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Autor: Higashi, Yoichi
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Repair of Damaged Floor Slabs

Réparation de planchers endommagés

Instandsetzung von Gebäudedecken

Yoichi HIGASHI
Prof. Dr.-Eng.
Tokyo Metropolitan Univ.
Tokyo, Japan

Y. Higashi, born 1921, received his engineering degree at Tokyo University. For 30 years, he has studied on the theory of structure and the reinforced concrete structure.

SUMMARY

The crack pattern and deflection of 48 damaged slabs in a 5-story reinforced concrete building with wide cracks and large deflections were measured. Two repair methods proposed were injection of epoxy resin into the cracks, and the casting of a concrete or mortar layer over the damaged slabs, depending on the degree of damage. Loading tests on one-way slab specimens similar to the actual slabs, and vibration tests on the actual slabs were carried out before and after repairing. The results of these tests show that the proposed methods of repair were very effective for the damaged slabs.

RESUME

Les fissures et les flèches de 48 planchers endommagés ont été mesurés. L'auteur propose deux méthodes de réparation, en fonction du dommage; l'une consiste à injecter de la résine d'époxy dans les fissures et l'autre, de superposer une couche de ciment ou de béton au-dessus du plancher endommagé. Les essais de charge sont réalisés sur des éprouvettes semblables. Des essais de vibration sur les planchers endommagés avant et après réparation sont effectués. Ceux-ci ont démontré l'efficacité des réparations proposées.

ZUSAMMENFASSUNG

Die Risse und die Durchbiegungen von 48 schadhaften Decken eines 5-stöckigen Stahlbetongebäudes wurden gemessen. Für die Reparatur wurde das Vergiessen der Risse mit Epoxidharz und das Aufbringen einer Beton- oder Mörtelschicht (je nach Beschädigung) vorgeschlagen. Statische Belastungsversuche bis zum Bruch an gleichartigen Platten sowie dynamische Versuche an den reparierten Decken wurden durchgeführt. Die Ergebnisse zeigten die Wirksamkeit der Reparaturmethoden.

1. INTRODUCTION

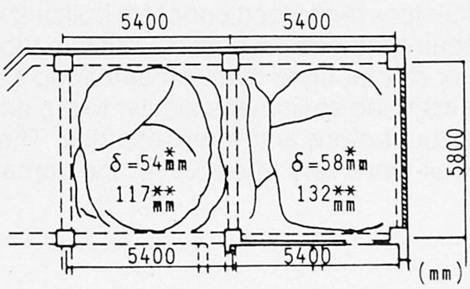
Recently, it has been a social problem that there were many floor slabs with wide cracks and large deflection under long-term load.[1),2)] The slabs of the building structures in Japan were generally composed of reinforced concrete two-way floor slabs monolithic with perimeter beams. In such slabs constructed before 4-5 years, many wide cracks at edges of the upper surface and at the center of the lower surface, and large deflection amounted to 2-6 cm have occured. Fig.1 and Fig.2 show the slabs with wide cracks and large deflection. These happened the residents of the buildings to be anxious about load capacity and to be inconvenient for living. The reasons of occuring such trouble of the slabs seemed to be bad quality of concrete, lack of curing times, lack of the slab thickness, lack of the effective depth of the slab by sinking of the upper reinforcements as construction, and overload during and after construction. Because of lack of publication and investigation about these troubles, the appropriate guides and methods to prevent such damages have been not established.

The objects of this study are to propose the methods to judge the damageness of the slabs and the methods to repair such damaged slabs and to discuss the effects by tests. In this study, the following investigation and tests were carried out.

1) measuring crack patterns and deflection of the damaged slabs in a apartment houses of reinforced concrete wall structure,
2) measuring the stiffness and strength of such slabs by loading tests and measuring the natural frequency by vibration tests to drop the steel ball,
3) proposing the repair methods to inject epoxy resin into cracks and to cast concrete on the damaged slabs,
4) tests on the one-way slab speciments damaged and repaired, whose span and depth were almost equal to the measured slabs,
5) vibration tests on the actual repaired slabs, in order to confirm the effects of repair.

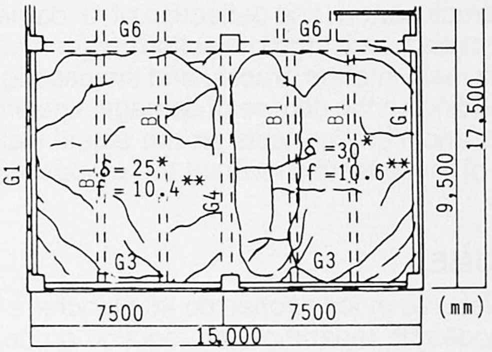
2. CRACK PATTERNS AND DEFLECTION OF THE DAMAGED SLABS IN ACTUAL BUILDING

Crack patterns and deflection of 48 damaged slabs of 16 flats in a actual 5-story apartment houses of reinforced concrete wall structure were measured.[5)] The plan of a flat is shown in Fig.3. The slabs consisted of three types, namely, SI (center to center span is 3.78 x 7.23 m), SII (3.78 x 6.39 m), SIII (3.78 x 3.78 m).



1) construction year :1961
2) girder section :350 x 700 mm
3) design depth :130 mm
4) natural frequency :
(12.5-13.0 Hz,before repair)
(18.2-20.5 Hz,after repair)
* : measured deflection at the center
**: measured depth

Fig.1 Square slabs with wide span[6)]



1) construction year : 1972
2) girder section(G1,G4);350 x 750 mm
(G3,G6);400 x 750 mm
3) beam section B1 ;300 x 650 mm
4) design depth ;120 mm
* : measured deflection at the center
**: measured frequency

Fig.2 Slabs with beams in a office Building[6)]

Figure 4 shows crack patterns of the most damaged slab. Cracks by constrain and shrinkage and by bending moment were mixed in the slab , but almost of wide cracks seemed to be by bending moment, judging from their occured place. There were many cracks whose width was more than 1.0 mm, and the width of a few cracks along the edges of short span reached 3.0 mm.

Table 1 shows the deflection at the center of SI and SII slabs and the total length of cracks at the upper and lower surfaces of the slabs. As the total length of the cracks increased, the deflection of the damaged slabs increased, and the deflection of two slabs were more than 4.0 cm.

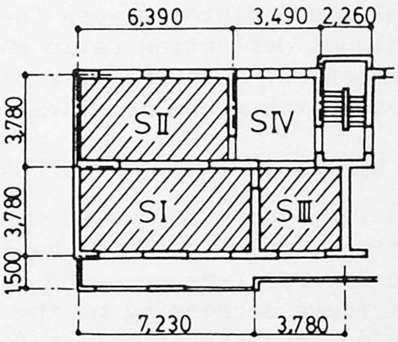
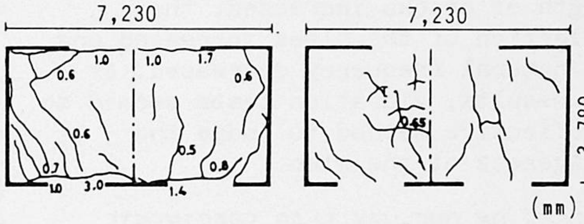


Fig.3 Plan of a flat

3.LOADING TESTS OF THE DAMAGED SLABS

In order to discuss the elastic behavior of the damaged slabs, loading tests were carried out on 4 pieces of SI slabs (3.78 x 7.23 m) in the houses named as 5D (story number is 5, flat number is D), 4D, 3A and 2C, whose damageness was differ from the others. These slabs were uniformly loaded by sacks of micro gravel (weigth is 30 kg) until the design live load (W_{LL}), and were unloaded after 4 hours. Residual deflection ratio, load-deflection curves and distribution of deflection were measured.



(a) Upper surface (b) Lower surface

Fig.4 Crack Patterns of the most damaged slab

Table.1 Measured results of the damaged slabs

story	flat number		A		B		C		D	
	type of slab		SI	SII	SI	SII	SI	SII	SI	SII
5	(1)	mm	98.0	95.0	106.0	—	116.0	—	108.0	109.0
	(2)	mm	39.0	21.0	26.3	16.0	19.5	4.5	48.3	17.5
	(3)	Hz	12.0	—	14.0	—	13.0	—	13.0	—
	(4)	m	137.0	112.0	106.0	79.0	71.0	79.0	105.0	102.0
4	(5)	m	25.0	33.0	32.0	8.0	22.0	29.0	22.0	23.0
	(1)	mm	107.0	—	106.0	104.0	120.0	—	—	—
	(2)	mm	15.0	11.0	27.5	15.5	35.0	16.0	43.3	27.0
	(3)	Hz	13.5	—	15.0	—	14.5	—	11.0	—
	(4)	m	35.0	38.0	36.0	27.0	29.0	23.0	26.0	20.0
3	(5)	m	3.0	5.0	7.0	8.0	17.0	8.0	13.0	9.0
	(1)	mm	100.0	—	102.0	100.0	115.0	—	—	—
	(2)	mm	11.5	8.0	27.5	28.5	8.5	2.5	14.8	6.5
	(3)	Hz	16.0	—	14.5	—	16.5	—	14.0	—
	(4)	m	27.0	20.0	32.0	21.0	30.0	25.0	22.0	8.0
2	(5)	m	7.0	6.0	7.0	8.0	7.0	4.0	8.0	2.0
	(1)	mm	107.0	—	100.0	—	117.0	—	113.0	100.0
	(2)	mm	21.5	10.0	25.8	17.0	24.3	12.5	31.0	20.5
	(3)	Hz	17.0	—	14.5	—	15.5	—	13.5	—
	(4)	m	37.0	30.0	62.0	46.0	17.0	71.0	81.0	77.0
1	(5)	m	7.0	0.0	10.0	6.0	6.0	3.0	7.0	3.0

(1) Slab depth
(2) Deflection at the center
(3) Natural frequency
(4) Total length of cracks on the upper surface
(5) Total length of cracks on the lower surface

Figure 5 shows the load-deflection curves of the slabs. The values of calculated stiffness with fixed edges and with supported edges were shown by the dotted lines, in this figure.The stiffness of the slab in 2C,which were damaged little, was intermediate between the both calculated values. But the stiffness and residual deflection ratio showed tendency to be larger, corresponding to their dameganess. However, these slabs were confirmed to have enough load capacity, because the slabs were kept in elastic under design live load, as shown in Fig.5.

4. VIBRATION TESTS OF THE DAMAGED SLABS

The free vebration waves of the slabs were measured by the pick-up for vertical motions, when the steel ball falled on the slabs from a heigth of 28 cm. Reading the natural frequency and maximum amplitude of the slabs from those waves, the stiffness decreasing of the slab was discussed.[5] The tests results were shown in Table 1 and Fig.6. It was found that the natural frequency decreased as the deflection of the damaged slabs increased. It showed a similar tendency to the results of other's studies.[2),6] Judging from Table 1, as the total length of cracks increased, the deflection of the slabs increased and the natural frequency decreased. As the results, vibration tests seemed to be effective method to judge the dameganess of the slab.

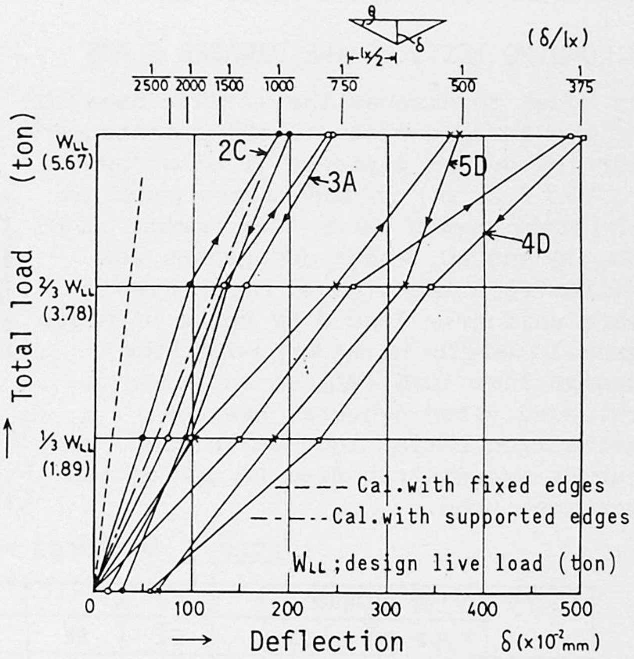


Fig.5 Loading tests results

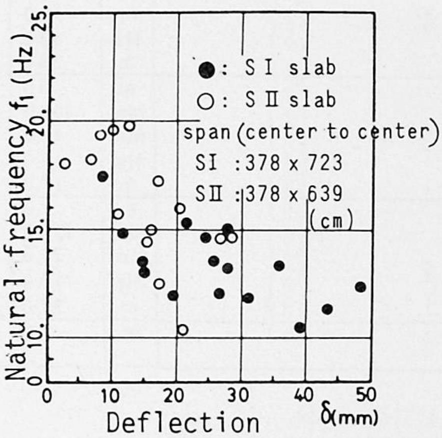


Fig.6 Vibration tests results

5.TESTS ON ONE-WAY SLAB SPECIMENTS FOR STUDY ON THE REPAIR METHODS

16 one-way slab specimens of reinforced concrete, whose depth and span were similar to SI slab and whose width was 30 cm , were tested under short-term and long-term loading before and after repair by various methods, and the effects of the repair methods were discussed.[3),4)]

The following three repair methods were combinated to use, and the repair methods of each specimens were shown in Table 2 and 3.

1) injecting epoxy resin into cracks whose width were more than 0.3 mm,

2) casting normal concrete or light-weight concrete or mortal on the damaged slab,

3) reinforcing by deformed bars (D13) or wire mesh (3.2 mm diameter @ 20.0 cm) as casting concrete or mortal.

5.1 Tests under Short-Term Loading

Each specimen was loaded by many oil jacks as shown Fig.7 until the residual deflection reached the values shown in Table 2, and was unloaded after cracks occured. And the specimens were reloaded after repaired as shown in Fig.8. The load-deflection curves of the specimens were shown in Fig.9, and the natural frequency by vibration tests and the stiffness and deflection were shown in Table 2. The stiffness of the slabs repaired by injecting epoxy resin into cracks increased by 0.78-0.96 as that of the damaged slab.

Moreover, the stiffness, natural frequency and load capacity of the slabs repaired by casting concrete increased, as the depth of concrete increased. Especially, the stiffness, natural frequency and load capacity of the slabs repaired by casting concrete after injecting epoxy resin were by far more than those of the undamaged slabs. These repair methods seemed to be very effective for the damaged slabs.

5.2 Tests under Long-Term Loading

8 one-way slab specimens of similar section and arrangement as shown in Fig.10 were uniformly loaded steel plates until the residual deflection reached the values shown in Table 3, and they were unloaded after cracks occured. After repair shown in Fig.8, the specimens were loaded under long-term live load for design (w_{LL} = 180 kg/cm^2).

The long-term deflection increase of each specimens was shown in Fig.11. The deflection increase of all slabs were almost constant after 450 days. The deflection of No.13 slab repaired by injecting epoxy resin into cracks was 60 % of No.12 slab damaged and was almost equal to that of No.11 slab undamaged. As the depth of casting concrete increased, the degree of the deflection increase became smaller than that of the undamaged slab.

The repair method by casting concrete after injecting epoxy resin into cracks did not only increase the stiffness and load capacity of the damaged slabs under short-term loading, but also was very effective for decreasing the deflection under long-term loading.

6. PROPOSAL REPAIR METHOD FOR THE DAMAGED SALBS

As the results of measuring the crack patterns and the deflection of damaged slabs, loading tests and vibration tests of the actual slabs, and loading tests of the one-way slab specimens, the damageness could be well judged by the deflection at the center of the slabs, and natural

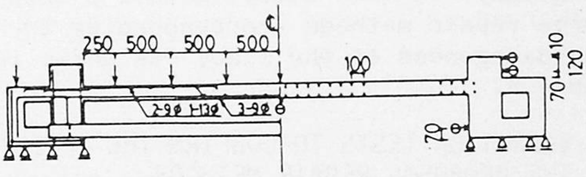


Fig.7 Specimen of short-term loading tests

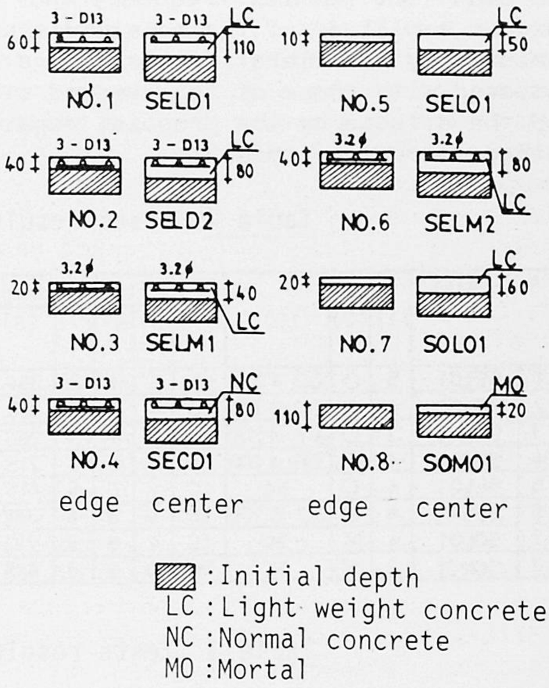


Fig.8 Sections of repaired slabs

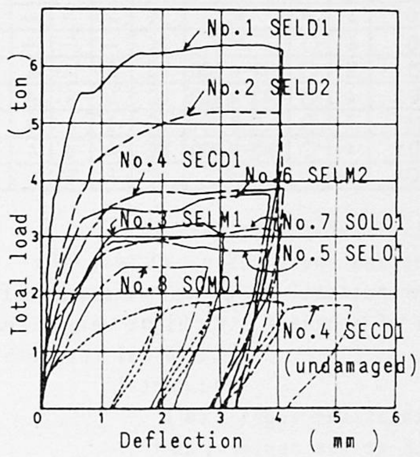
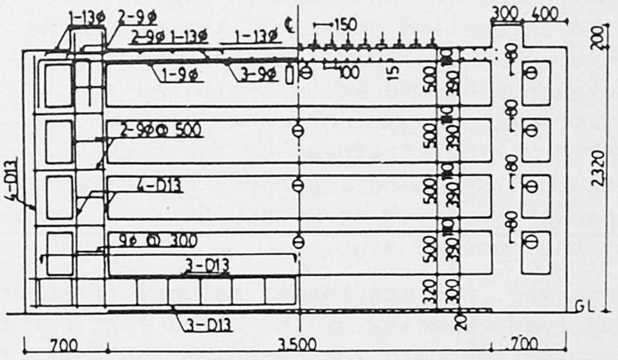


Fig.9 Load-deflection curves of the short-term loading tests

frequency. In this study, author proposed three repair methods ,corresponding to the damageness of the slab, as shown in Table 4.

7. VIBRATION TESTS TO CONFIRM THE EFFECTS OF THE PROPOSAL REPAIR METHODS

The above 48 damaged slabs of 16 flats in the actual 5-story apartment houses of reinforced concrete were repaired by the proposal methods. The repaired slabs consisted of three types, namely, SI,SII and SIII. The natural frequency and maximum amplitude of the repaired slabs measured by the vibration tests were compared with those of the damaged slabs, and the effects by the proposal repair methods were confirmed.[5]



bar arrangement   loading and measured points

Fig.10 Specimens of long-term loading tests

Table 2 Tests results under short-term loading

Specimens		(1)	(2)	(3)	(4)	Material property of concrete (5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13) W_H ton	(14) f Hz	(15) W_{RM} ton	(16) f_R Hz	$\frac{W_{RM}}{W_H}$	$\frac{f_R}{f}$
1	SELD1	5	O	D13 a 200	LC	6	11	3	354	1.4	0.32	1.65	7	3.09	26.4	7.17	44.0	2.32	1.67
2	SELD2	4	O	D13 a 200	LC	4	8	3	358	1.4	0.25	1.65		2.87	27.4	5.90	29.1	2.06	1.06
3	SELM1	2	O	3.2 @ 200	LC	2	4	3	286	1.4	0.21	1.60		2.62	25.9	3.64	28.2	1.39	1.09
4	SECD1	4	O	D13 a 200	NC	4	8	3	215	1.7	0.28	2.23	5	2.36	24.6	4.63	28.6	1.96	1.16
5	SELO1	4	O	X	LC	1	5	6	415	1.39	0.39	1.65		2.66	21.2	3.51	23.8	1.32	1.12
6	SELM2	4	O	3.2 @ 200	LC	4	8	6	388	1.34	0.36	1.65		2.46	20.4	4.45	26.3	1.81	1.29
7	SOLO1	4	X	X	LC	2	6	6	282	1,20	0.35	1.65		2.56	25.0	3.89	24.8	1.52	0.99
8	SOMO1	2	X	X	MO	0	2	6	425	2.09	0.32	—		2.51	23.8	3.03	21.4	1.21	0.90

Table 3 Tests results under long-term loading

Specimens		(1)	(2)	(3)	Material propaerty of concrete for repair (4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)		(13) W_M (ton)	(14) (c m)	Natural frequency (17) f_1	(18) f_2	(19) f_3	(20) f_4
11	LO001	0	X	X	X	—	—	—	—	—	—	—		—	—	18.1	—	—	—
12	LO002	4	X	X	X	—	—	—	—	—	—	—		2.21	3.65	20.4	19.5	—	—
13	LEO01	4	O	X	X	—	—	—	—	—	—	—		2.43	4.38	23.0	17.0	18.2	—
14	LELD1	5	O	D13- a 200	LC	6	11	4	363	1.36	0.34	1.65		2.93	6.63	25.5	17.4	20.1	39.8
15	LELD2	4	O	D13- a 200	LC	4	8	4	335	1.34	0.36	1.65		2.29	3.58	23.4	16.9	21.8	33.3
16	LELM1	2	O	3.2 @ 200	LC	2	4	4	—	—	—	—		1.77	1.97	23.6	15.4	21.0	27.3
17	LECD1	4	O	D13- a 200	NC	4	8	4	187	2.15	0.32	2.23		2.04	4.78	23.7	18.6	/	29.6
18	LELO1	4	O	X	LC	1	5	4	369	1.34	0.34	1.65		2.97	3.08	24.6	17.2	19.3	25.4

(1) Initial deflection (cm)
(2) Injecting epoxy resin O;Yes, X;No
(3) Reinforcement (x: No reinforcement)
(4) Type of concrete LC : Light weight concrete
NC : Normal concrete
MO : Mortal
(5) Depth at the edges (cm)
(6) Depth at the center (cm)
(7) Curing term (week)
(8) Compressive strength of concrete (kg/cm^2)
(9) Initial elastic modulus of concrete ($\times 10^6$ kg/cm^2)
(10) Strain at peak stress (%)
(11) Specific gravity

(12) Numbers of loading point
(13) Maximum load capacity of damaged slab(ton)
(14) natural frequency of damaged slab (Hz)
(15) Maximum load capacity of repaired slab(ton)
(16) Natural frequency of repaired slab (Hz)
(17) Natural frequency of undamaged slab (Hz)
(18) Natural frequency of damaged slab (Hz)
(19) Natural frequency of slab repaired by injecting epoxy (Hz)
(20) Natural frequency of slab repaired by injecting epoxy and casting concrete (Hz)

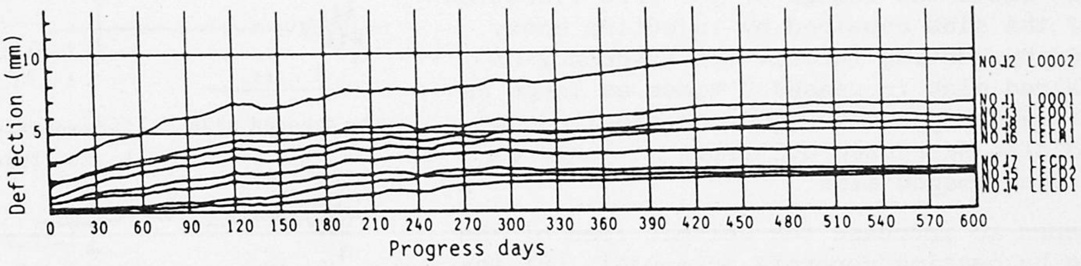


Fig.11 Long-term deflection increasing

Table 4 The Proposal repair methods

Damageness		methods
Deflection at the center δ (mm)	Natural frequency f (Hz)	
$\delta \leqq 15$	$f \geqq 15$	injecting epoxy resin into cracks whose width were more than 0.3 mm
$15 < \delta < 40$	$12 < f < 15$	casting mortal after injecting epoxy resin into cracks
$\delta \geqq 40$	$f \geqq 12$	casting concrete with reinforcing by wire mesh after injecting epoxy resin

Figure 12 shows the change of the natural frequency of the slabs repaired by injecting epoxy resin into cracks. The natural frequency of repaired slabs increased about 20-30 % than that of the damaged slabs. The measured results of the slabs repaired by casting mortal or concrete were shown in the dotted lines of Fig.12, and the natural frequency of such repaired slabs increased remarkably.

Figure 13 shows the relations between the natural frequency and maximum amplitude of the repaired slabs. The frequency increased and the amplitude decreased by injecting epoxy resin and still more by casting mortal or concrete.

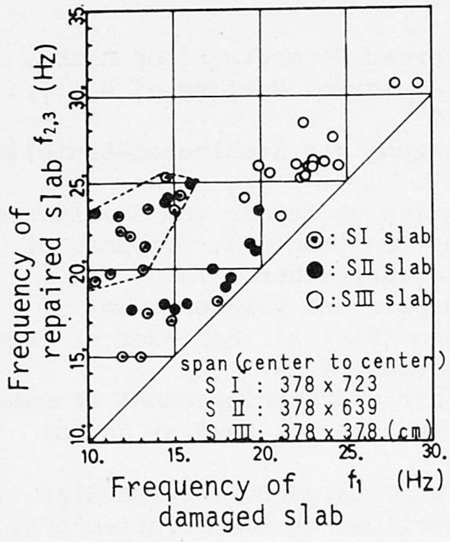


Fig.12 Increase of the Natural frequency of the slabs

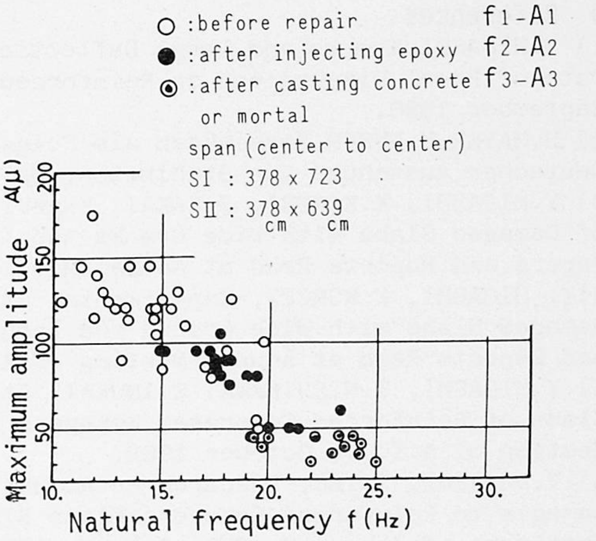


Fig.13 Relations between natural frequency and maximum amplitude

Figure 14 shows the change of the free vibration waves of the slab repaired by injecting epoxy resin and by casting mortal. The frequency of the repaired slab increased 2 times as large as that of the damaged slab, and the amplitude of repaired slab decreased 0.2 times as large as that of the damaged slab.

It happened to increase the seismic load of the building by casting concrete or mortal, but the increasing degree was less than 2 %, and it mattered little to consider the increase of the seismic load for design on this building

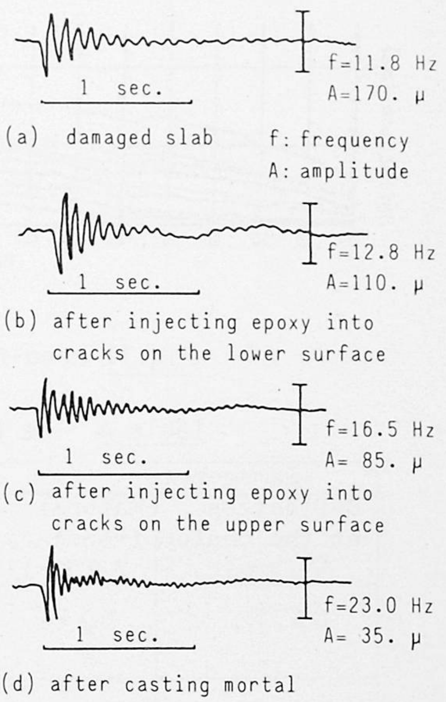


Fig.14 Waves changing of the repaired slab

8.CONCLUSION

1) As the measured results of the damaged floor slabs with wide cracks and large deflection, the stiffness by loading tests on the damaged slabs decreased and the natural frequency by vibration tests decreased, as the damageness of the slabs increased.
The damageness of the slabs could be judged from the deflection and natural frequency.
2) Author proposed the repair method by injecting epoxy resin into cracks and the strengthing methods by casting concrete or mortal on the damaged slab with or without reinforcing to increase the stiffness and load capacity, corresponding to the damageness of the slab.
3) The stiffness and load capacity of the one-way slab specimens repaired by injecting epoxy resin into cracks and by casting concrete or mortal on the surface were far more than those of the damgaed slabs and undamaged slabs.
The proposal repair methods seemed to be very effective for the damaged slabs.
4) As the results of vibration tests on the actual slabs, the natural frequency of the slabs repaired by injecting epoxy resin into crcaks and casting concrete or mortal were more than those of the damaged slabs.
It was confirmed that the proposal repair methods were very effective for the damaged slabs.

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