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Diaphragm Design of Metal-Clad, Wood-Frame Rectangular Buildings

American Society of Agricultural Engineers

STANDARD

ASAE-The Society for engineering in agricultural, food, and biological systems
2950 Niles Rd., St. Joseph, MI 49085-9659, USA ph. 269-429-0300, fax 269-429-3852, hq@asae.org

Diaphragm Design of Metal-Clad, Wood-Frame Rectangular Buildings

Developed by the ASAE Diaphragm Design of Metal-Clad, Post-Frame Rectangular Buildings Subcommittee of the Structures Group; approved by the Structures and Environment Division Standards Committee; adopted by ASAE September 1989; revised December 1990; reaffirmed December 1994, 1995, 1996, 1997; revised June 1998; approved as an American National Standard August 1998; revised editorially February 2000; reaffirmed February 2003 by ASAE and ANSI; revised editorially August 2003.

1 Purpose and scope

1.1 This Engineering Practice is a consensus document for the analysis and design of metal-clad wood-frame buildings using roof and ceiling diaphragms, alone or in combination. The roof (and ceiling) diaphragms, endwalls, intermediate shearwalls, and building frames are the main structural elements of a structural system used to efficiently resist the design lateral (wind) loads. This Engineering Practice gives acceptable methods for analyzing and designing the elements of the diaphragm system.

1.2 The provisions of this Engineering Practice are limited to the analysis of single-story buildings of rectangular shape.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Engineering Practice. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Engineering Practice are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Standards organizations maintain registers of currently valid standards.

AF&PA (American Forest & Paper Association) (1991), *National Design Specification® (NDS®) for Wood Construction. (AF&PA. Washington, D.C.)*

ASAE EP486 DEC97, *Post and Pole Foundation Design*

ASAE EP558 DEC98, *Load Tests for Metal-Clad, Wood Frame Diaphragms*

3 Definitions (see figures 1 and 2)

3.1 diaphragm: A structural assembly of metal cladding, including the wood or wood product framing, metal cladding, fasteners and fastening patterns, capable of transferring in-plane shear forces through the cladding and framing members.

3.2 diaphragm design: Design of roof (and ceiling) diaphragm(s), sidewall posts, endwalls, shearwalls, component connections, chord splices, and foundation anchorages, for the purpose of transferring lateral (e.g., wind) loads to the foundation structure.

3.3 Diaphragm dimensions

3.3.1 diaphragm length, d: Length of a building diaphragm in the plane of the diaphragm.

3.3.2 diaphragm span, b_h: Horizontal span of a building diaphragm having length, d.

3.3.3 diaphragm width, s: Distance between individual building frames; see also 3.10.

3.3.4 model diaphragm length, b: Length of a model diaphragm as measured parallel to the direction of applied load.

3.3.5 model diaphragm width, a: Length of a model diaphragm as measured perpendicular to the direction of applied load.

3.4 diaphragm fasteners: The various fasteners and fastener patterns used to connect the several components of the endwalls, shearwalls, and diaphragms. These include fasteners between cladding and purlins, between cladding and endwall girts, between diaphragm framing members, and between individual sheets of cladding (stitch fasteners).

3.5 Diaphragm shear stiffness

3.5.1 model diaphragm shear stiffness, c: The in-plane shear stiffness of a model diaphragm. Defined as the slope of the shear load-deflection curve between zero load and the load corresponding to the diaphragm allowable shear strength.

3.5.2 in-plane shear stiffness, c_p: The in-plane shear stiffness of an individual roof or ceiling diaphragm.

3.5.3 horizontal shear stiffness, c_h: The horizontal shear stiffness of an individual roof or ceiling diaphragm. It is obtained by adjusting diaphragm in-plane shear stiffness, c_p, for slope.

3.5.4 total horizontal diaphragm shear stiffness, C_h: The horizontal shear stiffness of the roof and ceiling assembly is calculated by summing the horizontal shear stiffness values of individual roof and ceiling diaphragms. Alternatively, this stiffness can be obtained from full-scale building tests.

3.6 diaphragm shear strength, V_a: The allowable design shear strength (see ASAE EP558) of a diaphragm in the plane of the cladding.

3.7 eave load, R: A concentrated (point) load, horizontally acting, that is located at the eave of each frame, and results in a horizontal eave displacement identical to that caused by application of the controlling combination of design loads. R is numerically equal to the horizontal force required to prevent horizontal translation of the eave when the controlling combination of design loads is applied to the frame.

3.8 endwall and shearwall stiffness, k_e: The ratio of a horizontal force applied at the eave to the corresponding deflection of an individual unattached wall. A wall is unattached when it is not connected to components that lie outside the plane of the wall.

3.9 frame stiffness, k: The ratio of a horizontal force applied at the eave to the corresponding deflection of the individual unclad post-frames.

3.10 frame spacing, s: The distance between frames. In the absence of stiff frames that resist lateral loads, the frame spacing is generally equated to the distance between adjacent trusses (or rafters) or to the model diaphragm width. Frame spacing defines the width (and therefore stiffness properties) of roof/ceiling diaphragm sections. Frame spacing may vary within a building.

3.11 metal cladding: The metal exterior and interior coverings, usually cold-formed aluminum or steel sheet, fastened to the wood framing.

3.12 model diaphragm: A laboratory tested diaphragm or a diaphragm analyzed using a validated structural model that is used to predict the behavior of a building diaphragm. Laboratory tested diaphragms should be sized, constructed, supported and tested in accordance with ASAE EP558.

3.13 post frame: A structural building frame consisting of a wood roof truss or rafters connected to vertical timber columns, or sidewall posts.

3.14 sidesway restraining force, Q: The total force applied to a frame by the roof/ceiling diaphragm.

3.15 shear transfer: The transfer of the resultant shear forces between individual sheets of cladding, between the ends of roof/ceiling diaphragms and frames and shearwalls, or between the bottom of the shearwalls and the base of the posts or foundation.

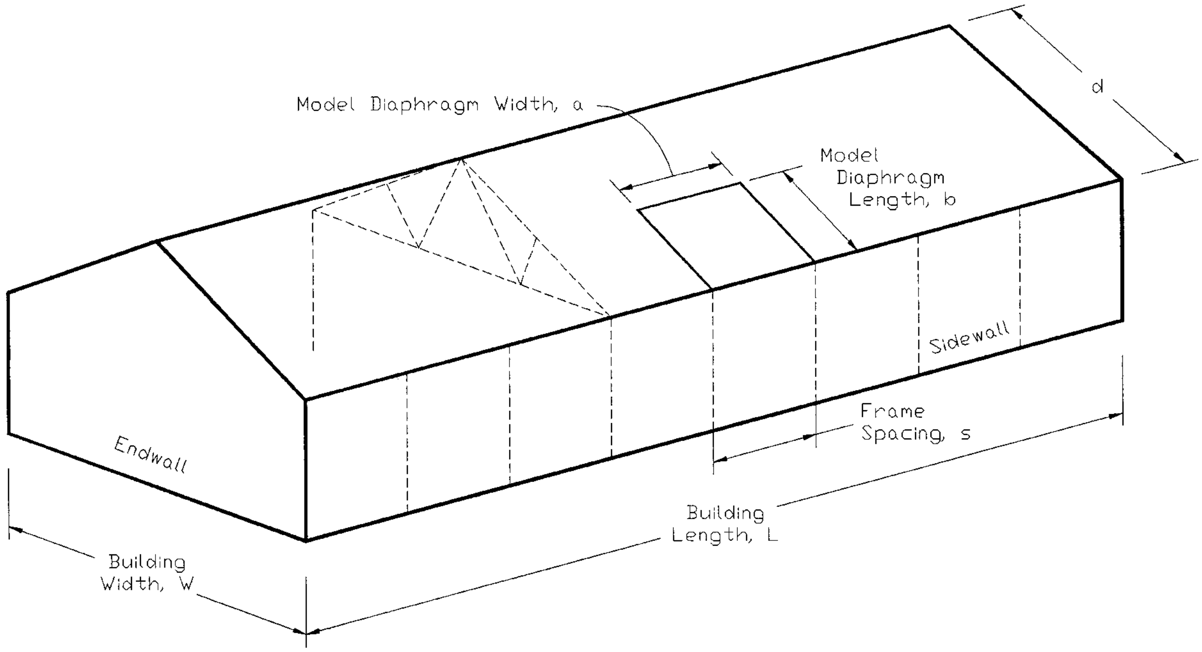

Figure 1 – Definition sketch for terminology

3.16 shearwall: An endwall or intermediate wall designed to transfer shear from the roof/ceiling diaphragm into the foundation structure.

3.17 wood frame: A structural building frame consisting of wood or wood-based materials. Wood trusses over studwalls and post and beam are examples of wood frames.

4 Diaphragm stiffness

4.1 General provisions. This section outlines procedures for determining the total horizontal shear stiffness, C_h, of a width, s, of the roof/ceiling assembly. This stiffness is defined as the horizontal load required to cause a unit shift (in a direction parallel to the trusses/rafters) of the roof/ceiling assembly over a spacing, s (figure 1). This stiffness can be obtained directly from full scale building tests (Gebremedhin *et al*., 1992), validated structural models, or using procedures outlined in clause 4.2.

4.2 Total horizontal shear stiffness, C_h. The total horizontal diaphragm shear stiffness, C_h, for the frame spacing, s, of the roof/ceiling assembly is defined as:

$$C_h = \sum_{i=1}^{n} c_{h,i} \tag{1}$$

where:

- $c_{h,i}$ is horizontal shear stiffness of diaphragm i with a width, s, from clause 4.3, N/mm (lbf/in.);
- n is number of individual roof and ceiling diaphragms in the roof/ceiling assembly (figure 2).

When the frame spacing, s, or roof/ceiling diaphragm construction varies along the length of a building, C_h may vary, and the building requires special analysis (see clause 7.3).

4.2.1 Excluding diaphragms. Diaphragm analyses may be simplified by excluding from an analysis any diaphragm that is considerably less stiff than others in the roof/ceiling system. For example, where a ceiling diaphragm is much stiffer than the roof diaphragm(s), the stiffness of the roof diaphragm(s) may be excluded from total stiffness calculations (i.e., equation 1). Nonstructural diaphragms that are framed or attached to a structural frame and/or structural diaphragm in a manner that requires the nonstructural diaphragm to translate with the structural frame and/or structural diaphragm should not be excluded from the analysis. A nonstructural diaphragm that is relatively stiff is likely to attract more load than it can safely support.

4.3 Horizontal shear stiffness of an individual diaphragm, $c_{h,i}$. The horizontal shear stiffness of an individual diaphragm can be calculated from the diaphragm's in-plane shear stiffness (equation 2) or from the in-plane stiffness of a model diaphragm (equation 3). Model diaphragms used to predict the horizontal stiffness of a building diaphragm shall be functionally equivalent to the building diaphragm. ASAE EP558 gives laboratory test procedures for obtaining model diaphragm shear stiffness.

$$c_{h,i} = c_{p,i}(\cos^2\Theta_i) \tag{2}$$

$$c_{h,i} = G(\cos\Theta_i)(b_{h,i}/s) \tag{3}$$

where:

- $c_{h,i}$ is horizontal shear stiffness of diaphragm i with width, s, and horizontal span $b_{h,i}$, N/mm (lbf/in.);
- $c_{p,i}$ is in-plane shear stiffness of diaphragm i with width, s, and horizontal span $b_{h,i}$, N/mm (lbf/in.);
- Θ_i is slope from the horizontal of diaphragm *i;*
- G is $c(a/b)$, effective shear modulus;
- $b_{h,i}$ is horizontal span of diaphragm i as measured parallel to trusses/rafters, m (ft);
- s is frame spacing, m (ft);
- c is in-plane shear stiffness of the model diaphragm, N/mm (lbf/in.);
- a is length of the model diaphragm as measured perpendicular to the direction of applied load, m (ft);
- b is depth of the model diaphragm as measured parallel to the direction of applied load, m (ft).

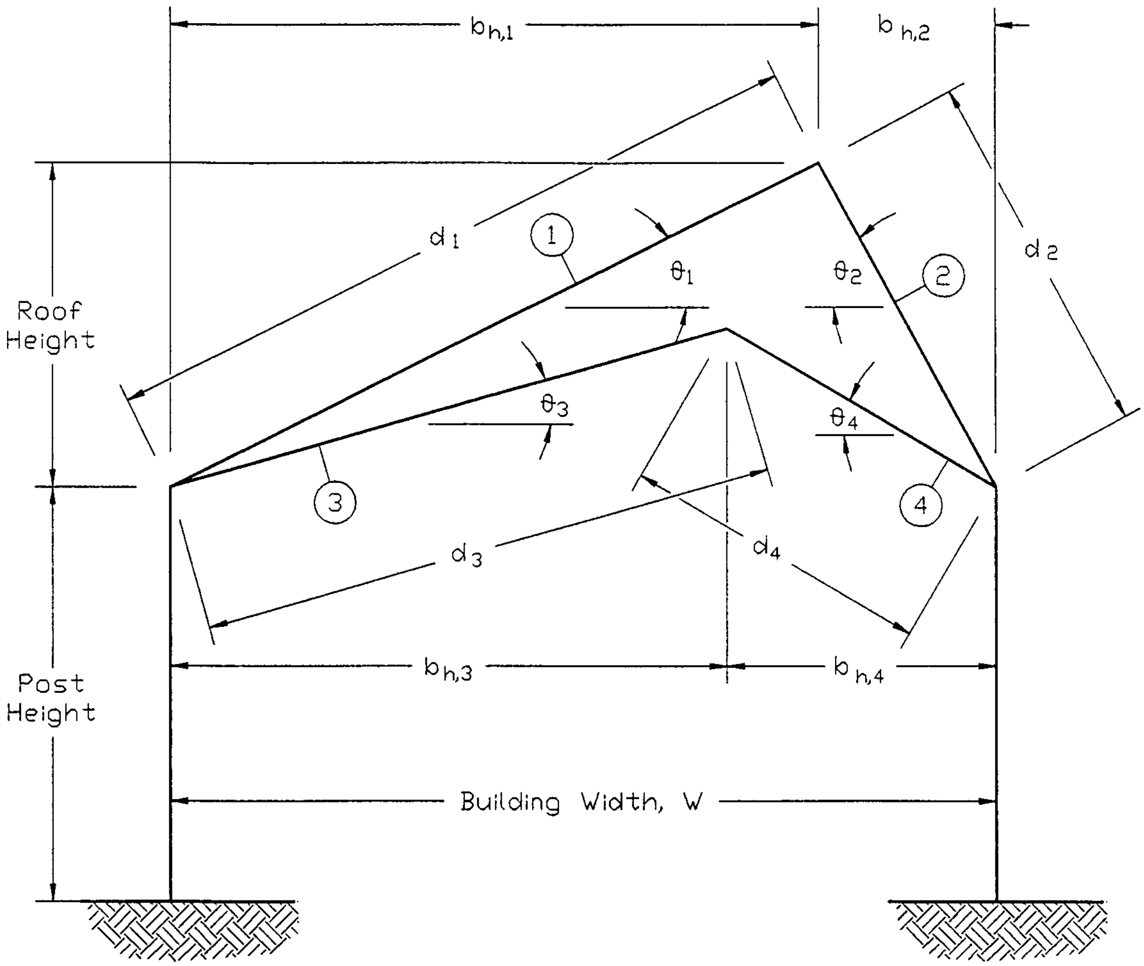

Figure 2 – Building cross section showing four individual diaphragms

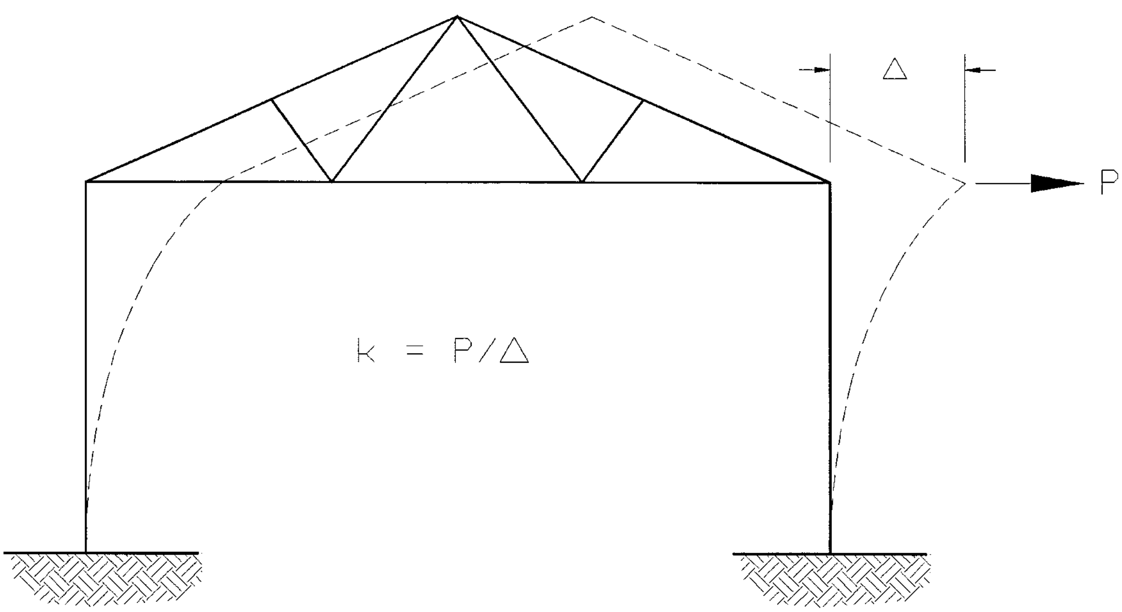

Figure 3 – Definition sketch for frame stiffness, *k*

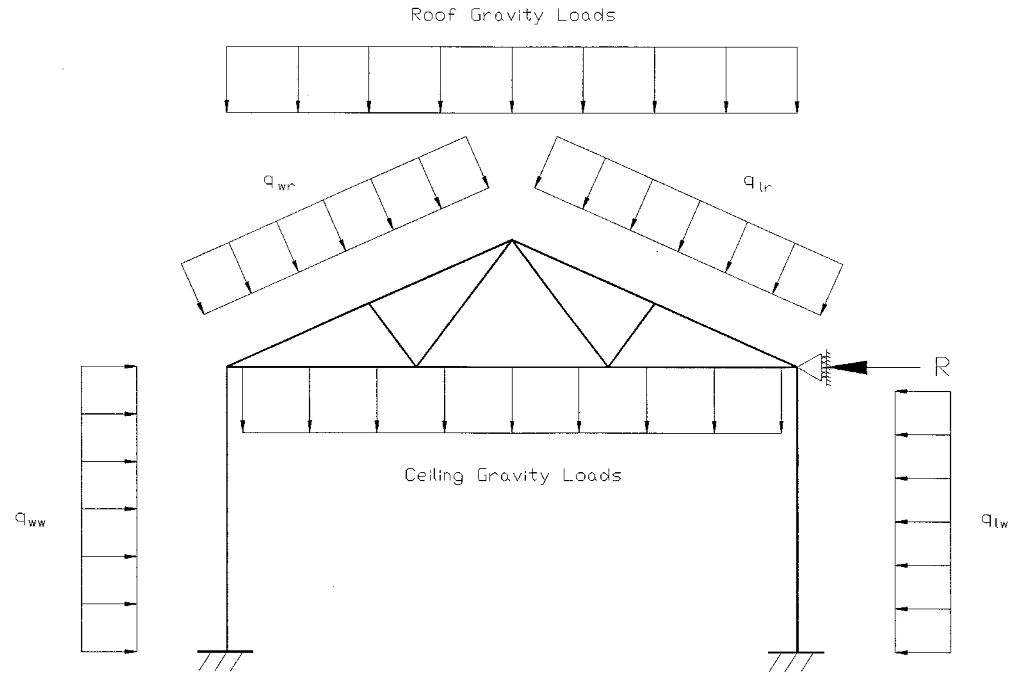

Figure 4 – Structural analog for obtaining eave load, *R*

5 Frame, endwall, and shearwall stiffness

5.1 General provisions. Frames, endwalls, and intermediate shearwalls transfer roof/ceiling loads to the foundation. The amount of load that a frame, endwall, or shearwall attracts is dependent upon its in-plane stiffness.

5.2 Frame stiffness, *k*. A horizontal force, *P*, applied at the eave of a building frame will result in a horizontal displacement of the eave, Δ (fig. 3). The ratio of the force *P* to the horizontal displacement Δ is defined as the horizontal frame stiffness, *k*. Frame stiffness is generally obtained with a plane-frame structural analysis program, e.g., PPSA (Purdue Research Foundation, 1993), METCLAD (Gebremedhin, 1987b), and SOLVER (Gebremedhin, 1987a). Frame stiffness is equal to zero when all posts in the frame are pin connected to both the truss and the base/foundation.

5.2.1 Frame stiffness can be calculated using equation 4 when: (1) trusses/rafters are assumed to be pin-connected to the posts, and (2) the base of each post is assumed fixed.

$$k = 3\sum_{i=1}^{n} (E_i I_i)/H_i^3 \tag{4}$$

where:

k	is	frame stiffness, N/mm (lbf/in.);
n	is	number of posts in the post-frame (normally 2);
E_i	is	modulus of elasticity of post i, N/mm^2 (lbf/in.^{2});
I_i	is	moment of inertia of post i, mm^4 (in.^{4});
H_i	is	distance from base to pin connection of post i, mm (in.).

5.3 Endwall and shearwall stiffness, k_e. Endwall and shearwall stiffness, like frame stiffness, is defined as the ratio of a horizontal force, *P*, applied at the eave of the wall, to the resulting horizontal eave displacement, Δ. Endwall and shearwall stiffness can be obtained directly from full scale building tests (Gebremedhin et al, 1992), validated structural models, or from tests of functionally equivalent assemblies (Gebremedhin and Jorgensen, 1993). ASAE EP558 gives laboratory test procedures that can be used to determine the stiffness of functionally equivalent walls.

6 Eave loads

6.1 General provisions. In diaphragm analysis, building loads are replaced by an equivalent set of horizontally acting, concentrated (ie, point) loads. These loads are located at the eave of each frame, endwall, and shearwall (ie, they are spaced a distance, *s*, apart), and therefore are referred to as *eave loads*. Eave loads and applied building loads are equivalent when they horizontally displace the eave an equal amount.

6.2 Eave loads, *R*, by plane-frame structural analysis. A horizontal restraint (vertical roller) is placed at the eave line as shown in figure 4 and the structural analog is analyzed with all external loads in place. The horizontal reaction at the vertical roller support is numerically equal to the eave load, *R*. Note that the vertical roller should always be placed at the same location that horizontal load *P* was placed when determining frame stiffness (clause 5.2).

6.3 Eave load calculation using frame base fixity factors. Eave loads resulting from wind loads can be estimated using equation 5.

$$R = s(h_{wr}q_{wr} - h_{lr}q_{lr} + h_{ww}f_w q_{ww} - h_{lw}f_l q_{lw}) \tag{5}$$

where:

R	is	eave load, N (lb);
s	is	frame spacing for interior frames and shearwalls, m (ft);
	is	one-half the frame spacing for endwalls, m (ft);
h_{wr}	is	windward roof height, m (ft);
h_{lr}	is	leeward roof height, m (ft);
h_{ww}	is	windward wall height, m (ft);
h_{lw}	is	leeward wall height, m (ft);
q_{wr}	is	design windward roof pressure, N/m^2 (lbf/ft^2);
q_{lr}	is	design leeward roof pressure, N/m^2 (lbf/ft^2);
q_{ww}	is	design windward wall pressure, N/m^2 (lbf/ft^2);
q_{lw}	is	design leeward wall pressure, N/m^2 (lbf/ft^2);
f_w	is	windward post fixity factor;
f_l	is	leeward post fixity factor.

Inward acting wind pressures have positive signs, outward acting pressures are negative (see figure 4). Equation 5 shall be modified for cases where pressures are not uniform over a wall or roof surface. In buildings with variable frame spacings, set s equal to the average of the frame spacings on each side of the eave load.

The frame base fixity factor(s), f_w and f_l, will equal 3/8 for substantial fixity at the groundline. The frame base fixity factor(s) will equal 1/2 for all other cases (see ASAE EP486).

For symmetrical base restraint and frame geometry, equation 5 reduces to:

$$R=s[h_r(q_{wr}-q_{lr})+h_w f(q_{ww}-q_{lw})] \quad (6)$$

where:

- h_r is roof height, m (ft);
- h_w is wall height, m (ft);
- f is leeward and windward post base fixity factor.

6.4 Maximum total diaphragm shear, V_h. A conservative value of maximum total diaphragm shear, V_h, due to wind load may be calculated by multiplying the equations in clause 6.3 by one-half the building length instead of the frame spacing, s.

$$V_h=\frac{1}{2}R(L/s) \quad (7)$$

where:

- V_h is maximum total diaphragm shear, N (lbf);
- R is eave load given by equation 5, N (lbf);
- L is building length, m (ft).

For symmetrical base restraint and frame geometry, the maximum diaphragm shear is conservatively estimated by:

$$V_h=\frac{1}{2}R(L/s) \quad (8)$$

where:

R is eave load given by equation 6, N (lbf).

7 Load distribution

7.1 General provisions. The distribution of horizontal loads to the various frames, walls, and diaphragms can be determined after diaphragm, frame, shearwall, and endwall stiffness values have been calculated and eave loads have been established. Use the procedure outlined in clause 7.2 to determine load distribution in a building without intermediate shearwalls and with constant values of: diaphragm stiffness, C_h; frame stiffness, k; endwall stiffness, k_e; and eave load, R. When one or more of these variables is not fixed, use methods referenced in clause 7.3. If the number of individual roof and ceiling diaphragms in the roof/ceiling assembly exceeds one, use the equation in clause 7.4 to determine the distribution of roof shear, V_h, to the individual diaphragms, and use the equation in clause 7.5 to determine the horizontal restraining force associated with each diaphragm.

7.2 Load distribution using tables. Tables 1 and 2 are used to determine the maximum total diaphragm shear V_h, and the maximum sidesway restraining force, Q, respectively, in buildings without intermediate shearwalls and with constant values of: diaphragm stiffness, C_h; frame stiffness, k; endwall stiffness, k_e; and eave load, R. Input parameters for tables 1 and 2 include: number of building frames (endwalls are counted as frames); ratio of diaphragm to frame stiffness, C_h/k; and ratio of endwall to frame stiffness, k_e/k. When establishing the values in tables 1 and 2, it was assumed that the eave load, R, for the endwalls was one-half the load applied to each interior frame.

7.2.1 Maximum total diaphragm shear, V_h. Table 1 contains shear force modifiers or *mS* values. Multiply the appropriate *mS* value by eave load R from clause 6.2 or 6.3 to obtain maximum total diaphragm shear. This value is the total shear, V_h, in the endwalls and in the diaphragm sections adjacent to the endwalls. This value will be less than the conservative estimate calculated using the equations in clause 6.4.

7.2.2 Sidesway restraining force, Q. Table 2 contains sidesway restraining force factors or *mD* values. Multiply the appropriate *mD* value by eave load R from clause 6.2 or 6.3 to obtain the sidesway restraining force, Q. The sidesway restraining force is the total force applied to the critical frame by the roof/ceiling assembly. The critical frame in a symmetric building without interior shearwalls is always the one closest to the building midlength.

7.3 Load distribution—detailed analyses. The force distribution method (Anderson et al, 1989) and computer program DAFI (Bohnhoff, 1992) are two methods that can be used to determine load distribution in a building in which the stiffness of individual frames differ, endwalls differ in stiffness, intermediate shearwalls are present, and eave loads and diaphragm stiffness values vary from frame to frame. The force distribution method is an iterative method for hand-calculating load distribution that is procedurally identical to the classical method of moment distribution. Computer program DAFI automatically formulates and solves a set of equations to obtain eave deflections. Both methods output individual frame, shearwall, endwall, and diaphragm forces.

7.4 In-plane shear force in individual diaphragms, $V_{p,i}$. The maximum in-plane shear force in an individual diaphragm, $V_{p,i}$, is given as

$$V_{p,i}=(c_{h,i}/C_h)V_h/(\cos\Theta i) \quad (9)$$

where:

- $V_{p,i}$ is maximum in-plane shear force in diaphragm i, N (lbf);
- $c_{h,i}$ is horizontal shear stiffness of diaphragm i with spacing s from clause 4.3, N/mm (lbf/in.);
- C_h is total horizontal diaphragm shear stiffness, C_h, for a spacing **s** of the roof/ceiling assembly, N/mm (lbf/in.);
- V_h is maximum total diaphragm shear from clause 6.4, 7.2.1, or 7.3, N (lbf);
- Θ_i is slope from the horizontal of diaphragm i.

7.5 Sidesway restraining force—individual diaphragms, Q_i. The total sidesway force applied to the critical frame by an individual diaphragm is given as

$$Q_i=(c_{h,i}/C_h)Q \quad (10)$$

where:

- Q_i is sidesway restraining force for diaphragm i, N (lbf);
- $c_{h,i}$ is horizontal shear stiffness of diaphragm i with spacing s from clause 4.3, N/mm (lbf/in.);
- C_h is total horizontal diaphragm shear stiffness, C_h, for a spacing **s** of the roof/ceiling assembly, N/mm (lbf/in.);
- Q is sidesway restraining force for the roof/ceiling assembly from clause 7.2.2 or 7.3, N/mm (lbf/in.).

8 Building diaphragm and shearwall design

8.1 General. All building components shall be checked to ensure that actual loads do not exceed allowable design values.

8.2 Diaphragms. The maximum in-plane shear in a diaphragm, $V_{p,i}$, cannot exceed the allowable shear strength, $V_{a,i}$, multiplied by the diaphragm length.

$$V_{p,i}\leqslant V_{a,i}d_i \quad (11)$$

where:

Table 1 – Shear force modifier (*mS*)

		Number of Frames (endwalls counted as frames)													
k_e/k	C_h/k	3	4	5	6	7	8	9	10	11	12	13	14	15	16
5	5	0.88	1.14	1.33	1.45	1.53	1.59	1.62	1.65	1.66	1.67	1.68	1.68	1.68	1.68
5	10	0.89	1.19	1.42	1.59	1.72	1.82	1.89	1.94	1.98	2.00	2.02	2.04	2.05	2.06
5	20	0.90	1.22	1.48	1.68	1.85	1.98	2.08	2.16	2.23	2.29	2.33	2.36	2.39	2.41
5	50	0.91	1.24	1.51	1.74	1.93	2.10	2.23	2.35	2.45	2.53	2.60	2.67	2.72	2.77
5	100	0.91	1.24	1.53	1.76	1.97	2.14	2.29	2.42	2.53	2.63	2.72	2.80	2.87	2.93
5	200	0.91	1.25	1.53	1.77	1.98	2.16	2.32	2.46	2.58	2.69	2.79	2.87	2.95	3.02
5	500	0.91	1.25	1.54	1.78	1.99	2.18	2.34	2.48	2.61	2.73	2.83	2.92	3.01	3.08
5	1000	0.91	1.25	1.54	1.78	2.00	2.18	2.35	2.49	2.62	2.74	2.84	2.94	3.02	3.10
5	10000	0.91	1.25	1.54	1.79	2.00	2.19	2.35	2.50	2.63	2.75	2.86	2.95	3.04	3.12
10	5	0.91	1.23	1.46	1.62	1.73	1.81	1.86	1.89	1.91	1.92	1.93	1.93	1.94	1.94
10	10	0.93	1.29	1.58	1.81	1.99	2.13	2.23	2.31	2.36	2.40	2.44	2.46	2.48	2.49
10	20	0.94	1.33	1.66	1.94	2.17	2.36	2.52	2.66	2.76	2.85	2.92	2.98	3.03	3.06
10	50	0.95	1.35	1.70	2.02	2.30	2.55	2.76	2.96	3.12	3.27	3.40	3.51	3.61	3.70
10	100	0.95	1.36	1.72	2.05	2.35	2.62	2.86	3.08	3.27	3.45	3.61	3.76	3.89	4.01
10	200	0.95	1.36	1.73	2.07	2.37	2.65	2.91	3.14	3.36	3.56	3.74	3.90	4.06	4.20
10	500	0.95	1.36	1.74	2.08	2.39	2.68	2.94	3.19	3.41	3.62	3.82	4.00	4.17	4.32
10	1000	0.95	1.36	1.74	2.08	2.40	2.68	2.95	3.20	3.43	3.64	3.84	4.03	4.20	4.37
10	10000	0.95	1.36	1.74	2.08	2.40	2.69	2.96	3.21	3.45	3.66	3.87	4.06	4.24	4.41
20	5	0.93	1.28	1.54	1.73	1.85	1.94	2.00	2.03	2.06	2.07	2.09	2.09	2.10	2.10
20	10	0.95	1.35	1.68	1.95	2.16	2.33	2.45	2.55	2.62	2.67	2.71	2.74	2.76	2.78
20	20	0.96	1.39	1.76	2.09	2.38	2.62	2.83	3.00	3.14	3.25	3.35	3.43	3.49	3.54
20	50	0.97	1.41	1.82	2.20	2.54	2.85	3.14	3.39	3.62	3.83	4.01	4.17	4.32	4.44
20	100	0.97	1.42	1.84	2.23	2.60	2.95	3.26	3.56	3.83	4.09	4.32	4.54	4.74	4.92
20	200	0.97	1.42	1.85	2.25	2.63	2.99	3.33	3.65	3.95	4.24	4.50	4.75	4.99	5.21
20	500	0.98	1.43	1.86	2.27	2.65	3.02	3.38	3.71	4.03	4.33	4.62	4.90	5.16	5.41
20	1000	0.98	1.43	1.86	2.27	2.66	3.03	3.39	3.73	4.06	4.37	4.66	4.95	5.22	5.48
20	10000	0.98	1.43	1.86	2.27	2.67	3.04	3.40	3.75	4.08	4.40	4.70	5.00	5.28	5.55
50	5	0.95	1.31	1.59	1.79	1.93	2.03	2.09	2.14	2.16	2.18	2.19	2.20	2.20	2.21
50	10	0.97	1.38	1.74	2.04	2.28	2.46	2.61	2.72	2.80	2.86	2.91	2.94	2.97	2.99
50	20	0.98	1.43	1.83	2.20	2.52	2.80	3.04	3.25	3.41	3.55	3.67	3.77	3.84	3.91
50	50	0.99	1.45	1.90	2.32	2.71	3.08	3.42	3.73	4.01	4.26	4.50	4.70	4.89	5.06
50	100	0.99	1.46	1.92	2.36	2.78	3.18	3.57	3.93	4.27	4.60	4.90	5.18	5.45	5.69
50	200	0.99	1.47	1.93	2.38	2.82	3.24	3.65	4.04	4.42	4.79	5.14	5.47	5.79	6.09
50	500	0.99	1.47	1.94	2.40	2.84	3.28	3.70	4.12	4.52	4.91	5.29	5.66	6.02	6.37
50	1000	0.99	1.47	1.94	2.40	2.85	3.29	3.72	4.14	4.55	4.96	5.35	5.73	6.11	6.47
50	10000	0.99	1.47	1.94	2.40	2.86	3.30	3.74	4.16	4.58	5.00	5.40	5.80	6.19	6.57
100	5	0.95	1.32	1.61	1.82	1.96	2.06	2.13	2.17	2.20	2.22	2.23	2.24	2.24	2.25
100	10	0.97	1.40	1.76	2.07	2.32	2.51	2.67	2.78	2.87	2.93	2.98	3.02	3.05	3.06
100	20	0.98	1.44	1.86	2.24	2.58	2.87	3.12	3.34	3.52	3.67	3.79	3.89	3.98	4.05
100	50	0.99	1.47	1.92	2.36	2.77	3.16	3.52	3.85	4.16	4.43	4.69	4.91	5.12	5.30
100	100	0.99	1.48	1.95	2.40	2.85	3.27	3.68	4.07	4.44	4.79	5.13	5.44	5.73	6.01
100	200	0.99	1.48	1.96	2.43	2.89	3.33	3.77	4.19	4.61	5.00	5.39	5.76	6.12	6.46
100	500	1.00	1.48	1.97	2.44	2.91	3.37	3.83	4.27	4.71	5.14	5.56	5.98	6.38	6.78
100	1000	1.00	1.48	1.97	2.45	2.92	3.39	3.85	4.30	4.75	5.19	5.62	6.05	6.48	6.89
100	10000	1.00	1.49	1.97	2.45	2.93	3.40	3.86	4.32	4.78	5.23	5.68	6.12	6.56	7.00
1000	5	0.95	1.33	1.63	1.84	1.99	2.09	2.16	2.20	2.23	2.25	2.27	2.27	2.28	2.28
1000	10	0.98	1.41	1.78	2.10	2.36	2.56	2.72	2.84	2.93	3.00	3.05	3.09	3.12	3.14
1000	20	0.99	1.45	1.88	2.28	2.63	2.93	3.20	3.43	3.62	3.78	3.91	4.02	4.11	4.18
1000	50	1.00	1.48	1.95	2.40	2.83	3.24	3.62	3.97	4.30	4.60	4.87	5.12	5.34	5.54
1000	100	1.00	1.49	1.97	2.45	2.91	3.36	3.79	4.21	4.61	4.99	5.35	5.69	6.02	6.32
1000	200	1.00	1.49	1.99	2.47	2.95	3.42	3.89	4.34	4.78	5.22	5.64	6.05	6.44	6.83
1000	500	1.00	1.50	1.99	2.49	2.98	3.46	3.95	4.42	4.90	5.37	5.83	6.29	6.74	7.18
1000	1000	1.00	1.50	2.00	2.49	2.98	3.48	3.97	4.45	4.94	5.42	5.90	6.37	6.85	7.31
1000	10000	1.00	1.50	2.00	2.50	2.99	3.49	3.98	4.48	4.97	5.47	5.96	6.45	6.94	7.43
10000	5	0.96	1.33	1.63	1.84	1.99	2.09	2.16	2.21	2.24	2.26	2.27	2.28	2.28	2.29
10000	10	0.98	1.41	1.79	2.10	2.36	2.57	2.72	2.85	2.94	3.01	3.06	3.10	3.12	3.14
10000	20	0.99	1.45	1.89	2.28	2.63	2.94	3.21	3.43	3.63	3.79	3.92	4.03	4.12	4.19
10000	50	1.00	1.48	1.95	2.40	2.84	3.25	3.63	3.98	4.31	4.61	4.89	5.14	5.36	5.57
10000	100	1.00	1.49	1.98	2.45	2.92	3.37	3.80	4.22	4.62	5.01	5.37	5.72	6.05	6.35
10000	200	1.00	1.50	1.99	2.48	2.96	3.43	3.90	4.35	4.80	5.24	5.66	6.08	6.48	6.87
10000	500	1.00	1.50	2.00	2.49	2.98	3.47	3.96	4.44	4.92	5.39	5.86	6.32	6.78	7.23
10000	1000	1.00	1.50	2.00	2.50	2.99	3.49	3.98	4.47	4.96	5.44	5.93	6.41	6.88	7.36
10000	10000	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	4.99	5.49	5.99	6.49	6.98	7.48

Table 1—Shear force modifier (*mS*) (*continued*)

k_e/k	C_h/k	Number of Frames (endwalls counted as frames) 17	18	19	20	21	22	23	24	25	26	27	28	29	30
5	5	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69
5	10	2.06	2.07	2.07	2.07	2.07	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08
5	20	2.43	2.44	2.46	2.46	2.47	2.48	2.48	2.49	2.49	2.49	2.49	2.49	2.50	2.50
5	50	2.81	2.84	2.87	2.89	2.92	2.94	2.95	2.97	2.98	2.99	3.00	3.01	3.01	3.02
5	100	2.98	3.03	3.07	3.11	3.14	3.18	3.20	3.23	3.25	3.27	3.29	3.30	3.32	3.33
5	200	3.09	3.14	3.19	3.24	3.28	3.32	3.36	3.39	3.42	3.45	3.48	3.50	3.52	3.54
5	500	3.15	3.22	3.28	3.33	3.38	3.43	3.47	3.51	3.55	3.58	3.61	3.64	3.67	3.70
5	1000	3.18	3.24	3.30	3.36	3.41	3.46	3.51	3.55	3.59	3.63	3.66	3.70	3.73	3.75
5	10000	3.20	3.27	3.33	3.39	3.45	3.50	3.54	3.59	3.63	3.67	3.71	3.74	3.78	3.81
10	5	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94
10	10	2.50	2.50	2.51	2.51	2.51	2.52	2.52	2.52	2.52	2.52	2.52	2.52	2.52	2.52
10	20	3.09	3.12	3.14	3.15	3.16	3.17	3.18	3.19	3.19	3.20	3.20	3.20	3.21	3.21
10	50	3.77	3.84	3.89	3.94	3.99	4.02	4.06	4.09	4.11	4.13	4.15	4.17	4.18	4.19
10	100	4.12	4.21	4.30	4.38	4.45	4.52	4.58	4.63	4.68	4.72	4.76	4.80	4.83	4.86
10	200	4.33	4.45	4.56	4.66	4.76	4.84	4.92	5.00	5.07	5.13	5.19	5.25	5.30	5.35
10	500	4.47	4.61	4.74	4.86	4.97	5.08	5.18	5.27	5.36	5.44	5.52	5.60	5.67	5.73
10	1000	4.52	4.66	4.80	4.93	5.05	5.16	5.27	5.37	5.47	5.56	5.65	5.73	5.81	5.88
10	10000	4.57	4.72	4.86	4.99	5.12	5.24	5.36	5.47	5.57	5.67	5.76	5.86	5.94	6.03
20	5	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10
20	10	2.79	2.80	2.80	2.81	2.81	2.81	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82
20	20	3.58	3.62	3.64	3.66	3.68	3.69	3.71	3.71	3.72	3.73	3.73	3.74	3.74	3.74
20	50	4.56	4.65	4.74	4.82	4.88	4.94	4.99	5.03	5.07	5.11	5.14	5.16	5.18	5.20
20	100	5.08	5.24	5.38	5.51	5.62	5.73	5.83	5.91	5.99	6.07	6.13	6.20	6.25	6.30
20	200	5.42	5.61	5.80	5.97	6.13	6.28	6.42	6.55	6.67	6.79	6.90	7.00	7.09	7.18
20	500	5.65	5.88	6.09	6.30	6.50	6.69	6.87	7.04	7.20	7.36	7.51	7.65	7.78	7.91
20	1000	5.73	5.97	6.20	6.42	6.64	6.84	7.03	7.22	7.40	7.58	7.74	7.90	8.06	8.21
20	10000	5.81	6.06	6.30	6.54	6.77	6.98	7.20	7.40	7.60	7.79	7.97	8.15	8.33	8.50
50	5	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.21
50	10	3.00	3.01	3.02	3.02	3.03	3.03	3.03	3.03	3.03	3.04	3.04	3.04	3.04	3.04
50	20	3.96	4.00	4.03	4.06	4.08	4.10	4.11	4.12	4.13	4.14	4.14	4.15	4.15	4.16
50	50	5.20	5.33	5.45	5.55	5.64	5.72	5.79	5.85	5.90	5.95	5.99	6.03	6.06	6.08
50	100	5.92	6.13	6.33	6.51	6.67	6.83	6.97	7.10	7.21	7.32	7.42	7.51	7.59	7.67
50	200	6.39	6.66	6.93	7.18	7.41	7.64	7.85	8.05	8.24	8.42	8.59	8.75	8.90	9.04
50	500	6.71	7.04	7.36	7.67	7.97	8.26	8.54	8.81	9.07	9.32	9.57	9.80	10.03	10.25
50	1000	6.83	7.18	7.52	7.85	8.18	8.50	8.80	9.10	9.40	9.68	9.96	10.23	10.50	10.75
50	10000	6.94	7.31	7.68	8.03	8.38	8.72	9.06	9.39	9.72	10.04	10.35	10.66	10.97	11.27
100	5	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
100	10	3.08	3.09	3.10	3.10	3.11	3.11	3.11	3.11	3.11	3.12	3.12	3.12	3.12	3.12
100	20	4.10	4.14	4.18	4.21	4.23	4.25	4.27	4.28	4.29	4.30	4.30	4.31	4.31	4.31
100	50	5.46	5.61	5.74	5.85	5.95	6.04	6.12	6.19	6.24	6.30	6.34	6.38	6.42	6.45
100	100	6.26	6.50	6.72	6.93	7.12	7.29	7.45	7.60	7.74	7.86	7.98	8.08	8.18	8.27
100	200	6.79	7.10	7.41	7.69	7.97	8.23	8.48	8.72	8.94	9.15	9.35	9.54	9.72	9.89
100	500	7.16	7.54	7.91	8.27	8.62	8.96	9.29	9.62	9.93	10.24	10.53	10.82	11.10	11.37
100	1000	7.30	7.70	8.10	8.49	8.87	9.24	9.61	9.97	10.33	10.67	11.01	11.35	11.68	12.00
100	10000	7.43	7.85	8.28	8.69	9.11	9.51	9.92	10.32	10.72	11.11	11.50	11.88	12.27	12.64
1000	5	2.28	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29
1000	10	3.15	3.16	3.17	3.18	3.18	3.18	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19
1000	20	4.24	4.29	4.32	4.36	4.38	4.40	4.42	4.43	4.44	4.45	4.46	4.46	4.47	4.47
1000	50	5.72	5.88	6.02	6.15	6.26	6.36	6.44	6.52	6.59	6.65	6.70	6.74	6.78	6.81
1000	100	6.61	6.87	7.12	7.35	7.57	7.77	7.95	8.12	8.28	8.43	8.56	8.68	8.79	8.89
1000	200	7.20	7.56	7.90	8.23	8.55	8.85	9.14	9.41	9.68	9.93	10.17	10.39	10.61	10.81
1000	500	7.62	8.05	8.48	8.89	9.30	9.70	10.10	10.48	10.86	11.22	11.58	11.93	12.27	12.61
1000	1000	7.78	8.24	8.69	9.15	9.59	10.04	10.47	10.91	11.33	11.75	12.17	12.58	12.99	13.39
1000	10000	7.92	8.41	8.90	9.39	9.87	10.36	10.84	11.33	11.81	12.29	12.77	13.25	13.73	14.20
10000	5	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29
10000	10	3.16	3.17	3.18	3.19	3.19	3.19	3.19	3.20	3.20	3.20	3.20	3.20	3.20	3.20
10000	20	4.25	4.30	4.34	4.37	4.40	4.42	4.43	4.45	4.46	4.46	4.47	4.48	4.48	4.48
10000	50	5.75	5.91	6.05	6.18	6.29	6.39	6.48	6.56	6.62	6.68	6.73	6.78	6.82	6.85
10000	100	6.64	6.91	7.17	7.40	7.62	7.82	8.01	8.18	8.34	8.49	8.62	8.74	8.86	8.96
10000	200	7.24	7.60	7.95	8.29	8.61	8.92	9.21	9.49	9.76	10.01	10.26	10.49	10.71	10.91
10000	500	7.67	8.11	8.54	8.96	9.38	9.78	10.18	10.57	10.96	11.33	11.70	12.06	12.41	12.75
10000	1000	7.83	8.30	8.76	9.22	9.67	10.12	10.57	11.01	11.44	11.88	12.30	12.72	13.14	13.55
10000	10000	7.98	8.47	8.97	9.46	9.96	10.45	10.94	11.44	11.93	12.42	12.91	13.40	13.89	14.38

Table 2 – Sidesway restraining force factor *(mD)*

		Number of Frames (endwalls counted as frames)													
k_e/k	C_h/k	3	4	5	6	7	8	9	10	11	12	13	14	15	16
5	5	0.75	0.64	0.52	0.43	0.34	0.28	0.22	0.18	0.14	0.12	0.09	0.08	0.06	0.05
5	10	0.78	0.69	0.59	0.52	0.44	0.39	0.33	0.28	0.24	0.21	0.18	0.15	0.13	0.11
5	20	0.80	0.72	0.64	0.58	0.51	0.46	0.41	0.37	0.33	0.30	0.26	0.24	0.21	0.19
5	50	0.81	0.74	0.67	0.62	0.56	0.52	0.48	0.44	0.41	0.38	0.35	0.32	0.30	0.28
5	100	0.81	0.74	0.68	0.63	0.58	0.54	0.50	0.47	0.44	0.41	0.38	0.36	0.34	0.32
5	200	0.82	0.75	0.69	0.64	0.59	0.55	0.52	0.48	0.46	0.43	0.41	0.38	0.36	0.35
5	500	0.82	0.75	0.69	0.64	0.60	0.56	0.52	0.49	0.47	0.44	0.42	0.40	0.38	0.36
5	1000	0.82	0.75	0.69	0.64	0.60	0.56	0.53	0.50	0.47	0.45	0.42	0.40	0.39	0.37
5	10000	0.82	0.75	0.69	0.64	0.60	0.56	0.53	0.50	0.47	0.45	0.43	0.41	0.39	0.37
10	5	0.83	0.73	0.60	0.51	0.41	0.34	0.27	0.22	0.17	0.14	0.11	0.09	0.07	0.06
10	10	0.86	0.79	0.70	0.63	0.54	0.48	0.41	0.36	0.30	0.26	0.22	0.19	0.16	0.14
10	20	0.88	0.83	0.76	0.70	0.64	0.58	0.52	0.48	0.43	0.39	0.35	0.31	0.28	0.25
10	50	0.90	0.85	0.80	0.75	0.71	0.66	0.62	0.58	0.55	0.51	0.48	0.45	0.42	0.39
10	100	0.90	0.86	0.81	0.77	0.73	0.70	0.66	0.63	0.60	0.57	0.54	0.51	0.49	0.46
10	200	0.90	0.86	0.82	0.78	0.75	0.71	0.68	0.65	0.63	0.60	0.57	0.55	0.53	0.51
10	500	0.90	0.86	0.82	0.79	0.75	0.72	0.70	0.67	0.64	0.62	0.60	0.58	0.56	0.54
10	1000	0.90	0.86	0.83	0.79	0.76	0.73	0.70	0.67	0.65	0.63	0.61	0.59	0.57	0.55
10	10000	0.91	0.86	0.83	0.79	0.76	0.73	0.70	0.68	0.66	0.63	0.61	0.59	0.58	0.56
20	5	0.87	0.78	0.65	0.56	0.45	0.38	0.30	0.25	0.19	0.16	0.13	0.10	0.08	0.07
20	10	0.91	0.85	0.76	0.69	0.60	0.54	0.46	0.41	0.35	0.30	0.26	0.22	0.19	0.16
20	20	0.93	0.89	0.83	0.78	0.72	0.66	0.60	0.55	0.50	0.46	0.41	0.37	0.33	0.30
20	50	0.94	0.91	0.87	0.84	0.80	0.76	0.72	0.69	0.65	0.62	0.58	0.55	0.51	0.48
20	100	0.95	0.92	0.89	0.86	0.83	0.80	0.77	0.75	0.72	0.69	0.66	0.64	0.61	0.58
20	200	0.95	0.92	0.90	0.87	0.85	0.83	0.80	0.78	0.76	0.73	0.71	0.69	0.67	0.65
20	500	0.95	0.93	0.90	0.88	0.86	0.84	0.82	0.80	0.78	0.76	0.74	0.72	0.71	0.69
20	1000	0.95	0.93	0.91	0.88	0.86	0.84	0.82	0.81	0.79	0.77	0.75	0.74	0.72	0.71
20	10000	0.95	0.93	0.91	0.89	0.87	0.85	0.83	0.81	0.80	0.78	0.76	0.75	0.73	0.72
50	5	0.89	0.81	0.68	0.59	0.48	0.40	0.32	0.26	0.21	0.17	0.13	0.11	0.09	0.07
50	10	0.93	0.88	0.80	0.73	0.65	0.58	0.50	0.44	0.38	0.33	0.28	0.24	0.21	0.18
50	20	0.96	0.93	0.88	0.83	0.77	0.72	0.66	0.61	0.55	0.51	0.46	0.41	0.37	0.34
50	50	0.97	0.95	0.93	0.90	0.87	0.84	0.80	0.77	0.73	0.70	0.66	0.63	0.59	0.56
50	100	0.98	0.96	0.94	0.93	0.90	0.88	0.86	0.84	0.81	0.79	0.76	0.74	0.71	0.69
50	200	0.98	0.97	0.95	0.94	0.92	0.91	0.89	0.88	0.86	0.84	0.82	0.81	0.79	0.77
50	500	0.98	0.97	0.96	0.95	0.94	0.92	0.91	0.90	0.89	0.88	0.86	0.85	0.84	0.83
50	1000	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91	0.90	0.89	0.88	0.87	0.86	0.85
50	10000	0.98	0.97	0.96	0.95	0.94	0.93	0.93	0.92	0.91	0.90	0.89	0.88	0.87	0.87
100	5	0.90	0.82	0.69	0.60	0.48	0.41	0.32	0.27	0.21	0.17	0.14	0.11	0.09	0.07
100	10	0.94	0.90	0.82	0.75	0.66	0.59	0.51	0.45	0.39	0.34	0.29	0.25	0.21	0.18
100	20	0.97	0.94	0.89	0.85	0.79	0.74	0.68	0.63	0.57	0.52	0.47	0.43	0.39	0.35
100	50	0.98	0.97	0.94	0.92	0.89	0.86	0.83	0.80	0.76	0.73	0.69	0.66	0.62	0.59
100	100	0.99	0.98	0.96	0.95	0.93	0.91	0.89	0.87	0.85	0.83	0.80	0.78	0.75	0.73
100	200	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.91	0.90	0.88	0.87	0.85	0.84	0.82
100	500	0.99	0.98	0.98	0.97	0.96	0.96	0.95	0.94	0.93	0.92	0.91	0.90	0.89	0.88
100	1000	0.99	0.98	0.98	0.97	0.97	0.96	0.95	0.95	0.94	0.93	0.93	0.92	0.91	0.91
100	10000	0.99	0.99	0.98	0.98	0.97	0.97	0.96	0.96	0.95	0.95	0.94	0.94	0.93	0.93
1000	5	0.91	0.83	0.70	0.61	0.49	0.41	0.33	0.27	0.22	0.18	0.14	0.11	0.09	0.07
1000	10	0.95	0.91	0.83	0.76	0.67	0.60	0.52	0.46	0.40	0.35	0.30	0.26	0.22	0.19
1000	20	0.98	0.95	0.91	0.87	0.81	0.76	0.70	0.65	0.59	0.54	0.49	0.45	0.40	0.36
1000	50	0.99	0.98	0.96	0.94	0.91	0.89	0.86	0.83	0.79	0.76	0.72	0.69	0.65	0.62
1000	100	0.99	0.99	0.98	0.97	0.95	0.94	0.92	0.90	0.88	0.86	0.84	0.82	0.79	0.77
1000	200	1.00	0.99	0.99	0.98	0.98	0.97	0.96	0.95	0.94	0.93	0.91	0.90	0.88	0.87
1000	500	1.00	1.00	0.99	0.99	0.99	0.99	0.98	0.98	0.97	0.97	0.96	0.95	0.95	0.94
1000	1000	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.97	0.97	0.97
1000	10000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99
10000	5	0.91	0.83	0.70	0.61	0.49	0.42	0.33	0.27	0.22	0.18	0.14	0.11	0.09	0.07
10000	10	0.95	0.91	0.83	0.76	0.68	0.61	0.53	0.46	0.40	0.35	0.30	0.26	0.22	0.19
10000	20	0.98	0.95	0.91	0.87	0.81	0.76	0.70	0.65	0.59	0.54	0.49	0.45	0.40	0.37
10000	50	0.99	0.98	0.96	0.94	0.92	0.89	0.86	0.83	0.79	0.76	0.72	0.69	0.65	0.62
10000	100	1.00	0.99	0.98	0.97	0.96	0.94	0.93	0.91	0.89	0.87	0.84	0.82	0.80	0.77
10000	200	1.00	1.00	0.99	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.90	0.89	0.87
10000	500	1.00	1.00	1.00	0.99	0.99	0.99	0.98	0.98	0.98	0.97	0.96	0.96	0.95	0.95
10000	1000	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.97
10000	10000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 2 – Sidesway restraining force factor (*mD*) *(continued)*

k_e/k	C_h/k	Number of frames (endwalls counted as frames) 17	18	19	20	21	22	23	24	25	26	27	28	29	30
5	5	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
5	10	0.09	0.08	0.07	0.06	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01
5	20	0.17	0.15	0.13	0.12	0.11	0.10	0.09	0.08	0.07	0.06	0.06	0.05	0.04	0.04
5	50	0.26	0.24	0.22	0.21	0.19	0.18	0.17	0.16	0.14	0.13	0.12	0.12	0.11	0.10
5	100	0.30	0.29	0.27	0.26	0.24	0.23	0.22	0.20	0.19	0.18	0.17	0.17	0.16	0.15
5	200	0.33	0.31	0.30	0.29	0.27	0.26	0.25	0.24	0.23	0.22	0.21	0.20	0.19	0.19
5	500	0.35	0.33	0.32	0.31	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.23	0.22	0.21
5	1000	0.35	0.34	0.33	0.31	0.30	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.23	0.23
5	10000	0.36	0.35	0.33	0.32	0.31	0.30	0.29	0.28	0.27	0.26	0.26	0.25	0.24	0.24
10	5	0.05	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
10	10	0.12	0.10	0.09	0.08	0.06	0.06	0.05	0.04	0.03	0.03	0.03	0.02	0.02	0.02
10	20	0.23	0.20	0.18	0.16	0.15	0.13	0.12	0.11	0.09	0.08	0.08	0.07	0.06	0.05
10	50	0.36	0.34	0.32	0.30	0.28	0.26	0.24	0.23	0.21	0.20	0.18	0.17	0.16	0.15
10	100	0.44	0.42	0.40	0.38	0.36	0.34	0.33	0.31	0.29	0.28	0.27	0.25	0.24	0.23
10	200	0.49	0.47	0.45	0.43	0.42	0.40	0.39	0.37	0.36	0.34	0.33	0.32	0.31	0.30
10	500	0.52	0.50	0.49	0.47	0.46	0.44	0.43	0.42	0.40	0.39	0.38	0.37	0.36	0.35
10	1000	0.53	0.52	0.50	0.49	0.47	0.46	0.45	0.43	0.42	0.41	0.40	0.39	0.38	0.37
10	10000	0.54	0.53	0.51	0.50	0.49	0.47	0.46	0.45	0.44	0.43	0.42	0.41	0.40	0.39
20	5	0.05	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00
20	10	0.14	0.12	0.10	0.09	0.07	0.06	0.05	0.05	0.04	0.03	0.03	0.03	0.02	0.02
20	20	0.27	0.24	0.22	0.20	0.17	0.16	0.14	0.13	0.11	0.10	0.09	0.08	0.07	0.06
20	50	0.45	0.42	0.40	0.37	0.35	0.33	0.30	0.28	0.27	0.25	0.23	0.22	0.20	0.19
20	100	0.56	0.53	0.51	0.49	0.47	0.45	0.43	0.41	0.39	0.37	0.35	0.34	0.32	0.31
20	200	0.63	0.61	0.59	0.57	0.55	0.53	0.52	0.50	0.48	0.47	0.45	0.44	0.42	0.41
20	500	0.67	0.66	0.64	0.63	0.61	0.60	0.59	0.57	0.56	0.55	0.53	0.52	0.51	0.50
20	1000	0.69	0.68	0.66	0.65	0.64	0.62	0.61	0.60	0.59	0.58	0.57	0.55	0.54	0.53
20	10000	0.71	0.69	0.68	0.67	0.66	0.65	0.64	0.63	0.62	0.61	0.60	0.59	0.58	0.57
50	5	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00
50	10	0.15	0.13	0.11	0.10	0.08	0.07	0.06	0.05	0.04	0.04	0.03	0.03	0.02	0.02
50	20	0.30	0.27	0.24	0.22	0.20	0.18	0.16	0.14	0.13	0.11	0.10	0.09	0.08	0.07
50	50	0.52	0.49	0.46	0.44	0.41	0.38	0.36	0.34	0.31	0.29	0.27	0.26	0.24	0.22
50	100	0.66	0.64	0.61	0.59	0.56	0.54	0.52	0.50	0.47	0.45	0.43	0.41	0.40	0.38
50	200	0.75	0.73	0.71	0.69	0.68	0.66	0.64	0.62	0.60	0.59	0.57	0.55	0.54	0.52
50	500	0.81	0.80	0.79	0.78	0.76	0.75	0.74	0.73	0.71	0.70	0.69	0.68	0.67	0.65
50	1000	0.84	0.83	0.82	0.81	0.80	0.79	0.78	0.77	0.76	0.75	0.74	0.73	0.72	0.71
50	10000	0.86	0.85	0.84	0.84	0.83	0.82	0.81	0.81	0.80	0.79	0.79	0.78	0.77	0.77
100	5	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00
100	10	0.16	0.13	0.11	0.10	0.08	0.07	0.06	0.05	0.04	0.04	0.03	0.03	0.02	0.02
100	20	0.31	0.28	0.25	0.23	0.20	0.18	0.16	0.15	0.13	0.12	0.11	0.09	0.08	0.08
100	50	0.55	0.52	0.49	0.46	0.43	0.41	0.38	0.36	0.33	0.31	0.29	0.27	0.25	0.24
100	100	0.70	0.68	0.65	0.63	0.60	0.58	0.56	0.53	0.51	0.49	0.47	0.45	0.43	0.41
100	200	0.80	0.78	0.77	0.75	0.73	0.71	0.69	0.68	0.66	0.64	0.62	0.61	0.59	0.57
100	500	0.87	0.86	0.85	0.84	0.83	0.82	0.81	0.80	0.79	0.77	0.76	0.75	0.74	0.73
100	1000	0.90	0.89	0.88	0.88	0.87	0.86	0.85	0.84	0.84	0.83	0.82	0.81	0.80	0.80
100	10000	0.92	0.92	0.91	0.91	0.90	0.90	0.90	0.89	0.89	0.88	0.88	0.87	0.87	0.86
1000	5	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00
1000	10	0.16	0.14	0.12	0.10	0.09	0.07	0.06	0.05	0.05	0.04	0.03	0.03	0.02	0.02
1000	20	0.33	0.29	0.26	0.24	0.21	0.19	0.17	0.15	0.14	0.12	0.11	0.10	0.09	0.08
1000	50	0.58	0.55	0.52	0.49	0.46	0.43	0.40	0.38	0.35	0.33	0.31	0.29	0.27	0.25
1000	100	0.74	0.72	0.69	0.67	0.64	0.62	0.60	0.57	0.55	0.53	0.50	0.48	0.46	0.44
1000	200	0.85	0.84	0.82	0.80	0.79	0.77	0.75	0.74	0.72	0.70	0.68	0.66	0.65	0.63
1000	500	0.93	0.93	0.92	0.91	0.90	0.89	0.88	0.87	0.86	0.85	0.84	0.83	0.82	0.81
1000	1000	0.96	0.96	0.95	0.95	0.94	0.94	0.93	0.93	0.92	0.92	0.91	0.90	0.90	0.89
1000	10000	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
10000	5	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00
10000	10	0.16	0.14	0.12	0.10	0.09	0.07	0.06	0.05	0.05	0.04	0.03	0.03	0.02	0.02
10000	20	0.33	0.30	0.26	0.24	0.21	0.19	0.17	0.15	0.14	0.12	0.11	0.10	0.09	0.08
10000	50	0.58	0.55	0.52	0.49	0.46	0.43	0.40	0.38	0.36	0.33	0.31	0.29	0.27	0.25
10000	100	0.75	0.72	0.70	0.67	0.65	0.62	0.60	0.58	0.55	0.53	0.51	0.49	0.47	0.45
10000	200	0.86	0.84	0.83	0.81	0.79	0.78	0.76	0.74	0.72	0.71	0.69	0.67	0.65	0.64
10000	500	0.94	0.93	0.92	0.92	0.91	0.90	0.89	0.88	0.87	0.86	0.85	0.84	0.83	0.82
10000	1000	0.97	0.96	0.96	0.96	0.95	0.95	0.94	0.94	0.93	0.93	0.92	0.91	0.91	0.90
10000	10000	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99

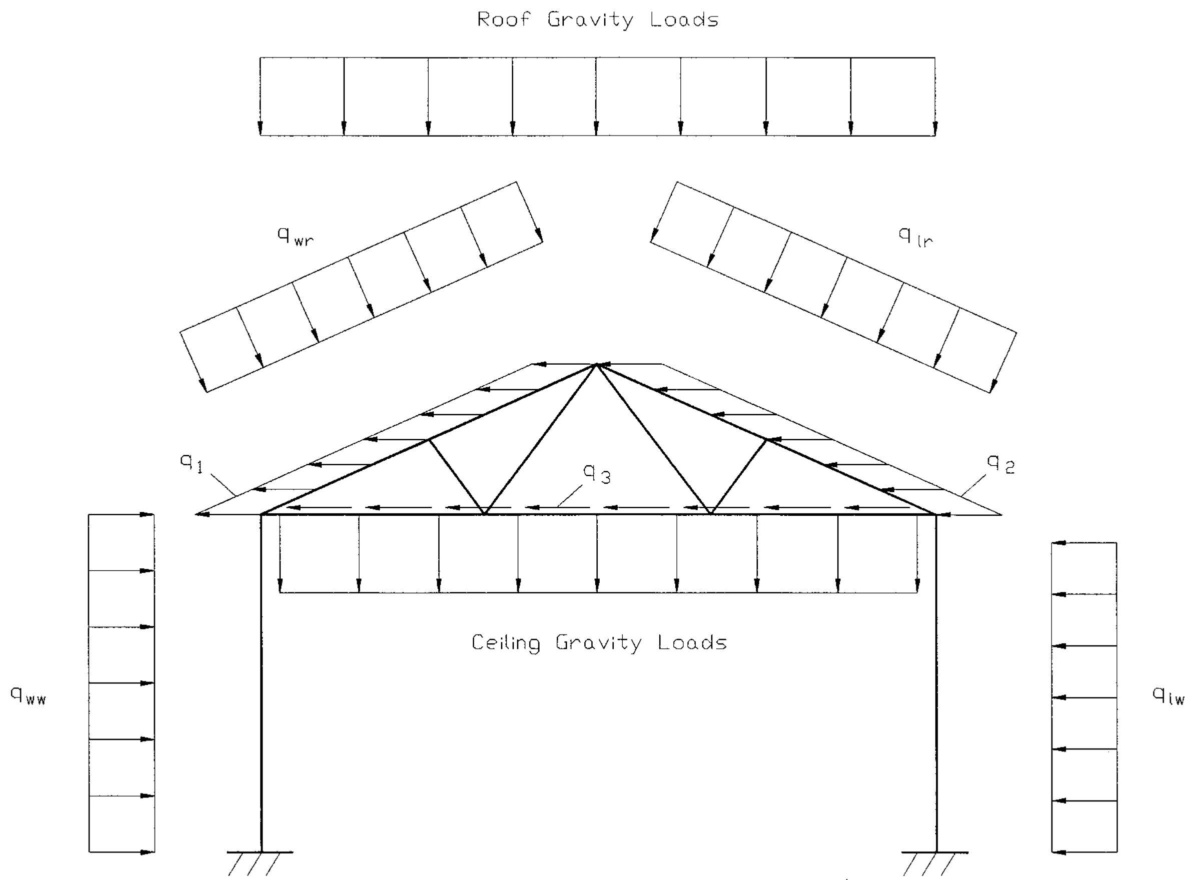

Figure 5 – Structural analog for a building with roof and ceiling diaphragms; sidesway restraining forces, *Qi*'s, converted to distributed loads, *qi*'s

$V_{p,i}$	is	maximum in-plane shear force in diaphragm *i* from clause 7.4, N lbf);
$V_{a,i}$	is	allowable in-plane shear strength of diaphragm *i*, N/m (lbf/ft);
d_i	is	length of diaphragm *i* as measured parallel to trusses/rafters (see figure 2), m (ft);
	=	$b_{h,i}/\cos\Theta_i$.

The allowable in-plane shear strength, $V_{a,i}$, is obtained from tests (ASAE EP558) or from validated structural models.

8.3 Diaphragm chords. The diaphragm chords shall be designed to resist axial forces caused by bending moments induced in the diaphragm by the applied loads. A conservative estimate of chord force is

$$P_{c,i} = (R/s)(c_{h,i}/C_h)L^2/(8b_{h,i}) \quad (12)$$

where:

$P_{c,i}$	is	maximum chord force in diaphragm *i*, N (lbf);
R	is	eave load from clause 6.2 or 6.3, N (lbf);
s	is	frame spacing, m (ft);
$c_{h,i}$	is	horizontal shear stiffness of diaphragm *i* with width s from clause 4.3, N/mm (lbf/in.);
C_h	is	total horizontal diaphragm shear stiffness, C_h, for a width s of the roof/ceiling assembly, N/mm (lbf/in.);
L	is	building length, m (ft);
bh,i	is	horizontal span of diaphragm *i* as measured parallel to trusses/rafters, m (ft).

More accurate chord forces may be used when estimated by full scale tests or structural engineering analysis.

8.4 Diaphragm-to-wall connections. Provisions shall be made for the transfer of shear from roof and ceiling diaphragms to endwalls and intermediate shearwalls. The design strength of these connections may be proven by tests of a typical connection detail. Where applicable, the building designer may use the National Design Specifications (NDS) for Wood Construction to design this connection.

8.5 Shearwalls. Endwalls and intermediate shearwalls shall have sufficient shear strength to transmit the induced loads from roof and ceiling diaphragms to the foundation system. The allowable shear capacity of endwalls and intermediate shearwalls, V_e, is obtained from tests (ASAE EP558) or from validated structural models. For buildings without intermediate shearwalls, the allowable shear strength of the endwalls shall be greater than the maximum total diaphragm shear force, V_h, or

$$V_h \leqslant V_e W \quad (13)$$

where:

V_h	is	maximum total diaphragm shear force, N (lbf);
V_e	is	allowable shear capacity of the endwall, N/m (lb/ftf);
W	is	building width, m (ft).

8.5.1 Doors and openings reduce the total shear capacity of walls. When doors or openings are present in an endwall, the following equation applies:

$$V_h \leqslant V_e(W - D_T) \quad (14)$$

where

D_T	is	total width of doors and openings in the endwall, m (ft).

8.5.2 The structural framing over doors or openings in walls acts as a drag strut transferring shear force across the opening. The header over the opening shall be designed to carry the force in tension and/or compression across the opening.

8.6 Shearwall-to-foundation connections. The connection system between endwalls and intermediate shearwalls and the foundation system shall be designed to resist the shear carried by the walls. The design of these connections may be proved by tests of a typical connection detail or by a calculation method appropriate for the foundation system.

8.7 Shearwall overturning. Diaphragm loading produces overturning moments in intermediate shearwalls and endwalls. These forces may be calculated using structural analyses that include the resisting action of sidewalls when they are present. ASAE EP486 is recommended for designing uplift resistance of embedded post foundations. For wall framing members attached to a slab, the connection between the members and slab should be designed by the provisions of the NDS.

8.8 Sidewall posts. Sidewall members (and frames) resist the lateral loads not transmitted to the foundation by endwalls and shearwalls. The post shall be designed for combined axial and bending moment according to the NDS. The moment and axial force are calculated by any method of frame analysis, using the design loads applied to a post-frame and the sidesway resisting forces from clause 7.5. Figure 5 gives a structural analog for a post-frame with the sidesway resisting forces distributed to the truss top and bottom chords as uniform loads, q_i

8.9 Endwall members. Endwall members shall be designed to meet wind pressure loads normal to the endwall surface as well as other design loads.

Annex A
(informative)
Bibliography

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