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THE RESPONSE CONTROL DESIGN OF HIGH-RISE BUILDING WITH LOW YIELD STEEL WALL

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ABSTRACT

Low yield steel walls (hereafter referred to as LYSW) can form an effective plastic hysteretic energy absorption system that serves as a damper capable of reducing response of buildings to earthquakes. LYSW can be fabricated and erected more easily than other types of damping systems. This paper will describe the basic vibration response properties of a high-rise building provided with LYSW and report on necessary design consideration for LYSW and effects expected of them. The paper will also introduce and comment on the results of the vibration analysis of a 31-storied office building provided with a LYSW system.

KEYWORDS

Yield strength ratio; accumulated strain; damping factor; response reduction; low yield steel walls; energy absorption; damper.

INTRODUCTION

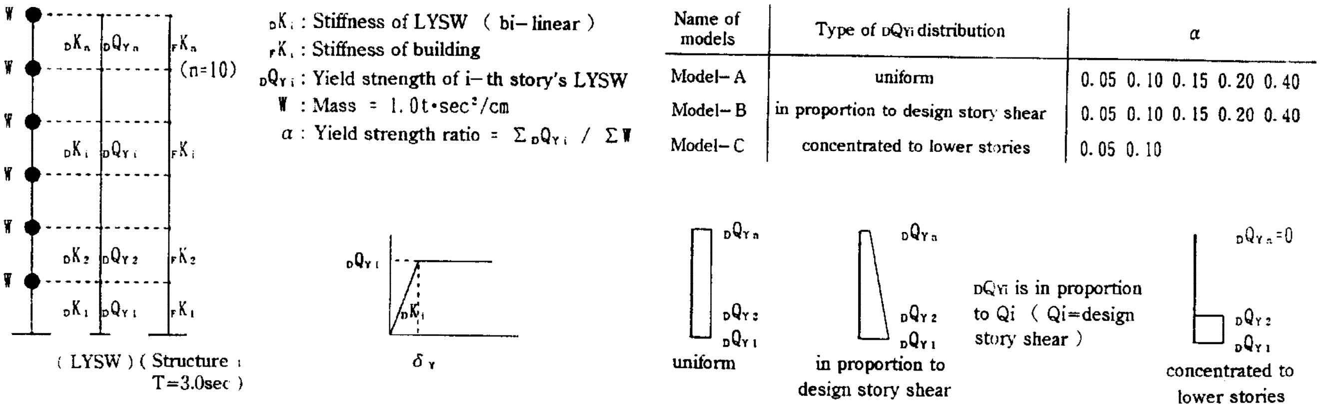
Recently, a number of seismic isolation systems and vibration damping systems that are practically usable for buildings have been developed. Some of them utilize the characteristics intrinsic to the materials used while others comprise large-scale mechanisms. This paper deals with LYSW which may be regarded as one of the seismic insulation systems. The LYSW system utilizes plastic hysteretic energy absorption capacity of low yield point steel plates to serve as damping mechanism. LYSW which can be fabricated and erected as easily as conventional normal steel aseismic walls, are featured by their high stability, durability and reliability.
The structural features of LYSW may be summarized as follows:

a) Since most of seismic force during a strong earthquake will be concentrated on LYSW, highly effective hysteretic energy absorption by these walls may be expected.

b) Hence, it may be expected that seismic force acting on vertical load carrying elements (e.g., columns and beams) will be greatly reduced.

c) Even if LYSW are badly damaged by seismic shocks, they are rather easily repairable or replaceable with new ones.

This paper will describe the basic vibration response properties of a high-rise building provided with LYSW and also introduce an example in which they are actually applied. As for the basic properties of the materials used for LYSW, the readers are referred to a paper by Nakagawa *et al.* (1996) mentioned in References.



Name of models	Type of $_DQ_{Yi}$ distribution	α
Model-A	uniform	0.05 0.10 0.15 0.20 0.40
Model-B	in proportion to design story shear	0.05 0.10 0.15 0.20 0.40
Model-C	concentrated to lower stories	0.05 0.10

Fig. 1. Analysis Models

Table 1 Content of analysis models

story	W tsec²/cm (Weight t)	$_FK_i$ t/cm (Damping coef)	$_DQ_{Yi}$ ($_DK_i$) of model-A t, (t/cm)				$_DQ_{Yi}$ ($_DK_i$) of model-B t, (t/cm)				$_DQ_{Yi}$ ($_DK_i$) of model-C t, (t/cm)	
			α=0.05	α=0.10	α=0.15	α=0.20	α=0.05	α=0.10	α=0.15	α=0.20	α=0.05	α=0..10
10	1.0 (980)	67(1.26)	49(30)	98(60)	147(89)	196(119)	19(11)	37(22)	56(34)	75(45)		
9	1.0 (980)	105(1.97)	49(30)	98(60)	147(89)	196(119)	29(18)	58(35)	88(53)	117(71)		
8	1.0 (980)	135(2.54)	49(30)	98(60)	147(89)	196(119)	38(23)	76(46)	113(69)	151(91)		
7	1.0 (980)	161(3.03)	49(30)	98(60)	147(89)	196(119)	45(27)	90(54)	135(82)	180(109)		
6	1.0 (980)	182(3.42)	49(30)	98(60)	147(89)	196(119)	51(31)	102(62)	153(123)	204(246)		
5	1.0 (980)	200(3.76)	49(30)	98(60)	147(89)	196(119)	56(34)	112(68)	167(101)	223(135)		
4	1.0 (980)	214(4.03)	49(30)	98(60)	147(89)	196(119)	60(36)	119(72)	179(108)	238(144)		
3	1.0 (980)	224(4.21)	49(30)	98(60)	147(89)	196(119)	63(38)	125(76)	188(114)	251(152)		
2	1.0 (980)	231(4.35)	49(30)	98(60)	147(89)	196(119)	65(39)	129(78)	194(117)	259(156)	245(148)	490(296)
1	1.0 (980)	235(4.42)	49(30)	98(60)	147(89)	196(119)	66(40)	132(80)	197(119)	263(159)	245(148)	490(296)

ANALYSES BY THE USE OF BASIC MODELS

Analysis Model

What is to be analyzed is a spring model with one degree of freedom per floor as shown in Fig. 1 and Table 1. The model consists of a building which has a mass (W) and a rigidity ($_FK$) and LYSW which have a rigidity ($_DK$) and a bearing capacity ($_DQ_Y$). For simplification, the number of mass points has been reduced to 10 although the building is about 30-storied. By using this model, a case study on time history response analyses was conducted. Parameters comprise input ground velocity, strength of LYSW ($_DQ_Y$ in shown in Fig. 1) and distribution - yield strength ratio (α as shown in Fig. 1).

For the input ground motions, the artificial waves as proposed by Teramoto *et al.*(1990) were used. The response spectra of these artificial waves are shown in Fig. 2 together with those of the El Centro and the Taft Earthquakes. Further, the building rigidity ($_FKi$) and the damping coefficient have been established as follows:

- Building Rigidity ($_FKi$) ••• First, the story shear Qi was obtained by taking a standard shear coefficient as 0.3 and assuming a distribution pattern of the shear coefficients as Ai as proposed by The Building Center of Japan (1991). Next, the value of $_FKi$, was determined in such a way that each story drift angle would become 1/300 for the applicable Qi. Thus,

$$Qi = Z \cdot Rt \cdot Ai \cdot C_0 \cdot Wi \quad (Wi = 1.0t \cdot sec^2/cm)$$

$$Qi/{}_FKi = \delta = h/300 = 4\ cm \quad (h = 1200\ cm)$$

$$\therefore\ {}_FKi = Qi/4 = Z \cdot Rt \cdot Ai \cdot C_0 \cdot Wi/4$$

- Coefficient of viscous Damping (Ci) ••• The damping coefficient (h) of the building was assumed as proportional to the rigidity, i.e., 2% of the primary natural period.

Thus,

$$Ci = (2 \cdot h/{}_1\omega) \cdot {}_FKi = ({}_1T \cdot h/\pi) \cdot {}_FKi$$
$$= (2.95 \cdot 0.02/\pi) \cdot {}_FKi \quad ({}_1\omega = 2 \cdot \pi/{}_1T)$$

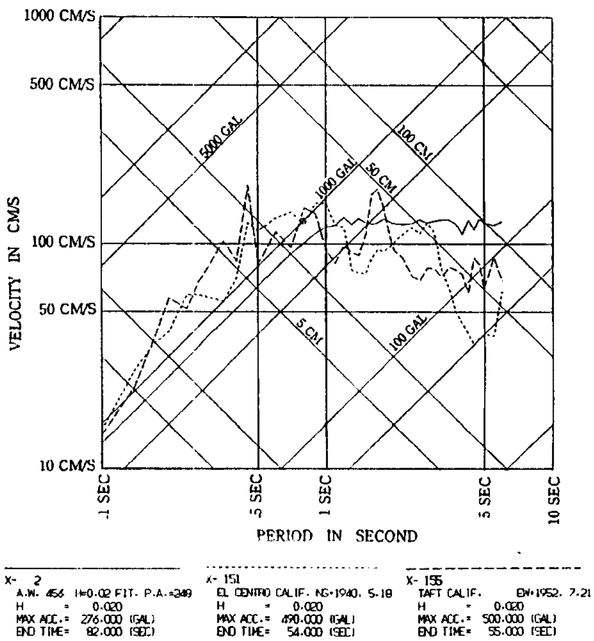


Fig. 2. Tripartite response spectrum of ground motion

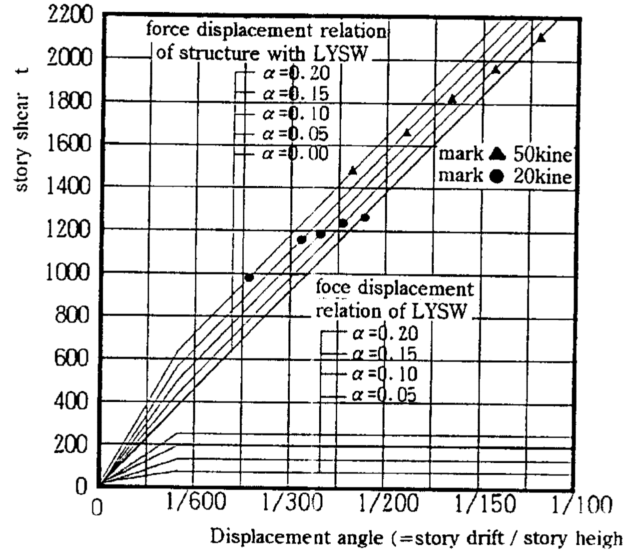
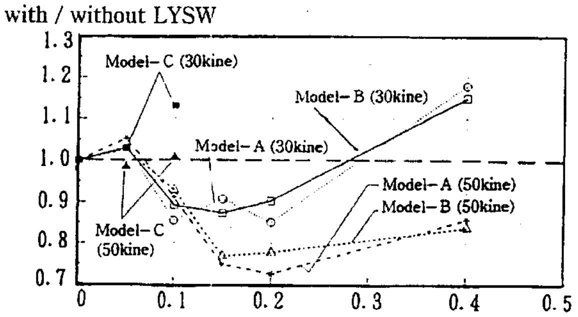
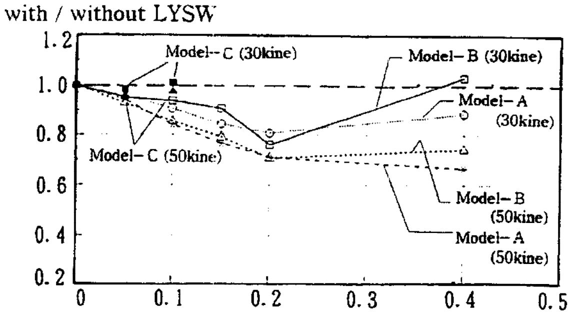


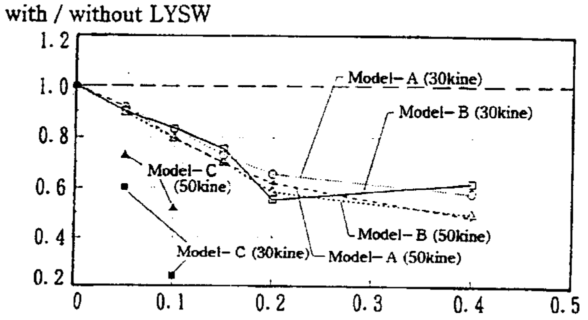
Fig. 4. Response values of Model-B on force drift relation curves



(a) Maximum acceleration of the top story



(b) Maximum base shear coefficients



(c) Maximum base shear coefficients of frame

Fig. 3. Comparison of response values with and without LYSW

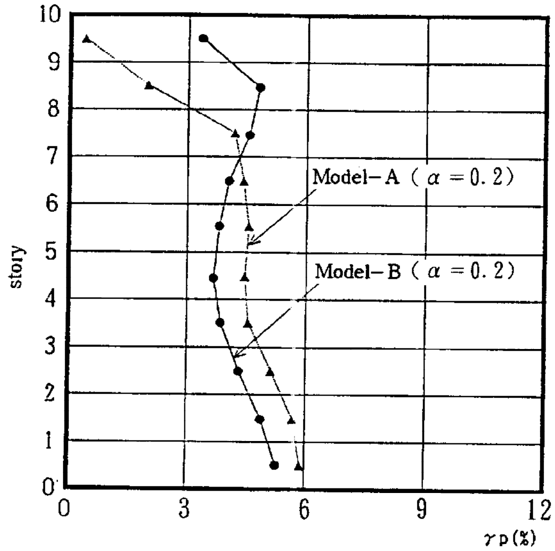


Fig. 5. Accumulated plastic strain value

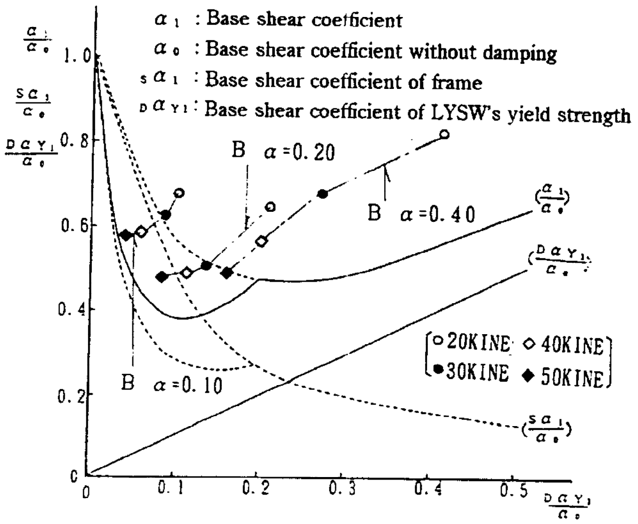


Fig. 6. Relation of Ds-value (α_1 / α_0) and $_D\alpha_{Y1} / \alpha_0$

Analysis Results and Consideration

Fig. 3 shows the ratio of $\alpha = 0$ (a case without LYSW) to $\alpha = 0.05 - 0.40$ (a case with LYSW) at the maximum response value obtained. From this figure, the following statement may be derived.

1) As the value of α increases, the response value decreases due to the effect of LYSW. However, if the value of α becomes too large, the response value will tend to increase.

2) The value of α which indicates the minimum value varies depending on the item to be evaluated. (The maximum response acceleration at the top of Model B is $\alpha = 0.15$ and the shear is $\alpha = 0.2$ at minimum.)

3) In the case of Model C, the maximum response shear, except the shear taken case of by LYSW, is small compared with that in other models.

Fig. 4 shows the maximum response as obtained by overlapping it on the force-drift relation curves. It is known from this figure that shear force and deformation vary as the yield level (the first flection point) changes. This difference is caused by the difference in hysteretic energy absorption resulting from α variation.

Fig. 5 shows the story-by-story distribution of accumulated plastic shear strains (γ_p = hysteretic energy absorption of each story/yield strength of each story). From this figure, it is known that the value of γ_p for each story in Model B is more uniform than that in Model A. This indicates that energy absorption by LYSW in Model A was greater at lower stories than at the upper stories. As for the overall hysteretic energy absorption, Model A does not differ much from Model B.

Fig. 6 shows the response values obtained for this model as plotted according to the prediction formula based on the energy balance as proposed by Kitamura (1994). In this figure, the $\alpha 1/\alpha 0$ taken on the ordinate corresponds to Ds values as proposed by The Building Center of Japan (1991). From this figure, it may be stated that where the input ground mution is 50 kine (cm/sec) or less, the response reduction effect becomes greatest when $\alpha = 0.2$ (i.e., when the value $\alpha 1/\alpha 0$ is small).

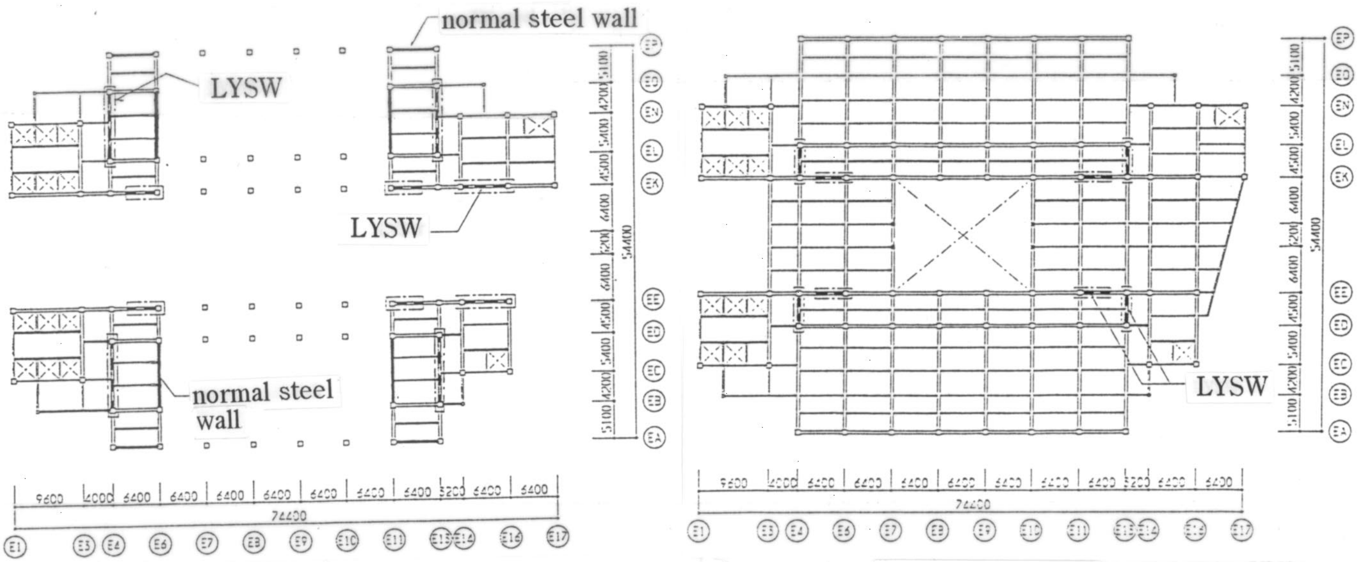
CASE STUDY : APPLICATION OF LYSW TO ACTUAL BUILDING

Based on the basic property studies described in the section above, the LYSW were applied to an actual building described below. In this section, the layout of LYSW in this building and their effects will be described on the basis of the results of the case studies conducted.

Outline of the Building

The building described herein as an example of actual application is a government office building to be used as a disaster prevention headquarters. The following basic data will give an outline image of the building (see Fig.7 and 8).

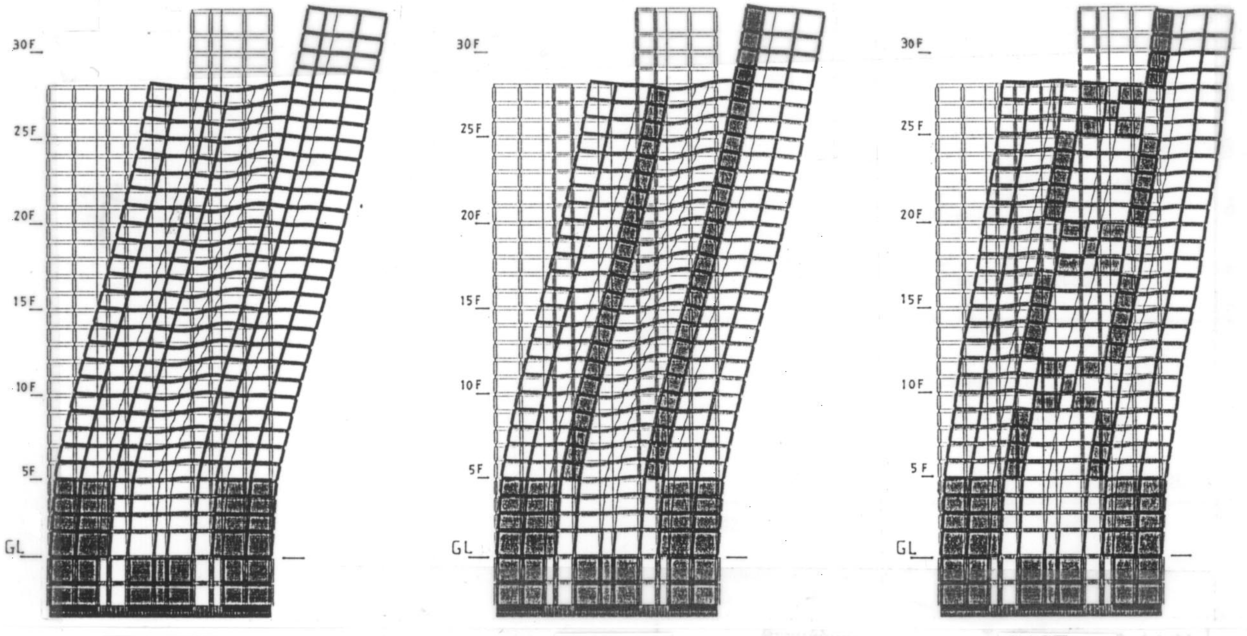
- Building name : Saitama National Government Building
- Location : Saitama-ken, Japan
- Number of basement floors : 2
- Number of stories above ground : 31
- Typical floor area : 3,208 m^2
- Total floor area : 121,248 m^2
- Standard floor height 4,200 mm
- Total height : 153,900 mm
- Typical bay size : 6,400 mm x 14,700 mm
- Basement structural type : steel reinforced concrete
- Structural type above ground : steel
- Total steel weight : 18,900 t
- Typical column size : 700 x 700 mm (maximum thickness 70 mm)
- Typical beam size : 900 mm - depth, 350 mm-wide H-section plate girder (maximum thickness 32 mm)
- Features :
  - a) The building has an atrium at the center of its floor plan.
  - b) In the low-rise block, only four cores form the aseismic elements.



(a) 2 ~ 4th floor

(b) Standard floor

Fig. 7. Framing plan



CASE−a
no LYSW

CASE−b
continuous pattern

CASE−c
staggered pattern

Fig. 8. Framing elevation (4−frame) and frame deformation diagram

Fig. 8 shows three kinds of frame arrangements (in Y-direction) presumable for this building. CASE-a is a frame planning in which no LYSW are used; in CASE-b, LYSW are placed continuous throughout a number of stories, and in CASE-c a part of LYSW used in CASE-b is laid out in a staggered pattern. The LYSW layout as used in CASE-c decreases deformation of LYSW due to bending and makes their deformation due to shears predominant, thereby enhancing the overall rigidity of the frame system. The LYSW layout used in CASE-c is also compatible with the floor layout planning. Fig. 8 also includes a diagram of deformation due to static loading.

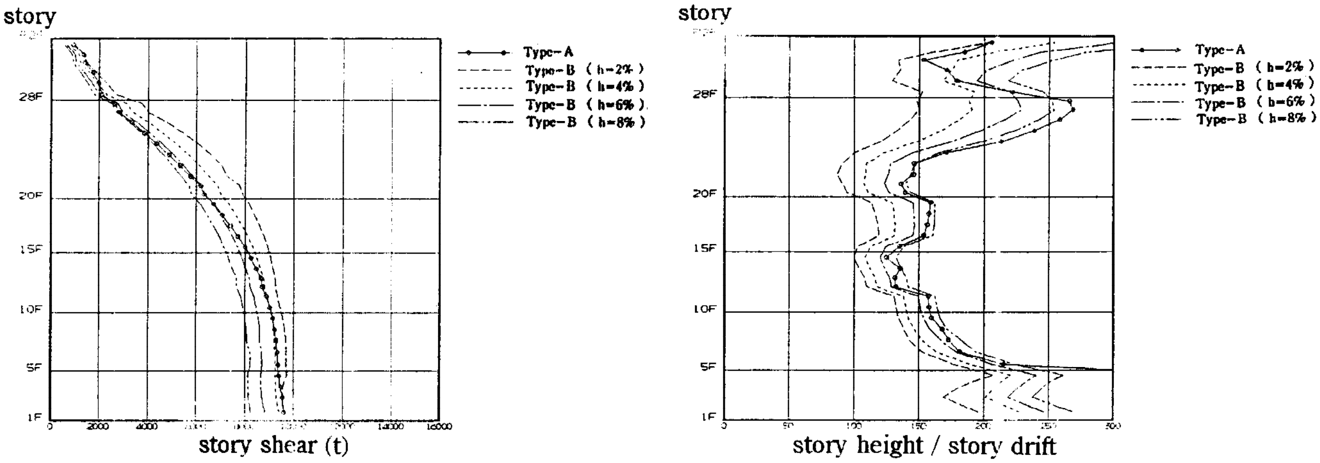
Vibration response analyses were conducted for the aforesaid three cases (by using the artificial waves), and the results thus obtained are indicted in Table 2. It is known from this table that while the maximum response shear at the first floor level was nearly identical in these three cases, the ratio of those at the mid-floor level (i.e., the 15th floor) in CASE-a, -b and -c was 1:0.87: 0.77. This means that the shear force was reduced by about 10 - 20% compared with the cases in which LYSW were absent. The ratio of the maximum story drift angles in CASES-a, -b and -c were 1:0.86:0.67.

As had been predicted, LYSW were proven to be most effective when used in the layout as represented by CASE-c. Hence, the layout as in CASE-c was used in application of LYSW to the actual building.

Table 2 Comparison of response value
(CASE-a, b, c)

response value	CASE-a	CASE-b	CASE-c
maximum story 15F shear (t) 1F	8110 9840	7100 10220	6260 9380
maximun dis-placement angle*	1/88 (13F)	1/102 (12F)	1/131 (6F)
initial natural period (sec)	3.12	2.98	2.64

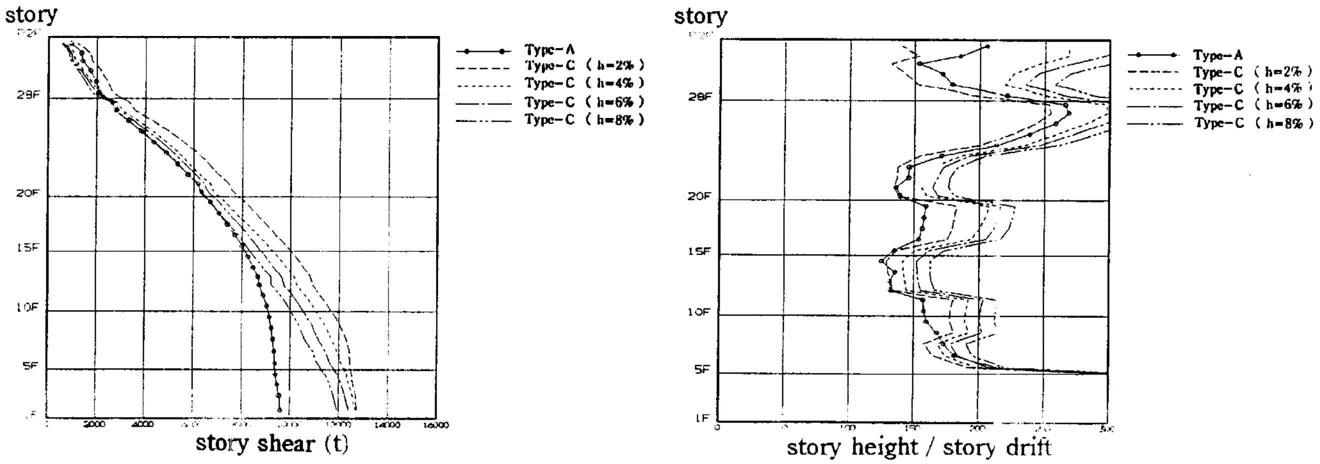
* = story drift / story height



(a) maximum story shear

(b) maximum displacement angle (story height / story drift)

Fig. 9. Comparison of type–A's response value and type–B's



(a) maximum story shear

(b) maximum displacement angle (story height / story drift)

Fig. 10. Comparison of type–A's response value and type–B's

Computation of Equivalent Damping Factor

In this subsection, the arrangement described in CASE-c and adopted for application is referred to as Type A. And, the response of this Type A will be compared with those of Type B and C in order to investigate the relationship between the effects of LYSW and the damping factor (h).

Type Studied:
- Type A : Provided with LYSW and has a damping factor of 2% (with LYSW located as described for CASE-c in the section above)
- Type B : Not provided with LYSW, the damping factor being varied between 2% and 8%.
- Type C : Elastic steel plate aseismic walls are used instead of LYSW with the damping factor being varied within a 2 - 8% range.

First, the result of the comparison of Type A with Type B is shown in Fig. 9. As shown in Fig. 9a), there is not much difference between Type A and B (h = 2%) in respect of the maximum story shear. This is because Type B has a long period which causes the input energy to be reduced. In terms of the maximum deflection angle as indicated in Fig. 9b), however, conspicuous difference is seen between them. If Type B is to have the same story drift angle as Type A, Type B must have its damping factor increased to about 7%. Hence, it may be stated that if evaluation is made on the basis of the drift angles, a building provided with LYSW is equivalent to a building not provided with LYSW in which the equivalent damping factor is increased by 5%.

Fig. 10 shows the result of comparative study of Type A and C. As seen in Fig. 10b), Type A and C (h = 2%) are not much different from each other in respect of the maximum response story drift angles. This is considered attributable to high rigidity of elastic steel plate earthquake resistant walls used in Type C. However, when comparison is made on the basis of their maximum response shears shown in Fig. 10a), conspicuous difference is observed between them. If Type C is to withstand the same study shear as Type A, Type C must have its damping factor increased to 8%. Thus, if evaluation is made on the basis of shear force, a building provided with LYSW may be regarded as being equivalent to a building provided with elastic steel plate earthquake resistant walls in which its damping factor is increased by 6%.

CONCLUSIONS

Basic earthquake response properties of buildings provided with LYSW were investigated. The following are the author's observations within the limits of the studies described in this paper.

1) From Basic Studies

   a) When reduction of earthquake response is considered, LYSW should have an optimum yield strength ratio (i.e., an optimum ratio of the total strength to the total building weight). Hence, it is preferable that the actual application of LYSW should be preceded by a case study similar to that described in this paper.

   b) It is believed that the purpose of LYSW can be effectively achieved when their strength distribution in the vertical direction is varied depending on the amount of story shear acting on respective stories. Such varied distribution of LYSW will help equalize the energy absorption at all story level of the building.

   c) If LYSW are to be concentrated at lower stories, careful consideration should be given to the maximum response shear apart from the response shear to be taken of by the LYSW.

2) From Studies on Application to An Actual Building

   a) It is desirable that LYSW be laid out in such a manner that drift due to shear will become a predominant factor of story drift.

   b) A building provided with LYSW that are effectively laid out is susceptible to much smaller structural deformation than a building not provided with LYSW. This difference in deformation amounts to 5% when expressed in terms of the equivalent damping factor.

   c) Further, a building provided with an effective LYSW system can reduce the shears acting on its structural system much more greatly than a building provided with elastic steel plate earthquake resistant walls. This difference has been found to amount to 6% when expressed in terms of the equivalent damping factor.

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