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EARTHQUAKE DAMAGES AND ELASTIC PROPERTIES OF THE GROUND

BY
RYŌ TANABASHI
AND
HATSUO ISHIZAKI

KYOTO UNIVERSITY, KYOTO, JAPAN

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1. Introduction.

It has been known quite a long time since that damages inflicted upon buildings by earthquake are closely related to some nature of the ground on which the buildings stand; always when the ground is a "good" one, the damages are relatively small. What the "good" ground means, however, is by no means made clear, and it is much to be hoped for to determine exactly what physical aspect of the earthcrust is in question. People in general believe that wooden houses on the "soft" ground suffer the calamity most, yet the terminology is here again far from scientific.

With this thought in mind, we have for several years endeavoured to explore the relations between the nature of the ground and the damages caused by earthquake. We made inquiries in areas visited by bigger earthquakes and tried to collect the data to establish the percentage of destroyed wooden houses. At the same time we employed elastic waves so as to examine the ground. Our findings made in several districts were already published; here it is our wish to sum up our discoveries and put down what we believe the conclusion of our efforts.

We are deeply indebted to Dr. Kenzō Sassa, Dr. Tojirō Ishihara, and Dr. Yoshitsura Yokoo, for the numerous valuable informations they furnished us about the subject. We are also grateful to Mr. Yoshio Baba, Mr. Motohiro Hatanaka, and other members of the Disaster Prevention Research Institute, Kyōto University, for their magnificent co-operation in our examinations and experiments.

2. Method of Inquiry.

There are diverse methods to be considered to make clear the relations of earthquake damages and the ground. Our present method, however, is limited to the statistical examination of destroyed buildings and the physical exploration of the ground by means of elastic waves, to be followed by the ultimate comparison of the results.

We have met with several problems in trying to determine the exact rate of earthquake damage. Some of them are as follows:

1) The structure of wooded buildings differs greatly with each local area. Earthquake-proof buildings are, of course, stronger against earthquake than houses built with no such consideration.

2) We are to decide between the rate of complete damage and that of partial damage in order to get the more reasonable rate.

3) There is no objective standard as to the distinction of each degree of damage; the judgment depends very much upon the examiners' viewpoints.

As for the first problem, as the wooden buildings of this country within one local area generally show a similar structure, it is not without meaning to compile the rates of damage if we limit our examination in one small district.

Further, our aim is to make clear the relations between earthquake damages and the ground, and the second problem would seem to be not so much relevant to the present inquiry. Either the rate of complete damage or that of partial damage will do well enough here. For convenience's sake, we shall call the percentage of completely and partially destroyed houses "the rate of damage"; we shall use both the rate of damage and the rate of complete damage from now on.

The rate of damage has been often used, not without meaning, as showing the intensity of earthquake. As is said above, the rate may or may not include partially destroyed houses, and it is not exactly scientific to believe that the rate of damage always correspond to the intensity of earthquake, to say nothing of the ambiguity of the term: "intensity".

Sometimes the rate of damage is shown as the rate of complete damage plus ½ the rate of partial damage. This is a wrong way of dealing with earthquake; no one can reasonably say that a completely destroyed house weighs exactly twice a partially destroyed house. Prof. Miyabe has already pointed out this error.

The third problem would also seem not to present us an insurmountable obstacle. Intrusion of opinions will be unavoidable in any statistical examination, and we would be able to avoid the danger to a great extent if we try to compare the rates acquired in a very much limited area.

We used the Sassa-C seismometer in our physical exploration of the ground; we recorded the velocity and the period of both longitudinnl and surface waves, and when it was possible the damping ratio.

We compared the figures thus acquired with the percentage of damages inflicted on wooden buildings.

From that comparison we can easily see that there is a close relationship between the physical structure of the ground and the destructive force of earthquake measured by the rate of damage. As the seismic wave is generally considered as elastic in nature, elastic waves will be the most suitable means to explore the structure of the ground. Moreover, as there are many instances where in a very limited area the damages caused by earthquake differ greatly in degree, the ground structure at deeper layers of the earthcrust has obviously little or nothing to do with earthquake damages. Accordingly our examination is made to the structure of the ground no farther than several decameters below the surface.

3. Areas under examination.

We chose as areas of our inquiry the Province of Mikawa (Hazu- and Hekikai-county, Aichi prefecture), Tottori city and her neighbour towns, Kōchi city and her suburbs, and Fukui city. All of these districts were recently visited by violent earthquakes and suffered great damages.

4. The Exploration at the Tottori Area.

A violent earthquake made a sudden attack at 5:40 p. m., Sept. 10, 1943, on Tottori city and her neighbouring towns. The toll rose up to 1,060; the wounded 3,250; and the houses it destroyed numbered 13,000. The damages are extraordinary heavy if we take into consideration the size and the population of the district. The seismic source was located at the point 14 km. south-west of Tottori city: presumably a spot near Yoshioka Hot Spring or the town of Kano.

1) The rate of damage:

There is a detailed official account of damages given to buildings made by each town or village around Sept. 25 of the same year. The figures in the Table I are taken from it. The rate of damage in the official account showed the ratio of the number of totally or partially destroyed houses and the total number of households at the end of 1942. As the residential buildings in this district are usually large in number than the households, we thought it more accurate to modify the official figures. At Bamba, where practically all the houses were destroyed, the official account showed the percentage of 193.6; we decided to deduce it to 100. All the rest of the figures are deduced proportionally to that of Bamba. The modified figures are shown to the right of the list.

The ratio of the complete damages to the complete and partial damages is listed in the last section of the Table 1. The curves of the Figure 1 are drawn according to the figures of the complete damages. The space 'A' shows the area where the damages were the heaviest; 'B' next to 'A'; and 'C' and 'D' follow in the degree of the intensity of destruction.

2) The exploration of the earthcrust:

We made an exploratory tour to the area at the beginning of October of the same year.

Eleven lines of survey shown in Fig. 1 were selected. Having taken lines of approximately 200 m. in length, the ground construction, the velocities of elastic waves, etc. were measured by means of the artificial seismic waves excited by dynamite explosion. Thus obtained time-distance curves of longitudinal waves are shown in Fig. 2 to Fig. 12. The ground construction, and the velocity and the period of surface wave are also shown. The velocities shown in the figures of the ground construction are that of longitudinal waves, and the velocity of surface wave is represented by v_s since its velocity cannot usually be distinguished from the velocity of transverse wave. Since the period of longitudinal wave, the damping coefficient, etc. are not considered as dircetly influential factors on the seismic damage, and accurate values could not be obtained, they were omitted.

5. The Exploration at the Province of Mikawa.

Hazu-, and Hekikai-county, Aichi-prefecture (Mikawa Province) were damaged considerably by the Tōkai-earthquake in Dec. 1944, and again in Jan. 1945 by the Mikawa-earthquake, a local earthquake in the province, suffered a greater damage.

The Tōkai-earthquake raged at 1:36 p. m., Dec. 7, 1944. Its seismic source was presumed to be at a spot about 20 km. south-south-east off Shima Peninsula: ten and several kilometers deep; and its felt radius reached to 620 km. The damages were severe at the ground of soft soil in Mie-, Aichi-, and Shizuoka-prefecture, and tidal waves attacked broad area spreading between Chōshi in the east and Tosa in the west. The Mikawa earthquake took place at 3:38 p. m., Jan. 13, 1945, and its source was presumed to be at a very shallow point in the Atsumi Bay. The damaged area was limited to Hazu-, and Hekikai-county, and a part of Takarai-, and Nukada-county near the seismic center, but in these areas the damages were severer than by the former earthquake.

1) The rate of damages:

We here present the data that were gathered by the town, and

Tabel 1. Percentages of destroyed houses in Tottori province
D_0 ...... Percentage of completely destroyed houses
D_1 ...... Percentage of partially destroyed houses

	Community	(D_0) %	(D) %	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D
Taishō-mura	Nodera	46.7	26.7	24.0	13.8	37.8	0.63
	Hattori	82.9	22.9	42.8	11.8	54.6	0.78
	Shōbu	84.7	19.4	43.8	10.0	53.8	0.81
	Yamagahana	47.4	26.3	24.5	13.5	38.0	0.64
	Kamikoyasu	67.3	23.6	34.7	12.2	46.9	0.74
	Nakakoumi	71.4	17.5	36.8	9.0	45.8	0.80
	Shinmichi	63.2	21.1	32.6	10.9	43.5	0.75
	Tokuo	30.5	52.2	15.7	26.9	42.6	0.37
	Total	65.3	25.3	33.7	13.6	47.3	0.71
Miho-mura	Mukōkuniyasu	15.0	57.5	7.7	29.7	37.4	0.21
	Takefu	0	39.3	0	20.2	20.2	0
	Kamiajino	5.5	12.7	2.8	6.6	9.4	0.30
	Asatsuki	3.6	36.4	1.9	18.8	20.7	0.09
	Shimoajino	0	7.0	0	3.6	3.6	0
	Genta	18.8	12.5	9.7	6.4	16.1	0.60
	Shimoajino, the East	24.7	21.1	12.8	10.9	23.7	0.54
	Total	15.6	28.6	8.0	14.8	22.8	0.35
Kurata-mura	Hinoto	2.5	37.5	1.3	19.3	20.6	0.06
	Entsūji	3.2	68.1	1.5	35.0	36.5	0.04
	Kuniyasu	90.9	34.5	47.0	17.8	64.8	0.72
	Kitadoi	277.8	37.3	—	—	—	—
	Yasaka	4.5	29.9	2.3	15.4	17.7	0.13
	Hashimoto	28.6	85.8	14.8	44.3	59.1	0.25
	Kurata	100.0	21.1	51.6	10.9	62.5	0.83
	Bamba	166.7	26.9	86.1	13.9	100.0	0.86
	Okishiro	68.3	30.0	35.3	15.5	50.8	0.69
	Kōsho	0	0	0	0	0	—
	Total	52.1	42.3	26.9	21.8	48.7	0.55
Yonesato-mura	Higashiōji	19	15	9.8	7.7	17.5	0.56
	Nakaōji	23	22.8	11.9	11.8	23.7	0.50
	Nishiōji	22	43.4	11.4	22.4	33.8	0.34
	Nagasuna	63	25.0	32.5	12.9	45.4	0.72
		17	20.6	8.8	10.6	19.4	0.45
		0	13.7	0	7.1	7.1	0
	Hisasue	8	13.1	4.1	6.8	10.9	0.38
	Koshiji	0	2.0	0	1.0	1.0	0
	Total	13.7	16.4	7.1	8.5	15.6	0.46
Tsunoi-mura	Sugisaki	26	49.1	13.4	25.4	38.8	0.35
	Amarube	44	7.6	22.7	3.9	26.6	0.85
	Ikuyama	0	0	0	0	0	—
	Hashiragi	11	23.8	5.7	12.3	18.0	0.32
	Anzōji	0	11.1	0	5.7	5.7	0
	Matsuki	6	0	3.1	0	3.1	1.00
	Hirooka	0	5.6	0	2.9	2.9	0

	Community	(D_0) %	(D) %	D_0 %	D_1 %	D (D_0+d_1) %	D_0/D
Omokage-mura	Nokorikodani	2	2	1.0	1.0	2.0	0.50
	Katori	0	0	0	0	0	—
	Negiya	0	0	0	0	0	—
	Total	13	13.9	6.7	7.2	13.9	0.48
	Niimura, Unzan, Shōrenji, Sakuradani, Imabaike	81	15.8	41.8	8.2	50.0	0.84
	Total	81	15.8	41.8	8.2	50.0	0.84
Ubeno-mura	Shingaki	0	20.8	0	10.7	10.7	0
	Tani	0	0	0	0	0	—
	Itaya	0	0	0	0	0	—
	Kamiasō	0	0	0	0	0	—
	Shimoasō	0	0	0	0	0	0
	Takaoka	9	15.8	4.6	8.2	12.8	0.36
	Minagi	0	3.2	0	1.7	1.7	0
	Miyanoshita	0	7.1	0	3.7	3.7	0
	Okuya	0	4.0	0	2.1	2.1	0
	Nakagō	0	0	0	0	0	—
	Kokubunji	0	7.1	0	3.7	3.7	0
	Sandaiji	0	0	0	0	0	—
	Hokkeji	0	0	0	0	0	—
	Chō	0	0	0	0	0	—
	Machiya	0	0	0	0	0	—
	Wakeda	0	0	0	0	0	—
	Hironishi	0	0	0	0	0	—
	Emimichi	0	0	0	0	0	—
	Tamaboko	0	0	0	0	0	—
	Okamasu	2	0	1.0	0	1.0	1.00
	Shimizu	0	7.1	0	3.7	3.7	0
	Yamane	0	—	0	—	—	—
	Total	1	3.3	0.5	1.7	2.2	0.23
Toyomi-mura	Shimodan	16	2	8.3	1.0	9.3	0.89
	Nosaka	58	7.7	30.0	4.0	34.0	0.88
	Ōtsuka	3	0	1.5	0	1.5	1.00
	Miyatani	25	13.6	12.9	7.0	19.9	0.65
	Shima	29	12.9	15.0	6.7	21.7	0.69
	Okema	0	0	0	0	0	—
	Ōmitsu	0	0	0	0	0	—
	Total	27.8	6.3	14.4	3.3	17.7	0.81
Sendaisui-mura	Tokuyoshi	47	53.1	24.2	27.4	51.6	0.47
	Yasunaga	37	63.1	19.1	32.6	51.7	0.37
	Akisato	31	68.8	16.0	35.6	51.6	0.31
	Nitsu	2	82.3	1.0	42.5	43.5	0.02
	Nangiri	41	58.5	21.2	30.2	51.4	0.41
	Bantō	21	66.7	10.8	34.4	45.2	0.24
	Total	30	66.3	15.5	34.2	39.7	0.39

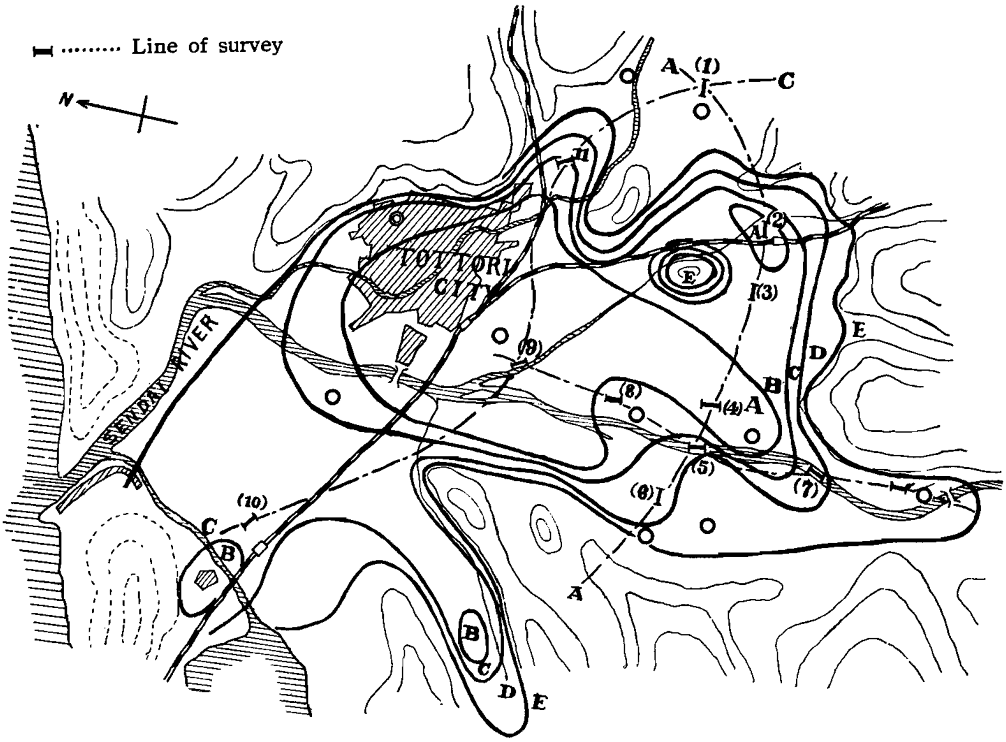


Fig. 1 The rate of damage and lines of survey at Tottori.

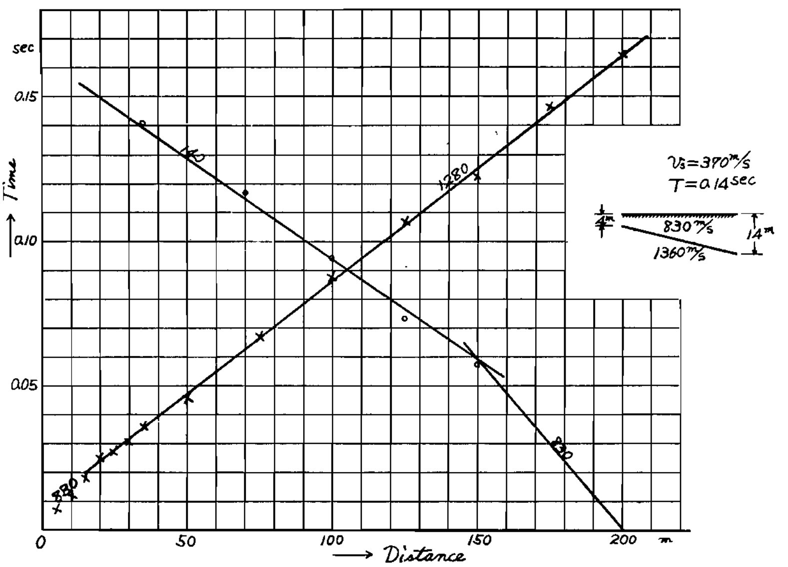
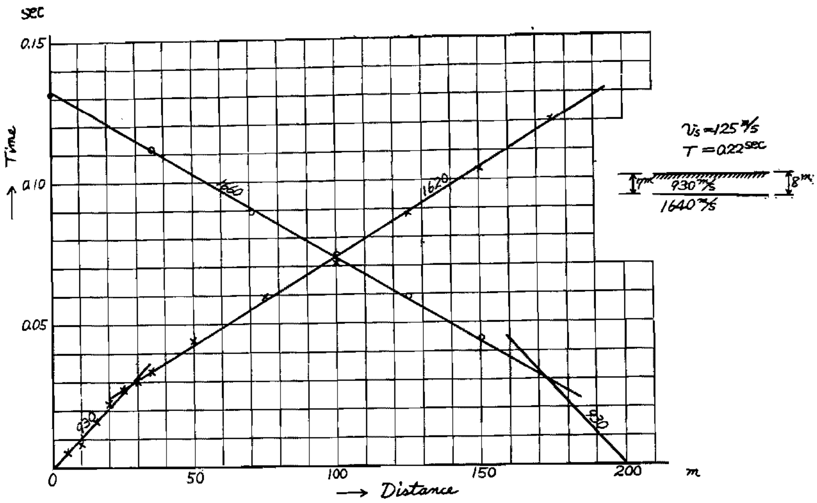


Fig. 2 (1) Kokubunji.



Pig. 3 (2) Tsunoi.

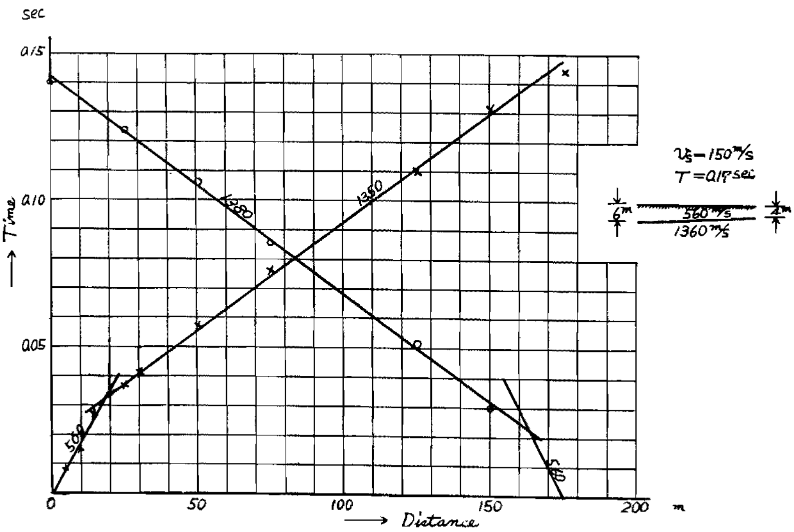


Fig. 4 (3) Hisasue.

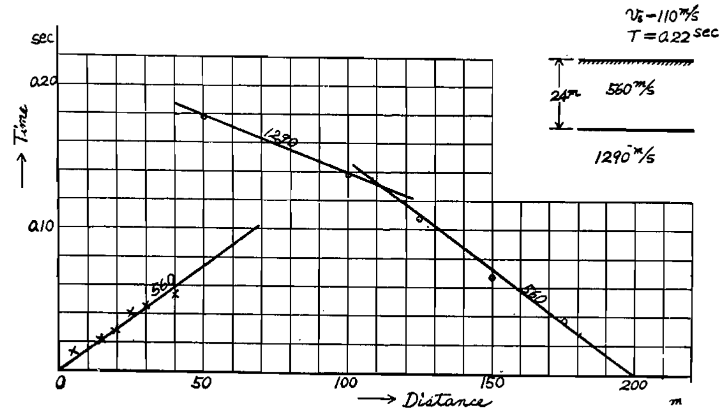


Fig. 5 (4) Bamba.

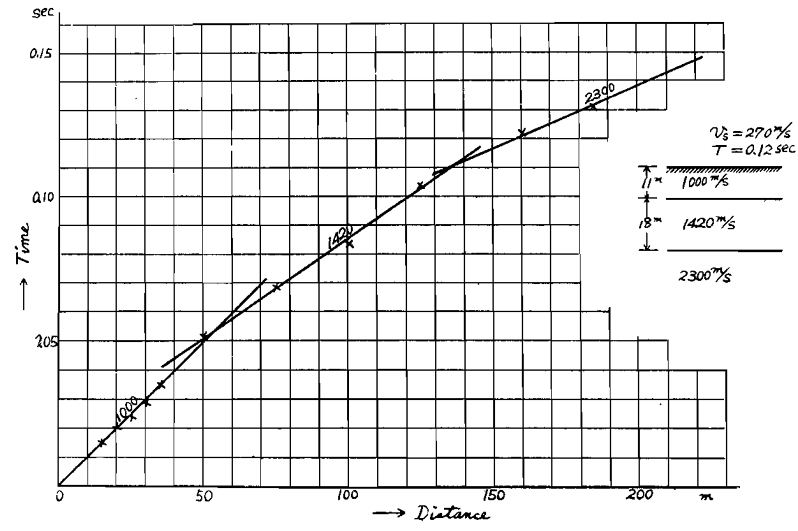


Fig. 6 (5) Kuniyasu.

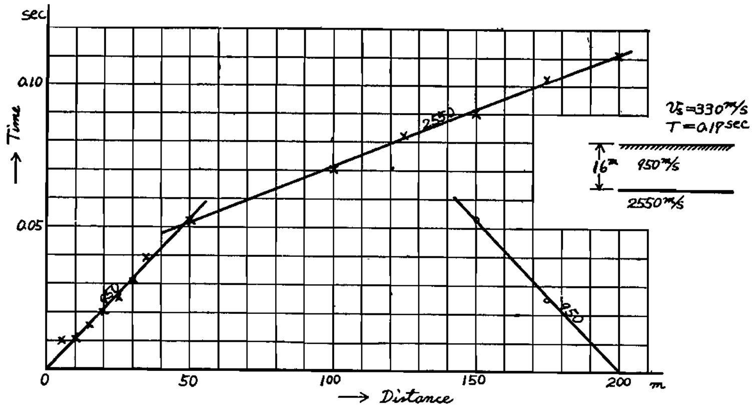


Fig. 7 (6) Shimoajino.

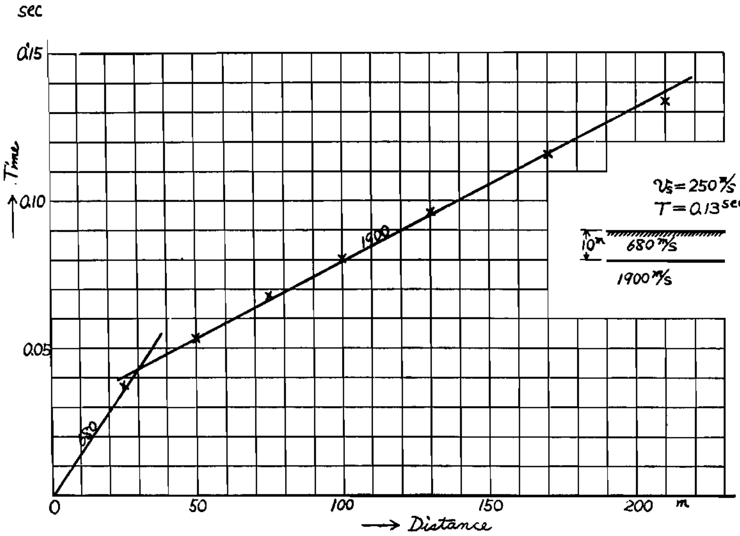


Fig. 8 (7) Entsūji.

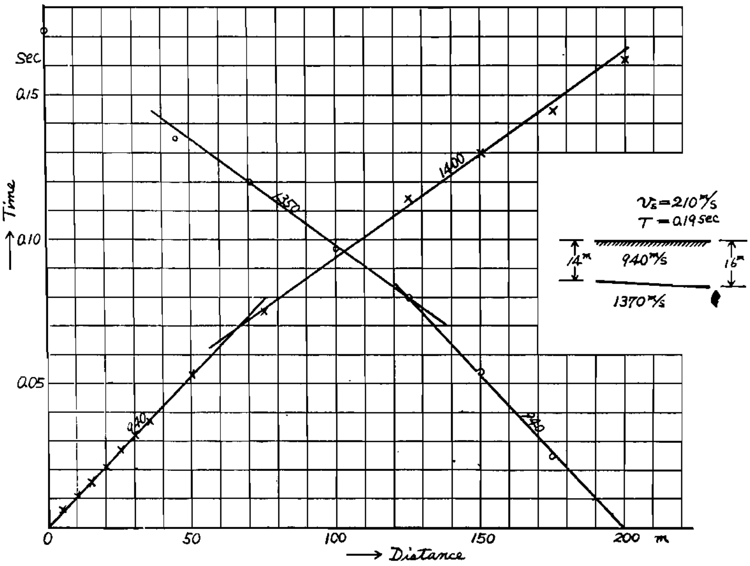


Fig. 9 (8) Kanō.

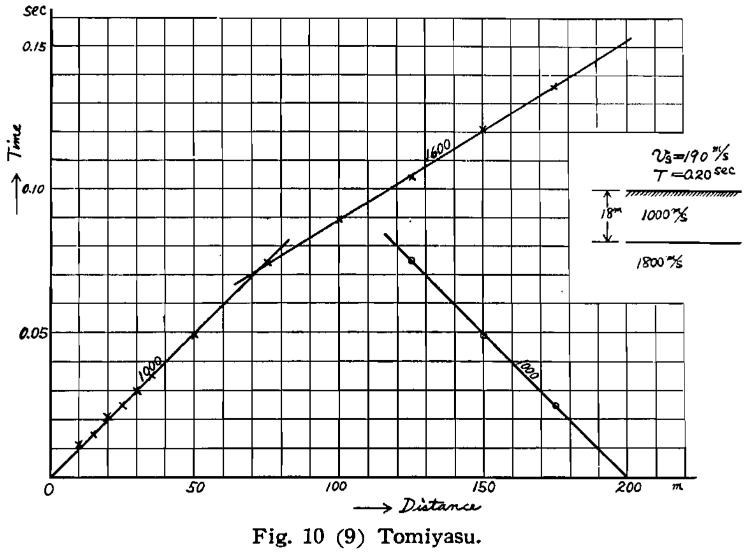


Fig. 10 (9) Tomiyasu.

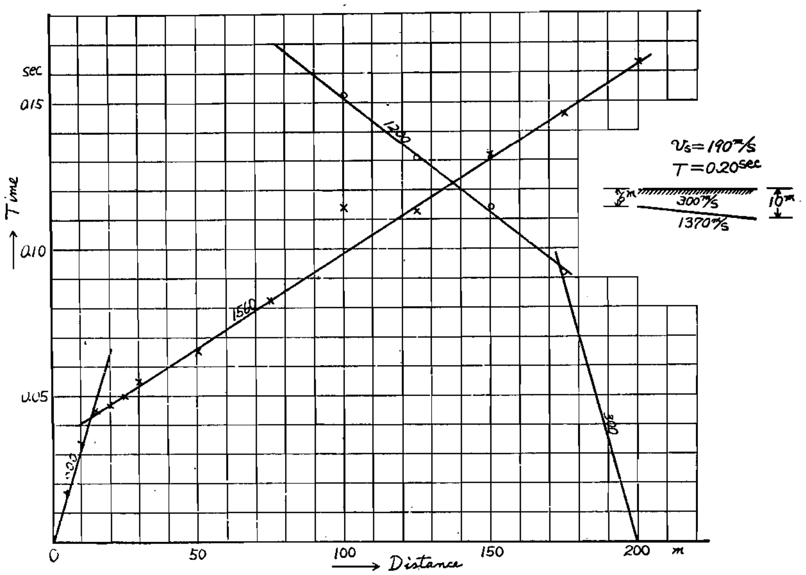


Fig. 11 (10) Koyama.

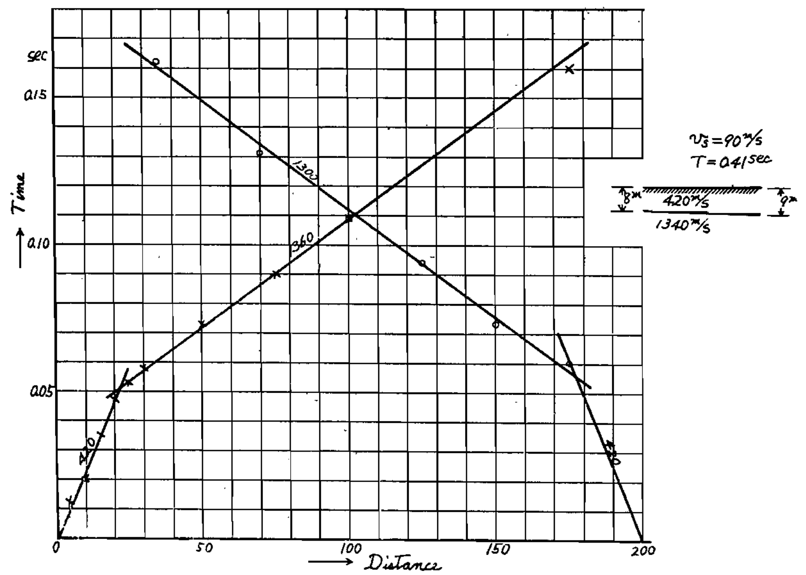


Fig. 12 (11) Iwakura.

Table 2. Percentages of destroyed houses in Hazu-district by Tōkai-earthquake
A......Total houses B......Houses destroyed completely
C......Houses destroyed partially

Town or Village	Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D
Hirasaka-chō		2322	121	105	5.2	4.5	9.7	0.54
Nishio-machi		4386	129	323	2.9	7.4	10.3	0.28
Miwa-mura		948	7	54	0.7	5.7	6.4	0.11
Fukuchi-mura	Koyakino	56	6	8	10.7	14.3	25.1	0.43
	Takuyajima	39	0	3	0	7.7	7.7	0
	Ugaike	82	17	27	21.2	3.3	24.5	0.87
	Kamatani	57	7	9	12.3	15.8	28.1	0.44
	Jūrōjima	30	6	9	20.0	30.0	50.0	0.40
	Hosoike	84	19	21	22.6	25.0	47.6	0.47
	Suwaki	21	7	3	33.3	14.3	47.6	0.70
	Kawaguchi	35	13	9	37.1	25.7	62.8	0.59
	Fukaike	36	3	10	8.3	27.8	36.1	0.23
	Hishiike	68	25	19	36.7	28.0	64.7	0.57
	Saitō	50	17	15	34.0	30.0	64.0	0.53
	Niike	51	20	16	39.3	31.4	70.7	0.56
	Naganawa	31	13	9	42.0	29.0	71.0	0.59
	Harisone	70	9	7	12.8	10.0	22.8	0.56
	Kami-dōmyōki	40	8	13	20.0	32.5	52.5	0.38
	Shimō-dōmyōki	25	2	5	8.0	20.0	28.0	0.29
	Kōyō	81	12	18	14.8	22.2	37.0	0.40
	Yatsugashiri	39	9	13	27.3	33.3	60.6	0.45
	Ichiko	115	40	40	34.8	34.8	69.6	0.50
	Hirakuchi	59	17	25	28.8	42.4	71.2	0.40
	Sasasone	46	6	18	13.1	39.1	52.2	0.25
	Yokote	52	9	8	17.3	15.4	32.7	0.53
	Tenchiku	37	9	12	24.4	32.4	66.8	0.37
	Nonomiya	21	7	4	33.3	19.1	52.4	0.64
	Total	1225	281	321	22.9	26.2	49.1	0.47
Isshiki-machi	Kaisei	118	27	21	23.0	17.8	40.8	0.56
	Akabane	134	11	23	8.2	17.2	25.4	0.32
	Jimei-kita	149	7	14	4.7	9.4	14.1	0.33
	Jimei-minami	88	10	10	11.4	11.4	22.8	0.50
	Yūgashima	51	11	26	21.5	51.0	72.5	0.30
	Hosokawa	34	6	22	17.6	64.7	82.3	0.21
	Koyabu	2	1	1	50.0	50.0	100.0	0.50
	Nakatozawa	111	10	22	9.0	19.8	28.8	0.31
	Ajihama	333	10	36	3.0	10.8	13.8	0.22
	Isshiki, the 1st	393	5	29	1.3	7.4	8.7	0.15
	" , the 2nd	350	9	27	2.6	7.7	10.3	0.25
	" , the 3rd	297	2	24	0.7	8.1	8.8	0.80
	" , the 4th	340	5	14	1.5	4.1	5.6	0.27
	Fujie	17	1	7	5.9	4.1	10.0	0.59
	Sakata	10	1	1	10.0	10.0	20.0	0.50
	Ikeda	90	20	57	22.2	63.4	85.6	0.26
	Maeno-kita	47	2	1	4.3	2.1	6.4	0.67
	Maeno-minami	102	5	5	4.9	4.9	9.8	0.50
	Taimai	100	5	33	5.0	33.0	38.0	0.13
	Ōtsuka	122	45	37	36.9	30.4	67.3	0.55
	Noda	60	5	20	8.3	33.3	41.6	0.20
	Matsukijima	317	25	48	7.9	15.1	23.0	0.34
	Semma	119	14	46	11.8	38.6	50.4	0.23

Town or Village	Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D
	Ikuta	235	38	85	16.2	36.2	52.4	0.41
	Sakatejima	94	14	20	14.9	21.3	36.2	0.41
	Sōgorō	18	3	3	16.7	16.7	33.4	0.50
	Total	3731	292	632	7.8	16.9	24.7	0.32
Yoshida-chō	Chitanido	60	5	18	8.3	30.0	38.3	0.22
	Kami-kawagishi	60	5	14	8.3	23.4	41.7	0.20
	Naka-kawagishi	69	2	2	2.9	2.9	5.8	0.50
	Shimo-kawagishi	55	3	7	5.5	12.7	18.2	0.30
	Sanjūjima, the 1st	53	11	19	20.6	35.9	56.5	0.36
	〃 the 2nd	43	7	8	16.3	18.6	34.9	0.47
	Nakakazu, the 1st	37	6	10	16.2	27.0	43.2	0.38
	〃 the 2nd	43	4	12	9.3	26.9	36.2	0.26
	Kyōei	48	4	3	8.3	6.3	14.6	0.57
		36	11	8	30.6	22.2	52.8	0.58
	Takagawara, the 1st	63	26	12	41.3	19.0	50.3	0.82
	〃 the 2nd	56	9	—	16.1	—	—	—
	Unotsu	50	14	—	28.0	—	—	—
	Takashima	67	12	27	17.9	40.3	58.2	0.31
	Hanarejima	27	11	3	40.7	11.1	51.8	0.78
	Ōshima	104	28	21	26.9	20.2	47.1	0.57
	Nishitomiyoshi	45	2	7	4.4	15.6	20.0	0.22
	Nakatomiyoshi	59	1	3	1.7	5.1	6.8	0.25
	Shimotomiyoshi	63	3	15	4.8	23.8	28.6	0.17
	Ichibatenjin	31	1	1	3.2	3.2	6.4	0.50
	Total	1069	160	190	15.0	17.8	32.8	0.46
Yokosuka-mura	Kami-yokosuka	478	15	41	3.1	8.6	11.7	0.26
	Shimo-yokosuka	108	8	19	7.4	17.6	25.0	0.30
	Nakano	66	1	1	1.5	15.1	16.6	0.09
	Komaki	30	3	1	10.0	3.3	13.3	0.75
	Kida	44	0	0	0	0	0	—
	Terashima	64	0	1	0	1.6	1.6	0
	Okayama	82	0	0	0	0	0	—
	Seto	22	0	0	0	0	0	—
	Sameuma	108	0	0	0	0	0	—
	Miyaseko	94	0	0	0	0	0	—
	Tsuhira	145	0	0	0	0	0	—
	Tomokuni	111	0	0	0	0	0	—
	Sakai	38	1	0	2.6	0	2.6	1.00
	Kyōtei	130	3	6	2.3	4.6	6.9	0.33
	Ogiwara	232	33	72	14.2	31.0	45.2	0.31
	Tomita	148	13	17	8.8	11.5	20.3	0.43
	Hachiman-kawada	22	2	4	9.1	18.2	27.3	0.33
	Total	1922	79	162	4.1	8.4	12.5	0.33
Toyosaka-mura		586	—	—	—	—	—	—
Haza-machi		1935	—	2	—	0.1	—	—
Muroba-machi		406	0	2	0	0.5	0.5	0
Terazu-machi		1065	20	124	1.8	11.7	13.5	0.13

Table 3 Percentages of destroyed houses in Hazu-, and Hekikai-country by Mikawa-earthquake
Hazu-country

Town or Village	Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D %
Nishio-machi	Shikino	33	19	—	57.5	—	—	—
	Shikoya	33	30	—	91.0	—	—	—
	Nakahara	35	25	—	71.5	—	—	—
	Tokutsugu	46	67	—	45.7	—	—	—
	Chōda	31	25	—	80.6	—	—	—
	Yorichika	20	16	—	80.0	—	—	—
	Imagawa	112	48	—	42.9	—	—	—
	Yasone	57	11	—	19.3	—	—	—
	Itō	100	75	—	75.0	—	—	—
	Kitakami	95	25	—	26.4	—	—	—
	Obama	104	13	—	12.5	—	—	—
	Yamashita-sumisaki	101	3	—	2.9	—	—	—
	Yorisumi	93	11	—	11.8	—	—	—
	Dōkōji	45	2	—	4.5	—	—	—
	Yatsuomote	93	17	—	18.3	—	—	—
	Togasaki	93	13	—	14.0	—	—	—
	Sakuramachi	88	5	—	5.7	—	—	—
	Kamimachi-nambu	109	21	—	19.3	—	—	—
	Shimomachi-hōkōji	117	10	—	8.6	—	—	—
	Total	1405						
Hirasaka-machi		2332	228	375	9.8	4.1	21.3	0.81
Terazu-machi		1128	130	650	11.5	16.1	25.9	0.38
Isshiki-machi		3770	256	768	6.8	57.6	69.1	0.17
Fukuch-mura		1225	455	—	37.2	—	—	—
Miwa-mura	Takaochi	38	38	0	100.0	0	100.0	1.00
	Shin-mura	32	10	12	31.2	37.5	68.7	0.45
	Higashi-asai	34	4	5	12.7	14.7	27.4	0.46
	Nishi-asai	104	14	24	13.5	23.1	36.6	0.37
	Kojima	101	33	49	32.6	48.5	81.1	0.40
	Komeno	15	8	8	53.4	53.4	—	—
	Ebara	135	107	20	79.2	14.8	94.0	0.84
	Waki	25	13	12	52.0	48.0	100.0	0.52
	Ōwada	27	27	0	100.0	0	100.0	1.00
	Takagawara	61	37	24	60.7	39.3	100.0	0.61
	Okajima	52	42	8	80.7	15.4	96.1	0.84
	Onaga	33	17	4	51.5	12.1	63.6	0.81
	Shino-nagara	61	10	47	16.4	77.0	93.4	0.18
	Kami-nagara	67	18	30	27.0	44.8	71.8	0.37
	Kaibuki	58	0	9	0	15.5	15.5	0
	Shimo-hazuno	51	1	5	2.0	9.8	11.8	0.17
	Kami-hazuno	48	0	2	0	4.2	4.2	0
	Mieshima	25	22	3	88.0	12.0	100.0	0.38
	Total	967	401	262	41.4	27.1	68.5	0.60
Toyosaka-mura		586	23	14	3.9	2.4	6.3	0.62
Sakaragawa		47	23	14	49.0	29.8	78.8	0.62
Muroba-mura		406	77	170	19.0	41.9	60.9	0.31

Town or Village	Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D %
Yokosuka-mura	Kami-yokosuka	478	329	124	68.8	26.0	94.8	0.73
	Shimo-yokosuka	108	40	60	39.7	55.6	95.3	0.42
	Nakano	66	5	20	7.6	30.3	37.9	0.20
	Komaki	30	15	5	50.0	16.7	66.7	0.75
	Kida	44	32	0	72.7	0	72.7	1.00
	Terashima	64	22	40	36.0	62.5	98.5	0.37
	Okayama	82	1	12	1.2	14.6	15.8	0.08
	Seto	22	0	2	0	9.1	9.1	0
	Sameuma	108	2	5	2.0	4.6	6.6	0.30
	Miyaseko	94	3	20	3.2	21.3	24.5	0.13
	Tsuhira	145	23	8	15.9	5.5	21.4	0.74
	Tomokuni	111	5	20	4.5	18.0	22.5	0.20
	Sakai	38	1	25	2.6	65.8	68.4	0.38
	Kyūtei	130	10	8	7.7	6.2	13.9	0.55
	Ogiwara	232	42	100	18.1	43.1	61.2	0.30
	Tomita	148	31	48	20.9	32.4	63.3	0.33
	Hachiman-kawada	22	10	5	45.4	22.7	68.1	0.67
	Total	1922	571	502	29.7	26.1	55.8	0.53
Yoshida-chō		1663	422	394	25.2	23.6	48.8	0.52
	Higashi-hazu	782	3	61	0.4	7.8	8.2	0.05
	Nishi-hazu	687	1	84	0.1	12.2	12.3	0.08
	Toba	259	10	29	3.9	11.2	15.1	0.26
	Terabe	189	0	38	0	20.1	20.1	0
	Total	1917	14	212	0.7	11.1	11.8	0.06
Sakushima		301	0	2	0	0.7	0.7	0

Hekikai-country

Town or Village	Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D
Anjō-machi		5593	186	518	3.3	9.3	12.6	0.26
Isami-machi	Iguiyama	23	0	3	0	13.0	13.0	0
	Noda	454	11	105	2.6	23.2	25.8	0.10
	Hanshirokami	169	2	23	1.2	13.6	14.8	0.08
	Takasu	158	2	25	1.3	15.8	17.1	0.08
	Ogakie	767	51	192	6.7	25.0	31.7	0.21
	Takadana	413	33	107	8.0	25.9	33.9	0.24
	Total	1984	98	455	4.9	22.9	27.8	0.18
Takahama-chō	Takahama	2300	17	199	0.4	8.7	9.1	0.05
	Yoshihama	650	13	229	11.2	35.2	46.4	0.24
	Takatori	340	58	113	17.1	33.2	50.3	0.34
	Total	3290	148	541	4.5	16.5	21.0	0.21
Shinkawa-machi		2700	7	271	0.3	10.0	10.3	0.03
Ohama-machi	Kami-ku	701	17	69	2.4	9.8	12.2	0.20
	Naka-ku	453	45	79	10.0	17.4	27.4	0.37
	Higashi-ku	471	5	46	1.1	9.8	10.9	0.10
	Nishi-ku	474	19	55	4.4	11.6	15.6	0.26
	Total	2099	86	249	4.1	11.9	16.0	0.26

Town or Village	Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D
Tanao-mura		1263	66	112	5.2	8.9	14.1	0.37
Asahi-mura	Washizuka	227	1	6	0.4	2.6	3.0	0.13
	Nihongi	225	2	6	0.9	2.7	3.6	0.25
	Kamiari	187	0	5	0	2.7	2.7	0
	Fushimiya	136	1	10	0.7	7.3	8.0	0.88
	Heishichi	328	2	21	0.6	6.4	7.0	0.86
	Maebama-shinden	83	0	16	0	19.3	19.3	0
	Fushimiya-sotoshinden	24	6	11	25.0	45.8	70.8	0.35
	Total	1210	12	75	1.0	6.2	7.2	0.14
Meiji-mura	Izumi	350	185	130	52.9	37.1	90.0	0.59
	Enokimae	175	44	102	25.1	58.3	83.4	0.30
	Nishihata	435	86	220	19.8	50.6	70.4	0.28
	Higashihata	371	78	124	21.0	33.4	54.4	0.39
	Nezaki	234	89	61	38.0	26.1	64.1	0.59
	Shirogairi	270	168	91	62.2	33.7	95.9	0.65
	Minaminakane	82	41	25	50.0	30.5	80.5	0.62
	Yonezu	383	95	125	24.8	32.6	57.4	0.43
	Total	2300	786	878	34.2	38.2	72.4	0.47
Sakurai-mura	Innai	64	6	14	9.4	21.9	30.3	0.31
	Horiuchi	51	3	11	5.9	21.6	27.5	0.21
	Nakabendō	54	3	6	5.5	11.1	16.9	0.33
	Higashimachi	102	4	14	4.0	13.7	17.7	0.23
	Nishimachi	105	3	8	2.9	7.6	10.5	0.28
	Shitaya	41	5	20	5.5	48.8	54.3	0.10
	Shiromuki	45	2	7	4.5	15.5	20.0	0.13
	Himekogawa	84	7	11	8.3	13.1	21.4	0.39
	Daichō	25	8	9	32.0	36.0	68.0	0.47
	Fukuchi	24	8	6	30.0	25.0	55.0	0.55
	Tenjin	51	3	13	5.9	25.5	31.4	0.19
	Komuki	36	2	9	5.6	25.0	30.6	0.18
	Kami	64	2	7	3.1	10.9	14.0	0.22
	Shimo	45	7	7	15.5	15.6	31.1	0.50
	Obayashi	21	12	7	57.2	33.3	90.5	0.63
	Yamada	38	21	5	55.3	13.2	68.5	0.81
	Iwane	45	2	14	4.5	31.1	35.6	0.13
	Nodera	41	13	13	31.7	31.7	63.4	0.50
	Teraryō	28	5	8	17.8	28.6	46.4	0.38
	Kida	137	9	36	9.7	26.3	36.0	0.27
	Fujii	110	92	12	79.4	10.9	90.3	0.88
	Murataka	37	3	3	8.1	8.1	16.2	0.50
	Kawashima	97	35	26	36.1	26.8	62.9	0.57
	Total	1345	255	266	19.0	19.8	38.8	0.49
Mutsumi-mura		1096	119	145	7.0	13.2	20.2	0.35
Yahagi-machi		2896	117	128	4.1	4.4	8.5	0.48
Kamigō-mura		1995	43	20	2.2	1.0	3.2	0.69
	Takegami	306	1	16	0.3	5.2	5.5	0.05
	Takenaka	64	0	0	0	0	0	—
	Takeshita	134	0	7	0	5.2	5.2	0
	Obayashi	112	0	0	0	0	0	—
	Nishida	31	0	0	0	0	0	—
	Wakabayashi	303	0	9	0	0	3.0	0

Town or Village	Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D
Takaoka-mura	Yoshiwara	102	0	6	0	5.9	5.9	0
	Kitanakane	44	0	1	0	2.3	2.3	0
	Hanazono	158	0	19	0	12.0	12.0	0
	Shinbaba	95	0	14	0	14.7	14.7	0
	Maebayashi	136	8	19	5.9	14.0	19.9	0.30
	Ōshima	45	0	3	0	6.7	6.7	0
	Nishiyama	71	0	3	0	4.2	4.2	0
	Honda	36	0	2	0	5.6	5.6	0
	Honji	42	0	0	0	0	0	—
	Machi	209	0	0	0	0	0	—
	Otoo	51	0	1	0	2.0	2.0	0
	Komaba	280	20	23	7.2	8.2	15.4	0.47
	Nakada	68	0	8	0	11.8	11.8	0
	Ippongi	56	0	0	0	0	0	—
	Sasahara	102	0	0	0	0	0	—
	Sōshindō	71	0	0	0	0	0	—
	Total	2516	29	131	1.2	5.2	6.4	0.19
Tomiagematsu-mura		1715	14	90	0.8	5.2	6.0	0.13
Shiritachi-machi		2774	38	206	1.4	7.4	8.8	0.16
Kariya-machi	Kariya	2467	13	31	0.5	1.3	1.8	0.28
	Korehariya	891	12	15	1.4	1.5	2.9	0.48
	Kuma	634	0	0	0	0	0	—
	Takatsunami	184	2	11	1.1	6.0	7.1	0.16
	Koyama	423	7	7	1.7	1.7	3.3	0.50
	Shigehara	248	8	23	3.2	9.3	12.6	0.25
	Total	4847	42	87	0.9	1.8	2.7	0.33

village offices, in a similar fashion as in the case of the Tottori area. They are shown in Table 2, and 3, the former is the damage caused by the Tottori earthquake, and the latter is that by the Mikawa earthquake. The percentage curves of the houses completely destroyed were drawn from the above data in Fig. 13 and 14.

2) The Exploration of the Earthgrounds:

The earthgrounds at the Province of Mikawa was explored in the same manner as in the Tottori area in April 1946, by means of the seven lines of survey shown in Fig. 13. The time-distance curves of elastic waves, the ground constructions, etc. thus obtained are shown in Fig. 15 to Fig. 21.

6. The Exploration in the vicinity of the Kōchi city.

A violent earthquake occured on Dec. 12, 1946, the seismic center being off the coast of Nankaidō. Its damaged area spread over Shikoku, Kyūshū, Kinki Chūgoku provinces, and a part of Chūbu province. The casualty rose up to 1,330; 9,100 houses were destroyed completely, 19,200 partially, 1,450 washed away, and 2,600 burnt down. The neighbouring

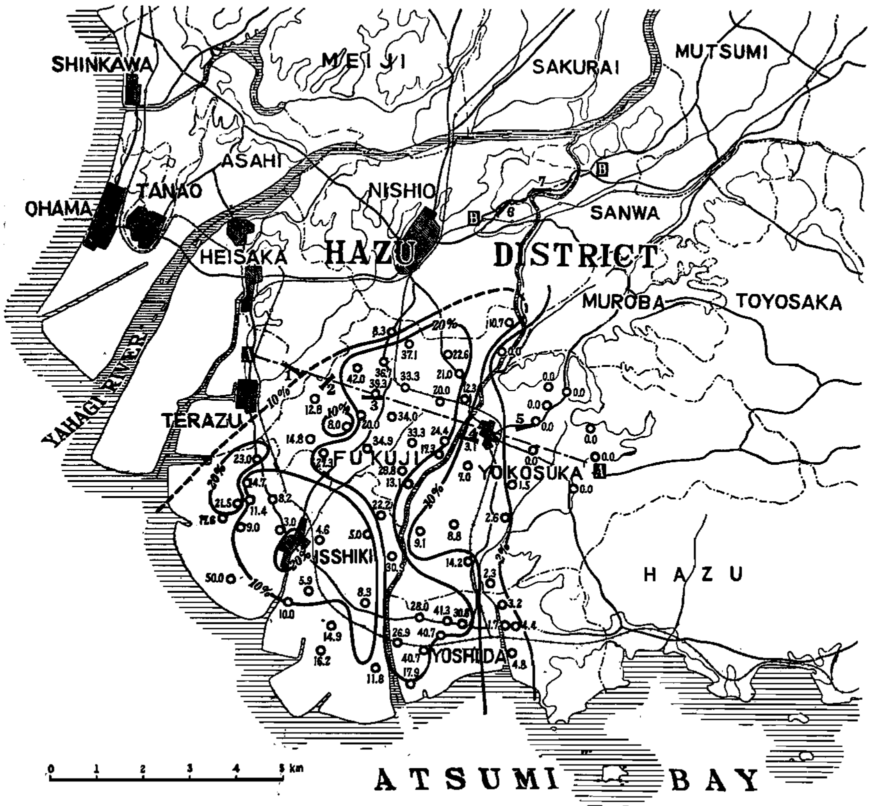


Fig. 13 The rate of damage at Mikawa by Tōkai-earthquake and lines of survey.

area of the Kōchi city was one of the areas suffered most from this earthquake.

1) The rate of damage:

The number of the houses destroyed in each community was investigated by the Kōchi City Office immediately after the earthquake. The rates of the houses completely and partially destroyed and the rate of total destruction were calculated from these data. The results of these calculations can be seen in Table 4. The percentage of the total destroyed houses is drawn in Fig. 22, and that of the houses completely destroyed is in Fig. 23. The scope where the houses are damaged including partial destruction spread over the almost entire city of Kochi, but when the complete destruction alone is considered, it is limited to a part of the city. Especially the area where the percentage of complete destrucion is quite high is limited to a small eastern part of the city. However, the curves of the total destroyed houses and the partially destroyed have a similar inclination.

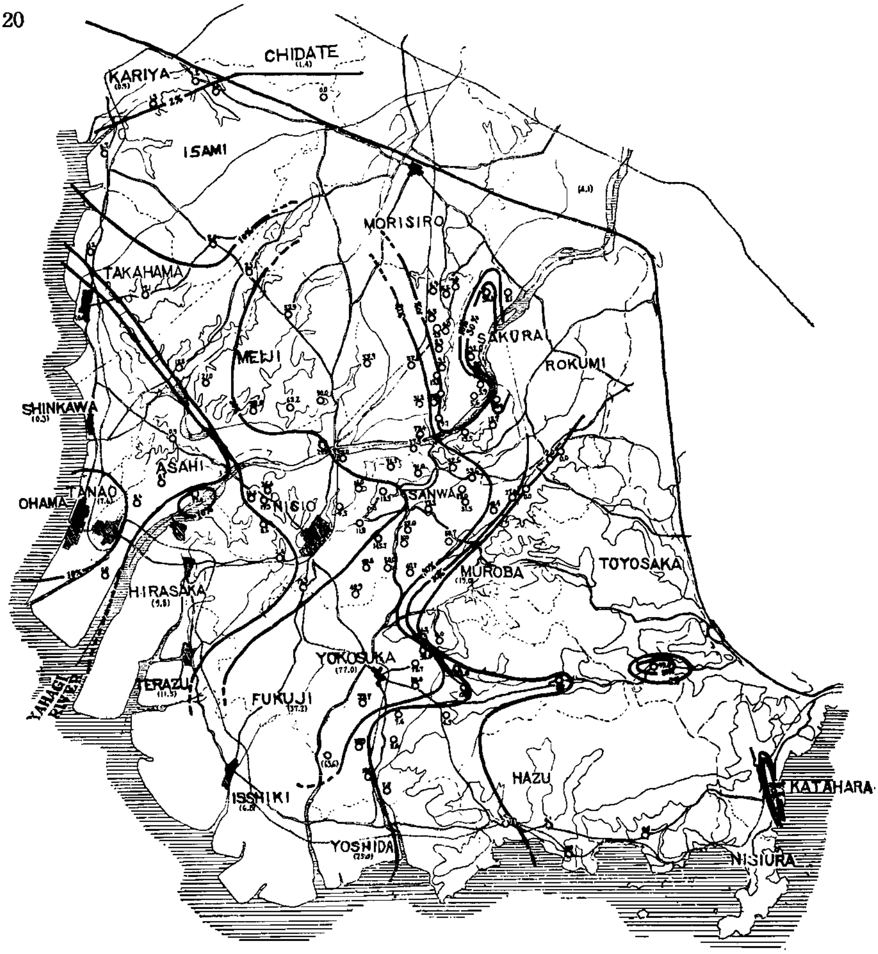


Fig. 14 The rate of damage at Mikawa by Mikawa-earthquake.

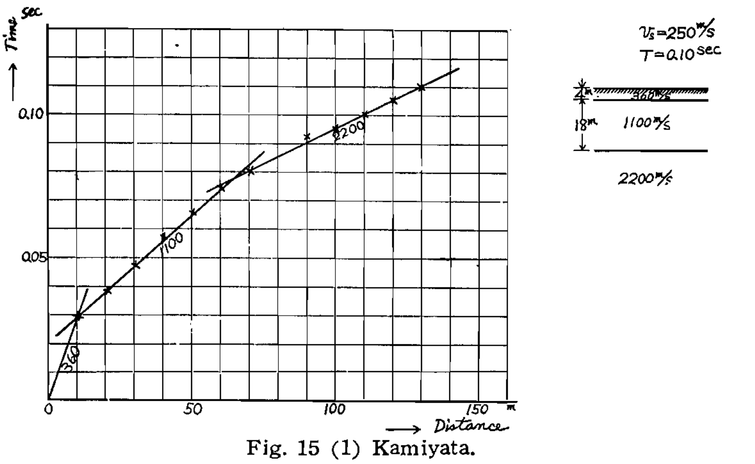


Fig. 15 (1) Kamiyata.

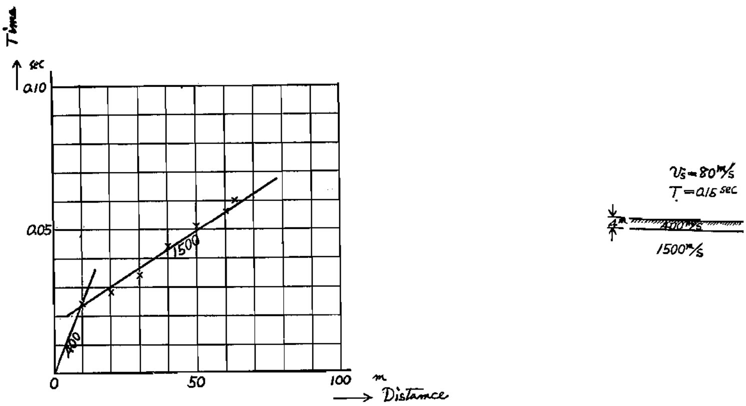


Fig. 16 (2) Kitahama-omizu.

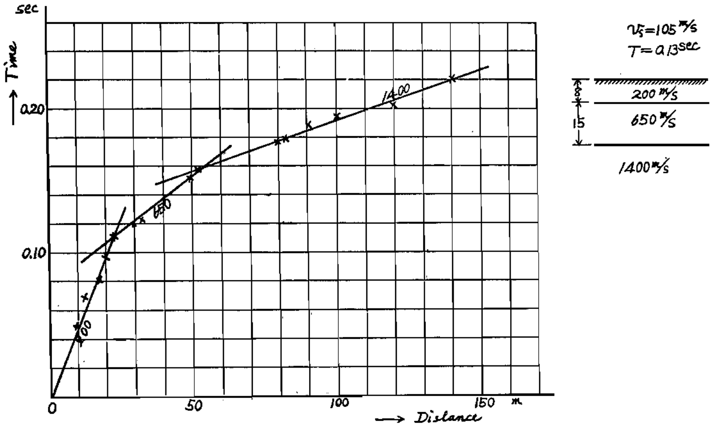


Fig. 17 (3) Niike.

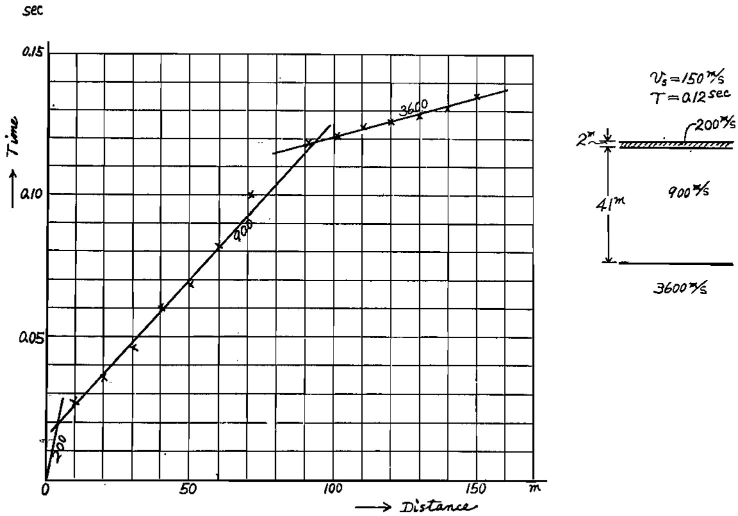


Fig. 18 (4) Yahagi-furukawa.

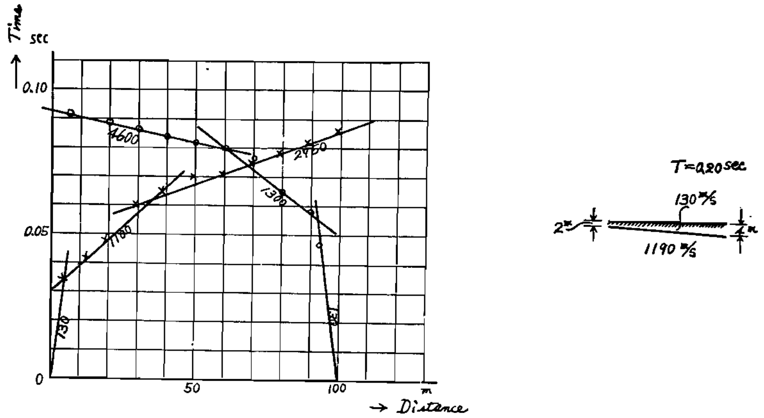


Fig. 19 (5) Kajiarai.

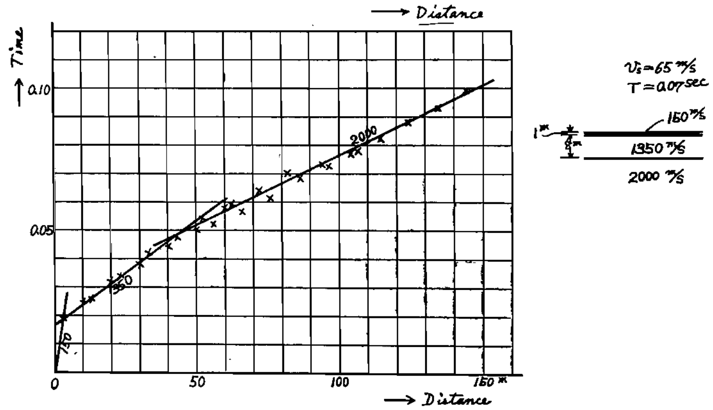


Fig. 20 (6) Dōkōji.

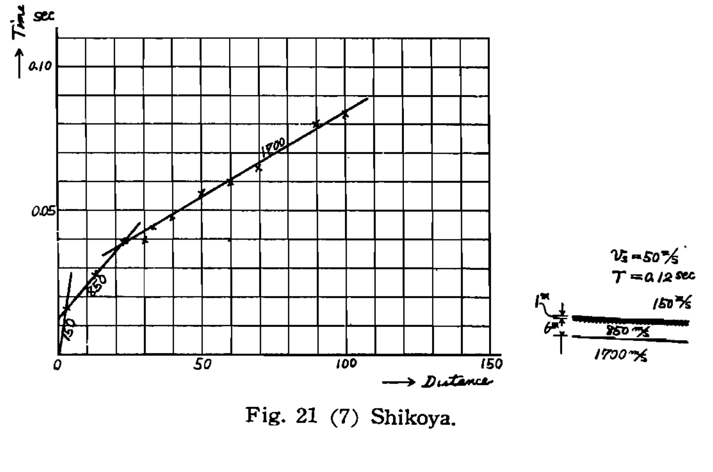


Fig. 21 (7) Shikoya.

Table 4. Percentages of destroyed houses at Kōchi.

Street	Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D
Asahi-machi	Isidachishiroyama	190			0	0	0	—
	Tamamizu-chō	167		9	0	5.4	5.4	0
	Iguchi ch-ōhigashi	235			0	0	0	—
	Iguchi-chō nishi	112			0	0	0	—
	Nakasugachō-higashi	154			0	0	0	—
	Nakasuga chō-naka	219	1	1	0.5	0.5	1.0	0.50
	Nakasuga chō-nishi	179			0	0	0	—
	Nakasugachō-minami	86			0	0	0	—
	Asahi chō 1 chōme higashi	186			0	0	0	—
	Asahi chō 1 chōme nishi	237			0	0	0	—
	Asahi chō 2 chōme	187			0	0	0	—
	Asahi chō 3 chōme higashi	190			0	0	0	—
	Asahi chō 3 chōme naka	143			0	0	0	—
	Asahichō seibu	175			0	0	0	—
	Asahichō minami	192	1		0	0.5	0.5	0
	Akaishi-chō	137			0	0	0	—
	Asahiekimae-chō	184			0	0	0	—
	Motomachi	190			0	0	0	—
	Motomachinishi	127			0	0	0	—
	Minamimotomachi	123			0	0	0	—
	Simotorimachi naka	162			0	0	0	—
	Simotorimachi nishi	62			0	0	0	—
	Yamatehokutan	162			0	0	0	—
	Fukui-chō	153			0	0	0	—
	Asahikamimachi	101			0	0	0	—
	Asahitenjin-chō	153			0	0	0	—
	Hongu-chō	72			0	0	0	—
	Kami hongu-chō	79		1	0	1.3	1.3	0
	Nagoōyama-chō	118			0	0	0	—
	Tsukanohara-chō	57			0	0	0	—
	Suigen-chō	206			0	0	0	—
	Adachirendai-chō	63			0	0	0	—
	Hongu-chō higashi	75	1		1.3	0	1.3	1.00
Kami-machi	Kitaho-kōnin chō	202		13	0	6.4	6.4	0
	Kitahokōnin chō 4.5 chōme	72		1	0	2.0	2.0	0
	Honmachisuji 5 chōme	179			0	0	0	—
	Suidō-chō 1 chōme	134	2	21	1.5	1.5	3.0	0.50
	Suidō-chō 2.3 chōme	56	1		1.8	0	1.8	1.00
	Suidō-chō 5 chōme	126		4	0	3.2	3.2	0
	Torimachi 1.2 chōme	161		20	0	12.4	12.4	0
	Torimachi 4 chōme	101	3		3.0	0	3.0	1.00
	Torimachi 5 chōme	104		10	0	9.6	9.6	0
	Minami Hōkō-nin chō 1 chōme	103	1	41	1.0	39.8	40.8	0.02
	Minami Hōkō-nin chō 2.3 chome	75		16	0	21.4	21.4	0
	Minami Hōkō-nin cho 4 chome	114		10	0	0	0	—
	Tsukiyashikishita	71		8	0	14.1	14.1	0
	Tsukiyashikiue	72			0	11.1	11.1	0
	Tsukiyashiki soto	13			0	0	0	—
	Honmachisuji 2 chome	15		15	0	100.0	100.0	0

Street	Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D
Kūchi-machi	Masugata	86	1	1	1.2	1.2	2.4	0.50
	Kanekobashi	102	1		1.0	0	1.0	1.00
	Takashū-cho	157		6	0	3.8	3.8	0
	Katamachi Tojin-cho	152	1	19	0.7	15.2	15.9	0.04
	Nakajima-cho kami 12 chome	102		16	0	15.7	15.7	0
	Nakajima-cho kami 3 chome	97	4	9	4.1	9.3	13.4	0.31
	Nishihikawa-cho higashi	84	3		3.6	0	3.6	1.00
	Nishihikawa-cho	106	3	13	2.8	12.3	15.1	0.19
	Kitayoriki-cho	122	4		3.3	0	3.3	1.00
	Honyoriki-cho	91			0	0	0	—
	Ottesuji ue	150			0	0	0	—
	Eikokuji-cho	120	1		0.8	0	0.8	1.00
	Obiya-cho	154			0	0	0	—
	Hachiken-cho	131	1		0.8	0	0.8	1.00
	Marunouchi	90		4	0	4.5	4.5	0
	Nishi Hirokoji	124			0	0	0	—
	Obiya-cho 1	132			0	0	0	—
	Honmachi	84			0	0	0	—
Minami-machi	Shiromi-cho higashi	153	34	119	21.2	77.9	99.1	0.21
	Soiromi-cho nishi	82	12	25	14.6	30.5	45.1	0.32
	Nojin-cho	110	47	63	42.6	57.4	100.0	0.43
	Higashi kutanda nakanoshima	75	15	13	20.0	17.3	37.3	0.54
	Saien-cho	93	4	6	4.3	6.5	10.8	0.40
	Mimani-tabuchi	96	11	75	11.5	78.2	89.7	0.13
	Higashi-tojin-chū	115	4	51	3.5	44.4	47.9	0.07
	Urado-chū	105		8	0	7.6	7.6	0
	Yaoya-chū	72	2	12	2.8	16.7	19.5	0.14
	Kita-nūiin-cho	120	45	27	37.5	22.5	60.0	0.63
Kita-machi	Teppo-cho	122	25	92	20.4	75.5	95.9	0.21
	Kita shinmachi higashi	85	21	64	24.7	75.3	100.0	0.25
	Kita-shinmachi nishi	129	43	53	33.3	41.2	74.5	0.45
	Naka-shinmachi higashi	130	88	42	67.8	32.2	100.0	0.68
	Naka shinmachi 1 chome	72	19	41	26.4	57.0	83.4	0.32
	Naka shinmachi 2 chome	76	43	30	56.6	39.5	96.1	0.59
	Minami shinmachi 2 chome	124	72	52	58.0	42.0	100.0	0.58
	Minami shinmachi 3 chome	93	17	76	18.4	81.6	100.0	0.18
	Minami shinmachi 4 chome	87	7	80	8.1	91.9	100.0	0.08
	Tabuchi-cho kita	141	26	60	18.4	42.6	61.0	0.30
	Shimichi-machi	217	6	1	2.8	0.5	3.3	0.85
	Yamada-machi higashi	32		13	0	40.6	40.6	0
	Kitashinmachi naka	99	29	64	29.3	64.6	93.9	0.31
Gechi	Wakamatsu-cho	148	38	23	25.7	15.5	41.2	0.62
	Tokiwa-cho	77	10	38	13.0	49.5	62.5	0.21
	Hūei-cho minami	75	21	35	28.0	46.8	74.8	0.37
	Hūei-cho naka	67	28	33	41.8	49.3	91.1	0.46
	Hūei-cho kita	89	37	50	41.6	56.1	97.7	0.43

Street	Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D
	Hōeicho minamishin-machi	112	99	13	88.4	11.6	100.0	0.88
	Hōei-cho nakashinmachi	120	110	10	91.7	8.3	100.0	0.92
	Chiyori-cho	206	86	120	41.7	58.3	100.0	0.42
	Hinode-chohigashi	76	15	59	19.8	77.6	97.4	0.20
	Hinoae-cho nishi	104	74	29	71.2	27.8	99.0	0.72
	Hinode-cho Tabuchidōri	85	26	59	30.6	69.4	100.0	0.31
	Yayoi-cho	220	108	68	49.1	30.9	80.0	0.61
	Shiromi-cho	75	25	50	33.3	66.7	100.0	0.33
	Kitanōjin-cho	85	66	18	77.7	21.2	98.9	0.79
Kodaka-saka	Echizen-cho minami	94	1	2	1.1	2.1	3.2	0.34
	Echizen-cho kita	110		2	0	1.8	1.8	0
	Sakurababa minami	59		2	0	3.4	3.4	0
	Sakurababa kita	96		3	0	3.1	3.1	0
	Daizensama-cho minami	101		7	0	6.9	6.9	0
	Daizensama-cho-kitε	116		5	0	4.3	4.3	0
	Nishimachi-higashi	135		3	0	2.2	2.2	0
	Nishimachi-nishi	89		3	0	3.4	3.4	0
	Nishimachi-kita	78		3	0	3.9	3.9	0
	Miyamaecho-minami	124		3	0	2.4	2.4	0
	Miyamaecho-kita	113		4	0	3.5	3.5	0
	Miyamaēcho-higashi	81		2	0	2.5	2.5	0
	Yamabana-cho	108		1	0	0.9	0.9	0
	Shinyashiki	125		3	0	2.4	2.4	0
	Shinyashiki kitanonishi	150		4	0	2.8	2.8	0
	Johokuhachitan-cho	91		12	0	13.2	13.2	0
Eno-kuchi	Ozumachi	158		34	0	21.5	21.5	0
	Kami ōkawasuji	156		2	0	1.3	1.3	0
	Naka ōkawasuji	120		32	0	26.7	26.7	0
	Ōkawasuji	142	3	133	2.1	91.5	93.6	0.02
	Tahara machi	227	1	2	0.4	0.9	1.3	0.31
	Iriake-cho	144		1	0	0.7	0.7	0
	Saiwai-cho	92		3	0	3.3	3.3	0
	Horagajima-cho minami	132	1		0.8	0	0.8	1.00
	Horagajima-cho kita	84			0	0	0	0
	Nakasuidō seinan	100		55	0	55.0	55.0	0
	Nakasuido kita sagami-cho	81	9	53	11.1	66.6	77.7	0.14
	Kotobuki-cho higashi	176	1	27	0.6	15.4	16.0	0.38
	Kotobuki-cho nishi	132		13	0	10.0	10.0	0
	Enokuchi-chūbu	177			0	0	0	—
	Shioya-cho higashi	108	5	64	4.6	59.2	63.8	0.07
	Shioyacho-nishi	92		43	0	46.8	46.8	0
	Atagocho 2 chome	59		2	0	3.4	3.4	0
	Kitahonmachi 1 chome higasni	118	6	36	5.1	30.6	35.7	0.14
	Kitahonmachi 2 chome	53	1	30	1.9	56.7	58.6	0.32
	Shinhon-machi 2 chome	198	4	33	2.0	16.7	18.7	0.11
	Ūshinosuke-cho	101	4	54	4.0	53.5	57.5	0.07
	Hijima	30		1	0	3.3	3.3	0
	Nakasuidō-cho higashi	181	14	163	7.8	90.0	97.8	0.08
	Nakasuido cho nishi	119	13	35	10.9	29.0	39.9	0.27
	Shinhonmachi 1 chome	100	2	65	2.0	65.0	67.0	0.05

Street	Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D
Shiōe	Shioyasaki-cho	89	1		1.1	0	1.1	1.00
	Yakuchi-cho	222	30	92	13.5	40.6	54.1	0.25
	Takami-cho	16	1		6.3	0	6.3	1.00
	Shioshin cho	478	19	85	4.0	17.8	21.8	0.18
	Doi-cho	10		3	0	30.0	30.0	0
	Sanbashidōri 3 chome	234	13	23	5.6	9.8	15.4	'036
	Sanbashidōri 5, 6 chome	525	42	38	8.0	7.3	15.3	0.52
	Harami-nishimachi	88		2	0	2.3	2.3	0
	Kitahyakkokucho	192		14	0	7.3	7.3	0
	Harami-nakamachi	79		1	0	1.3	1.3	0
	Harami-higashimachi	6		2	0	33.3	33.3	0
	Shinden-cho	329	22	28	6.7	8.5	15.2	0.44
	Sanbashidōri 1 chome harumo	306	9	28	2.9	9.2	12.1	0.24
	Kawase-cho 1 chome	65	4	17	6.2	26.2	32.4	0.19
	Kawese-cho 2 chome				0	0	0	—
	Koishimoto-cho	83	2	6	2.4	7.2	9.6	0.25
	Tenjin-cho				0	0	0	—
	Tenjin-cho higashi				0	0	0	—
	Fudeyama-cho				0	0	0	—
Hata	Atagoyama	114			0	0	0	—
	Higashi-taizenji	71			0	0	0	—
	Nishi-taizenji	87			0	0	0	—
	Kita-taizenjii	97			0	0	0	—
	Naka-taizenj	80			0	0	0	—
	Maesato	110			0	0	0	—
	Mitani	46			0	0	0	—
	Manatsubuchi	33			0	0	0	—
	Shikishima bōsekicho	50			0	0	0	—
Kamoda	Kamobedaka	137			0	0	0	—
	Kamobeue	93			0	0	0	—
	Kamobeshita	97			0	0	0	—
	Miyadera	21			0	0	0	—
	Takagami	27			0	0	0	—
	Motomura	36			0	0	0	—
	Kōza	29			0	0	0	—
	Matumoto	34			0	0	0	—
	Toyoda	40			0	0	0	—
	Nishiyama-sarutani	127	2	14	1.6	11.0	12.6	0.13
	Yoshino	64			0	0	0	—
	Yakoku-dani	14			0	0	0	—
Uizuki	Higashi-kuma	62			0	0	0	—
	Naka-kuma	60			0	0	0	—
	Nishi-kuma	96			0	0	0	—
	Mama	101			0	0	0	—
	Enkoji	121			0	0	0	—
	Shibamaki	21			0	0	0	—
Tōbu	Takasu	262	123	139	47.0	53.0	100.0	0.49
	Kazushima	98			0	0	0	—
	Araki	83			0	0	0	—
	Karaya	39			0	0	0	—
	Tōwa	108	5	36	4.6	33.4	38.0	0.12
	Izumi	59			0	0	0	—
	Kuraya	22			0	0	0	—

Street	Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D
	Mitsuta	29		7	0	24.2	24.2	0
	Marutani	38			0	0	0	—
	Sakamoto	51			0	0	0	—
	Mitsuishi	104			0	0	0	—
	Minami-suie	39			0	0	0	—
	Kita-suie	114			0	0	0	—
	Harami	58			0	0	0	—
	Nagae	23		5	0	2.18	2.18	0
	Hukuura	9			0	0	0	—
	Yagashira	22		4	0	18.2	18.2	0
Asakura	Minami-yokomachi minami	142			0	0	0	—
	Minami-yokomachi	105		2	0	1.9	1.9	0
	Kita-yokomachi	98			0	0	0	—
	Maeda	48			0	0	0	—
	Ebibashi	54		2	0	3.7	3.7	0
	Shōnan	57			0	0	0	—
	Ebigawa-cho kita	103			0	0	0	—
	Ebigawa-cho minami	100			0	0	0	—
	Ōtani	212			0	0	0	—
	Harigi	51			0	0	0	—
	Minami-shiroyama	59			0	0	0	—
	Kita-siroyama	51			0	0	0.	—
	Kura	52			0	0	0	—
	Akebono-cho 1 chome	89			0	0	0	—
	Akebono-cho higashi	141			0	0	0	—
	Miyamaeoku	104			0	0	0	—
	Yoneda	72			0	0	0	—
	Sōanji	55			0	0	0	—
	Yukikawa	86			0	0	0	—
	Ryoke-karaiwa	61			0	0	0	—
	Haribara	19			0	0	0	—
	Kamisato	17			0	0	0	—
	Yoko-machi	73			0	0	0	—
Misato	Hukii	52			0	0	0	—
	Ōtani	42			0	0	0	—
	Sunaji	98	2	13	2.0	13.3	15.3	0.13
	Higashi-machi	105		12	0	11.4	11.4	0
	Koike	81		3	0	3.7	3.7	0
	Nakagumi	76	3	31	4.0	40.8	44.8	0.09
	Nishi-kami-machi	76	2	20	2.6	26.3	28.9	0.09
	Nishi-naka-machi	34		7	0	20.6	20.6	0
	Nishi-shimo-machi	52			0	0	0	—
	Nakajima	56		4	0	7.2	7.2	0
	Tozu	21			0	0	0	—
	Tanesaki ikku	120	1	30	0.8	25.0	25.8	0.03
	Tanesaki nakaku	I16	24	30	20.7	25.8	46.5	0.44
	Tanesaki yonku	122	32	90	26.2	73.8	100.0	0.26
	Tanesaki goku	160	11	30	6.9	18.8	25.7	0.27
	Tanesaki rokku	174	8	40	4.6	23.0	27.6	0.17
	Yagoi-cho	163			0	0	0	—
	Niida				0	0	0	—
	Kowakecho	42	7		16.7	0	16.7	1.00
Nagahama	Tōhoku	139	1	2	0.7	1.4	2.1	0.33
	Tōnan	170		17	0	10.0	10.0	0
	Seihoku	100	1	10	1.0	10.0	11.0	0.09
	Seinan	181	3	19	1.7	10.5	12.2	0.14

Street	Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_c/D
	Tsukiyama	101			0	0	0	—
	Manji-nishi	10	2	3	20.0	30.0	50.0	0.40
	Manji-higashi	170			0	0	0	—
	Yokotano	46		1	0	2.1	2.1	0
	Hinodeno	37			0	0	0	—
	Hokuji-naka	77	1	2	1.3	2.6	3.9	0.33
	Monzen	87			0	0	0	—
	Nishi-shioya	152	1	3	0.6	1.8	2.4	0.25
	Uga	56			0	0	0	—
	Yokobama	187		2	0	1.1	1.1	0
	Zosen	68		1	0	1.5	1.5	0
	Seinanura	84		7	0	8.3	8.3	0
	Tōnanura	85			0	0	0	—
	Urado-nishi	104		7	0	6.7	6.7	0
	Urado-higashi	109		2	0	1.8	1.8	0
	Katsurahama	124		12	0	9.7	9.7	0
	Minase-hokubu	172		1	0	0.6	0.6	0
	Minase-chubu	81			0	0	0	—
	Saka sakamoto	73			0	0	0	—
	Sakasakamoto nanbu	86	2	2	2.3	2.3	4.6	0.50
	Higashi-shioya	181	10	10	5.5	5.5	11.0	0.50
Ichimiya	Tokutani	54			0	0	0	—
	Yonemoto	35			0	0	0	—
	Nakaso	44			0	0	0	—
	Kamiso	45			0	0	0	—
	Kitano-higashi	82			0	0	0	—
	Kitano-nishi	65			0	0	0	—
	Nabeshima	32			0	0	0	—
	Seibu	89			0	0	0	—
	Azamino-higashi	62			0	0	0	—
	Azamino-nishi	86			0	0	0	—
	Iwaya	45			0	0	0	—
	Azami no oku	41			0	0	0	—
	Kureno	66			0	0	0	—
	Shigekura	64			0	0	0	—
	Irisada	31			0	0	0	—
Hushida	Ishibuchi-nishi	27			0	0	0	—
	Ishibuchi-naka	24		1	0	4.2	4.2	0
	Ishibuchi-higashi	31			0	0	0	—
	Shinyashiki	32			0	0	0	—
	Nishitani	31			0	0	0	—
	Kawabarashima	30			0	—	—	—
	Jizōdo	31		15	0	46.5	46.5	0
	Nakashiba	24			0	0	0	—
	Shimotsuki	25			0	0	0	—
	Koyama	10			0	0	0	—

2) The Exploration of the Grounds:

The earthground of the Kōchi city were examined in April 1948 by the method above mentioned, excepting that the lines were elongated in some case, and deeper ground constructions of the

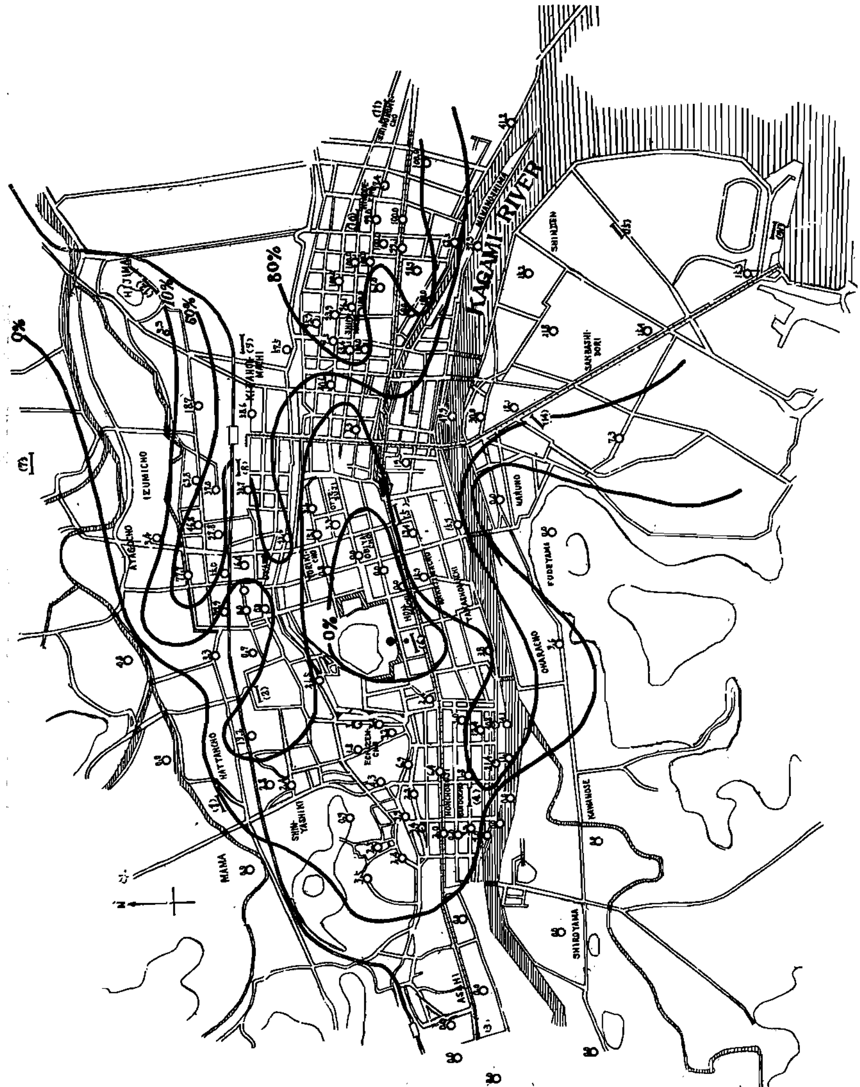


Fig. 22 The rate of damage and lines of survey at Kōchi.

points were explored. The lines of survey were shown in Fig. 22, 17 in number. The time-distance curves, the constructions of grounds, etc. are shown in Fig. 24 to Fig. 40.

Fig. 23 The rate of complete damage at Kōchi.

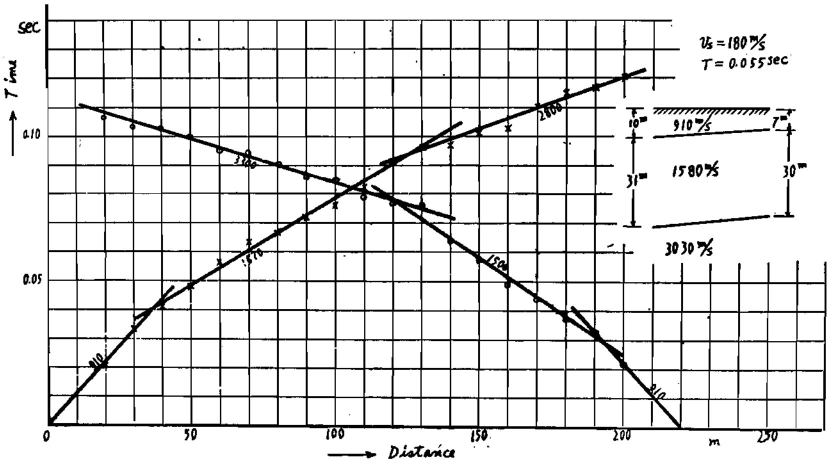


Fig. 24 (1) Minami-mama.

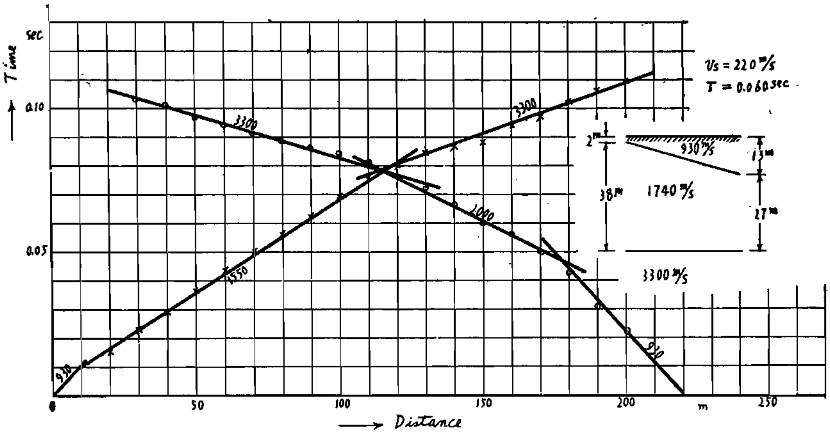


Fig. 25 (2) Kōchi High School.

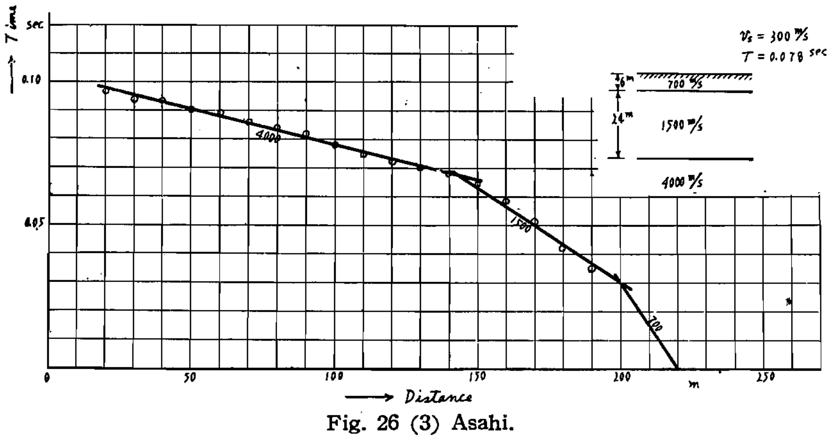


Fig. 26 (3) Asahi.

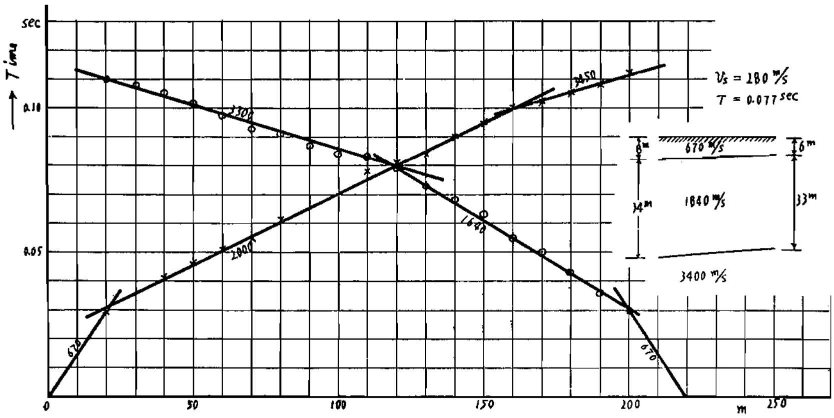


Fig. 27 (4) Suidō-chō.

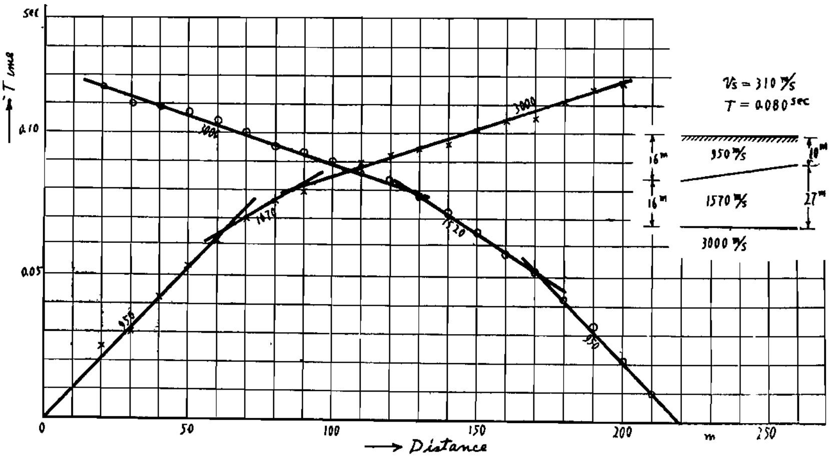


Fig. 28 (5) Horizume.

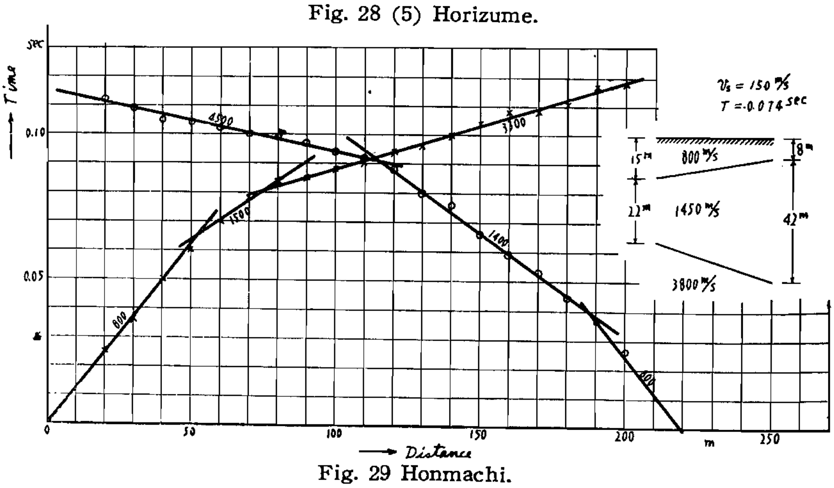


Fig. 29 Honmachi.

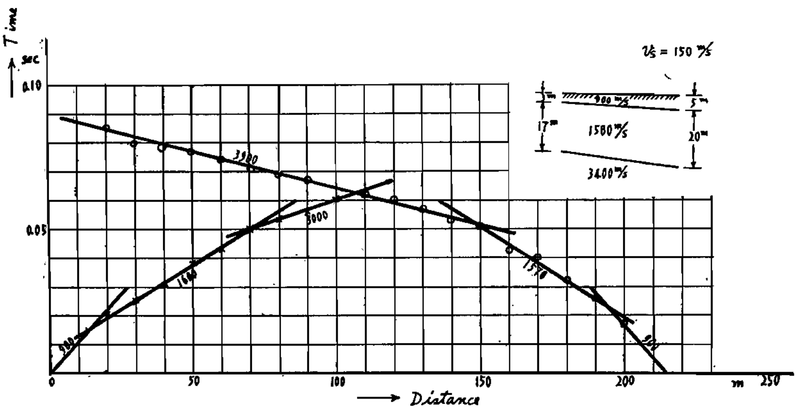


Fig. 30 (7) Shikishima-bōseki.

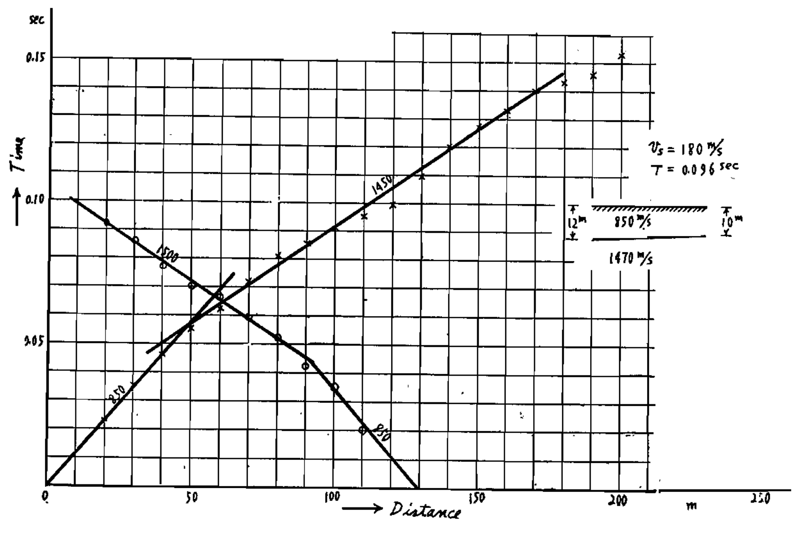


Fig. 31 (8) Kitanhon-cho, 1-chōme.

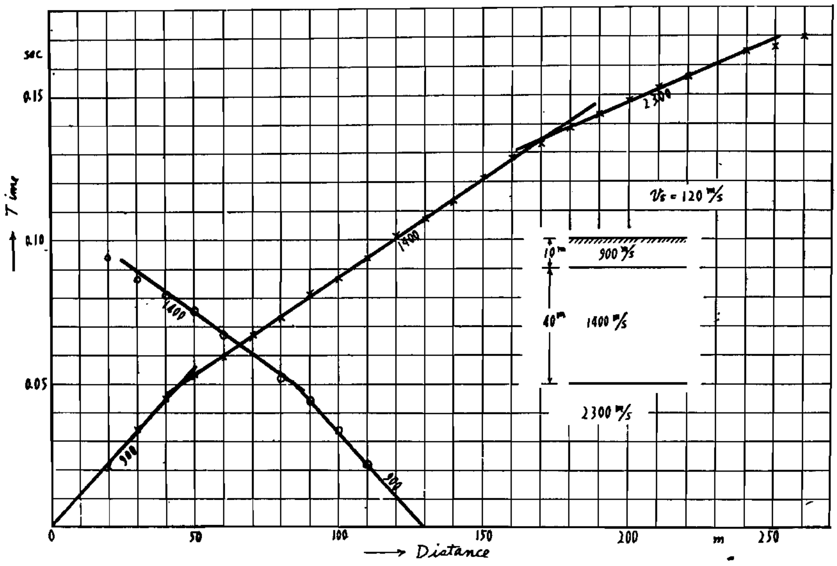


Fig. 32. (9) Kitahon-chō, 3-chōme.

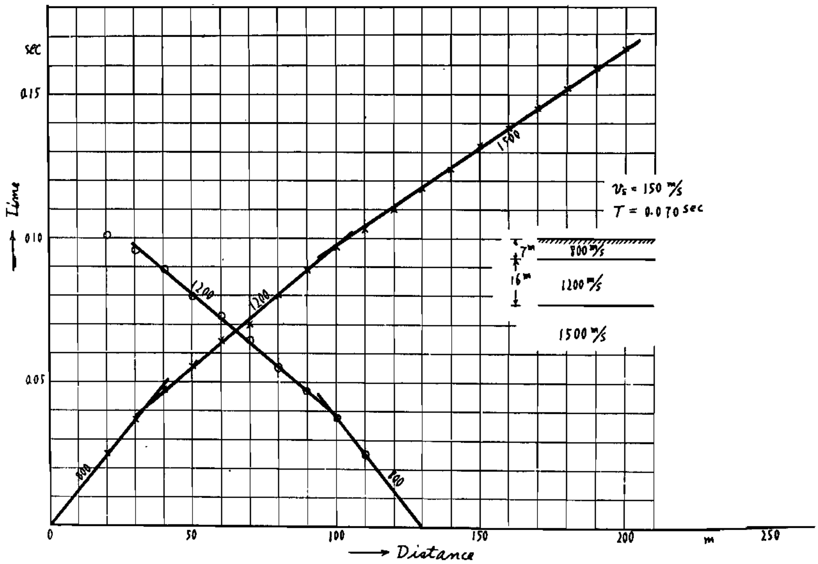


Fig. 33 (10) Hinode-chō.

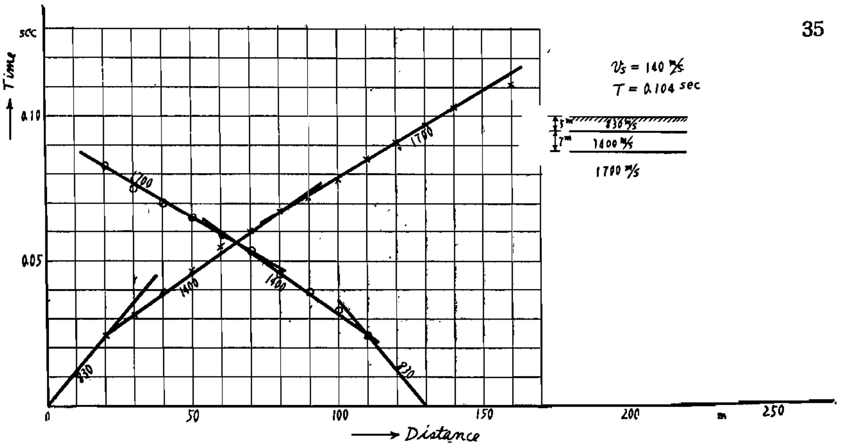


Fig. 34 (11) Shinonome-chō.

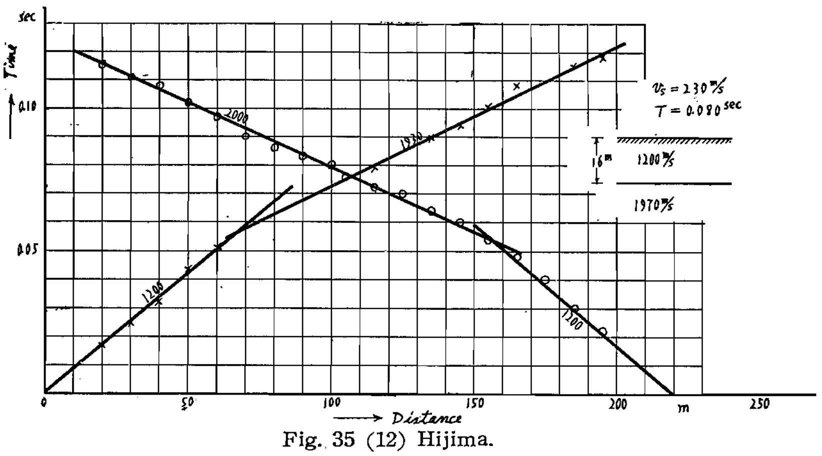


Fig. 35 (12) Hijima.

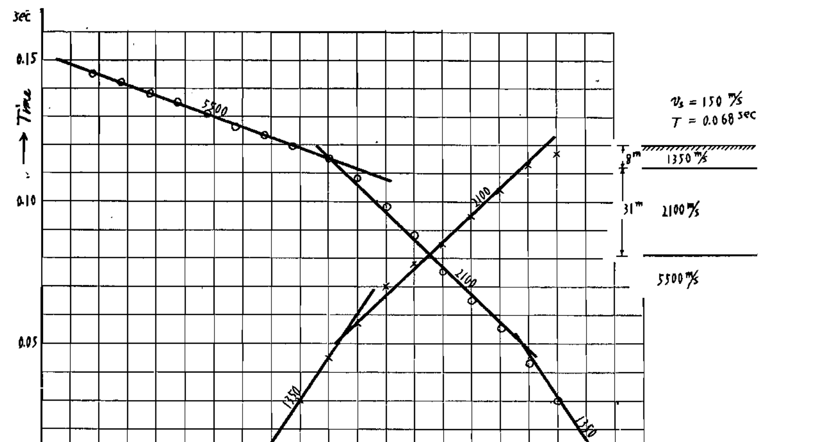


Fig. 36 (13) Takasu.

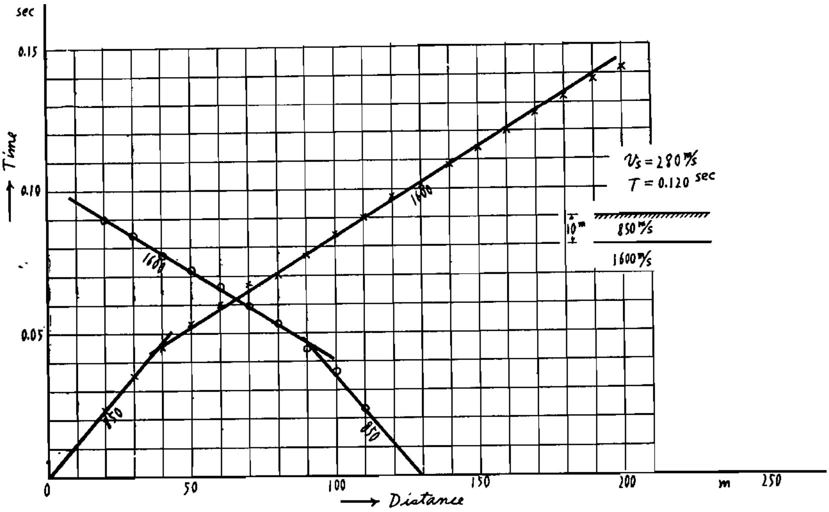


Fig. 37 (14) Kochi Techmical School.

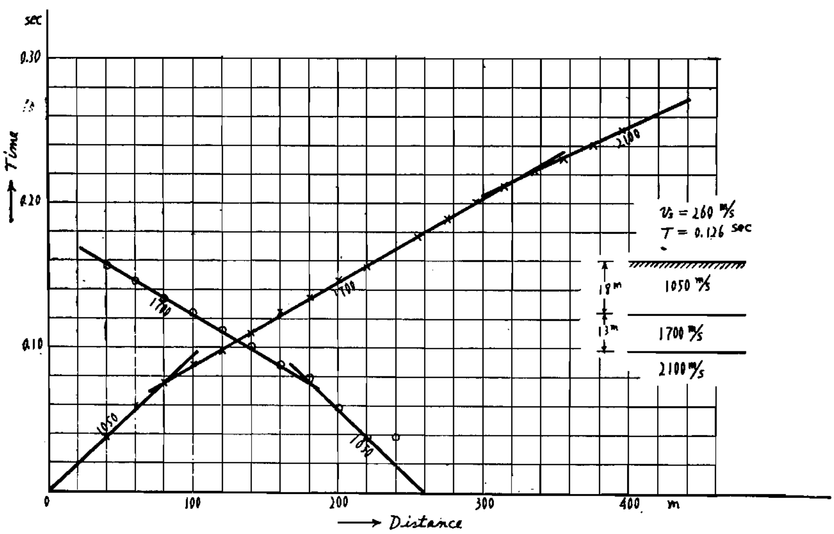


Fig. 38 (15) Nakazutsumi.

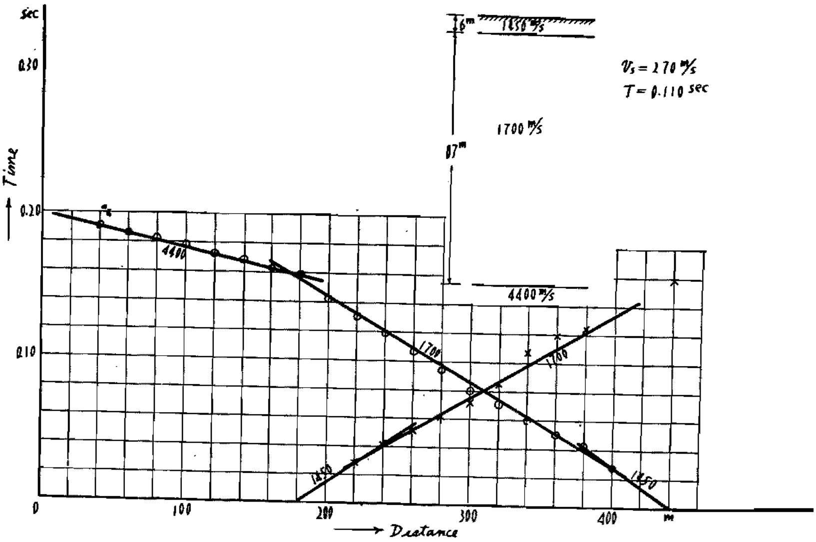


Fig. 39 (16) Tanabejima.

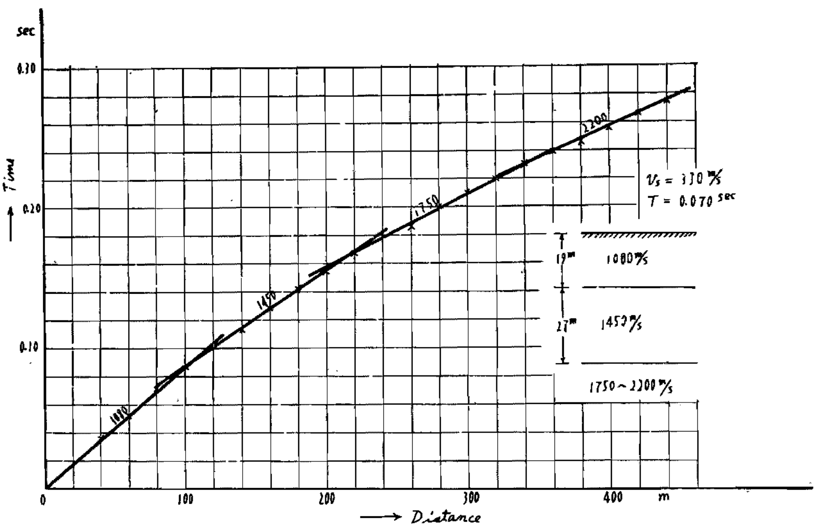


Fig. 40 (17) Sanbashi.

7. The Exploration at the Fukui city.

The vicinity of the Fukui city was attacked by a violent earthquake at 4:13 p. m., June 28, 1948. The area attacked violently by this earthquake was limited to the northern part of Fukui Prefecture, a local earthquake in a small area around Fukui Plain. But in Fukui Plain, it was extremely furious. The area where the percentage of the houses completely destroyed was close to 100% was almost all over the plain; 63,000 houses were crashed completely, 18,500 partially, 4,000 burnt down. The casualty was 8,500; 5,200 were killed, and 3,300 were injured. The seismic center is presumed to have been at a spot near the lower reaches of the Kuzuryū River.

1) The rate of damage:

The number of the houses destroyed in each community was investigated also in the city by her office immediately after the shake, on which our calculation of the destruction rates was based. These values are shown in Table 5. Although the rates for each community are also presented in the table, the number of the houses in a community was usually too small to make calculations on the rates. Thus we were obliged to sum up these houses for each street to obtain the percentages. These values were later employed to compare with the result of the ground examinations. The rates in the area ravaged by fire were obtained only from the houses exempted, and these values are not as accurate as the others. From the above data the percentage curve ot the totally destroyed houses is drawn in Fig. 14.

In Table 5, the proportion of the rate of the houses completely destroyed to the total rate of the houses destroyed was obtained. The proportion is 1 or close to it for the most cases, showing that the earthquake in this area was extremely violent.

2) The Exploration of the Grounds:

The earthgrounds of the Fukui city were examined in Oct. 1948 in the way mentioned above on the five lines shown in Fig. 41. The time-distance curves of elastic waves, the ground constructions, etc. are shown in Fig. 42 to Fig. 46.

8. The Comparison of the Reults of the Explorations of Grounds with the Rates of the Wooden House Destruction.

The physical natures obtained above such as the depth of each layer, the velocity of longitudinal waves, the velocity and the period of surface wave are shown in Table 6 to 9, with the rates of destruction and complete destruction of the houses at the points where the explorations were made obtained from the investigations mentioned above, in the columns at the right side. However, the rate of house destruction sometimes shows, as can be seen from the explorations

Table 5. Percentages of destroyed houses at the Fukui-city

SOUTHERN PART

		Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D
	Shimouma	Shimauma-cho	78	76	2	97.5	2.5	100.0	0.98
	Itagaki	Itagki-cho	110	104	6	94.5	5.5	100.0	0.95
	Kasuga	Minami Toyoda	28	19	7	68.0	25.0	93.0	0.73
		Kita Toyoda	20	11	8	55.0	40.0	95.0	0.58
		Toyoda	25	17	7	68.0	28.0	96.0	0.71
		Kasuga izumi	45	23	2	51.0	4.4	55.4	0.92
Honda-ku		Shin kakiuchi	30	22	6	73.3	20.0	93.0	0.79
		Kasuga higashi	49	43	6	87.8	12.2	100.0	0.88
		Kasuga naka	20	16	3	80.0	15.0	95.0	0.84
		Kasuga minami	31	26	5	84.0	16.0	100.0	0.84
		Kasuga moto	38	32	4	84.3	10.5	94.8	0.89
		Kasuga ue	20	17	3	85.0	15.0	100.0	0.85
		Kida shin	33	21	8	63.8	24.3	88.1	0.72
		Kasuga shin	33	25	0	75.8	0	75.8	1.00
		Kasuga	35	21	12	60.0	34.2	94.2	0.64
		Ippongi	50	40	10	80.0	20.0	100.0	0.80
		Total	457	333	81	73.0	17.7	90.7	0.80
	Ippongi	Ippongi	31	18	13	58.2	41.8	100.0	0.58
	Honda	Honda	22	22	0	100.0	0	100.0	1.00
	Hamado	Ichi-chome	80	45	5	55.3	6.3	61.6	0.90
		Ni-chome	120	97	23	81.0	19.0	100.0	0.81
		San-chome	73	29	41	39.7	56.2	95.9	0.41
		Yon-chome	47	40	7	85.1	14.9	100.0	0.85
		Sakae machi	45	38	7	84.4	15.6	100.0	0.84
		Tetsudo-kaikan	45	44	0	98.0	0	98.0	1.00
		Total	410	293	83	73.3	20.2	93.5	0.78
	Tsukimi	Kita-gumi minami	48	32	8	66.7	16.7	83.4	0.80
		Yamaski-gumi	74	30	29	40.6	39.2	79.8	0.51
		Imasaka	21	7	2	33.3	9.5	42.8	0.78
		Akasaka	118	42	18	35.6	15.2	50.8	0.70
		Hamae	62	51	10	80.7	16.1	96.8	0.83
		Tsukimi-naka	22	6	5	27.3	22.8	50.1	0.54
		Total	345	168	72	48.8	20.9	69.7	0.70
Toyo-ku	Aoi	Kami-gumi kami	50	50	0	100.0	0	100.0	1.00
		Kami-gumi shimo	32	32	0	100.0	0	100.0	1.00
		Naka-gumi	49	48	1	98.0	2.0	100.0	0.98
		Shimo-gumi	38	38	0	100.0	0	100.0	1.00
		Total	169	168	1	99.9	0.1	100.0	1.00
	Toyo	Nakanomotoyama	9	9	0	100.0	0	100.0	1.00
		Ara-machi	62	54	7	87.2	1.13	98.5	0.88
		Haire	43	21	13	48.8	30.2	79.0	0.62
		Nishi-aburaya	22	22	0	100.0	0	100.0	1.00
		Toyoshin-machi	61	60	1	98.5	1.5	100.0	0.99
		Total	197	166	21	84.2	10.7	94.9	0.84
	Hotta	Ichi no kumi	33	27	3	81.8	9.1	90.9	0.90
		Ni no kumi matsu	12	7	5	58.4	41.6	100.0	0.58
		Ni no kumi take	14	14		100.0	0	100.0	1.00
		Ni no kumi ume	7	4	3	57.0	43.0	100.0	0.57

	Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D
	San no kumi	23	10	13	43.5	56.5	100.0	0.44
	Shi no kumi	15	9	6	60.0	40.0	100.0	0.60
	Go no kumi	16	9	7	56.3	43.7	100.0	0.56
	Roku no kumi	53	8	45	15.1	84.9	100.0	0.15
	Total	173	88	82	50.9	47.4	98.3	0.51
Shōwa	Ichi no kumi ichi	27	27		100.0	0	100.0	1.00
	Ichi no kumi ni	16	16		100.0	0	100.0	1.00
	Ichi no kumi san	27	26		96.3	0	96.3	1.00
	Ni no kumi	102	100	2	98.1	1.9	100.0	0.98
	San no kumi	54	52	1	96.3	1.9	98.2	0.98
	Shi no kumi nishi	29	28	—	96.5	0	96.5	1.00
	Shi no kumi higashi	42	39	3	92.8	7.2	100.0	0.93
	Shi no kumi kita	35	34	1	97.1	2.9	100.0	0.97
	Go no kumi	—	—	—	—	—	—	—
	Mutsumikai	60	59	1	98.3	1.7	100.0	0.98
	Roku no kumi	61	45	16	73.8	25.2	100.0	0.74
	Total	453	426	24	94.2	5.3	99.5	0.95
Hikawa	Dai ichi	32	15	17	46.9	53.1	100.0	0.47
	Dai ni	26	10	16	38.5	61.5	100.0	0.39
	Higashi-machi	29	25	4	86.3	13.7	100.0	0.86
	Tsuji-machi	35	35	0	100.0	0	100.0	1.00
	Total	122	85	37	69.6	30.4	100.0	0.70
Kagematsu	Kannon	31	17	5	54.9	16.1	71.0	0.77
	Kami	21	5	4	23.8	19.1	42.9	0.55
	Shimo	21	5	14	23.8	66.7	90.5	0.26
	Total	73	27	23	37.0	31.5	68.5	0.54
Asahi	Asahi machi	28	27	1	96.4	3.6	100.0	0.96
	Kita gumi	28	3	25	10.7	89.3	100.0	0.11
	Minami gumi	16	16	0	100.0	0	100.0	1.00
	Total	72	46	26	63.9	36.1	100.0	0.64
Ide	Kami	55	20	12	36.4	21.8	58.2	0.63
	Naka	52	23	17	44.2	32.7	76.9	0.57
	Total	107	43	29	40.2	27.1	67.3	0.60
Fudō	Kami	31	1	6	3.2	19.4	22.6	0.14
	Naka	27	3	17	11.1	63.0	74.1	0.15
	Total	58	4	23	6.9	39.7	46.6	0.15
Kotobuki	Hompōji	21	1	8	4.8	38.1	42.9	0.11
	Kotobuki kami-machi	22	4	9	18.2	41.0	59.2	0.31
	Kotobuki nak-amachi	50	9	41	18.0	82.0	100.0	0.18
	Total	93	14	58	15.1	62.4	77.5	0.19
Kawakami	Shima gumi	28	6	18	21.4	64.4	85.8	0.25
	Hari machi	20	8	12	40.0	60.0	100.0	0.40
	Tsūanji	31	6	13	19.4	42.0	61.4	0.32
	Horikōji	18	0	7	0	39.0	39.0	0
	Total	97	20	50	20.6	51.5	72.1	0.29
Yamaoku	Yamatoen	84	2	82	2.5	97.5	100.0	0.03
	Yonao	63	35	28	55.6	44.4	100.0	0.56
	Yonaomoto	(27)	—	—	—	—	—	—
	Yamaoku	91	45	46	49.5	50.5	100.0	0.50
	Total	238	82	156	34.5	65.5	100.0	0.35

		Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D
Tateya-ku	Keya	Kami	31	15	10	48.5	33.2	81.7	0.59
		Naka machi	24	6	18	25.0	75.0	100.0	0.25
		Higashi machi	18	4	2	22.0	11.1	33.3	0.67
		Ni no kumi	30	13	3	43.3	10.0	53.3	0.81
		Shi no kumi	15	6	1	40.0	6.7	46.7	0.86
		Go no kumi	11	1	7	9.1	63.6	72.7	0.13
		Roku no kumi	25	7	18	28.0	72.0	100.0	0.28
		Shichi no kumi	42	13	29	28.6	71.4	100.0	0.29
		Hachi no kumi	26	6	5	23.0	19.2	42.2	0.54
		Total	222	71	93	32.0	41.9	73.9	0.43
	Sanai	Keyashin	30	7	23	23.3	76.7	100.0	0.23
		Sanai	47	16	31	34.0	66.0	100.0	0.34
		Kogurauchi	26	1	1	3.4	3.4	6.8	0.50
		Total	103	24	55	23.3	53.4	76.7	0.30
	Iwabori	Ishizaka	14	4	2	28.6	14.3	42.9	0.67
		Iwabori	29	2	6	6.9	20.7	27.6	0.25
		Total	43	6	8	14.0	18.6	32.6	0.43
	Takiwagi	Jingūdera ue	30	5	15	18.3	50.0	68.3	0.27
		Futaba	16	6	10	37.5	63.5	100.0	0.38
		Motokeya	19	5	7	26.4	37.0	63.4	0.42
		Midori	32	2	29	6.3	90.6	96.9	0.65
		Total	97	18	61	18.6	62.9	81.5	0.23
	Aioi	Kami gumi	17	9	8	53.0	47.0	100.0	0.53
		Shimo gumi	30	7	22	23.3	73.3	96.6	0.24
		Higashi gumi	23	11	10	45.7	43.6	89.3	0.51
		Total	80	27	40	33.8	50.0	63.8	0.53
	Ashibane kami	Ashibane kami	61	21	40	34.5	65.5	100.0	0.35
		Atago	27	3	7	11.1	26.0	37.1	0.30
		Total	88	24	47	27.3	53.4	80.7	0.34
	Ashibane shimo	Ishiba kami	27	11	13	40.8	48.2	89.0	0.46
		Ishiba shimo	30	8	12	26.7	40.0	66.7	0.40
		Ashiba nishi	18	3	11	16.7	61.1	77.8	0.21
		Total	75	22	36	29.4	48.0	77.4	0.38
	Tsuzura	Tsuzura shin	12	2	10	16.7	83.3	100.0	0.17
		Mitsuya	16	7	9	43.8	56.2	100.0	0.44
		Kubo	37	12	25	32.4	67.6	100.0	0.32
		Aratama	15	5	7	33.3	46.7	80.0	0.42
		Dōgo	26	7	19	27.0	73.0	100.0	0.27
		Total	106	33	70	31.1	66.0	97.1	0.32
	Sakae	Minami sakae	30	1	5	3.3	16.7	20.0	0.17
		Kita sakae	42	3	1	7.2	2.4	9.6	0.75
		Sōei	19	2	17	10.5	89.5	100.0	0.11
		Total	91	6	23	6.6	25.3	31.9	0.21
	Wakamatsu	Higashi Wakamatsu	36	4	5	11.1	13.9	25.0	0.44
		Nishi-teramachi	27	1	2	3.7	7.4	11.0	0.33
		Wakamatsu	45	8	3	17.8	6.7	24.5	0.73
		Butai	14	4	6	28.6	42.8	71.4	0.40
		Total	122	17	16	13.9	13.1	27.0	0.52
	Tōen	Syōei	17	3	5	17.6	29.4	47.0	0.37
		Kyōei	20	3	6	15.0	30.0	45.0	0.33

		Community	A	B	C.	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D
		Takayama	20	3	8	15.0	40.0	55.0	0.27
		Tōenkami	46	4	14	8.7	30.4	39.1	0.22
		Nakaguki	31	3	8	7.7	25.8	33.5	0.23
		Tōenshimo	24	1	6	4.2	25.0	29.2	0.14
		Total	158	17	47	10.8	29.8	40.6	0.27
	Yūraku	Yūraku	36	11	14	30.6	38.9	69.5	0.44
		Masago	17	2	14	11.8	82.5	94.3	0.13
		Niitaka	19	4	1	21.1	5.3	26.4	0.80
		Kaitō	23	4	12	17.4	52.2	69.6	0.25
		Total	95	21	41	22.1	43.1	65.2	0.34
	Midori	Suehiro	22	1	9	4.5	41.0	45.5	0.10
		Kodera rakuyūkai	14	2	12	14.3	85.7	100.0	0.14
		Kodera kita	11	1	8	9.1	72.8	81.9	0.11
		Matsuo	14	4	4	28.6	28.6	57.2	0.50
		Total	61	8	33	13.1	54.1	67.2	0.19
	Yakata	Nakatateya	26	5	21	19.2	80.8	100.0	0.19
		Kyū tarui	15	0	2	0	13.3	13.3	0
		Shimotateya	32	0	7	0	21.0	21.0	0
		Shin-yakata	19	3	2	15.8	10.5	26.3	0.60
		Total	92	8	32	8.7	34.8	43.5	0.20
	Tamai	Tamai	29	4	23	13.8	79.3	93.1	0.15
		Daishin	29	2	27	6.8	93.2	100.0	0.07
		Total	58	6	50	10.3	86.2	96.5	0.11
	Chitose	Nagao	27	3	6	11.1	22.2	33.3	0.33
		Higashichitose	31	0	15	0	48.5	48.5	0
		Nishichitose	49	7	9	14.3	18.4	32.7	0.44
		Meirin	23	5	18	21.8	78.2	100.0	0.22
		Total	130	15	48	11.5	37.0	48.5	0.24
WESTERN PART									
Higashi Yasui-ku	Akisato	Dai ichi no kumi	49	31	18	63.3	36.7	100.0	0.63
		Dai ni no kumi	47	38	9	80.8	19.2	100.0	0.81
		Dai san no kumi	26	9	17	34.6	65.4	100.0	0.35
		Dai shi no kumi	19	12	7	63.2	36.8	100.0	0.63
		Minami-akisato nikumi	178	110	34	61.8	19.1	80.9	0.77
		Minami-akisato ichikumi	44	44	0	100.0	0	100.0	1.00
		Minami-akisato sankumi	22	22		100.0	0	100.0	1.00
		Total	385	266	85	69.1	22.1	91.2	0.76
	Sugaya	Sugaya	28	28	0	100.0	0	100.0	1.00
	Minakoshi	Minakoshi	17	15	2	88.3	11.7	100.0	0.88
		Kyōdōryō	18	18	0	100.0	0	100.0	1.00
		Total	35	33	2	94.3	5.7	100.0	0.94
	Iizuka	Iizuka	28	55	3	89.3	10.7	100.0	0.89
	Ōse	Ōse	29	27	2	93.1	6.9	100.0	0.93
	Kadoore	Kadoore	31	28	3	90.3	9.7	100.0	0.90
	Shimoichi	Shimoichi	46	9	33	19.6	71.8	91.4	0.21
	Kanaya	Kanaya	27	3	16	11.1	59.3	70.4	0.16
	Higashi-akisato	Nagata 1	19	19	0	100.0	0	100.0	1.00
		Nagata 2	17	17	0	100.0	0	100.0	1.00

		Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_1/D
Minato-ku		Nagata 3	20	20	0	100.0	0	100.0	1.00
		Enoki-dai ich no kumi	22	20	0	91.0	0	91.0	1.00
		Gojyokai	1	1	0	100.0	0	100.0	1.00
		Enoki-dai ni no kumi	12	12	0	100.0	0	100.0	1.00
		Enoki-dai san no kumi	46	42	4	91.5	8.5	100.0	0.92
		Enoki-dai shi no kumi 1	33	30	3	91.0	9.0	100.0	0.91
		Enoki-dai shi no kumi 2	19	19	0	100.0	0	100.0	1.00
		Enoki-dai shi no kumi 3	23	21	2	91.3	8.7	100.0	0.91
		Higashi-akisato shi	49	49	0	100.0	0	100.0	1.00
		Total	261	250	9	95.9	3.4	99.3	0.97
	Sakai	Sakai	42	42	0	100.0	0	100.0	1.00
	Terute kami	Kyūyawata	22	14	8	63.7	36.3	100.0	0.64
		Kimachi	30	24	6	80.0	20.0	100.0	0.80
		Kyōmachi	23	12	11	52.2	47.8	100.0	0.52
		Agarichimachi	11	8	3	72.8	27.2	100.0	0.73
		Total	86	58	28	67.4	32.6	100.0	0.67
	Terute naka	Yama machi	28	16	12	57.2	42.8	100.0	0.57
		Ebisu machi	34	16	16	47.0	47.0	94.0	0.50
		Shio machi	24	16	8	66.7	33.3	100.0	0.67
		Mutsumi machi	16	5	11	31.3	68.7	100.0	0.31
		Total	102	53	47	52.0	46.1	98.1	0.53
	Terute shimo	Kamimifune	29	20	9	69.0	31.0	100.0	0.69
		Tachibana	11	8	3	72.8	27.2	100.0	0.73
		Total	40	28	12	70.0	30.0	100.0	0.70
	Minato kami	Yawata	10	8	2	80.0	20.0	100.0	0.80
		Shinmifune	10	7	3	70.0	30.0	100.0	0.70
		Shimomifune	11	11	0	100.0	0	100.0	1.00
		Hanazono	39	22	17	56.4	43.6	100.0	0.56
		Total	70	48	22	68.6	31.4	100.0	0.69
	Minato shimo	Kamifuku 1 kumi	24	21	3	87.6	12.9	100.0	0.88
		Kamifuku 2 kumi	39	32	7	82.1	17.9	100.0	0.82
		Misono ichi kumi	6	5	1	83.3	16.7	100.0	0.83
		Misono motomachi	17	16	1	94.2	5.8	100.0	0.94
		Minato tachibana	9	8	1	88.9	11.1	100.0	0.89
		Minato kōenchi	25	21	4	84.1	15.9	100.0	0.84
		Doihara	16	16	0	100.0	0	100.0	1.00
		Minato shin	23	21	2	91.4	8.6	100.0	0.91
		Minato	20	18	2	90.0	10.0	100.0	0.90
		Minato kōenchi Kita gumi 1	18	15	3	83.4	16.6	100.0	0.83
		Minato kōenchi kita gumi 2	15	13	2	86.7	13.3	100.0	0.87
		Total	212	186	26	87.8	12.2	100.0	0.88
	Kagetsu kami	Seibu	26	22	4	84.6	15.4	100.0	0.85
		Kitanishiyama	27	25	2	92.6	7.4	100.0	0.93
		Higashinishiyama	15	13	2	86.7	13.3	100.0	0.87

	Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D
	Nishi yamanaka	36	32	4	88.9	11.1	100.0	0.89
	Total	104	92	12	88.5	11.5	100.0	0.89
Kagetsu naka	Kagetsu nishi	20	18	2	90.0	10.0	100.0	0.90
	Higashigumi	26	22	4	83.3	16.7	100.0	0.83
	Total	46	40	6	87.0	13.0	100.0	0.87
Kagetsu shimo	Kami-nishiyama ue	Lost by Fire			—	—	—	—
	Higashi aoyamachi	14	6	8	42.9	57.1	100.0	0.43
	Total	14	6	8	42.9	57.1	100.0	0.43
Inui shin	Fukusyō	Lost by Fire			—	—	—	—
	Dai ichi	25	25	0	100.0	0	100.0	1.00
	Dai ni	39	37	2	94.9	5.1	100.0	0.95
	Dai san	26	25	1	96.1	3.9	100.0	0.96
	Dai shi	41	34	7	82.9	17.1	100.0	0.83
	Dai go	26	25	1	96.1	3.9	100.0	0.96
	Dai roku	19	19	0	100.0	0	100.0	1.00
	Dai shichi	19	19	0	100.0	0	100.0	1.00
	Dai hachi	30	30	0	100.0	0	100.0	1.00
	Dai ku	33	29	4	87.9	12.1	100.0	0.88
	Dai jūichi kumi	16	15	0	93.8	0	93.8	1.00
	Dai jūni kumi	20	16	3	80.0	15.0	95.0	0.84
	Dai jūichi	32	31	1	96.9	3.1	100.0	0.97
	Dai jūni	30	30	0	100.0	0	100.0	1.00
	Dai jūsan	38	35	3	92.1	7.9	100.0	0.92
	Dai jūshi	23	23	0	100.0	0	100.0	1.00
	Dai jūgo	Lost by Fire			—	—	—	
	Dai juroku	23	23	0	100.0	0	10.00	1.00
	Asahi gumi	22	20	2	91.0	9.0	100.0	0.91
	Shiei ha gumi	19	14	5	73.8	26.2	100.0	0.74
	Total	481	450	29	93.5	6.0	99.5	0.94
Minato shin	Dai ichi	25	25	0	100.0	0	100.0	1.00
	Dai ni	71	68	3	95.8	4.2	100.0	0.96
	Dai san	48	45	3	93.7	6.3	100.0	0.94
	Dai shi	16	16	0	100.0	0	100.0	1.00
	Total	160	154	6	96.2	3.8	100.0	0.96
Kagetsu shin	Dai ichi	30	24	6	80.0	20.0	100.0	0.80
	Dai ni	17	10	7	58.9	41.1	100.0	0.59
	Dai san 1	9	8	1	88.9	11.1	100.0	0.89
	Dai san 2	15	10	5	66.7	33.3	100.0	0.67
	Dai san 3	9	7	2	77.8	22.2	100.0	0.78
	Dai go	20	15	5	75.0	25.0	100.0	0.75
	Dai roku	36	32	4	88.9	11.1	100.0	0.89
	Dai shichi	22	20	2	91.0	9.0	100.0	0.91
	Dai hachi	51	46	5	90.2	9.8	100.0	0.90
	Dai ku 1	18	16	2	88.9	11.1	100.0	0.89
	Dai ku 2	15	10	5	66.7	33.3	100.0	0.67
	Dai jū	34	28	6	85.3	14.7	100.0	0.85
	Dai jūichi	34	30	4	88.2	11.8	100.0	0.88
	Dai jūni	34	28	6	85.3	14.7	100.0	0.85
	Dai jūsan	46	40	6	87.0	13.0	100.0	0.87
	Dai jūshi	34	27	7	79.4	20.6	100.0	0.79
	Dai jūgo	29	21	8	72.5	27.5	100.0	0.73
	Dai jūroku	29	23	6	70.7	29.3	100.0	0.71
	Dai jūshichi	25	25	0	100.0	0	100.0	1.00
	Dai jūhachi	16	11	5	68.8	31.2	100.0	0.69
	Total	523	431	92	82.4	17.6	100.0	0.82

		Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D
	Inui kami	Dai ichi	9	9	0	100.0	0	100.0	1.00
		Dai ni	5	3	2	60.0	40.0	100.0	0.60
		Total	14	12	2	85.7	14.3	100.0	0.86
	Inui naka	Dai san	Lost by Fire			—	—	—	—
		Akibagumi	31	29	2	93.7	6.3	100.0	0.94
		Dai roku	27	24	3	88.9	11.1	100.0	0.89
		Dai shichi	28	27	1	96.5	3.5	100.0	0.97
		Total	86	80	6	93.0	7.0	100.0	0.93
	Inui shimo	Dai hachi	12	10	2	83.3	16.7	100.0	0.83
		Dai ku	26	25	1	96.2	3.8	100.0	0.96
		Dai jū	20	19	1	95.0	5.0	100.0	0.95
		Dai jūichi	36	32	4	88.9	11.1	100.0	0.89
		Shiobune-cho	3	3	0	100.0	0	100.0	1.00
		Total	97	89	8	91.8	8.2	100.0	0.92
EASTERN PART									
Hinode-ku	Hinode kami	Ichi no kumi	18	18	0	100.0	0	0	1.00
		Ni no kumi	40	19	21	47.5	52.5	100.0	0.48
		Shi no kumi	20	11	9	55.0	45.0	100.0	0.55
		Go no kumi	22	9	13	41.0	59.0	100.0	0.41
		Total	100	57	43	57.0	43.0	100.0	0.57
	Hinode naka	Hakusan-machi	28	8	20	28.6	71.4	100.0	0.29
		Kannon-cho	51	10	41	19.6	80.4	100.0	0.20
		San no kumi	38	8	30	21.0	79.0	100.0	0.21
		Shi ho kumi	17	3	14	17.6	82.4	100.0	0.18
		Go no kumi	31	6	25	19.4	80.6	100.0	0.19
		Roku no kumi	27	5	22	18.5	81.5	100.0	0.19
		Shichi no kumi	29	13	16	44.9	55.1	100.0	0.45
		Usyō-machi	55	17	38	31.0	69.0	100.0	0.31
		Nakajina	42	17	25	40.5	59.5	100.0	0.41
		Shinzaimoku	26	11	15	42.4	57.6	100.0	0.42
		Total	344	98	246	28.5	71.5	100.0	0.29
	Hōei shimo	Eiheiji	28	8	20	28.6	71.4	100.0	0.29
		Nishi eiheiji-cho	17	17	0	100.0	0	100.0	1.00
		Shinobu gumi	1	1	0	100.0	0	100.0	1.00
		Wariba	12	4	8	33.0	66.7	100.0	0.33
		Total	58	30	28	51.0	48.3	100.0	0.52
	Yotsuimoto	Dai ichi	47	26	21	55.3	44.7	100.0	0.55
		Dai ni	22	3	19	13.6	86.4	100.0	0.14
		Dai san	14	4	10	28.6	71.4	100.0	0.29
		Yamanomae	42	36	6	85.7	14.3	100.0	0.86
		Total	125	69	56	55.2	44.8	100.0	0.55
	Yonematsu	Yonematsu	42	42	0	100.0	0	100.0	1.00
Asahi-ku	Toyoshima kami	Shironohashimoto	41	18	23	43.9	56.1	100.0	0.44
	Toyoshima naka	Tōkōji	57	32	25	56.1	43.9	100.0	0.56
		Arakawa	9	4	5	44.4	55.6	100.0	0.44
		Tōkōji-machi san no kumi	21	19	2	90.6	9.4	100.0	0.91
		Kōri gumi	27	22	5	81.5	18.5	100.0	0.82
		Zaimoku	40	24	16	60.0	40.0	100.0	0.60

	Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D
	Minami gumi	35	20	15	57.0	43.0	100.0	0.57
	Total	189	121	68	64.0	36.0	100.0	0.64
Toyoshima-shimo	Moto shiro no hashi shin naka gumi	25	18	7	72.1	27.9	100.0	0.72
	Kyūban-chō higashi gumi	30	18	12	60.0	40.0	100.0	0.60
	Nishi gumi	38	11	27	29.0	71.0	100.0	0.29
	Kyū shiro no hashi Yoko machi						—	—
	Total	93	47	46	50.5	49.5	100.0	0.51
Teyose-kami	Sanban-cho	16	4	12	25.0	75.0	100.0	0.25
	Yoban-cho	19	5	14	26.3	73.0	100.0	0.26
	Nishi gumi	25	5	20	20.0	80.0	100.0	0.20
	Asahinishi gumi	25	4	21	16.0	84.0	100.0	0.16
	Asahi gumi	24	15	9	62.6	37.4	100.0	0.63
	Hinomiya gumi	9	4	5	44.4	55.6	100.0	0.44
	Total	118	37	81	31.4	68.6	100.0	0.31
Teyose-naka	Minami gumi	29	8	21	27.6	72.4	100.0	0.28
	Kita gumi	15	5	10	33.3	66.7	100.0	0.33
	Naka gumi	21	3	18	14.3	85.7	100.0	0.14
	Goban-cho inshi gumi	44	25	19	56.9	43.1	100.0	0.57
	Asahi gumi	31	11	20	35.4	64.6	100.0	0.35
	Total	140	52	88	37.2	62.8	100.0	0.37
Teyose-shimo	Ichi no kumi	17	17	0	100.0	0	100.0	1.00
	Ni no kumi	5	5	0	100.0	0	100.0	1.00
	San no kumi	8	8	0	100.0	0	100.0	1.00
	Shi no kumi	4	4	0	100.0	0	100.0	1.00
	Go no kumi	4	4	0	100.0	0	100.0	1.00
	Hirokōji	11	11	0	100.0	0	100.0	1.00
	Total	49	49	0	100.0	0	100.0	1.00
Hinode-shimo	Higashi-ichi no kumi	33	7	26	21.2	78.8	100.0	0.21
	Dai ni	30	5	24	16.7	80.0	96.7	0.17
	Higashi-san no kumi	31	12	17	42.0	54.9	96.9	0.43
	Higashi-dai shi	28	7	21	25.0	75.0	100.0	0.25
	Higashi-dai go	19	8	11	42.2	57.8	100.0	0.42
	Higashi-roku no kumi	11	3	8	27.3	72.7	100.0	0.27
	Dai shichi	23	10	13	43.6	56.4	100.0	0.44
	Higashi-hachi no kumi	22	13	9	59.2	40.8	100.0	0.59
	Higashi ku no kumi	11	3	8	27.3	72.7	100.0	0.27
	Total	208	69	137	33.2	65.9	99.1	0.33
Yoshino-kami	Ichi no kumi	9	9	0	100.0	0	100.0	1.00
	Ni no kumi	3	3	0	100.0	0	100.0	1.00
	San on kumi	12	12	0	100.0	0	100.0	1.00
	Shi no kumi	9	9	0	100.0	0	100.0	1.00
	Shi no kumi nishi	8	8	0	100.0	0	100.0	1.00
	Go no kumi	17	17	0	100.0	0	100.0	1.00
	Roku no kumi	4	4	0	100.0	0	100.0	1.00
	Total	62	62	0	100.0	0	100.0	1.00
Yoshino-naka	Ichi no kumi	9	9	0	100.0	0	100.0	1.00

		Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_c/D
		Ni no kumi	2	2	0	100.0	0	100.0	1.00
		San no kumi	14	14	0	100.0	0	100.0	1.00
		Shi no kumi	23	23	0	100.0	0	100.0	1.00
		Higashi gumi	17	17	0	100.0	0	100.0	1.00
		Total	65	65	0	100.0	0	100.0	1.00
	Yoshino-shimo	Kōsei kai	10	10	0	100.0	0	100.0	1.00
		Ichi no kumi	31	31	0	100.0	0	100.0	1.00
		Ni no kumi	21	21	0	100.0	0	100.0	1.00
			62	62	0	100.0	0	100.0	1.00
	Katsumi	Kita-ku	21	21	0	100.0	0	100.0	1.00
		Minami-ku	21	21	0	100.0	0	100.0	1.00
		Akatsuki	26	26	0	100.0	0	100.0	1.00
		Akebono	30	30	0	100.0	0	100.0	1.00
		San-chome	13	13	0	100.0	0	100.0	1.00
		Ni-chome kita-ku	8	8	0	100.0	0	100.0	1.00
		Ni-chome minami-ku	17	17	0	100.0	0	100.0	1.00
		Total	136	136	0	100.0	0	100.0	1.00
	Detsukuri	Kami	23	23	0	100.0	0	100.0	1.00
		Shimo	21	21	0	100.0	0	100.0	1 00
		Total	44	44	0	100.0	0	100.0	1.00
	Miyuki-shimo	Dai ichi	10	10	0	100.0	0	100.0	1.00
		Dai ni	16	16	0	100.0	0	100.0	1.00
		Dai san	25	8	17	32.0	68.0	100.0	0.32
		Dai shi	47	17	30	36.2	63.8	100.0	0.36
		Total	98	51	47	52.0	48.0	100.0	0.52
	Shiro no hashi kami-machi	Shiro no hashi kami-machi	46	23	23	50.0	50.0	100.0	0.50
	Shiro no hashi-naka	Dai ichi	44	20	24	45.5	54.5	100.0	0.46
		Dai ni	43	37	6	86.1	13.9	100.0	0.86
		Total	87	57	30	65.5	34.5	100.0	0.66
	Shiro no hashi-shimo	Dai ichi	36	11	25	30.6	69.4	100.0	0.31
		Dai ni	39	7	32	17.9	82.1	100.0	0.18
		Dai san	35	7	28	20.0	80.0	100.0	0.20
		Dai shi	35	5	30	14.3	85.7	100.0	0.14
		Dai go	19	5	14	26.3	73.7	100.0	0.26
		Total	164	35	129	21.4	78.6	100.0	0.21
	Shimo no kita	Tetsudō kansya ichi no kumi	35	32	3	91.5	8.5	100.0	0.92
		〃 ni no kumi	38	5	33	13.2	86.8	100.0	0.13
		〃 san no kumi	31	6	25	19.4	80.6	100.0	0.19
		Kōsei-machi	45	4	41	8.95	91.1	100.0	0.09
		Shieijūtaku	95	49	46	1.60	48.4	100.0	0.52
		Nishi-shieijūtaku	26	7	19	26.9	73.1	100.0	0.27
		Total	270	103	167	38.2	61.8	100.0	0.38
	Kami kitano	Kami kitano-machi	85	85	0	100.0	0	100.0	1.00
Wada-ku	Shimo kitano	Shimokitano-machi	51	51	0	100.0	0	100.0	1.00
	Nishikata	Nishikata-macchi	49	49	0	100.0	0	100.0	1.00
	Fuchigami	Fuchigami-cho	40	40	0	100.0	0	100.0	1.00

		Community	A	B	C	D_0 %	D_1 %	D (D_0+D_1) %	D_0/D
Maruyama-ku	Wada higashi	Wada higashi	48	48	0	100.0	0	100.0	1.00
	Wadanaka	Wada kami	21	21	0	100.0	0	100.0	1.00
		Shimmei	25	25	0	100.0	0	100.0	1.00
		Wadanaka higashi	50	50	0	100.0	0	100.0	1.00
		Wadanaka nishi	57	57	0	100.0	0	100.0	1.00
		Total	153	153	0	100.0	0	100.0	1.00
	Kawamasu	Kawamasu	51	51	0	100.0	0	100.0	1.00
	Shimonaka	Shimonaka	36	36	0	100.0	0	100.0	1.00
	Higashi-imaizumi	Higashi-imaizumi	68	68	0	100.0	0	100.0	1.00
	Kita-imaizumi	Kita-imaizumi	55	55	0	100.0	0	100.0	1.00
	Kita-yatsui	Kita-yatsui	49	49	0	100.0	0	100.0	1.00
	Minami-yatsui	Minami-yatsui	55	55	0	100.0	0	100.0	1.00

stated above, wide difference at a minute distance. And the explorations were mostly made on roads, vacant lots, school grounds, etc. Therefore, the points where the explorations were made and the points where accurate rates of house destruction are known usually do not coincide strictly speaking. Thus when the accurate percentage of destruction at an explored point was known, it was entered as it is, and when the rate was presumed from the figures above (Fig. 1, 13, 14, 22, 23, and 41) the number was marked with brackets in the table. When the rate was more questionable, it was omitted.

Now, using the values shown in Table 6 to 9, a comparison of the nature and the destruction rate. Since we could not foresee which factor of the ground nature has a greater influence, we made comparison for each of these factors.

1) The Velocity of Longitudinal Waves v_p and the Rates of Complete and Total Destruction:

Heretofore, damage at the ground of so-called soft soil has been said to be severer. Since the velocity of longitudinal wave v_p is

$$v_p=\sqrt{\frac{\lambda+2\mu}{\rho}} \tag{1}$$

λ, μ: Lamé's constants
ρ: density.

So a slow velocity indicates a soft ground. Therefore, at first points are plotted in Fig. 47 (a) and (b) to determine the relation between v_p and the percentage of the completely destroyed and the total rate of

F.........Houses burnt down
E.........Houses survived

	Street	Damages	
Junka-ku	Sakura-kami, Sakuran-aka, Sakura-shimo, Nishiki-kami, Nishiki-naka, Nishiki-shimo, Sakaekami, Sakaenaka, Sakaeshimo, Toyoshima-kami, Toyoshima-naka, Ōde, Misono, Hinodemoto, Ogahata, Ninomaru, Sannomaru, Gohonmaru	A	2227
		F	1348
		B	470
		C	378
		E	31
		D_0 %	53.5
		D_1 %	43.0
		D %	96.5
		D_0/D	0.55
Hōei-ku	Hōei-naka, Hōei-shimo (Tetsunishi), Higashi-kami, Higashi-shimo, Edokami, Edashimo, Hoeikami, Onoe kami, Onoe-naka, Onoe-shimo, Oimatsu-kami, Oimatsu-naka	A	1203
		F	18
		B	1024
		C	375
		E	16
		D_0 %	72.4
		D_1 %	26.5
		D %	68.9
		D_0/D	0.73
Shimpō-ku	Oimatsu-shimo, Matsugae-kami, Matsugae-naka, Matsugae-shimo, Hikawa-kami Hikawa-shimo, Kiyokawa-kami, Kiyokawa-naka, Kiyokawa-shimo	A	703
		F	—
		B	402
		C	237
		E	15
		D_0 %	61.4
		D_1 %	36.3
		D %	97.7
		D_0/D	0.63
Matsumoto-ku	Matsumoto-kami, Matsumoto-naka, Matsumoto-shimo, Machiya, Daiganji, Ikuhisa, Kyōda	A	1004
		F	4
		B	754
		C	185
		E	8
		D_0 %	79.6
		D_1 %	19.5
		D %	99.1
		D_0/D	0.80

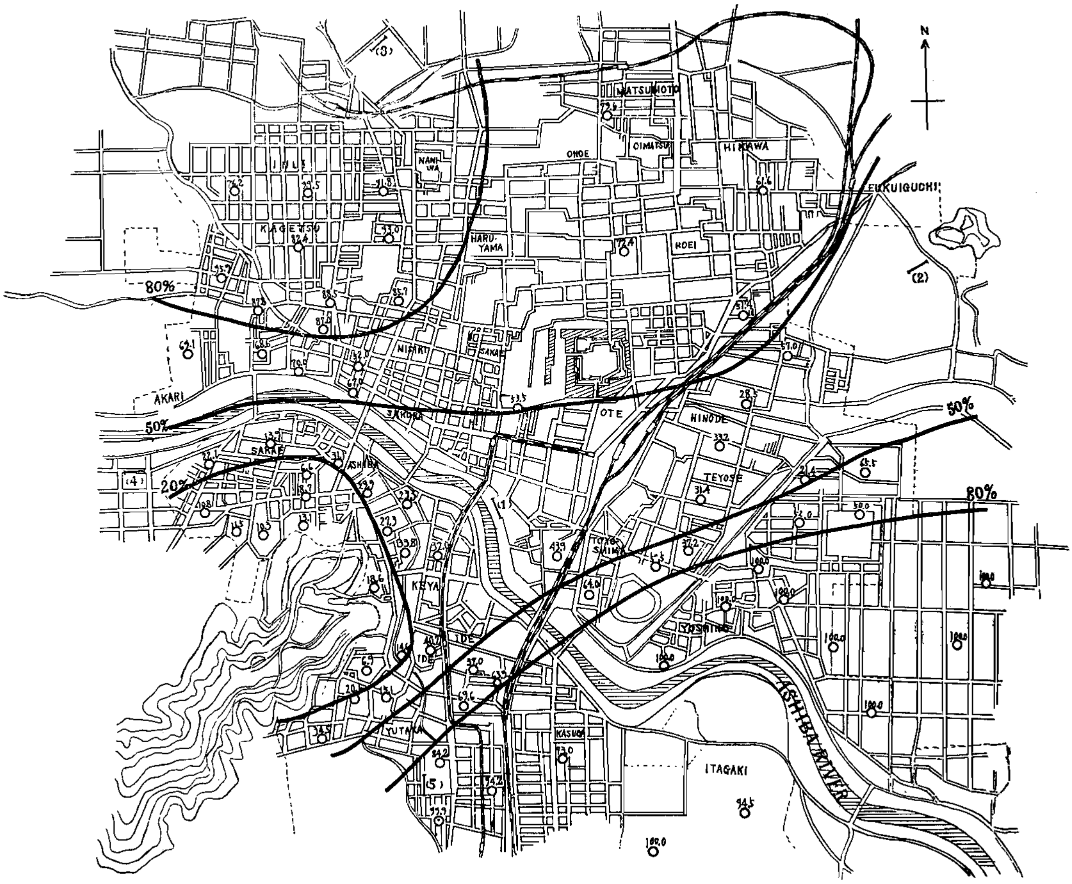


Fig. 41 The rate of damage and lines of survey at Fukui.

the destroyed houses. For the v_p here, v_{p1}, the velocity of longitudinal waves in the surface layer, was taken. However, the v_p at (5) Kuniyasu, Tottori Prefecture was omitted because the esploration was made at riverside and the value seemed to be too large. In the following comparison, the values at this points are omitted.

As can be seen from the figure, at the points were the velocity v_p is large, damages are small, and larger damages where the velocity is small. This agrees with the fact that at the soft ground, the damage is severer in tendency. But distinct relations between v_{p1} and the rates cannot be obtained.

2) The Velocity of Surface Waves v_s and the Rates:

v_s is not known clearly whether it is the velocity of surface wave or of transverse wave as mentioned before. It is shown as v_s because when the surface wave is Raleigh's wave, the velocity is almost equal

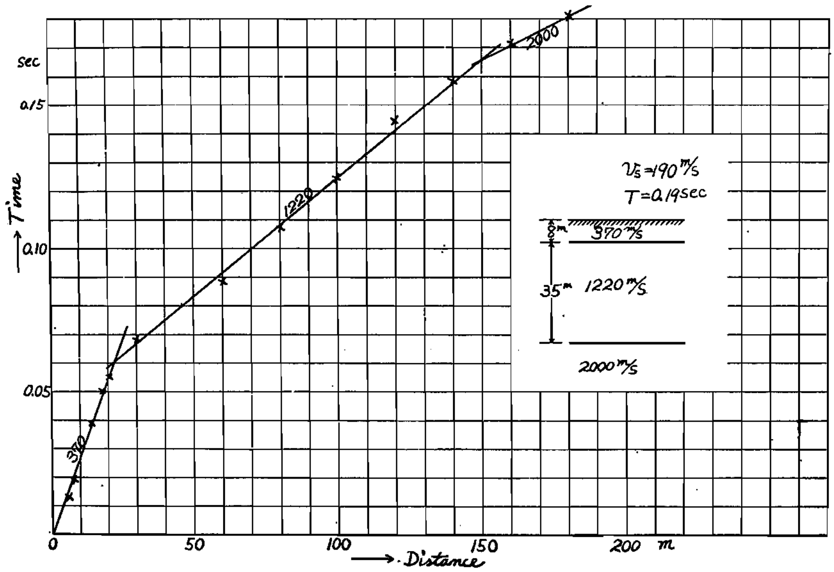


Fig. 42 (1) Saiwai bashi.

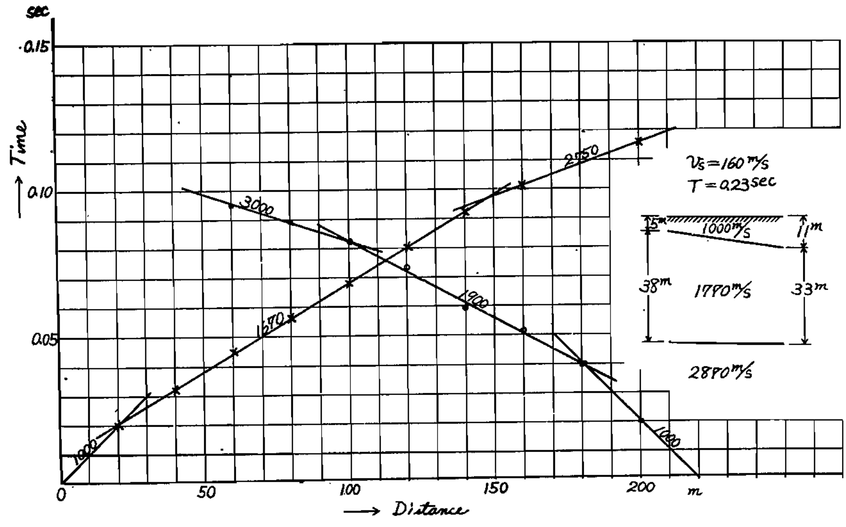


Fig. 43 (2) Fukuiguchi.

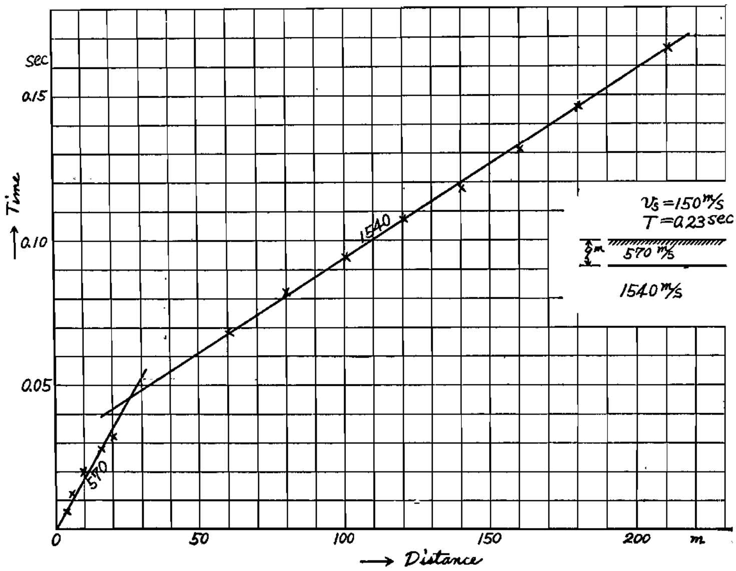


Fig. 44 (3) Fukui Technical High School.

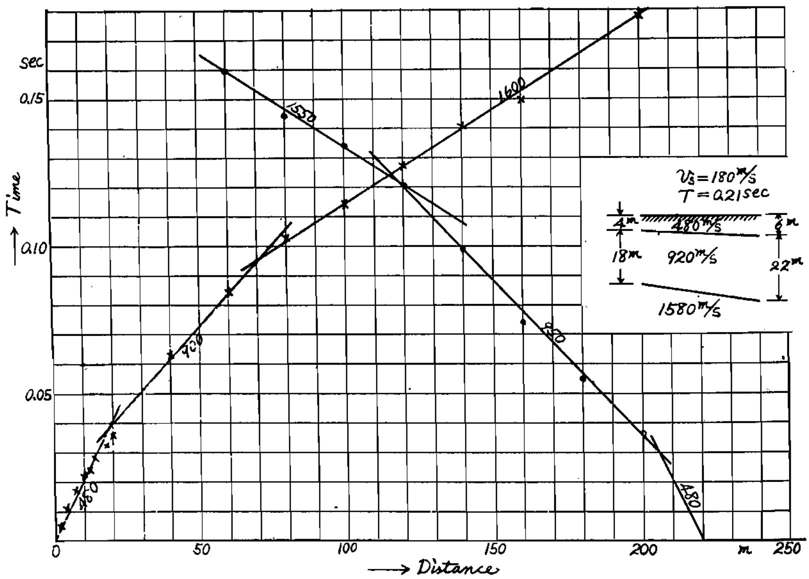


Fig. 45 (4) Akari.

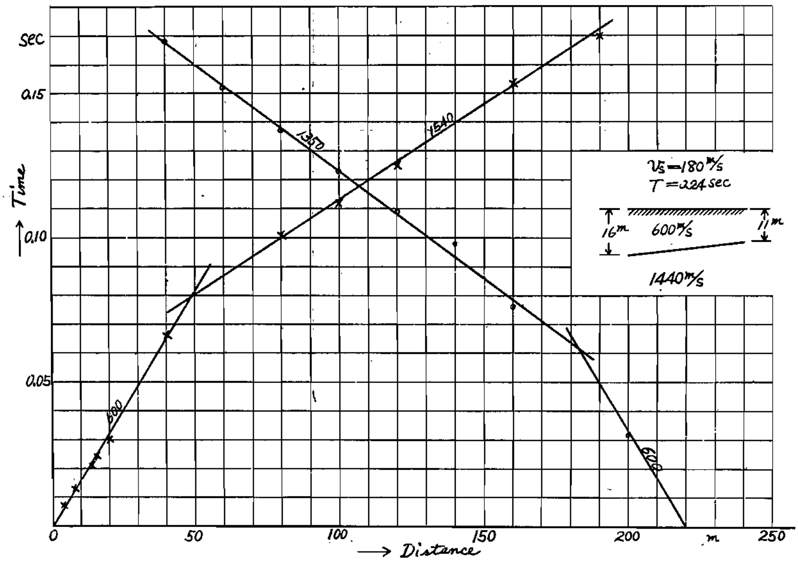


Fig. 46 (5) Daiwa-bōseki.

Table 6. Natures of grounds and percentages of destroyed houses at Tottori.

Station	Surface Layer		2nd Layer		3rd Layer	v_s	T	D_0	D
	v_{p1} m/s	h_1 m	v_{p2} m/s	h_2 m	v_{p3} m/s	m/s	sec	%	%
1) Kokubunji	830	4~14	1360			370	0.14	0	4
2) Tsunoi	930	7~8	1640			125	0.22	23	27
3) Hisasue	560	6~4	1360			150	0.17	4	11
4) Bamba	560	24	1290			110	0.22	86	100
5) Kuniyasu	1000	11	1420	18	2300	270	0.12	(47)	(65)
6) Shimoajino	950	16	2550			330	0.17	0	4
7) Entsūji	680	10	1900			250	0.13	2	37
8) Kanō	940	14~16	1370			210	0.19	—	—
9) Tomiyasu	1000	18	1800			190	0.20	—	—
10) Koyama	300	6~10	1370			190	0.20	(20)	(30)
11) Iwakura	420	8~9	1340			90	0.41	—	—

Table 7. Natures of grounds and percentages of destroyed houses at Mikawa.

Station	Surface Layer		2nd Layer		3rd Layer	v_s	T	On the occasion of Tōkai-earthquake		On the occasion of Mikawa Earthquake	
	v_{p1} m/s	h_1 m	v_{p2} m/s	h_1 m	v_{p3} m/s	m/s	sec	D_0 %	D %	D_0 %	D %
1) Kamiyada	360	4	1100	18	2200	250	0.10	5	10	10	25
2) Kitahama-omizu	400	4	1500			80	0.15	—	—	—	—
3) Niike	200	8	650	15	1400	105	0.13	40	70	—	—
4) Yahagi-furukawa	200	2	900	41	3600	150	0.12	3	10	70	95
5) Kajiarai	130	2~4	1190				0.20	0	0	(50)	(70)
6) Dōkōji	150	1.4	1350	8	2000	65	0.07	0	—	20	—
7) Shikoya	150	1.2	850	6	1700	50	0.12	0	—	90	—

Table 8. Natures of grounds and percentages of destroyed houses at Kōchi.

Station	Surface Layer		2nd Layer		3rd Layer	v_s	T	D_0	D
	v_{p1} m/s	h_1 m	v_{p2} m/s	h_2 m	v_{p3} m/s	m/s	sec	%	%
1) Minami-mama	910	7~10	1580	30~31	3030	180	0.055	0	0
2) Kōchi High School	930	2~13	1740	27~38	3300	220	0.060	0	(1~10)
3) Asahi	700	6	1500	24	4000	300	0.078	0	0
4) Suido-chū	670	6~8	1840	33~34	3400	280	0.077	0	3
5) Horizume	950	10~16	1570	16~27	3000	310	0.080	0	5~15
6) Honmachi	800	8~15	1450	22~42	3800	150	0.074	0	0
7) Shikishima-bōseki	900	3~5	1580	20~17	3400	150		0	0
8) Kitahon-chō, 1-chōme	850	10~12	1470			180	0.096	5	36
9) Kitahon-chō, 3-chōme	900	10	1400	40	2300	120		4	58
10) Hinode-chū	800	7	1200	16	1500	150	0.070	70	100
11) Shinonome-chū	830	5	1400	7	1700	140	0.104	(20)	(80)
12) Hijima	1200	16	1970			230	0.080	0	3
13) Takasu	1350	8	2100	31	5500	150	0.068	—	—
14) Kōchi Technical School	850	10	1600			280	0.120	5	10
15) Nakazutsumi	1050	18	1700	13	2100	260	0.126	7	15
16) Tanabejima	1450	6	1700	87	4400	270	0.110	—	—
17) Sanbashi	1080	19	1450	27	2000	330	0.070	8	15

Table 9. Natures of grounds and percentages of destroyed houses at Fukui.

Station	Surface Layer		2nd Layer		3rd Layer	v_s	T	D_0	D
	v_{p1} m/s	h_1 m	v_{p2} m/s	h_2 m	v_{p3} m/s	m/s	sec	%	%
1) Saiwai-bashi	370	8	1220	35	2000	190	0.19	20~30	75
2) Fukuiguchi	1000	5~11	1770	33~38	2870	160	0.23	(10)	(30)
3) Fukui Tech. High School	570	9	1540			150	0.23	90	100
4) Akari	480	4~6	920	18~22	1580	180	0.21	20	65
5) Daiwa-bōseki	600	11~16	1440			180	0.24	90	100

v_p: Velocity of the longitudinal wave T: Period of the surface wave
v_s: Velocity of the surface wave D_0: Percentage of completaly destroyed houses
h: Thickness of the layer D: Total ratio of destroyed houses

to the velocity of transverse wave even if it is a surface wave. If v_s is the velocity of transverse wave,

$$v_s = \sqrt{\frac{\mu}{\rho}} \tag{2}$$

and v_s also is the quality which represents the hardness of the grounds. So from the consideration as in the preceeding section, the relations between v_s and the rate of the completely destroyed houses and the total percentage of the destroyed houses are shown in Fig. 48 (a) and (b). The results are almost comparable with the relations of v_p and the destruction rates, that is, where v_s is large, damage is smaller. But the distinct relation is not seen.

3) The Thickness of the Surface Layer and the Rates:

Next, considering that the percentages seemed to be affected by the depth of the rather soft layer near the surface, the depth of the surface layer h_1 was compared with the rates. The relations are shown in Fig. 49 (a) and (b). The points where an accurate thickness was not obtained were omitted. It can be concluded when h_1 is thicker, damage is severer for the cases of Tottori and Fukui, but the same cannot be stated for the case of Kōchi.

4) The Period of Surface Waves T and the Rates:

The period of surface waves is a function of elastic moduluses, density, thickness of layers, etc. of the grounds, and it appears to show some physical nature of the grounds. Here it was compared with the rate ot house destruction in Fig. 50 (a) and (b). In this case, too, an inclination can be seen that at place where T is longer, damage is severer, but the location of the points in Fig. 50 is considerably irregular.

For the above four cases, we investigated the relations of damage to v_p, v_s, h, and T independently, but a distinct relation with the rates

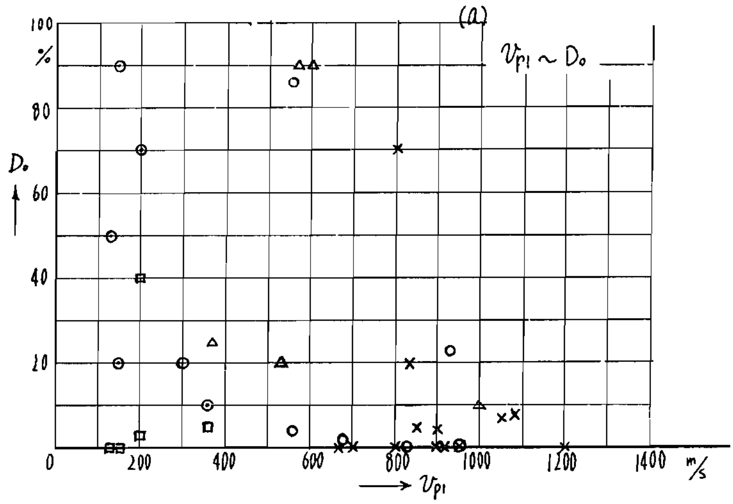


Fig. 47 (a)

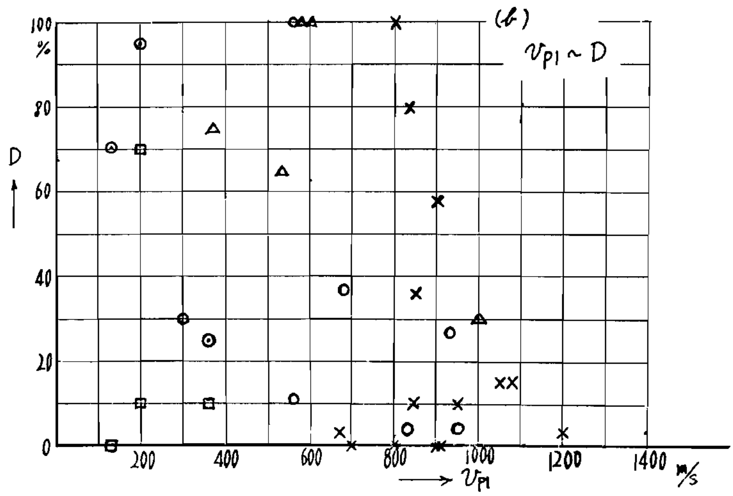


Fig. 47 (b)

○ …… Tottori　　× …… Kōchi

△ …… Fukui

□ …… Mikawa (by Tōkai-earthquake)

⊙ …… Mikawa (by Mikawa-earthquake)

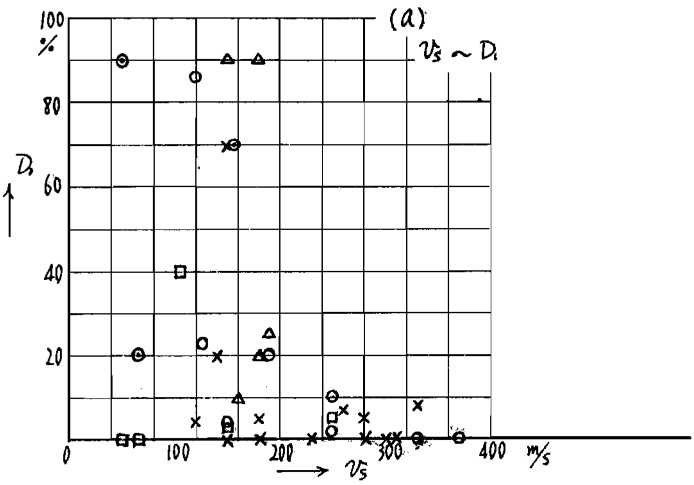


Fig. 48 (a)

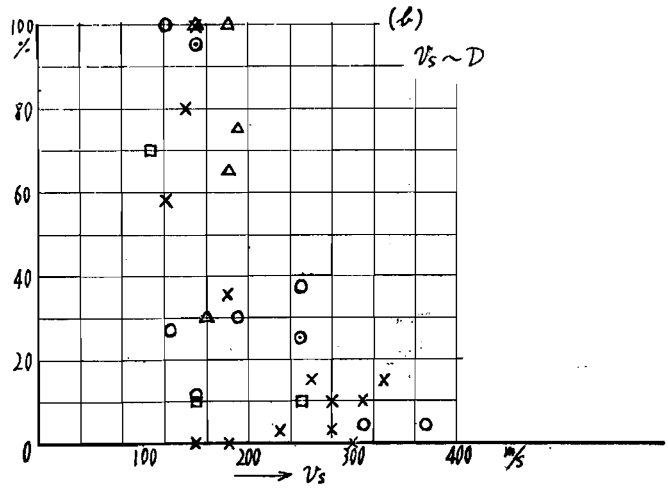


Fig. 48 (b)

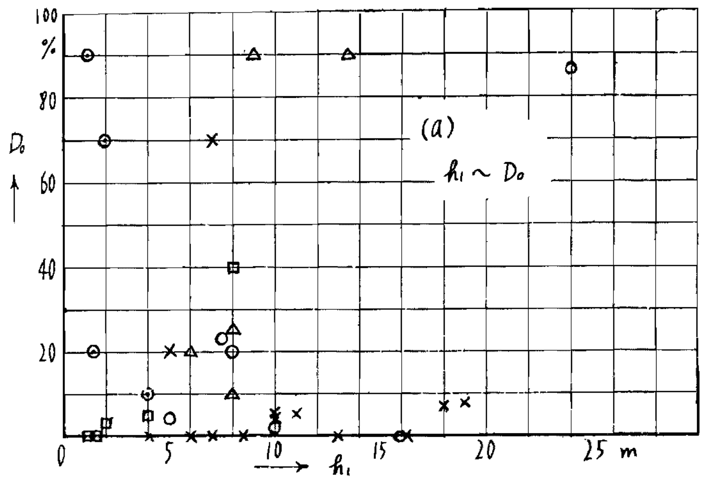


Fig. 49 (a)

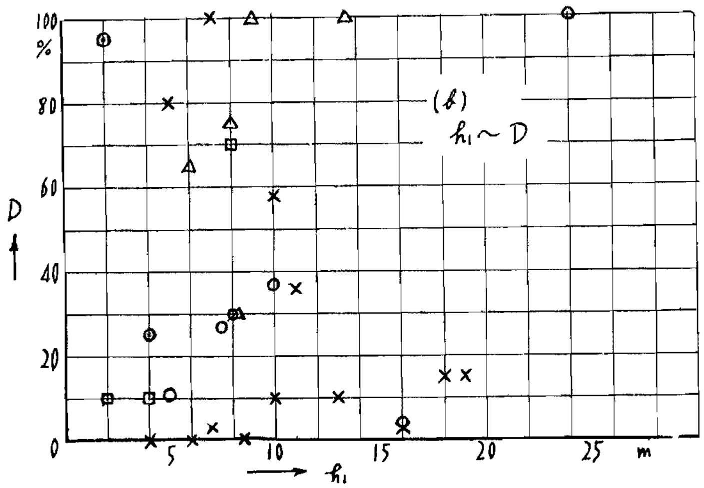


Fig. 49 (b)

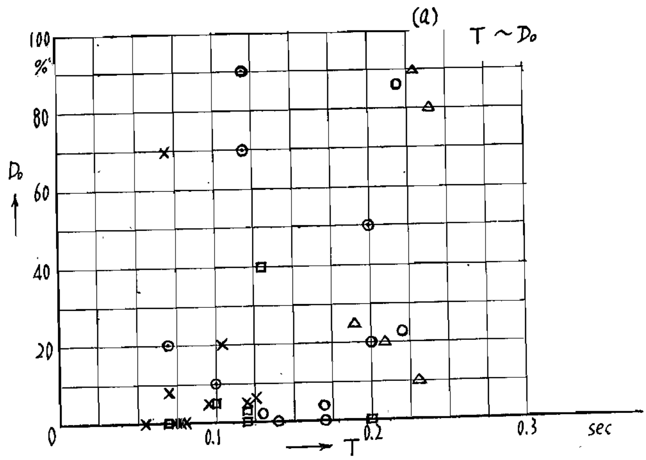


Fig. 50 (a).

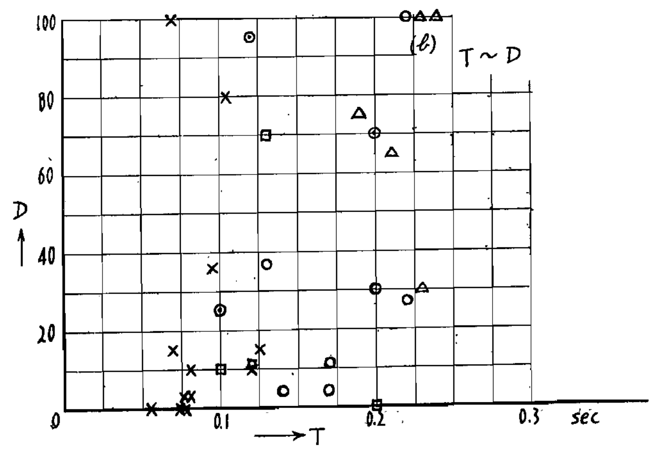


Fig. 50 (b)

Table 10. Tottori.

Station	(i) h_1/v_{p1} $\times 10^{-2}$s	(ii) h_1/v_s $\times 10^{-2}$s	(iii) v_{p1}/v_s	(iv) h_1' m	(v) $h_1'v_s$ $\times 10^{-2}$s
(1)	—	—	2.24	—	—
(2)	0.81	6.00	7.44	6.4	5.1
(3)	0.89	3.34	3.74	5.9	3.9
(4)	4.29	21.8	5.09	31.0	28.2
(5)	—	—	—	—	—
(6)	1.69	4.85	2.88	5.5	1.7
(7)	1.47	4.00	2.72	6.7	2.7
(8)	1.60	7.15	4.48	19.5	9.3
(9)	1.80	9.49	5.26	11.3	6.0
(10)	2.66	4.21	1.58	9.0	4.7
(11)	2.02	9.45	4.67	10.0	11.1

Table 11. Mikawa.

Station	(i) h_1/v_{p1} $\times 10^{-2}$s	(ii) h_1/v_s $\times 10^{-2}$s	(iii) v_{p1}/v_s	(iv) h_1' m	(v) h_1'/v_s $\times 10^{-2}$s
(1)	1.11	1.60	1.44	6.1	2.44
(2)	1.00	5.00	5.00	4.0	5.00
(3)	4.00	7.58	1.91	23.1	22.00
(4)	1.00	1.33	1.33	3.7	2.46
(5)	—	—	—	—	—
(6)	0.93	2.16	2.31	1.5	2.31
(7)	0.80	2.40	3.00	2.3	4.60

in any case cannot be seen although there seemed to be a tendency. We next will seek the relations between the combined values of the above items and damage.

5) h_1/v_{p1} and the rates:

We have shown the fact that when the velocity of longitudinal waves v_p is larger, damage tends to be smaller, and the thickness of the surface layer is thicker, it tends to be greater. When this is taken into consideration, there seems to be a relation between h_1/v_{p1} and damage. Points were plotted in Fig. 51 (a) and (b) for determining this relation. The values of h_1/v_{p1} were calculated from the quantities in Table 6 to 9, and are shown in column (i), Table 10 to 13. Fig. 51 does not reveal a relation between h_1/v_{p1} and the percentages. A better relation can be seen in Fig. 48 where v_{p1} alone was considered.

6) h_1/v_s and the rates:

In a similar consideration as in the case of (5), the relation between h_1/v_s and the rates of house destruction are shown in Fig. 52 (a) and (b). The values of h_1/v_s are shown in column (ii), Table 10 to 13. In this case the tendency of the relation is little clearer than in the case (5), but the relation is not so distinct.

7) v_{p1}/v_s and the rates:

In Fig. 53 (a) and (b) shown the relations between v_{p1}/v_s and the rates. The values of v_{p1}/v_s are shown in column (iii), Table 10 to 13. If v_s is the velocity of transverse wave, v_{p1}/v_s is a function of Poisson's ratio only, and it is so far said to have a relation to damage. In Fig. 53, a tendency is seen that as v_p/v_s grows larger, the damage becomes greater. But in this case, too, the relation is not quite clear.

Table 12. Kōchi.

Station	(i) h_1/v_{p1} $\times 10^{-2}$s	(ii) h_1/v_s $\times 10^{-2}$s	(iii) v_{p1}/v_s	(iv) h'_1 m	(v) h'_1/v_s $\times 10^{-2}$s
(1)	0.93	4.72	5.05	7.5	4.2
(2)	—	—	4.22	—	—
(3)	0.86	2.00	2.33	6.0	2.0
(4)	1.12	2.50	2.39	5.0	1.8
(5)	1.37	4.20	3.06	11.5	3.7
(6)	—	—	5.34	—	—
(7)	0.44	2.67	6.00	3.5	2.3
(8)	1.29	6.11	4.72	11.5	6.4
(9)	1.11	8.34	7.50	12.0	10.0
(10)	0.88	4.66	5.34	23.0	15.3
(11)	0.60	3.57	5.93	9.3	6.6
(12)	1.33	6.96	5.22	6.2	2.7
(13)	0.59	5.34	9.00	1.6	1.1
(14)	1.18	3.57	3.03	8.7	3.1
(15)	1.71	6.92	4.04	12.5	4.8
(16)	0.41	2.22	5.38	1.2	0.4
(17)	1.76	5.76	3.28	21.6	6.5

Table 13. Fukui.

Station	(i) h_1/v_{p1} $\times 10^{-2}$s	(ii) h_1/v_s $\times 10^{-2}$s	(iii) v_{p1}/v_s	(iv) h'_1 m	(v) h'_1/v_s $\times 10^{-2}$s
(1)	2.16	4.21	1.95	10.6	5.6
(2)	0.80	5.00	6.25	5.2	3.2
(3)	1.58	6.00	3.80	8.6	5.7
(4)	1.13	3.33	2.94	11.6	6.4
(5)	2.25	7.50	3.34	15.0	8.3

8) h_1'/v_s and the Rates:

There was not a distinct relation between h_1/v_{p1} or h_1/v_s to damage, but it seemed to be contradictory that the thickness of surface layer h_1 is taken as the same value with no regard to the magnitude of the velocity of longitudinal waves of the second layer, or to the hardness of the second layer. Accordingly, the value must be corrected is some way if h_1 is to be taken into account. As the simplest method for its correction, we determined a certain standard velocity v_{p2} of the second layer and when the velocity v_{p2} of a point is different from it, h_1 is corrected assuming that the velocity of longitudinal wave changes linearly from the surface to the second layer. If h_1' is the corrected value of h_1,

$$h_1' = h_1 \frac{V_{p2} - v_{p1}}{v_{p2} - v_{p1}} \tag{3}$$

As the value of V_{p2}, here we take 1,500 m/s that is the average value of those in Table 6 to 9. Thus h_1' and h_1'/v_s were calculated and are shown in columns (iv) and (v), Table 9 to 13.

The relations h_1'/v_s to the percentage of the completely destroyed houses and the total destruction percentage which contains the partially destroyed houses are shown in Fig. 54 (a) and (b). The relations here are far clearer than any of the former cases, and it can be seen that as h_1'/v_s increases, the damage becomes severer.

In spite of the fact that the points of (11) Shinonome-chō, Kochi Prefecture and (7) Entsūji, Tottori Prefecture show a similar tendency as other points in the case of the complete destruction rate, the values of h_1'/v_s in the case of the total destruction rate are too large. It seems that their damage were affected by the surrounding bad ground soil, for the rates of the destroyed houses there are small, but those of surrounding points were very large. But the relation between the rate of the complete house destruction and the total rate of destruction is not yet clear, and anything definite cannot be stated.

Despite the fact that the problem of the relations between the nature of grounds and damage is very complicated, we consider, that h'/v_s shows best the goodness of grounds for earthquake-proofing at present.

9. Consideration on the Results.

It would be sure that the damage of houses by earthquakes is affected by the amplitude and the seismic waves at the ground surface. How the length of periods changes by the nature of grounds is not yet clear, but if the change is not too great, we must first consider the amplitude. Especially to wooden houses, the magnitude of the amplitude affects damage greatly.

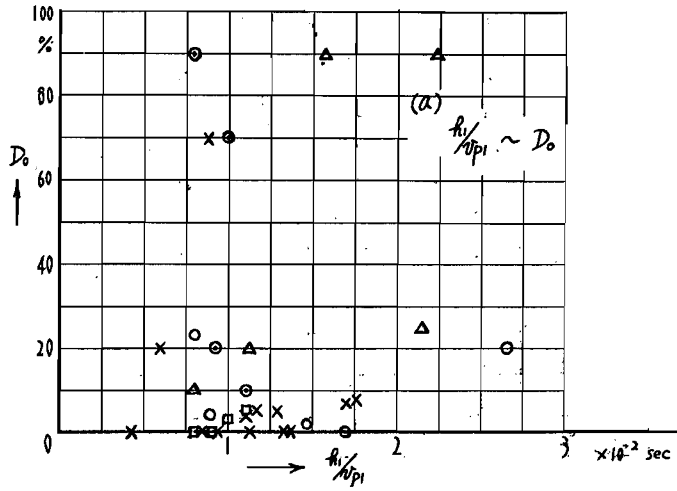


Fig. 51 (a)

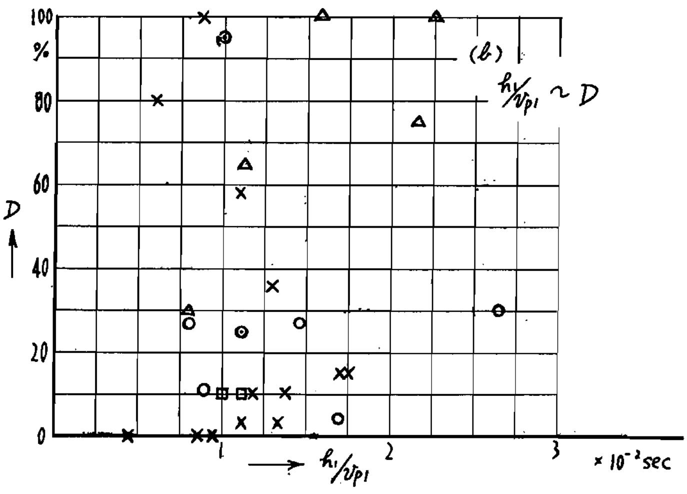


Fig. 51 (b)

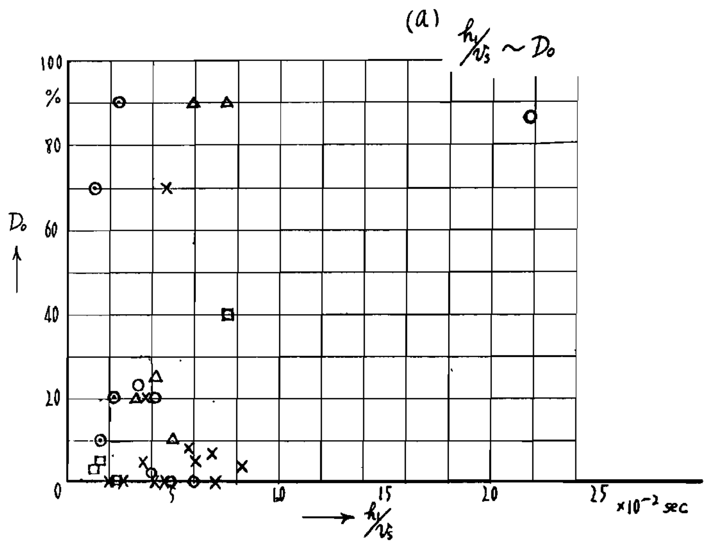


Fig. 52 (a)

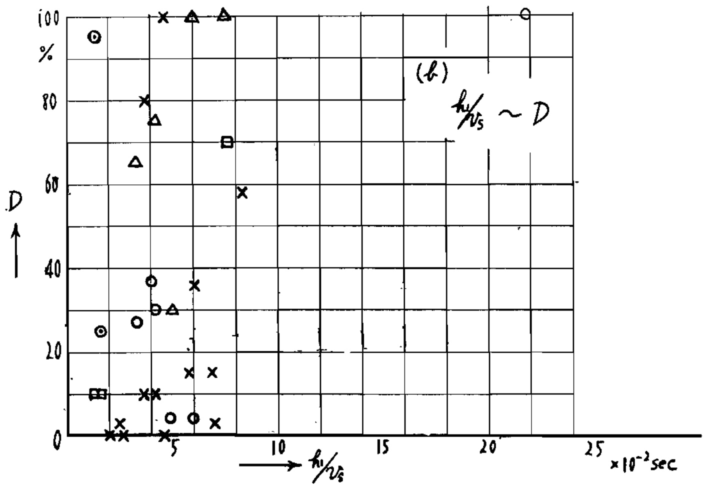


Fig. 52 (b)

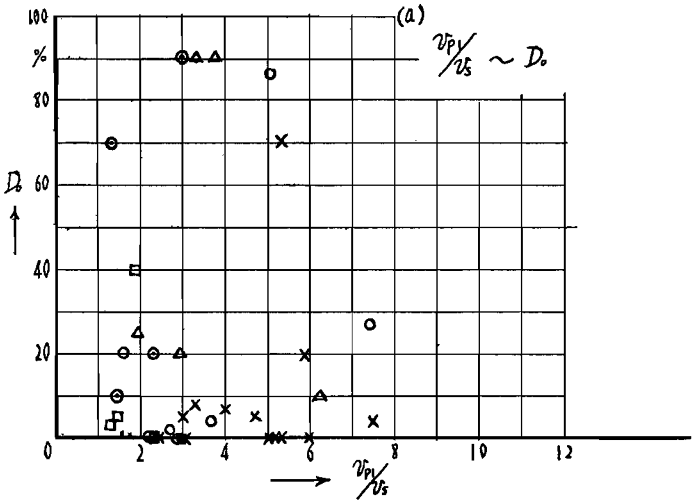


Fig. 53 (a)

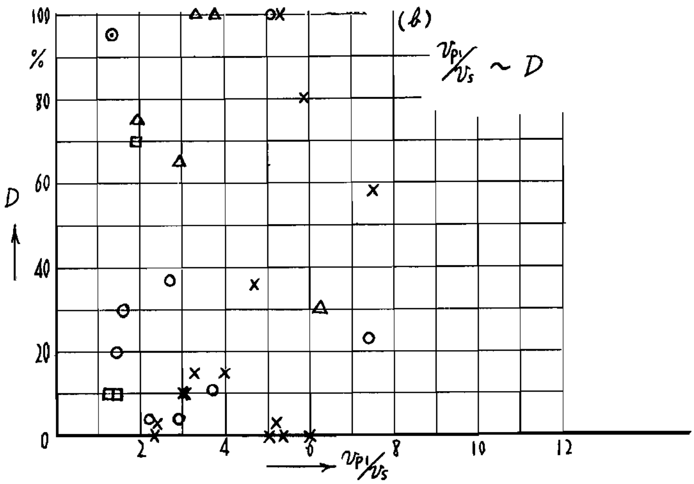


Fig. 53 (b)

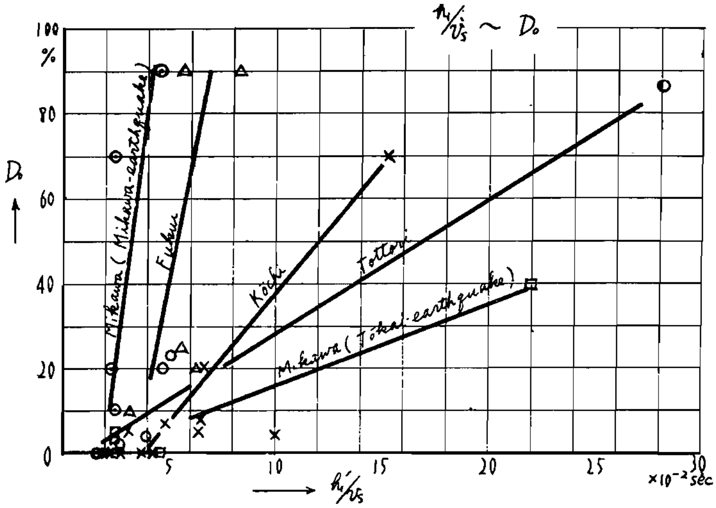


Fig. 54 (a)

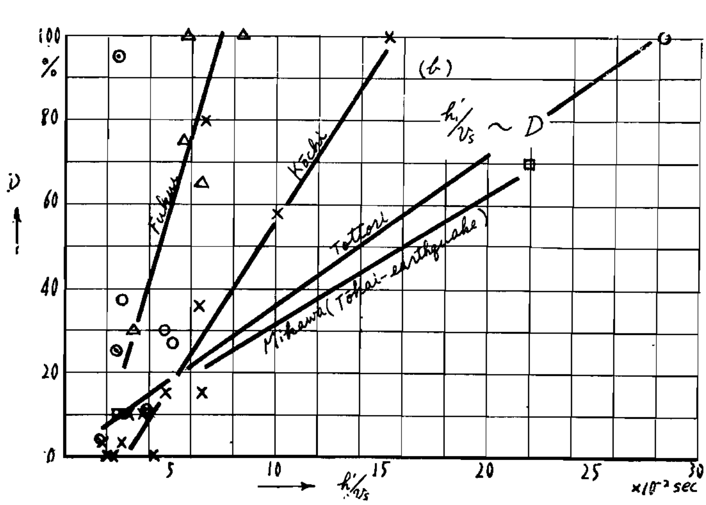


Fig. 54 (b)

There are many theoretical researches on the nature of seismic waves at the ground surface, but they all stand on some large assumptions and the results are quite complicated. Therefore it is difficult to apply their results to the present study. Here we consider the results of the above sections in a comparatively simple way. If the damage on wooden house are affected by the amplitude, we must first consider the surface wave since the larger vibrations of earthquake are known in general to be the surface wave. It will be represented by Rayleigh's wave. Assuming that the ground is a conformal elastic body, the horizontal displacement of Rayleigh's wave u at the surface is

$$u = K\{(K^2-k^2)e^{-\alpha z}-\alpha\beta e^{-\beta z}\}C\sin(pt-Kx). \qquad (4)$$

Here the x-axis is taken horizontally, and the z-axis vertically in the downward direction. C is a sonstant, and K is a root of

$$(2K^2-k^2)^2-4K^2\alpha\beta = 0 \qquad (5)$$

and

$$\alpha = \sqrt{K^2-h^2}, \qquad \beta = \sqrt{K^2-k^2} \qquad (6)$$

$$h^2 = \frac{\rho}{\lambda+2\mu}p^2. \qquad k^2 = \frac{\rho}{\mu}p^2 \qquad (7)$$

When the velocity of Rayleigh's wave is v_R,

$$K = \frac{p}{v_R}$$

In the range $v_p/v_s=0\sim10$, we can consider

$$V_R \fallingdotseq V_s,$$

so

$$K \fallingdotseq k.$$

Put this relation into the equation (6),

$$\beta \fallingdotseq 0$$

From the equation (4),

$$u \fallingdotseq Ck^3e^{-\alpha z}\sin(pt-K_x) \qquad (8)$$

Now assuming that an equal amplitude β_0 are given, at a place where depth is H,

$$\beta_0 \fallingdotseq Ck^3e^{-\alpha H}$$

Putting this equation into the equation (8), C being eliminated,

$$u \fallingdotseq \beta_0 e^{\alpha(H-z)}\sin(pt-K_x) \qquad (9)$$

The amplitude of the surface is represented by β,

$$\beta = \beta_0 e^{\alpha H} \tag{10}$$

From the equation (10), we can see the amplitude of the ground surface β depends on the magnitude of αH.

On the other hand, from the equation (6),

$$\alpha = \sqrt{K^2 - h^2} \fallingdotseq \sqrt{k^2 - h^2}$$

$$= p\sqrt{\left(\frac{1}{v_s}\right)^2 - \left(\frac{1}{v_p}\right)^2} \tag{11}$$

Accordingly,

$$\alpha H = pH\sqrt{\left(\frac{1}{v_s}\right)^2 - \left(\frac{1}{v_p}\right)^2}$$

$$= p\frac{H}{v_s}\sqrt{1 - \left(\frac{v_s}{v_p}\right)^2} \tag{12}$$

Now the values of v_p/v_s range from 1.5 to 10 and $(v_s/v_p)^2$ are so small that they can be neglected. Then,

$$\alpha H \fallingdotseq p\frac{H}{v_s} \tag{13}$$

If the amplitude of a constant depth are not so variable by the location, we can calculate approximate values for the amplitude at the surface from the results of the examinations of grounds by the equation (13). In the similar manner as at the end of the last section, put

$$H = h_1',$$

then the equation (13) is

$$\alpha H \fallingdotseq p\frac{h_1'}{v_s} \tag{14}$$

So it is reasonable that $p\frac{h_1'}{v_s}$ relates to damage on houses. Moreover, it can be said that the value of h_1'/v_s shows the goodness of grounds to wooden houses.

Although in the equation (12) we neglected $(v_s/v_p)^2$, it does not effect so much even if it is taken into calculation. It seems to be more to suitable to neglect it for the accuracy of our explorations.

If the equation (12) intransformed,

$$\alpha H \fallingdotseq p\frac{H}{v_p}\sqrt{\left(\frac{v_p}{v_s}\right)^2 - 1} \tag{15}$$

From this equation, it seems also reasonable that as the value of v_p/v_s increase, the damage becomes severer, as seen in the case of (7) in the last section.

If the surface wave at the surface is taken into account, the amplitude of it becomes larger as the value of h_1'/v_s increases. This fact coinsides with the result of the preceeding section, the comparison to damages. Accordingly, we can use the value of h_1'/v_s as an indicator of the goodness of grounds.

10. Conclusion.

The authors have shown that the damage on wooden houses was most affected by the value of h_1'/v_s of grounds, by comparison of the percentage of the houses destroyed with the results of physical explorations of grounds with elastic waves. And this fact has been explained theoretically, if the amplitude of seismic wave at the surface is assumed to depend on the surface wave.

Naturally as it can not be considered that the complicated seismic movement or the nature of grounds is not represented by such a simple factor alone as above problems, on other physical natures and the rest must be attended to in future. At psesent, however, the results deduced theoretically are too complicated, and the percentage of the houses destroyed is not so accurately determined that it can be compared with the detailed data of physical natures, even though the damping ratio of waves, etc. are accurately measured. Since the meaning of the rate of destruction is not quite clear either, one will have to be content with the present situation as long as he employs a method as the one used in our present research. But the method of correcting h_1 stated in the article was used for the sake of convenience, and it must be reconsidered. The method of the exploration is also expected to be improved. However, the actual damage of violent destructive earthquakes and its statistics are most valuable data to anticipate damages in future, though they are not sufficient. Up-to-date, there has not been any attempt to analyse the data scientifically as the authors have tried in this paper. Since different conclusions from ours on the subject will be possible, the statistics of damages were shown in detail in the tables.

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