The Sakura-jima Eruptions and Earthquakes. VI.

[Notes on the Destructive Earthquake of Jan. 12, 1914, and Miscellaneous Remarks on the Eruptions of Sakura-jima.]

By **F. OMORI.**

(*With Plates* LXXXVIII–CVII.)

CHAPTER I. NOTES ON THE DESTRUCTIVE SAKURA-JIMA EARTHQUAKE OF JAN. 12, 1914.

1. Time of Occurrence. The destructive Sakura-jima earthquake on Jan. 12, 1914, was tromometrically observed at the Seismological Institute and the Osaka meteorological observatory at the radial distances of 958 and 560 km. respectively, as follows :—

	Time of Commencement.	Duration of the 1st prel. tremor.
Seismological Institute (Tokyo) ...	6^h 30^m 21^s P.M.	130.7 sec.
Osaka Met. Observatory.	6 29 28	70.9

The time of earthquake commencement at the origin itself estimated from the Tokyo and Osaka observations is found to be 6. 27. 57 P.M., or very nearly 6^h 28^m P.M.

The maximum frequency of the fore-shocks of different intensities taken together was attained between 8 P.M. on the 11th and 10 A.M. on the 12th, that is to say, during the 14 hours preceding the commencement of the actual eruption. If we confine our attention to the stronger of the fore-shocks, namely, those of moderate and strong intensities, the maximum frequency occurred between about 6 and 11 P.M. on the 11th. (See Table I.) It may be concluded that the premonitory earthquakes, which were the result of the underground volcanic tension trying to create the exits for the emission of the eruptive materials, had already reached the climax in frequency and intensity some dozen hours prior to the outburst. The violent and fairly extensive earthquake at 6. 28 P.M., on the 12th, took place, on the other hand, about 8½ hours after the commencement of the latter, and is to be considered, not as belonging to the group of the fore-shocks, but as a non-local tectonic disturbance induced by the volcanic eruption.

Table I. List of Moderate and Strong Earthquakes felt in Kagoshima in Jan. 1914.

Time of Occurrence.	Intensity.	Time of Occurrence.	Intensity.
Jan. 11, 1914.		**Jan. 11, 1914.**	
h m s		h m s	
4 01 40 A.M.	Moderate.	9 00 00 P.M.	Moderate. Houses shaken.
4 26 40	,, Houses shaken.	9 08 00	,, ,,
5 58 00	,, ,,	9 52 00	,, ,,
9 57 45	Strong. Clocks stopped.	9 59 00	,, ,,
11 46 54	Moderate. Houses shaken.	10 00 00	,, ,,
0 27 11 P.M.	,, {Strong vert. motion. Ground cracked.	10 24 00	,, ,,
0 43 00	Strong. Clocks stopped.	10 58 00	Strong. ,,
1 24 00	Moderate. Houses shaken.		
2 54 50	,, ,,	**Jan. 12, 1914.**	
3 52 10	,, ,,	0 40 00 A.M.	Strong. Houses shaken.
4 12 10	,, ,,	3 35 00	Moderate. ,,
5 24 00	,, ,,	4 08 00	,, ,,
6 47 00	,, ,,	4 43 00	,, ,,
6 53 00	,, ,,	5 49 00	Strong. ,,
7 01 00	,, ,,	6 03 00	Moderate. ,,
7 22 10	,, ,,	6 15 30	,, ,,
7 30 20	,, ,,	6 32 00	,, ,,
7 42 02	,, ,,	7 46 00	,, ,,
7 51 00	,, ,,	8 27 00	Strong. ,,
8 12 00	,, ,,	**6 28 00** P.M.	**Destructive.**
8 23 00	,, ,,	**Jan. 13, 1914.**	
8 34 00	,, ,,	4 09 00 P.M.	Strong. Houses shaken.

2. Tokyo Registers.* The different tromometers in the Seismological Institute (Hongo, Tokyo) have given well defined registers of the destruc-

* Record at the Kagoshima Meteorological Observatory of the commencement of the destructive earthquake motion has been reproduced in No. 5 of this Volume.

tive Sakura-jima earthquake on Jan. 12, 1914. Figs. 2, A and 2, B (Pls. LXXXIX., A and B) is a slightly enlarged reproduction (magnification = 26) of the earlier and the main portions of the diagram furnished by the duplex pendulum tromometer, composed of the upper, or ordinary, pendulum of height = 4.0 m. and of weight = 150 kg., and of the lower, or inverted pendulum of height = 0.58 m. and of weight = 32 kg., with the resultant oscillation period of 19 sec. From the diagram it will be seen that the movements in the preliminary tremor, 2 m. 9.3 sec. in duration, were executed in the S. W.–N. E. directions ; the very first displacement being, according to the high magnification instrument registers, in the direction of N. 64° E., accompanied by an upward movement. The seismic origin was, therefore, at the approximate distance of 960 km. to the S. 64° W. of Tokyo, a position quite close to Sakura-jima. In the principal portion, the motion was composed at first of the transverse vibration, but subsequently again of the large longitudinal vibration, followed by alternations of the two sets of waves of gradually decreasing amplitude.

The maximum movements (= 2a) recorded by the different instruments at the Seismological Institute was as follows :—

	Magnification.	Actual 2a.
E. W. Compt. Horizontal Pendulum	(= 10), ...	...2.95 mm.
,, ,, ,,	(= 15), ...	...2.90 ,,
,, ,, ,,	(= 30), ...	...2.83 ,,
		Mean...**2.9** ,,
N. S. ,, ,, ,,	(= 10), ...	...1.65 mm.
,, ,, ,, ,,	(= 20), ...	...1.40 ,,
		Mean...**1.6** ,,
Vertical Component Tromometer	(= 10), ...	...0.7 mm.

To give a comparison, the maximum motion (= 2a) of the local semi-destructive Asama-yama earthquake of July 16, 1912, registered in Tokyo at the radial distance of 135 km. was as follows :—

	Magnification.	Actual 2a.
E. W. Compt. Horizontal Pendulum,	(= 10) ...	...1.65 mm.
,, ,, ,,	(= 15) ...	...1.53 ,,
,, ,, ,,	(= 30) ...	...1.95 ,,
		Mean...**1.71** ,,
N. S. ,, ,, ,,	(= 10) ...	...2.45 mm.
Vertical Compt. Tromometer	(= 10) ...	...0.70 ,,

Taking the distance difference into consideration, the Sakura-jima earthquake on Jan. 12, 1914, seems to have been some 10 times larger than this strong volcanic Asama earthquake.

Figs. 3, 4, and 5 (Pl. XC.) give the E. W., the N. S., and the vertical component registers at Hongo of the Sakura-jima earthquake.

3. Area of Earthquake Motion. The Sakura-jima earthquake was fairly great, and the area of sensible motion included the whole of Kyushu (except the province of Chikzen at the north), the s.w. extremity of Chugoku, and the N.W. portion of Shikoku, extending to the maximum distance of 360 km. in the N.E. direction to the vicinity of Hiroshima (province of Aki) and Imahal (province of Iyo, Shikoku). Toward the s.s.w. the shock was felt at the islands of Akseki-jima (悪石嶋) and Takara-jima (寳嶋) at the radial distance of about 350 km., but was unfelt at Nase (O-shima, Lyukyu) a little futher on. Toward the N.W. the radial distance of the sensible motion area was limited, to 210 km., the shock having been felt at the s.w. part of the Goto islands group, but not felt at the islands of Iki and Tsushima. It is likely that the sensible motion was propagated also to a comparatively short distance toward the S.E.

The area of moderate intensity motion which included the whole central and southern parts of Kyushu and some of the Satsuma islands, had the maximum radial distance of about 185 km., to Nagasaki and the vicinity toward the N.N.W., and the Yaku-shima (屋久嶋) and Nakano-shima (中之嶋) toward the s.s.w.

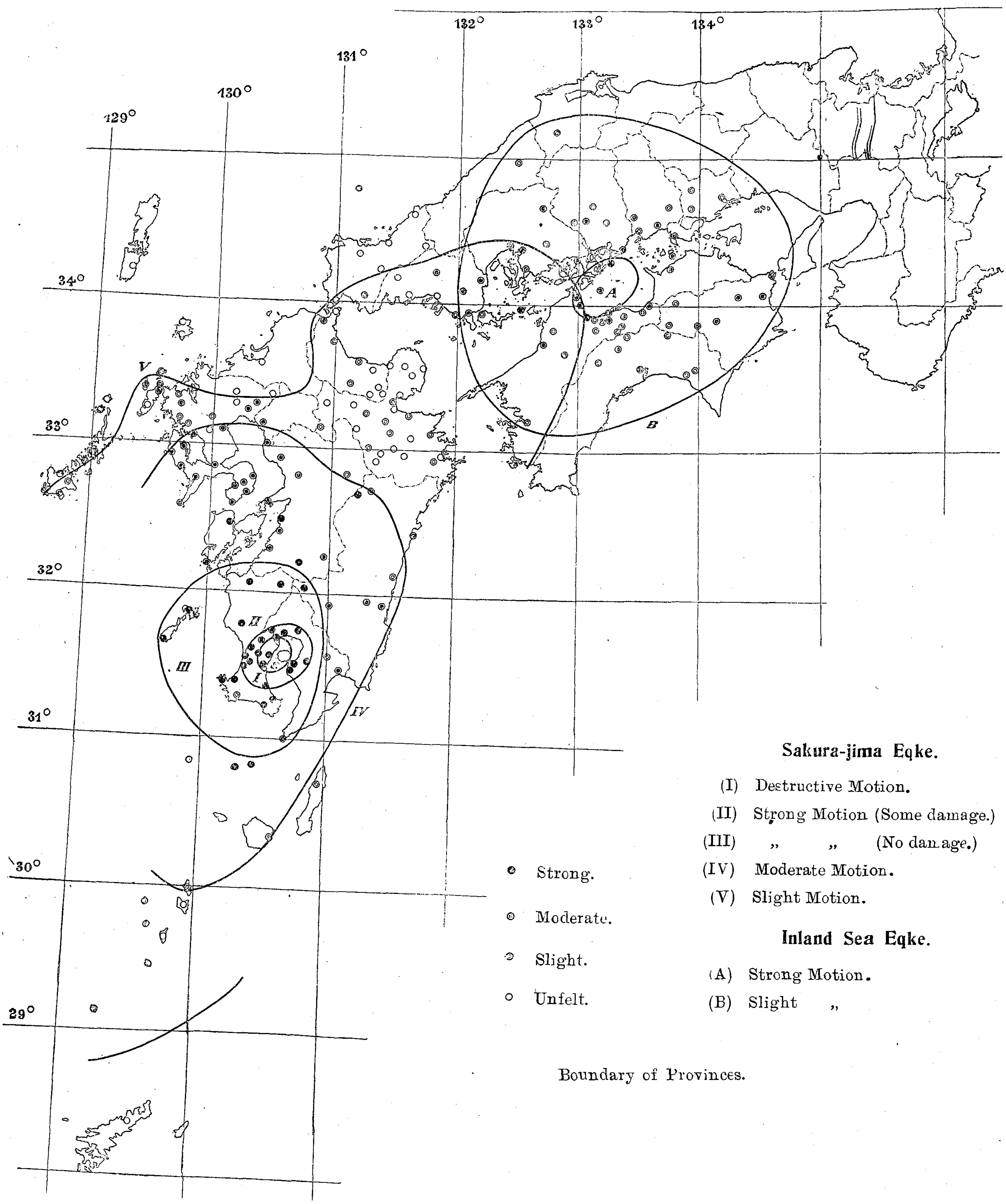
The area in which the earthquake was felt strongly without causing damage extended over Satsuma, Osumi (except its eastern portion), and the Koshiki-jima islands (上下甑嶋), the maximum radial distance being 70; 90; and 80 km. toward the N.; the w.; and the s.s.w. respectively.

The area of strong motion, in which slight damage was caused, was an ellipse including the region bordering on the Inner Kagoshima Bay, of the major and minor diameters of 60 and 45 km. respectively.

Finally, the violent motion area, in which serious damage was caused to the buildings, was a small ellipse including the island of Sakura-jima and the city of Kagoshima and the vicinity, with the major and minor diameters of 30 and 25 km. respectively. At the Moe-jima, off the N.E. coast of Sakura-jima, the earthquake was not very severe, none of the tomb-stones having been overturned.

From the map (fig. 1) it will be observed that the sensible earthquake motion was mainly propagated toward the N.E. and toward the s.s.w., namely, along the extension of the Japan islands arc. Such was also the case with the

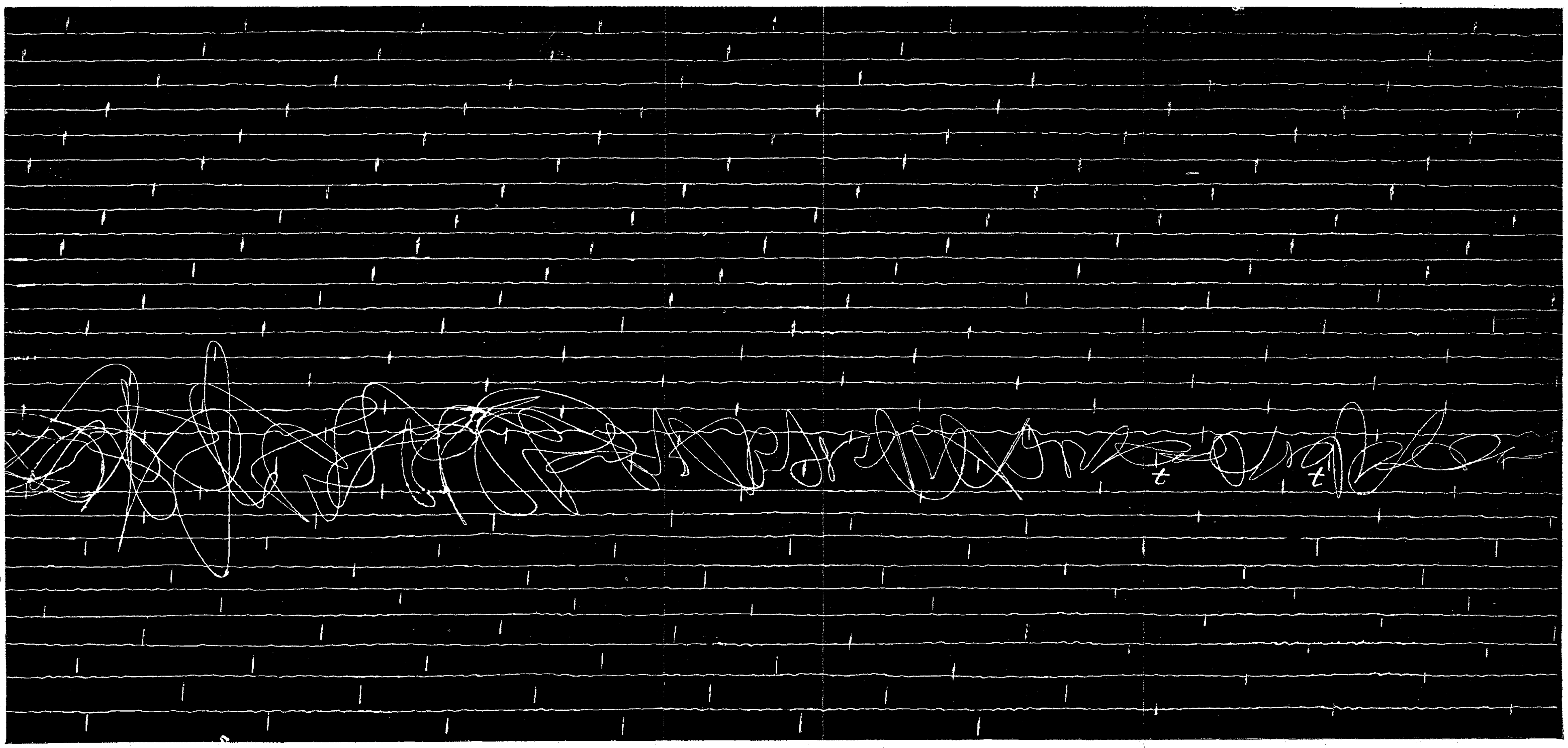
Fig. 1. Map showing the Area of Disturbance of the Sakura-jima and the Inland Sea Earthquakes on Jan. 12, 1914.



Pl. LXXXIX, B.

Fig. 2, B.

(Fig. 2, B is continued from Fig. 2, A.) t......Successive minute marks.



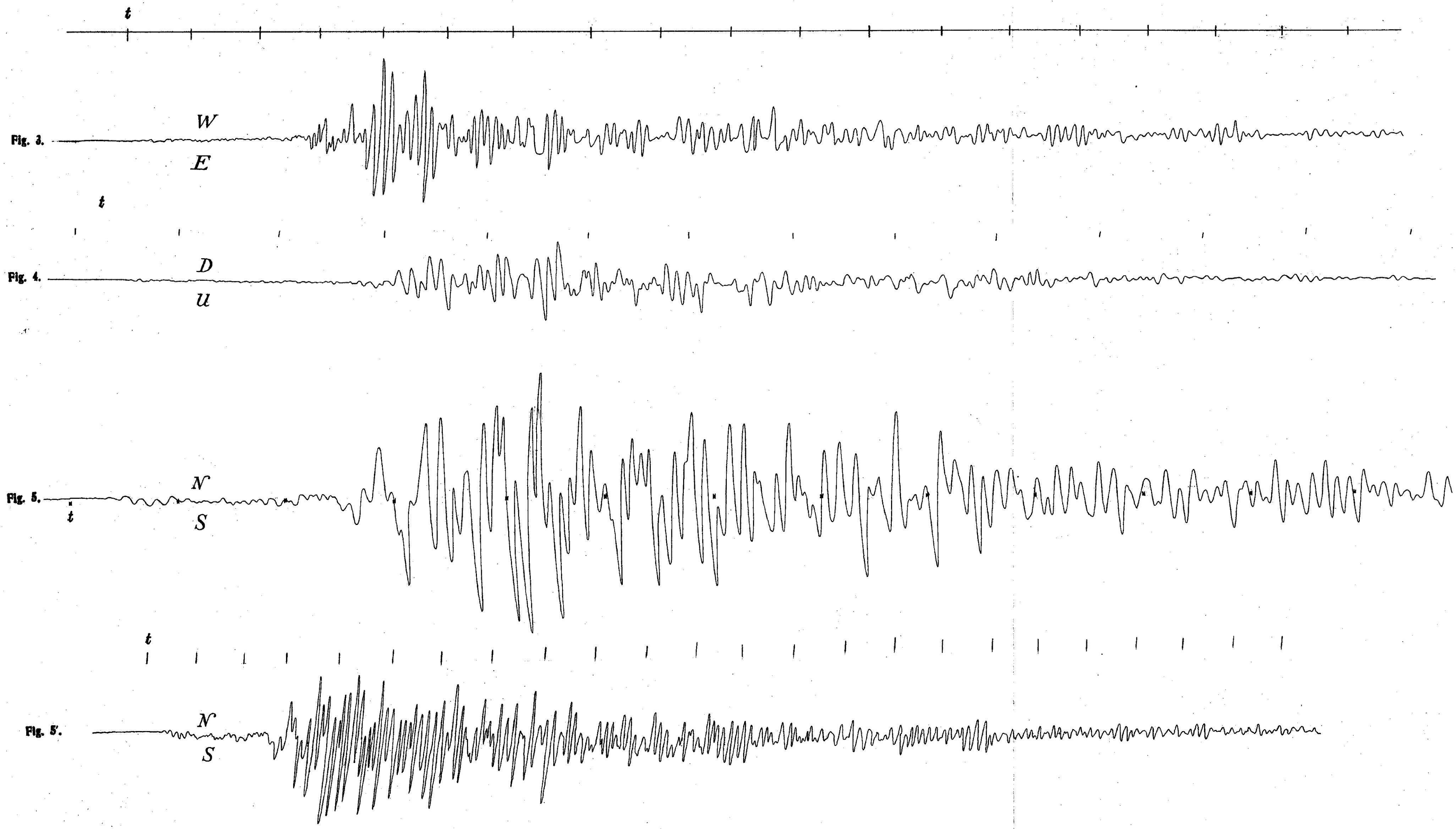
ab......Preliminary Tremor, composed of the longitudinal wave.

b......Commencement of the Principal Portion, at first composed of the transverse wave, but subsequently composed of the longitudinal wave.

Tokyo Observation of the Sakura-jima earthquake of Jan. 12, 1914, at 6. 28 P. M.

(1 Time Mark Interval = 1 minute.)

Fig. 3. E.W. Component (magnification = 10), at Hongo.
Fig. 4. Vertical Component (magnification = 20), at Hongo.
Fig. 5. N.S. Component (magnification = 30), at Hitotsubashi.
Fig. 5'. N.S. Component (magnification = 20), at Hongo.



Figs. 5. and 5.' The individual vibrations can be identified in the diagrams obtained at the two different stations of Hongo and Hitotsubashi.

Itoshima (糸嶋) earthquake of 1898 in the western part of the province of Chikzen (Kyushu).

4. Focal Depth of the Destructive Sakura-jima Earthquake. The origin of the destructive earthquake on Jan. 12, 1914, at $6\frac{1}{2}$ P.M., was probably situated in the Kagoshima channel, between the former islet of Karasu-jima and the coast of the city of Kagoshima, at about 4 km. to the S.E. of the Kagoshima meteorological observatory, say, at $\varphi = 31° 35'$ N., $\lambda = 130° 35'$ E. According to the seismographical registers at the latter, the duration of the preliminary tremor of the fore-shocks was on the average 1.9 sec., while that of the aftershocks was found also to be practically identical, namely, 1.94 sec. (See this Volume, No. 5.) The duration of the preliminary tremor of the destructive earthquake may probably, without a sensible error, be taken to be 1.9 sec., which according to my calculation formula given in the Bulletin, Vol. IX, No. 1, corresponds approximately to the central distance of 14 km. This is to be regarded as denoting, not the surface radial distance from the epi-centre, but the direct distance between the place of observation and the seismic focus or centre; the formula here utilized being, for the shorter distances, based on the observations of the earthquake motion caused by the explosions of the Asama-yama volcano, for which the source of disturbance lay at the surface itself. The focal depth is found to be about 13 km. (See fig. 6.)

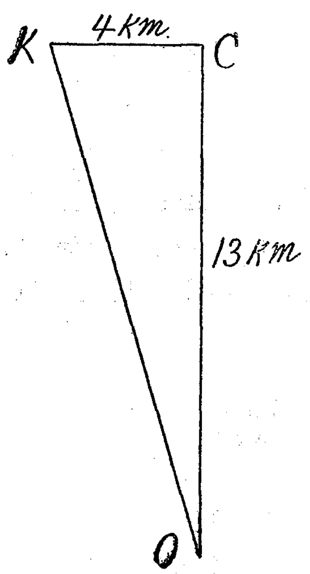


Fig. 6.

O......Eqke. Focus
C......Epicentre.
K......Kagoshima Met. Observatory.

The destructive earthquake in question took place during the explosive phase of the volcanic outburst of Sakura-jima, about four hours before its intensity culmination, and some 24 hours before the commencement of the lava outflow. The earthquake was, therefore, probably caused by the strong underground expansive volcanic force, which must have imparted an initial upward impulsive motion to the district in the epifocal area, as is verified by the seismographical record at Kagoshima. (See this Volume, No. 5, Pl. LXXVII.)

5. Seismic Damage in Kagoshima. The damage in the city of Kagoshima due to the strong earthquake on Jan. 12, at 6. 28 P.M. was, according to the report of the prefectural office, as follows :—

Killed...	...8 men and 4 women (including 3 wounded who subsequently died).
Wounded	...15 men and 12 women.
Horses and cattle	...24 killed.
Buildings... ...	...39 totally collapsed*; 130 half collapsed; 977 partially damaged.
Boats	...13 totally wrecked, 22 partially damaged.
Roads	...Damaged at 12 places, total area 383 *tsubo*.†
Bridges	...5 damaged.
Stone wall ...	...Damaged at 675 places, total area 6,265 *tsubo*.†
Board fences ...	...Damaged at 110 places.

Table II., communicated by the Police Office of Kagoshima, gives the numbers of the buildings* totally or partially destroyed in the different streets of the city, by the strong earthquake at 6. 28 P.M. on the 12th. The total amount of the damage was as follows :—

	Number of the dwelling houses.	Nnmber of the ware houses, etc.
Totally destroyed,	29	86
Partially destroyed,	117	181
Slightly damaged,	9,405	1,055

Thus only about 0.2 % of the total number of the dwelling houses in the city have been overthrown by the shock. The greatest amount of destruction occurred naturally in the made grounds and the strand streets, such as Kasuga-cho (春日町), Yanagi-machi (柳町), Sumi-cho (須美町), Ogawa-machi (小川町), Kinsei-cho (金生町), Daikok-cho (大黒町), Izumi-cho (泉町), Shiomi-cho (汐見町), Seisan-cho (生產町), Naka-machi (中町), Gofuk-cho (吳服町), and Higashi-Sengok-cho (東千石町), at the sea coast portions of the old city quarters to the north of the Kotsuki-gawa; and Tokiwa-cho (常盤町), Take (武町), Korai-cho, (高麗町), Kamino-sono (上ノ園), and Arata-machi (荒田町), in the newer portions of the city to the south of the same river.

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* In the official estimates the number of the buildings totally destroyed often includes those standing whose damage is so heavy as to necessitate a rebuilding.

† 1 *tsubo* = 36 sq. *shaku* = 36 sq. feet nearly.

Table II. Damage to Buildings in the City of Kagoshima caused by Strong Earthquake of Jan. 12, 1914.

Street.	町 名	Total Number of Houses.	Dwelling Houses.				Ware Houses, etc.			
			Total Collapse.	Half Collapse.	Slight Damage.	Sum.	Total Collapse.	Half Collapse.	Slight Damage.	Sum.
Tsuzumigawa	鼓川	147	—	1	131	132	3	5	30	38
Inari	稲荷	179	—	1	144	145	2	8	56	66
Shimizu	清水	296	—	—	212	212	3	10	71	84
Kasuga	春日	216	—	2	215	217	3	2	30	35
Takashi	鷹師	171	—	—	163	163	—	—	9	9
Yakushi	薬師	171	—	—	154	154	5	1	2	8
Nishida	西田	432	—	2	384	386	3	3	23	29
Shinyashiki	新屋敷	377	—	—	170	170	—	—	35	35
Tokiwa	常盤	222	1	—	218	219	1	1	1	3
Take	武	167	—	—	173	173	—	7	—	7
Korai	高麗	303	—	—	361	361	—	1	7	8
Kaminosono	上ノ園	231	—	4	232	236	1	2	4	7
Kami-Arata	上荒田	268	—	—	352	352	1	5	4	10
Shimc-Arata	下荒田	639	1	4	742	747	4	—	4	8
Shimo-Tatsuo	下龍尾	294	—	6	210	216	14	12	44	70
Kami-Tatsuo	上龍尾	280	2	4	208	214	4	14	48	66
Ikenoue	池ノ上	241	—	6	181	187	1	14	56	71
Yamashita	山下	681	3	2	408	413	—	5	51	56
Yasui	易居	319	2	1	237	240	7	2	12	21
Seisan	生産	63	1	—	54	55	3	—	11	14
Muika	六日	66	3	2	25	30	—	—	4	4
Tsuki	築	46	1	—	23	24	3	6	5	14
Shin	新	211	—	3	102	105	—	—	20	20
Horic	堀江	285	—	1	180	181	—	—	30	30
Matsubara	松原	466	—	5	98	103	—	—	25	25
Izumi	泉	162	1	—	166	167	—	1	35	36

Table II. Damage to Buildings in the City of Kagoshima caused by Strong Earthquake of Jan. 12, 1914. (*Cont.*)

Street.	町名	Total Number of Houses.	Dwelling Houses.				Ware Houses, etc.			
			Total Collapse.	Half Collapse.	Slight Damage.	Sum.	Total Collapse.	Half Collapse.	Slight Damage.	Sum.
Shiomi.	汐見	65	—	—	110	110	1	1	36	38
Sumiyoshi.	住吉	183	1	5	150	156	2	3	40	45
Susaki.	洲崎	30	3	—	20	23	1	2	10	13
Higashi-Sengok.	東千石	460	—	6	425	431	7	3	15	25
Naka.	中	160	1	13	136	150	1	15	17	33
Kinsei.	金生	112	2	3	110	115	1	15	38	54
Funats.	船津	164	—	—	113	113	5	3	15	23
Daikok.	大黒	177	2	15	182	199	1	5	12	18
Gofuku.	呉服	119	1	8	97	106	—	15	22	37
Yamanokuchi.	山ノ口	548	—	6	262	268	4	7	44	55
Hinokuchi.	樋ノ口	554	—	—	270	270	—	—	45	45
Kajiya.	加治屋	426	—	—	216	216	—	—	41	41
Sonta.	草牟田	307	—	—	198	198	—	—	12	12
Shinshoin.	新照院	273	—	—	117	117	—	—	7	7
Nishi-Sengok.	西千石	472	—	—	229	229	—	—	13	13
Hiranomachi.	平之町	463	—	—	200	200	—	—	11	11
Shioya.	鹽屋	633	2	10	340	352	1	1	35	37
Ogawa.	小川	178	2	3	150	155	2	5	15	22
Ebis.	惠美須	148	—	—	130	130	—	1	1	2
Izumiya.	和泉屋	112	—	—	55	55	—	—	3	3
Kruma.	車	141	—	—	85	85	1	—	5	6
Yanagi.	柳	147	—	2	145	147	—	4	—	4
Mkaie.	向江	28	—	2	16	18	—	—	—	—
Sakai.	榮	62	—	—	30	30	1	—	1	2
Nagata.	長田	322	—	—	56	56	—	2	—	2
Reisui.	冷水	172	—	—	20	20	—	—	—	—
Sum.	合計	13,389	29	117	9,405	9,551	86	181	1,055	1,322

6. Stone Structures. The comparatively large amount of the seismic damage was due to the existence of the dwelling houses, ware-houses, retaining walls and fences made of the soft tuff-like andesite which came widely in use within the ten years preceding the eruption. The majority of these structures, which are very poorly mortared and little better than simple piles of the stone blocks, are much damaged by earthquake shocks, being seismically far weaker than ordinary brick buildings. Especially the fence walls proved very dangerous, as, being propped by buttresses on the inner side, where the ground is generally higher than on the outside street, these were overturned toward the latter quite easily. Of the 9 cases of the direct mortality in the city none was due to house collapse, all the victims having met their death on the street by the overthrowing of the stone fence walls. The building stones are chiefly of the following five species :—

(1) Isousu-ishi (磯臼石)............... Used in better class buildings and in stone bridges.
(2) Ono-ishi (小野石).................. Used in buildings.
(3) Kajiki-ishi (加治木石) .... „ „
(4) Kogashira-ishi (河頭石) .... „ better class buildings.
(5) Iso-ishi (磯石) .... „ stone fence walls.

Through the kindness of Mr. J. Oi, chief of the public works department of the Kagoshima prefecture, I have procured 8 specimens of the stones of the species (1), (2), (4) and (5), out of which 81 test pieces were formed. According to the results of the testing, (Table III), the Iso-ishi (5) were found to be very weak, the tensile strength being about 70 lbs. per sq. inch. Even of the hardest Isousu-ishi the tensile strength did not exceed 228 lbs. per sq. inch.

石材	Stone Specimen.	Density.	Ultimate Tensile Strength. (lbs. per sq. in.)
磯石 (軟質)	Iso-ishi (soft).	—	70
„ „	„ („).	—	73
„ (硬質)	„ (hard).	2.03	123
小野石	Ono-ishi	—	150
„	„	2.00	221
加治木石	Kajiki-ishi.	—	155
河頭石	Kogashira-ishi.	2.34	172
磯臼石	Isousu-ishi.	2.12	228

It is needless to add that the different stone species in question can be used, with proper mortar and under adequate design, as good building material for earthquake-proof structures. Thus, the one story stone buildings of the Kagoshima Prison have sustained no seismic damage.

I reproduce below the results obtained by Dr. S. Uchida, of the Architecture Department, in connection with the building stones used in Kagoshima.

Stone Specimen.		Weight per cubic foot, (in lbs.).	Ultimate Strength (in lbs. per sq. in.), against		
			Crushing.	Stretching.	Cross Breaking.
河頭石	Kogashira-ishi.	146	7180	276	565
硬質磯石	Iso-ishi (hard).	133	4910	—	729
軟質磯石	Iso-ishi (soft).	114	1460	—	—
小野石	Ono-ishi.	108	2590	—	—
加治木石	Kajiki-ishi.	106	2180	133	545

I mention here two cases of fracture of the small stone columns. At the

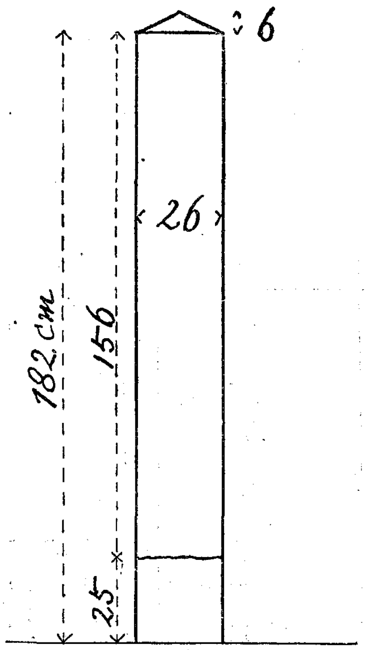


Fig. 12. Broken Stone Monument at the Terukni Shrine, Kagoshima.

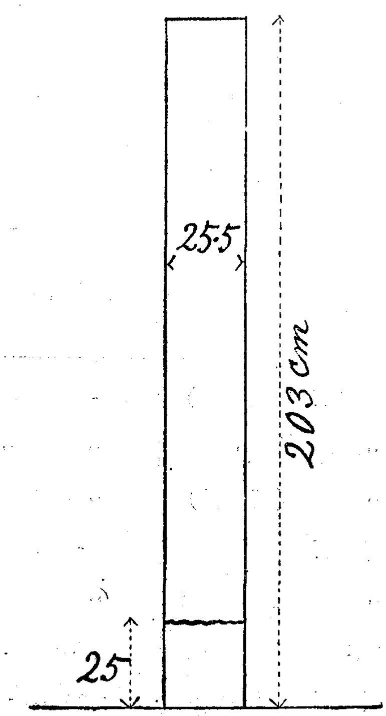


Fig. 13. Broken Stone Gate Post of the Kagoshima Meteorological Observatory.

(F. Omori, phot.)

Fig. 7. Large overturned Stone Lanterns at Gion-nc-su, in the northern part of Kagoshima.

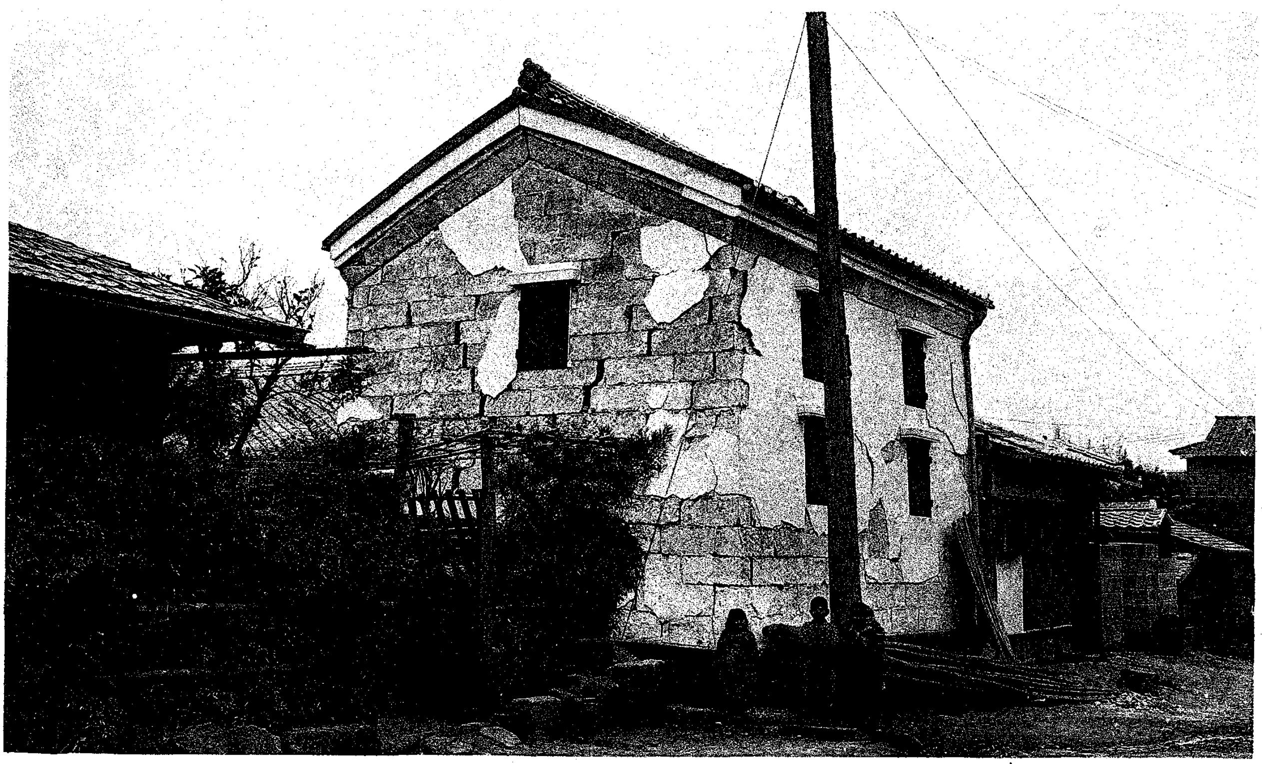


Fig. 8. A Stone Ware-house, in northern part of Kagoshima, badly cracked along mortar joints.

(F. Omori, phot.)

Fig. 9. Stone Fence Wall of the Kagoshima Prison. Stones below the horizontal crack line scratched off.

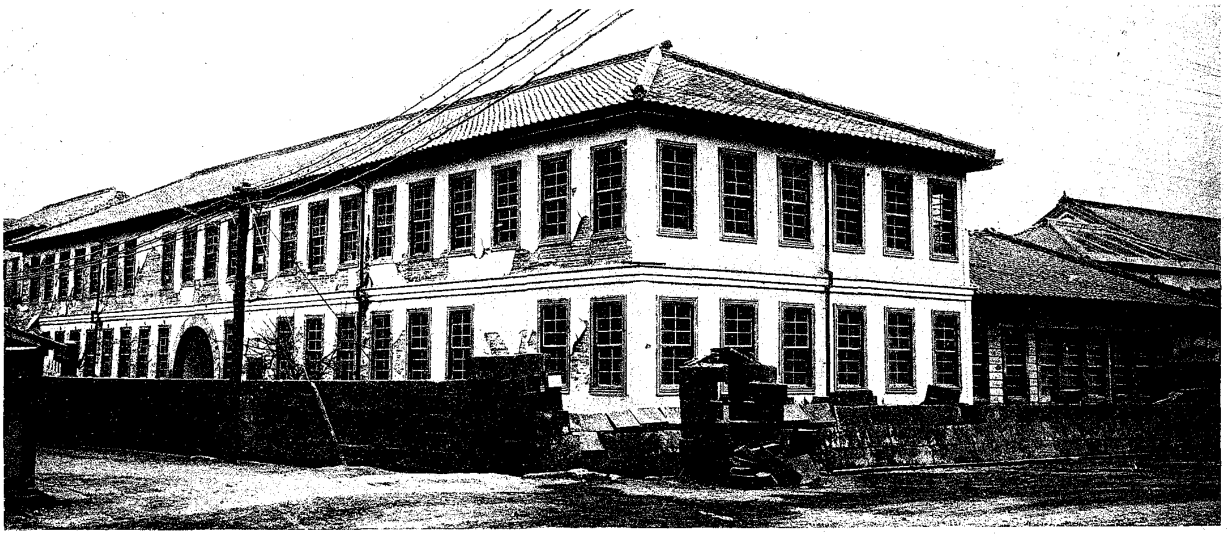


Fig. 10. Part of the Prefectural Buildings: The plasters on the E. and W. longer sides were much cracked and shaken down. The N. fence stone wall was partially overthrown.

Fig. 11. An E. End House of a Row of Street Buildings parallel E. W. much thrown out of the vertical.

Terukni shrine (照國神社), a stone monument, 26 cm. square in section, and 188 cm. in height (fig. 12), was broken at 25 cm. height from base. The intensity ($=\alpha$) of motion neccesary for producing the fracture* in question is, assuming the tensile strength to be 50 lbs. per sq. inch, found to be equal to an acceleration of about 5990 mm./sec^2.

Again, of the two similar stone gate posts (fig. 13) of the meteorological observatory, situated on the hill to the N. W. of Kagoshima, one remained uninjured, while the other was broken at the height of 25 cm. from base; the posts being each 203 cm. in height and 25.5×27.5 cm. in section. The seismic stability is, assuming the tensile strength to be 50 lbs. per sq. inch, found to be equal to an acceleration of 4630 mm./sec^2.

The seismic stability of each of these columns was thus sufficiently great and must certainly have been much higher than the actual intensity of the earthquake motion concerned. It is likely that the columns were broken near the base where some weak points or cracks had existed.

* For the calculation of the seismic stability of columns, see the Publications of the Imp. Earthq. Inv. Comm., No. 4.

Table III. Tensile Strength of the Various Building Stones used in Kagoshima.

(Measured by F. Omori.)

磯 石 Iso-ishi.	磯 石 Iso-ishi.	小 野 石 Ono-ishi.	加 治 木 石 Kajiki-ishi.
No. 1 Specimen.*	No. 2 Specimen.	No. 4 Specimen.	No. 6 Specimen.
97.2	93.9		173.3
96.9	93.3	189.5	172.9
76.7	88.1	185.2	156.9
74.8	88.0	182.5	140.9
73.8	83.9	166.3	120.9
73.6	78.4	157.2	(Mean) **155.0**
71.4	74.1	150.0	
70.7	72.6	149.2	河 頭 石 Kogashira-ishi.
69.3	72.6	147.9	
68.8	69.9	144.8	No. 7 Specimen.
67.9	68.0	144.4	197
58.9	62.9	140.6	192
58.8	62.8	127.4	180
57.4	15.1	121.8	173
51.7	(Mean) **73.1**	100.0	170
51.6		(Mean) **150.4**	166
(Mean) **69.5**			159
	No. 3 Specimen.	No. 5 Specimen.	141
	159	248	(Mean) **172**
	145	245	
	134	234	磯 臼 石 Isoüsu-ishi.
	125	232	
	115	230	No. 8 Specimen.
	115	212	268
	98	211	238
	91	159	230
	(Mean) **123**	(M an) **221**	221
			213
			199
			(Mean) **228**

* Gate post of the Kagoshima Met. Observatory.

7. Direction of Motion in Kagoshima. In the city of Kagoshima numerous stone lanterns and tomb stones were overturned. (See fig. 7.) These being small columns generally not cemented to the pedestal, and of heights under 2 metres, with, in the case of the former, stems square or circular in section, serve as a simple sort of standing column seismometer and give indications of the direction of the maximum earthquake motion. The observations of the overturned bodies, mentioned below, have been made in the following different places:—Terukni Shrine, West Honganji, Nanrinji, Fukshoji, etc., in the central and southern parts of the city; the military cemetery, Jokomyoji, Tanoura, etc., in the northern part.

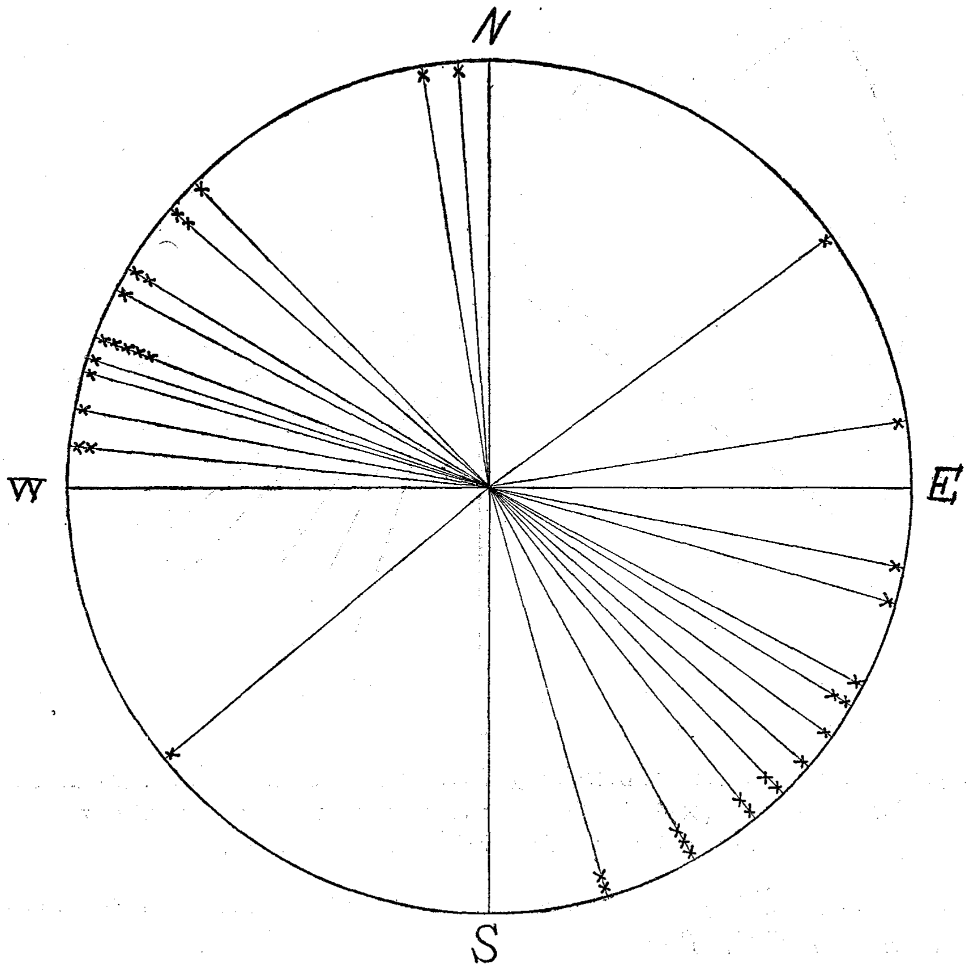


Fig. 14. Diagram showing the Overturning Directions in the Northern Part of Kagoshima.
Each small cross (×) indicates a monument or stone lantern overthrown in the direction of the radius on which it lies.

Terukni-jinsha (照國神社):—A slender square stone column was broken at base and overthrown towards N. 30°W. The kurin, or high nine-ring post projecting above the top roof, of the 5-story stupa (pagoda), inclined toward S.80°E. A square stem stone lantern was overthrown toward S.46°E. At Yamashitacho (山下町) a gate post, 1 × 1 shaku in size and 9 shaku in height, was thrown toward S.40°E.

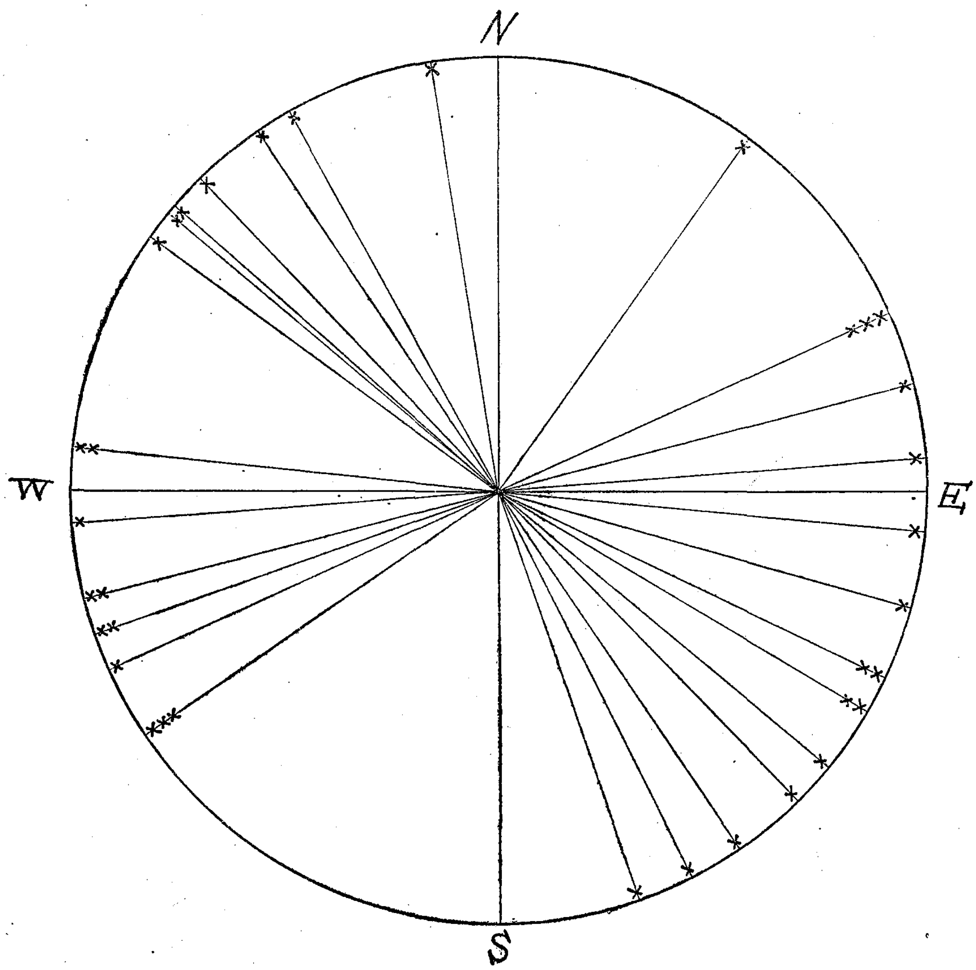


Fig. 15. Diagram showing the Overturning Directions in the Southern Part of Kagoshima.
Each small cross (×) indicates a monument or stone lantern overthrown in the direction of the radius on which it lies.

West Honganji Temple:—The top of a large square-stem stone lantern was thrown toward S.55°E.

Btokukai (武德會):—Two square stone gate posts were overthrown toward S.60°E. and toward N.80°W.

Iwasaki Saw Mill:—The factory building was overthrown eastward.

Nanrinji (南林寺):—The monument for the victims of the Sakura-jima eruption of 1779, facing S.55°E., was thrown toward the latter direction.

Cylinder stem stone lanterns overthrown toward		Square-section tomb stones overturned toward		
N.70°E.	N.80°W.	N.40°E.	N.25°W.	S.75°W.
N.70°E.	S.80°W.	N.80°E.	N.45°W.	S.15°E.
N.46°W.	S.70°W.	N.70°E.	S.30°E.	S.80°W.
N.40°W.	S.60°E.	N.5°W.	S.60°W.	S.60°W.
		N.50°W.	S.75°W.	S.60°W.
		W.		

Fkushoji (福祥寺) :—An octagonal stem stone lantern was overturned toward S.70°E. The top of a cylinder stem stone lantern was thrown toward S.40°E.

One of the two stone gate posts of the Kagoshima Meteorological Observatory, 27.5 × 25.5 cm. in section and 203 cm. in height, was broken at 25 cm. from base and thrown toward the N.55°W.

Military Cemetery :—Numerous stone lanterns and tomb stone were overturned.

Square stem stone lantern overturned toward		Square section tomb stone overturned toward	
N.65°W.	N.65°W.	S.45°E.	N.45°W.
N.80°W.	N.70°W.	S.70°E.	N.75°W.
N.80°W.	N.85°E.	N.55°W.	N.65°W.
N.40°W.	S.35°E.	N.58°W.	N.68°W.
N.65°W.	S.75°E.	N.65°W.	N. 5°W.

Fort Ground :—Square section tomb stones were overturned mostly toward N.58°E. A stone lantern with cylinder stem was overturned toward S.58°E. Another with square stem was overturned toward S.25°E.

Jokomyoji (淨光明寺) :—Several large stone lanterns and monuments dedicated to the successive ancestral lords of the princely family of Shimazu were overthrown.

Square stem stone lanterns overturned toward		Square section tomb stones overturned toward	
S.25°E.	S.35°E.	S.12°E.	S.40°E.
S.50°E.	N.45°W.	S.12°E.	S.55°W.
S.40°E,		S.55°E.	N.

Summary. The directions of overturning given above refer to the magnetic north and south. Making the declination correction of 5° west, the 36 observations made at the military grave-yard, the Jokomyoji temple, and other places in the northern part of Kagoshima give the mean result of

N.61°W–S.61°E. The remaining 36 observations at Nanrinji and other places in the southern part of the city give the mean direction of N.76°W–S.76°E. (See figs. 14 and 15.) It will be observed that the overturning direction, which indicated the direction of the strongest motion in the northern part of the city was approximately identical with that of the vibration at the commencement of the earthquake as shown by the ordinary seismograph diagram obtained at the Kagoshima meteorological observatory. (See this Volume, No. V.).

At Tanoura (田ノ浦):—Two large stone lanterns (fig. 7) were not overturned, while two others exactly like these standing nearby were overturned respectively toward S.55°E. and S.25°E. For one of these, with the stem 59 cm. (=2x) square in section, the height (=y) of the centre of gravity is found to be 170 cm. The intensity or acceleration ($=\alpha$) of the earthquake motion necessary for overturning the structure regarded as a "small body," would be $\alpha=\frac{x}{y}\times g=1690$ mm./sec.^{2}, g being the acceleration due to the gravity. These stone lanterns, with the base dimension of nearly 2 feet, are, however, to be regarded rather as belonging to the category of "large body," and the range (=2a) of the earthquake motion necessary for the overturning would be some 37 cm., according to the equation: $2a=\frac{h}{y}\times x$, in which h (=214 cm.) is the height of the centre of percussion of the whole column with respect to the ground surface.

The mean direction of the maximum earthquake motion in the different parts of Kagoshima taken together was N.68°W.–S.68°E. This direction is probably habitual to the Kagoshima district and is almost exactly normal to the extension of the Kirishima, Sakura-jima and Kaimon-dake volcanic chain.

In the case of the Tokyo district, the maximum motion in the stronger earthquakes is generally executed in an E.–W. direction irrespective of the position of the seismic origin; the usual type of the maximum vibration which occurs at the commencement of the principal portion, consisting of an eastward displacement (single amplitude) followed by the counter westward displacement (double amplitude). Amongst the others, in the semi-destructive earthquake of June 20, 1894, the maximum displacement was directed toward the S.71°W. The prevailing direction in the earthquakes disturbing the Tokyo district, or the Kwanto provinces at large is normal to the course of the Fuji volcanic chain. It is conceivable that in a district situated not far distant from a volcanic chain the principal earthquake motion has the habit of taking place at right angles to the latter.

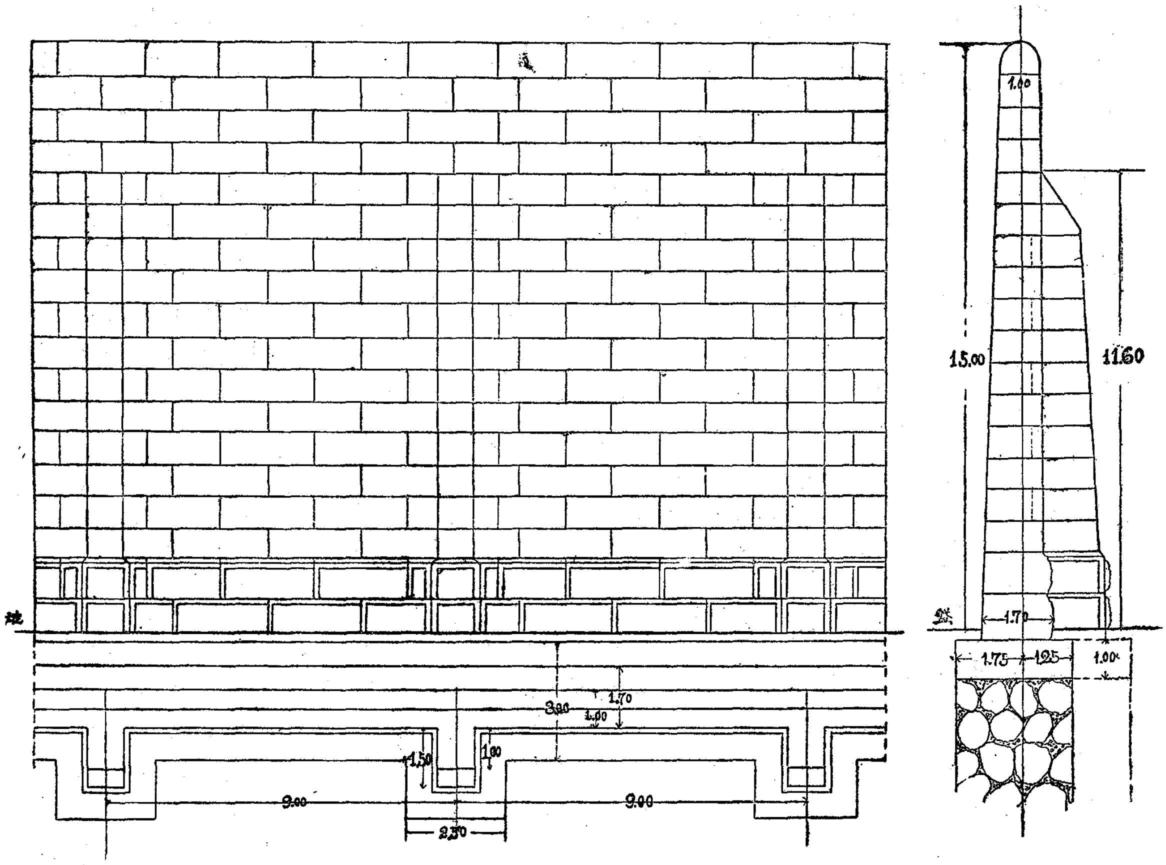


Fig. 16. Elevation, Plan, and Section of the Wall of the Kagoshima Prison.
Dimensions are given in *shaku.* (1 *shaku*=0.994 foot.)

8. Damage to Buildings and the Direction of Motion. The direction in Kagoshima of the maximum vibration of the destructive earthquake on Jan. 12, at 6. 28 P.M., was nearly E.–W. (See § 7). Consequently the seismic damage to the buildings, partitions and masonry walls were different according to directions. Thus, the walls running parallel N.–S. were overthrown, or tended to be overthrown, by being cracked at their bases. If not thus cracked, those walls remained intact. On the other hand, the walls in an E.W. direction were in very many cases damaged by being cracked obliquely in two systems of lines mutually normal and inclined at an angle of 45° to the base, sometimes resulting in the falling down of the broken pieces at the central portion. Fig. 10 illustrate the occurrence of the two different types of crack: the 2-story wooden building, part of the prefectural office, had its north and south side plastered walls much cracked and shaken down, while the east and west end walls were not damaged; the enclosure stone wall had, however, its east side partially overthrown, while the south side remained intact.

Fig. 9 shows the seismic damage done to the front, or east, side of the enclosure wall of the Kagoshima Prison. The wall, 15 feet in height and 1.7 feet in base thickness, (fig. 16), with buttresses on the outside at successive distances of 9 feet, was cracked near the base through the whole length; the parts of the buttresses just below the horizontal crack being in very many cases torn off and thrown down. This was the result, as is shown by the photograph, of a relatively outward motion of the portion of the wall above the plane of fracture. It seems thus likely that the first strong displacement, at the commencement of the principal portion of the earthquake, was directed westwards, or away from the Sakura-jima, while the counter and larger movement took place eastwards or toward the island.

Fig. 11 illustrates a case, in which the houses at the east end of a row of the shops along a street parallel west-east, were considerably pushed eastwards, a broken partition wall in the N.S. direction being also much inclined toward the same direction. Several of the high enclosure walls and slender partitions in the E.W. direction received no seismic damage.

9. Effect on Masonry Break-Water. The masonry breakwater protecting the Daimonguchi made-ground (大門口) to the south of the harbour of Kagoshima is 500 *ken* (=3000 *shaku**=909 metres) in length and extends almost exactly in the N.–S. direction, being normal to the corresponding radius proceeding from the centre of Sakura-jima. (See fig. 17.) It had been originally constructed between April 1901 and Jan. 1902, having received improvement repairs in 1904–1905. As will be seen from fig. 20, the structure is, notwithstanding its apparent solidity, in reality a sort of embankment with the coping 6 *shaku* in width and 17.5 *shaku* above the low water line, filled in with gravel and earth, and lined on the outside with a layer of stone blocks.

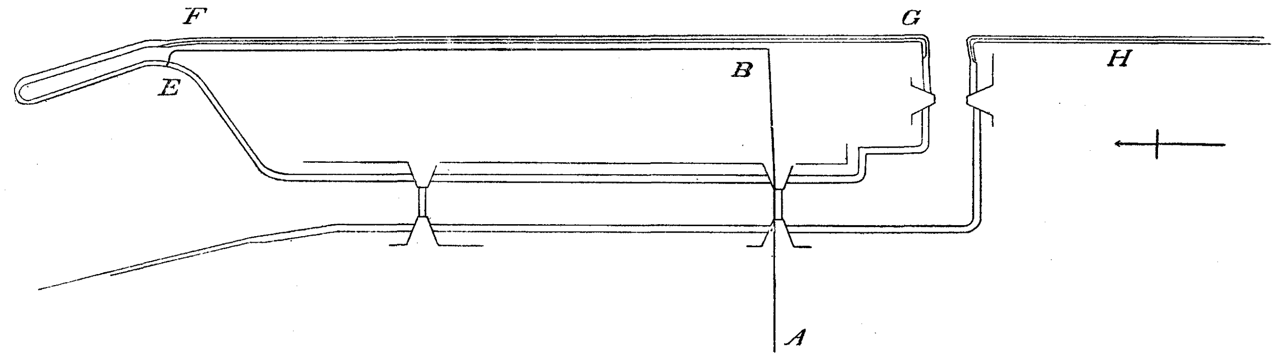
The strong earthquake of Jan. 12th produced no cracking or other apparent serious damage of the breakwater. A careful measurement made by the Public Works Department of the Kagoshima prefecture indicated, however, that the horizontality of the coping was deranged, the maximum amount or range of the relative elevation and depression along the whole length of 1340 *shaku* or 406 metres of the portion examined (figs. 18 and 19) being 0.145 *shaku* (=0.044 m.). The break-water, which was approximately normal to the direction of the maximum earthquake motion, underwent a far greater transverse deformation; the whole structure having been thrown out slightly in a curve form outwards, or toward the free east side, with the

* 1 *shaku*, or Japanese foot, =0.994 English foot.

Fig. 17. Plan of the Masonry Breakwater and the Canal, of the Kagoshima Harbour.

FG, H......Breakwater Walls.
FG.........Portion examined whose deformation is indicated in figs. 18 and 19.
ABE........Oil Pipes.

(Scale: 1/4000.)



Earthquake Effect on the Masonry Breakwater of the Kagoshima Harbour.

(Length Scale: 1/1,400.)

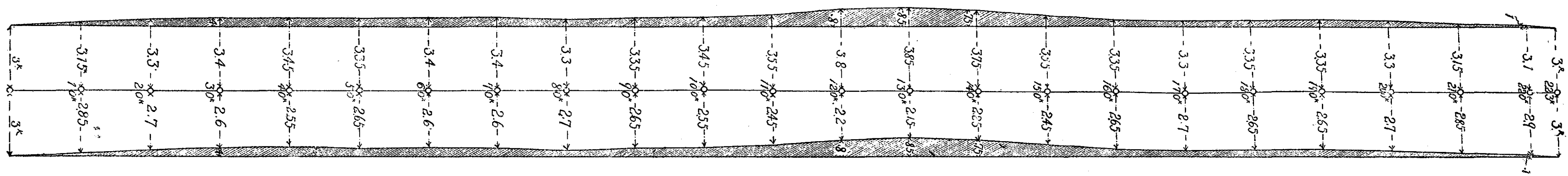


Fig. 18. Plan of the Breakwater, showing the Lateral Deformation. (Tansverse Scale: 1/70.)

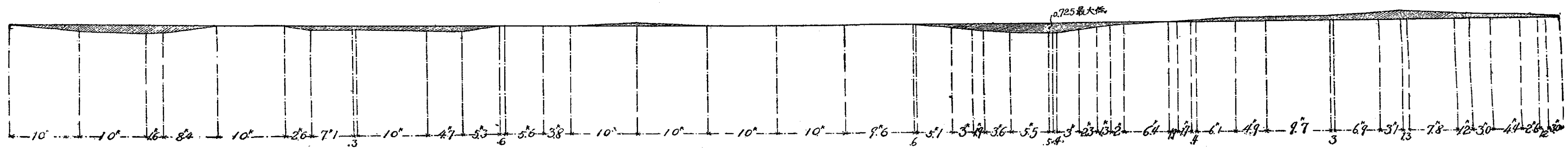
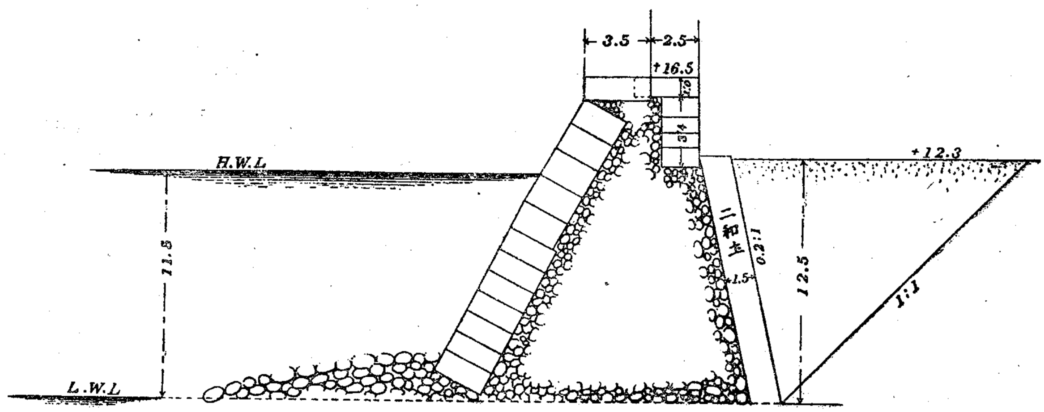


Fig. 19. Vertical Deformation of the Top Surface of the Breakwater. (Vertical Scale: 1/12.)

Length, in *ken* (1 *ken* = 6 *shaku*).
Width and Height, in *shaku* (1 *shaku* = 0 994 foot).

maximum displacement of 0.85 *shaku*=0.26 metre near the middle of the length.

Fig. 20. Section of the Breakwater of the Kagoshima Harbour.
Dimensions in foot.



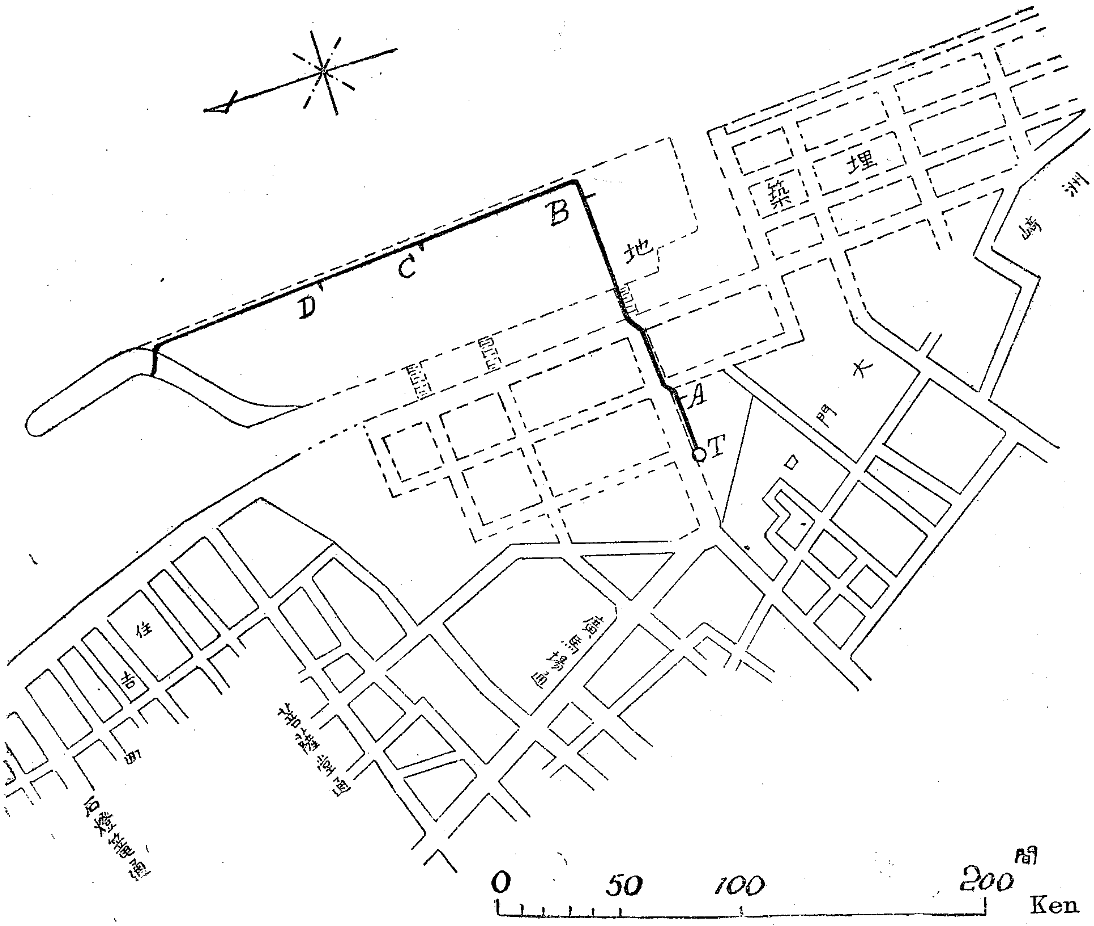
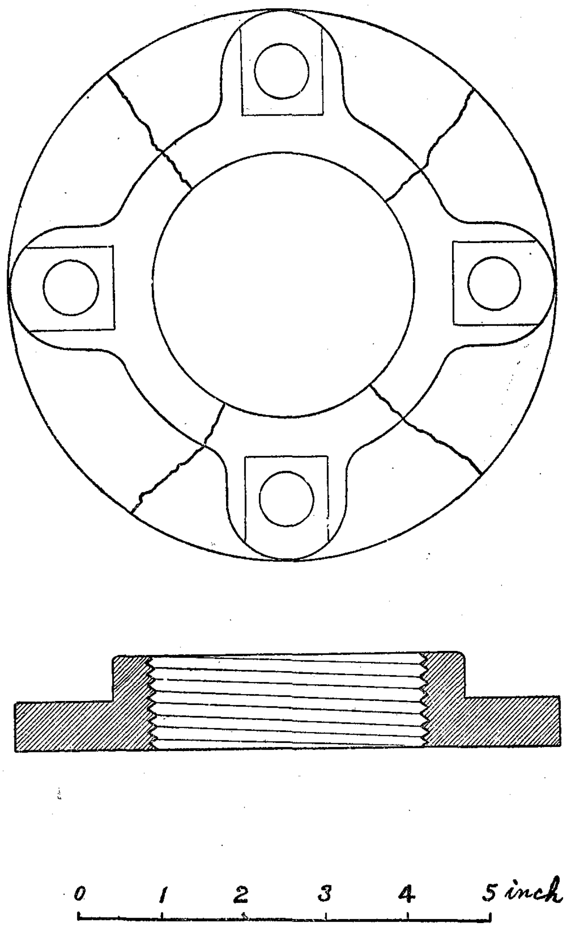


Fig. 21. Map showing the Location of the Oil Conducting Pipes (DBAT).
A, B, C, D......Points of fracture of the pipe joints. T......Tank.
Dotted lines indicate the made grounds.

Beside the above-mentioned vertical and lateral relative deformations at different points along the length of the breakwater wall, the latter has also probably been bodily displaced, possibly through a range of some 1 foot normal to its length, as may be judged from the manner of the seismic damage done to the iron pipes laid in the immediate vicinity. (See below.)

10. Oil Pipes. For the conduction of petroleum there had been laid 3″ cast iron gas pipes at the depth of 2 feet, for the length of 1130 *shaku*=343 metres, on the made ground, parallel to and at the distance of 12 feet inside the breakwater wall above mentioned. At the south end the pipes are laid for the extension of 700 feet toward the west, across the made ground and the canal, to the New York Standard Oil Company's tank at Matsbara-machi (松原町). (See fig. 21.) In consequence of the softness of the made ground and especially of the movement of the breakwater wall, the iron tubes were broken by the earthquake shock at three places *B*, *C*, and *D* the damage occurring in each case at the screw-joint coupling. At *C* and *D*, near the middle of the N.-S. length, the broken tubes were torn apart respectively 3″ and 4″. At *B*, a short distance after the bending toward the west, the tubes were torn apart through the range of 13″, evidently due to the transversal bodily displacement of the wall. (See fig. 23.) At *A* (fig. 21) near the oil tank, a 3″ pipe was torn off at a joint, breaking the flange there into 4 pieces (fig. 22).

Fig. 22. Broken 3″ Gas-Pipe Flange Coupling.



11. Gas Pipes in the City of Kagoshima. The aggregate length of the main and subsidiary gas pipes existing in the city of Kagoshima at the time

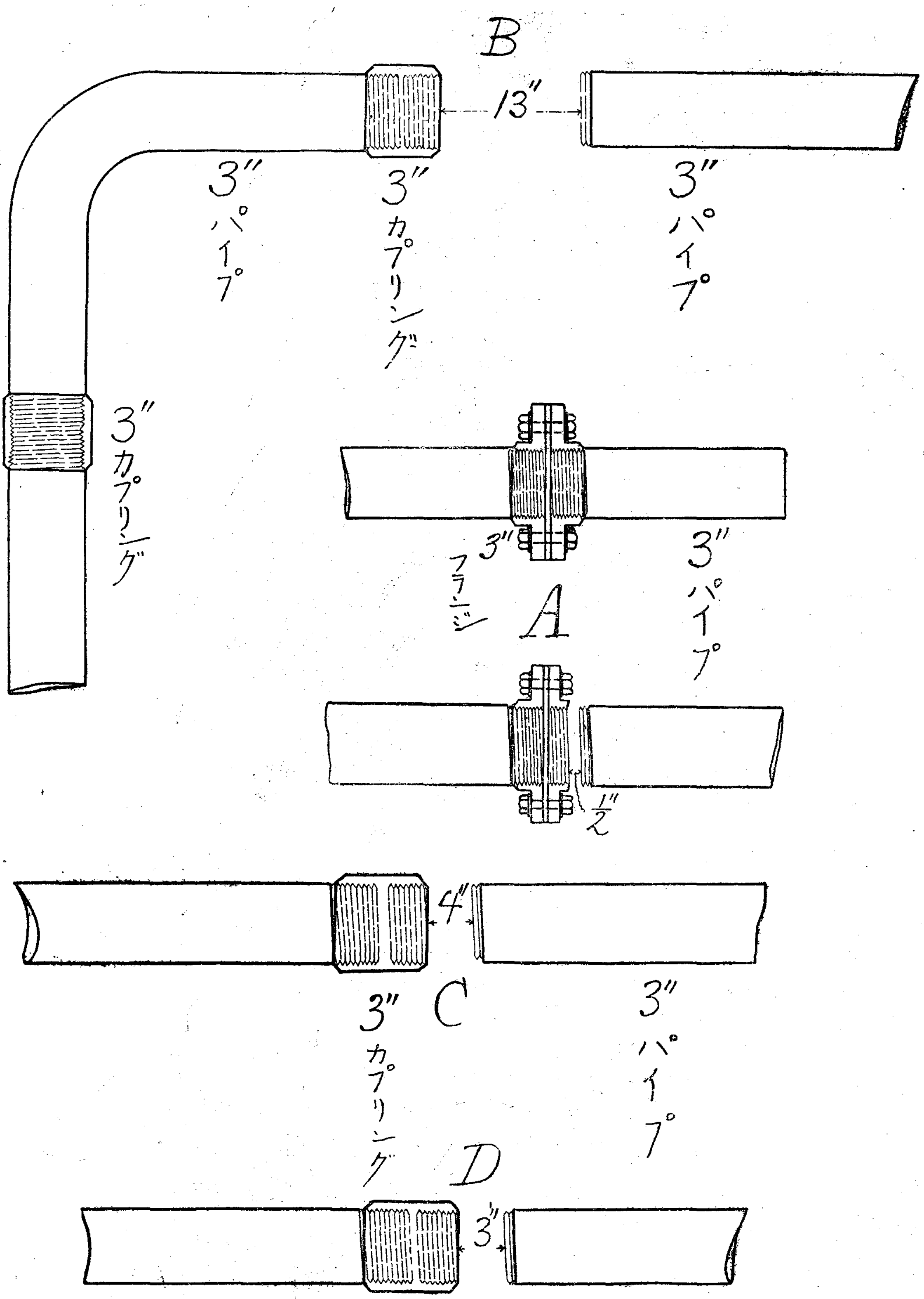


Fig. 23. Joint Fracture of the 3" Oil Pipes.

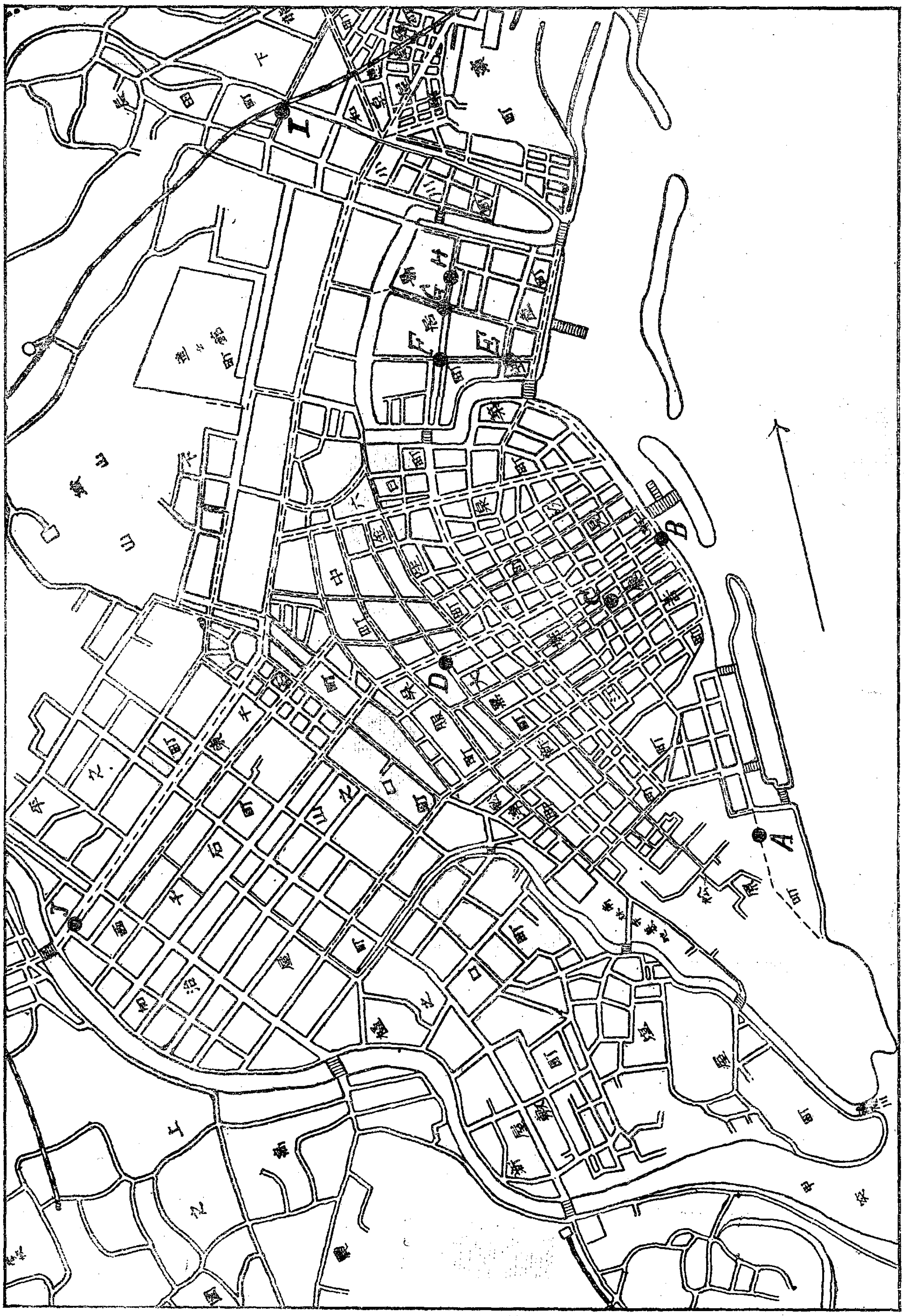


Fig. 24. Map of the City of Kagoshima, showing the Places (A, B, C......J) where the gas pipes were broken by the earthquake of Jan. 12, 1914. (Dotted lines indicate the location of the 2″ to 8″ gas pipes.)

of the Sakura-jima eruption of 1914 were respectively 47,394 and 88,126 *shaku*,* as follows :—

Main Pipe.	
8″ Diameter...	... 6,261 *shaku*
6″ „ ...	... 7,586
4″ „ ...	... 7,764
3″ „ ...	...25,783
Sum	...47,394

Subsidiary Pipe.	
2″ Diameter ...	...11,500 *shaku*
1″½ „ ...	... 7,564
1″¼ „ ...	...10,427
1″ „ ...	...12,790
¾″ „ ...	...42,027
½″ „ ...	... 3,818
Sum	...88,126

The main pipes were of cast iron, while the subsidiary pipes were mostly of wrought iron. There was no case of fracture or other serious damage done to the larger main pipes except at one place on the made ground near the south end of the Canal (運河) of the Kagoshima harbour, where an 8″ pipe was drawn out of socket together with the lead to the amount of 3″½. Cases of mere joint loosening were, however, numerous, especially along the 3″ and 6″ pipes on the Bosato-dori, one of the main streets of Kagoshima, which runs parallel east and west, namely, approximately in the direction of the strongest earthquake motion. In vicinity of the High School (造士館), there was a case of pulling out of a screw joint at the point of normal branching of 2″ wrought iron pipes from the line, the 6″ pipes laid along the Yakata-baba street running in a N.N.E.–S.S.W. direction.

Damage to the wrought iron pipes of 1″ to 2″ diameters, which was confined to screw joints, took place in nine cases, as follows :—

Locality.	Direction of Street.	Position indicated id Fig. 24.	Size and material of Coupling.
Smiyoshi-cho (住吉町).	N.–S.	B	2″ Cast iron.
Yasui-cho (易居町).	W.N.W.-E.S.E.	F	2″ „
„	„	E	2″ Wrought iron.
Kruma-cho (車町).	N.E.-S.W.	I	1″½ Cast iron.
———	———	—	1″½ „
Smiyoshi-cho (住吉町).	W.S.W.–E.N.E.	C	1″½ Wrought iron.
Yasui-cho (易居町).	W.N.W.–E.S.E.	D	1″¼ Cast iron.
Konaya-dori (小納屋通).	N.–S.	G	1″¼ Wrought iron.
Yasui-cho (易居町).	N.E.N.-S.W.S.	H	1″ „

* 1 *shaku*=1 metre/3.3 = 0.994 English foot.

Cast-iron Gas-pipe broken in Wrought Iron Socket.

(×).........Broken End of Gas-pipe.

Fig. 25.

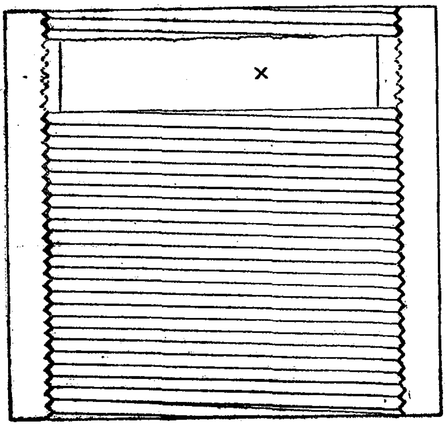


Fig. 26.

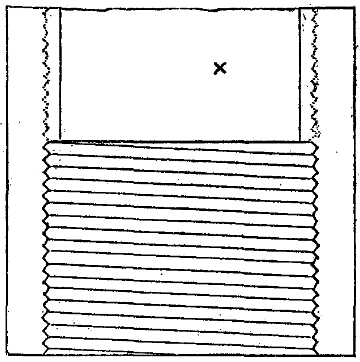


Fig. 27.

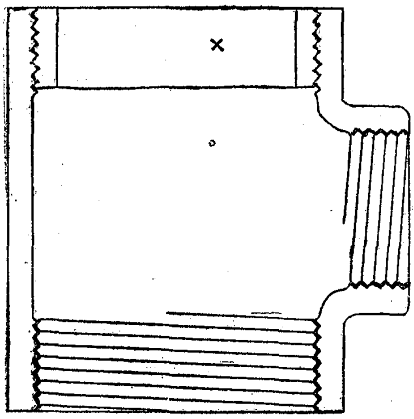


Fig. 28.

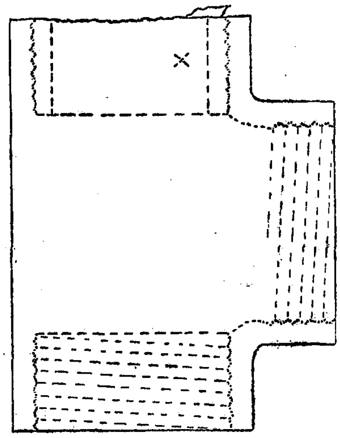


Fig. 25. 2″ Pipe.
Fig. 27. 1″½ „

Fig. 26. 1″½ Pipe.
Fig. 28. 1″ „

As will be seen from figs. 25 and 26, in each of the three cases of the simple joints, *E*, *C*, and *G*, with no transverse branching, the thin end of the tube fitting into the wrought iron coupling was broken at, or a slight distance within, the edge of the latter, due evidently to the reduction to 1½ mm. or so of the thickness of the tubing by the screw cutting. None of the wrought iron couplings were broken.

The six other screw joints for the connection of the 1″¼ to 2″ pipes were of cast iron and fitted also for a normal side insertion of 1″ wrought iron pipe.

Broken Cast-iron Gas-pipe Socket.

Fig. 29.

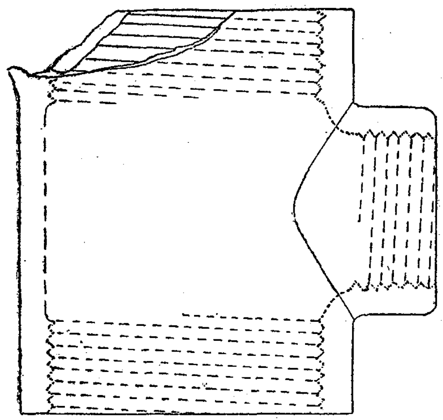


Fig. 30.

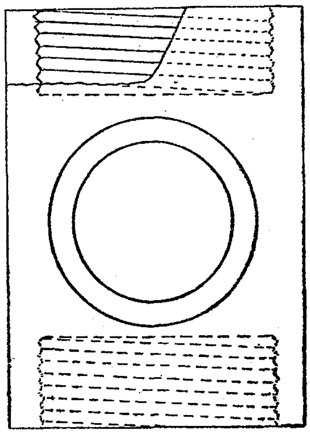


Fig. 31.

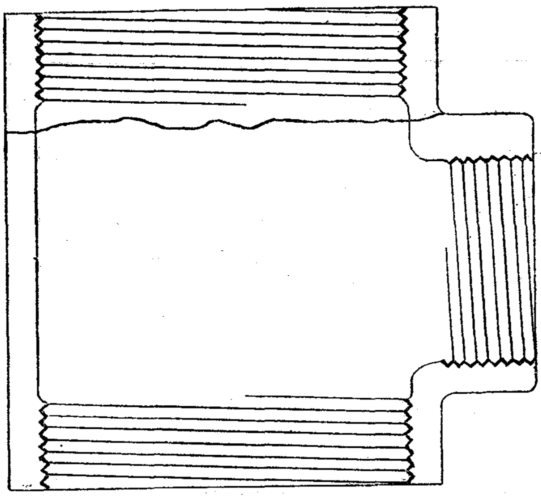


Fig. 29. 1″½ Pipe.
Fig. 30. 1″¼ „
Fig. 31. 2″ „

Four of these, *B*, *F*, *D*, and *I*, (figs. 29, 30, and 31) were broken transversally in a complete or partial manner at the junction with the latter. In case of the 2″ pipe joint, *B* (fig. 31), laid along the strand street, extending nearly north-south, namely, approximately normal to the direction of the maximum earthquake motion, the coupling was obviously broken by the strong transverse thrust exerted by the 1″ pipe branching from it eastwards or westwards. In the 1″ joint *H* (fig. 28), the coupling was not damaged, but one of the adjoining 1″ pipes had its screwed end torn off and partly crushed inside, showing clearly that the effect was due, not to a tension, but to a cross bending action. In the remaining 1″½ joint, the socket was not damaged, but the screw end of one of the pipes fitting into it was broken off apparently by tension.

Beside the damage done to the joints above mentioned, there was a case of fracture of a 2″ cast brass main cock on the Sengok-babadori (千石馬場通) at the east abutment of the Nishida-bridge (西田橋) in the western part of the city.

Again, at several places the ¾″ gas-metre pipes were torn off.

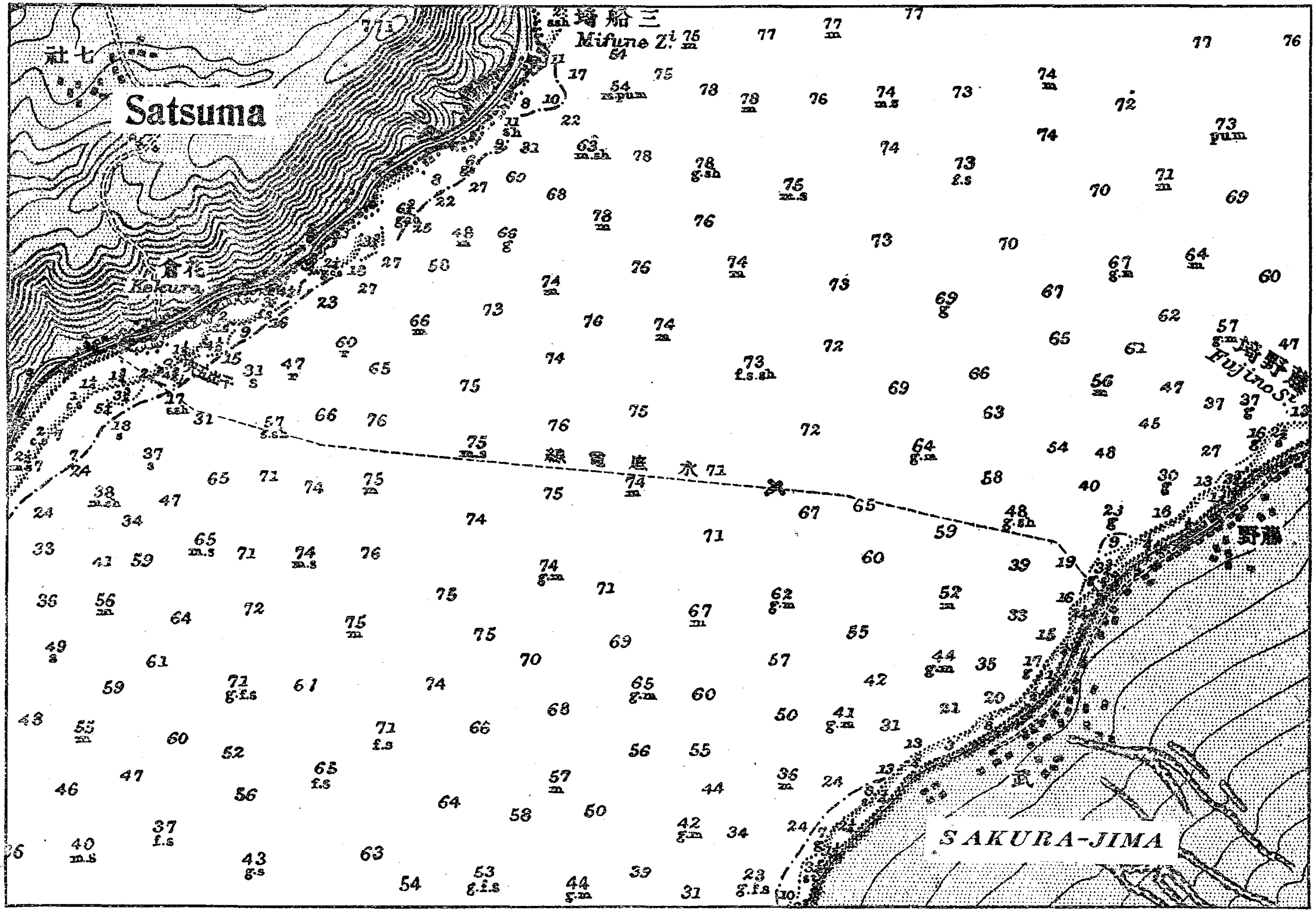
A partial gas circulation was restored 11 days after the commencement of the eruption, namely, on Jan. 23rd, the general gas light use throughout the city having been effected two days later on. During the subsequent days, till Feb. 21st, the leakage amounted to 45%. At the commencement of April next it was reduced to 25%, being still much greater than the value of 15% for the epoch previous to the occurrence of the earthquakes.

12. Damage to the Railways. The damage done to the railways was slight and restricted to the distance of 9 km. to the north, and 15½ km. to

Table IV. Damage to the Railways.

Mileage. (from Moji.)	Damage to the Railway.
	Main Kyushu Line.
$233^m\ 21^c$	A stone block about 70 c. ft. in volume, thrown down from the right-hand side cliff, obstructed the road.
$233^m\ 37^c$	A stone block about 40 c. ft. in size fell on the road.
234^m	54 stone blocks varying in size from 2 to 100 c. ft. were precipitated on the road from the mountain slope on the righthand side about 200′ in height, bending one rail and breaking 8 sleepers.
$235^m\ 16^c - 21^c$	108 stone blocks of 2 to 200 c. ft. in size fell on the road from the mountain slope on the righthand side about 300′ in height, breaking 4 and bending 11 rails, breaking 6 fish-plate joints, and breaking 40 sleepers.
$235^m\ 30^c - 35^c$	About 20 stone blocks of 20 to 800 c. ft. in size fell on the road from the mountain slope on the righthand side about 150′ high, breaking 5 and bending 7 rails, and breaking 15 and bending 3 fish-plate joints.
$235^m\ 37^c$	A stone block about 200 c. ft. in size fell on the road from the right-hand side cliff, causing the bending of a rail.
$235^m\ 39^c$	2 stone blocks about 80 c. ft. in size fell on the road.
	Kagoshima-Sendai Line.
$3^m\ 0^c - 30^c$ (Between Take and Manju-ishi.)	The approaches to the bridge were depressed 4″ to 9″.
$3^m\ 70^c - 4^m$	The railway was slightly bent and the embankment was cracked 3″ wide and 3 chains long.
9 27 – 29 (Between Manju-ishi and Ijuin.)	A cutting slid down over an area of 58 sq. *tsubo*.

Fig. 32. Chart of the Kagoshima Channel. Depth in fathoms.



Dotted line shows the location of the Submarine Cable.
(×)......Point of Fracture.

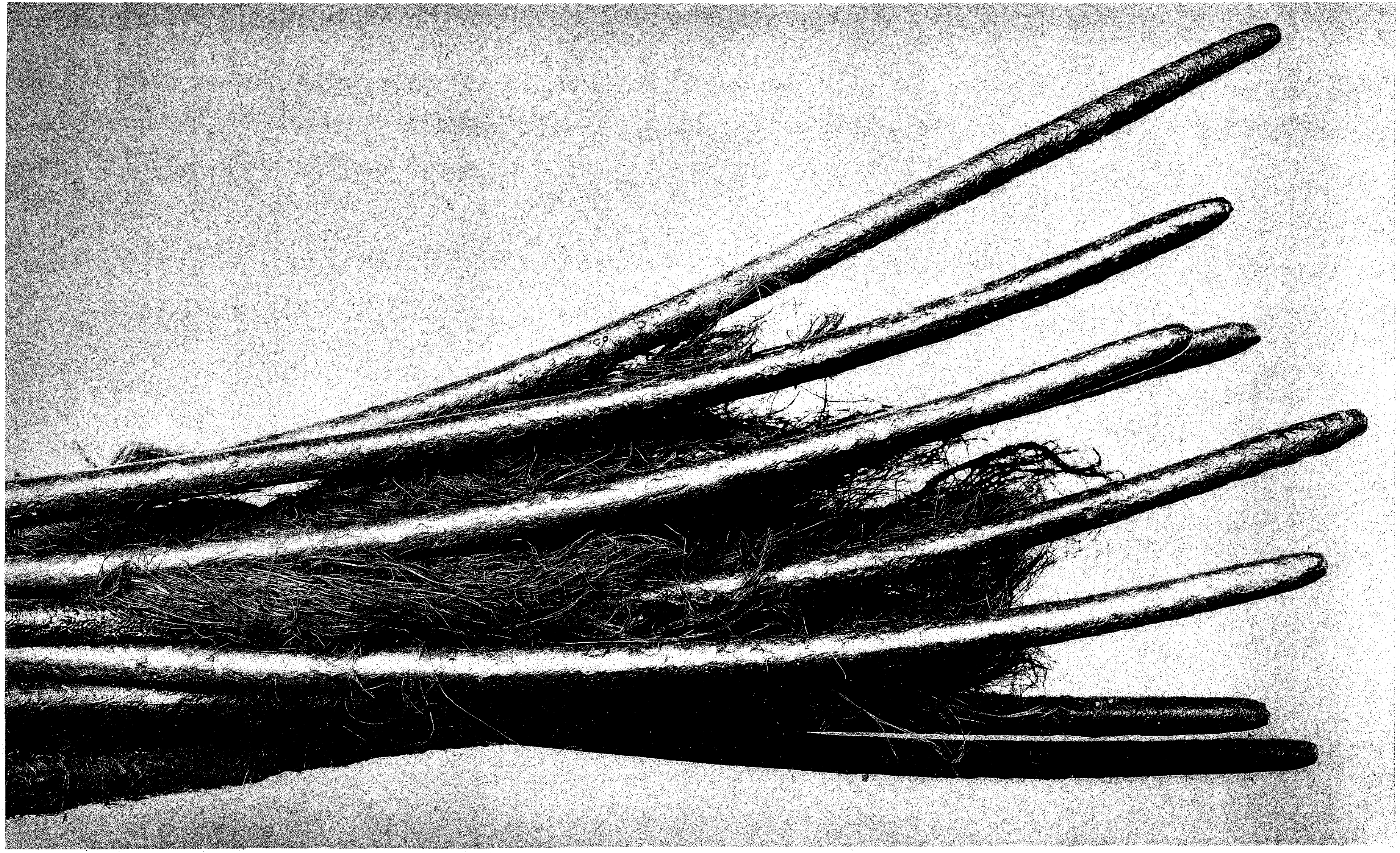


Fig. 33. An enlarged view of the Broken End of the 1″ Telegraphic Cable between Kagoshima and Sakura-jima.

1″ Telegraphic Cable between Kagoshima and Sakura-jima.

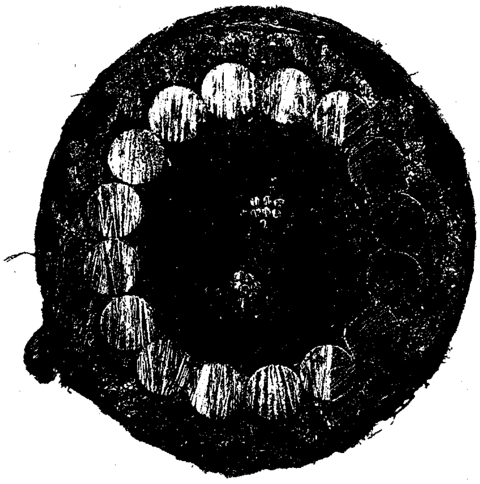


Fig. 34. Section.

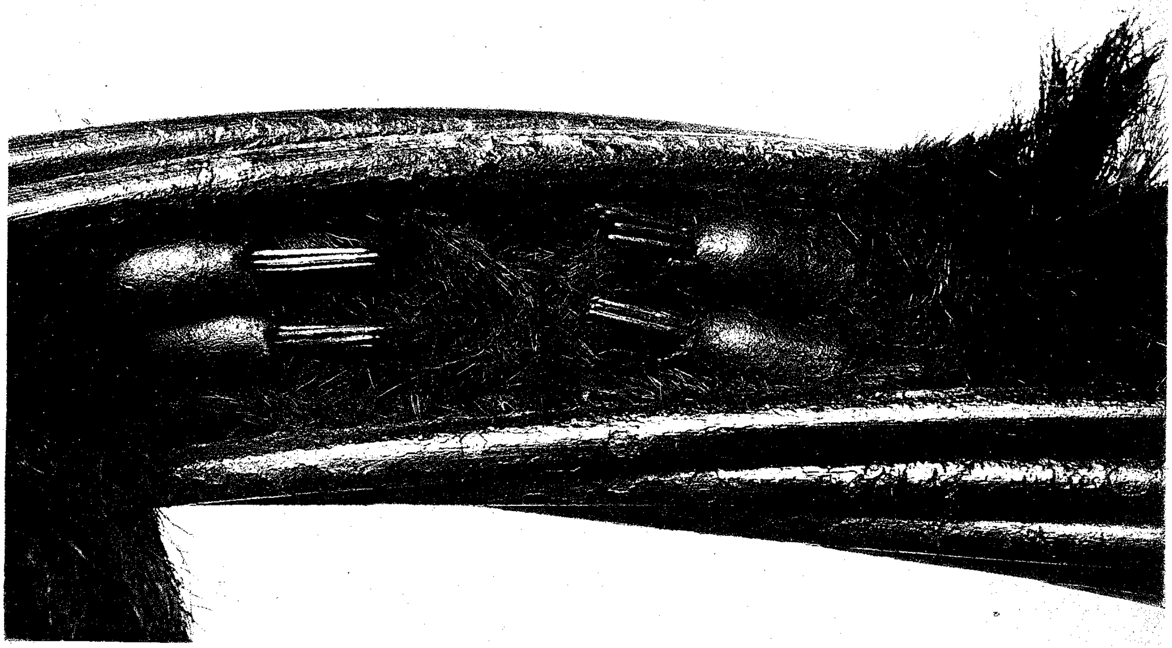


Fig. 35. An Inside Core-breaking.

the west of Kagoshima. On the main Kyushu line laid to the north of the city along the steep western coast of the bay, there were at 7 different places, between the mileages of $233^{m}\ 21^{c}$ and $235^{m}\ 39^{c}$, cases of precipitation of rock fragments from the cliff walls or the high mountain flanks on the righthand side of the road, resulting in a temporary obstruction or in the damage to the rails and sleepers. On the branch Kagoshima-Sendai line there were at three places, between the mileages of $3^{m}\ 0^{c}$ and $9^{m}\ 29^{c}$, cases of a small land slip and of damage to the embankment.

CHAPTER II. SEISMIC DAMAGE TO SUBMARINE CABLE.

13. Submarine Cable Between Kagoshima and Sakura-jima. The damage done to the telegraph cable across the Kagoshima channel at the time of the recent Sakura-jima eruption furnishes a simple and interesting case of the action of submarine telluric convulsions. The broken cable has been examined very carefully by Dr. S. Inada,* of the Department of Communications, the result of his investigations being embodied in a short but valuable paper contributed to the Denki Gakkai Zasshi (Journal of the Electrotechnical Society), No. 344, (1917). The following description of the cable and of the damage done to it in §§ 14 and 15 and Tables V and VI are translations from Dr. Inada's paper.

The telegraph cable across the Kagoshima channel laid on Nov. 20, 1912, between Take, at the N.W. corner of Sakura-jima and Kekura 3 km. to the N. of Kagoshima, had the length of 1.812 sea miles, with the slack of about 7%, and the total weight of 12.6 tons, being composed of the double-core lines of the shore-end and intermediate types, as follows :—

Sakura-jima End.	(III)	(II)	Kagoshima End. (I)
Type.	Double-core Shore-end type.	Double-core Intermediate type.	Double-core Shore-end type.
Length.	0.405 n. mile.	1.012 nautial mile.	0.395 n. mile.
Armour Sheath.	10 = 300 mil	16 = 175 mil.	10 = 300 mil.
Weight of Core.	100 lbs. per n. mile.	100 lbs. per n. mile.	100 lbs. per n. mile.
Weight of Insulating Materials.	120 „	120 „	120 „ „
Weight per nautical mile.	8.7 tons.	5.6 tons.	8.7 „ „

* Besides furnishing me with detailed accounts of his investigations, Dr. Inada has very kindly presented to the Seismological Institute the specimen pieces of the damaged cable.