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.

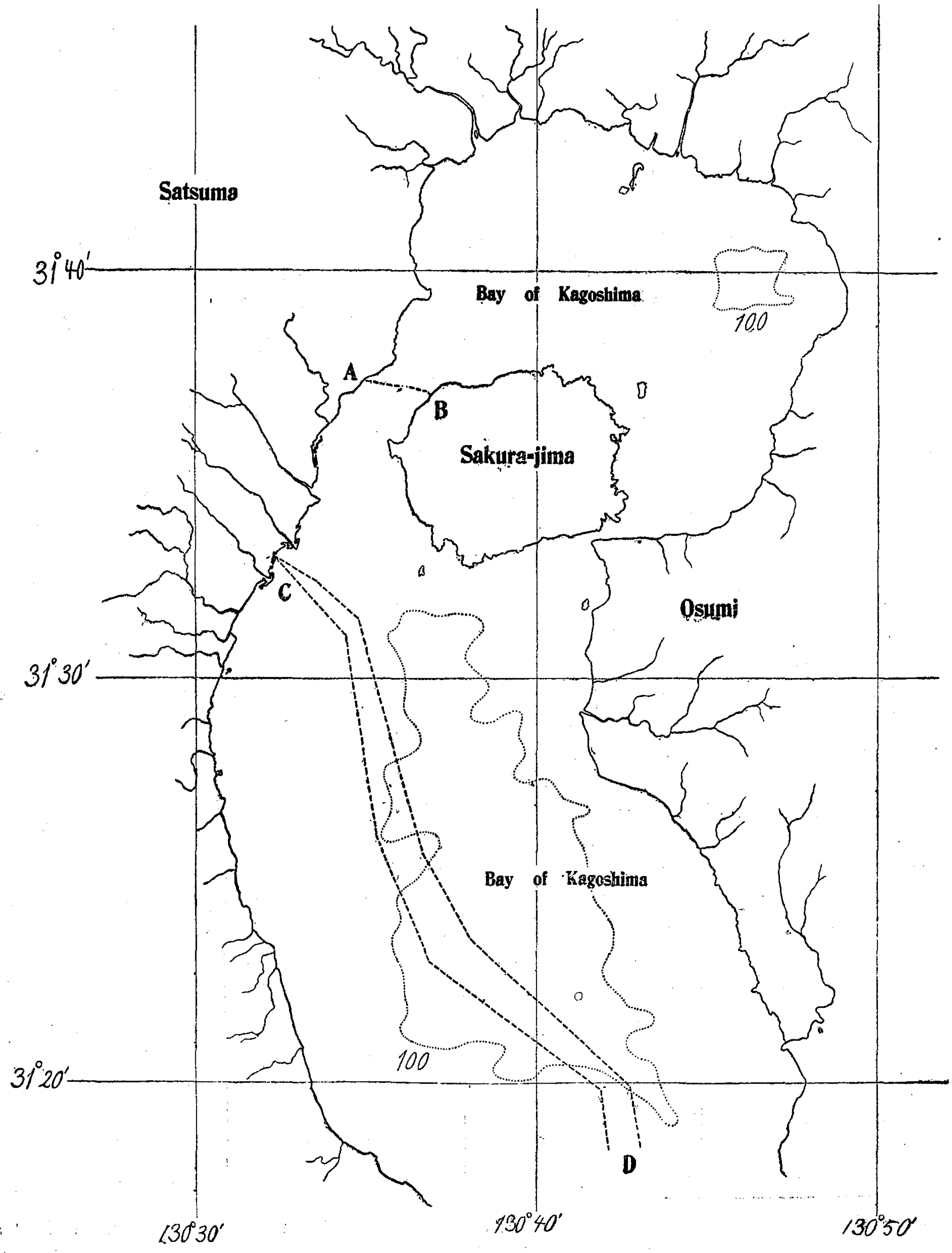
The telegraph cable across the Kagoshima channel laid on Nov. 20, 1912, between Take, at the N.W. corner of Sakura-jima and Kekura 3 km. to the N. of Kagoshima, had the length of 1.812 sea miles, with the slack of about 7%, and the total weight of 12.6 tons, being composed of the double-core lines of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

Fig. 36. Chart of the Kagoshima Bay, showing the Location of the Submarine Cables.

AB......Cable broken by the Earthquake of Jan. 12, 1914.
CD......Cables not damaged „ „



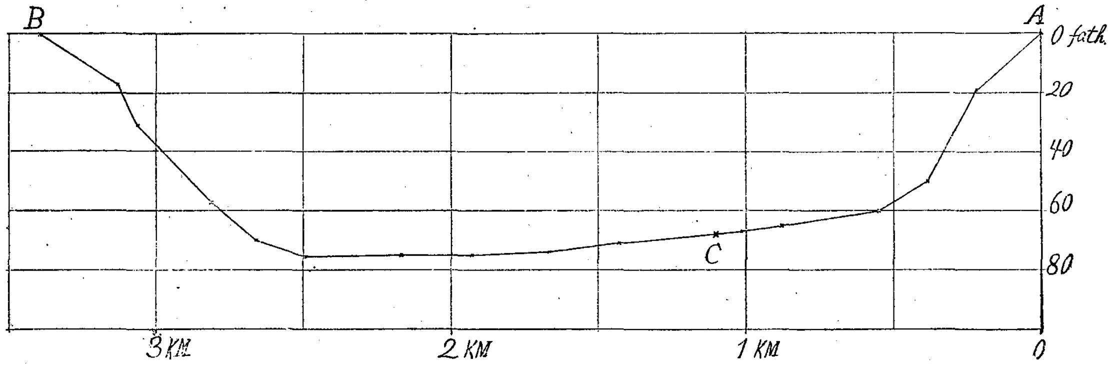
The double-core shore type line used in the Sakura-jima and Kagoshima side sections (I) and (II), 0.395 and 0.405 nautical miles in length respectively, had the diameter of 1.6 inches and had an armour sheath composed of ten 300-mil diameter iron wires, of tensile strength = 25 tons per sq. inch. Again, the double-core intermediate type line used in the middle section (II), 1.012 nautical miles in length, had the diameter of 1.3 inches, the armour sheath being made up of sixteen 175-mil diameter iron wires, of tensile strength = 30 tons per sq. in. The sectional area and the breaking tensile strength of the iron sheaths were as follows :—

Line.	Sectional Area.	Tensile Strength.
Double-core Shore-end Type.	0.706 sq. inch.	17.6 tons.
„ Intermediate Type.	0.387 „	11.6 „

As will be seen from figs. 32, 37, and 38 the cable crossed the deep northern portion of the Kagoshima channel, whose banks have steep declivity and whose bottom, generally muddy and favourable for the laying of cables, was 50 to 75 fathoms in depth.

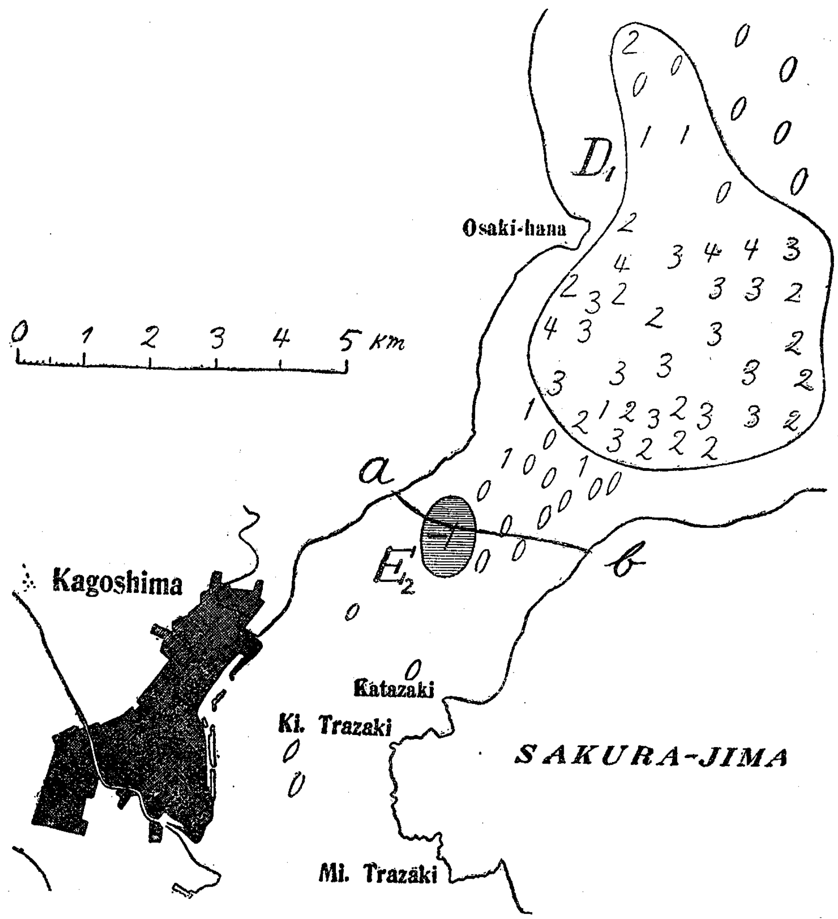
14. Damage to the Cable. On the day of the Sakura-jima eruption, Jan. 12th, 1914, the cable functioned without hinderance till about 2 P.M., when the telegraphic operation was suspended, the island being then nearly deserted and the Sakura-jima terminal post and the neighbouring houses burnt by the hot lava fragments. On trial the next morning the communication was found cut off. The interrupted cable was left in the damaged condition for nearly 3 years, till Dec. 1916, when the cable laying steamer Okinawa-Maru was dispatched to the scene of disturbance for examination. Although the pumice and ashes had been precipitated to a thickness of over 1 foot, the cable terminal, buried sufficiently deep in the ground, was found intact, thereby indicating the submarine location of the point of damage. The latter was ascertained to be at the distance of 0.577 sea-mile from the coast of Sakura-jima, where the intermediate type cable was torn apart obviously by a powerful tension, and the iron wires of the armour sheath were stretched some 3 mm. and then broken, there being no contorsion of the line and no scratching of the outside surface as would have been the case, had the damage been due to a cross breaking, for example, caused artificially by anchor casting. There was also no indication of the cable having been buried by the volcanic débries to any considerable extent, as it was pulled up without ex-

Fig. 37. Diagram showing the Water Depth (in fathoms) along the Submarine Cable between Kagoshima and Sakura-jima.



B......Kagoshima (W.) End. **C**......Point of Cable Fracture.
A......Sakura-jima (E.) End.

Fig. 38. Chart of the S. W. Portion of the Inner Kagoshima Bay, showing Changes in the Depth before and after the Sakura-jima Eruption of 1914.



ab......Submarine Cable.
D$_1$......One of the portions of the bay where the bottom was depressed more than 1 fathom.
E$_2$......One of the elevated portions of the bay bottom.

The figures indicate the amount of change of the water depth, in fathoms, plus (+) when augmented, and minus (−) when lessened.

periencing much resistance (tension). It is to be remarked that the cable was broken, not at the steep banks of the Kagoshima strait, but at the flat bottom about one-third of the width from the coast of Sakura-jima.

The cable was repaired by substituting a new intermediate-type line for the length of 1,111 metres, between the two points P and Q, 530 and 1,567 metres distant from the Sakura-jima and the Kagoshima ends respectively. What was remarkable was the fact that, apart from the fracture at the point C (fig. 37) the old pulled-up portions of the cable, CQ and PC, were found somehow damaged and incapable of transmitting electic current. On stripping off the armour sheathing, the core lines and the serving were found cut off, at first the two together at short distances, then the serving only, at longer intervals with increase of the distance from the point of fracture. This internal damage was ascertained to extend from the latter for the distances of 58 and 167 metres toward the Sakura-jima and the Kagoshima sides respectively.

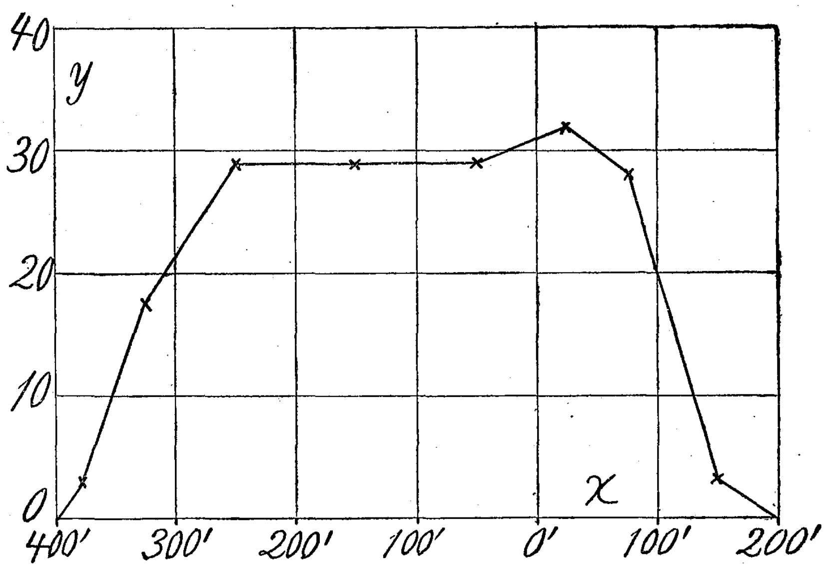
	Sakura-jima side.	Kagoshima side.
Core and Serving broken together.	20 places	26 places.
Serving only broken	46 ,,	168 ,,

The average interval between the successive core or serving breakage was, according to Tables V and VI, on the whole constant and equal to 1.7 feet for the distances of 102 and 319 feet from the point of cable fracture toward the Sakura-jima and the Kagoshima ends respectively, as follows :—

Direction.	Successive Length.	Mean Interval between successive points of breakage.	N=Number of breakage for the length of 50′
Westwards from the Point of Fracture C.	117′.9 } Sum, 319′.3	1′.84 } Average, 1′.7	27
	103.9	1.68	30
	97.5	1.58	32
	57.6	2.74	18
	18.0	18.0	28
Eastwards from the Point of Fracture C.	46.9 } Sum, 101.8	1.56 } Average, 1′.7	32
	54.9	1.77	28
	88.0	14.7	3.4

The frequency ($=N$), or the number of breakage for the length of each 50 feet, was thus approximately 30 for the distance of 420 feet about the point of fracture, the decrease being thereafter very quick. (See the illustration in fig. 39.).

Fig. 39. Diagram showing the Frequency of the Core and Serving Breakage of the Submarine Cable.



{x=Distance, in foot, from the point of Fracture.
{y=Number of Breakage for every 50-foot Length.

15. Effect of Electric Discharge. The cable was also affected electrically by the Sakura-jima eruption which was accompanied by marked display of lightnings from among the smokes; there being found a trace of a powerful electric discharge at the distance of 1,020 metres from the Sakura-jima end, where the serving in the cable was charred black to the size of a pea.

16. Cause of Cable Fracture. From § 14 it will be seen that the cable was torn apart as the result of a strong tension which existed locally for the extension of only $58+167=265$ metres about the point of fracture, the breaking of the core lines and the serving at numerous places being evidently the antecedent effects produced by the application of the same force. The exact moment of the cable fracture can not be ascertained. But most naturally we are led to connect the effect in question with the destructive earthquake shock at $6\frac{1}{2}$ P.M. on the 12th (January, 1914), which was followed about $1\frac{1}{2}$ hours later on by small *tsunami* (tidal waves). The latter caused some damage in the hourbour of Kagoshima, but was insignificant along the other parts of the coast of the Kagoshima bay, being probably the result of the formation of vertical disturbances of the sea bottom in the immediate vicinity.

The fracture of the cable was probably not the direct effect of the earthquake shock itself. Thus, suppose a portion *ab* (fig. 40) of the cable to be more or less buried in the sandy or muddy material of the sea bottom, while the adjacent portion *bc* was suspended in the water. If the direction of the earthquake motion, of intensity $=a$ mm/sec.^{2} be parallel to the cable, the destructive force at *b* would be equal to

$$P=\frac{W}{g}\times a,$$

where W is the weight of the free portion *bc*, and *g* the acceleration due to the gravity. The cable, of the intermediate type, would be broken if P becomes equal to the tensile strength, namely, 11.6 tons. In that case we have

$$W=gP\times\frac{1}{a}=9800\times 11.6\times\frac{1}{a}.$$

If $a=2000$ mm./sec^2. and 3000 mm./sec.^{2}, W becomes respectively 58 and 34.8 tons. But, as the weight per mile of the intermediate-type cable was 5.6 tons, these values of W correspond to the length of 10 and 6 miles, being much greater than the whole length of the cable. In other words, the fracture in the manner here assumed would be impossible, although the direction of the strong earthquake motion was in reality approximately parallel to the extension of the cable.

On the other hand, the earthquake very likely produced, or was followed by the formation of, a vertical displacement, or a horizontal displacement, or displacements in the two directions combined, at the sea bottom. (1), As a simple case of a vertical displacement, let us suppose the sea bottom, *abc* (fig. 41), originally plane, was partly upheaved and partly depressed and converted into a curved form *a d b e c* (fig. 42). The cable, formerly in contact with the sea bottom, would be stretched into a sort of chord across the curve, *dc*, and might be broken by tension, if buried or otherwise fixed at the two ends *d* and *c*. (ii), with regards to the horizontal displacement, the portion of the sea bottom, *ac*, might have suffered an elongation, in which case the cable would naturally be broken by tension. That there took place some disturbances of the sea-bottom of the nature here supposed at the time of or soon after the severe earthquake is very probable, as the latter was followed by a *tsunami*. Further, the great Sakura-jima eruption (1914) was attended by a subsequent depression of the ground, which was specially marked in the Inner Kagoshima Bay. In fact the bottom of the latter was generally depressed from ½ to 4 fathoms, with the exception of the two isolated portions where the ground was elevated to the amount of 1 to 3 fathoms; the submarine cable under consideration having been laid just across one of these elevated areas, (fig. 38). Again, the different trigonometrical points in Sakura-jima and about the Kagoshima bay were more or less displaced horizontally; the change at the N. and N.W. parts of the island being much greater than along the coast of Kagoshima and amounting to 2.62 to 4.52 metres, directed toward the N.E. or the N.*) From these facts it may be concluded that the bottom of the northern part of the Kagoshima strait, across which the cable had been laid, was subject to pronounced vertical changes combined with the elongation movements in the horizontal direction.

Diagram illustrating the Tension Effect on the Submarine Cable (*ac*).

Fig. 40.

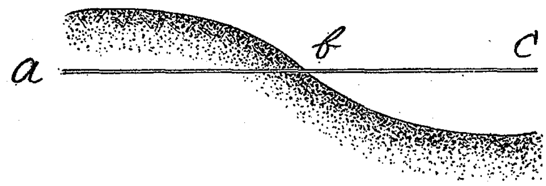


Fig. 41.

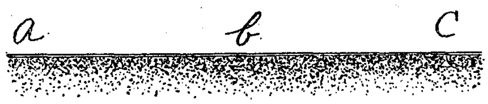
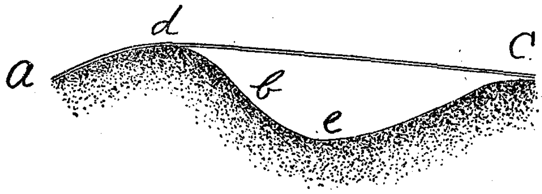


Fig. 42.



Now with regards to the action of a strong tension along a submarine telegraphic cable, the first effect will be to untwist slightly the outside iron wires, thereby pressing tightly the inside serving. The latter and the thin copper core wires, subject to stretching, willt hus be virtually clamped at several points along the length of the cable under tension and prevented from sliding within the armour sheath. As the result the serving and the core wires will be cut at numerous places one after the other with the increase of the tension, whose application may be supposed to be gradual. This process goes on till the iron sheath wires are finally torn apart. Such was probably what took place with the cable between Kagoshima and Sakura-jima under question. The average interval between the successive points of breakage of the serving and the core was 1.7 feet, being a little longer than the length of the armour sheath corresponding to one complete convolution of the constituent iron wires, which was equal to about 1.3 feet.

*) See the Bulletin, Vol. VIII, Nos. 2 and 4.

From the existence of numerous breakage points in the core and the service it is to be inferred that the sea-bottom changes which exerted the tension along the cable was formed gradually. Had the application of the tension been instantaneous, the cable would have been broken at a single place, without damaging the material inside the armour at several points.

As will be seen from fig. 33, the iron wires of the sheath, each of diameter = 175 *mil*, were first drawn out a little with an appreciable reduction of the diameter and were then broken. From fig. 35, which illustrates the damage done to the core, it will be seen that the gum-covering was also drawn out and contracted before the breaking of the thin copper wires.

17. Cables between Kagoshima and Onejime. In May 1910 two telegraph cables were laid across the outer Kagoshima bay between the town of Taniyama 8 km. to the south of the city of Kagoshima and the town of Onejime on the coast of the province of Osumi. The submarine lines run in the direction of N. W.—S. E. Although they are at the nearest distance of only about 5 km. from the S. W. coast of Sakura-jima, they received no damage from the recent volcanic and seismic convulsions, due doubtless to the absence of the marked sea-bottom disturbances in the bay to the south of Sakura-jima.

18. A Case of Non-seismic Cable Fracture. The breaking at several points of the serving and the core is probably not limited to the case of the Sakura-jima earthquake under consideration, but may *always* take place when a submarine telegraphic cable is broken by tension. This was exemplified in the course of the repair work on the intermediate type cable in the Tsugar strait (between Aomori and Hakodate) in 1910, which had been laid in 1890, and partly much buried.* While the cable, whose sheathing was composed of 12 iron wires of 0.175 inch diameter, was being hauled up, it was broken by a tension of 9 tons near the wheel about 15 feet distant from the paying-out drum. The portion, which fell into the sea, had to be abandoned and could not be examined. But, for about 40 feet of the paying-out drum end of the broken cable, the serving and the core were found cut to pieces, varying from 0.5 to 4 feet in length.

*) The details of the repair work were kindly communicated to me by Dr. Inada in a letter under the date of July 9, 1920.

Table V. Damage to the Core and Serving of the Kagoshima and Sakura-jima Cable on the Adjacent Sakura-jima Side of the Point of Fracture.

(* 1 shaku = 0.994 foot.)

Interval.*	Damage.	Interval.	Damage.	Interval.	Damage.
shaku		shaku		shaku	
1.1	Core broken.	1.3	Jute broken, Core intact.	1.0	Jute broken, Core intact.
1.5	Jute broken, Core intact.	1.7	Core wire broken.	1.5	,,
1.3	Core broken.	1.0	Jute broken, Core intact.	1.6	,,
2.0	,,	1.3	Core wires broken.	1.0	,,
1.1	,,	1.4	Jute broken, Core intact.	2.9	,,
1.6	,,	1.4	,,	0.6	,,
1.1	,,	2.1	,,	2.0	,,
2.3	,,	1.6	Core wires broken.	1.1	,,
1.5	,,	1.8	Jute broken, Core intact.	4.0	,,
1.3	,,	1.2	,,	0.8	,,
1.8	,,	3.7	Core wires broken.	1.2	,,
4.5	Jute broken, Core intact.	3.0	Jute broken, Core intact.	1.2	,,
2.0	,,	1.1	,,	4.8	,,
1.6	Core broken.	1.6	,,	2.0	,,
1.2	Jute broken, Core intact.	1.6	,,	16.0	,,
1.0	Core wires broken.	1.2	,,	18.0	,,
1.9	,,	0.9	,,	6.0	,,
1.5	,,	1.4	,,	22.0	,,
1.8	,,	1.2	,,	2.0	,,
1.7	Jute broken, Core intact.	0.9	,,	24.0	,,
1.2	,,	2.0	,,	(Thereafter no more damage.)	
0.8	Core wires broken.	2.4	,,		
0.9	Jute broken, Core intact.	2.9	,,		

Table VI. Damage to the Core and Serving of the Kagoshima and Sakura-jima Cable on the Adjacent Kagoshima Side of the Point of Fracture.

Interval.	Damage.	Interval.	Damage.	Interval.	Damage.
shaku		shaku		shaku	
1.3	Core and Jute broken.	1.2	Core contracted.	2.1	Jute broken, Core intact.
1.9	,,	1.9	Jute broken, Core intact.	1.15	,,
1.7	,,	1.7	,,	1.5	,,
1.7	,,	1.2	,,	2.4	,,
2.2	,,	1.9	,,	1.7	,,
2.2	,,	2.3	,,	2.6	,,
1.4	,,	3.2	,,	2.4	,,
2.4	,,	1.0	,,	1.0	,,
1.0	,,	1.6	,,	1.2	,,
2.0	,,	2.0	,,	1.5	,,
1.0	,,	1.6	,,	1.1	,,
1.6	,,	1.7	,,	1.7	,,
1.6	,,	2.7	,,	1.9	,,
7.7	(Not examined.)	1.7	,,	1.3	,,
		2.1	,,	2.3	,,
1.6	Core contracted.	2.7	,,	0.6	,,
2.8	Core and Jute broken.	1.7	,,	1.1	,,
2.7	,,	2.2	,,	1.5	,,
4.1	,,	1.6	,,	1.2	,,
1.7	,,	2.3	,,	1.6	,,
2.0	,,	1.7	,,	2.2	,,
1.3	,,	1.3	,,	1.5	,,
1.1	,,	1.7	,,	1.7	,,
1.5	,,	2.1	,,	2.4	,,
1.5	,,	1.7	,,	1.8	,,
1.5	,,	1.6	,,	0.8	,,
1.7	Jute broken.	2.1	,,	2.3	Jute and Core broken.
2.4	Core contracted.	1.5	,,	1.7	Jute broken, Core intact.
1.8	,,	1.5	,,	2.0	,,
3.0	,,	2.4	,,	1.3	,,
1.7	,,	2.6	,,	2.6	,,
1.1	,,	1.5	,,	1.6	,,
1.4	Core and Jute broken.	2.3	,,	1.2	,,
1.7	,,	1.4	,,	1.2	,,
1.1	,,	2.1	,,	1.5	,,

Table VI. Damage to the Core and Serving of the Kagoshima and Sakura-jima Cable on the Adjacent Kagoshima Side of the Point of Fracture.

(Continued.)

Interval.	Damage.	Interval	Damage.	Interval.	Damage.
shaku 1.4	Jute broken, Core intact.	shaku 1.9	Jute broken, Core intact.	shaku 2.1	Jute broken, Core intact.
2.0	„	2.2	„	1.1	„
1.9	„	2.0	„	1.2	„
1.5	„	0.8	„	1.1	„
2.1	„	1.4	„	1.7	„
1.4	„	2.0	Jute and Core broken.	2.0	„
1.7	„	2.3	Jute broken, Core intact.	1.7	„
2.0	„	2.1	„	2.2	„
1.3	„	1.1	„	2.1	„
2.4	„	1.1	„	1.9	„
1.8	„	1.2	G.P. turned yellow, Core wire broken.	0.9	„
1.2	„	2.4	G.P. charred black, Core broken.	4.0	„
1.1	„	1.2	Jute broken, Core intact.	1.4	„
1.7	„	1.2	„	2.0	„
2.2	G. P. cracked.	1.7	„	2.0	„
1.2	„	1.3	„	2.4	„
1.3	„	1.7	„	4.0	„
1.7	Jute broken, Core intact.	1.3	„	1.5	„
1.1	Jute and Core broken.	1.4	„	1.8	„
1.6	Jute broken, core intact.	1.6	„	2.5	„
1.4	„	1.4	„	2.0	„
1.8	„	1.3	„	1.3	„
1.9	„	1.2	„	1.1	„
1.8	„	1.5	„	2.9	„
1.3	Jute and Core broken.	1.6	„	2.6	„
2.5	Jute broken, Core intact.	1.4	„	2.3	„
1.2	„	1.3	„	4.2	„
1.4	„	1.2	„	3.2	„
1.9	„	1.5	„	2.5	„
2.6	„	1.6	„	2.3	„
1.6	„	1.4	„	5.4	„
1.5	„	0.8	„	6.0	„
1.1	„	0.9	„	18.0	„
1.8	„	1.3	„		
2.1	„	1.7	„	(Hereafter not examined.)	