Steel is Changing the Los Angeles Skyline

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VISITORS TO THE city of Los Angeles recently have noticed a great change in the character of the city. Today, tall multi-storied structures are projecting above the skyline —many twenty story buildings, some thirty stories, and at least one in the design stage of forty-five stories. Construction records are being broken daily.

Prior to 1957, the city was flat; the important building structures were "box-like", all apparently the same height. By law, the buildings were limited to thirteen stories and not more than 150 ft in height.

NEW CODE PROVISIONS

In that year, 1957, through efforts of many civic-minded individuals, including many practicing structural engineers and architects, the height limitations were removed and new building codes adopted. It was in the latter area that the structural engineers took a leading part. The California coast is in an active seismic area and some of the world's greatest earth tremors have occurred in that state. "Could tall multi-story structures be safely built in a seismic area?" This was the question to be answered.

The Structural Engineers Association of California, after several years of intensive study, developed and recommended a practical code which has been adopted by all the large cities in the state and by the International Conference of Building Officials. This code was developed along well established principles of earthquake design. "The major objective", to quote the code's introduction, "was to consider the dynamic response of structures." In a practical way, the new code emphasized:

1. The criteria of *stiffness*—namely, that the total shear or load should be distributed to the various resisting elements in proportion to their rigidities.
2. The necessity of *continuity*—that is, the interconnection of all parts to form a single unit.
3. The evaluation of response performance of different types of construction.
4. The desirability of a high degree of energy absorptive capacity.

Specifically, Section 2314(j) of the code requires:

> *Structural Frame.* Buildings more than thirteen stories or 160 ft in height shall have a complete moment resisting space frame capable of resisting not less than 25 percent of the required seismic load for the structure as a whole. The frame shall be made of a ductile material or a ductile combination of materials. The necessary ductility shall be considered to be provided by a steel frame with moment resistant connections or by other systems proven by tests and studies to provide equivalent energy absorption.

Here is the crux of the matter. The value of continuity and ductility is recognized, and the high energy absorption capacity inherent in a tough steel frame is noted. Steel is used as a standard to which all other systems may be compared.

This construction activity not only has its rewards, but also its practical problems. In recent years, the multistoried buildings designed by the author's firm generally fall into two categories.

The first type includes those structures in which the vertical loads are carried by a steel frame and the horizontal forces are resisted either by concrete shear walls or by braced frames and vertical trusses. These buildings can economically utilize the newer high-strength steels. In fact, just a few years ago, the author's firm redesigned a 22 story steel frame building with concrete shear walls from A7 to A36 steel with an overall saving of approximately 10 percent. If A441 steel had been available at that time, it is estimated that an additional saving of from 5 to 10 percent would have been possible. In another seventeen story structure, the introduction of four vertical trussed frames located symmetrically in the central core section saved, it is estimated, 2 lbs of steel per square foot of floor area. These savings represent something

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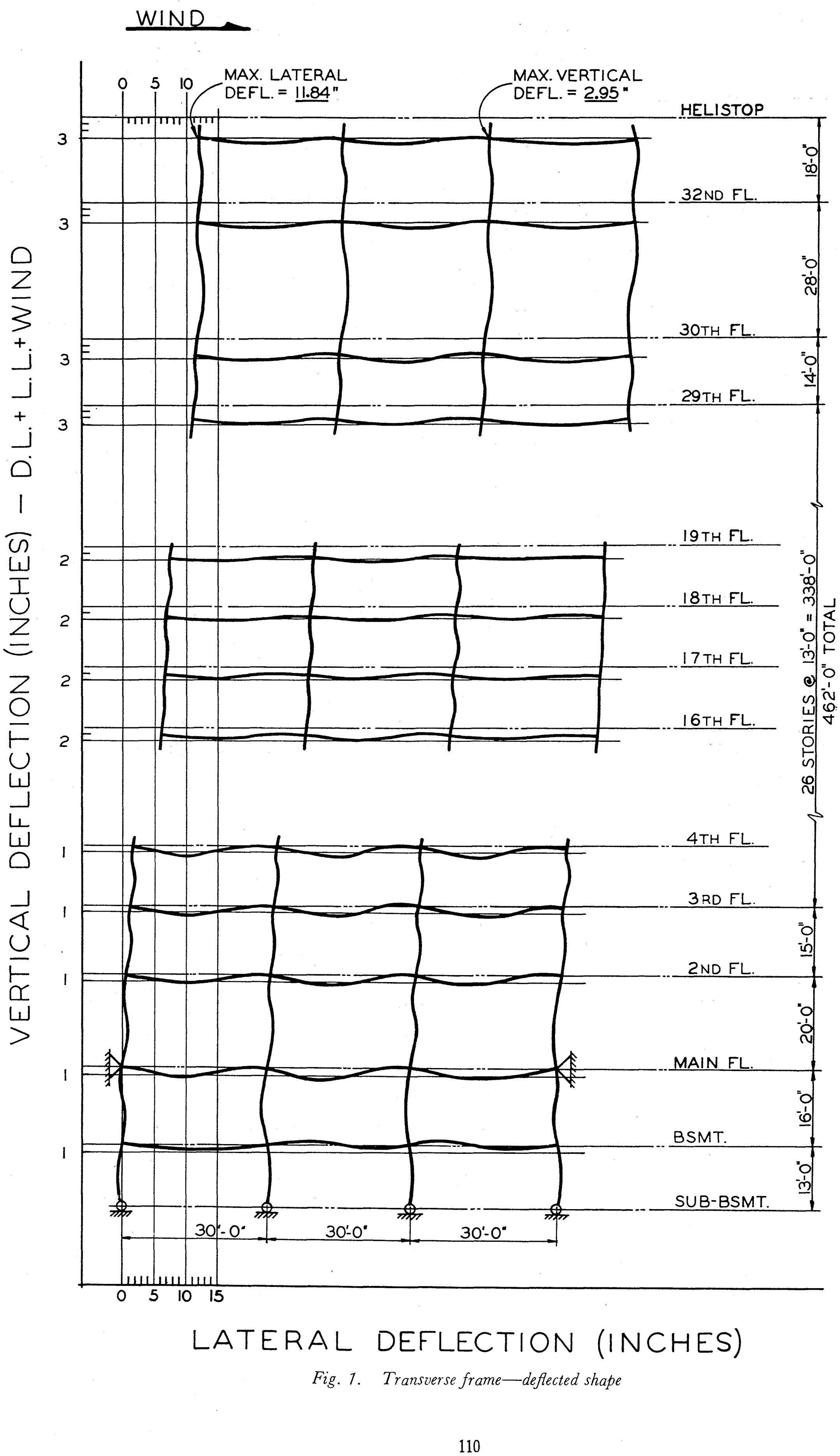

Fig. 1. Transverse frame—deflected shape

more than 10 percent of the cost of the steel. In these structures, the structural engineer designs the steel frames for strength alone and supports the vertical loads in the most economical way possible.

The second type is the modern building devoid of all classical masonry walls, clad either in glass or non-structural window wall panels. In this case, the structural engineer must rely exclusively on the basic structural frame to resist all the forces of nature. There are no structural walls, no opportunities to insert braced frames. All forces, vertical and horizontal, must be resisted by the structural frame.

SYMMETRY

Several fundamental concepts become extremely important. The first is *symmetry*. Since the goal in distributing lateral loads is to make realistic assignment of shears to the various resisting frames in conformance with actual behavior, the more uniform and symmetrical the structure, the better is the response or behavior. Torsional motion is thereby eliminated, or at least greatly reduced. Symmetrical design also reduces the necessary engineering man-hours, and results in lower construction costs due to the inherent duplication, simpler detailing and fabrication.

The engineering problems in designing an asymmetrical system in comparison seem very complex. Asymmetry dictates a series of trials and errors, in which the frames are computed for an estimated load, the deflections calculated, and the magnitude of the actual load adjusted to the rigidity of the frame. This process must then be repeated until the loading, rigidity and deflection are in balance.

STIFFNESS

The second important design concept is *stiffness*. The lateral movements of the structure, or "strain" in engineering terms, must be controlled to within tolerable limits. The design for strength is not enough.

The requirements for "stiffness" design may vary with the locality and magnitude of the forces encountered. In the Los Angeles area, the so-called "drift" control is limited to $0.0025H$ for the differential horizontal movement of the structure when subjected to wind forces. This value is consistent with the wind velocities recorded by the weather bureau for the coastal plains in the Southern California area. Although it might seem that this criterion is not sufficiently restrictive, it can be justified by comparing the design forces assumed, and the actual forces generated by the relatively low wind pressures.

The limiting deflection control for seismic forces is twice the value for wind loads, or $0.005H$. This requirement is somewhat academic, however, since in tall structures, the value for wind forces usually controls the design. Design for "stiffness" should not be underestimated. Careful deflection control of a vibrating structure is extremely important to insure the comfort of the occupants.

The significance of this requirement on the design of steel frames can best be illustrated by an actual example. The structure to be considered is a thirty-two story building, four columns in the transverse direction, seven columns on the longitudinal axis. The bay spacing is 30 ft-0 in., the height is 433 ft. Figure 1 illustrates the deflected shape of the structural frame.

In checking the stresses in the frame, designed for drift control, it was found that:

1. The axial stresses in a typical interior column were:

1st story	16.3 ksi
10th story	16.3 ksi
20th story	13.1 ksi
30th story	4.5 ksi

   The average axial stress was 15,000 psi based on a total column shortening of 2.95 in. in 462 ft of column length.
2. The flexural stresses in the girders were in general approximately two-thirds of the allowable stresses.
3. The drift control was influenced 25 percent by the columns and 75 percent by the girders. Joint rotation is more effectively controlled by increasing the size of the girders than by increasing the size of the columns.

The variations in the axial unit stress from floor to floor are not of major importance. However, any great variation in the axial unit stress of the columns for any one floor is very important. The accumulative effect of an imbalance in the column compression shortening may result in uneven, or out-of-level, floors. For example, a differential of 2,500 psi in the average axial stress for the columns in a thirty-two story structure would cause variations in the floor levels of as much as ½-in.

Obviously, in this structure there was no reason to use high-strength steel. The stresses were low, and because the E value (the modulus of elasticity) is practically the same for all types of steel, A36 steel was chosen solely on the basis of economy.

The methods of computation for multi-story building framing are changing constantly. Years ago, the portal method was used; later (but not chronologically), the cantilever concept, moment distribution, various graphical solutions, and slope deflection methods were used. Each had its special emphasis. In recent years, joint coefficients modified by member stiffness, and very often a computer analysis based on strain-energy concepts, have become very effective tools. In the last five years, all of the frame design in the author's office has been done with the help of an electronic computer from which both the stresses of all members and the lateral and vertical deflections of all joints can be determined. This computer analysis accounts for the column shortening of the frame, permits a determination of the "drift" control, and checks the allowable and actual stresses in the members. In other words, the computer analysis records both the primary frame stresses and the secondary stresses resulting from lateral deflection and vertical column shortening. In one twenty-eight story frame in which the adjacent columns were rotated on their axes, the curvature of the weak axis columns was found in some instances to be in the reverse direction, influenced by the large stiffness of the adjacent, strong axis columns and the secondary stresses. This condition would have been difficult to detect by the old classical methods, but was readily apparent in the computer results.

The design lengths of columns in a frame must have special attention. The column length is no longer the story height, but in accordance with the more sophisticated requirements of the new code the effective length is actually the distance between the points of contraflexure at buckling under vertical load only. Here again, the computer analysis is a great aid in solving these more complex provisions. Two articles published in the *AISC Engineering Journal* January, 1964, pertain to this subject, and clarify many aspects of these design problems: *Effective Column Length—Tier Buildings* by T. R. Higgins, and *Lateral Support for Tier Building Frames* by T. V. Galambos.

CONTINUITY

The third important design concept is *continuity*. The efficiency and economy in supporting vertical loads with continuous framing has been well established and documented. The resistance to lateral loads by continuous frames likewise has been ably attested. Just recently, the earthquake which occurred in Alaska once again subjected buildings to a severe test. Preliminary engineering reports and pictures taken at the scene prove the adequacy of good, well designed construction, particularly those with well executed steel frames.

The problems in the design of a frame chiefly occur in the connections. Should the engineer use a bolted joint, a welded joint, or a combination of both? He may use rivets, machine bolts, high strength bolts, or many types of special fasteners. Each fabricator has special shop procedures and is very sure that the particular welded or bolted assembly used is more economical and better than any other fabrication. Some advocate direct beam to column welding; others prefer shop welding plates to the columns and field bolting to the beams; still others recommend bolted split-tee connections.

Here the dilemma begins. What should the consultant do? He must design as economically as possible; he must have the cooperation of the fabricator. Further, there are certain building conditions and criteria to be satisfied. In general, shop welding and field bolting is probably preferable. This procedure tends to minimize large inspection costs, tends toward a greater degree of reliability, and furnishes a connection which adequately supports the vertical load moments and shears, and provides an excellent connection for restraining seismic forces. However, this is an area in which the cooperation of both the consulting engineer and the fabricator is essential. Thus, adaptations to particular shop practices and the particular preferences of the engineer can be resolved.

With the increasing height and complexity of modern buildings has come a greater awareness of the many problems inherent in their design and construction. The structural engineer is re-examining basic criteria and methods of design. The concepts of symmetry, stiffness control, and continuity should prove to be useful tools.