14. *Heights of Tunamis and Damage to Structures.*

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Introduction. During our inspection tour of the districts that were seriously damaged by the present Tunami we noticed the existence of a close relation between the height of the sea water and the geographical feature of the region affected by the seismic sea waves, and also that there are certain limits to the heights reached by the water at which it could cause the destruction of houses. For the purpose of making clear these points it was necessary to accurately explore the inundated area and measure the heights attained by the sea water. In the circumstances, plane table surveys and levelling surveys were resorted not only to determine the heights of the water, but also to map the geographical features of the inundated regions; the results of which form the subject of this paper.

In the regions that were washed by the Tunami the heights to which they reached could be told by the indisputable traces left on the walls and windows of the houses. The marks could be found everywhere even nearly two months or more after the occurrence of the Tunami.

Plane table survey. We began this study by constructing maps to large scales, such as 1/1000∼1/2000. In this work a plane table 40 cm ×40 cm and an alidade (not provided with telescope) were employed. Generally speaking, in filling in the geopraphical details of a triangulation survey by straight forward plane table work, provided care is taken to obtain good intersections, it is known that the accuracy is such that no point will be displaced by an appreciable amount on the plane: i.e., that the accuracy is restricted by the scale of the map being prepared. The following is the source of error that need at all to be considered.

The errors due to inaccurate centering of the table may be very appreciable for large scale maps on such occasions as when point a, representing station for the instrument on the map, happens not to be immediately above the corresponding point A on the ground. Thus, if d be the horizontal displacement of a from the vertical through A in a direction at right angles to AB, and if the length of line $AB=L$ although that of its representation AB on the plan $=l$, then the error in the direction ab is d/D radians, and the displacement of b from its true position relative to a is ld/L. The maximum value of d is hardly likely to exceed 0·3 m at most, so that the displacement is negligible—provided it is less than 1/100 cm on the map, unless of course L/l is less than 3000. Thus, in this work the table was centered to an accuracy of within 0·1 m.

Levelling. The relative heights of the various points to be measured were determined with a "Y" level. The inclination of the line of collimation corresponding to the displacement of the bubble by one division (2 mm) is 1 minute of angle. Level staves of 4 m length were used.

In beginning the levelling, the datum plane, that is the plane of zero height must be assumed. The mean of the heights of high and low tide was chosen for the datum plane.

As the sea at the time of the Tunami was practically at mean sea level, the heights measured in this way do not differ much from the heights actually attained by the sea water.

To determine the geographical features, a sufficient number of points were chosen, and their positions marked on the map being constructed on the plane table, after which the heights of these points above the datum plane were determined by levelling. Strictly speaking, the datum plane does not agree with the so-called mean sea level, so that the heights of the points thus determined do not agree with the heights given on ordinary maps, but at this discrepancy does not affect the relative heights of the various points on the ground measured, there is no objection to the method adopted.

The determination of the heights reached by the sea water were, as already stated, based on marks, such as stains left on the walls, seaweeds adhereing to trees, debris washed up on low hills, etc. The heights of these marks above the datum plane were sometimes measured in two stages. First, the height of the point lying just at the foot of the mark was measured and, secondly, the height of the mark above that point was measured. The sum of these two heights gives that actually attained by the sea water.

Where the Tunami was destructive, such marks, naturally were difficult to find, owing to houses being either washed away or demolished, whence it follows that in the study of damage to houses caused by the Tunami, the present surveys were confined to places where the seismic sea waves were not very destructive.

Contours. In this work, the contour lines are only close enough to give a general idea of the geographical features of the inundated area, and to enable the reader to see to what heights the present Tunami attained. On gentle slopes the contours are drawn for every half meter, while for steep places they are figured on the map for every meter or more.

The surveys, which begun in May, ended in June, 1933, taking 33 days in all. During this period the work was carried out at the following fourteen places: Kamaisi, Ureisi, Hongô in Tôni, Ryôri, Sirahama in Ryôri, Hongô in Yosihama, Ryôisi, Tadakosi, Nezaki, Ogati, Ooduti, Ando, Hosoura, Yamada. The results obtained in these places will now be briefly described.

In the Figures 13∼26, the boundaries of the inundated areas are shown with cross-hatchings and the area within which the houses were destroyed with close dots. The numerals in Italics near the small plain circles are heights of the measured points from the datum plane, while those in larger and heavier type are the heights reduced to sea level of the waves attained at the points whose positions are indicated by black circles.

Kamaisi. Kamaisi is an important sea port on the Pacific coast of N.E. Japan. This port sustained serious damage in the present Tunami. The section of the town near the sea was inundated and the busiest part of it destroyed by the fire which broke out immediately after the onslaught of the Tunami. The sea water here attained a height of about 4 m. Marks left by the Tunami were found on almost every house that remained standing, be-

Fig. 1. Map of Kamaisi and Ureisi. 1/50,000. The areas which are enclosed by thick lines were surveyed.

Northern: Kamaisi.
Southern: Ureisi.

ing particularly prominent on the houses near the eastern end of the town, where the surveys for this region were made.

Although in the map (Fig. 13), the reduced heights of the sea water differ, though slightly from one another, it may be said that the water at the time of the Tunami was practically at the same level everywhere. Close examination shows however that the heights of the water were greater at points near the seashore than at points remote from it, which is probably due to the fact that the Tunami in its progress through narrow streets and alleys between houses and other objections lost some of its force.

Ureisi. In Ureisi, a hamlet adjacent to the town of Kamaisi (see Fig. 1), houses near the seashore were destroyed by the Tunami, which left only a few that had partially collapsed. The water, here rose to a height of 3·80 m above the datum plane. The ground on which stood the demolished houses is comparatively low ground, being less than 2 m, so that the sea water must here risen more than 1 m above the ground. (See Fig. 14.)

Hongô in Tôni. The Tunami was very destructive in this village, (see Fig. 2). Except one, every house was washed away, while one-third of the inhabitants were killed or missing. The sea, at the time of the Tunami rose to a height of 11 m. According to the levelling survey of the water heights, based on marks left on the cliffs surrounding this village, the surface of the inundating water was almost of the same level as in the case of Kamaisi. According to eyewitnesses, the Tunami after first invading the southern margin of this hamlet, rushed in, taking a circuitous route. This was clearly confirmed upon drawing the contours based on our levelling survey. As the southern part of this village is rather lower than the northern, it could be seen that the water washed first the southern margin of this village. (See Fig. 15.)

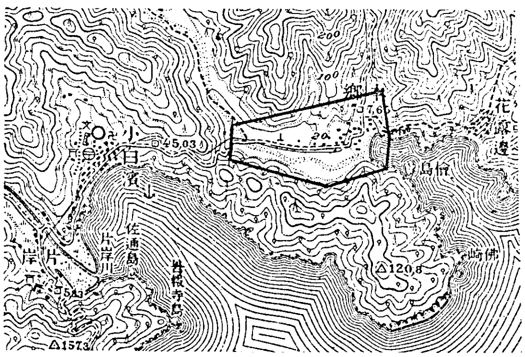

Fig. 2. Map of Hongô in Tôni. 1/50,000. The area which is enclosed by thick lines was surveyed.

Ryôri. As will be seen from the maps, Figs. 3 and 16, the plain is narrowed by the cliffs near the seashore. All houses lying on ground lower than 4·5 m were either washed away or totally destructed. The most landward point of the inundated area shows a height of 6·59 m. It was acertained that the sea water could demolish houses if the height of the water from the ground exceeds 2 m.

It is noteworthy that in the eastern part of the river embankment which runs NW to SE, (see Fig. 16), the level of the water was much lower than that in the western part of the same embankment, the reduced height being about 4 m. This is probably because the eastern flat part is wider than the western, though the former is narrower where it touches the sea. The water, at the time of the Tunami, rushed through this narrow part, and spreading over this area was consequently reduced in height. On the cliffs near the seashore, wave marks were found at such heights as 9·61 m, 8·21 m, and 7·40 m above the datum plane, suggesting that the water had heaped up at the mouth of this plain.

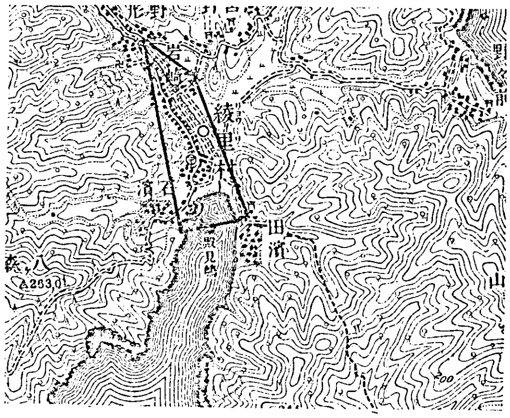

Fig. 3. Map of Ryôri. 1/50,000. The area which is enclosed by thick lines was surveyed.

Sirahama in Ryôri. The maximum height of the sea water in the present Tunami was attained in this hamlet. It was 28·69 m above datum plane. The geographical features of this region are shown in Fig. 17, from which we can see that this region is a V-shaped valley opening to the sea. The water gradually increased in height as it proceeded inland.

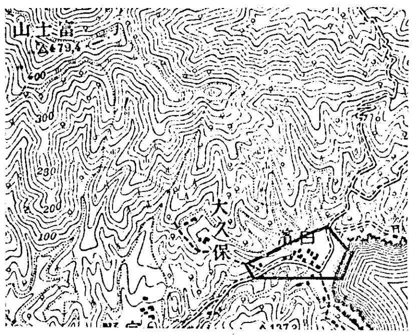

Fig. 4. Map of Sirahama in Ryôri. The area which is enclosed by thick lines was surveyed. 1/50,000

Hongô in Yosihama. The water, which was very high here, reached 16·77 m at maximum. Fortunately, there were only a few houses on the low ground. The heights reached by the water were more or less alike throughout this region. (See Fig. 18.)

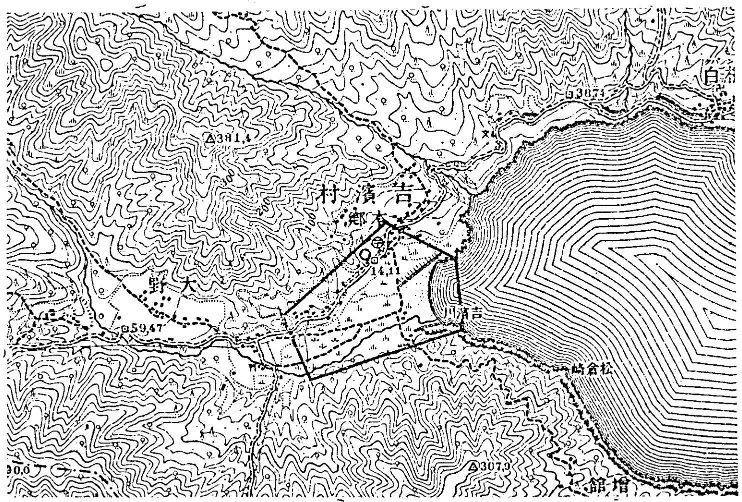

Fig. 5. Map of Hongô in Yosihama. 1/50,000.
The area enclosed by thick lines was surveyed.

Ryôisi. The geographical features of this village are similar to those of the village of Hongô (Tôni) (see Figs. 6 and 19). The houses on low ground were all washed away. The heights of the water measured at various points showed practically the same values, so that the Tunami was of nearly uniform height at all points of the village, not being higher in some part than another.

Tadakosi. The height of the tunami here was about 7 m. Almost

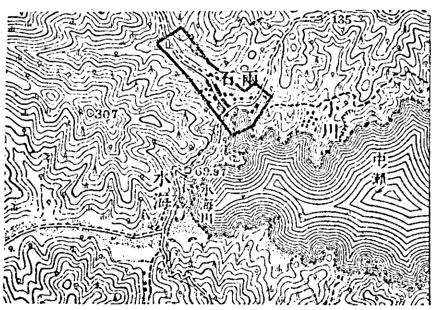

Fig. 6. Map of Ryôisi. 1/50,000
The area which is enclosed by thick lineswas surveyed.

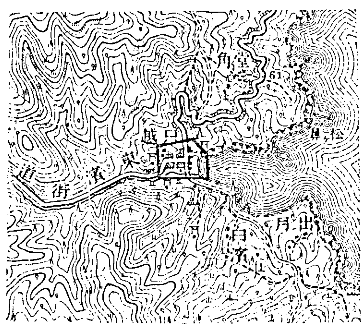

Fig. 7. Map of Tadakosi. 1/50,000.
The area enclosed by thick lines was surveyed.

every house on ground lower than 5 m. above mean sea level were washed away. The height attained by the Tunami was somewhat greater inland in the inundated area than at other points. (See Fig. 20.)

Nezaki. Here the heights reached by the water were comparatively great, being 18·04 m at maximum. Houses on low ground, lower than 12 m above mean sea level, were demolished. The water decreased in height as it proceeded landward. (See Fig. 21.)

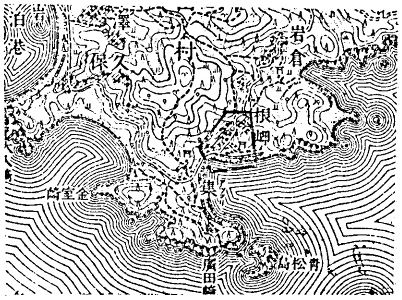

Fig. 8. Map of Nezaki. 1/50,000. The area which is enclosed by thick lines was surveyed.

Ogati. This town is situated at the head of Ogati Bay. (See Fig. 9.) The main street runs parallel to the seashore. The Tunami inundated this town to a height of about 4·5 m at its eastern extremity, while at its western extremity, which is the head of the bay, the water rose 6 m. Between these two extremities, the heights showed gradual increase as one goes landward. (See Fig. 22.)

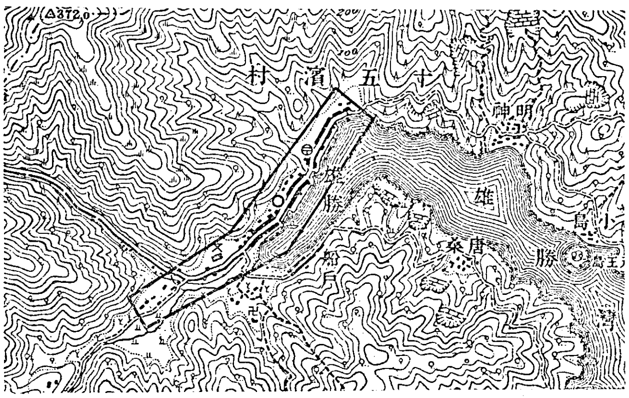

Fig. 9. Map of Ogati. 1/50,000. The area which is enclosed by thick lines was surveyed.

Ooduti. All houses near the seashore were destructed. The reduced heights of the water was about 3·5 m. As the ground was very flat the inundated area was comparatively large. The houses which were destroyed were those on low ground, less than 2 m above mean sea level. (See Fig. 23.)

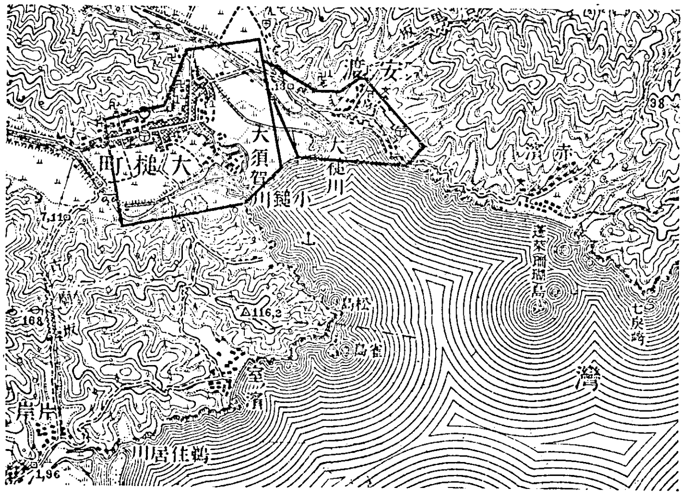

Fig. 10. Map of Ooduti and Ando. 1/50,000.
The areas which are enclosed by thick lines were surveyed.
Eastern : Ando. Western : Ooduti.

Ando. This village, which lies next to Ooduti (see Fig. 10), sustained serious damage to it houses on the seashore. The maximum height attained by the Tunami was 3·4 m. (see Fig. 24.)

Hosoura. Hosoura is a town lying along a widely streched harbour opening to the north, (see Fig. 11). The present surveys were limited to a region lying to the east of the newly built railway. At the time of the Tunami, the water rushed into this harbour, washing the houses away in all directions. Measurementsshowed comparatively irregular distribution of the heights. The houses in this town proved unsafe for water higher than 2 m. (See Fig. 25.)

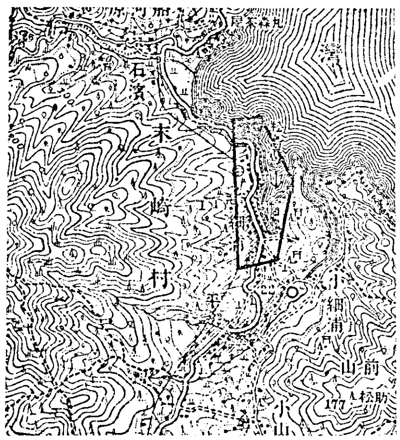

Fig. 11. Map of Hosoura. 1/50,000.
The area which is enclosed by thick lines was surveyed.

Yamada. Houses near the seashore were seriously damaged, while those in the southern end of this town, where the ground is very low and flat, were all washed away. The height of the lowest ground was found to be 1·17 m above mean sea level, from near which point the water rushed in. Where the houses were destroyed, the water probably reached 2 m and more. (see Fig. 26.)

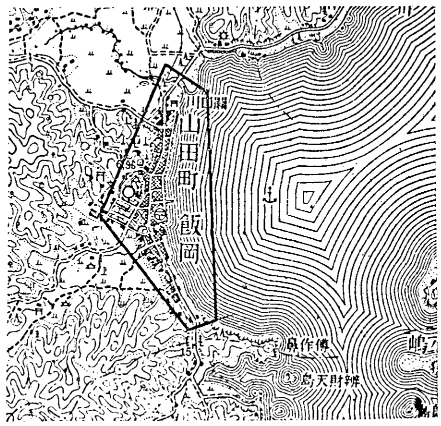

Fig 12. Map of Yamada. 1/50,000
The area which is enclosed by thick lines was surveyed.

Conclusions. The conclusions from the present surveys are as follows:

(1) The water does not always increase its height as it goes inland. Although along a V-shaped valley, such as Sirahama in Ryôri, the water increased in height considerably as it proceeded inland, in some cases it was found that the water decreased in height as it proceeded landward.

(2) The damage to houses, especially of the ordinary Japanese wooden type, both one and two-storied houses were partially damaged when the water attained to a height of 1·0∼1·5 m above the ground.

At water heights of 1·3 m, the houses that were not firm on their foundation began to float.

When the height of the water exceeded 2 m, the ground floor totally collapsed and the upper floor came down. Thus one-storied houses and tall houses of poor construction could not escape destruction.

The above stated facts apply only when the velocity of the water was not much greater than 10 m per second—the value was probable in the present Tunami. If the velocity is less than this, the houses can resist the oncaming waves as in the case of Ogati.

(3) The inclination of the ground, as Prof. Ishimoto points out, is an important factor that determines the velocity of the water, in which case, the velocity is a factor that is easily measurable.

In conclusion, the author's thanks are due to Prof. Ishimoto for his kind guidance and also to Messrs. T. Kodaira, T. Sugiyama, Y. Wada, and N. Arai for their valuable assistance throughout the course of this survey.

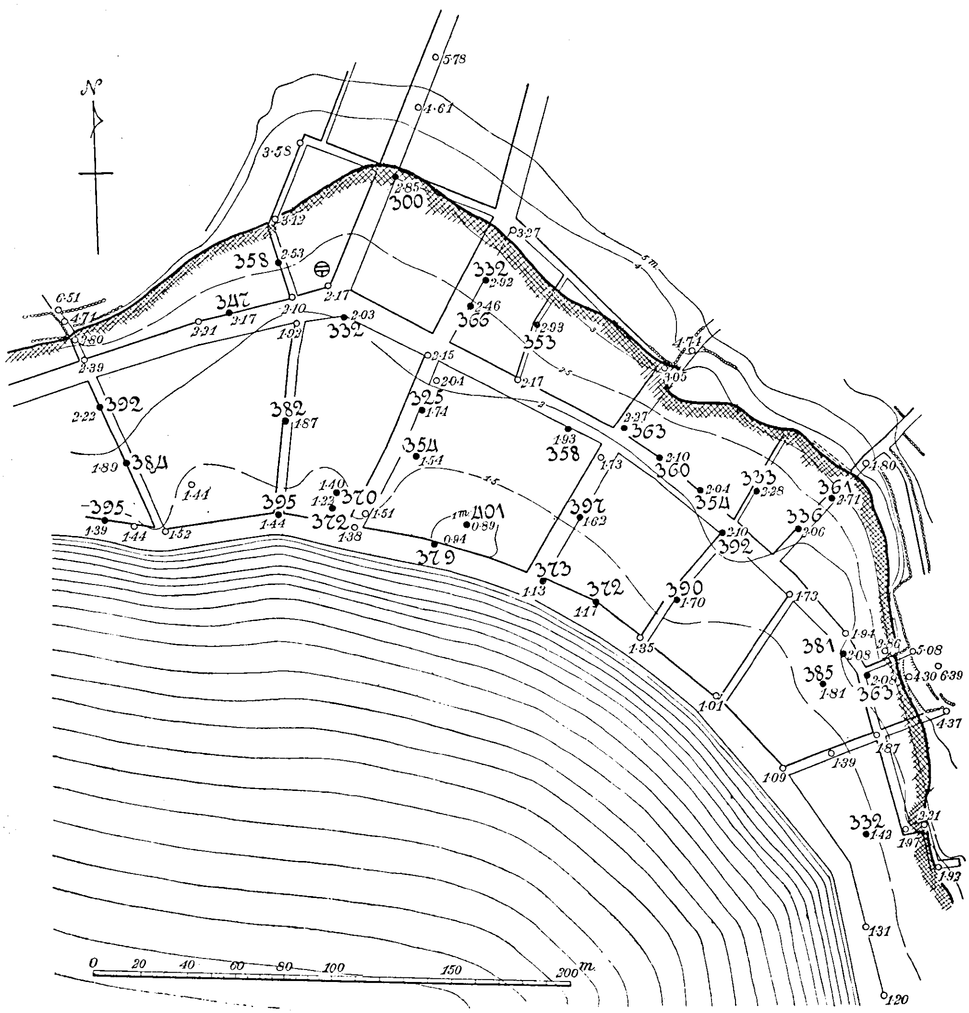

Fig. 13. Kamaisi. $\left(\frac{6}{19}\times\right.$ *the original map*$\left.\right)$

Numerals in heavier type are the reduced heights of the water in cm.

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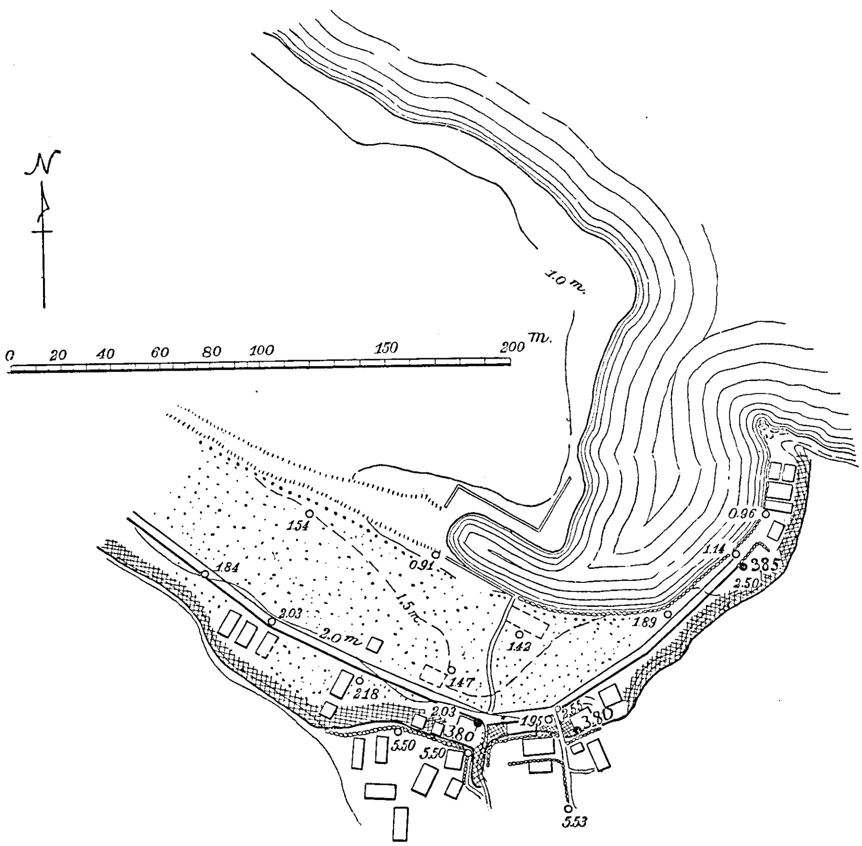

Fig. 14. Ureisi. $\left(\frac{1}{2}\times the\ original\ map\right)$

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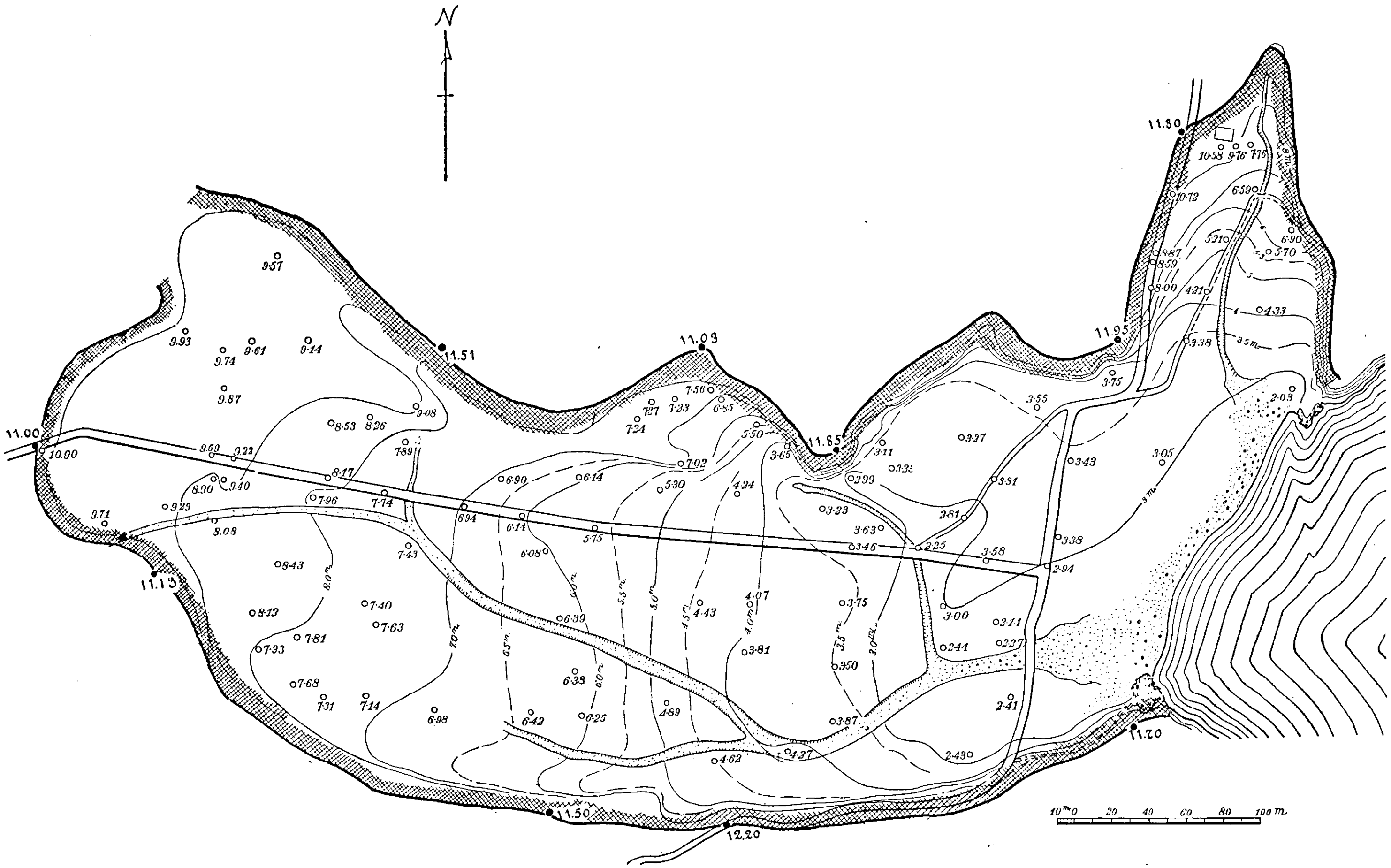

Fig. 15. Hongô in Tôni. $\left(\frac{15}{37} \times \textit{the original map}\right)$

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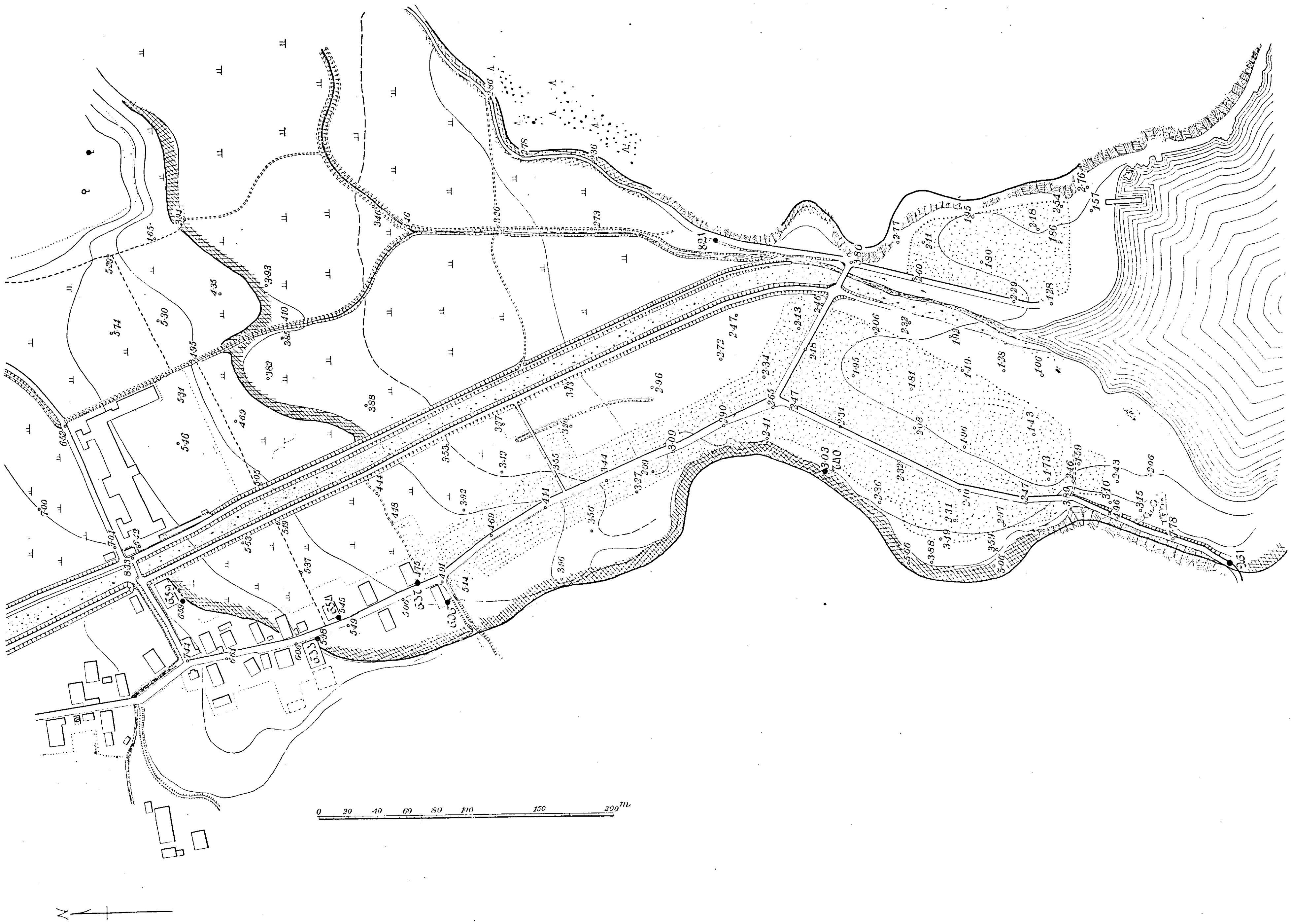

Fig. 16. Ryôri. $\left(\frac{10}{34}\times\right.$*the original map*$\left.\right)$

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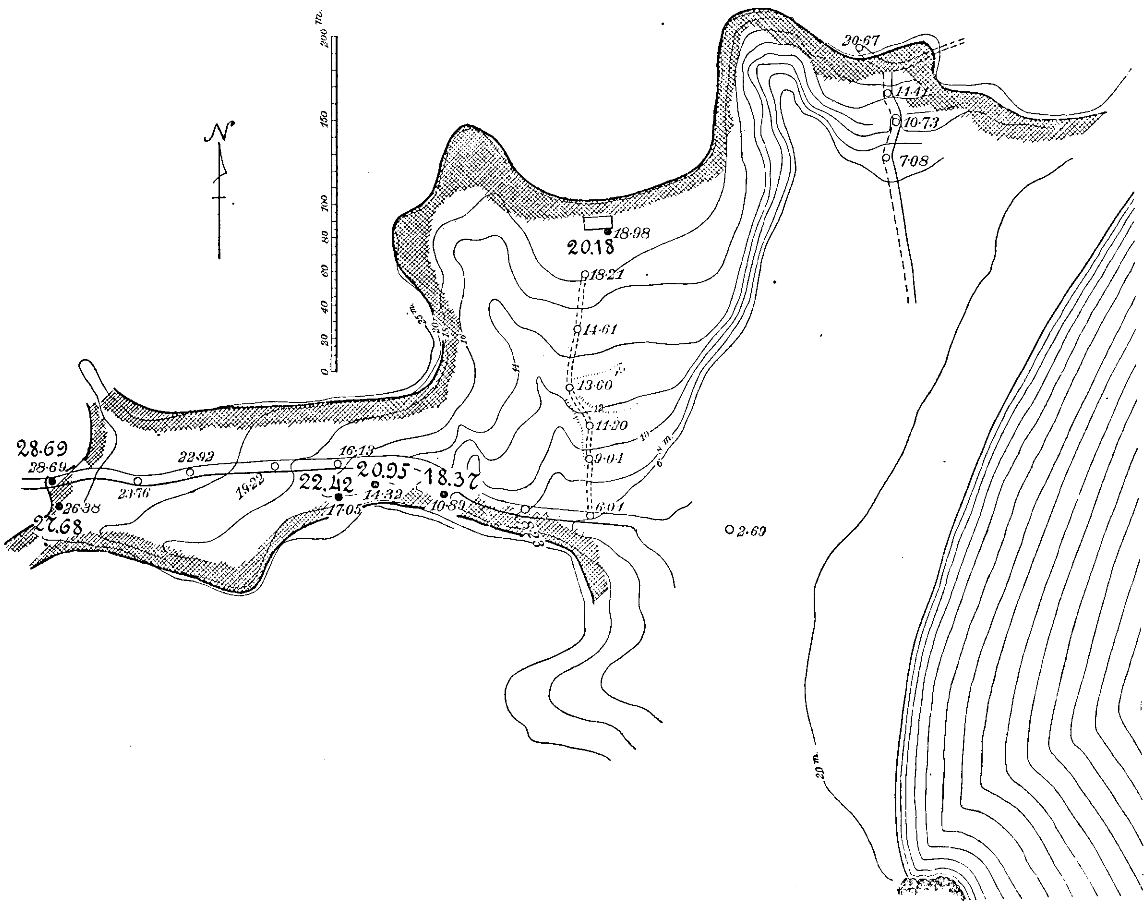

Fig. 17. Shirahama, Ryori-mura.

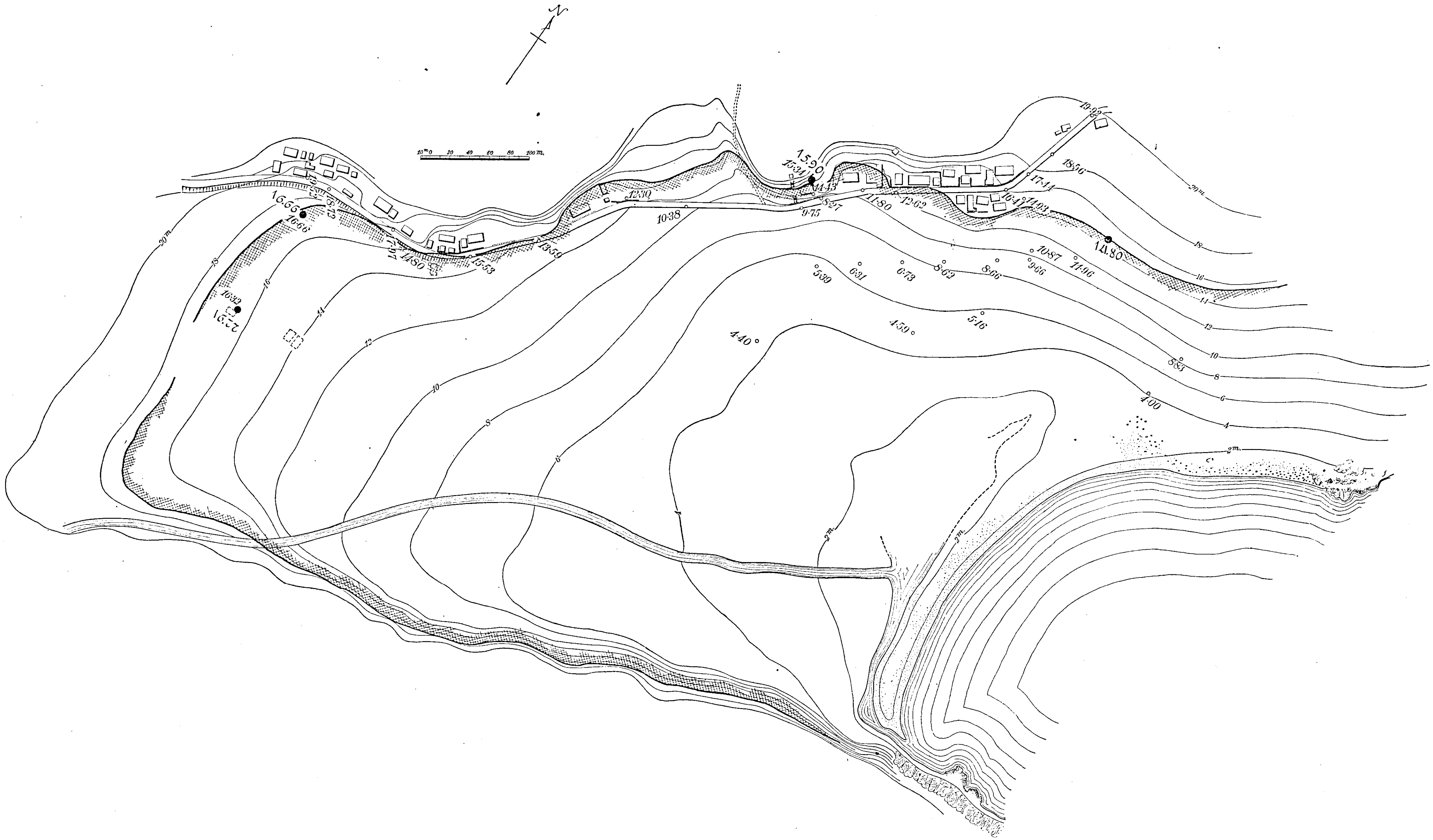

Fig. 18. Hongô in Yosihama. $\left(\frac{20}{63}\times\right)$ *the original map*

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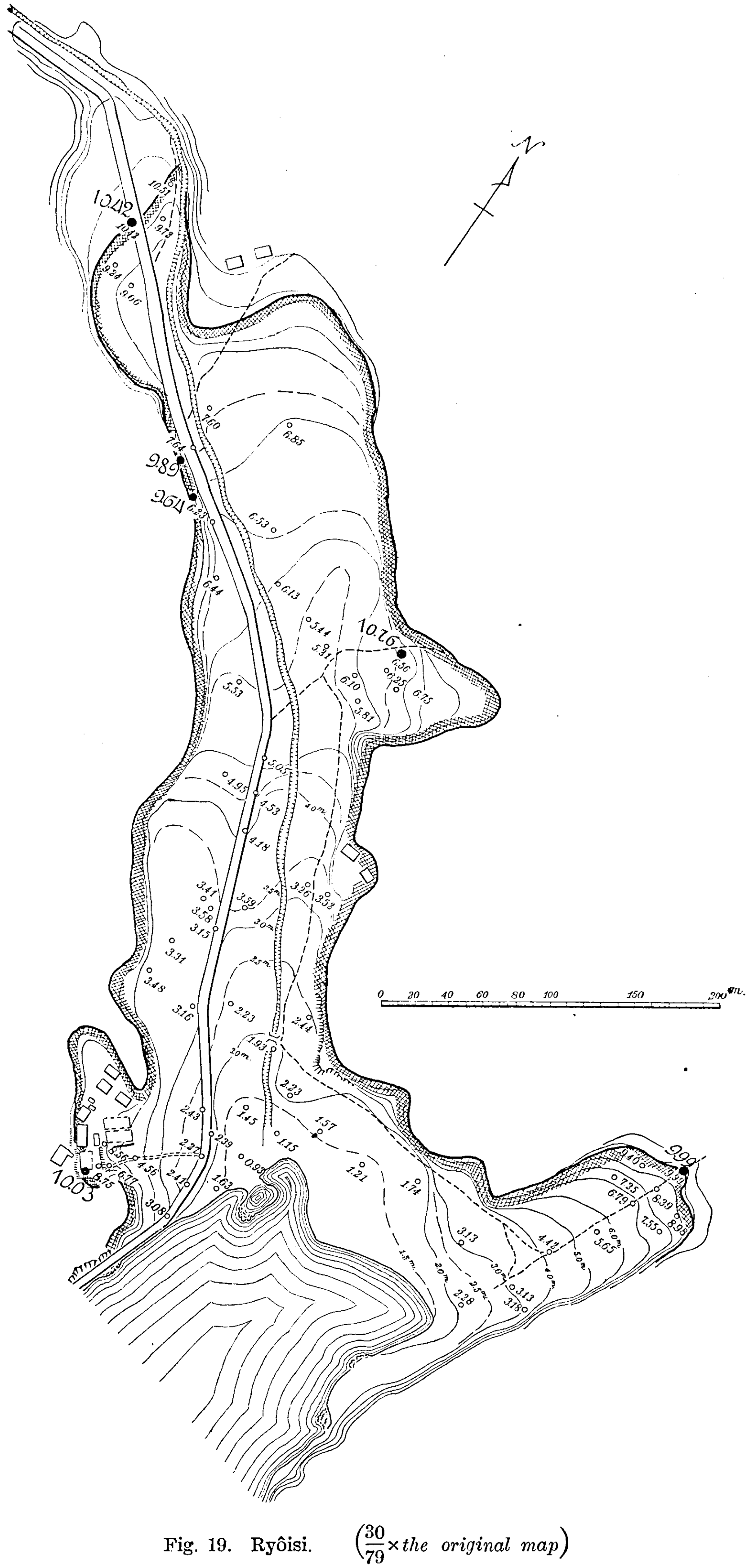

Fig. 19. Ryôisi. $\left(\frac{30}{79}\times\right.$ *the original map*$\left.\right)$

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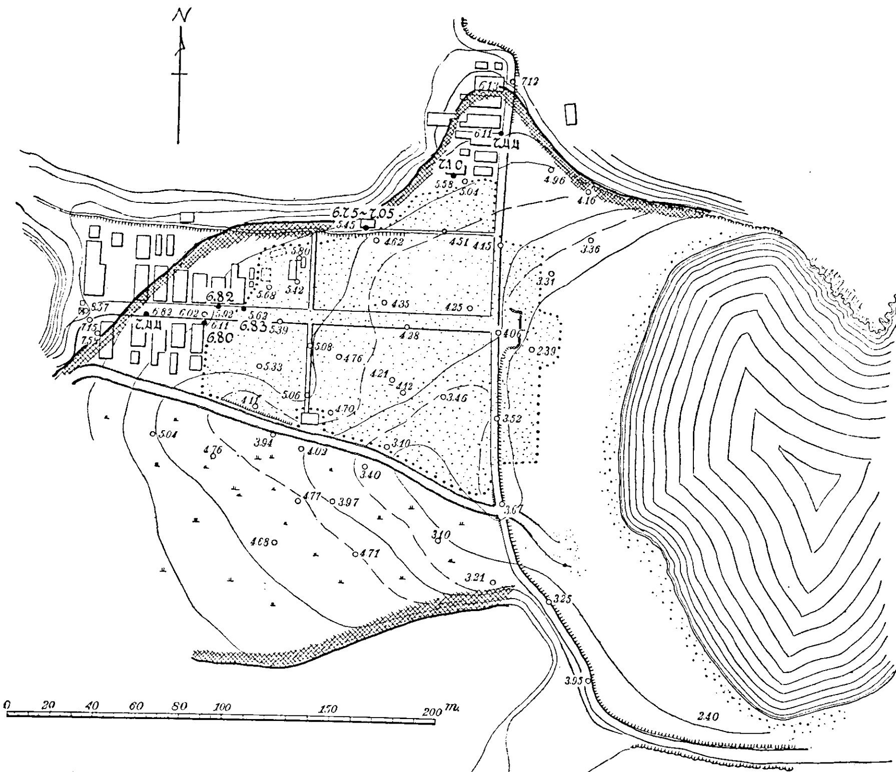

Fig. 20. Tadakosi. $\left(\frac{11}{40}\times \textit{the original map}\right)$

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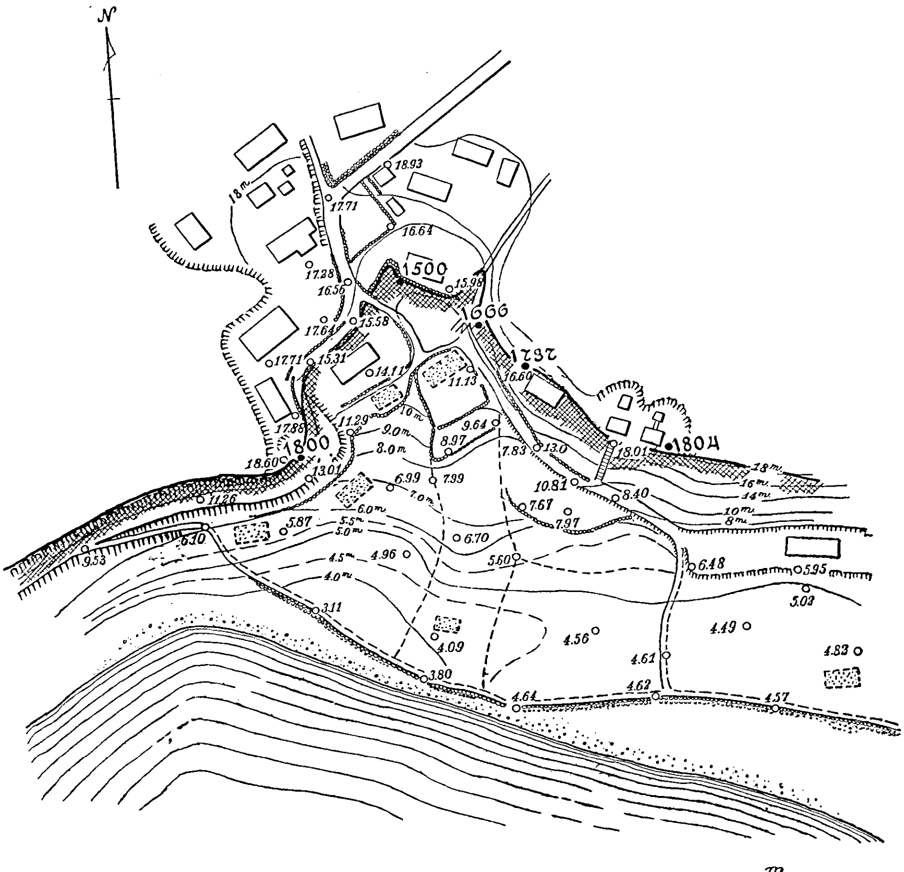

Fig. 21. Nezaki. $\left(\frac{3}{7} \times \text{the original map}\right)$

Numerals in heavier type are the heights of the water in cm.

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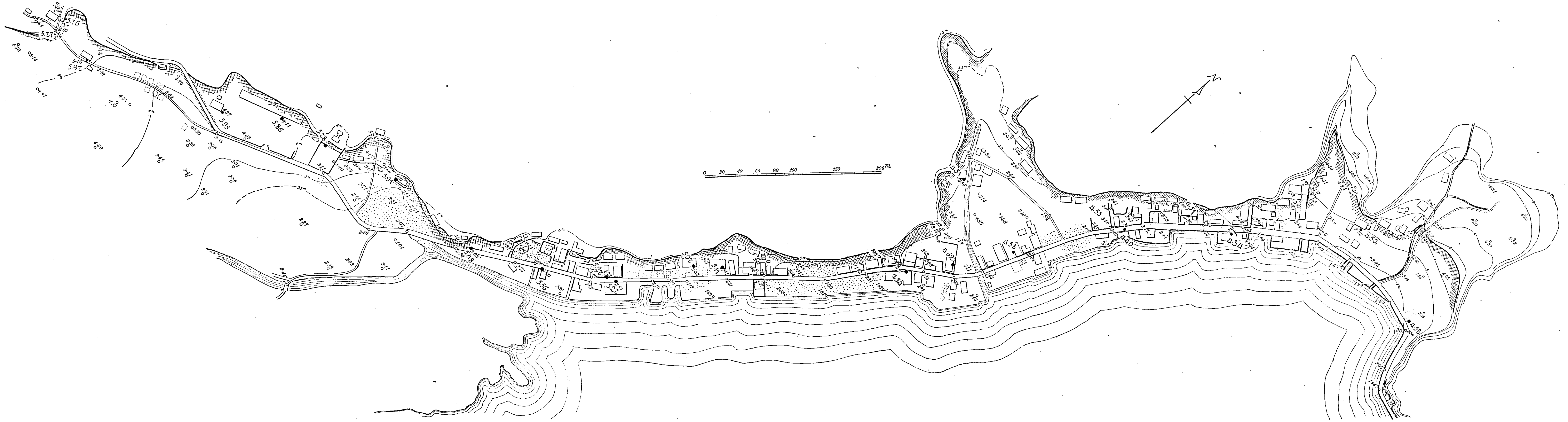

Fig. 22. Ogati.

Fig. 23. Ooduti. $\left(\frac{20}{77}\times \textit{the original map}\right)$

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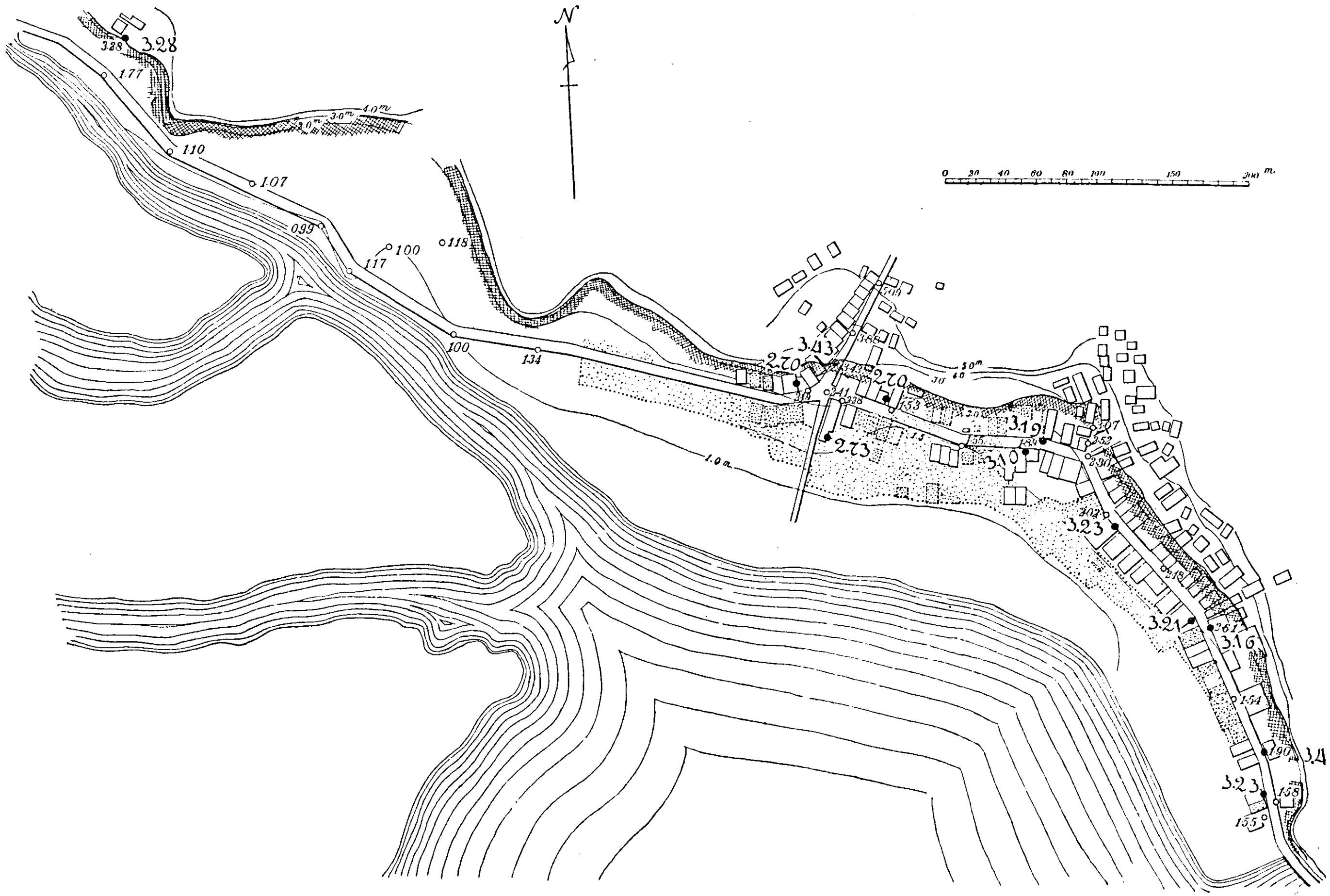

Fig. 24. Ando.

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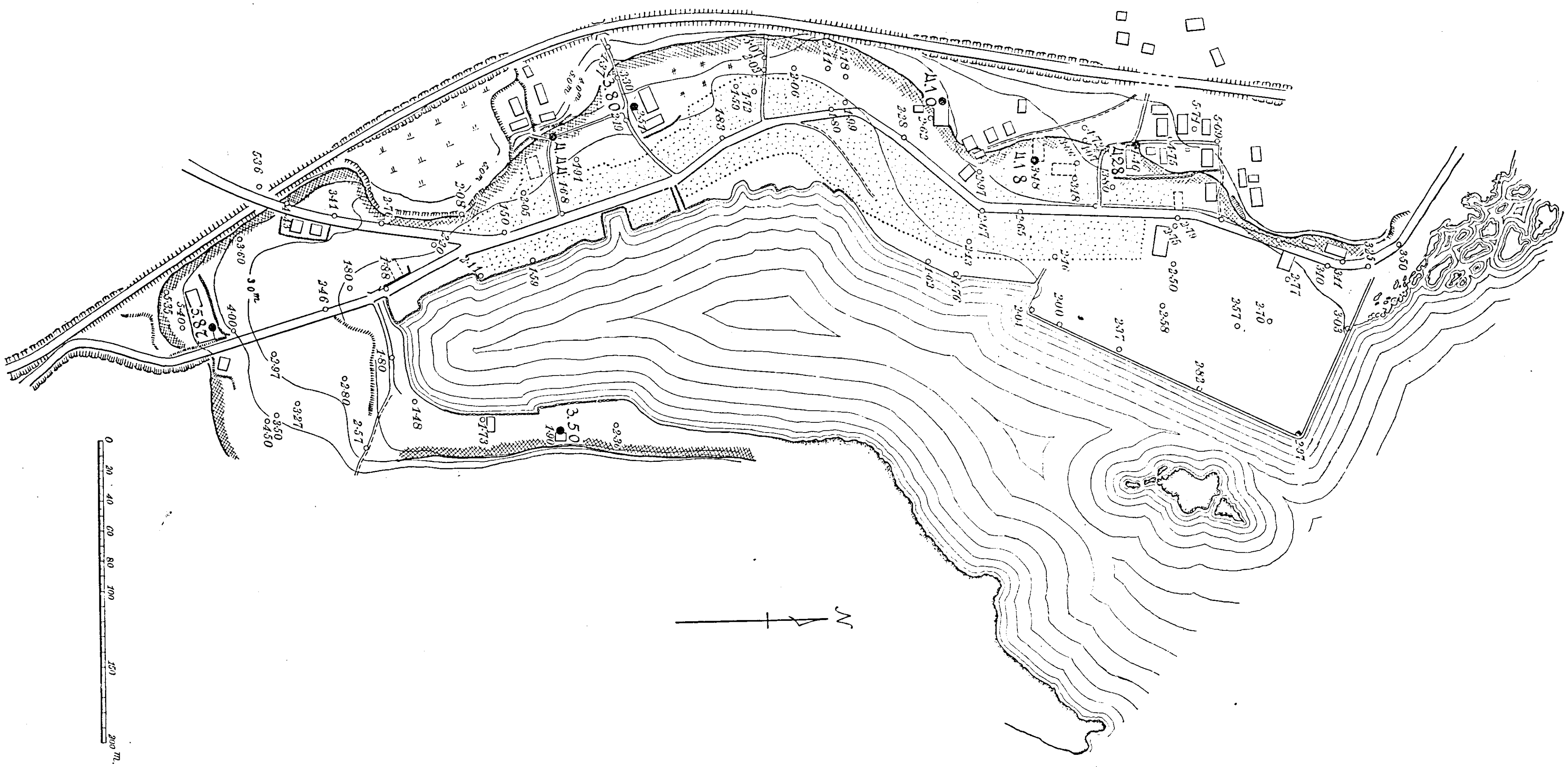

Fig. 25. Hosoura. $\left(\frac{30}{79}\times \textit{the original map}\right)$

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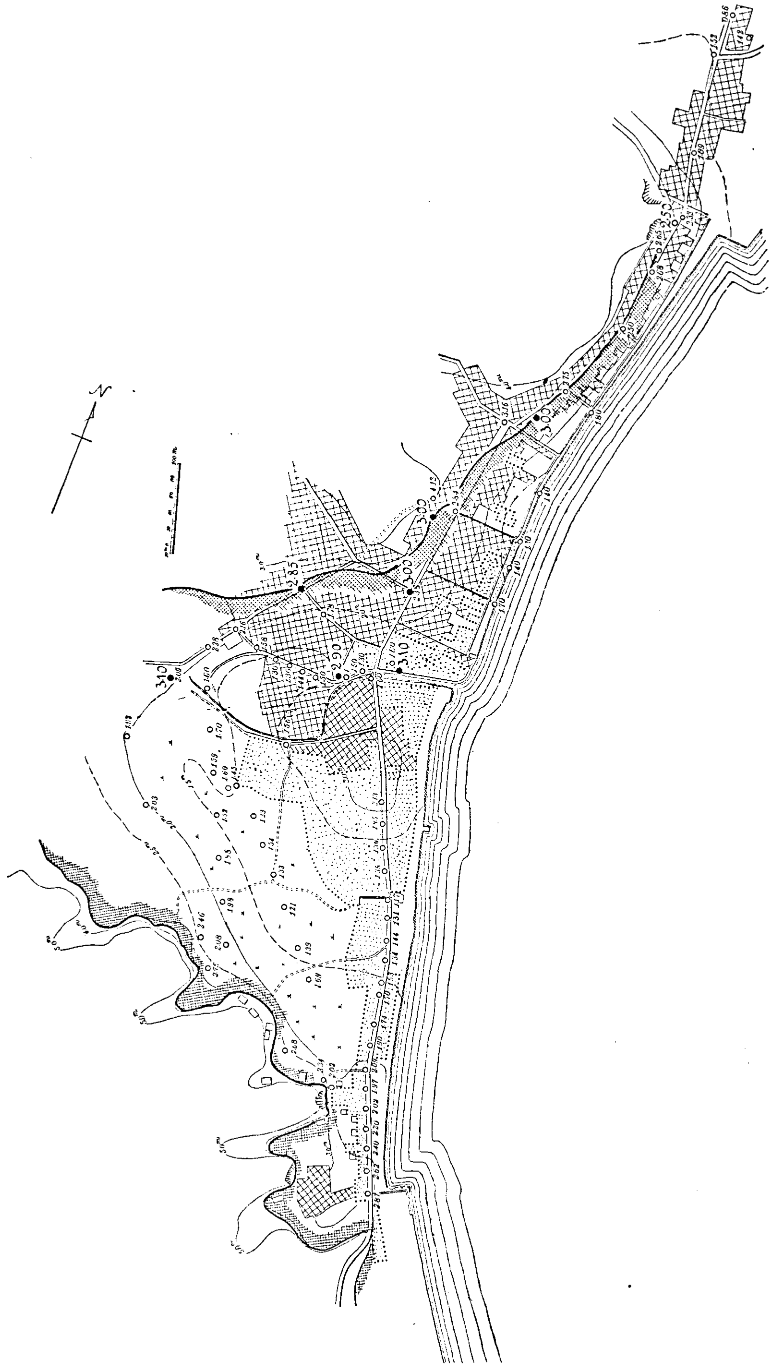

Fig. 26. Yamada. $\left(\frac{10}{45}\times \textit{the actual}\right)$

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14. 津浪の高さと構造物の被害

地震研究所　那　須　信　治

今回の津浪によりて被害を受けた地方を視察してゐた間に津浪の高さと地形及家屋の被害程度とには或る關係があることに氣が附いた．これ等の點を明瞭にするためには浸水區域と津浪の高さとを正確に知る必要が生じた，そこで平板測量と水準測量とによつて地形の測量及浸水の高さを正確に測定することゝした．

平板測量によつて 1/1000〜1/2000 の地形圖を作りそれに浸水區域を正確に書き入れた．測板の離心は 10 糎以下とした．

水準測量によつては地上の各測點の高さを潮汐干滿の平均海水面から測つた．又浸水高を測るには津浪の殘して置いた明瞭なる痕跡を見付けてその高さを矢張り平均海水面から測つた　斯くすることによつて津浪が或る地方で海岸から奥に進むに從つて高さを増すや否やを調べることが出來る．これには 1 目盛 (2 粍) 水泡が動けば角 1′ を示す“Y”レベルを用ひた．

測量は 5 月に始まり 6 月に終つた．その間 33 日を費して下記 14 箇所で行はれた，釜石，嬉石唐丹村本郷，綾里，綾里白濱，山田，大槌，安渡，細浦，只越，吉濱村本郷，兩石，根岬，雄勝．

附圖中浸水區域はクロス，ハツチングを以て示してある．白丸につけてあるイタリツクの數字は標高を示し肉太で黒丸の近くに附けてある數字は浸水の高さを海面から測つて出した價である．

等高線は浸水區域の地形及び水の高さを表はすに十分なる程度に止めてある．

此の測量結果より次の事が判つた．

(1) 津浪は浸水區域の一番奥の所では必ずしも標高を増すとは限らない．V 字型の谷に沿つては浸水點の標高は増す場合は確かにある．例へば綾里白濱の如きはそれである．然しある場合はこれと反對であることもある．

(2) 家屋の被害と浸水した高さを調べて見ると水が 1·0〜1·5 米の高さで家を浸すと家は大抵半壞程度に破壞される．又水が 1·3 米位になると土臺に密着してゐない家は浮き出す．

　水の高さが 2 m 以上になると 1 階は全く破壞され 2 階は地上に落ちる．1 階家及構造の弱い家は大概破壞を免れない．

　但し以上の事柄は水の速度が毎秒 10 米以下 (恐らく今回の津浪ではこの位であつたらう) の場合に就いて言ひ得ることで水の速度がこれよりも小さい場合にはもう少し高く浸水しても家の被害は輕少なこともある．今回の雄勝の場合がこの例と思はれる．

(3) 地面の傾斜が速度を決定するに必要な要素であるといふことは石本教授の指摘されたことであるが，もし然りとすれば此の様な測量によつて速度を推定することが出來ると思ふ．