SEISMIC RESPONSE OF UPLIFTING SHEAR WALL - FLEXURAL FRAME INTERACTION SYSTEMS

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SUMMARY

In order to improve the seismic design philosophy for a medium-rise reinforced concrete framed structure consisting of some flexural frames and multistoried structural base rotating walls with uplifting, the fundamental seismic response analysis of an idealized multi-degrees-of-freedom system was examined. The quantitative factors influencing the structural stability were carried out and the peculiar response properties induced by the base rotation and uplifting of the wall under real strong earthquake excitations on periodic changes, displacement amplitudes, and the others were investigated, parametrically.

INTRODUCTION

The usefulness of a structural wall situated in a well-ballanced position in a multistoried framed structure of reinforced concrete has long been recognized empirically. Cyclic inertia lateral loads induced by an earthquake excitation are likely to consentrate excessively on the wall as a large cantilever for the higher lateral stiffness of the wall than that of the other peripheral frames in a framed structure if the basement should be generally assumed to be fixed to the ground in a step of the structural planning. There is, however, a limit to an ability of the transmission of tensile stress between the basement without an anchor and ground surface. Hence, it can be anticipated that high overturning moments originating at the basement of the wall may cause the footing to rotate and critically uplift with separation from ground surface rather than cause great damage in shear or flexure to the shear panel of the wall, especially when it is supported on footing foundations. In a seismic design structures, heavy emphasis is placed on ductility and for the reason the designer must ensure that a shear failure can never occur. Therefore, the base rotating shear wall with uplifting is very effective for seismic design on advantageous respects. But it has been indicated in Refs. 1, 2, and 3 that hysteretic path of the relation between restoring forces and deformations at the top of the wall isolated from the other frames becomes a single curve which is retraced in reverse and has no hysteretic loop-area just corresponding to an ability of a ductile structure to dissipate the energy by postelastic deformations. In recent years, some researchers have reported on the effect of base rotation and uplifting of the wall coupled or noncoupled with the flexural frames (Refs. 4, 5, and 6).

The purposes of this paper are to describe the interactive behaviors between the base rotating shear wall with uplifting and flexural frames

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through the nonlinear static and the seismic response analyses, focusing on structural stabilities, periodic changes, and the others.

MECHANICAL MODELS

For making a structural stiffness matrix of a three-dimensional framed structure, a typical model was disassembled into some plane-frames situated on planes in parallel with an analytical direction. An isolated plane-frame called "a coupled system unit" consisting of a multistoried structural wall as a large cantilever, boundary beams, and some beam-columns. And the other peripheral plane-frames were called "flexural frame units" in this paper. Every isolated frames were finally reassembled into an idealized model by being connected at each floor level with rigid members pin-supported at the both side-ends for floor slabs as the horizontal diaphragms. All structural member models are illustrated in Fig.1 and as follows:

(1) Flexural members: Beams and columns were idealized as elastic line-elements with two nonlinear rotational springs at both restrained ends and plastic deflections were likely to concentrate at critical end-sections. The nonlinear and cyclic properties of the bending stiffness formed as the nodal moment- rotational angle relations were incrementally estimated by using the well-known rule of the Degrading- Trilinear model respectively prepared to each flexural member. The shear deformation within the member was negleted and any beam-to-column joint was assumed to be rigid.

(2) Structural Wall: Deformations within the structural wall induced by bending, shear, base rotation, and uplifting were independently considered as systematically shown in Fig.1 and the wall was idealized as two vertical pin-supported line elements with infinitely rigid beams at top and bottom floor levels and one horizontal spring at each floor base. Since the web section was always kept plane by the rigid beam, the bending stiffness was determined by interlocking the two axial stiffnesses of the vertical line-elements. On the other hand, the shear stiffness was determined only by the horizontal spring and the hysteretic property was obtained with tracing the Origin-Oriented model indicated in Ref.7.

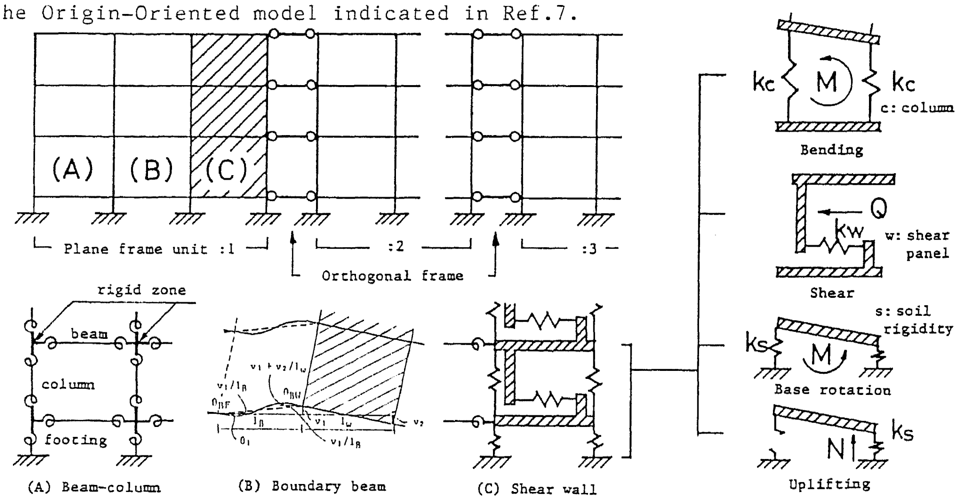


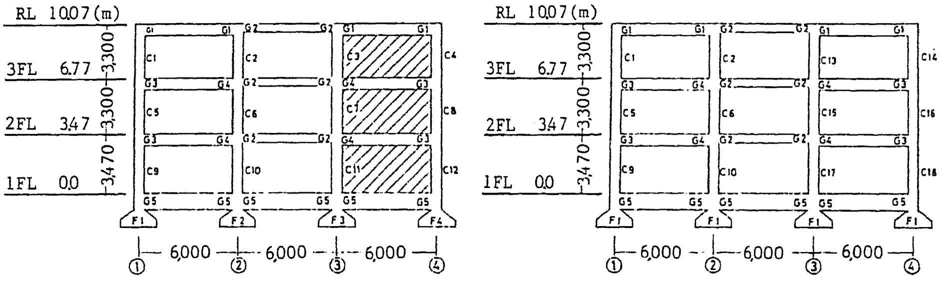
Fig.1 Idealized Mechanical Models

(3) Footings: The footing under the isolated column was idealized as a pin support with an elastic rotational spring but under the wall boundary column was idealized as a nonlinear axial spring only acting on compressive soil reactions at the center of the boundary column line. When the gravity load was overcome by the overturning effect, the footing was made separate from ground surface (meant uplifting of the wall) and no tensile load was carried by the separated spring.

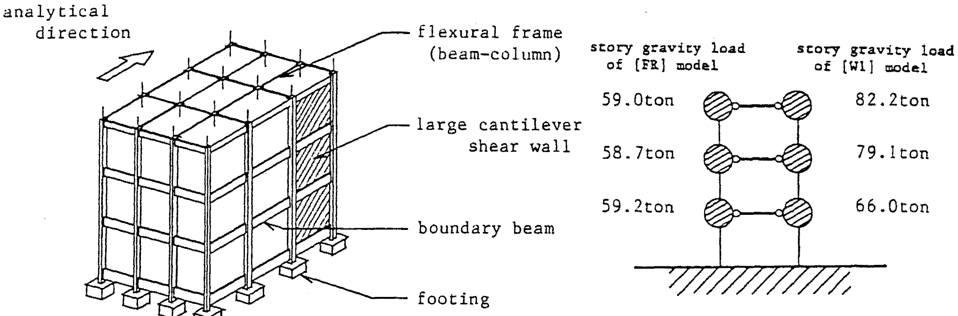
COMPUTER SIMULATION MODEL

Two types of the structural frame unit model having three stories and three bays were prepared for simulations and they are shown in Fig.2. One of them was a simple Flexural Frame unit called 'FR' model (Fig.2.b) and it was designed to form yield-hinges in most parts of the critical sections of the beam in a limit state. And the other was a coupled system unit called 'W1' model which consisted of flexural beam-columns and a large cantilever shear wall eccentrically situated in the plane of an analytical direction (Fig.2.a). Details of cross sections and others were given in Ref.2.

In order to discuss the interactive behavior between flexural frames and the base rotating shear wall, the nonlinear static and seismic response analyses were applied to a variety of the assembled analytical model called an idealized combination model (e.g.'F1W1') as imaginally shown in Fig.2.c. Table 1 shows the list of simulation models including the two simple frame units examined in this paper.



(a) Coupled system unit of [W1] model (b) Flexural frame unit of [FR] model



(c) Idealized combination model

Fig.2 Computer Simulation Models

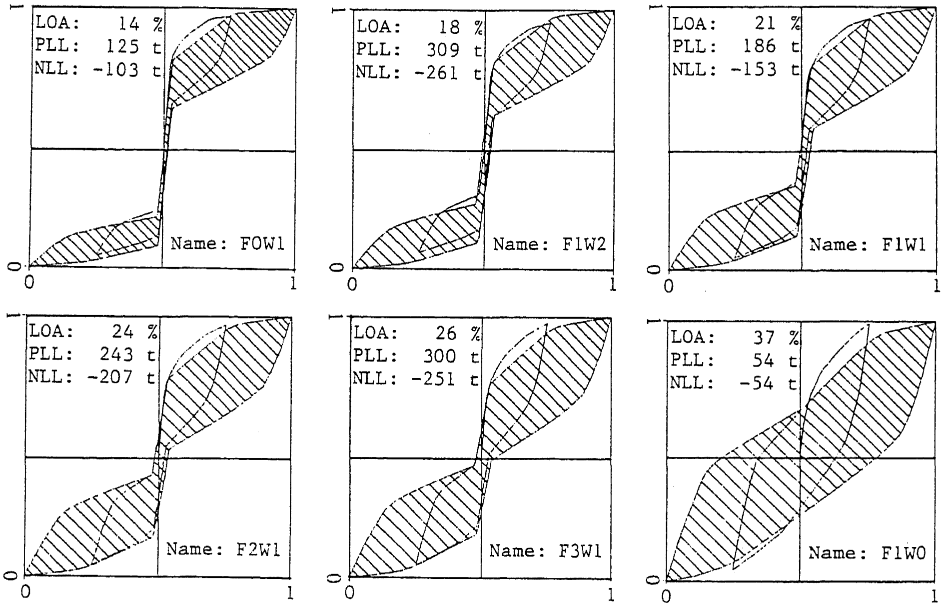
Table 1 Outline of Examples

Case	Name	Feature and Notation of Analytical Models
No.1	F0W1	Simple frame model of a coupled system unit of [W1] , see Fig.2
No.2	F1W0	Simple frame model of a flexural frame unit of [FR] , see Fig.2
No.3	F1W2	Idealized combination model consists of 1-[FR] and 2-[W1] units
No.4	F1W1	Idealized combination model consists of 1-[FR] and 1-[W1] units
No.5	F2W1	Idealized combination model consists of 2-[FR] and 1-[W1] units
No.6	F3W1	Idealized combination model consists of 3-[FR] and 1-[W1] units

FACTORS INFLUENCING STRUCTURAL STABILITY

Load-Deflection Curves and Failure Modes

Fig.3 shows the typical hysteretic curves derived from the nonlinear static analysis on the condition that cyclic lateral reversal loads were applied in small increments for step-by-step procedure but in retaining the triangular vertical distribution patterns for more practically simulating the deflected shape of the first mode of vibrations. The abscisa and the ordinate of axes were normalized by the width between the maximum and the minimum values of the base shear force and the lateral deflection from the top floor to the basement. The curves excepting the simple flexural frame unit of the 'F1W0' became the peculiar shape as 'S' of an alphabet since they were severely subjected with the influence of the base rotation and



Notes, LOA: Normalized hysteretic loop-area, PLL: Maximum load level, and NLL: Minimum load level

Fig.3 Hysteretic Load-Deflection Curves

Table 2 Capacities of Base Shear Force

NAME	UPLFT.LL Av.(ton)	MAX.LL(ton)		TRN.LL(ton)	
		Pos.	Neg.	Pos.	Neg.
FOW1	+/-80	125	-103	34	-57
F1W2	+/-186 (+/-184)	309 (304)	-261 (-260)	54 (50)	-100 (-96)
F1W1	+/-104 (+/-104)	186 (179)	-153 (-157)	16 (16)	-43 (-39)
F2W1	+/-129 (+/-128)	243 (233)	-207 (-211)	0 (-2)	-27 (-21)
F3W1	+/-150 (+/-152)	300 (287)	-251 (-265)	-21 (-20)	-13 (-3)
F1WO	+/-24	54	-54	-18	18

Notes,
UPLFT.LL: Average load level at uplifting of the wall
MAX.LL : Maximum and minimum load level
TRN.LL : Load level of turning point, (uplifting to nonuplifting)

uplifting of the wall. Plastic hinges developed at the critical sections of the beam and the base of each column, but the remainder of columns and the shear panel were made keep elastic. The lateral story displacements were, therefore, distributed vertically on triangular straight line before and after uplifting of the wall. Even if yieldings should be intended to commence at the critical sections of the column in a story of an alternative combination model, the beam- sidesway mechanism should occur through the influence of geostatical base rotation of the uplifting wall.

Capacities of Restoring Base Shear Force

The three specific base shear force capacities obtained are given in Table 2 and they means as follows:

(1) the average base shear force capacity at the beginning of uplifting of the wall: 'UPLFT.LL'
(2) the maximum and the minimum base shear force capacities in a limit state: 'MAX.LL- Pos./Neg.'
(3) the base shear force at the turning point reversely from a state of uplifting to that returning to initial position of nonuplifitng: 'TRN.LL-Pos./Neg.'.

Restoring base shear force capacities of the combination models were also estimated approximately by accumulating the unitary values of the 'F1WO' and the 'FOW1' in proportion to the number of the constituent frame units in the combination model. The constructive results are given in the parentheses in this table. The calculations carried out by the nonlinear static analysis were very in good agreement with roughly estimated values. This was because of the following two reasons. One was that the base shear capacities of the flexural frame unit in an ultimate state was able to be calculated by assuming the failure hinge-mechanism as the beam-sidesway one for the enforced lateral story displacements vertically distributed on a triangular straight line due to high rigidity of the shear panel which was elastically remained before and after uplifting of the wall. And the other reason was that the uplifting capacity of an isolated shear wall was easily estimated only by the normal gravity loads, the span length of the wall and the restoring yielding moments of the boundary beams.

Properties of Hysteretic Damping

The LOA value denoted in Fig.3 shows the loop-area ratio of the cross-hatched part in each load-deflection curve which is drawn on the normalized coordinates. If it is divided by (2π), it can be regarded as the hysteretic damping in the stational state of vibrations corresponding to an equivalent viscous damping factor on the dynamic theory. The hysteretic damping of the framed structure consisting of some simple frame units and a base rotating shear wall should be also estimated from the similar procedure as the above and if the cross-hatched part of only post-uplifting of the base rotating shear wall were picked up and reassembled on an alternative axis vertically condensed into the state without a part of nonuplifting, the new hysteretic load-deflection curve should be practically equivalent to the curve of the flexural frame unit.

RESULTS OF SEISMIC RESPONSE ANALYSIS

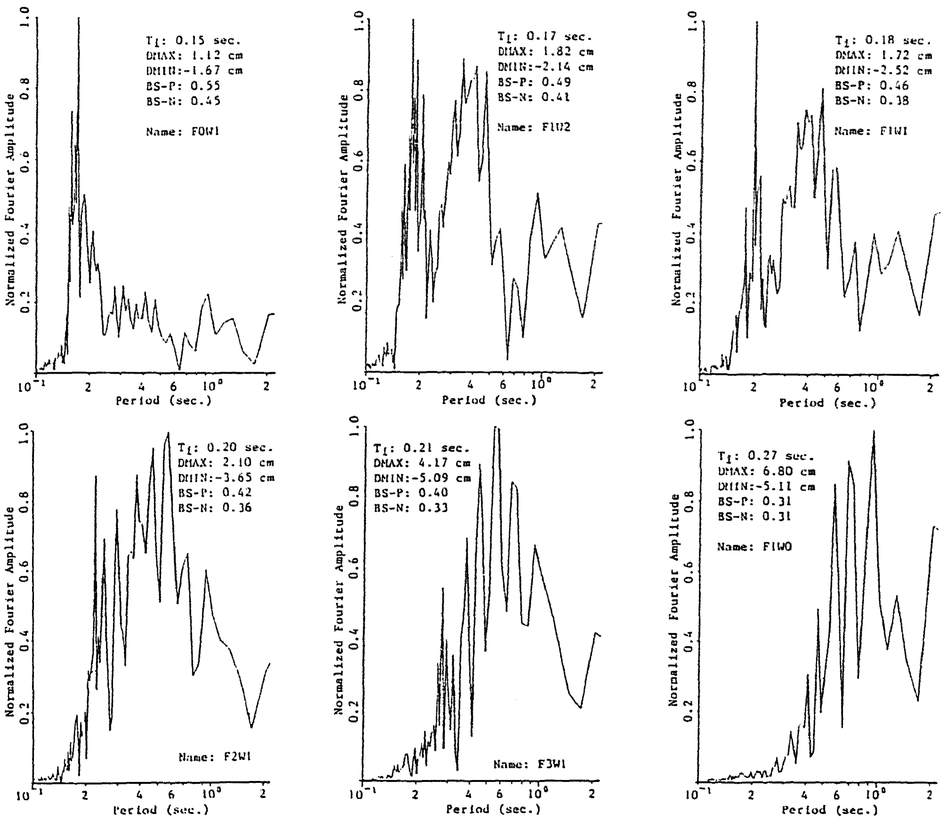
Fourier Spectrum

In order to discuss the periodic properties on the time-hystories of the displacement amplitude, the Fourier spectra were analyzed and they are shown in Fig.4. The relative Fourier amplitudes normalized by the maximum value are given on an axis of the ordinate and the periods are set on log-scaled axis of the abscissa. The natural period at the initial stage of the analytical model obtained as an eigen value for the first mode, the maximum and the minimum displacement amplitudes of the response, and the base shear coefficients to both positive and negative directions derived from deviding the base shear capacities by the total gravity load (BS-value) are denoted in the figure.

According to the results, it can be seen that the natural periods of only between 0.3 and 0.5 sec. at the initial stage before uplifitng of the wall were highly developed in the case of the coupled system unit of the 'FOW1'. On the other hand, two peaks of the period before and after uplifting were relatively developed in cases of the combination models because the story stiffness was made to deteriorate with yieldings of the flexural members during instantaneous stages of uplifting but it had to be return to initial stiffness at near the stage of nonuplifting.

Maximum Displacement Amplitude

It has been naturally recognized that the displacement amplitude in responses under same earthquake excitations is decreased by increasing the maximum Base Shear force capacity (BS-value) of the simulation model. But even if the BS-value was kept constant, the uplifting base shear force had strong effect on the seismic response. The relations between the uplifting base shear force ratio which is suited to the degree of hardness on base rotation with uplifting and the maximum displacement amplitude of response normalized by the unitary value of the 'FOW1' are shown in Fig.5. It can be seen that the uplifting base shear force of the base rotating wall is very beneficial for the seismic design of the practical framed structure.



Notes, T_i: Fundamental natural-period, DMAX: Maximum displacement amplitude at the top to base, DMIN: Minimum displacement amplitude at the top to base, BS-P: Base shear coefficient to positive load, BS-N: Base shear coefficient to negative load

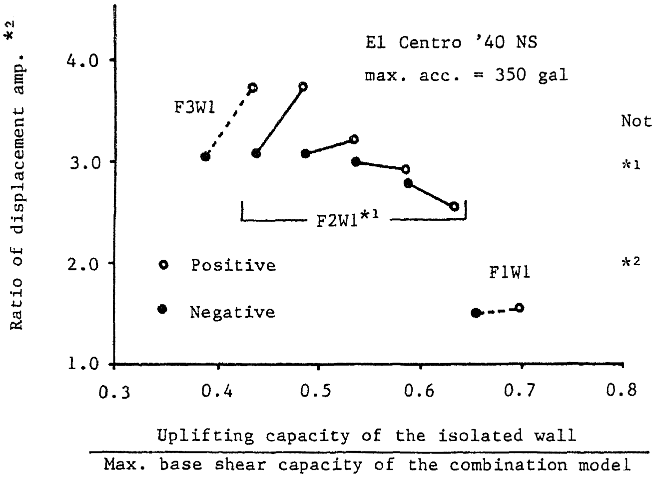
Fig.4 Fourier Spectra Diagram

CONCLUSIONS

Findings derived from this study are summarized as follows:

(1) Hysteretic behaviors of the base shear force capacities and the hysteretic dampings can be estimate by accumulating the unitary values of the simple flexural frame unit and the coupled system unit in proportion to the number of them within the framed structure because the failure hinge mechanism of the flexural frame is allowed to be fixed as the beam-collapse type due to the forced distribution pattern of the story drifts affected by the high rigidity of the shear panel of the uplifting wall.

(2) Two types of the natural period before and after uplifting of the wall are highly developed on Fourier-spectra diagram for some simulation models. When the number of simple flexural frame increases againt the frame having the base rotating shear wall with uplifting, the component of short period diminishes but that of long period after uplifting 'and yielding of



Notes,

*1 : Maximum base shear capacity of each case is kept constant but only uplifting capacity is varied.

*2 : displacement amp. normalized by that of the 'F0W1'

Fig.5 Relation Between Uplifting Capacity and Maximum Displacement Amplitude

members increases. The superiority between the elastic short period and inelastic long period is subject to the influence not only of the maximum base shear capacity but also of the uplifting base shear force of the wall.

(3) Even if the maximum base shear force capacities are kept constant, the uplifting base shear force has strong effect on the seismic response of the simulation models. Therefore, the increasing of the base shear force capacity of the base rotating shear wall is very effective to improve the seismic performance of the reinforced concrete structure as far as the wall is designed to never broken in flexure or shear.

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