4 Frame Design

4.1 FRAME DESIGN BY ELASTIC ANALYSIS

Traditionally, portal frame analysis and design in Australia has been elastic rather than plastic. Although AS 4100 [1] is a limit states code with section and member capacities based on the plastic moment of resistance, the main method in the code for determining the forces and bending moments in a frame is still elastic analysis whether linear or non-linear. Plastic analysis may lead to more economical structures in some cases but the availability of plastic design software is limited. By contrast, design software for elastic design has continually evolved and is now very user-friendly. There is also the added complication of the non-uniform, asymmetric nature of the wind load which makes plastic design even more difficult. Hence plastic design tends to be very labour intensive and elastic analysis is needed anyway to calculate deflections. Methods of plastic design were demonstrated in previous editions of this book.

In the Australian wind code AS/NZS 1170.2 [2], coefficients for external pressures, unless the roof pitch is 10° or greater, or h/d is greater than 0.5, decrease in steps starting from −0.9 at the windward edge to −0.5 to −0.3 to −0.2, or alternatively from −0.4 to 0, +0.1 and +0.2. For transverse wind cases, this non-uniform pressure can be handled easily by an elastic analysis using a plane frame computer program. In fact, it would be extremely difficult to take advantage of the reduction in pressure and achieve an economical structure without recourse to a plane frame computer program.

In the design of rafters and columns in portal frames, the selection of the member sizes may be governed by the ultimate *strength limit state*, or by limiting deflections in the *serviceability limit state*. For the strength limit state, the design axial and bending capacities ϕN_c and ϕM_{bx} respectively are obtained through a consideration of flexural and flexural-torsional buckling respectively.

To obtain an economical rafter design, it is important to ensure that the design bending strength is as close as possible to the section capacity ϕM_{sx}, which for many sections will be the plastic moment capacity $\phi S f_y$. This capacity is usually achieved by the use of adequate restraints such as fly braces to restrain the inside rafter and column flanges laterally when in compression. Of course, there are some cases where deflections govern the design, and these are discussed in Section 4.9 of this chapter.

4.2 COMPUTER ANALYSIS

4.2.1 Load Cases

For computer analysis, using load cases which are complete in themselves is recommended. For example, internal pressure should be a load case by itself, and not combined with an external pressure case. The loads on columns and rafters should not be separated. Recommended load cases for a computer analysis are as follows:

1. Dead Load (DL) or (*G*)
2. Live Load (LL) or (*Q*)
3. Transverse Wind Maximum Uplift (TW1) (external only)
4. Transverse Wind Minimum Uplift (TW2) (external only)
5. Longitudinal Wind on First Internal Frame (LW1) (external only)
6. Longitudinal Wind on Downwind Frame (LW2) (external only)
7. Internal Pressure under Transverse Wind (IPTW)
8. Internal Pressure under Longitudinal Wind (IPLW)
9. Internal Suction under Transverse Wind (ISTW)
10. Internal Suction under Longitudinal Wind (ISLW)

Extra load cases may be necessary for non-symmetrical buildings, for buildings where the transverse wind terrain category is different on one side from the other, and for buildings where it may be an advantage to consider different wind speeds in different directions. Transverse wind load combinations with internal suction are not often critical, but designers should check such combinations nevertheless. It is possible that the hogging moment at the downwind knee joint will be worse under dead load, transverse wind and internal suction (1.2DL + TW + IS) than under dead load plus live load (1.2DL + 1.5LL). This particularly affects the downwind column as its unrestrained inside flange will be in compression. The internal suction case (IS) can be obtained simply by factoring the internal pressure load case by an appropriate negative number but the design example in this book uses separate load cases for internal suction.

The recommended load combinations for a computer analysis are:

- **LC20**: *1.2DL + 1.5LL*
- **LC21**: *0.9DL + TW1 (maximum uplift) + IPTW*
- **LC22**: *0.9DL + TW2 (minimum uplift) + IPTW*
- **LC23**: *1.2DL + TW2 (minimum uplift) + ISTW*
- **LC24**: *0.9DL + LW1 (maximum uplift) + IPLW*
- **LC25**: *1.20DL + LW2 (minimum uplift) + ISLW*

Note that the loading code AS/NZS 1170.0 [3] states that it is not necessary to consider live load and wind load acting simultaneously.

The distribution of bending moment will not vary much from the trial to the final section properties provided that the ratio of trial column and rafter second moments of area is similar to that finally adopted. Some computer programs allow for shear deformations, although the effect is not significant. To account for shear deformations in Microstran, the web area must be input. The web area can be taken as the overall depth D times the web thickness t_w.

4.2.2 Methods of Analysis

AS 4100 permits a number of types of analysis consisting of first and second order elastic analysis, first and second order plastic analysis and advanced structural analysis. First and second order *elastic* analysis are covered in this chapter.

First order elastic analysis assumes the frame remains elastic and that its deflections are so small that secondary effects resulting from the deflections (second order effects) are negligible. First order analysis is generally carried out using plane frame analysis computer programs. Despite the basic assumption of first order analysis, second order effects are not negligible. Second order effects are essentially P-Δ effects which arise from the sway Δ of

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