DAMAGED AND NON DAMAGED REINFORCED CONCRETE MODERN BUILDINGS AT THE OOITA-EARTHQUAKE, APR. 21, 1975, JAPAN

by

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SYNOPSIS

In spite of being adjacent to the epicenter of the Ooita-Earthquake, Apr. 21, 1975, in Japan, there existed damaged- and non-damaged reinforced concrete buildings at the same time and place. Applying the new fundamental aseismic design [1] proposed by the authors to such buildings, the causes of the differences between damaged- and non-damaged phenomena are made clear, and the validity of the authors' theorem to the aseismic design on low-rise and rigid-type reinforced concrete buildings is verified.

1. INTRODUCTION

On Apr. 21, 1975, the Ooita-Earthquake occurred at the central zone of Ooita-prefecture in Japan. The most noteworthy fact is the simultaneous existence of damaged- and non-damaged reinforced concrete buildings in spite of being very adjacent to the epicenter. These phenomena are considered to be very rare and important test results of structures with real scale. To make clear the causes of such differences may bring out very essential and useful knowledges for an aseismic design of reinforced concrete buildings.

The authors already proposed a new fundamental aseismic design method of low-rise and rigid type reinforced concrete buildings[1], but there was a lack of experimental verification on an entire building with real scale. Consequently, the purposes of this paper are to apply the authors' aseismic design approach to such damaged- and non-damaged reinforced concrete buildings and to make clear the causes of such differences.

2. THE OOITA-EARTHQUAKE

On Apr. 21, 1975, a destructive earthquake occurred at the central part of the Kyushu-island in Japan, and gave many and heavy damages to buildings, railways and roads. According to the report of the Board of Meteorology, the magnitude was 6,4, the depth of the seismic origin was zero and the epicenter exists on N.L.33°08' and E.L.131°21'. The feature of the Ooita-Earthquake is that the seismic origin is very shallow and the damaged region is relatively narrow.

The heaviest damage due to the Ooita-Earthquake is the fracture of a reinforced concrete (RC) building, Kuju Lake Side Hotel. The epicenter lies about 7 km south-south-east from the Hotel. According to the recent investigations, the epicenter is considered to exist the nearer to the Hotel.

3. DAMAGES OF RC-BUILDINGS

There exist several low-rise RC-buildings around the Yamashita Lake adjacent to the epicenter. The most noteworthy fact is that damaged- and non-damaged RC-buildings exist at the same time and place. In this paper

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four RC-buildings with different grades of fracture are picked up. The locations, key plans and photographs of them are shown in Figs. 1, 2 and Photo 1, which is taken after the Ooita-Earthquake. The outlines of structures and damages are as follows:

K : Kuju Lake Side Hotel (Fig. 2(a), Photo 1(a)) is a 4-story RC-building with 1-story basement composed of A, B and C blocks such as shown in Fig.2 (a) connected by simple expansion joint above footing beams, and 2nd. to 4th. floors are used as guest rooms. Damages were concentrated to the first story, and the C block was completely crushed down. In the A block, columns and walls suffered heavy and non-repairable damages but the upper floors were sustained. The damages of the B block was lighter than the A block. The under ground story and the 2nd. to 4th. stories are sound except local and slight cracks of concrete in the A, B and C blocks.

Y : Yamashita Lake Inn (Fig. 2(b), Photo 1(b)) is a 3-story (locally 4-story) RC-building. No damage is observed except very slight cracks on shear walls.

W : Dormitory for Women (Fig. 2(c), Photo 1(c)) is a 3-story RC-building. No damage is observed.

M : Dormitory for Men (Fig.2(d),Photo 2(d)) is a 2-story RC-building, designed as a Wall Type RC-structure, the main structural elements of which are RC shear walls. there was no damage.

4. CAUSES OF FRACTURE AND SURVIVAL

The authors had already proposed a new fundamental aseismic design of reinforced concrete structures at the 5th. WCEE, 1973 in Rome [1]. The essential principle is summarized as follows:

Considering a reinforced concrete building to be composed of three kinds of aseismic units, i.e. long column (LCu), short column (SCu) and shear wall (SWu) such as shown in Fig. 3, the entire relationship between story shear force Q - story displacement δ has to show a saw-toothed characteristic such as shown in Fig. 4, each peak point of which corresponds to the fracture of each aseismic unit. Let α, β and γ be the number of pieces of aseismic units, LCu, SCu and SWu, and the aseismic characteristics, fracture modes, wall ratios w, natural periods T and critical number of stories n_{cr} of a reinforced concrete building are able to be illustrated in the α/γ - β/γ plane [1] such as shown in Fig. 5.

The grade of damages, wall ratios w, seismic weight per unit floor area $\overline{W}$, number of pieces of LCu α, and SCu β of several damaged- and non-damaged buildings shown in Fig. 2 and Photo 1 are listed in Table 1. Using α, β and w, the symbols of grade of damages in Table 1 are able to be plotted in Fig. 5. All of them belong to SW-Fracture-Mode and locate around the origin, then its enlargement is shown in Fig. 6, in which the value within parenthesis after symbol names is $\overline{W}$ in Table 1 which corresponds to the critical number of story n_{cr} drawn as contour-chainlines in Figs. 5 and 6 calculated under the condition that seismic coefficient is the unity and seismic weight per unit area is 1 t/m^2 [1]. Fig. 6 shows the fact that the more distantly locate these points from the origin, and the more nearly access the value $\overline{W}$ in parenthesis to n_{cr}, the more heavily increase the grades of their damages, and that the aseismic safety or capacity of reinforced concrete buildings is able to be well evaluated by means of the factors, α, β, γ, w and n_{cr}.

Although the aseismic characteristics in Fig. 5 are calculated in the case of specified structural dimensions [1] which are considered to be standard and general in low-rise reinforced concrete buildings such as shown in the first column in Table 2, in reality, however, each building has different and various dimensions. In order to verify the more exact story shear capacities and fracture modes, the relationships between story shear force coefficient k (= story shear force(Q) / seismic weight(W)) and lateral displacement δ of several typical buildings are calculated and shown in Fig. 7 by using the structural dimensions described in Table 2, which are abstracted as typical values. Calculations are carried out by means of the equations already introduced in the previous paper [1] of the authors. Fig. 7 shows the fact that the all buildings concerned here belong to SW-Fracture-Mode and that shear wall ratio w is the most effective aseismic factor in these cases. When the maximum story shear coefficient k is about the unity, damages are the heaviest, and then the larger increases the value k, the lighter become damages. These facts agree well with what Fig. 6 means.

5. CONCLUSIONS

In order to make clear the causes of the differences between damaged- and non-damaged reinforced concrete structures at the Ooita-Earthquake, Apr. 21, 1975, Japan, the new fundamental aseismic design [1] on low-rise and rigid-type reinforced concrete buildings proposed by the authors are applied. As results, not only the validity of the authors' aseismic design is verified, but also the following facts are made clear ; These all buildings adjacent to the epicenter belong to shear wall fracture mode, and shear wall ratio w becomes the main aseismic controlling factor. The more the story shear force coefficient k (= Q / W) increases, the lighter become the damages of such buildings, and the minimum required value of k for aseismic safety is about the unity.

6. BIBLIOGRAPHY

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[2] Architectural Institute of Japan : Report on the Damages of Reinforced Concrete Structures at the 1975 Ooita-Earthquake, AIJ, 1976, Tokyo.

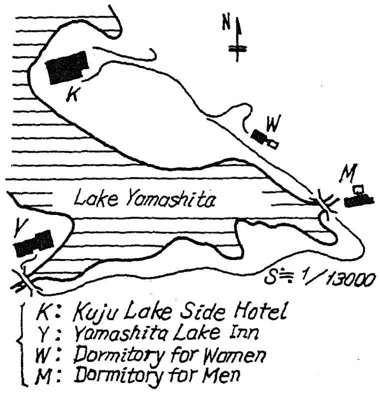
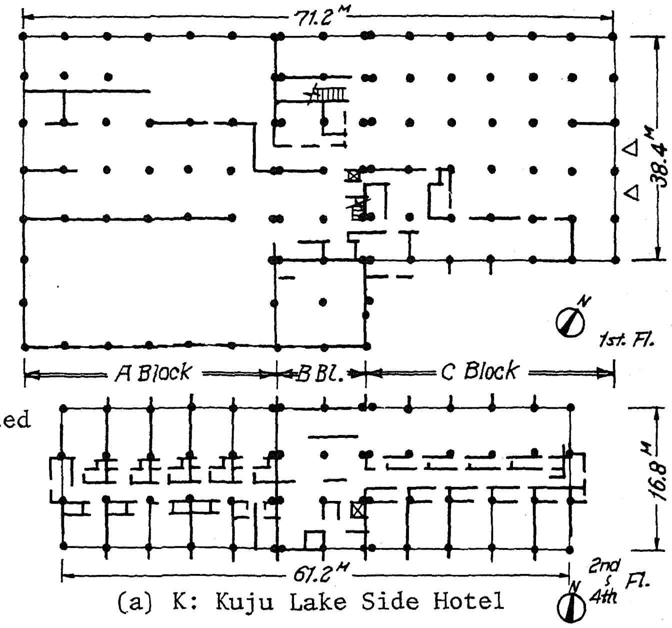
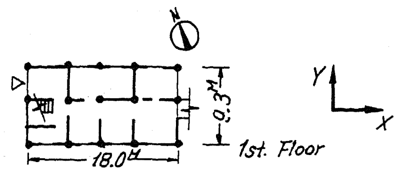


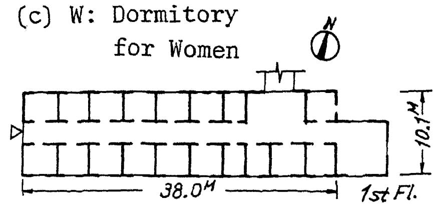
Fig.1 Disposition of Reinforced Concrete Buildings



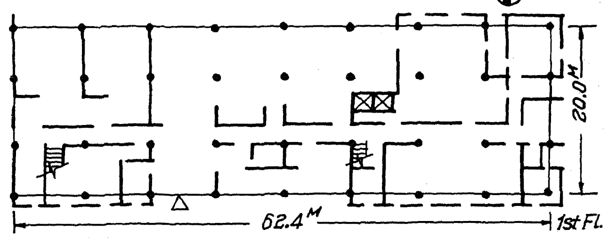
(a) K: Kuju Lake Side Hotel



(c) W: Dormitory for Women



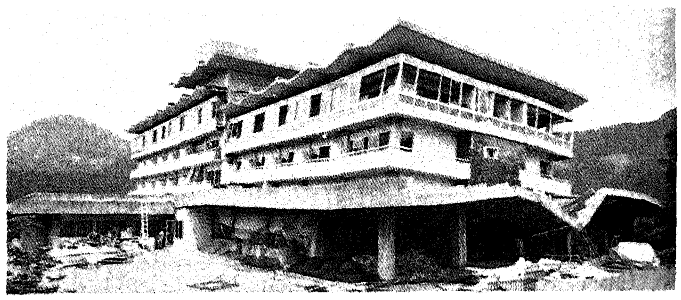
(d) M: Dormitory for Men



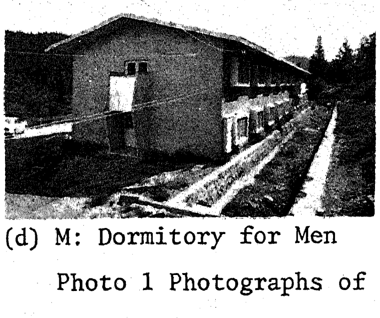
(b) Y: Yamashita Lake Inn

Fig.2 Key Plans of RC Buildings around Lake Yamashita (S=1/800)

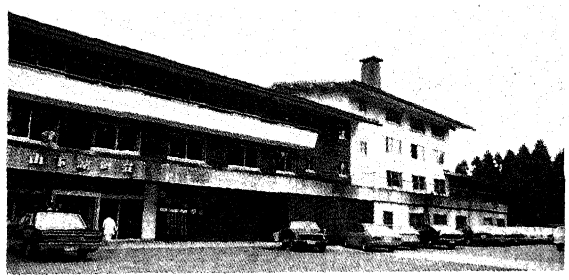
(c) W: Dormitory for Women



(a) K: Kuju Lake Side Hotel



(d) M: Dormitory for Men



(b) Y: Yamashita Lake Inn

Photo 1 Photographs of RC Buildings Taken after the Ooita-Earthquake

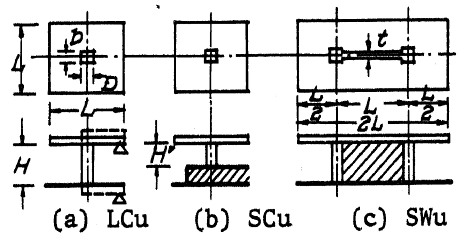


Fig.3 Units of Aseismic Element

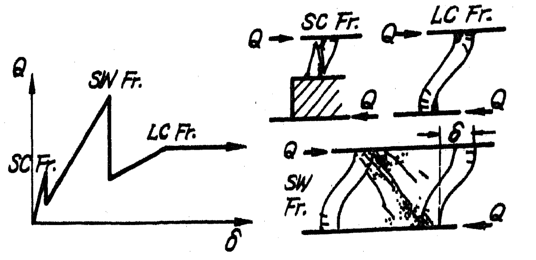


Fig4. Fracture Modes in Q - δ Relation

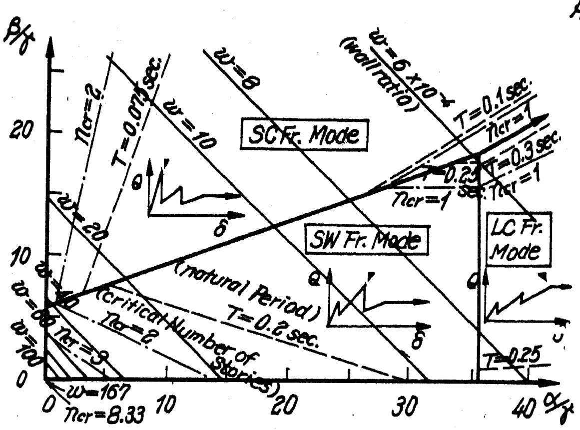


Fig.5 Aseismic Characteristics of Middle and Low Rise Reinforced Concrete Buildings

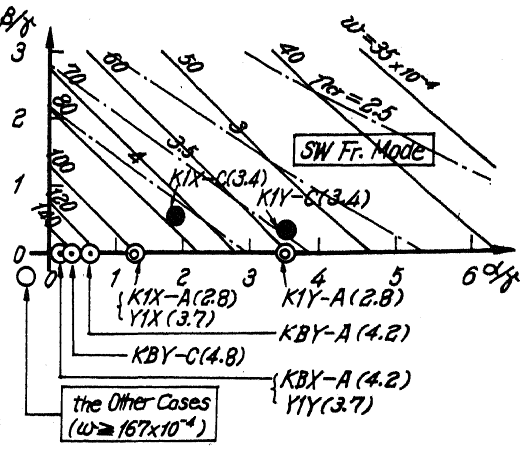


Fig.6 Evaluation of Aseismic Capacity in α/γ-β/γ Plane

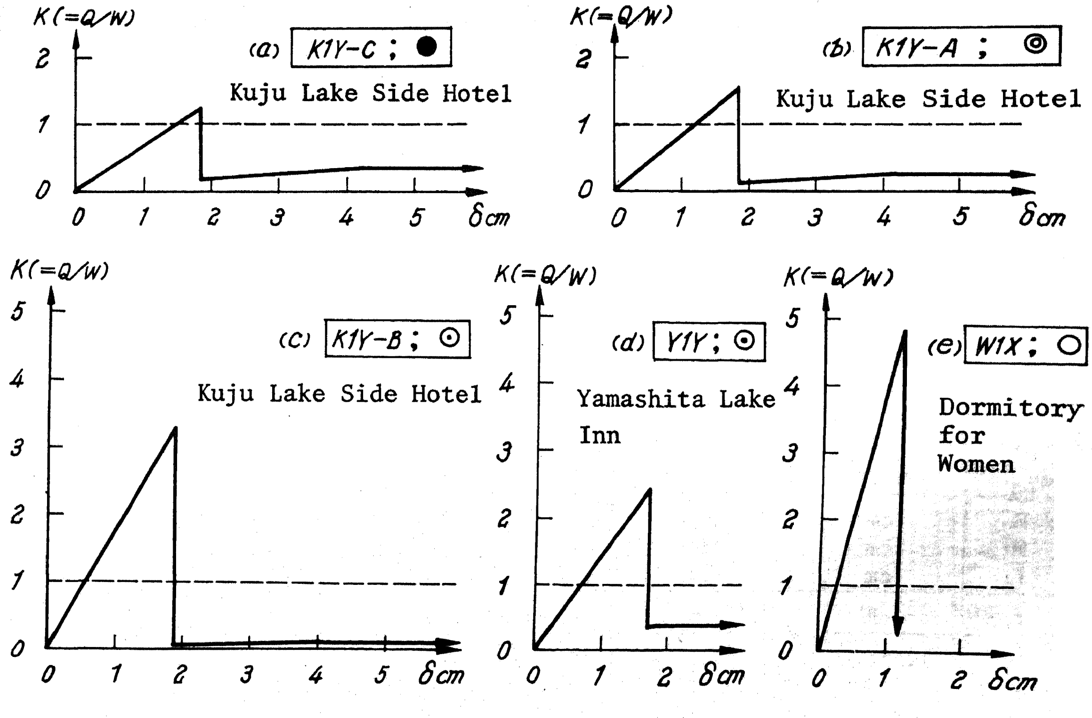


Fig.7 Relationships between Story Shear Force Coefficient K and Lateral Displacement δ

Table 1 Values of Aseismic Factors

Notation Unit	Damage	w cm²/m²	$\overline{W}$(W/A) t/m²	α Number	β Number
KBX-A*1	*6	152*2	4.2*2	28	0
KBY-A	⊙	125	4.2	27	0
KBX-B	⊙	210	6.0	13	0
KBY-B	⊙	180	6.0	18	0
KBX-C	⊙	174	4.8	15	0
KBY-C	⊙	142	4.8	24	0
K1X-A	◎	100	2.8	21	0
K1Y-A	◎	60	2.8	29	0
K1X-B	⊙	265	4.5	11	0
K1Y-B	⊙	224	4.5	5	0
K1X-C	●	73	3.4	25	7
K1Y-C	●	57	3.4	35	3
K2X-A	⊙	212	4.6	18	0
K2Y-A	⊙	373	4.6	2	1
K2X-B	⊙	335	7.0	6	0
K2Y-B	⊙	329	7.0	3	4
K2X-C	⊙	188	4.3	14	0
K2Y-C	⊙	297	4.3	1	3
Y1X	⊙	100*3	3.7*4	28	0
Y1Y	⊙	153*3	3.7*4	22	0
W1X	○	335*3	3.6*4	0	0
W1Y	○	200*3	3.6*4	2	0
M1X,Y	○	≧180*5	2.4*4	0	0

*1 Notation of RC Buildings

□□□-□
- Name of Block (only in K)
- Direction (X or Y)
- Number of Story
- Symbol of Buildings (shown in Fig.1)

*2 Data on Kuju Lake Side Hotel are refered to Bibliography [2]
*3 Expected Values
*4 as $W/A = 1.2\ t/m^2$
*5 as RC Wall Type Structure
*6 Grade of Damages

- ● Catastrophe
- ◎ Heavy or Middle
- ⊙ Light
- ○ Sound

Table 2 Structural Dimensions

Notation	Unit	Stand. (Fig.5)	K1Y-C	K1Y-A	K1Y-B	Y1Y	W1X
f_c	kg/cm²	200			200		
σ_y	kg/cm²	4000			3500		
p_t	%	0.65	0.90	0.90	0.90	0.37	—
ψ	—	0.13	0.157	0.157	0.157	0.064	—
b	cm	60	55	55	55	65	—
D	cm	60	55	55	55	65	—
d_{t1}	cm/cm	0.1	0.1	0.1	0.1	0.1	—
H	cm	300	450	450	450	300	230
H'	cm	150	75	—	—	—	—
L	cm	600	550	550	550	700	450
t	cm	20	15	15	15	15	12
α	Number	α	35	29	5	22	—
β	of	β	3	—	—	—	—
γ	Pieces	γ	6	8.4	10.4	13	10
W	ton	$L^2(\alpha+\beta+2\gamma)$	3001	3250	1737	3250	600