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THE INTERACTION OF SHEAR DIAPHRAGMS AND DIAGONAL BRACING

By

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INTRODUCTION

Shear diaphragms and rod or cable bracing have long been structural components of metal building systems. Both resist lateral loads due primarily to wind and other dynamic forces. As parts of roofs, floors, and walls, diaphragms and diagonal bracing control sway, stabilize pin jointed structures, and can lower stresses in rigid frames. A typical diaphragm and diagonal brace structure is shown in Figure 1.

When shear diaphragms are combined with either diagonal bracing or rigid frame action, the forces can be distributed proportionally to each component of stiffness providing the respective loads do not exceed the linear elastic limit of the component and the end conditions are able to transfer those forces into the respective systems. Separately, the stiffnesses of each has been theoretically and experimentally determined, but a design procedure which accounts for the interaction of the two systems has not yet been widely accepted.

Presently, the metal building industry utilizes one system or the other. If the diaphragm is incapable of withstanding the entire lateral load, diagonal bracing is then designed to resist that load, without considering any interaction between the two systems. If both systems were considered acting together the coupled system could result in smaller diagonals and/or lighter gage steel in the diaphragm.

PREVIOUS RESEARCH

Research of the interaction of diaphragms and diagonal bracing has been limited. A paper by Fisher and Johnson [1] studied the effects of a pretensioned rod and diaphragm system. Fisher and Johnson's conclusions supported the theory that the distribution of load between the coupled system could be analytically determined according to stiffness. Cold formed rod and diaphragm systems would require an elastic approach since their ultimate loads could not be easily predicted due to the brittle-type thread failures that occurred. Hot rolled rod and diaphragm systems could use an ultimate strength approach because these rods were never failed - they continued yielding along the entire length without any connection problems.

Therefore, the elastic and inelastic behavior of a combined system can be analyzed by superimposing the load-deflection curves of the individual components. Load-deflection curves for a diaphragm, 1/4", and, 3/8" diameter rods are shown in Figure 2.

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STIFFNESS RELATIONSHIPS

Diaphragm stiffness for a configuration shown in Figure 3a can be expressed as:

$$(K)diaph = G' * (L)diaph / (H)act \qquad \text{EQ. (1)}$$

See "List of Symbols" for definitions of terms.

The stiffness of a diagonal brace in the global coordinate system as shown in Figure 3b can be expressed as:

$$(K)brace = \frac{AE}{B(\sqrt{(H/B)^2 + 1.0})^3} \qquad \text{EQ. (2)}$$

Throughout this paper, references to diagonal stiffness, loads applied and resisted, and deflections are in global system coordinates unless otherwise noted.

The combined system shown in Figure 3c resists the applied load such that:

$$(P)total = (P)brace + (P)diaph \qquad \text{EQ. (3)}$$

Stiffness for the combined system is then:

$$(K)total = \frac{(P)total}{\Delta} = (K)brace + (K)diaph \qquad \text{EQ. (4)}$$

Therefore, in a combined diaphragm and diagonal brace system, the total system stiffness is the sum of the stiffnesses of the diaphragm and diagonal brace within the elastic range of each component.

The diagonal must be designed such that it can recieve the load that exceeds the diaphragm capacity and maintain a compatible deflection. To find the diagonal brace area required, it is known that:

Load to brace: $$(P)brace = \frac{(K)brace}{(K)total} * (P)total \qquad \text{EQ. (5)}$$

Load to diaphragm: $$(P)diaph = \frac{(K)diaph}{(K)total} * (P)total \qquad \text{EQ. (6)}$$

Substituting equations (2) and (4) into equation (5) and solving for the area:

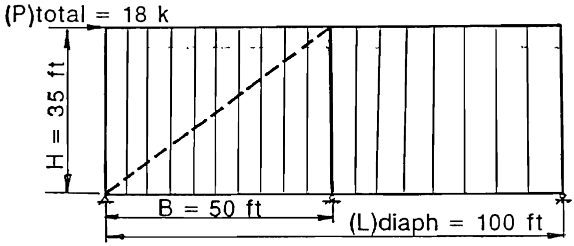
$$\boxed{(A)brace\text{-}req'd = (K)diaph \left[\frac{(P)total}{(P)diaph} - 1.0\right] * \frac{B(\sqrt{(H/B)^2 + 1.0})^3}{E} \qquad \text{EQ. (7)}}$$

Equation (7) represents the minimum area that produces a slope such that at the maximum allowable diaphragm load and corresponding deflection, the load taken by the brace plus the load in the diaphragm is equal to the total applied load. A larger diameter diagonal would have a greater stiffness or slope and take a greater percentage of the total load.

The stress in a brace designed from equation (7) will not exceed the

allowable brace stress provided the maximum diaphragm deflection is less than the allowable deflection for the brace. If, on the other hand, the allowable brace deflection is less than that allowed by the diaphragm, a stiffness design by equation (7) would overstress the diagonal brace. For example:

Example 1:



Known: The diaphragm is 100 feet long and 35 feet high of screw-down panel with a stiffness G'= 4.5 k/in and an ultimate strength (S)ult = 0.282 k/ft. The total applied wind load is 18.0 kips. Design a 36 ksi yield (58 ksi ultimate) brace for the system according to stiffness.

Solution:

(S)des = (S)ult/F.S. = 0.282 k/ft / 2.35 = 0.120 k/ft

(P)diaph = (S)des * (L)diaph = (0.120) * (100) = 12.0 k

(K)diaph = G' * (L)diaph/H = (4.5)(100)/(35) = 12.86 k/in

EQ. (7) $(A)\text{brace-req'd} = \dfrac{(12.86)(18/12-1.0)(50)(12'')\left(\sqrt{(35/50)^2 + 1.0}\right)^3}{29500 \text{ ksi}}$

(A)brace-req'd = 0.238 sq.in. or 9/16" dia. rod (0.2485 sq.in.)

This stiffness method finds the required stiffness of a diagonal brace so that at the maximum diaphragm deflection, the load in the brace plus the load taken by the diagonal equals the total applied load, with no consideration for the stress in the diagonal. The stiffness criteria is met, but the stress in the diagonal is:

$$(f)\text{brace} = \frac{(P)\text{brace}}{A} * \frac{(L)\text{brace}}{B} = \frac{(6.0 \text{ k})}{(0.2495)} * \frac{\sqrt{(50)^2 + (35)^2}}{(50)}$$

(f)brace = 29.5 ksi > 25.5 ksi allow. OVERSTRESSED

Therefore, to design diagonal bracing to interact with diaphragms, a stiffness approach that also considers the diagonal bracing allowable strength must be used.

STRENGTH RELATIONSHIPS

The allowable load resisted by a diaphragm can be written as:

$$(P)diaph = (S)des * (L)diaph \qquad \text{EQ. (8)}$$

The allowable diaphragm deflection is then:

$$(\triangle all)diaph = \frac{(S)des * H}{G'} = \frac{(P)diaph}{(K)diaph} \qquad \text{EQ. (9)}$$

Allowable diagonal bracing strength as specified by the AISC Manual for Steel Construction is:

(F)all = 0.33 * (F)ult based on the nominal body area

For a full definition and restrictions that apply see reference [3]. This allowable stress may be increased by 1/3 for wind and seismic loads. However, this increase does not apply to diaphragms.

Therefore, a strength design of a diagonal brace for the system shown in Figure 3b could be expressed as:

$$\boxed{(A)brace\text{-}req'd = \frac{(P)brace\ \sqrt{(H/B)^{\wedge}2 + 1.0}}{(F)all} \qquad \text{EQ. (10)}}$$

The corresponding maximum deflection for the diagonal brace system is:

$$(\triangle all)brace = \frac{(F)all * B * ((H/B)^{\wedge}2 + 1.0)}{E} \qquad \text{EQ. (11)}$$

Equation (10) represents the minimum area required to prevent the diagonal brace from being overstressed when a load P is applied as in Figure 3b and equation (11) gives the corresponding maximum system deflection $\triangle$. <u>The allowable deflection for the diagonal system is solely dependent on the configuration and allowable stress, diameter has no effect</u>.

Diagonal brace design by stiffness has been presented, but another possible design approach would be to design by strength. For diaphragm and brace interaction, this procedure would essentially design the diagonal for the amount of the total load not taken by the diaphragm capacity. A strength method without considering any deflection criteria would be incorrect and inconsistent with the stiffness interaction previously derived. Example 2 is the same as example 1 but instead it illustrates the problem with a straight strength approach:

Example 2:

See example 1 for drawing of system.

Known: (L)diaph = 100 ft   G' = 4.5 k/in
(P)total = 18 k   (S)ult = 0.282 k/ft

Design a 36 ksi yield (58 ksi ultimate) brace for the system according to strength.

Solution:

(S)des = (S)ult/F.S. = 0.282 k/ft / 2.35 = 0.120 k/ft
(P)diaph = (S)des * (L)diaph = (0.120) * (100) = 12.0 k

(P)brace = (P)total-(P)diaph = 18.0 - 12.0 = 6.0 k

EQ. (10) $$\text{(A)brace-req'd} = \frac{6.0 * \sqrt{(35/50)^2 + 1.0}}{4/3(0.33)(58\ \text{ksi})}$$

(A)brace-req'd = 0.287 sq.in. or 5/8" dia. rod (0.3068 sq.in.)

This method appears straightforward but is not correct in most applications. The true load recieved by each of the systems would be:

EQ. (2) $$\text{(K)brace} = \frac{(0.3068)(29500)}{50(12)(\sqrt{(35/50)^2 + 1.0})^3} = 8.29\ \text{k/in}$$

EQ. (1) (K)diaph = G' * (L)diaph/H = 4.5 * (100)/(35) = 12.86 k/in

EQ. (4) (K)total = 8.29 + 12.86 = 21.15 k/in

EQ. (5) (P)brace = 8.29/21.15 * 18.0 = 7.06 k

EQ. (6) (P)diaph = 12.86/21.15 * 18.0 = 10.94 k

Note: (P)diaph = 10.94 k compared to previously assumed 12.0 k and (P)brace = 7.06 k compared to assumed 6.0 kip. The stress in the diagonal is then:

$$\text{(f)brace} = \frac{\text{(P)brace}}{A} * \frac{\text{(L)brace}}{B} = \frac{(7.06)\ \sqrt{(50)^2 + (35)^2}}{(0.3068)\qquad (50)}$$

(f)brace = 28.09 ksi > 25.5 ksi allow. OVERSTRESSED

As this example shows, the strengths of the diagonal and diaphragm system should not be directly added without considering compatibility. However, example 1 illustrated that a pure stiffness (compatibility) approach could also overstress the diagonal. Therefore, a design method must be developed to consider both criteria.

STIFFNESS AND STRENGTH RELATIONSHIPS

Diagonal bracing designed to interact with shear diaphragms must satisfy strength and stiffness requirements set by equations (7) and (10). However, the area required by strength must always be greater than or equal to the area required for stiffness. The two equations can then be written as:

(A)brace-req'd strength >= (A)brace-req'd stiffness

$$\frac{\text{(P)brace} * \sqrt{(H/B)^2 + 1.0}}{\text{(F)all}} \geq \text{(K)diaph} \left[\frac{\text{(P)total}}{\text{(P)diaph}} - 1.0\right] * \frac{B(\sqrt{(H/B)^2+1.0})^3}{E}$$

$$\frac{E}{(F)all\ B\ ((H/B)^2 + 1.0)} >= \frac{(K)diaph \left[\frac{(P)total}{(P)diaph} - 1.0\right]}{(P)total - (P)diaph}$$

$$\frac{1}{(\Delta\,all)brace} >= \frac{(K)diaph}{(P)diaph} = \frac{1}{(\Delta\,all)diaph}$$

$$(\Delta\,all)brace >= (\Delta\,all)diaph$$

Therefore,

$$(\Delta\,all)ratio = \frac{(\Delta\,all)brace}{(\Delta\,all)diaph} >= 1.0 \qquad \text{EQ. (12)}$$

When the allowable deflection ratio in equation (12) is greater than or equal to 1.0, the required brace stiffness will control and the diagonal would be designed using equation (7). However, if the allowable deflection ratio is less than 1.0, the required brace strength would control and the diagonal would be designed using equation (10).

When equation (10) controls, the load taken by the diaphragm may not be the full capacity of the diaphragm, therefore, to find the corresponding load in the diaphragm at the controlling diagonal deflection:

$$\boxed{(A)brace\text{-}req'd = \frac{((P)total-(K)diaph*(\Delta\,all)brace)\ \sqrt{(H/B)^2 + 1.0}}{(F)all}}$$

EQ. (13)

Example 3 is similar to examples 1 and 2 but instead, the diagonal brace will be designed considering stiffness and allowable diagonal stress:

Example 3:

See example 1 for drawing of system.

Known: (L)diaph = 100 ft   G' = 4.5 k/in
(P)total = 18 k   (S)ult = 0.282 k/ft

Design a 36 ksi yield (58 ksi ultimate) brace for the system meeting stiffness and strength requirements.

Solution:

(S)des = (S)ult/F.S. = 0.282 k/ft / 2.35 = 0.120 k/ft
(P)diaph = (S)des * (L)diaph = (0.120) * (100) = 12.0 k
(K)diaph = G' * (L)diaph/H = 4.5(100/35) = 12.86 k/in

EQ. (11) $$(\Delta\,all)brace = \frac{4/3(0.33)(58)(50)(12)((35/50)^2+1.0)}{29500\ ksi} = 0.773\ in$$

EQ. (9) $(\Delta\,all)diaph = 12.0\ k\ /\ 12.86\ k/in = 0.933\ in$

EQ. (12) $(\Delta all)ratio = 0.773 / 0.933 = 0.829 < 1.0$

Since, $(\Delta all)ratio < 1.0$ the stress in the diagonal will control, therefore, design the brace using equation (13):

$$(A)brace\text{-}req'd = \frac{(18.0 - 12.86 \text{ k/in}*0.733 \text{ in})\sqrt{(35/50)^2 + 1.0}}{4/3(0.33)(58 \text{ ksi})}$$

$$= 0.410 \text{ sq.in. or } 3/4'' \text{ dia. steel rod } (0.442)$$

Check the stiffnesses and stress in the diagonal:

EQ. (2) $$(K)brace = \frac{(0.442 \text{ sq.in.})(29500 \text{ ksi})}{50(12)(\sqrt{(35/50)^2 + 1.0})^3} = 11.95 \text{ k/in}$$

$$(K)diaph = 12.86 \text{ k/in}$$

EQ. (4) $(K)total = 11.95 + 12.86 = 24.81$ k/in

EQ. (5) $(P)brace = 11.95/24.81 * 18.0 = 8.67$ k

EQ. (6) $(P)diaph = 12.86/24.81 * 18.0 = 9.33$ k

The stress in the diagonal is then:

$$(f)brace = \frac{(P)brace}{A} * \frac{(L)brace}{B} = \frac{(8.67)}{(0.442)}\frac{\sqrt{(50)^2 + (35)^2}}{(50)}$$

$$(f)brace = 23.9 \text{ ksi} < 25.5 \text{ ksi allow.} \quad \text{ok.}$$

Note that the load in the diaphragm, 9.33 k is less than what was assumed, 12 k, when it was designed according to stiffness in example 1. If the diaphragm were neglected the required rod area would be:

EQ. (10) $$(A)brace\text{-}req'd = \frac{(18 \text{ k})\sqrt{(35/50)^2 + 1.0}}{4/3(0.33)(58 \text{ ksi})}$$

$$(A)brace\text{-}req'd = 0.861 \text{ sq.in. or } 1\ 1/16'' \text{ dia. rod}$$

In this case, a combined diaphragm and diagonal system produced a 48 percent savings in steel for the diagonal. Diagonal braces can be designed to interact with the diaphragm by a modified stiffness method that assures the diagonal will not be overstressed. However, there are some circumstances when it would be beneficial to neglect the diaphragm.

NEGLECTING DIAPHRAGM ACTION

When diagonal bracing is designed to interact with diaphragms, deflections remain compatible. When the maximum system deflection is controlled by the diagonal, strength will always control the design, but if the maximum system deflection is controlled by the diaphragm, a stiffness method is used to design the diagonal. However, for some cases, there exists a point when combining a

system requires a diagonal stiffness that exceeds the stiffness of a diagonal designed to take all of the applied load. If this is the case, the diaphragm may be neglected.

Both equations (7) and (10) define the slope of the linear elastic range for the diagonal. The point when the area required to satisfy stiffness exceeds the area required if the diagonal brace were designed to take all of the load can be expressed as:

Set: (A)brace-req'd stiffness >= (A)brace-req'd strength total load

$$(K)\text{diaph}\left[\frac{(P)\text{total}}{(P)\text{diaph}}-1.0\right] * \frac{B(\sqrt{(H/B)^2+1.0})^3}{E} \geq \frac{(P)\text{total} * \sqrt{(H/B)^2 + 1.0}}{(F)\text{all}}$$

$$(K)\text{diaph}\left[\frac{1}{(P)\text{diaph}} - \frac{1}{(P)\text{total}}\right] \geq \frac{E}{(F)\text{all} * B\,((H/B)^2 + 1.0\,)}$$

$$\frac{(K)\text{diaph}}{(P)\text{diaph}} - \frac{(K)\text{diaph}}{(P)\text{total}} \geq \frac{1}{(\Delta\,\text{all})\text{brace}}$$

Let $$\frac{(P)\text{total}}{(K)\text{diaph}} = (\Delta\text{tot})\text{diaph} \qquad \text{EQ. (14)}$$

$$\frac{1}{(\Delta\,\text{all})\text{diaph}} - \frac{1}{(\Delta\,\text{tot})\text{diaph}} \geq \frac{1}{(\Delta\,\text{all})\text{brace}}$$

$$\frac{(\Delta\,\text{all})\text{brace}}{(\Delta\,\text{all})\text{diaph}} - \frac{(\Delta\,\text{all})\text{brace}}{(\Delta\,\text{tot})\text{diaph}} \geq 1.0$$

or

$$\frac{(\Delta\,\text{all})\text{brace}}{(\Delta\,\text{all})\text{diaph}} \geq \frac{(\Delta\,\text{all})\text{brace}}{(\Delta\,\text{tot})\text{diaph}} + 1.0 \qquad \text{EQ. (15)}$$

$$(\Delta\,\text{all})\text{ratio} \geq (\text{max})\text{interaction}$$

Therefore, when the allowable deflection ratio is greater than the maximum interaction expression, design the diagonal brace to take the entire applied load, neglecting the diaphragm. Example 4 is identical to the previous examples except that the diaphragm stiffness, G' has been changed to 18 k/in to illustrate this point.

Example 4:

See example 1 for drawing of system.

Known: (L)diaph = 100 ft   CHANGE: G' = 18.0 k/in
(P)total = 18 k   (S)ult = 0.282 k/ft

Design a 36 ksi yield (58 ksi ultimate) brace for the system meeting stiffness and strength requirements, but neglect diaphragm action if beneficial.

Solution:

(S)des = (S)ult/F.S. = 0.282 k/ft / 2.35 = 0.120 k/ft
(P)diaph = (S)des * (L)diaph = (0.120) * (100) = 12.0 k
(K)diaph = G' * (L)diaph/H = 18.0(100/35) = 51.43 k/in

EQ. (11) $(\Delta\text{all})\text{brace} = \dfrac{(F)\text{all} * B * ((H/B)\hat{}2 + 1.0)}{E} = 0.773 \text{ in}$

EQ. (9) $(\Delta\text{all})\text{diaph} = 12.0 \text{ k} / 51.43 \text{ k/in} = 0.233 \text{ in}$

EQ. (14) $(\Delta\text{tot})\text{diaph} = (P)\text{total}/(K)\text{diaph} = 18.0/51.43 = 0.350 \text{ in}$

EQ. (15) $\dfrac{(\Delta\text{all})\text{brace}}{(\Delta\text{all})\text{diaph}} >= \dfrac{(\Delta\text{all})\text{brace}}{(\Delta\text{tot})\text{diaph}} + 1.0$

$$\frac{0.773}{0.233} >= \frac{0.773}{0.350} + 1.0$$

3.32 >= 3.21 TRUE

Since (Δall)ratio > (max)interaction, the diagonal can be designed to take all of the load, neglecting the diaphragm:

EQ. (10) where (P)brace = (P)total

$$(A)\text{brace-req'd} = \frac{(P)\text{total}\sqrt{(H/B)\hat{}2 + 1.0}}{(F)\text{all}} = \frac{(18.0)\sqrt{(35/50)\hat{}2 + 1.0}}{4/3(0.33)(58 \text{ ksi})}$$

(A)brace-req'd = 0.861 sq.in. or 2-3/4" dia. steel rods (0.442)

If the diagonal would have been designed according to the stiffness equation (7), the required rod area would be larger:
Note (Δall)ratio >= 1.0:

$$(A)\text{brace-req'd} = \frac{(51.43)(18/12.0 - 1.0)(50)(12)(\sqrt{(35/50)\hat{}2 + 1.0})\hat{}3}{29500 \text{ ksi}}$$

(A)brace-req'd = 0.951 sq.in. or 2-13/16" dia steel rods (0.5185)

Therefore, for this example, designing the two systems for interaction requires 10 percent more steel than if the diagonal was designed to take all of the load.

The diaphragm will still interact with the diagonal brace for lower applied loads because the load distribution according to stiffness always applies. However, the system is now allowed to deflect past the allowable deflection limit set by the diaphragm, which could overstress the diaphragm:

EQ (2) with 2-3/4" dia. rods:

$$(K)\text{brace} = \frac{(0.884)(29500)}{(50)(12)(\sqrt{(35/50)\hat{}2 + 1.0})\hat{}3} = 23.90 \text{ k/in}$$

$(K)diaph = 51.43$ k/in

EQ. (4) $(K)total = 23.90 + 51.43 = 75.33$ k/in

EQ. (5) $(P)brace = 23.90/75.33 * 18.0 = 5.7$ k

EQ. (6) $(P)diaph = 51.43/75.33 * 18.0 = 12.3$ k

The load to the diaphragm is 0.3 k over its allowable capacity while the load in the rod is much less than the design capacity of 18 kips.

Neglecting the diaphragm is often a standard practice for many metal building manufactures. For stiffer diaphragms, this greater allowable system deflection can cause problems. Excessive deflection to a diaphragm causes panel warping, buckles, tears, screw hole elongations, or fastener failures which can directly result in water leakage.

Figure 4 is a plot of the area of diagonal brace required versus the allowable deflection ratio at applied loads of 16, 18, and 20 kips. The configuration used is identical to example 1 except that the diaphragm stiffness is varied so that the allowable deflection ratio also varies. When the allowable deflection ratio is less than 1.0, strength controls the design, above 1.0, stiffness controls, and when the ratio exceeds the maximum interaction expression $((\triangle all)brace/(\triangle tot)diaph + 1.0)$, the diaphragm may be neglected.

RECOMMENDATIONS

When considering the interaction of diaphragms and diagonal bracing, three possible design cases can occur:

1. Diaphragm alone: When the total lateral load is less than or equal to the strength capability of the diaphragm, no diagonal bracing is required.

2. Diaphragm and diagonal interaction: When the total load exceeds the allowable diaphragm resistance, the excess may be resisted by a diagonal brace.

3. Diagonal brace alone: When the required diagonal brace area found by combining the two systems exceeds the required diagonal area for resisting the entire load, the diaphragm may be neglected. A design procedure for the interaction of diaphragm and diagonal bracing would primarily consist of finding the allowable deflections of each system, then design for the one that controls. In most circumstances the designer is given the diaphragm material either for the roof or walls and knows the type of diagonal bracing typically used. Therefore, with the geometry, diagonal brace yield strength, and the diaphragm stiffness and strength, G' and (S)des known, the allowable deflections of each system may be found without yet designing the diagonal brace. A design approach flow chart is shown in Figure 5.

Special consideration should be given to interuptions of diaphragm sheets due to openings or nonstructural sheets. Conservatively, the effective length of diaphragm may be taken as the total length minus the sum of the widths of the openings measured parallel the the length of the diaphragm.

CONCLUSIONS

From the theoretical strength and stiffness analysis of the diaphragm and diagonal bracing systems, the following conclusions can be made:

1. The total strength of a combined system can be analytically determined according to the stiffness of the respective systems.

2. An elastic design procedure for a combined diaphragm and diagonal bracing system requires a stiffness approach that considers the stress in the diagonal.

3. A diagonal design that neglects the interaction of the diaphragm can cause excessive deflection and hence damage the diaphragm.

5. The stiffnesses of the diagonal brace connections are important to consider when combining diagonal and diaphragm strengths.

6. There are three possible cases for design: no diagonal brace needed, interaction of the brace and the diaphragm, and a case when it is more beneficial not to combine the systems and neglect the diaphragm.

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LIST OF SYMBOLS

A	=	diagonal brace area (sq.in.)
(A)brace-req'd	=	required diagonal brace area (sq.in.)
B	=	width of bay where diagonal bracing is considered (in.)
E	=	modulus of elasticity (29,500 ksi)
(F)all	=	allowable stress in diagonal brace (ksi)
(f)brace	=	actual stress in diagonal brace (ksi)
(F)ult	=	diagonal brace ultimate strength (ksi)
G'	=	diaphragm shear stiffness (k/in)
H	=	height of bay for diagonal or diaphragm perpendicular to applied load (in.)
(H)act	=	actual diaphragm height for new configuration perpendicular to applied load (in.)
(K)brace	=	diagonal brace stiffness in global coordinates (k/in)
(K)diaph	=	stiffness of actual diaphragm configuration (k/in)

(K)total	= combined brace and diaphragm stiffness (k/in)
(L)diaph	= effective length of diaphragm measured parallel to applied load (in)
(P)brace	= amount of total load taken by the diagonal bracing system in global coordinates (k)
(P)diaph	= amount of total load taken by the diaphragm system (k)
(P)total	= total applied load on the system (k)
(S)des	= diaphragm design strength (k/in)
Δ	= global system deflection measured parallel to the direction of applied load (in.)
(Δall)brace	= global allowable diagonal brace deflection measured parallel to direction of applied load (in.)
(Δall)diaph	= global allowable diaphragm deflection measured parallel to the direction of applied load (in.)
(Δall)ratio	= allowable deflection ratio = (Δall)brace/(Δall)diaph
(Δtot)diaph	= deflection of diaphragm from total load = (P)total/(K)diaph
(max)interaction	= maximum ratio when combining systems is no longer beneficial

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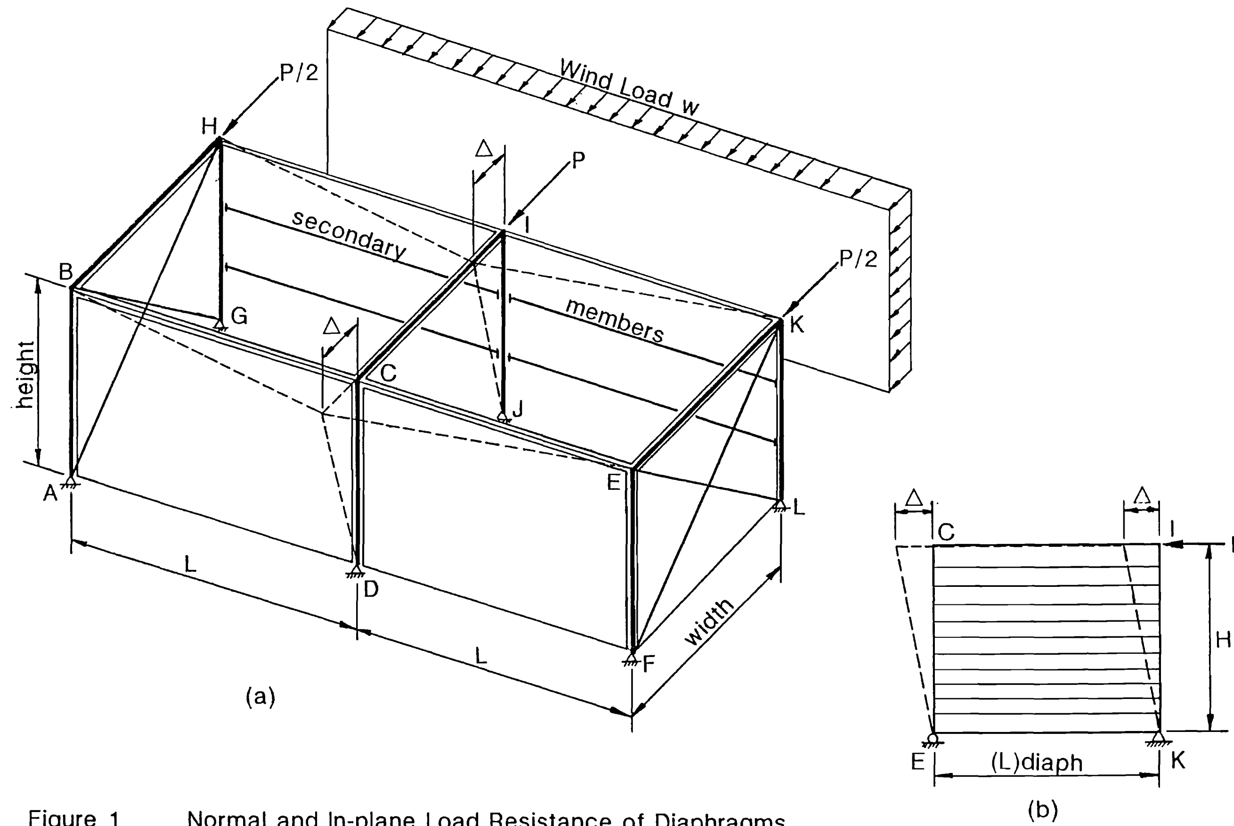


Figure 1 Normal and In-plane Load Resistance of Diaphragms

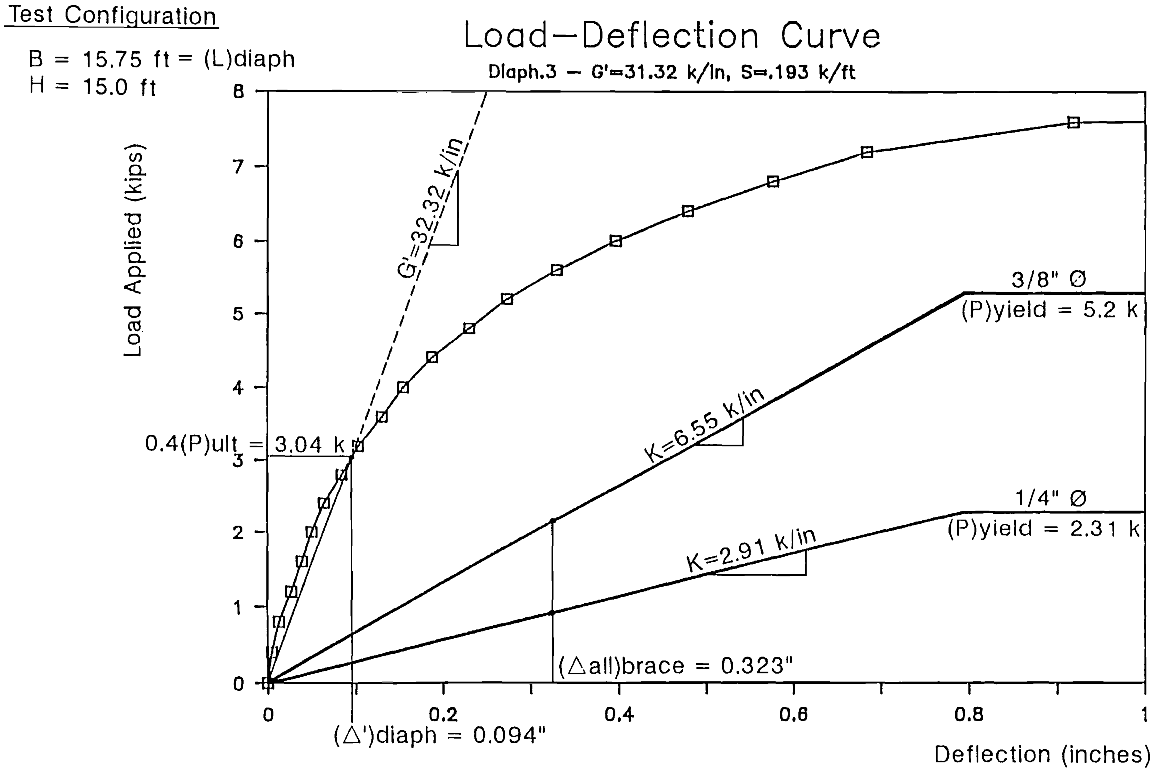
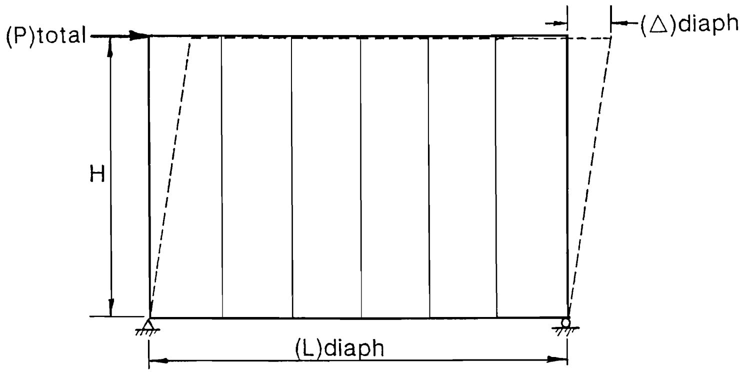
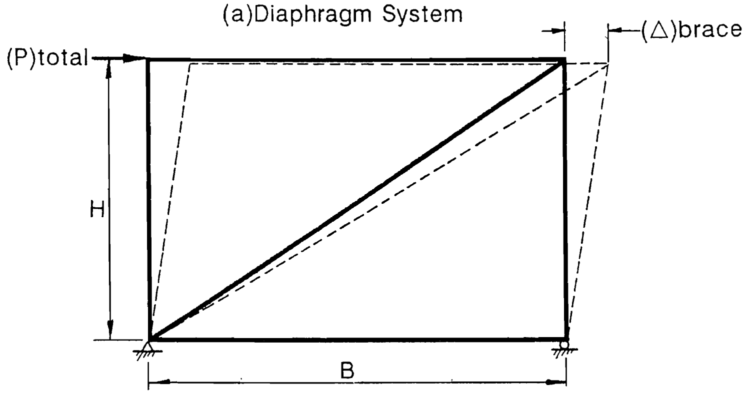


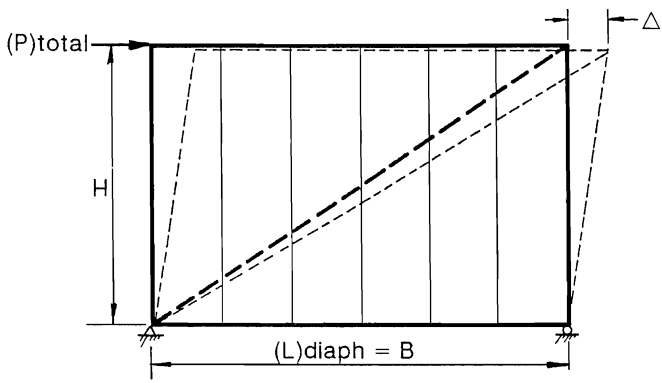
Figure 2 - Diaphragm, 1/4", and 3/8" Diameter Rod Load-Deflection Curves



(a)Diaphragm System



(b)Diagonal Brace System



(c)Combined System

Figure 3 - Typical Diaphragm, Diagonal, and Combined Systems

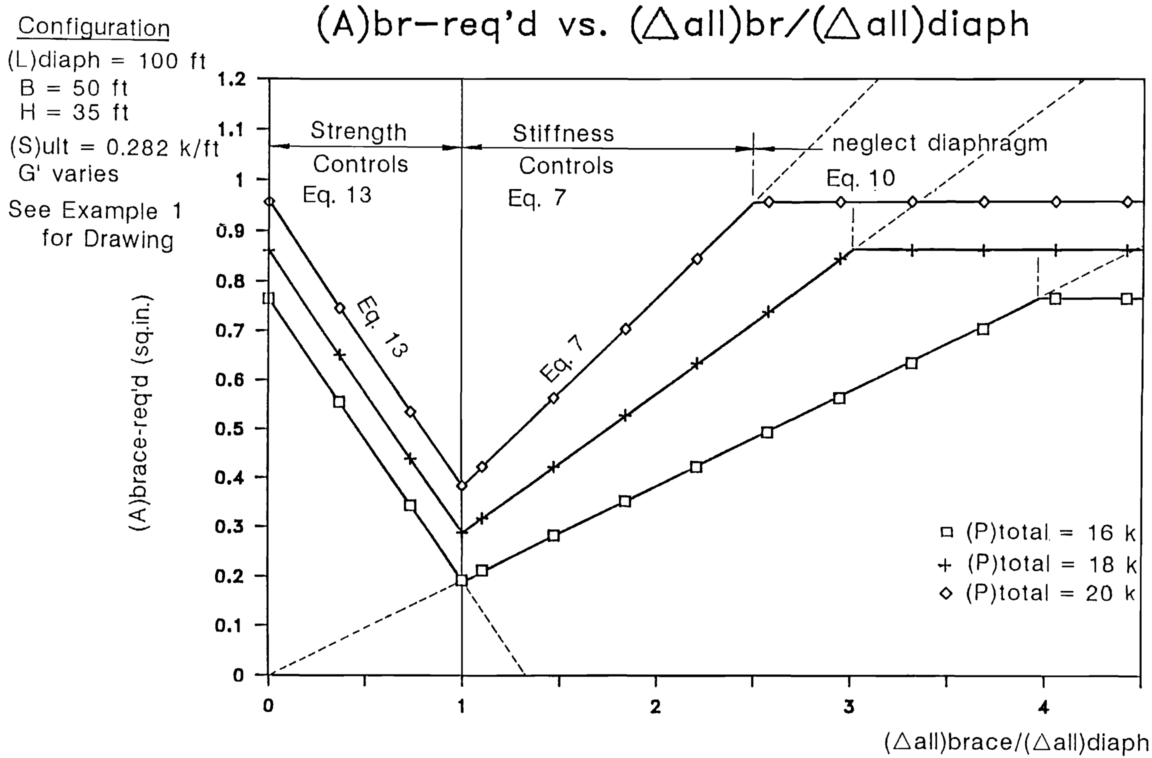


Figure 4 Equations 7, 10, and 13 Plotted

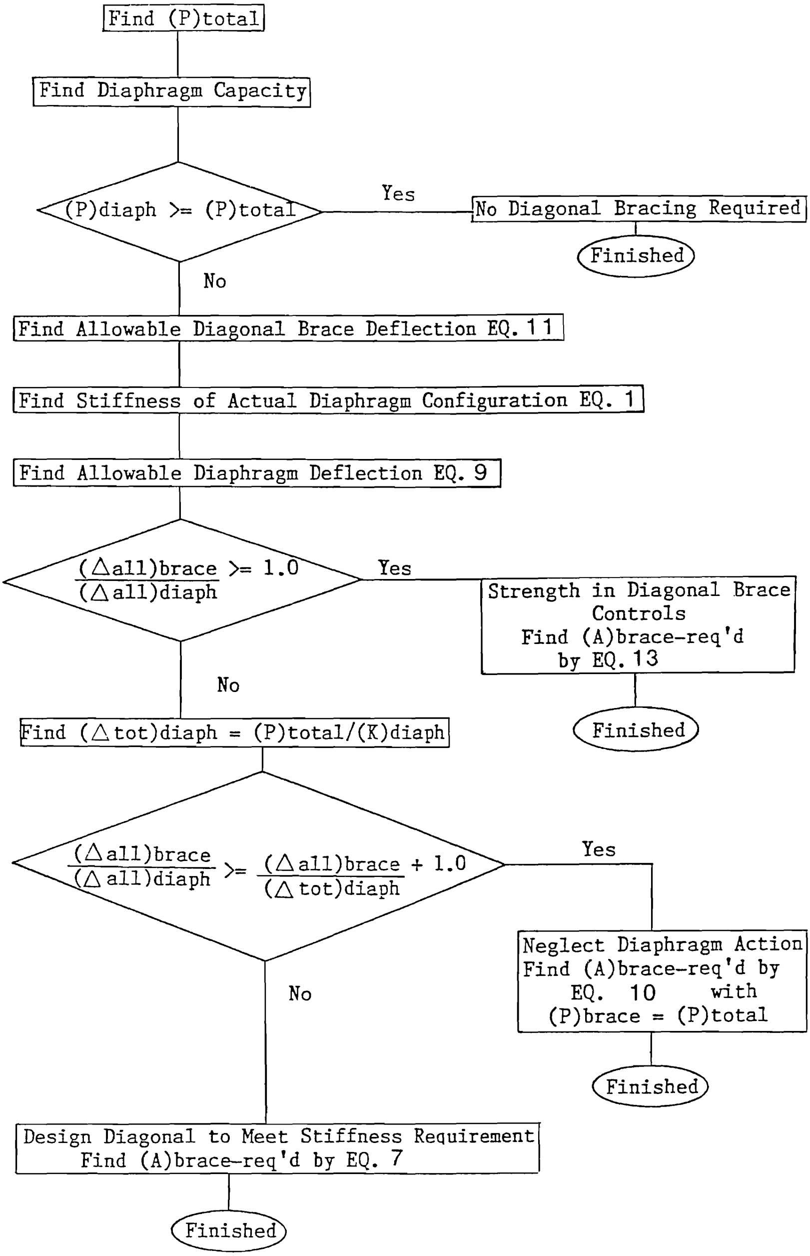


Figure 5 - Design Procedure Flow Chart