ASEISMIC DESIGN PROCEDURE FOR STAGGERED TRUSS FRAMED BUILDINGS

by

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SYNOPSIS

The staggered truss system can be analyzed by statically determinate techniques. Moreover, the elastic limit and ultimate strength state of the truss depend only upon the properties of the truss chord members at the central open panel. These characteristics permit a convenient and simple elastic limit - ultimate strength design procedure. Each step of this design procedure is explained.

INTRODUCTION

The design procedure described herein was developed to permit easy incorporation of new knowledge as it becomes available, while permitting maximum flexibility to the design engineer and maintaining the general design philosophy expressed by the Structural Engineers Association of California (4) which is:

"1. Resist minor earthquakes without damage; 2. Resist moderate earthquakes without structural damage, but with some nonstructural damage; 3. Resist major earthquakes, of the intensity of severity of the strongest experienced in California, without collapse, but with some structural as well as nonstructural damage."

STAGGERED TRUSS FRAMING SYSTEM

The staggered truss framing system (3) utilizes story-deep trusses spanning the full width of the building in alternate stories. These trusses are staggered in a "running bond" pattern along the length of the building usually with an open central panel in each truss to provide an uninterrupted corridor. Although the trusses are usually fully assembled with welded connections before shipment to the building site, Gupta and Goel (1) have shown that the trusses can be assumed as pin-connected. The top and bottom chords at the central and adjacent panels must be a continuous member to develop a stable truss. The typical truss analyzed is shown in Fig. 1. With an assumed relative distribution of vertical shear force at the central panel to the top and bottom chord members, the truss is statically determinate.

The statically determinate trusses are analyzed for gravity loads by usual procedures. Since the trusses connect into the weak direction of the columns with a simple connection, the columns accummulate the

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truss reactions with no moment. For lateral loads, such as wind and code seismic forces, the accumulated lateral forces are transmitted from the top chord of a truss to its bottom chord by the diagonal web members and from the bottom chord of one truss to the top chords of the adjacent trusses by horizontal shear in the floor diaphragm system (Fig. 2). In tall buildings this accummulated horizontal floor diaphragm shear force becomes large. Thus, the staggered truss framed building transmits the lateral forces primarily by truss action in each story - not as alternately trussed. This substantially increases the lateral stiffness of this system compared to open moment frame or alternately trussed buildings.

One of the most significant characteristics which influence the earthquake response of these buildings is the shear forces and moments in the top and bottom chord members of the open central panel. The elastic limit and ultimate strength of these members can be used to design the remaining truss members to remain elastic for the ultimate state for the entire truss. This knowledge of the ultimate state for each truss is essential to this design procedure.

DESIGN PROCEDURE

1. In consultation with engineering geologists and foundation engineers, establish appropriate elastic limit design spectra for the proposed building site. Further, select one or more time history accelerograms for the maximum probable earthquake at the building site.

2. Make a preliminary design of the staggered truss structure. Procedures for establishing this preliminary design have been illustrated by Gupta and Goel (1). The truss members are analyzed for gravity forces as if the truss were pin-connected to all elements except for the central three panels of the truss, figure 1, assuming a distribution of shear to the top and bottom chords in the central panel. The truss members are designed in the usual manner for combined gravity and lateral forces according to code requirements for wind or seismic forces. It is practical to use identical trusses for several story levels.

3. Estimate the natural frequencies and mode shapes of the system. One technique suitable for desk computation is described by Hanson, Goel and Berg (2). Since the design spectra are smooth functions, approximate frequencies and mode shapes are sufficient.

4. Calculate the design story shears for the building. Having the elastic limit design spectra, the natural frequencies, and mode shapes, use standard mode analysis techniques to calculate the story shear at each level for each mode of practical interest. Sum the absolute values of the shears at each story to give the elastic limit story shear. Usually the first three or four modes are sufficient.

5. Design the chord members for the elastic limit story shear. The elastic limit moments at the ends of the open central panel chord members establish the minimum elastic section modulus which can be used. This modulus is directly proportional to the elastic limit story shear,

the width of the open central panel, and the height of the truss and inversely proportional to the span of the truss and the minimum yield stress of the chord members. Moments caused by gravity loading, although small, should be included.

6. Determine the maximum column loads for the ultimate mechanism. With the chord members designed for the elastic limit story shears, increase the lateral forces to cause the chord members to reach their plastic moment values. These plastic moment values determine the ultimate shear force in the chord members of the open central panel which determine the ultimate story shear at that level. The ultimate chord shear forces could be accummulated from the top story to the foundation to give the ultimate earthquake column axial forces. It is recommended that a reasonable reduction in this accummulated ultimate value be added to the gravity load axial forces in each column. The column is then designed to remain elastic and below its critical load. The column sizes will usually be governed by the longitudinal seismic requirements rather than those in the truss direction as calculated above.

7. Design the truss members and floor diaphragms. Use the ultimate story shear to calculate the maximum earthquake forces in the truss members. Combine the forces with the dead load and live load forces to provide the design forces for the truss members which must remain within the elastic limit and below the critical buckling loads for all possible combinations of earthquake and gravity loads.

The maximum floor shear which equals half of the ultimate story shear must be transmitted from the truss chords to the floor system and across the floor panel to the next truss elastically. This is a critical step in the design because early failure of this element would uncouple the staggered trusses and result in excessive lateral displacements at that level.

8. Verify that the structure has controlled inelastic responses. As a check on the inelastic behavior of these buildings until more experience with their design is available, it is recommended that the inelastic dynamic response of the building be computed for one or more time history accelerograms representative of the maximum probable earthquake to be expected at the building site. Careful analysis of the results of these inelastic dynamic response may reveal desirable modifications to the design.

CONCLUDING REMARKS

This design procedure results in an economical structure which remains elastic for the design earthquake and has ductile inelastic response to any more severe earthquake. This design procedure is illustrated in reference 2.

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