벽체와 기둥의 강성비와 형상비에 따른 지하외벽의 최대부재력 산정

김영찬† · 김동건*
부경대학교 건축학부 · *뉴테크구조
(2002. 4. 10. 접수 / 2002. 8. 8. 채택)

Estimation of Maximum Member Force in Basement Wall according to Stiffness and Aspect Ratios of Wall and Column

Young-Chan Kim† · Dong-Gun Kim*
Department of Architecture, Pukyoung National University · *Newtech Structure
(Received April 10, 2002 / Accepted August 8, 2002)

Abstract : A numerical study using linear finite element analysis is performed to investigate the behavior of basement wall subject to soil and water pressure. Currently, structural design of basement wall is based on the assumption for boundary condition of plate, which may lead to the erroneous results. In this study, parametric studies are performed to investigate the variation of moment and shear force according to column-to-wall stiffness ratios and aspect ratios. Scaled factors applicable to the design of basement wall are proposed with the illustration of design examples.

요 약 : 토압 및 수압을 받는 지하외벽의 거동을 파악하기 위하여 유한요소를 이용한 수치적 연구를 수행하였다. 지하외벽의 구조설계는 판의 경계조건을 가정하여 이루어지는데 이 가정으로 인하여 잘못된 결과를 초래할 수 있다. 본 연구에서는 벽체와 기둥의 강성비와 형상비에 따른 모멘트와 전단력의 변화에 대한 변수해석을 수행하였다. 지하외벽의 설계에 적용할 수 있는 수정계수와 설계에의 적용예를 제시하였다.
Key words : wall design, plate analysis, column/wall, stiffness

1. Introduction

Currently, the structural design of basement wall is based on one-way design of slab simply supported at the floor level by floor slab or on two-way slab design with wall-column and wall-girder. In practice, it is common to conduct one-way or two-way slab analysis according to the aspect ratio.[1)] This may leads to erroneous results, causing over- or under-estimation of member forces.

In the previous study,[2)] it is pointed out that the stiffness ratio of wall-column and wall should be accounted in the design. However, the authors mentioned that their study has limit in application to practice as the following assumption are made : (1) simply supported boundary condition at the floor level, (2) water pressure was not included, (3) only center-span wall among 3 span was investigated.

To extend the applicability of this study the two boundary conditions at the floor level were made: (A) a roller with rotational restraint, (B) a simple support, while fixed condition is assumed at the bottom of wall. In addition to the center-span wall, the end-span wall is investigated. Also, to accommodate general loading condition lateral loading due to surcharge and soil or water pressure is separately considered. Using analysis result scaled factor approach applicable to estimation of maximum member forces in basement wall under lateral loading are proposed with the illustration of design examples.

†To whom correspondence should be addressed.
yckim@pknu.ac.kr

2. Modeling of Basement Wall

Two boundary conditions are considered at the top of basement exterior wall(Fig. 1) : (A) a roller with rotational constraint, (B) a simple support, while, at the bottom fixed condition is assumed. In addition to soil surcharge, soil and hydraulic pressure are accounted for.

To investigate the influence of column-to-wall stiffness ratio(R_S) and aspect ratio(Ra) on the force distribution walls with the following dimension are analyzed

1) Wall height(H) is 5m and seven wall lengths(L) are selected : 2.5, 3.75, 5, 6.25, 7.5, 8.75, 10m. The corresponding aspect ratio(H/L) ranges from 0.5 to 2.0. Each model is analyzed for RS of 0.5, 1.0, 2.0 and 5.0.

2)Wall thickness and column width are 300mm and 500mm, respectively. Column depth is determined according to R_S.

Linear static analysis is done using 4-node plate element and 2-node beam element of the finite element program MIDAS.[3] The FE mesh and boundary condition of a wall is shown in Fig. 2.

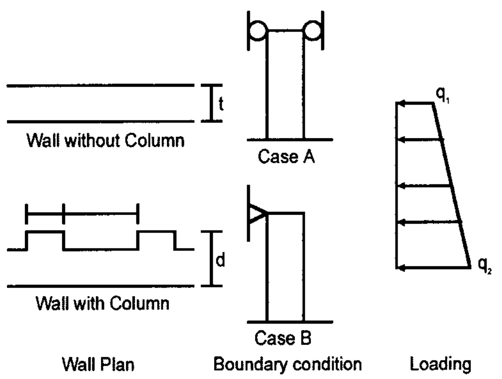

Fig. 1. Model configuration and loading

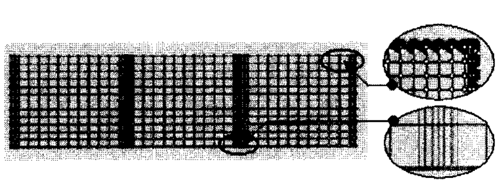

Fig. 2. FE mesh and boundary condition of a wall

3. Comparison of Analysis Result

In Figs. 3~7, the results from two-way analysis and FE analysis are compared for aspect ratio of 1.0, q_1=0.85t/m^2, and q_2=8.5t/m^2. In these figures, 4F, 3F, 1S stand for four-side fixed, three-side fixed, one-side simple support boundary condition, respectively. Five maximum member forces are compared: positive, negative moments in vertical and horizontal direction, and shear in vertical direction. As shown in Figs. 3 and 4, two-way analysis underpredicted moments in vertical direction by 4~87%, while over- predicting those in horizontal direction by 676% in Fig. 6. For shear force the difference between two analysis is less than 3%.

The difference between the center-span and the end-span decreased as R_s increased. As regarding R_s, if column stiffness is increased, member forces in vertical direction are decreased and those in horizontal direction are increased because member force is transferred

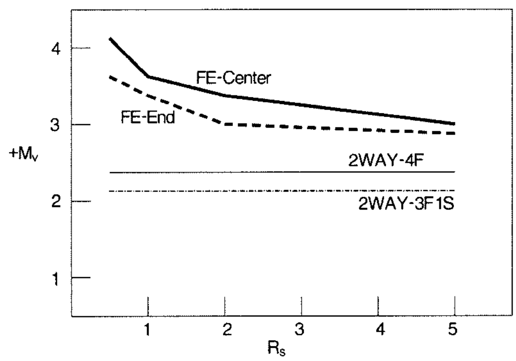

Fig. 3. Maximum positive moment in vertical direction

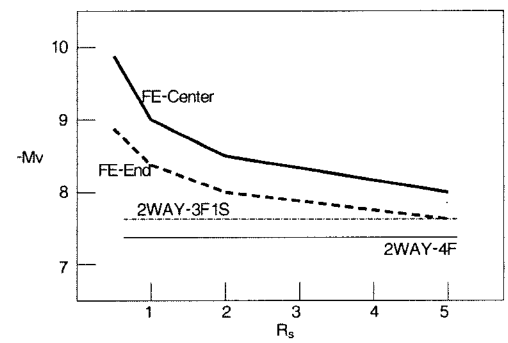

Fig. 4. Maximum negative moment in vertical direction

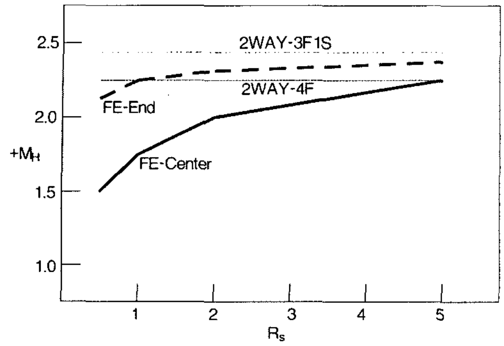

Fig. 5. Maximum positive moment in horizontal direction

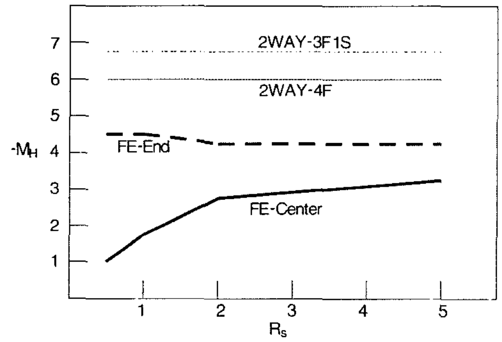

Fig. 6. Maximum negative moment in horizontal direction

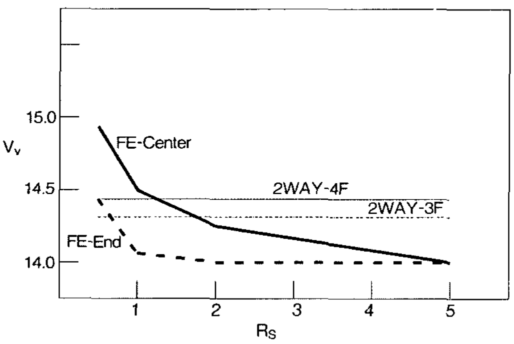

Fig. 7. Maximum shear in vertical direction

to column. When column stiffness is decreased, member forces in vertical direction are increased and those in horizontal direction are decreased because force is transferred to slab and basement.

For the wall without column under the same condition, the forces are compared in Table 1. It is noticeable that two-way analysis is similar to FE analysis with case A boundary condition. If the boundary condition at the top of the wall is close to simple support, the force from two-way analysis should be increased by 15% for shear force which is essential in determining wall thickness.

Table 1. Comparison of forces for wall without column system

R_a	Force	Two-way analysis	This study	
			Case A	Case B
1	$+M_v$(t · m)	2.35	2.68	2.67
	$-M_v$(t · m)	7.29	7.38	7.65
	$+M_H$(t · m)	2.25	2.25	2.86
	$-M_H$(t · m)	6.07	6.22	6.69
	V_V(t)	14.46	14.07	14.25
2	$+M_v$(t · m)	4.93	5.09	6.4
	$-M_v$(t · m)	11.17	11.17	14.22
	$+M_H$(t · m)	1.51	1.32	2.38
	$-M_H$(t · m)	6.57	6.8	8.7
	V_V(t)	15.59	15.78	17.96

Combining the effect of uniform and linearly varying loading separately, forces in a plate can be calculated by eq (1).

$$M = \alpha \cdot q_1 \cdot L_x^2 + \beta \cdot (q_2 - q_1) \cdot L_x^2$$
$$V = \alpha \cdot q_1 \cdot L_x + \beta \cdot (q_2 - q_1) \cdot L_x \quad (1)$$

where, α and β are scaled factors for uniform(q_1) and linearly varying(q_2) loading, respectively, and L_x=min(H, L). In this study, scaled factors are obtained as follows : (1) perform FE analysis and get member forces, (2) plug these into eq(1), (3) calculate scaled factors. Scaled factors is listed in the appendix.

4. Illustration of Design Example

4.1. Design Example 1-a wall with column

Design condition: Ra=1.7(H=6m, L=10.2m), Rs=1.5, t=0.3m, b=0.5m, d=0.938m, q_1=0.68, q_2=10.95t/m^2. Using Table A1, scaled factor is interpolated for given Ra and Rs. The factors for the positive moment in vertical direction in the center-span wall are α=0.040, β=0.0206. Then, plugging these into eq(1), we have

$$+M_V = 0.040 \times 0.68 \times 6^2 + 0.0206 \times (10.95 - 0.68) \times 6^2 = 8.60 \text{tf} \cdot \text{m}$$

Similarly, the rest of forces can be calculated and compared with two-way analysis in Table 2.

Table 2. *Comparison of maximum forces*

Forces	Two-way analysis	This study			
		Center-span		End-span	
		Case A	Case B	Case A	Case B
$+M_v$(t · m)	8.37	8.60	10.95	8.56	10.56
$-M_v$(t · m)	19.54	19.79	24.88	19.66	24.28
$+M_H$(t · m)	2.45	2.89	3.87	3.43	4.51
$-M_H$(t · m)	12.00	5.68	6.98	8.49	11.28
V_V(t · m)	23.68	23.84	26.74	23.93	26.68

4.2. Design Example 2-a wall without column

Design condition : R_a=3.5(H=6m, L=21m), t=0.3m, q_1=0.68, q_2=7.14t/m^2. From Table A11 scaled factors for shear in vertical direction are α=0.507, β=0.352. Then, plugging these into eq(1), we have

$$V_V = 0.507\times0.68\times6+0.352\times(10.95-0.68)\times6 = 15.7\text{tf}$$

The forces are compared with two-way analysis in Table 3. It is interesting that this wall is classified as a one-way slab as Ra is larger than 2, but the result depends on the boundary condition rather than R_a.

Table 3. Comparison of maximum forces

	One-way analysis	Two-way analysis	This study	
			Case A	Case B
$+M_v$(t · m)	8.65	6.11	6.04	8.63
$-M_v$(t · m)	18.56	13.47	13.60	18.38
$+M_H$(t · m)	-	1.80	2.19	2.76
$-M_H$(t · m)	-	7.92	8.16	10.46
V_V(t)	18.05	15.67	15.7	18.07

5. Conclusions

From the numerical simulation of force distribution in a basement wall system the findout of this study is as follows:

- When R_s is less than 2, moments in horizontal direction in the center-span wall and in the end-span wall are quite different.
- As the negative moment in horizontal direction is sensitive to R_s, the moment predicted with scaled factor showed relatively high error.
- For the prediction of shear force 2-way and FE analysis showed similar result, implying that shear force is less sensitive to R_s.
- Scaled factor proposed in this study can be utilized to approximately estimate member force without resorting to FE analysis

References

1) R. Bares, Tables for the Analysis of Plates, Slabs and Diaphragms based on the Elastic Theory, MacDonald and Evans, Ltd, 1979.
2) B.E. Yoo S.K. Kang and Y.T. Cho, "A Study on the Behavior of Basement Wall," Review of Architecture and Building Science. Vol. 45, No. 8, pp. 35-40, 2000.
3) Posdata, MIDAS, User's manual, 2000.

Appendix

List of Scaled Factors

1. Center-Span in Wall with column($\times10^{-4}$)

Table A1. Positive moment in vertical direction

R_s \ R_a	α			β		
	1.0	1.5	2.0	1.0	1.5	2.0
0.5	343	395	418	178	203	213
1.0	310	385	417	163	199	213
2.0	279	378	416	150	196	212
5.0	251	372	415	137	194	212

Table A2. Negative moment in vertical direction

R_s \ R_a	α			β		
	1.0	1.5	2.0	1.0	1.5	2.0
0.5	705	792	826	430	476	493
1.0	653	781	826	403	470	493
2.0	606	771	825	379	465	493
5.0	562	763	825	356	461	492

Table A3. Positive moment in horizontal direction

R_s \ R_a	α			β		
	1.0	1.5	2.0	1.0	1.5	2.0
0.5	127	119	117	65	60	60
1.0	150	135	129	76	68	66
2.0	170	148	138	86	74	71
5.0	189	159	146	96	80	74

Table A4. Negative moment in horizontal direction

R_s \ R_a	α 1.0	α 1.5	α 2.0	β 1.0	β 1.5	β 2.0
0.5	85	151	183	47	78	94
1.0	155	225	253	81	115	129
2.0	219	285	306	113	145	155
5.0	279	337	349	143	171	177

Table A5. Shear in vertical direction

R_s \ R_a	α 1.0	α 1.5	α 2.0	β 1.0	β 1.5	β 2.0
0.5	4716	5030	5063	3342	3502	3515
1.0	4596	5046	5085	3282	3510	3526
2.0	4487	5058	5102	3227	3517	3535
5.0	4385	5070	5115	3177	3523	3542

2. End-Span in Wall With Column($\times 10^{-4}$)

Table A6. Positive moment in vertical direction

R_s \ R_a	α 1.0	α 1.5	α 2.0	β 1.0	β 1.5	β 2.0
0.5	297	383	416	157	198	213
1.0	271	375	416	146	195	212
2.0	249	371	415	136	194	212
5.0	232	368	415	129	192	212

Table A7. Negative moment in vertical direction

R_s \ R_a	α 1.0	α 1.5	α 2.0	β 1.0	β 1.5	β 2.0
0.5	630	777	826	391	468	493
1.0	592	767	825	371	463	492
2.0	557	762	825	353	461	492
5.0	533	758	825	341	459	492

Table A8. Positive moment in horizontal direction

R_s \ R_a	α 1.0	α 1.5	α 2.0	β 1.0	β 1.5	β 2.0
0.5	0.0179	0.0164	0.0156	0.009	0.0083	0.0079
1.0	0.0188	0.0166	0.0156	0.0095	0.0084	0.0079
2.0	0.0196	0.0168	0.0156	0.0099	0.0085	0.008
5.0	0.0204	0.0171	0.0156	0.0103	0.0086	0.008

Table A9. Negative moment in horizontal direction

R_s \ R_a	α 1.0	α 1.5	α 2.0	β 1.0	β 1.5	β 2.0
0.5	0.0382	0.04	0.04	0.0195	0.0203	0.0203
1.0	0.0375	0.04	0.04	0.0191	0.0203	0.0203
2.0	0.0368	0.04	0.04	0.0188	0.0203	0.0203
5.0	0.0361	0.04	0.04	0.0185	0.0203	0.0203

Table A10. Shear in vertical direction

R_s \ R_a	α 1.0	α 1.5	α 2.0	β 1.0	β 1.5	β 2.0
0.5	4559	5059	5098	3260	3517	3533
1.0	4441	5066	5109	3200	3521	3538
2.0	4368	5072	5117	3168	3525	3543
5.0	4321	5078	5124	3145	3528	3546

3. Wall Without Column($\times 10^{-4}$)

Table A11. Scaled factors

R^s \ R_a	α 1	α 2	α 3	α 5	β 1	β 2	β 3	β 5
$+M_V$	211	414	425	424	118	211	215	215
$-M_V$	511	825	833	831	331	493	497	496
$+M_H$	212	145	148	154	106	73	75	78
$-M_H$	514	569	565	564	268	293	293	291
V_V	4415	5143	5071	5065	3204	3557	3521	3517