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Earthquake analysis on five-story reinforced masonry building – Analyses on service and yield phase response

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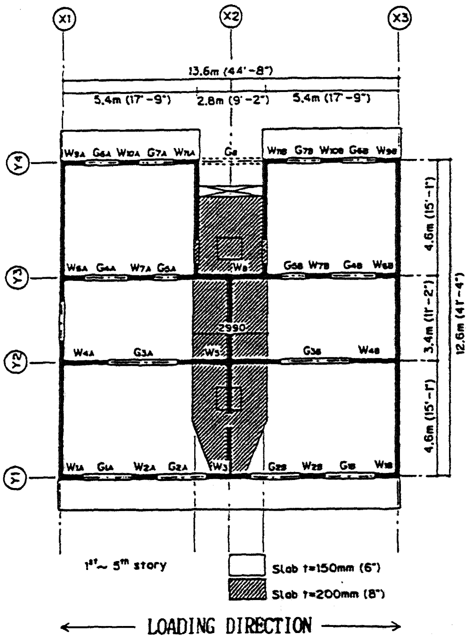
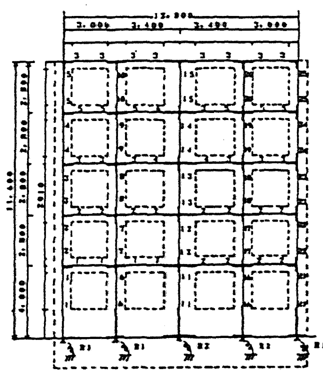
ABSTRACT: Non-linear analyses were conducted to simulate the static test of a Full Scale Five-Story Reinforced Masonry Building (test building). This test was conducted under the U.S.-JAPAN Coordinated Earthquake Research Program on Masonry Buildings. In the elastic region of test building, the effective length of transverse wall and reinforced slab, and also the foundation condition are discussed. By using non-linear frame model analysis, the maximum shear carrying capacity was calculated in several cases of effective length of transverse members. The analytical results can simulate test result that these buildings have a enough strength capacity because of three dimensional effects of transverse members of its box type structure.

1. INTRODUCTION

Seismic test of the five story full scale reinforced masonry building [Ref.1] was conducted at Building Research Institute from October 1987 to January 1988 under the U.S.-JAPAN Coordinated Earthquake Research Program on Masonry Research. Through this seismic test, overall behavior of the test building in elastic stage and in inelastic stage was obtained. In elastic stage, the test building is so rigid that the characteristics in elastic range are very sensitive to the condition of foundation, and in inelastic stage, the effective width of transverse member, such as transverse wall and reinforced concrete slab, contributes to lateral force carrying capacity of the test building. Test results showed that the base shear carrying capacity is 1.0 G, on the other hand, the design base shear coefficient was 0.5 G.



a) Plan Geometry and Reference Notation



b) Y1 FRAME

Fig. 1 Test Building and Frame Model

This paper discusses on the reason why there is much difference between design and test results as well as on the elastic behavior by mean of frame model analysis. It is also possible to develop the simplified method in order to define the shear force distribution of each member at the ultimate limit stage based on this frame analysis results [Ref. 2].

2. METHOD

2.1 Model

The test building shown in Fig.1 is idealized to four frames. Beam model that represents each member, walls and beams, has rigid zones at both ends. In order to represent the nonlinearity of members, one-component model consisting of flexural spring at the both edges of member and a shear spring at the center of member is considered.

Characteristics of flexural spring and shear spring for each member are illustrated in Figs. 2 and 3, respectively. For flexural spring $_y$ is assumed to be 1/800 for 1m long wall and beam, 1/1500 for 2m long wall and 1/3000 for 4m long wall. Maximum flexural strength is calculated by the equation in Ref. 2. Those values are listed in Table 1. For shear spring nominal shear cracking stress assumed to be 15kg/cm^2. Therefor $_c$ becomes almost 1/4000 rad. The tangent stiffness after shear-cracking is assumed to be 0.03 times as the elastic stiffness.

The value of Young's Modulus (E) is defined from the prism compressive test results. In this analyses mean values of E and F_m are used (E=196t/cm^2, F_m=196kg/cm^2 and G=86kg/cm^2).

The joint part of wall and beam are treated as rigid zone in this analysis. In elastic analysis this rigid zone is assumed to be illustrated as in Fig.4 and in inelastic analysis full part of beam-wall joint is assumed to be rigid zone.

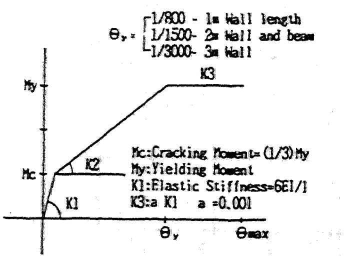


Fig. 2 Flexural Spring

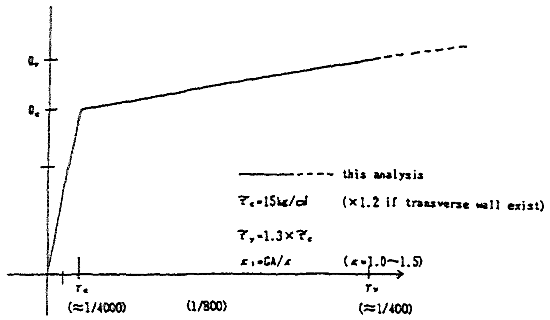


Fig. 3 Shear Spring

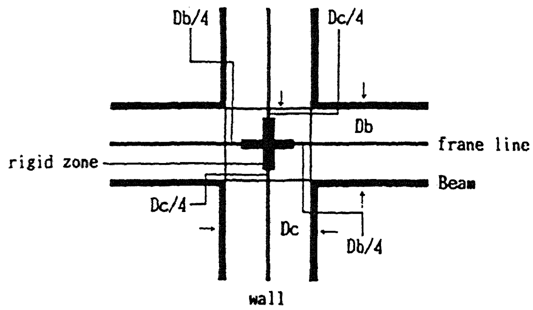


Fig. 4 Assumption of rigid zone

Table 1 Flexural and Shear Characteristics

a) Beam [t*cm]

Member	M_{y1}	M_{y2}	Member	M_{y1}	M_{y2}
$_{R,4}G_{1,2}$	677	5178	$_{R,5}G_4$	482	8448
$_5G_{1,2}$	677	5000	$_{4,3}G_4$	677	8667
$_5G_{2A\#}$	677	5460	$_2G_{4A}$	677	9150
$_5G_{2B\#}$	677	5178	$_2G_{4B}$	677	8447
$_4G_{2A\#}$	1159	5678	$_2G_4$	677	8667
$_4G_{2B\#}$	1159	5678	G_5	677	8447
$_3G_{1,2}$	889	5530	$_{R,5}G_{6,7}$	677	4959
$_2G_{1A,2A}$	889	5660	$_4G_{6,7}$	677	5178
$_2G_{1B,2B}$	889	5530	$_{3,2}G_{6,7}$	889	5660
$_RG_3$	889	9150	$_{3,2}G_{6A*}$	1371	5660
$_5G_3$	1228	9589	$_{3,2}G_{6B*}$	1371	5660
$_4G_3$	1335	9940	#:inner side		
$_{3,2}G_3$	1556	9940	*:outer side		

M_{y1}:Ultimate moment at lower side in tention
M_{y2}:Ultimate moment at upper side in tention
Including re-bars in slab whose effective width is the half of the span length in the transverse direction.
Rebars of slab in Y1 frame : 16D10 and 4D13
Rebars of slab in Y2 frame : 28D10 and 8D13
Rebars of slab in Y1 frame : 28D10 and 8D13
Rebars of slab in Y1 frame : 16D10 and 4D13
I=15.6*10^{5}cm^4
θ_y=1/800 rad.
Area for shear stiffness(A) : 1501 cm^2
Shear cracking strength :
27 tonf = 15 kg/cm^2*A*1.2
1.2 : Effect of RC slab
Foundation beam :
I=721.67*10^5, A=28775 cm^2

2.2 Foundation

Test specimen is fixed to testing floor (depth is 2.00m). Test specimen is too rigid to consider the foundation as fix. In this analysis foundation beam ($I=121.67 \times 10^5 cm^4$) and testing floor ($I=600 \times 10^5 cm^4$) and the rotational stiffness due to P_C bars are considered. Table 2 lists the properties of Rocking springs.

3. RESULTS

3.1 Elastic stage

Four case studies are performed. The parameter among Model 1 though Model 3 is an effective width of transverse member to inertia moment. Each member in Model 1 considers the rectangular section as its inertia moment. Model 2 take the full width of transverse member into each member's inertia moment. The inertia moment of Model 3 is defined according to the tentative design guidelines [Ref. 3] This design guideline recommends that amplification factor of inertia moment is not more than 2.0, and this factor of almost all members with transverse member are limited to be 2.0. These three cases, Model 1 through Model 3, are assumed fix end condition. Model 4 considers the effect of the foundation, other conditions besides the foundation are the same as the Model 3.

The vibration period of each model is tabulated in Table 3. Experimental results are also listed in this table. Model 4 is the most match to the test result in these models.

3.2 Inelastic stage

Monotonic loadig analysis is carrid out by using Model 4. Lateral force distribution is the same as the full scale test. The rigid zone is assumed to be the full part of the panel zone surrounded with walls and beams. This is based on the fact that the purpose of this analysis is to predict the lateral load capacity of the test building from the component strength at their critical section, and also that the stiffness degradation of each member is so dominant to the total stiffness of the test building that rigid zone of wall-beam panel is assumed not to affect on the total stiffness of the test structure. Maximum moment capacity of each member is calculated with the full effect of re-bars in transverse members.

Figure 5 shows the each story shear force vs. story drift angle relationships. Good agreements between test results and this analysis are obtained.

Table 1 Flexural and Shear Characteristics
b) wall [t•cm, cm^4, ton, rad., cm^2]

Member		M_y	I, Q_c, A	Member		M_y	I, Q_c, A
W_{1A}	5	3786	I =30.7E5	W_{2A}	5	1653	I =15.4E5
	4	2819	Q_c =33.8		4	1889	Q_c =28.2
	3	2553	θ_y=1/800		3	2015	θ_y=1/800
	2	1421	A =1881		2	2553	A =1881
	1	123			1	2789	
W_3	5	7881	I =90.8E5	W_{2B}	5	1653	I =15.4E5
	4	8643	Q_c =61.2		4	1928	Q_c =28.2
	3	10600	θ_y=1/1500		3	2271	θ_y=1/800
	2	11433	A =3401		2	2089	A =1881
	1	12318			1	3045	
W_{1B}	5	3096	I =30.7E5	W_{4A}	5	10544	I =249.6E5
	4	4492	Q_c =33.8		4	8178	Q_c =68.0
	3	5929	θ_y=1/800		3	8781	θ_y=1/1500
	2	7490	A =1881		2	6784	A =3781
	1	9050			1	4192	
W_5	5	31301	I =1164E5	W_{4B}	5	7559	I =249.6E5
	4	34997	Q_c =143.3		4	11555	Q_c =68.0
	3	43395	θ_y=1/3000		3	16200	θ_y=1/1500
	2	47091	A =7961		2	20510	A =3781
	1	50787			1	21058	
W_{6A}	5	4709	I =30.7E5	W_{7A}	5	2042	I =15.4E5
	4	2897	Q_c =33.8		4	2719	Q_c =28.2
	3	2002	θ_y=1/800		3	3497	θ_y=1/800
	2	100	A =1881		2	4576	A =1881
	1	100			1	5473	
W_8	5	29564	I =1164E5	W_{7B}	5	1106	I =15.4E5
	4	39489	Q_c =143.3		4	848	Q_c =28.2
	3	48778	θ_y=1/3000		3	488	θ_y=1/800
	2	62474	A =7961		2	430	A =1881
	1	68629			1	100	
W_{6B}	5	4003	I =30.7E5	W_{9A}	5	3251	I =30.7E5
	4	6337	Q_c =33.8		4	1756	Q_c =33.8
	3	8773	θ_y=1/800		3	773	θ_y=1/800
	2	11210	A =1881		2	100	A =1881
	1	13592			1	100	
W_{10A}	5	1256	I =7.8E5	W_{11A}	5	2831	I =30.7E5
	4	1669	Q_c =22.5		4	4731	Q_c =33.8
	3	1912	θ_y=1/800		3	6722	θ_y=1/800
	2	2057	A =1501		2	8922	A =1881
	1	2201			1	11123	
W_{10B}	5	1256	I =7.8E5	W_{11B}	5	4369	I =30.7E5
	4	1669	Q_c =22.5		4	2964	Q_c =33.8
	3	1786	θ_y=1/800		3	1492	θ_y=1/800
	2	1809	A =1501		2	100	A =1881
	1	1826			1	100	
W_{9B}	5	3606	I =30.7E5				
	4	5519	Q_c =33.8				
	3	7660	θ_y=1/800				
	2	9867	A =1881				
	1	12221					

Q_c=15(kg/cm^2)•A•{ 1.0 for - shaped wall; 1.2 for T shaped wall or + shaped wall
A : Area for shear stiffness and strength

And this figure also shows that the effect of re-bars in transverse wall on flexural strength and characteristic of flexural and shear spring are evaluated properly in this analysis.

4. CONCLUSION

Total behavior of full scale test is well followed by the frame model analysis consisting of simple beam model.

In elastic analysis rigid zone recommended in design guidelines is reasonable and in ultimate analysis full part of wall-beam joint is adequate to be treated as rigid zone. And the recommendation for effective width of transverse member is reasonable. It is also important for discussing the elastic behavior of such a rigid structure to consider the condition of foundation.

In inelastic stage reinforcing bars in the transverse members are very effective on the ultimate shear carrying capacity.

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Table 2. Properties of Rocking Spring

R1	105 * 10e4 t*cm	for 1m long wall
R2	420 * 10e4 t*cm	for 2m long wall
R3	1700 * 10e4 t*cm	for 4m long wall

$Kt = 2* 32 * Es * D^2/l = 105 * D^2$

$Es = 2100\ t/cm^2$

$32 = 8\ cm^2$

l: length of PC bar: 320cm

D: wall length

Table 3. Natual Period (sec)

MODE	M1	M2	M3	M4	TEST
1st	0.184	0.120	0.159	0.169	0.157
2nd	0.055	0.039	0.048	0.052	0.049
3rd	0.029	0.022	0.026	0.028	0.026
4th	0.020	0.016	0.018	0.019	0.019
5th	0.016	0.013	0.015	0.015	0.013

Fix end condition

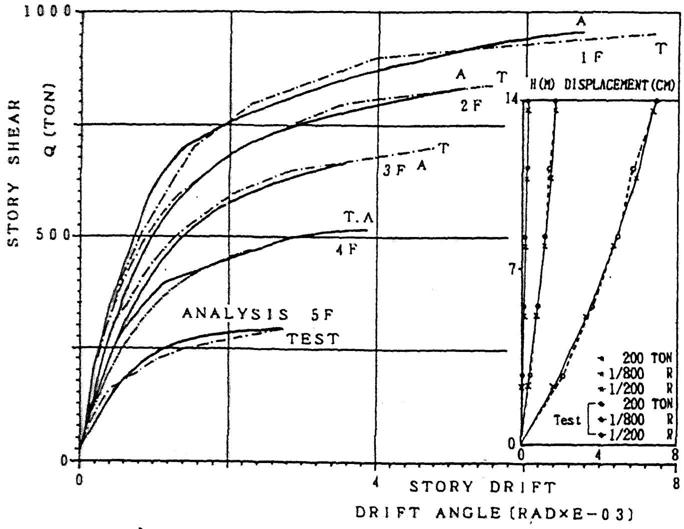

Fig. 5 Each Story Shear vs. Story Drift