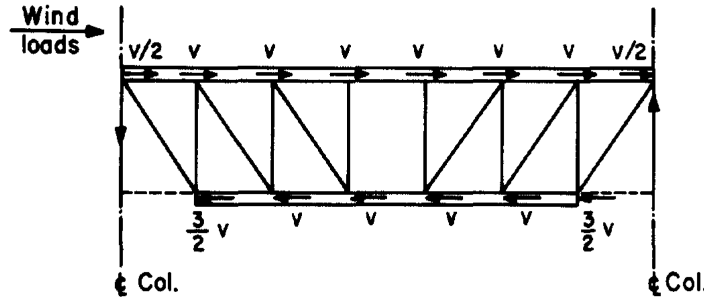

Figure 9

members is made in the usual manner for an ideal pin-connected truss (Fig. 9).

In practice, the bottom chord is connected to the column, thus causing a local bending in the column. The research study indicates that the relative stiffness of the truss and floors is sufficiently greater than the column stiffness, so that the local bending in the column is reduced to an insignificant amount in most structures. The designer must verify this assumption for his particular design, which may vary from that of the research study. Computer programs can assist in this determination.

At the top and second stories where it is not feasible to place a truss in the staggered arrangement, posts and hangers are used to support the roof and second floor. These are usually placed at the panel points of the trusses, in order to avoid additional secondary moments in the chords. The trusses supporting the roof and second floor will, of necessity, have heavier members than the other regular trusses.

COLUMNS

The general requirements for columns are to support the total gravity and wind loads acting on the structure in the transverse and longitudinal directions.

Gravity loads are distributed to the columns in the usual manner of proportioning floor areas, taking due account of load reductions permitted by the local codes. These gravity loads are considered to be applied as direct axial forces to the columns, because the truss connection is on the web of the column.

Wind forces acting on the building produce direct loads in the columns as a result of the truss action of the double-planar system of framing. The column loads are determined from the bending moment, M, at any level, Z, from the top and which may be expressed as

$$M = \tfrac{1}{2} WZ^2$$

where W is the uniform wind load per foot of building height. For other wind loadings, a comparable calculation is made. The wind load in the column is computed on the basis of the cantilever beam action and is expressed as

$$P = M/D$$

where

P = column axial load
M = bending moment as above
D = transverse width of building

Wind acting in the longitudinal direction of the building is resisted by a portal frame if no bracing is present, or a series of braced bays if the architectural features of the curtain wall permit it. In either case, the usual methods of analysis and design prevail.

The selection of the column section is based on the design consideration of all the axial loads and moments acting in the transverse and longitudinal directions of the building.

Research has indicated that an intermediate column receives 90 percent of its load from the top chord connection to the truss. Therefore, for design purposes, it is assumed that all the load on the column is applied at the top chord connection of the truss to the column (Fig. 10).

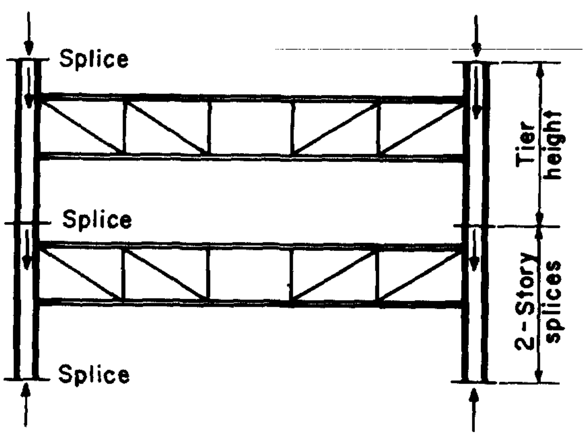

Figure 10

The effective length of the column is determined by the usual considerations. In the transverse direction, the column is restrained about the weak axis of the section by the attachment to the top and bottom chords of the truss. Therefore, the effective length is the actual unbraced story height. In the longitudinal direction, buckling of the column depends upon the type of framing, portal or braced. For the portal frame, the effective length is determined by the AISC alignment charts or by rational methods. For the braced frame, the actual unbraced story height becomes the effective length.

When all direct loads, moments, and effective lengths have been determined, the column may be designed for the combined actions according to the AISC Specification. [2]

At ground level, sufficient bracing must be provided to transfer the wind shear to the foundations. This may be accomplished by diagonal braces extending from a panel point of the lowest truss to the foundation.

FABRICATION

The staggered truss system of steel framing lends itself to a mass production operation of fabricating the trusses. Jigs and fixtures may be built to accommodate the truss geometry and the slight variations in member sizes.

Truss members are usually of rolled shapes, such as wide flange sections, structural tees, channels, or angles. The fabrication of the trusses is by welding and/or bolting. Welding can easily be performed in the down hand position for each side of the truss. When one side has been completed, the entire fixture holding the truss may be rotated 180° to enable the welders to continue with the down hand position on the newly exposed side.

Because the trusses are stiff and the resulting deflections small, high strength steels may be used to advantage for all the members of the truss. Columns in most buildings using this staggered system of floor trusses may also be efficiently designed using high strength steels.

ERECTION

For most building heights, erection of the steel framing and floors for the staggered truss system may be accomplished by a tower crane such as the hammerhead or by a mobile truck or crawler crane with tower attachment, located in a suitable position to reach all corners of the building.

By the nature of the interaction and interdependency of the floors, trusses, and columns, the erection sequence must be programmed to include every structural component as the building rises. Columns at the first story level are two and three stories high in order to start the staggered pattern of the trusses. Subsequent column lengths are two stories high until another adjustment is made near the top to close the building at the roof line.

As a result of the interdependency of the structural members, temporary bracing must be provided to prevent buckling of the structure as a whole and lateral buckling of the trusses until the floors are connected.

Because the floors may be used to brace the building during erection, they must be firmly connected to the truss chords. This operation should be performed before each new set of columns is erected, in order to provide a stable structure as the building becomes taller. Temporary lateral bracing may be installed in lieu of the floor slabs, as necessary, to expedite steel erection.

Longitudinal bracing may be considered to be provided when the spandrel beams are installed as erection proceeds. The spandrel beams are usually of sufficient stiffness so that additional temporary bracing is generally not required in this direction.

SUMMARY

The staggered truss system for steel framing is an efficient structural system for high rise apartments, hotels, motels, dormitories, and hospitals. The arrangement of story-high trusses in a staggered pattern at alternate column lines provides large column-free areas for room layouts.

The interaction of the floors, trusses, and columns makes the structure perform as a single unit, thereby taking maximum advantage of the strength and rigidity of all the components simultaneously. Each component performs its particular function, totally dependent upon the others for its performance.

The staggered truss system of steel framing has become an economical system for high rise, high density occupancy buildings.

ACKNOWLEDGMENTS

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