IV-27. On Determining Rigidites of Masonry Shear Wall Elements

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ABSTRACT

When designing masonry shear wall buildings the lateral loads must be distributed by considering the relative rigidities of the shear elements whenever rigid floor or roof diaphragms are encountered.

Several methods are currently in use by design offices to determine these rigidities. The preciseness of their results varies considerably and, in some cases, can result in substantial overloading of shear elements.

This paper: (a) evaluates the various methods and compares their results to results from more precise analytical procedures; (b) presents an adaptation of an existing design method that greatly improves the preciseness of the results with little, if any, additional time expended; (c) compares the results of using several differently formulated finite elements to solve this problem and then considers the effect of varying parameters not normally considered in the usual design procedure such as the effect of the stiffness of the bond beam/diaphragm or parapet.

INTRODUCTION

When designing masonry shear wall buildings the lateral loads must be distributed by considering the relative rigidities of the resisting elements whenever rigid floor or roof diaphrams are encountered. Although the problems are essentially the same for single and for multiple storied structures, this paper will be limited specifically to a discussion of single-story configurations.

It is acknowledged that many times the precise determination of the distribution of lateral forces and resulting stress values may not be warranted and are determined by methods more approximate than those enumerated here. However, it is felt that a review and critique of the available computational procedures is of value.

DESCRIPTION OF PROCEDURES

Because of the limitation of space, background will be limited to simply defining the more important concepts leaving to the reader to review the references for additional information if desired.

The methods selected for review are those that appear to be most commonly used in design offices. Several others can be found in the literature[1,2] but do not appear to be in common use.

Each of the procedures require the assembly of elements to represent a complete wall. The type of element and the method of assembly lead to computational differences and to varying numerical results.

First the types of elements will be designated and then the assemblage described.

In a sense all of these elements may be thought of as "finite elements." The elements are as shown in Fig. 1.

(A) Fixed, Shear-Flexure Element

This element contains both shear and flexural deformation contributions. Its development is commonly available[3, others] and results in the expression:

$$\Delta_F = \frac{Ph^3}{12EI} + \frac{1.2Ph}{AG} \qquad \textit{EQN 1}$$

where E, I, A, & G are the usual material and section properties, "P" is the force and "H" is the length. The first term is the flexural contribution and the second is the shear contribution.

(B) Cantilever, Shear-Flexure Element (Figure 2)

This element is the same as element (A) except that one end is free to rotate as well as translate.

$$\Delta_c = \frac{Ph^3}{3EI} + \frac{1.2Ph}{AG} \qquad \textit{EQN 2}$$

(C) Plane Stress Finite Element[4]

This element has many forms and formulations. The results quoted in this paper are obtained using rectangular linear-strain elements based upon an assumed displacement and solved by direct stiffness procedure. Other elements including inplane rotation approximations are available[5,6] and have been used for shear wall analysis[7].

Deflection Addition Method (DAM)[2,8]

The wall to be analyzed is divided into elements by horizontal lines extended from the top and bottom of all openings. Using the inverse relatinship of rigidity (R) and deflection (Δ) elements are combined in either series or parallel to form subassemblies that in turn are combined to finally determine the rigidity of the entire wall. This is basically a hand-calculation method. Elements A and/or B may be used.

Deflection Subtraction Method (DSM)[2,9]

The effect of the openings on the rigidity is accounted for by computing the deflection for a subassembly with openings and subtracting the difference between the rigidity of the pierced subassembly and an unpierced subassembly from the rigidity of the total unpierced wall. These calculations can be done by hand. Elements A or B can be utilized.

Modified Deflection Addition Method (MDAM)[10]

At times the solution by the Deflection Addition Method is hampered because it is in an arrangement that results in a statistically indeterminate problem if applied appropriately. This technique transforms the procedure into a stiffness procedure facilitating solution. The shear force assigned by each element is readily obtained.

Finite Element Method (FEM)[4]

The direct stiffness method is used to assemble elements of (C) formulation into a model of the wall and solve for displacements. Stresses in each element can easily be obtained by back substitution. This procedure implies the use of an electronic computer.

Comparative Examples

Previously[2] comparison has been made for simple wall segments by various methods including the Deflection Addition Method (DAM) and Deflection Subtraction Method (DSM). That study demonstrated that (DAM) can result in a pierced wall having a larger rigidity than an equally dimensioned unpierced wall for which the rigidity is computed in a compatible manner. (DSM), by virtue of its procedure has a built in assurance that a pierced wall rigidity will not exceed the rigidity of its equal in an unpierced wall.

However both methods have several common limitations. Some seemingly simple arrangements of openings result in statically indeterminate configurations. Figure 3 shows such a wall.

This wall when indiscriminatly reduced to a statically determinate form[8] can yield large errors.

Below are the results from solution for the rigidity of this wall by several methods.

METHOD	*R*	*R (SOLID WALL)*
DAM[2]	14.01	9.84
MDAM[10]	6.70	9.84
FEM (PLANE STRESS)[10]	7.57	9.62

The error in the use of DAM is caused by reduction to a statically determinate system by improper elimination of elements. Several examples of treating the same wall by assigning extreme values $(0,\infty)$ to the stiffness of a judiciously selected wall element[10]:

ASSUMPTION	*R*
$K_4 = 0$	5.29
$K_4 = \infty$	7.28
$K_5 = 0$	6.60

Since K_4 must lie between zero and infinity, then 5.29 and 7.28 are bounds on the mathematically precise solution (6.70) using this (DAM) method. It can be logically reasoned that if the system is rendered statistically determinate by neglecting an element of low rigidity ($K_5 = 0$) an acceptable solution should follow ($R = 6.60$).

If another wall of the same outside dimensions but different arrangements of openings (Figure 4) is considered the following results are obtained.

METHODS	*R*	*R (SOLID WALL)*
DAM[2]	2.17	9.84
DSM	1.81	8.92
MDAM[9]	2.07	9.84
FEM (PLANE STRESS)[9]	1.69	9.61

The values shown for the Deflection Subtraction Method (DSM) were obtained following Reference 2. Whether the fixed shear flexure or cantilever shear flexure element is used appears to have much less effect on the solution than the method employed. For example, if all fixed elements are used on the preceding wall in the DSM, instead of the mixture as recommended, R is equal to 1.83 instead of 1.81. Compared to the range of 1.69 to 2.17 this is a negligible variation. That this should be anticipated can be seen by referring to equations 1 and 2. The shear contribution to deflection is unaffected by the prescribed end condition. Since, in most single-story shear walls the important elements are proportioned such that shear predominates, it should be expected that the end conditions selected should have little effect.

SUMMARY

For very simple walls (single or double openings) the results of any of the methods discussed normally provide acceptable results particularly when used in comparison to other simple walls for the determination of distribution of shear forces.

As the walls become more complex the validity of the results tends to be more questionable, especially if statically indeterminant systems are encountered. The literature does not reveal any attempt to establish experimentally the stiffnesses of complex single-story shear walls. Therefore the question of which method yields the most appropriate results cannot be completely resolved at this time. It is the author's opinion that the finite element solution, when a fine mesh is employed, will provide answers consistent with the mathematical and physical assumptions (isotropic, homogenous, linear, elastic, small deflections) and therefore adequate for design.

This leads to these concluding comments:

1. None of the hand methods reviewed here yield predictably accurate results over all single story configurations if finite element computations are used as a reference.

2. Major electronic computation capability is needed to enable use of a finite element mesh sufficiently fine to ensure results that can be used with confidence. Although programs are commonly available, the computer equipment requirements will discourage day-to-day use in many design environments.

3. Experimental investigation of a variety of wall configurations is needed.

4. A simple, approximate method needs to be developed that can be used with some determined level of confidence. Many shear-walls are of nominal design and a simple check will suffice. When warranted, the few walls not falling within the confidence level could be checked by a more rigorous procedure.

5. The effect of the stiffness of the diaphram, bond beam, footing stem, and foundation needs to be investigated. Some work[7] indicates that it can have a noticeable effect on the absolute wall rigidity. However, the relative effect (and hence shear force distribution) has not been evaluated.

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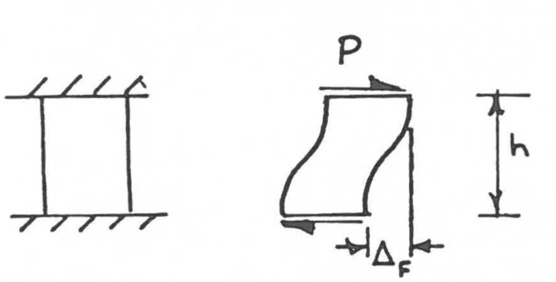

Figure 1. Fixed Shear/Flexure Element

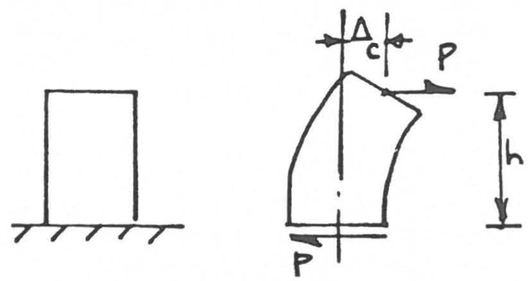

Figure 2. Cantilever Shear/Flexure Element.

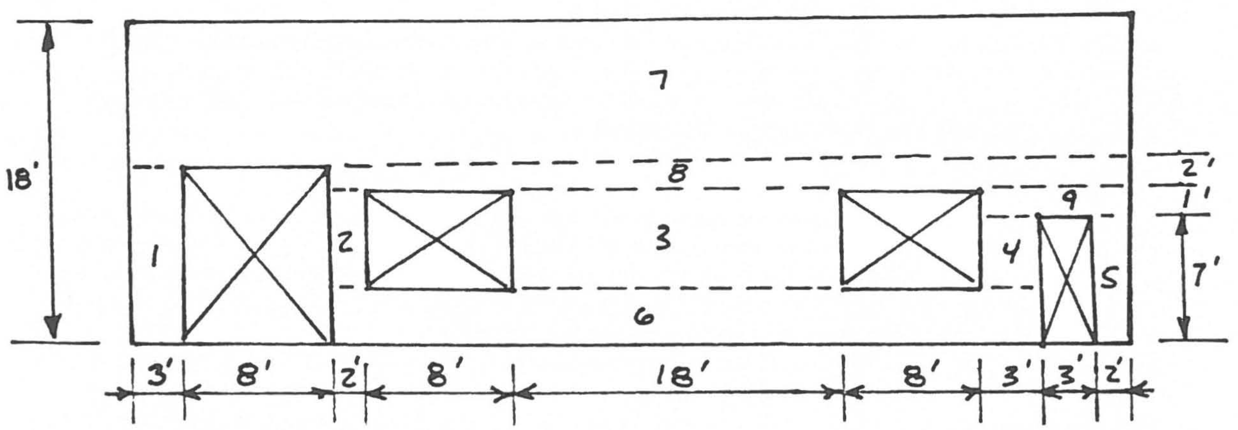

Figure 3. Example Shear Wall.

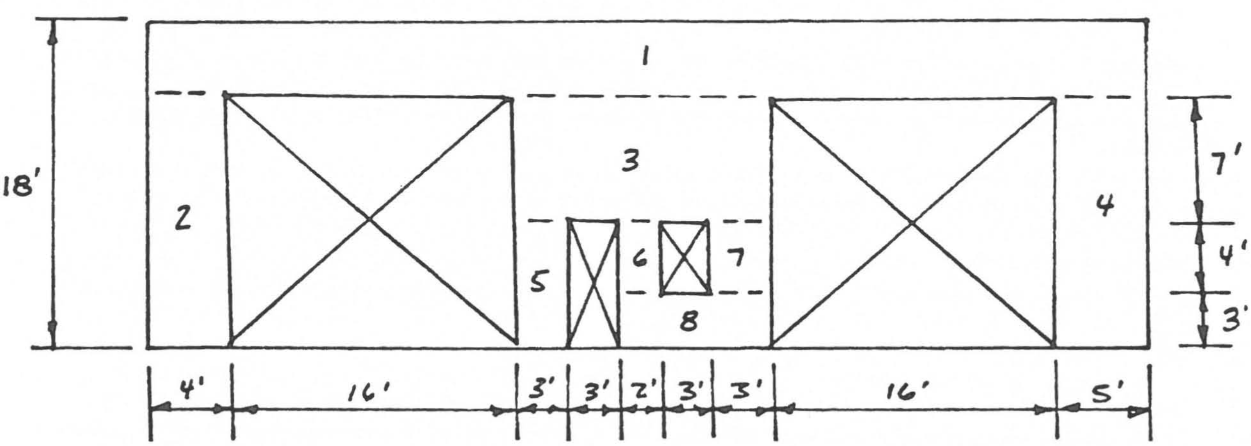

Figure 4. Example Shear Wall.