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Experimental and analytical study on the seismic resistibility of wooden wall-frame constructions subjected to horizontal forces

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ABSTRACT: This report is the study on the seismic resistibility of wooden wall-frame dwellings by static and dynamic structural analyses and experiments. The auther presents property of beam actions and effectiveness of vertical connections of walls which meets walls at a right angle in a horizontal plane, and proposes the dynamic model for the seismic response analysis. Moreover, pseudo-dynamic tests are attempted for the two storied wall-frame structures. The application of the proposed model to the response analyses of the real 3-storied building are explained.

1 OBJECT

In recent years, 3-storied wooden dwellings are frequently constructed in JAPAN. But there are many problems about the structural theory, methods of design and calculations and seismic resistibility related to fire protection during severe earthquakes. And, the study on dynamic properties and response analysis of 3-storied dwellings have been rarely tried.

The objectives of this paper are to study the static properties (beam actions of frames and effectivness of vertical connections with the pendicular walls), the hysteresis and the response properties to earthquakes.

2 STATIC LOADING TEST

The static loading tests were attempted for several types of full-sized plane wall-frame structures and with walls at a right angle in a horizontal plane (shown in figure 1). Static vertical loads at the top and then cyclic horizontal loads were applied.

The specimen is named as following examples.

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C2-315 or VC2(-315 is omitted)
|||  |     └─V :dynamic experiments
|||  └──────Static vertical load (kg/m).
||└─────────Number of specimens
|└──────────Type name of structures
└───────────⎵:static experiments
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The specification of the structures is most popular in Japan. The section of studs is 38mm ×89mm and the spacing of studs is 455mm. And, the plywoods of 7.5mm thick were used.

The author got the values of 1.2~1.5 for a beam action (Type B, C/A) and 1.3~1.4 for perpendicular walls (D/C) and 2 for total effects (including lintels) as the magnification factor in respect to strength and stiffness of these structures.

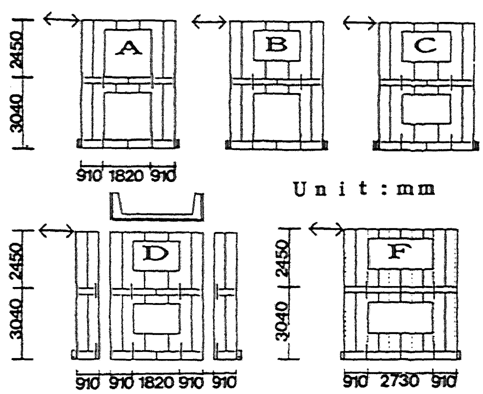


Figure 1. Specimens of static loading tests

3 STATIC NON-LINEAR ANALYSIS

Above-mentioned values are verified by the following non-linear finite element analysis in which structures are modeled as the assemblage of plane stress elements of sheathing plates and header joists, beam elements of studs, lintels and top and bottom rails, and equivalent non-linear stiffnesses of nails, metal joints and crushing displacements of woods (studs to rails and sheathing plates each other).

The first step of analyses is the vertical loading stage and the second is the horizontal one. The step by step iterations was continued until convergence of non-linear elements.

4 HYSTERESIS MODEL

The Degrading Multi-Linear model based on loading experiments and analyses is proposed. The values in figure 4 are decided from above-mentioned experiments and analyses. And the certification of the compatibility of this model was done by computer simulations of static loading tests (see figure 5 and 6).

The figure 6 is hysteresis of experiments and the copmputer simulations of the proposed models. These results show good adaptability of the proposed model except the second story of C type.

The figure 5 is the properties of residual displacements after the peak displacements and residual shear force after the peak shear force of each cyclic loadings. The sign of i is the cycle number, r is residual and max. is the maximum of positive and negative story drifts or story shear forces.

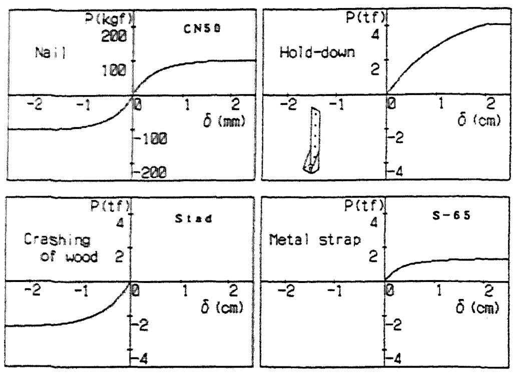


Figure 2. Models of joints for analysis

The example values of the First Story of Type C

	Initi. Value	Degrading Coeff.
K_1	1530	$(1-0.10Y_p/6.5)$
K_2	800	$(1-0.10Y_p/6.5)$
K_3	500	$(1-0.25Y_p/6.5)$
K_4	$K_3/2$	$K_3/2$
Y_0	0.5	1.0
Y_2	1.025	$(1+2.25y_p/6.5)$
Y_3	1.050	$(1+4.00y_p/6.5)$
Y_p	1.025 +0.4	

Unit $K_{1\sim4}$:Kgf/cm, $Y_0 \sim Y_p$:cm

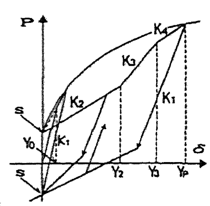


Figure 4. Hysteresis model

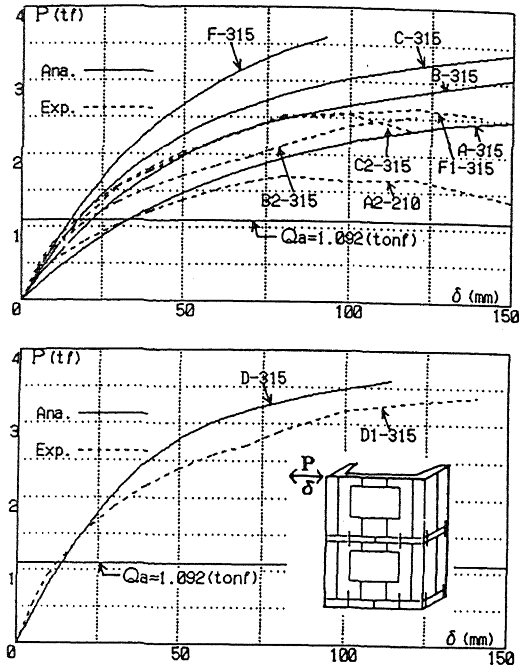


Figure 3. Skeleton curve (test and analysis)

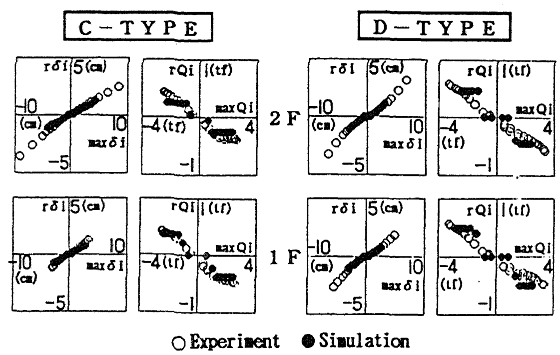


Figure 5. Residual displacements and residual shear force (:Experiments :Simulations)

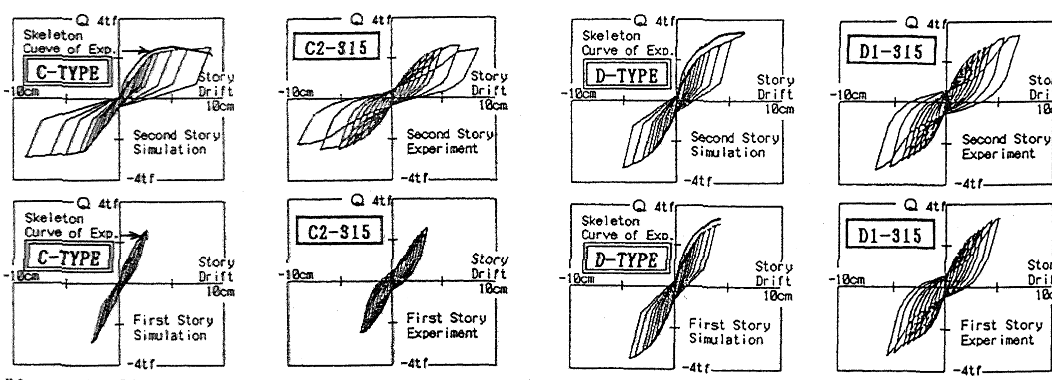


Figure 6. Simulations of hysteresis (compared with the static loading tests)

5 PSEUDO-DYNAMIC TEST

Pseudo-dynamic tests were attempted to certify the hysteresis models for numerical dynamic analyses. The method of time-step integrations is based on the central finite difference method. And instant stiffnesses were calculated from control displacements and loads measured by load cells.

Recorded acceleration data of El Centro, May 18, 1940 (NS component) were adopted for tests of the duration time of 10 seconds. The time interval is 0.01 second. For the investigation of the non-linearity of hysteresis, extremely large accelaration of ground motion was used. And, the damping factor was settted to 0 as well as following numerical analyses.

Two pseudo masses which supposed equal each other, were decided from the supposed fundamental period and initial stiffnesses of preliminary tests.

And two types of 2-storied structures are tested. Results of experiments and analyses were shown in the table 1 and figure 8.

6 NON-LINEAR NUMERICAL RESPONSE ANALYSIS

For the certification of the dynamic model, non-linear numerical response analyses were done under the same condition to experiments. According to these tests and analyses, if initial stiffnesses and skeleton curves of each story are given, the proposed hysteresis model shows good adaptability. But after the maximum response at about 5 seconds, the stiffness of experiments tends to be lower than analyses.

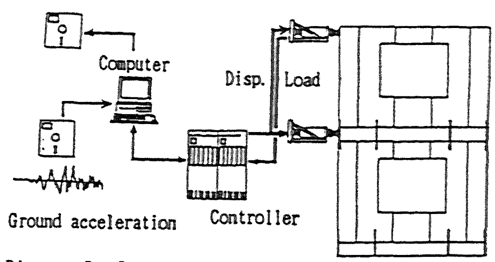


Figure 7. Set-up of pseudo-dynamic tests

Table 1. List of conditions and results of pseudo-dynamic tests and response analyses

Spec. Name	sec T0	tK Kgf/cm 1F	tK Kgf/cm 2F	sK Kgf/cm 1F	sK Kgf/cm 2F	W Kgf 1F=2F	cm/sec² α	δ cm (rad.) [Ana.] 1F	δ cm (rad.) [Ana.] 2F	X cm RF	Q t 1F	Q t 2F
VC-1	.3	1525	1094	1530	1100	1176	714	4.08(1/ 79)[3.30]	2.66(1/ 97)[1.98]	6.74	2.56	1.60
VC-2	.3	1722	1292	1530	1100	1176	714	3.63(1/ 89)[3.30]	2.26(1/114)[1.98]	5.87	2.46	1.72
VC-3	.3	1959	1132	1530	1100	1176	714	3.48(1/ 92)[3.30]	3.20(1/ 80)[1.98]	6.63	2.41	1.75
VC-4	.2	1842	1145	1530	1100	519	1020	1.71(1/188)[1.78]	1.67(1/154)[1.38]	3.38	1.83	1.25
VC-5	.3	1713	1229	1530	1100	1176	1020	7.50(1/ 43)[3.30]	3.95(1/ 65)[1.98]	11.45	3.17	2.34
VD-1	.3	1401	1450	1400	1450	1205	714	3.91(1/ 82)[—]	1.65(1/156)[—]	5.40	2.05	1.38
VD-2	.3	1999	1777	2000	1780	1646	714	5.70(1/ 56)[5.72]	2.89(1/ 89)[1.80]	8.46	3.00	2.09

tK: Initial stiffness of story shear (measured) sK: Initial stiffness of story shear (adopted)
W: Pseudo weight α: Maximum groung acceleration δ: Maximum response of story drift (angle)
X: Maximum response of horizontal disiplacement Q: Maximum shear force T0: fundamental period

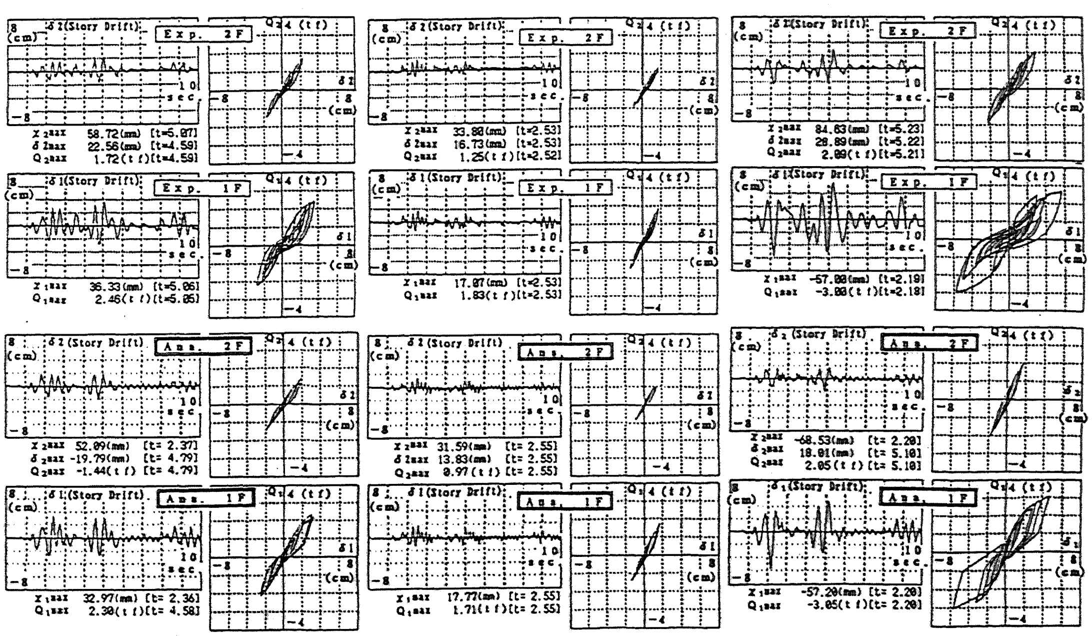


Figure 8. response (VC-2, 714gal) (VC-4, 1020gal) (VD-2, 714gal)

7 APPLICATION TO RESPONSE ANALYSIS OF THE REAL 3-STORIED BUILDING

For the estimation of seismic resistibility related to the fire protection during severe earthquakes, response analyses of the actual 3-storied building were done by this model.

Static loading tests for the study on static properties and for giving damage to this structure equivalent to severe earthquakes, and the fire test was done by Building Research Institute of Ministry of Construction in Japan.

In this auther's investigation, the dynamic model was decided from considering data of the above-mentioned test of the real structure and racking tests done by the same research group. Stiffnesses of story-shear were evaluated as sum of plywood and gypsum-board sheathing. And considering beam actions and effectiveness of perpendicular walls, the 2 times of original stiffness was adopted for analyses.

In the case of this building, the maximum response of displacements is 1/150 radian for ground motions with 300 cm/sec^2 and 1/100 radian for 400 cm/sec^2.

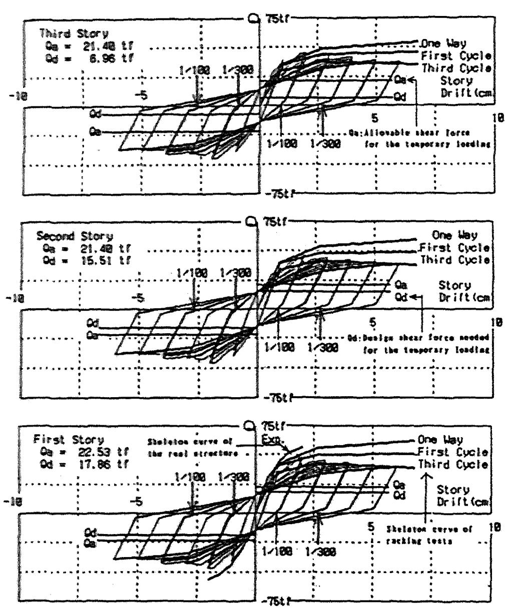
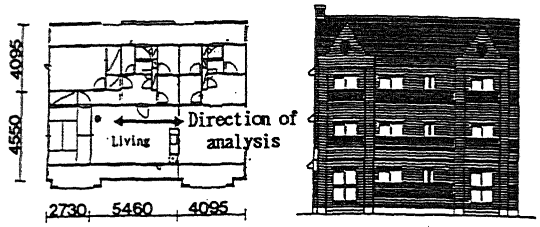


Figure 10. Supposed skeleton curves

8 CONCLUSION

These non-linear finite element analyses show good adaptability to results of loading tests and gives effective data for response analysis as skeleton curves. And the compatibility of the proposed hysteresis was certified by experiments and analyses.

According to this study, the quantitative property of response of ordinary 3-storied buildings was obtained.



Story height:2,700mm(All Floor)
Weight :RF;22.44tf 3F;32.66tf 2F;34.22tf
Figure 9. The building for response analysis

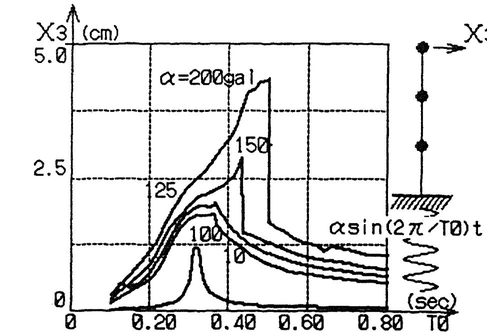


Figure 11. Response spectrum for simple harmonic ground motions (duration time of 8 sec.)

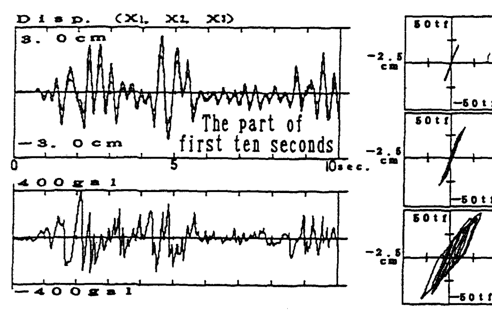


Figure 12. The example of responses for El Centro May 18,1940 NS component

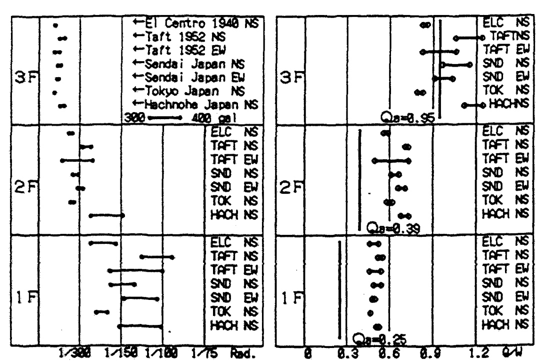


Figure 13. Displacement responses at roofs for recorded seismic waves (300 and 400 gal)