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ON THE DAMAGE TO THE HAKODATE COLLEGE BY THE TOKACHIOKI EARTHQUAKE, 1968

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1. General view of the damages to reinforced concrete buildings in Hakodate City

Only one four-storied school-building of reinforced concrete construction at the Hakodate College was heavily destroyed by the Tokachioki earthquake, 1968, although the other reinforced concrete buildings in the same area suffered a little or no damage.

The campus of the College is situated on a hill in the eastern suburbs of Hakodate City as is shown in Fig. 1. Originally, there were four buildings in the campus as is shown in Fig. 2: one steel-framed gymnasium and three reinforced concrete buildings (the main four-storied school-building, a three-storied school-building and a three-storied dormitory).

The Hakodate Technical College which has a number of reinforced concrete buildings is located near this campus: a three-storied school-building, three three-storied dormitories and ten two-storied dwelling-houses.

After the earthquake, some cracks were observed in these buildings, but almost no damage was detected in their structural strength, excepting the four-storied building the present paper is now concerned.

Speaking of the damaged buildings in Hakodate City, details of damages in all the reinforced concrete buildings in four specific regions shown in Fig. 1 were investigated. The number of buildings of reinforced concrete in these regions was 270 at the time of the earthquake, but the number of damaged buildings was rather small. Fig. 1. shows the percentages of these damaged buildings, where symbol N means no damage and M_A, M_B, S_A, S_B mean the following classifications of damages:

- M_A: partially damaged in the reinforced concrete frames and the earthquake-resisting walls, in which some repair is required.
- M_B: somewhat damaged in the expansion joints, outdoor emergancy staircases, penthouses of the roofs, chimneys and attached corridors, in which some repair is required.
- S_A: cracks were observed in the reinforced concrete frames and the earthquake-resisting walls, in which no repair is required.
- S_B: slightly damaged in non-structural members like partition walls, curtain walls and fixtures.

The above-mentioned observations include 24 school-buildings of primary schools, middle schools and high schools. A half of them are three-storied and the remaining each quarter is four-storied and two-storied. Distribution of the degree of damages is classified according to the items of damages as follows: M_A-1, M_B-0, S_A-7, S_B-8, N-8. The data show that the number of buildings with no damage is about one-third of the observed school-buildings.

It is notable that this result is considerably different from the percentage of buildings with no damage in whole number of observed buildings.

2. Structure of the destroyed school-building of the Hakodate College

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This four-storied school-building had a long and narrow plan of an open L-shape as is shown in Fig. 3. The east wing (9.1 m $\times$ 27.3 m) was finished in 1964 and the north-west wing (9.1 m $\times$ 72.8 m) was constructed in 1966. There was an expansion joint near the bent corner of the building which was included in the second work of construction. The structure of this expansion joint was somewhat incomplete, because the floor slab of each story was constructed continuously over the joint, although the external girders and walls were separated from the columns at the joint (see Fig. 3).

In the structural design, the columns were 50 cm $\times$ 80 cm which is the common dimension in each floor. The axial reinforcement of the column in the first story consisted of 26 plain bars of 22 mm diameter and the reinforcing ratio corresponded to 2.47 %. Hoops were 9 mm in diameter and the spacing was specified to be 200 mm throughout the whole length of the column.

The wall girders in the long direction of the building were 20 cm in thickness and 150 cm in depth, to which the floor slabs were connected at the middle of the girder depth. These girders were connected to the columns so that the insides of girder and column were flush as is shown in Fig. 4. The eccentricity between the axes of girder and column was 30 cm. The footing girders in the same direction had a cross-section of 20 cm $\times$ 180 cm and the eccentricity between girder and column was the same as those in the upper floors.

Besides the above-mentioned structural columns, there were non-structural pilasters which had a cross-section of 45 cm $\times$ 57 cm in the middle of each spacing between structural columns. The pilasters were reinforced with only four plain bars of 16 mm diameter and they had no foundation. About a half of pilasters were used as the chimneys with clay pipes inside.

The dimension of girders in the short direction was 40 cm $\times$ 75 $\sim$ 100 cm. The beams in the short direction of 30 cm $\times$ 70 cm were also arranged in the middle of each spacing between girders, rigidly connected to the pilasters.

There were considerably small amounts of bearing walls in this school-building, as is shown in Table 1.

3. Details of the damage

Newspapers reported immediately after the earthquake that the four-storied building collapsed into three-storied one in a moment (Fig. 6). Almost all of the columns and walls in the first story were exhaustively destroyed. These damages were considerably intensified by the aftershock which attacked the building in the evening on the same day.

There was some difference of damages between the north-west wing block and the east wing block of the building. In the former, the skeleton upper than the second story fell down so that the bottom of wall-girders of the second floor touched the top of the first floor wall-girders, because all of the columns in the first story were destroyed into pieces (Fig. 7). Regarding the upper stories, the columns and wall-girders in the middle one-third of the north-west wing were severely damaged (Fig. 9). Especially, the girder-column joints were destroyed and the pilasters fell down separated from the wall-girder (Fig.10). In the east wing, the damages of columns of the first story were some what less and the columns at the east end of the building kept almost their original forms, though many severe cracks were observed on them (Fig. 8). These crack patterns suggested that the column would be subjected to a large shearing force in the long direction of the building (Fig. 11).

Almost all of the columns in the upper stories of the whole building also had many shear cracks of the same kind (Fig. 12, 13). Some spiral cracks which spread on the surfaces of columns were also observed. This feature of cracks suggested that the columns would be subjected to considerably large torsional moments (Fig. 14).

Of course, all of the walls in the first story were damaged. The walls with a thickness of 10 cm around the main entrance, which was situated in the center of the east wing, were obliquely shorn into two parts and fell down overlapping each other (Fig. 15).

The walls with the thickness of 12 cm, which were located at the both sides of the staircase in the middle of the north-west wing, were badly damaged in the first story, so that the staircase from the first floor to the second floor was destroyed (Fig. 9).

The external wall with thickness of 20 cm which was located at the bent cornor of the building was broken as will be seen in Fig. 16.

Moreover, the emergency staircase of steel construction which was anchored to the outside of the north-west end wall was shaken off and overturned.

4. Informations obtained from the sufferers of the earthquake

When the earthquake attacked this building, about two hundred students were studying in the north-west wing block in four classes: one class in the second-story, two classes in the third-story and one class in the fourth-story. The informations obtained from these students and professors could be summerized as follows:

(1) The vibration of the building in the short direction became severe in the first 15 seconds, then it continued more than two minutes. About a half of students (all students in the second-story and a large part of students in the third-story) took their refuge to the outdoor passing through down the staircase in the north-west wing. However, the other students, especially almost all students in the fourth-story stayed in their lecture-room by the guidance of the professor.

(2) Some students who intended to take refuge a little later found the destruction of the staircase in the first-story, and ran toward the outdoor emergency staircase. Unfortunately this staircase was overturned and a student who was descending along the staircase was shaken off and heavily injured.

(3) After about three minutes from the beginning of the earthquake, (it was impossible to prove this period), the students who still stayed in the upper stories felt a shock and then they felt as if they were on the descending elevator, because the floors fell down slowly about two meters. People who had already taken refuge on the ground reported that the building block B severely knocked on the block A, and then the block A knocked on the block B, and that immediately after these knockings the whole building fell down as slow as a slow-motion picture.

(4) After the earthquake ceased, the students in the upper stories tried to take refuge along the firehoses which were hanged from the window to the ground and four students including a female student succeeded. In the meanwhile it was informed that the staircase in the east end of the building as well as the corridors of upper stories were still available to pass through, and all persons could safely go outside.

5. Checkup of the structural design of the building

The structure of the building was calculated by the "Standard Method for the Calculation of Reinforced Concrete Structures" recommended by Architectural Institute of Japan. The strength of concrete was specified to be 180 kg/cm^2 and the coefficient of horizontal force was assumed to be 0.18. The procedure of numerical calculation was generally acceptable, but the following questions were remained on the structural design:

(1) The connecting joint of column and wall-girder.

a) The eccentricity between the axes of wall-girder and column would cause a torsional moment in the column (Fig. 14). However, the effect of this eccentricity had been neglected.

b) There was no consideration to secure the anchorage of the reinforcement of wall-girder to the column. Moreover, some of the reinforcement of wall-girder was arranged outside the reinforcement of the column (Fig. 4).

c) The effect of rigid zone of joint panel was neglected in the stress analysis. It would derive unsafe error for the estimation of bending moments of the members.

(2) The axial reinforcement of column

The axial reinforcement of column was saved about 20 % by taking the adjacent reinforcement into consideration as is shown in Fig. 5. In the normal calculation, the reinforcement should be 34-22ϕ instead of 26-22ϕ which was specified in the blue-print. It had been already clarified by the authors that those kinds of saving of axial reinforcement would derive a pretty amount of decrease in column strength in case of bi-axial bending moment.

(3) Pilasters and internal walls

Since the pilasters and the internal walls which had actually a large stiffness in the original state were neglected in the stress analysis, they had very poor reinforcement. Therefore, it can be supposed that the pilasters and those walls would easily be destroyed, because they would have pretty large share of shearing force at first. It can also be supposed that their destruction would cause a sudden increase of shearing force in the main columns.

(4) Incomplete expansion joint

The structures were calculated by assuming that the building consisted of two isolated blocks. However, the floor slab of each story was constructed continuously over the expansion joint. It would be very difficult to estimate the effect of the interaction between two blocks in the case of a severe earthquake.

6. Some investigations after the earthquake

(1) The foundation of the building

In spite of the heavy damages of the building, it seemed that the foundation of every column was not damaged, because the cracks which were observed in the footing-tie wall-girders were very slight. The result of the survey on the level of whole footing-tie wall-girders which was undertaken by Mr. S. Takamiya showed a maximum unevenness of about 3 cm. However, it is difficult to judge whether this unevenness was directly caused by the earthquake or it was inherent from the time of construction.

The authors made a load test on the ground near the building to obtain the load-depression curves shown in Fig. 17. As the estimated weight of the building on each footing of column was about 20 t/m^2, it could be supposed that the design of footing had been reasonably acceptable and probably uneven setting of the foundation would not occur even in the case of the earthquake so far as the above-mentioned load test is referred.

(2) The geological survey of the underground

Mr. S. Takamiya made a number of core-boring tests of the underground near the damaged building as is shown in Fig. 18.

The basic stratum of tuff is distributed at 8～9 meters under the ground surface. There are two layers of sandy loam of about 3 meters thickness above the stratum of tuff. The penetration test shows a comparatively small N-value for the lower layer. Besides, a very soft humus of 30～40 cm thickness is sandwitched between these two layers.

(3) Period of micro-tremor of the ground

An investigation on the micro-tremor of the grounds was carried out by Mr. M. Kawaji. The results shown in Table 2 suggest that the ground near the destroyed building might have a singular property for the earthquake compared with the other ground.

(4) Quality of concrete used for the building

According to the observation on the crushed pieces of the concrete, the mixture consited of too much fine sands and very little quantity of gravels. The compressive strength presumed from the Schmidt hammer test were considerably less than the designed strength as are shown in Table 3. Further, the compressive strength of concrete sampled from the skeleton of building also showed poor values as are shown in Table 4. These facts immediately mean that the shearing strength of concrete as well as bond strength between concrete and reinforcement were also inferior to the specified values in design. Of course, the influence of the low strength of concrete is to be most serious for the column.

(5) Details of actual columns

The cross-sections of 43 columns in the first story were carefully measured and it was found that 12 columns had obviously smaller dimensions than the designed cross-section.

As regards the hoops of columns, they were distributed with a spacing of about 250 mm though the spacing was specified to be 200 mm. Moreover, there was no hoop in the column at some of the joint panels of columns and girders.

(6) Period of proper vibration of building

An approximate calculation on the period of proper vibration of the north-west wing of the destroyed building was performed by the following assumptions:

(a) The expansion joint was sufficiently effective.

(b) Lateral shear distribution coefficient for the column was estimated by "Dr. Muto's method". As regards the wall, the shearing deformation was taken into consideration.

(c) The vertical load was taken as the sum of the dead load and the decreased live-load according to the official specification of Japanese Building Code.

(d) In the calculation for the short direction, bending and shearing deformations of slabs were taken into account. The two-dimensional model of 4 mass points in vertical direction and 8 mass points in long direction was adopted to represent the building structure.

(e) The period of proper vibration was calculated by "Power Method".

The results are summerized in Table 5,
where A: all of the columns and pilasters had the stiffness, walls were also taken into consideration.
A': walls in the first story on the both sides of the staircase lost their resistance.
B: only the pilasters in the first story lost their stiffness.
C: all of the pilasters and walls in every story lost their stiffness.

The results of the same kind of the calculation on the non-damaged school-building are shown in Table 6. It must be noticed that the plan of the three-storied school-building was located perpendicular to that of the destroyed building.

(7) Experimental study on the models of the columns.

An experimental investigation was carried out to study the behavior of the failure of reinforced concrete member under the combined stress of axial force, bending moment and shearing force. The details of the investigation are described in another paper.

7. Presumption on the causes of the destruction

It is said that people felt the vibration in the short direction at first. If the informations obtained from them were reliable, the deformation of the building in the short direction would have influence on the first damage, though the vibration in the long direction would also take part in the failure. The authors presumed that the first damage of the building would be the failure of the walls around the staircase in the north-west wing block. Because, the walls were not designed to resist the shearing force, however the existence of walls would cause pretty large shearing force in them.

It was a special feature of this earthquake that nearly constant vibration continued more than two minutes after the main shock of about a half minute.

After the destruction of the above-mentioned walls, the period of the proper vibration of building would increase, as is suggested in Table 5(A'), and it would be possible that the deformation of building was intensified. The largest deformation of the structural frame would occur at the frame No.7 or No.8, because the building was connected with the east wing block at the frame No.16, and the frame No.1 was stiffened by the load-bearing wall. Moreover, the large deformation in the short direction of the frame would give rise to the additional deformation in the long direction due to the open L-shaped plan of the building.

It could be supposed that the repetition of such large deformations of the frame was continued for a few hundred cycles and that the bond strength between concrete and the axial reinforcement of column was gradually weakened.

Finally the columns of the frame No.7 or No.8 were destroyed because of the resultant shearing forces (in short direction and long direction) acted on the cracked columns. And then the failure of all the columns in the first story would be caused one after another. Therefore, the building looked like to have fallen down very slowly. Thus, the collapse of the building would have started at the middle one-third of the north-west wing block before the whole building was pulled down successively.

It can be supposed that the out-door emergency staircase would be shorn off from the wall when the building was collapsed.

Table 1. Wall rate in each direction of plan in the first story (cm/m^2)

	Collapsed building		Survived three-storied building
	East wing	North-west wing	
Short direction	12.2	2.6	4.5
Long direction	4.3	0.9	1.5

The wall rate means the ratio of the total length of walls in each direction of plan to the floor area. The values in the table are represented by converting into the nominal length of wall with a thickness of 15 cm so as to hold the cross-sectional area of wall the same with that of the actual wall.

Table 2. Period of micro-tremor (by Mr. M. Kawaji)

Orientation		N-S		E-W		U-D	
Position		Predom. period	Mean period	Predom. period	Mean period	Predom. period	Mean period
Around the destroyed building	a		0.36	(0.10 / 0.44)	0.26	(0.26 / 0.34)	0.29
	b	0.10	0.21	0.08	0.20	0.14	0.15
	1	0.18	0.22	0.18	0.20	0.16	0.16
	c	0.32	(0.48 / 0.50)		(0.56 / 0.44)		
	k		0.50		0.44		
	d	0.16	0.28	0.44	0.46	0.12	0.17
	e	0.44	0.42			0.14	0.22
	f	0.14	0.16	0.14	0.15	0.18	0.16
	s		0.52	0.54	0.51	0.16	0.24
	j				0.44		
	p		0.29	0.06	0.25	(0.18 / 0.34)	0.27
	r	(0.44 / 0.48)	0.45		0.35	0.14	0.21
The 3-storied school-building	g	0.10	0.10	0.08	0.12	0.08	0.10
	2	0.06	0.10	0.10	0.10	0.06	0.10
The dormitory	3	0.10	0.14	0.08	0.12	0.10	0.11
The Hakodate Techn. College	4	0.10	0.12	0.10	0.12	0.10	0.12
A high school	5	0.08	0.09	0.02	0.07	0.08	0.09
The Hakodate Weather Bureau in the city	6	0.10	0.13	0.12	0.15	0.10	0.15

Table 3. Concrete strength presumed by Schmidt hammer

	Column	Measured hardness R	Presumed strength F_c kg/cm^2
East Wing	1C S16-A	31.1	171
	1C S17	28.5	145
	1C S21	29.1	151
	1C N16	31.1	171
	1C N17	30.3	160
	1C N18	31.3	173
	1C N20	28.7	147
	Mean		159
North-west Wing	1C S4	28.9	149
	1C S5	30.1	161
	1C S6	26.2	122
	1C S8	29.4	154
	1C S9	25.3	113
	1C S10	31.9	179
	1C S12	33.0	190
	1C S13	37.1	230
	1C S16	34.8	208
	1C N1	23.0	90
	1C N2	26.5	125
	1C N10	28.4	144
	1C N11	35.2	212
	1C N13	23.7	97
	1C N15	22.0	80
	1C N16	29.9	159
	Mean		151

Hardness is the average value of measured values at 20 points.
The formula for presumption is $F_c = 10\,R - 140$.

Table 4. Concrete strength by core-sampling
(by Mr. T. Hattori)

The position		Size of test piece cm	Specific gravity	Compr. strength kg/cm^2	Young's mod. at $F_c/3$ $10^5\ kg/cm^2$
column	$_1C_{S9}$	$15^{\phi} \times 30$	2.21	108	1.52
	$_1C_{S7}$	$15^{\phi} \times 15$	2.18	151	
	$_1C_{N9}$	$15^{\phi} \times 15$	2.18	76	
	$_1C_{N7}$	$10.2^{\square} \times 20$	2.24	102	1.44
	$_1C_{N7}$	$10.2^{\square} \times 20$	2.25	103	1.27
	$_1C_{N8}$	$15^{\phi} \times 30$	2.22	(87)	1.38
	$_1C_{N8}$	$15^{\phi} \times 30$	2.23	96	
pilaster	$_1P_{N9}$	$15^{\phi} \times 30$	2.17	170	1.72
	$_1P_{N9}$	$15^{\phi} \times 30$	2.17	142	1.34
girder	$_2G_{S12}$	$15^{\phi} \times 15$	2.30	130	1.32

Table 5. The estimated period of proper vibration of the building (sec.)

		A	A'	B	C
Long direction	T_1	0.223	—	0.250	0.273
	T_2	0.076	—	0.081	0.095
	T_3	0.049	—	0.050	0.062
Short direction	T_1	0.229	0.283	0.401	0.552
	T_2	0.157	0.168	0.222	0.273
	T_3	0.110	0.114	0.122	0.192

Table 6. The estimated period of proper vibration of the three storied school-building (sec.)

Long direction	T_1	0.150
	T_2	0.058
	T_3	0.039
Short direction	T_1	0.222
	T_2	0.106
	T_3	0.096

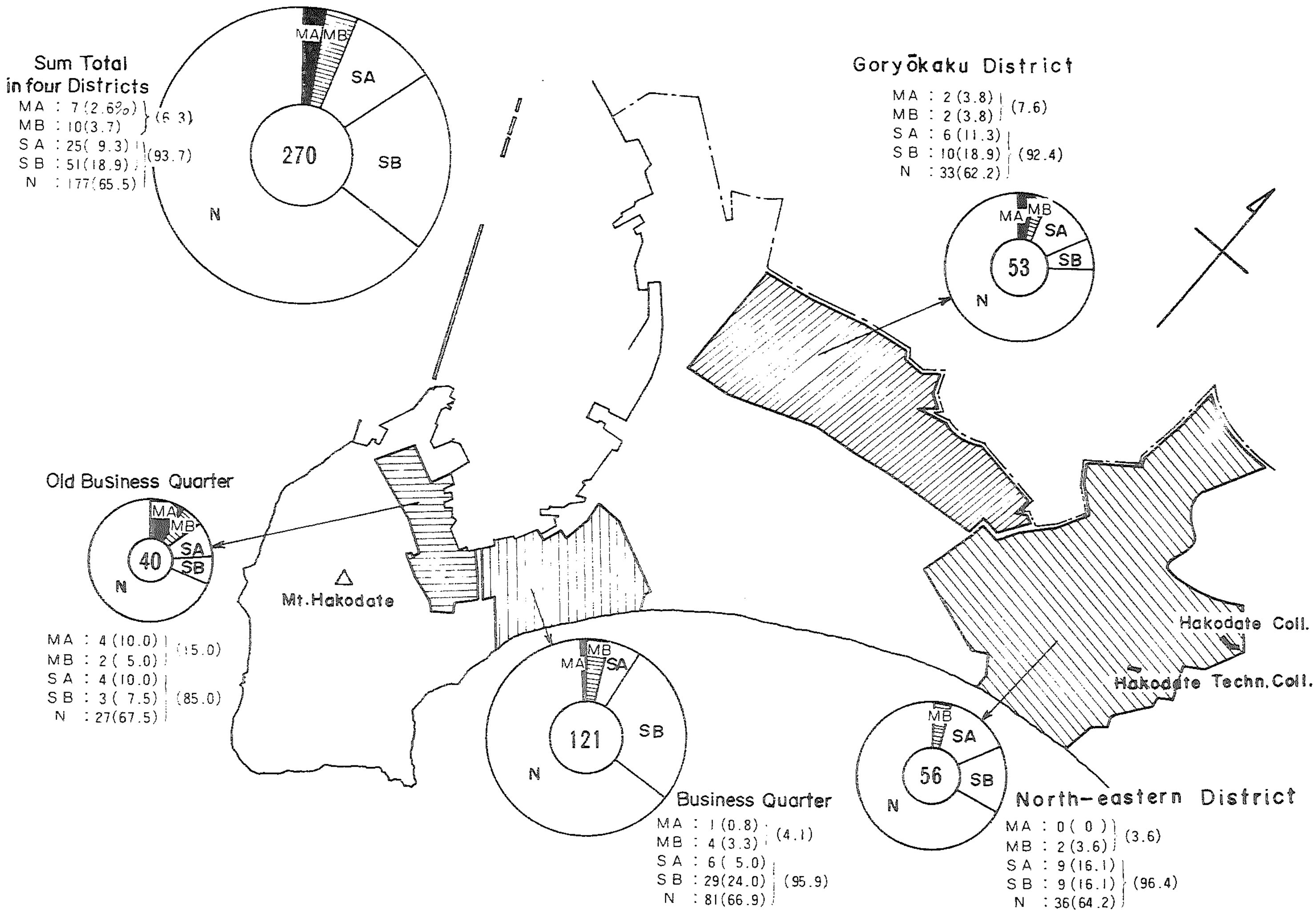


Fig. 1. Damages to reinforced concrete buildings in four specific regions in Hakodate City

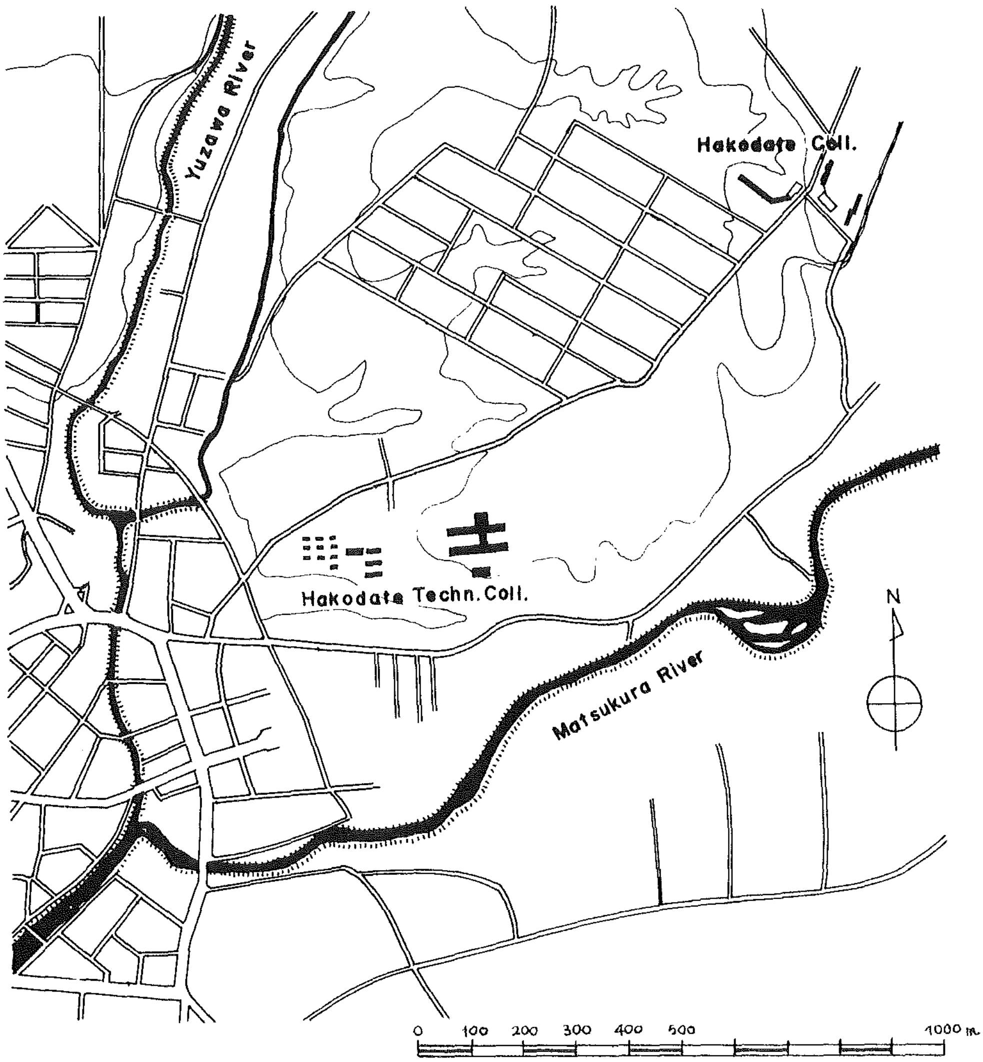


Fig. 2. Map of the vicinity of the Hakodate College

Fl.	1st. work	2nd. work	Total
Floor Area m²			
1	282.764	695.394	978.158
2	282.764	695.394	978.158
3	282.764	695.394	978.158
4	282.764	695.394	978.158
P	29.906	48.003	77.909
Total	1,160.962	2,829.579	3,990.541

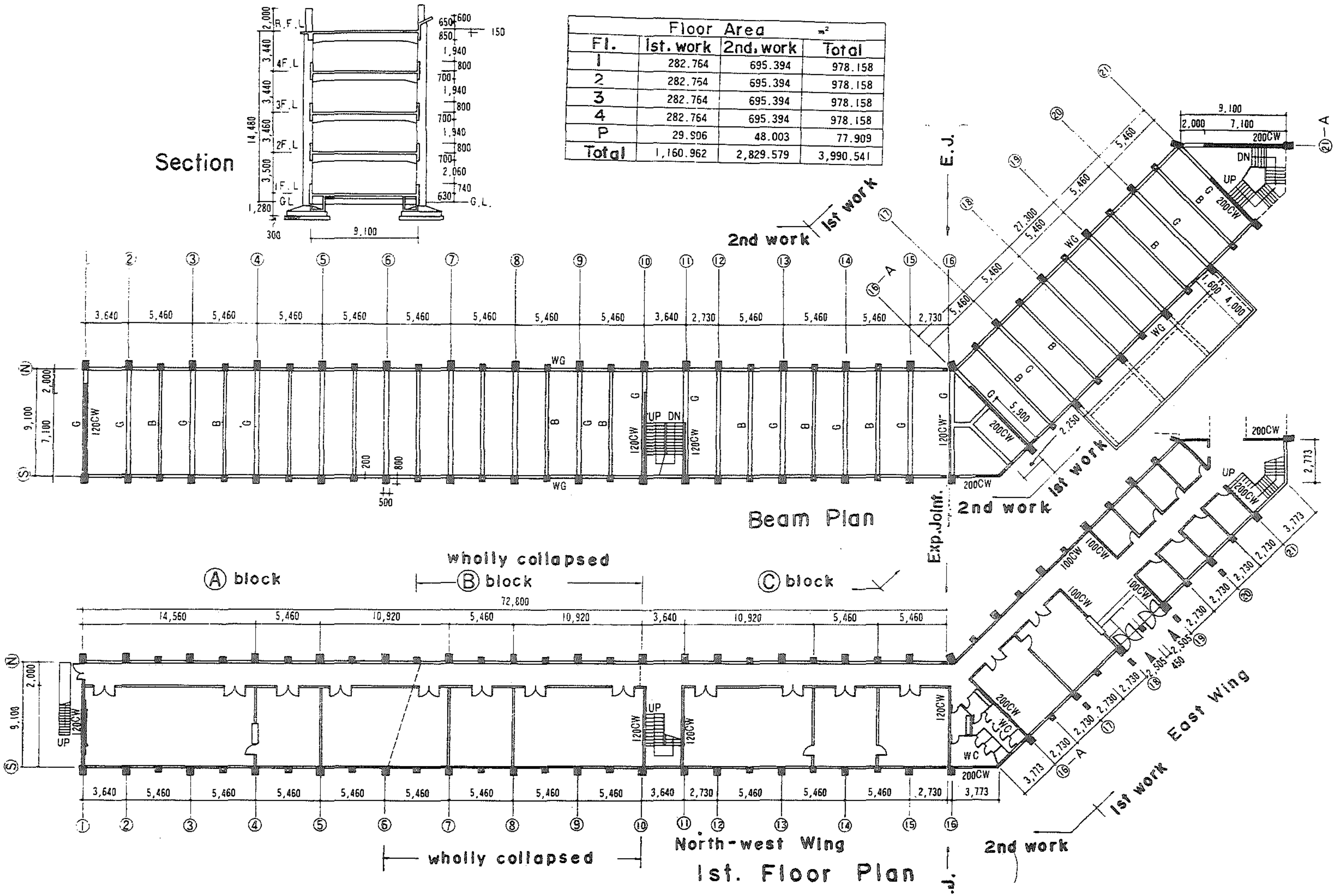


Fig. 3. Plan and Section

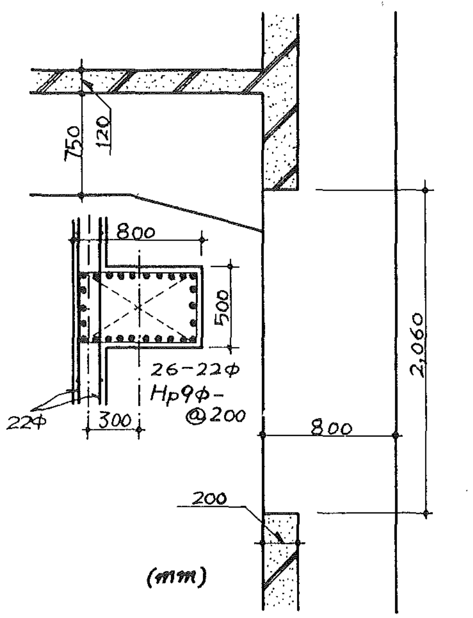


Fig. 4. Details of the first story column

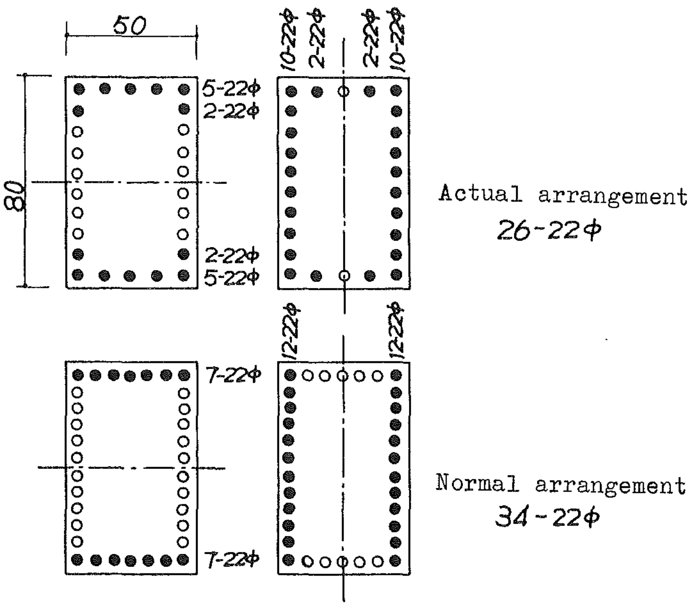


Fig. 5. Saving the axial reinforcement
in the columns

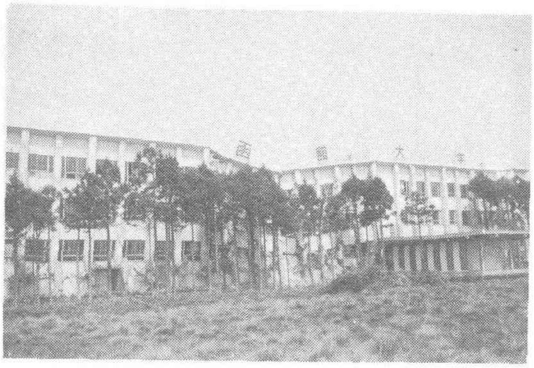


Fig. 6. South-side view of North-west Wing

East Wing ←┼→ North-west Wing

Fig. 7. North-side view

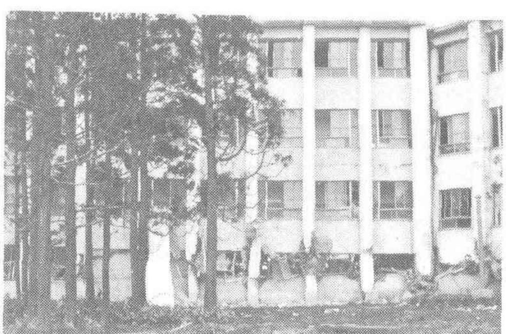


Fig. 8. North-side view of East Wing

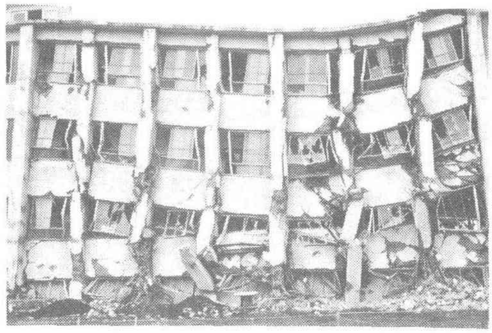


Fig. 9. North-side view of North-west Wing

Fig. 10. Wall-girder — pilaster joint

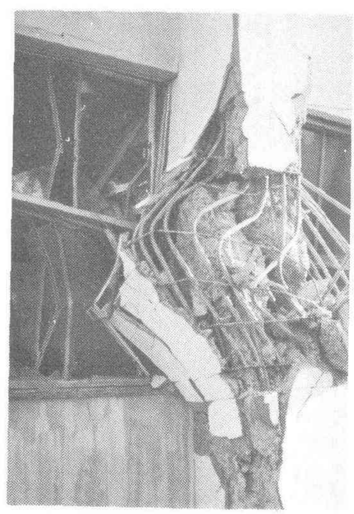


Fig. 11. First story column in East Wing

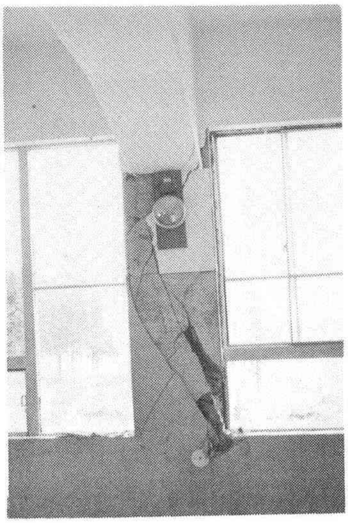


Fig. 12. Second story column in North-west Wing

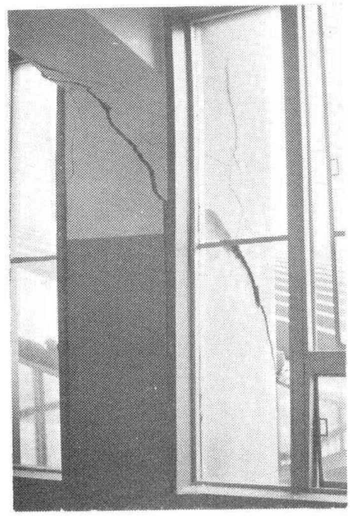


Fig. 14. Second story column in North-west Wing

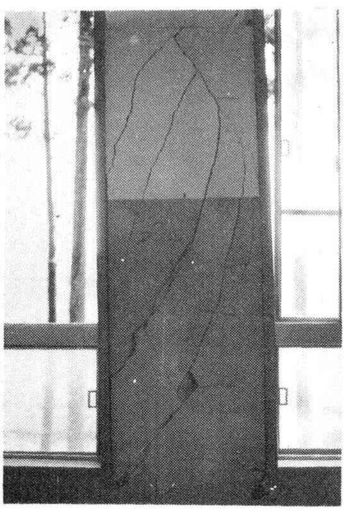


Fig. 13. Second story column in North-west Wing

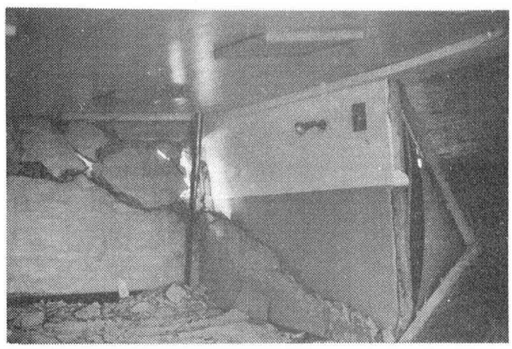


Fig. 15. First story wall in East Wing

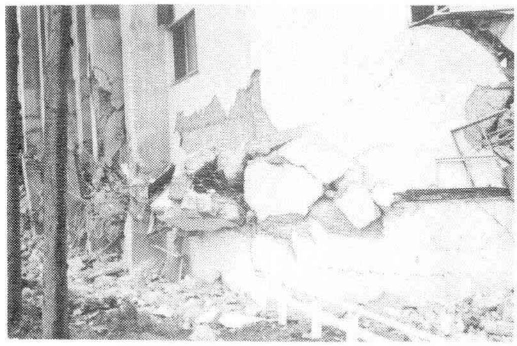
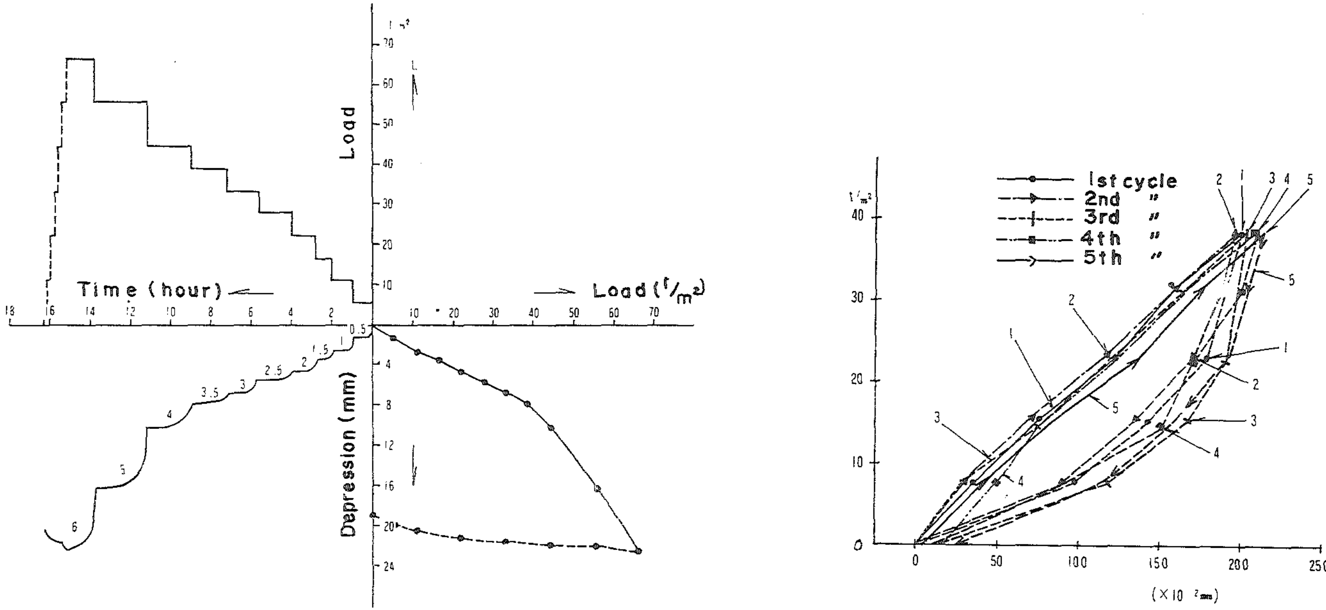


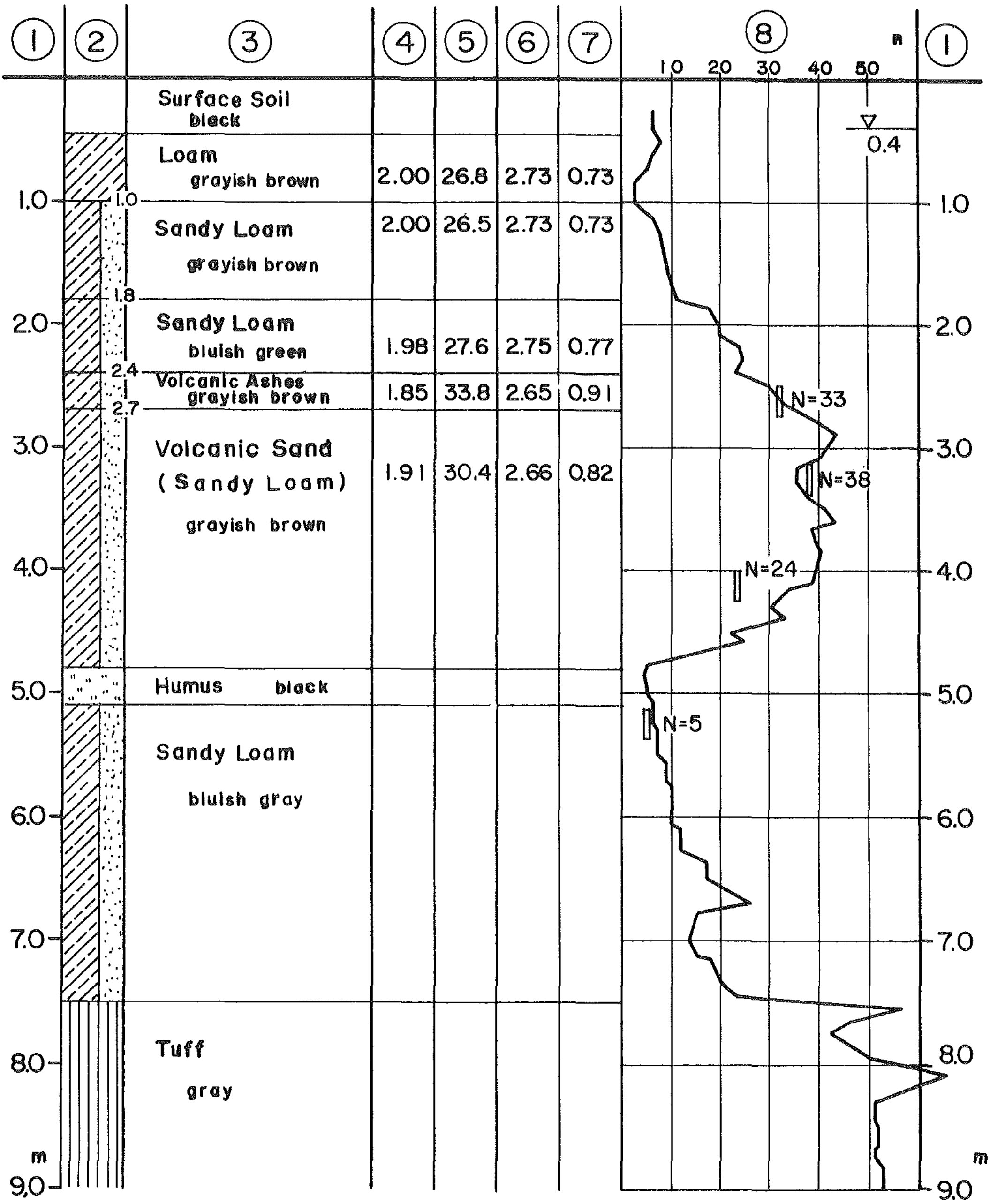
Fig. 16. External wall in the bend



Load-Depression Curve

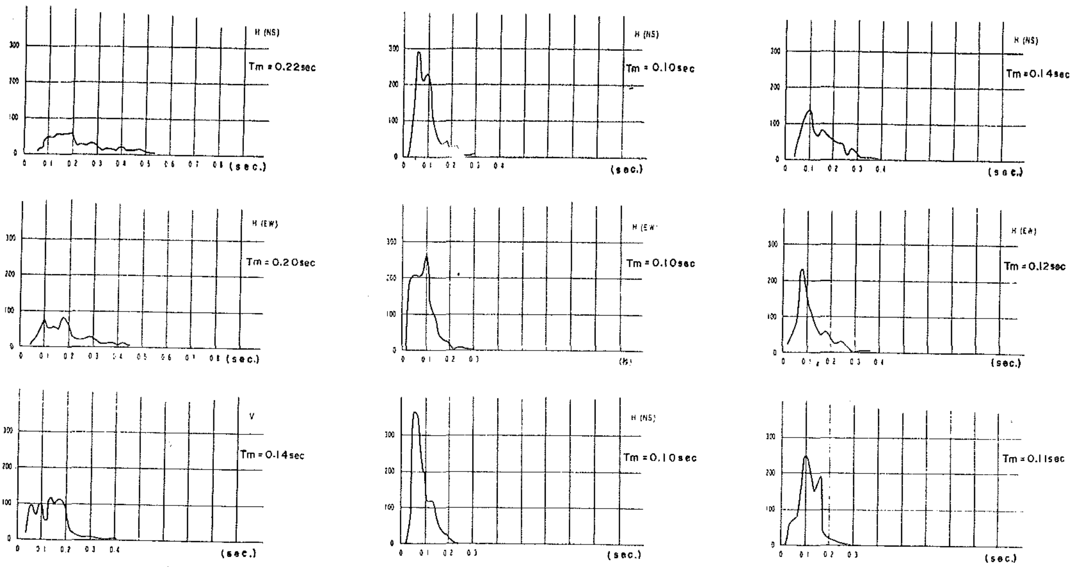
Depression under Quickly Repeated Load

Fig. 17. Load — Depression Curves of Soil



① Depth
② Symbol
③ Sort and Hue
④ Weight in Unit Volume (t/m^2)
⑤ Moisture Ratio (%)
⑥ Specific Gravity
⑦ Void Ratio
⑧ n-Value by Symplified Penetration Test

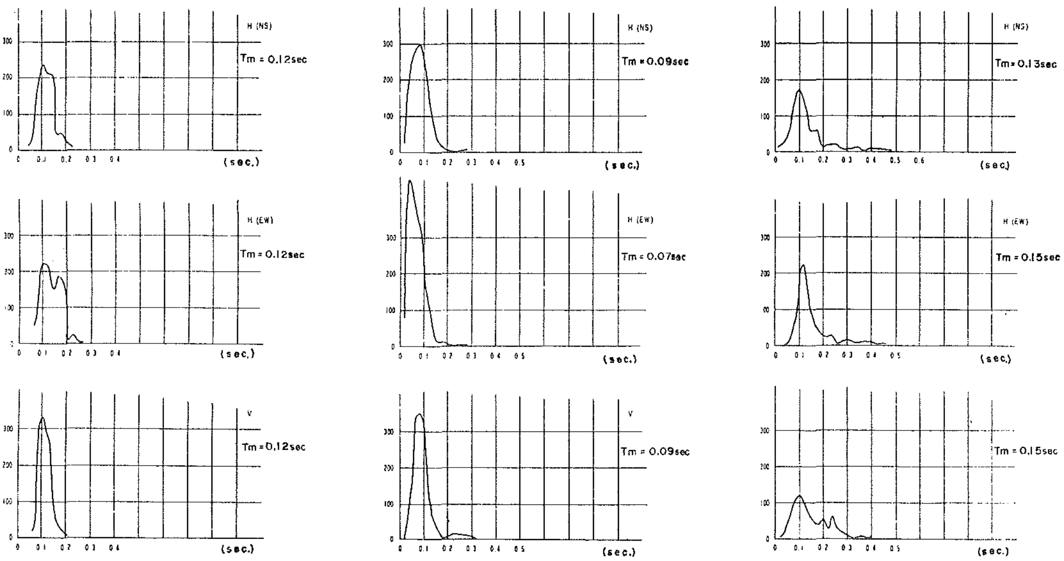
Fig. 18. Soil Profile (by Mr. S. Takamiya)



Hakodate college No. 1.
The destroyed building

Hakodate College No. 2.
The three-storied building

Hakodate College No. 3.
Dormitory



Hakodate Technical College

A high school in the city

Hakodate Weather Bureau

Fig.19. Frequency Spectra of Microtremor
(by Mr. M. Kawaji)