Forces on Bracing Systems

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INTRODUCTION

The bracing systems that are the subject of this work are structural components or assemblies that are intended to prevent buckling or reduce the effective unsupported length of columns, towers, truss chords, and other members or structures loaded in compression. (In some applications, the same system is also used to resist externally applied loads.) Widely varying criteria, with little or no rational basis, are in use for the design of these bracing systems.

It is generally recognized that bracing systems need stiffness (to limit deformation of the braced components or structures and to cause them to behave in the intended manner) and strength (to provide the necessary stabilizing forces). In many situations, the stiffness and strength requirements are related to each other: reduced stiffness allows greater deformation, which in turn results in increased force on the bracing.

Rigorous analysis to determine the required stiffness and strength of bracing systems can be very complicated. Fortunately, rigorous analysis is rarely necessary. The simple, approximate, bounded solution proposed in this paper is applicable to most situations that designers are likely to face.

PROPOSED TECHNIQUE

The proposed technique is based on the fact that, typically, there is a clear and direct relationship between the displaced configuration of the braced element or structure and the magnitude of the stabilizing force that must be provided by the bracing system. It is important to note that the "displaced configuration" in the preceding statement is the configuration after all displacements have occurred, including those caused by deformation of the bracing system. While bracing stiffness is not mentioned explicitly, it is significant in that it affects the displaced configuration. The proposed general procedure for determining bracing forces for design consists of the following steps:

1. Estimate the critical displaced geometry of the structure, i.e., the geometry that results in the largest value of the particular bracing force that is being determined. The critical geometry may be different for different bracing components; maximum forces on the different components may not occur simultaneously. The estimated displaced configuration should include the effects of initial imperfections, deformations due to externally applied loading, and deformations due to bracing or stabilizing effects.
2. Compute the bracing force corresponding to the displaced configuration assumed in Step 1. Use this force for design of the bracing.
3. Verify that deformations (including bracing deformation due to the force calculated in Step 2) are within the limits assumed in Step 1.

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The structure shown in Fig. 1 can be used to illustrate the calculation of bracing force corresponding to an assumed geometry (Step 2 of the proposed procedure). A compression member, which could represent a column or a truss chord, is braced laterally at several locations. The brace locations and the restraining forces supplied by the bracing are indicated by horizontal arrows. The bracing force that is to be determined is denoted as *F*. The member is considered to be hinged at the brace locations. The hinge assumption is not necessary for the validity of the procedure; however, it simplifies the calcula-

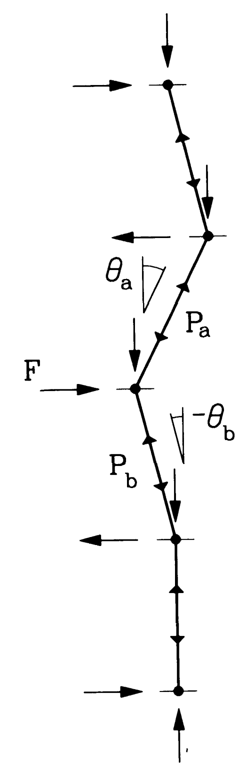

Fig. 1. Forces on displaced configuration of braced compression member.

tions. In a real design situation, assuming hinges at brace points would be conservative in that it could be expected to result in higher bracing forces. To satisfy statics at the brace location:

$$F = P_a\theta_a - P_b\theta_b \qquad (1)$$

where P_a, P_b, θ_a, and θ_b are axial forces and skew angles (relative to a common datum) of the member segments adjacent to the brace point, as indicated in Fig. 1. The rules of statics also result in the following shear forces in the bracing system due to forces from the braced member:

$$S_a = P_a\theta_a \qquad (2a)$$

$$S_b = P_b\theta_b \qquad (2b)$$

where S_a and S_b are shear forces in the bracing system at the locations denoted by the subscripts. These shear forces are, simply, the transverse components of the force in the braced member. If P_a and P_b are approximately equal and both are denoted as P, the formula for F can be simplified to:

$$F = P(\theta_a - \theta_b) \qquad (3)$$

Use of these relationships in the complete procedure for calculation of bracing forces for design will be illustrated in the following example.

EXAMPLE

A column in a multistory building supports a load of approximately 5,000 kips. It is a "leaning" column, i.e., it is not part of the building's lateral load-resisting system but is braced, through the floors, by the lateral load-resisting system. The column will be designed as though it were hinged at the floors (i.e., $K = 1$). The lateral load-resisting system will be designed to limit interstory drift due to wind and other lateral loads to 0.0025 times the story height. For what horizontal force should the column-to-floor connection be designed?

Figure 1 and the corresponding relationship between bracing force and structure geometry are applicable to the column in this example. The force for design of the column-to-floor connection (which is the bracing force F in Fig. 1) may be determined as follows:

1. Estimate the maximum out-of-plumbness of the column and the maximum difference in out-of-plumbness between adjacent stories. The maximum out-of-plumbness of any story of the column is taken to be as follows: 0.0020 due to erection tolerances, 0.0025 due to deformation of the lateral load-resisting system (as specified), and a negligible amount due to deformation of the floor diaphragm and the column-to-floor connection, for a total of 0.0045. The tilt due to erection tolerances could be in the opposite direction in the adjacent story. The deformation of the lateral load-resisting system might be less in the adjacent story, but it is not likely to be zero or in the opposite direction; as a reasonable worst-case assumption, it will be taken as one-half the maximum value of 0.0025. Thus, overall maximum difference in out-of-plumbness between adjacent stories ($\theta_a - \theta_b$) is 0.0045 + 0.0020 – 0.0025 / 2, which amounts to a total of 0.00525.
2. Calculate F, the maximum horizontal force at the column-to-floor connection. The maximum bracing force F is ($\theta_a - \theta_b$) times the compression in the column, or 0.00525 times 5,000 kips, which amounts to 26 kips. Use this force for design of the column-to-floor connection. This is the maximum force at a given floor; maximum values will not occur simultaneously at all floors. The maximum horizontal shear force in the lateral load-resisting system due to bracing forces from this column would be equal to the maximum out-of-plumbness times the column load, or 0.0045 times 5,000 kips, which amounts to 23 kips.
3. Verify that the actual maximum out-of-plumbness and difference in out-of-plumbness between adjacent stories will not be greater than the assumed values. Check that the deformations due to all design loads, including the bracing forces calculated in Step 2, are within the limits assumed in Step 1.

For simplicity, the calculations in this example were carried out at service loads; the deformations considered were those that were expected to occur under unfactored service loads. To obtain consistent margins of safety, it would be more appropriate to calculate bracing forces on the basis of expected deformations due to factored loads. In this example, the column tilt due to interstory deformation of the lateral load-resisting system under factored loads could be taken as 0.0035 (instead of 0.0025 at service loads); out-of-plumbness due to erection tolerances would be unchanged, and the overall maximum value of ($\theta_a - \theta_b$) would be 0.00575, which results in a column-floor bracing force of 0.00575 times the column load.

This example was a particularly simple application of the proposed procedure for calculating bracing forces, since the column-floor bracing force in a multistory building is not likely to have a significant effect on the displaced geometry of the structure. (Deformation of the building's lateral load-resisting system due to column bracing effects is likely to be much smaller than the deformation due to wind or other external loading.) In other applications, such as lightly braced truss chords, it may be necessary, sometimes, to go back to Step 1 with a new and more severe estimate of displaced shape after completing one cycle of the three steps.

SUMMARY AND CONCLUSIONS

A simple technique for determining forces on bracing systems has been proposed. The procedure is approximate; however, it is adequate for design since it yields a bounded solution that can be verified to ensure that actual forces on the bracing will not be greater than the values indicated by the proposed method.

As an example of the use of the proposed technique, bracing requirements for a column in a multistory building were studied. The horizontal restraining force for design of the column-to-floor connection was found to be about 0.6 percent of the load in the column, based on certain assumed erection tolerances and limits on interstory drift due to lateral load.

While this example was intended only for illustrative purposes, similar studies of this and other bracing situations—with plausible extreme values of the factors that determine the results—could be used to establish general rules for the design of common types of bracing systems.