

Simplified Frame Analysis (Portal Method)
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Chapter 2

Simplified Frame Analysis

2.1 INTRODUCTION

The final design of the structural components in a building frame is based on maximum moment, shear, axial load, torsion and/or other load effects, as generally determined by an elastic frame analysis (ACI 8.3). For building frames of moderate size and height, preliminary and final designs will often be combined. Preliminary sizing of members, prior to analysis, may be based on designer experience, design aids, or simplified sizing expressions suggested in this book.

Analysis of a structural frame or other continuous construction is usually the most time consuming part of the total design. For gravity load analysis of continuous one-way systems (beams and slabs), the approximate moments and shears given by ACI 8.3.3 are satisfactory within the span and loading limitations stated. For cases when ACI 8.3.3 is not applicable, a two-cycle moment distribution method is accurate enough. The speed and accuracy of the method can greatly simplify the gravity load analysis of building frames with usual types of construction, spans, and story heights. The method isolates one floor at a time and assumes that the far ends of the upper and lower columns are fixed. This simplifying assumption is permitted by ACI 8.8.3.

For lateral load analysis of a sway frame, the Portal Method may be used. It offers a direct solution for the moments and shears in the beams (or slabs) and columns, without having to know the member sizes or stiffnesses.

The simplified methods presented in this chapter for gravity load analysis and lateral load analysis are considered to provide sufficiently accurate results for buildings of moderate size and height. However, determinations of load effects by computer analysis or other design aids are equally applicable for use with the simplified design procedures presented in subsequent chapters of this book.

2.2 LOADING

2.2.1 Service Loads

The first step in the frame analysis is the determination of design (service) loads and lateral forces (wind and seismic) as called for in the general building code under which the project is to be designed and constructed. For the purposes of this book, design live loads (and permissible reductions in live loads) and wind loads are based on *Minimum Design Loads for Buildings and Other Structures*, ASCE7-02.^{2.1} References to specific ASCE Standard requirements are noted (ASCE 4.2 refers to ASCE 7-02, Section 4.2). For a specific project, however, the governing general building code should be consulted for any variances from ASCE 7-02.

Design dead loads include member self-weight, weight of fixed service equipment (plumbing, electrical, etc.) and, where applicable, weight of built-in partitions. The latter may be accounted for by an equivalent uniform load of not less than 20 psf, although this is not specifically defined in the ASCE Standard (see ASCE Commentary Section 3.2).

Design live loads will depend on the intended use and occupancy of the portion or portions of the building being designed. Live loads include loads due to movable objects and movable partitions temporarily supported by the building during maintenance. In ASCE Table 4-1, uniformly distributed live loads range from 40 psf for residential use to 250 psf for heavy manufacturing and warehouse storage. Portions of buildings, such as library floors and file rooms, require substantially heavier live loads. Live loads on a roof include maintenance equipment, workers, and materials. Also, snow loads, ponding of water, and special features, such as landscaping, must be included where applicable.

Occasionally, concentrated live loads must be included; however, they are more likely to affect individual supporting members and usually will not be included in the frame analysis (see ASCE 4.3).

Design wind loads are usually given in the general building code having jurisdiction. For both example buildings here, the calculation of wind loads is based on the procedure presented in ASCE 6.0. Design for seismic loads is discussed in Chapter 11.

2.6 LATERAL LOAD ANALYSIS

For frames without shear walls, the lateral load effects must be resisted by the “sway” frame. For low-to-moderate height buildings, lateral load analysis of a sway frame can be performed by either of two simplified methods: the Portal Method or the Joint Coefficient Method. Both methods can be considered to satisfy the elastic frame analysis requirements of the code (ACI 8.3). The two methods differ in overall approach. The Portal Method considers a vertical slice through the entire building along each row of column lines. The method is well suited to the range of building size and height considered in this book, particularly to buildings with a regular rectangular floor plan. The Joint Coefficient Method considers a horizontal slice through the entire building, one floor at a time. The method can accommodate irregular floor plans, and provision is made to adjust for a lateral loading that is eccentric to the centroid of all joint coefficients (centroid of resistance). The Joint Coefficient Method considers member stiffnesses, whereas the Portal Method does not.

The Portal Method is presented in this book because of its simplicity and its intended application to buildings of regular shape. If a building of irregular floor plan is encountered, the designer is directed to Reference 2.2 for details of the Joint Coefficient Method.

2.6.1 Portal Method

The Portal Method considers a two-dimensional frame consisting of a line of columns and their connecting horizontal members (slab-beams), with each frame extending the full height of the building. The frame is considered to be a series of portal units. Each portal unit consists of two story-high columns with connecting slab-beams. Points of contraflexure are assumed at mid-length of beams and mid-height of columns. Figure 2-11 illustrates the portal unit concept applied to the top story of a building frame, with each portal unit shown separated (but acting together).

The lateral load W is divided equally between the three portal units. The shear in the interior columns is twice that in the end columns. In general, the magnitude of shear in the end column is $W/2n$, and in an interior column it is W/n , where n is the number of bays. For the case shown with equal spans, axial load occurs only in the end columns since the combined tension and compression due to the portal effect results in zero axial loads in the interior

columns. Under the assumptions of this method, however, a frame configuration with unequal spans will have axial load in those columns between the unequal spans, as well as in the end columns. The general term for axial load in the end columns in a frame of n bays with unequal spans is:

$$\frac{Wh}{2n\ell_1} \text{ and } \frac{Wh}{2n\ell_n}, \ell_n = \text{length of bay } n$$

The axial load in the first interior column is:

$$\frac{Wh}{2n\ell_1} - \frac{Wh}{2n\ell_2}$$

and, in the second interior column:

$$\frac{Wh}{2n\ell_2} - \frac{Wh}{2n\ell_3}$$

Column moments are determined by multiplying the column shear with one-half the column height. Thus, for joint B in Fig. 2-11, the column moment is $(W/3)(h/2) = Wh/6$. The column moment $Wh/6$ must be balanced by equal moments in beams BA and BC, as shown in Fig. 2-12.

Note that the balancing moment is divided equally between the horizontal members without considering their relative stiffnesses. The shear in beam AB or BC is determined by dividing the beam end moment by one-half the beam length, $(Wh/12)(\ell/2) = Wh/6\ell$.

The process is continued throughout the frame taking into account the story shear at each floor level.

2.6.2 Examples: Wind Load Analyses for Buildings #1 and #2

For Building #1, determine the moments, shears, and axial forces using the Portal Method for an interior frame resulting from wind loads acting in the N-S direction. The wind loads are determined in Section 2.2.1.2.

Moments, shears, and axial forces are shown directly on the frame diagram in Fig. 2-13. The values can be easily determined by using the following procedure:

- (1) Determine the shear forces in the columns:

For the end columns:

$$\text{3rd story: } V = 12.0 \text{ kips}/6 = 2.0 \text{ kips}$$

$$\text{2nd story } V = (12.0 \text{ kips} + 23.1 \text{ kips})/6 = 5.85 \text{ kips}$$

$$\text{1st story: } V = (12.0 \text{ kips} + 23.1 \text{ kips} + 21.7 \text{ kips})/6 = 9.50 \text{ kips}$$

The shear forces in the interior columns are twice those in the end columns.

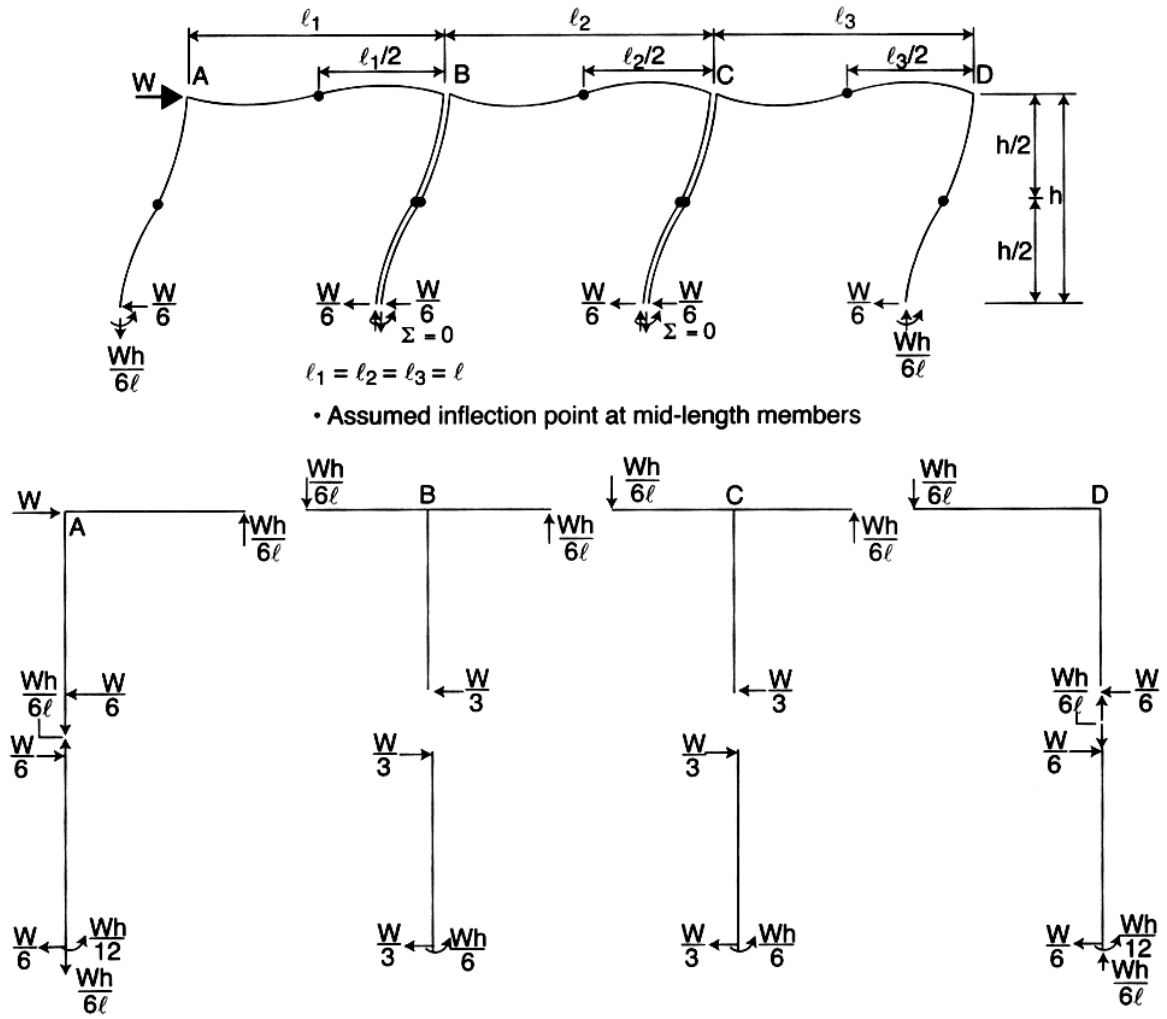


Figure 2-11 Portal Method

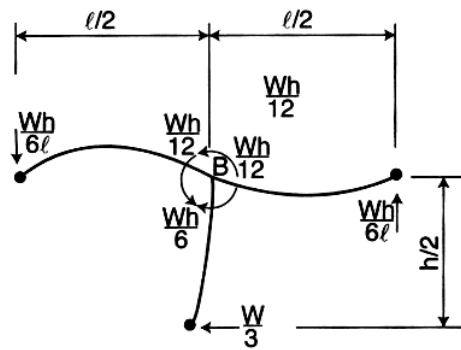


Figure 2-12 Joint Detail

(2) Determine the axial loads in the columns:

For the end columns, the axial loads can be obtained by summing moments about the column inflection points at each level. For example, for the 2nd story columns:

$$\Sigma M = 0 : 12(13 + 6.5) + 23.1 (6.5) - P (90) = 0$$

$$P = 4.27 \text{ kips}$$

For this frame, the axial forces in the interior columns are zero.

(3) Determine the moments in the columns:

The moments can be obtained by multiplying the column shear force by one-half of the column length.

For example, for an exterior column in the 2nd story:

$$M = 5.85(13/2) = 38.03 \text{ ft-kips}$$

(4) Determine the shears and the moments in the beams:

These quantities can be obtained by satisfying equilibrium at each joint. Free-body diagrams for the 2nd story are shown in Fig. 2-14.

As a final check, sum moments about the base of the frame:

$$\Sigma M = 0: 12.0(39) + 23.1(26) + 21.7(13) - 10.91(90) - 2(61.53 + 123.07) = 0 \quad (\text{checks})$$

In a similar manner, the wind load analyses for an interior frame of Building #2 (5-story flat plate), in both the N-S and E-W directions are shown in Figs. 2-15 and 2-16, respectively. The wind loads are determined in Section 2.2.1.1.

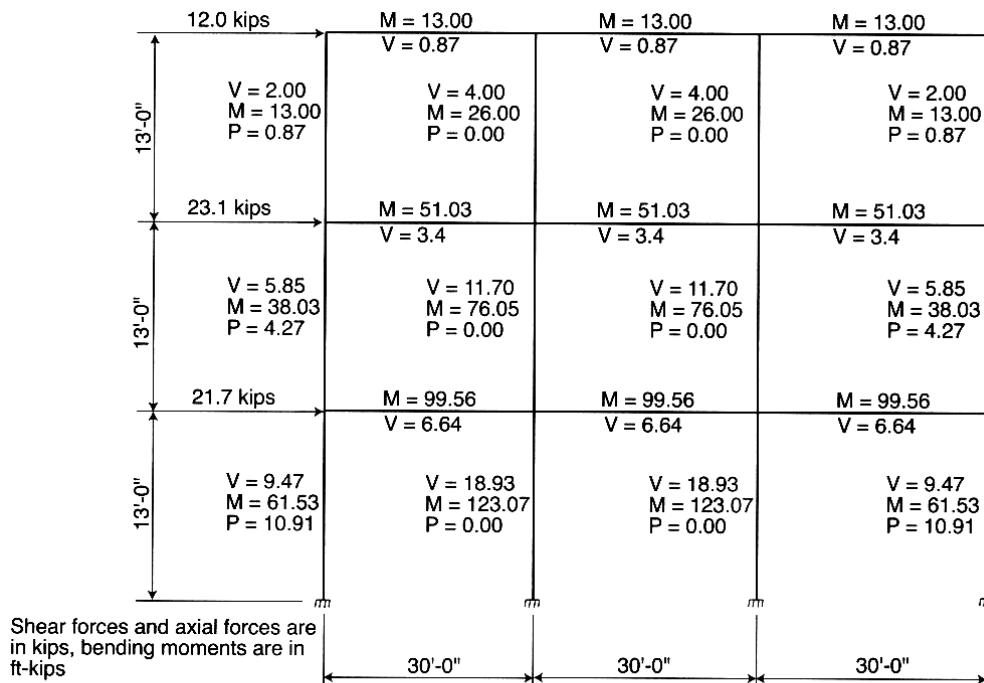


Figure 2-13 Shear, Moments and Axial Forces Resulting from Wind Loads for an Interior Frame of Building #1 in the N-S Direction, using the Portal Method

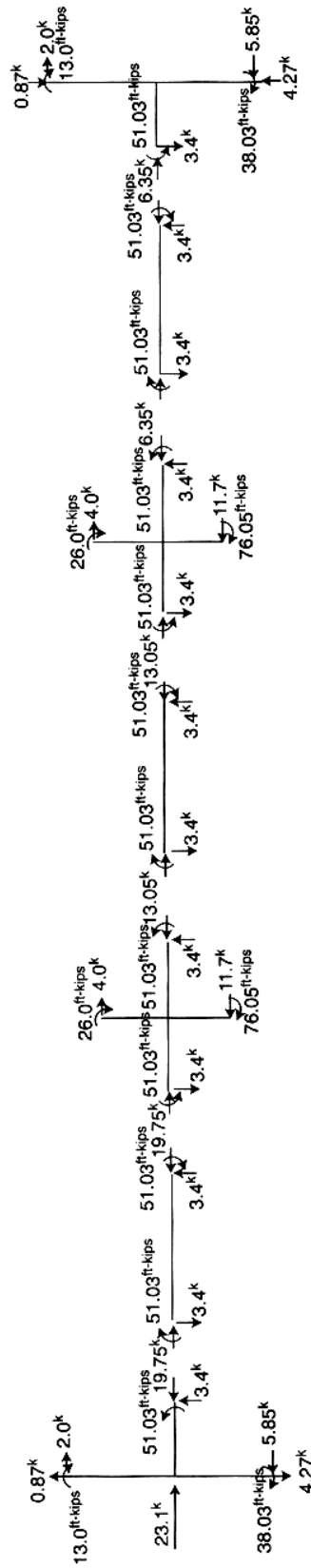


Figure 2-14 Shear Forces, Axial Forces, and Bending Moments at 2nd Story of Building #1