V–7. A Comparison of Masonry Design Parameters

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ABSTRACT

Structural design of composite masonry walls consisting of bonded brick and concrete masonry wythes is complicated by the lack of an acceptable procedure for the consideration of the effects of slenderness and eccentricity in such construction.

Current United States wall design procedures for brick and concrete masonry include the effects of slenderness and eccentricity on reducing wall compressive strengths. However, since these two procedures differ in their method of consideration of these important parameters, in practice, the designer has little guidance available for including these effects in a composite wall. As a result, the brick wythe is often ignored.

The purpose of this paper is to compare the design parameters for brick and concrete masonry load bearing walls in an attempt to evaluate the significance of differences between the two approaches. Also, a recently developed alternative stress reduction design procedure is included in the comparisons.

Numerical comparisons of these three design approaches are presented for typical wall units in multi-story load bearing structures. Stress reduction factors for walls under varying magnitudes of axial compression in both single and double curvature are included.

The results of this study provide a means of developing a generalized approach to the consideration of slenderness and eccentricity which could be used in composite wall design.

INTRODUCTION

The relatively thin walls typical of modern engineered load bearing masonry structures require careful consideration in design of slenderness effects and gravity load eccentricities. Weak axis bending of masonry walls is of particular importance due to the low tensile strength of masonry construction. In load bearing high-rise structures, it is not unusual for the masonry walls to consist of a mixture of brick, concrete masonry and composite construction consisting of a brick wythe and a concrete masonry wythe bonded together.

The design of brick walls is specified in Ref. (1) and the design of concrete masonry walls is specified in Ref. (2). Although allowable design stresses and allowable loads for composite construction are presented in Refs. (3, 4), there is at present no widely accepted specification covering the design of composite walls.

As a first step in developing a unified design specification for masonry walls, this paper compares the design procedures recommended by BIA and NCMA. In addition, a third design method presented in Ref. (5, 6) which is not limited to either brick or concrete masonry is compared to the BIA and NCMA requirements in order to permit some observations concerning its validity as a general design procedure. The paper will be limited to solid masonry walls.

DESIGN PARAMETERS

All of the aforementioned design procedures are based on the computation of stress reduction factors which relate the strength of a wall element to that of an axially loaded wall. The general procedure for computing the appropriate stress reduction factors for each of the three design procedures is given below.

Brick Institute of America

The basic equation for computing the allowable axial load on a wall is:

$$P = C_e C_s f_m A \tag{1}$$

in which f_m = allowable axial compressive stress; A = wall cross-sectional area; C_e = eccentricity coefficient; and C_s = slenderness coefficient. The stress reduction factor, which consists of the product C_eC_s, depends on the wall slenderness ratio, the magnitude of the virtual eccentricity of the gravity loading and the type of wall curvature induced by the loading (i.e. single or double curvature).

Detailed equations for computing C_e and C_s are given in Ref. (1) and will not be repeated herein. The BIA procedure considers the possibility of weak axis wall bending due to either misalignment of the gravity loading, joint fixity, and direct application of wind load on the exposed wall surface.

National Concrete Masonry Association

The basic equation for allowable gravity load on a wall is:

$$P = R f_m A \tag{2}$$

in which the stress reduction factor R depends only on the wall slenderness ratio. The NCMA design procedure considers weak axis bending only as a result of externally applied wind or seismic loads. In this case it can be shown[7] that the stress reduction factor R depends not only on wall slenderness, but also the equivalent eccentricity of the gravity loading induced by the weak axis bending moment. However, the NCMA procedure does not distinguish between single and double curvature.

Stress Reduction Design[5,6]

This method which will be referred to as Stress Reduction Design (SRD), considers both slenderness and curvature effects. Three types of bending are considered:

a. walls in double curvature with equal but opposite wall eccentricities
b. walls in single curvature with zero eccentricity at one end
c. walls in single curvature with equal end eccentricities.

The general design procedure is as follows:

1. Determine the type of wall bending.
2. Determine the end eccentricity of the wall axial load.
3. Compute the stress reductions from figure 1 or 2.

The type of wall bending is determined by the wall loading.

The eccentricity factor, ε, which is equal to e/t, is computed from the following equations:

For double curvature

$$\varepsilon = \frac{\dfrac{4.35\psi' + K + 9.25\gamma}{9.25\psi'} - \sqrt{\left(\dfrac{4.35\psi' + K + 9.25\gamma}{9.25\psi'}\right)^2 - \dfrac{1.881\gamma}{\psi'}}}{2} \quad (3)$$

For single curvature

$$\varepsilon = \frac{\dfrac{3.8\psi' + K + 9\gamma}{9\psi'} - \sqrt{\left(\dfrac{3.8\psi' + K + 9\gamma}{9\psi'}\right)^2 - \dfrac{1.689\gamma}{\psi'}}}{2} \quad (4)$$

where

$K = \dfrac{2E_sI_sH}{E_wI_wL}$

$\gamma = \dfrac{M}{P_1 t}$

$\psi' = 1 + \dfrac{P_u}{P_1}$

M = $\rho wL^2/12$ or slab negative moment capacity at wall (whichever is smaller)

t = wall thickness

H = wall height

L = floor span

P_u = load in wall above the slab-wall joint

P_1 = load in wall below the slab-wall joint

E_sI_s, E_wI_w = properties of the slab or wall

w = uniform slab load

ρ = percent of joint rigidity (dependent) on precompression stress at joint

COMPARISON OF STRESS REDUCTION FACTORS

In order to compare the various design procedures, appropriate stress reduction factors were computed by varying the slenderness ratio, h/t, and the design eccentricity, e, for each method. The results of these computations are given in Table 1 for three, h/t, values. The three types of wall curvature listed in the table as a, b, c, correspond to the bending shapes listed above.

PRACTICAL COMPARISONS

In order to further compare the design procedures, sample calculations were performed for an exterior loadbearing wall in a 10-story building. A nominal wall thickness of 8″ and a story height of 9′-4″ were selected to produce a slenderness ratio of approximately 15. The assumed loads were as follows:

Roof live load = 30 psf
Roof dead load = 80 psf
Floor live load = 40 psf
Floor dead load = 100 psf

The 8″ thick concrete floor spans 24′-0″. Two loading cases were considered: (1) dead load plus reduced live load; (2) dead load plus live load plus perpendicular wind. For the calculations following the BIA procedure, two joint fixity conditions were assumed. The wall floor joint was first assumed to be pinned and the gravity load eccentricity computed assuming a triangular bearing pressure distribution. The second condition assumed that the joint was fixed for live load and pinned for dead load. Thus in this latter case, a live load moment of $wL^2/24$ was used in the walls.

The stress reduction factors were computed for the method given in Ref. (6) using the following values of ρ in Eq. (3):

Precompression Stress	Percent Rigidity ρ
10–25 psi	.5
25–100 psi	.8
100–200 psi	.9
> 200 psi	1.0

Also, stress reduction factors were computed assuming that the slab negative moment capacity was limited to a moment sufficient to cause a slab tensile stress of $3\sqrt{4000}$ psi. In both cases, the moment at the roof-wall joint, which is always assumed to be pinned, was taken as equal to the roof-slab gravity reaction times t/6.

The stress reduction factors for each method are presented in Table 2.

ANALYSIS OF RESULTS

Based on the results presented in Table 1, the following observations are presented:

1. Differences between the NCMA and BIA procedures increase with increasing e/t values.
2. In general the BIA values are more conservative than the NCMA values.
3. Large differences exist between the stress reduction factors predicted by the NCMA and BIA procedures, particularly for wall curvatures other than double curvature.
4. The BIA and SRD values tend to follow the same general trends and are in reasonable agreement although the BIA values are generally more conservative.

Also, based on information presented in Table 2, the following additional observations are presented:

1. With the exception of floors 8 and 9, differences between the three procedures tend to reduce with increasing wall axial load.
2. In general, the BIA procedure gives the most conservative values.

OBSERVATIONS

Although the stress reduction factor comparisons presented herein are of limited scope, a few general observations are presented in an attempt to stimulate further consideration of this important area of future research.

NCMA Procedure

This procedure is relatively easy to use in design but has the following deficiencies:

a. does not consider wall curvature configuration
b. does not consider wall moments induced by either floor bending, or restraint to slab rotation afforded at the wall-floor joint.

BIA Procedure

This procedure is practical for use in design, and does consider important parameters such as eccentricity, wall slenderness, and type of wall bending.

However, eccentricity values recommended for design are somewhat arbitrary and may not reflect conditions in an actual structure.

SRD Method

This procedure is also practical for use in design and in addition to including all of the parameters included by the BIA procedure, provides some basis for more accurately estimating wall moments.

Based on this work, it appears obvious that a comprehensive study is required before final judgement is passed on any of the methods considered. In particular, the accurate determination of wall moments for use in design is of paramount importance. Nevertheless, it may be stated that at present the NCMA and BIA procedures can lead to significantly different stress reduction factors, and that the stress reduction design method may be a feasible alternative design approach for composite construction.

REFERENCES

1. Brick Institute of America, "Recommended Practice for Engineered Brick Masonry," November 1969.
2. National Concrete Masonry Association, "Specification for the Design and Construction of Load-Bearing Concrete Masonry," February 1975.
3. United States Department of the Army Technical Manual TM 5-809-3, "Masonry Structural Design for Buildings," December 1973.
4. National Concrete Masonry Association, "Nonreinforced Concrete Masonry Design Tables," 1971.
5. Colville, James, "Simplified Design of Load Bearing Brick Masonry Walls," Proceedings, British Ceramics Society Sixth International Symp. on Loadbearing Brickwork, December 1977.
6. Colville, James, "Analysis and Design of Brick Masonry Walls," University of Maryland, June 1977.
7. Colville, James, "Report on Computer Program for the Rational Analysis of Masonry Structures," Masonry Institute of Maryland, Inc., January 1976.

TABLE 1—Variation of Stress Reduction Factors with Eccentricity and Slenderness Ratio

(a)h/t = 0

e/t		NCMA All	BIA			SRD		
			(a)	(b)	(c)	(a)	(b)	(c)
	0	0.98	1.00	0.93	0.80	1.00	1.00	1.00
$\frac{1}{24}$	.042	0.97	1.00	0.93	0.80	1.00	1.00	1.00
$\frac{1}{12}$	.083	0.95	0.90	0.82	0.70	1.00	1.00	1.00
$\frac{1}{6}$	.167	0.92	0.77	0.66	0.52	1.00	0.90	0.71
$\frac{1}{4}$	.250	0.89	0.69	0.55	0.39	0.80	0.67	0.50
$\frac{1}{3}$	.333	0.87	0.61	0.44	0.26	0.53	0.45	0.23

(b) h/t = 15

e/t		NCMA All	BIA (a)	BIA (b)	BIA (c)	SRD (a)	SRD (b)	SRD (c)
	0	0.95	0.90	0.80	0.60	1.00	1.00	1.00
$\frac{1}{24}$	.042	0.92	0.90	0.80	0.60	1.00	1.00	1.00
$\frac{1}{12}$	.083	0.90	0.81	0.70	0.52	1.00	1.00	0.88
$\frac{1}{6}$	.167	0.86	0.69	0.57	0.39	0.99	0.66	0.61
$\frac{1}{4}$	.250	0.83	0.62	0.47	0.29	0.75	0.57	0.30
$\frac{1}{3}$	.333	0.79	0.55	0.38	0.19	0.50	0.37	0.11

(c) h/t = 20

e/t		NCMA All	BIA (a)	BIA (b)	BIA (c)	SRD (a)	SRD (b)	SRD (c)
	0	0.88	0.80	0.67	0.40	1.00	0.98	0.85
$\frac{1}{24}$	.042	0.85	0.80	0.67	0.40	1.00	0.98	0.85
$\frac{1}{12}$	.083	0.83	0.72	0.59	0.35	1.00	0.86	0.73
$\frac{1}{6}$	.107	0.78	0.62	0.48	0.26	0.90	0.68	0.40
$\frac{1}{4}$	.250	0.74	0.55	0.40	0.20	0.68	0.45	0.16
$\frac{1}{3}$	.333	0.70	0.49	0.32	0.13	0.45	0.23	0.06

TABLE 2—Comparison of Stress Reduction Factors in an Exterior Wall in a 10-Story Building

Floor No.	No Wind					With Wind				
		BIA		SRD			BIA		SRD	
	NCMA	(1)	(2)	(1)	(2)	NCMA	(1)	(2)	(1)	(2)
10	.95	.63	—	1.0	1.0	.48	.46	—	1.0	1.0
9	.95	.89	—	.58	.37	.75	.59	—	.53	.33
8	.95	.89	.56	.85	.38	.82	.69	.31	.82	.37
7	.95	.90	.70	1.0	.52	.85	.75	.47	1.0	.50
6	.95	.90	.69	1.0	.65	.87	.75	.55	1.0	.63
5	.95	.90	.71	1.0	.70	.88	.75	.60	1.0	.70
4	.95	.90	.74	1.0	.78	.89	.75	.64	1.0	.78
3	.95	.90	.77	1.0	.86	.90	.75	.69	1.0	.84
2	.95	.90	.80	1.0	.93	.90	.75	.73	1.0	.91
1	.95	.90	.81	1.0	.93	.91	.75	.77	1.0	.91

Note: BIA Case (1)—Pinned; Case (2)—Fixed for live load.
SRD Case (1)—Wall moment limited by slab capacity; Case (2)—Wall moment not limited by slab capacity.

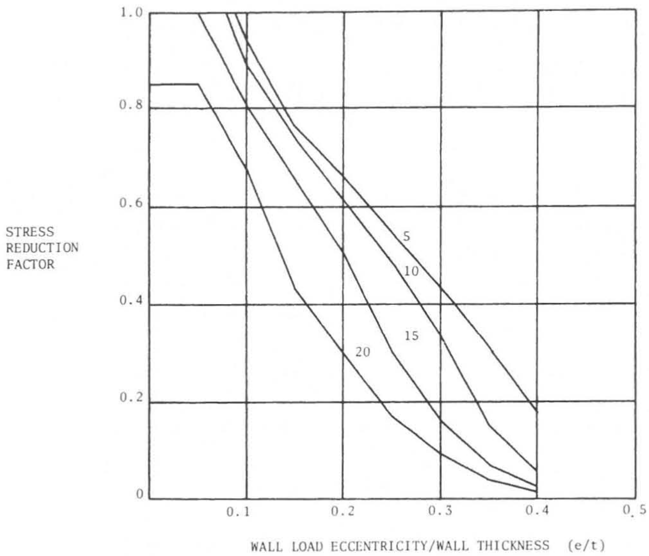

Figure 1. Plot of e/t and Stress Reduction Factor for Various Slenderness Ratios (H/t) (Single Curvature)

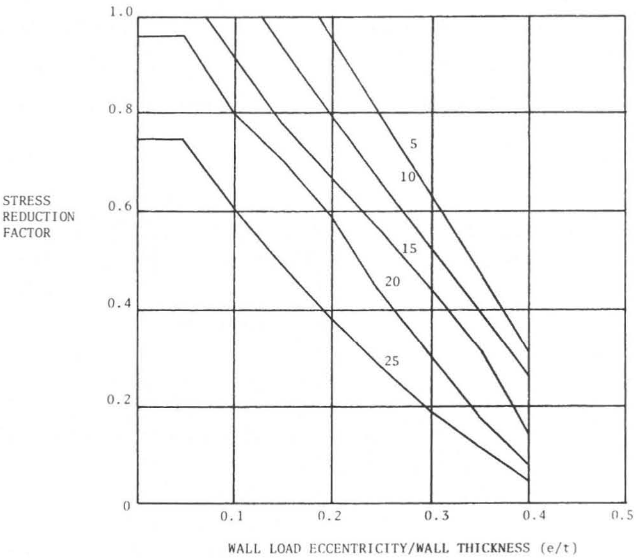

Figure 2. Plot of e/t and Stress Reduction Factors for Various Slenderness Ratios (H/t) (Double Curvature)