15. *Relations between the Earthquake Damage and the Structure of Ground in Nagoya City.*

By Syun'itiro OMOTE and Setumi MIYAMURA,

Earthquake Research Institute.

(Read Nov. 21, 1950.—Received Dec. 20, 1950.)

1. Introduction.

Certain relations are likely to exist between the geologic structures of the ground at a place and the earthquake damage produced on it. The authors have investigated this problem, with special reference to the city of Nagoya which is one of the typical places in which the relations are manifested. The subsurface geologic structures in Nagoya are known by seismic prospectings which covered the large part of the city, and, on the other hand, the details of the distribution of earthquake damages wrought by the Tokaido Earthquake of Dec. 7, 1944 have been made fairly clear through the efforts of the municipal authorities. Consequently sufficient data are now available for the purpose of the present study.

2. Topography of Nagoya City.

The general topography of the city will been seen in Fig. 1. Generally speaking, the hilly grounds, which cover the eastern and northern parts of the city, gradually slope down towards south-west. The south-west part of the city consists mainly of paddy fields, which have expanded out year after year by reclamation. The history of expansion of these low-lands may be traced in Fig. 5, compliled by Mr. Ota as the result of his long investigations of it. (cf. §4.)

3. The distribution of earthquake damage.

Nagoya was attacked by a violent shock on Dec. 7, 1944 and a lot of houses were destroyed. Most of the original records by the municipal and governmental authorities which contained data as to the detailed statistics of the houses destroyed were unfortunately burnt down during the world War II fires. Fortunately some of the original records have escaped the fire, while others were prepared again by the said authorities. Consequently,

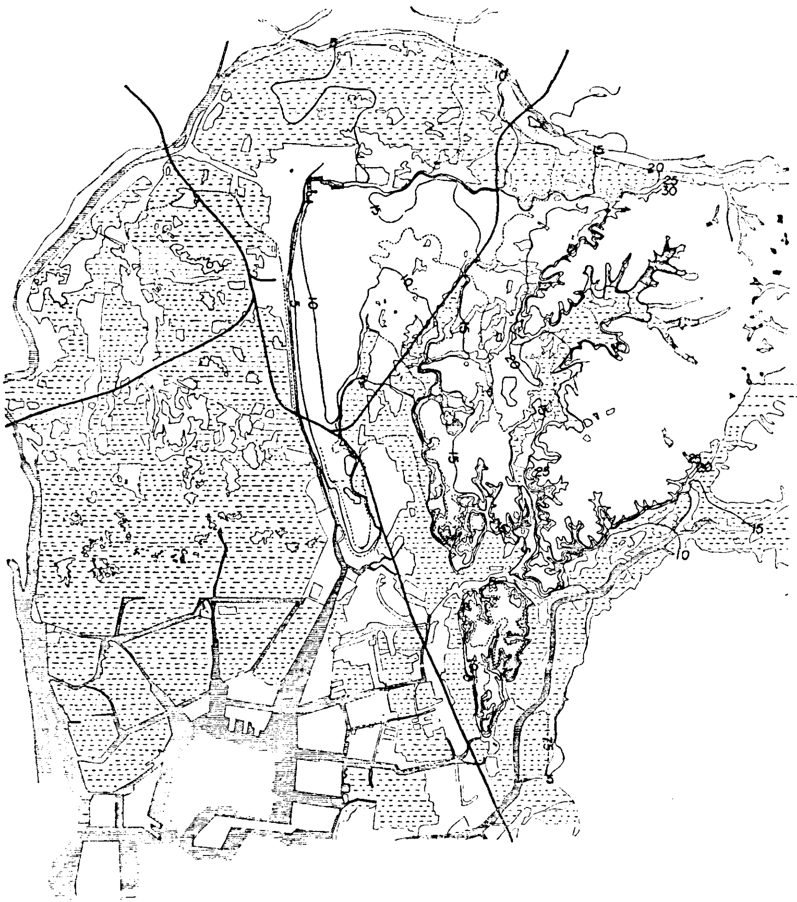


Fig. 1. General topography of Nagoya City.
N.B. : Paddy field.before 1900 A.D.

the distribution of destroyed houses has been made pretty clear throughout the whole city. A) The city is divided into 14 administrative divisions (*ku*), for each of which the damage rate *k* was calculated. *k* is defined as the ratio of (the number of the totally destroyed houses plus 1/2 of that of the partly destroyed houses) to (the total number of houses), both within the unit division under question respectively. Fig. 2 shows the distribution of the value of *k* thus calculated for the "*ku*" division. B) Each *ku* is divided into several subdivisions called "*ren-ku*", and the damage rate *k* for each "*ren-ku*" has been calculated, the result being shown in Fig. 3. In these figures, we see clearly that large damage rates are confined in some particular divisions. C) For the purpose of examining the distribution of the damage rate in the city in more datail, we further investigated the distribution in still smaller divisions "*tyo*" into which each "*ren-ku*" is divided. The damge rate with respect to each *tyo* is shown in Fig. 4. In the figure we see that the value of the damage rate for each *tyo* is by no means the same as that for *ren-ku* to which it belongs; some being very small while others very large.

4. The structure of ground within the city.

The subsurface geologic structure of Nagoya City was made clear by means of various methods. The geology of Nagoya is in general as follows:

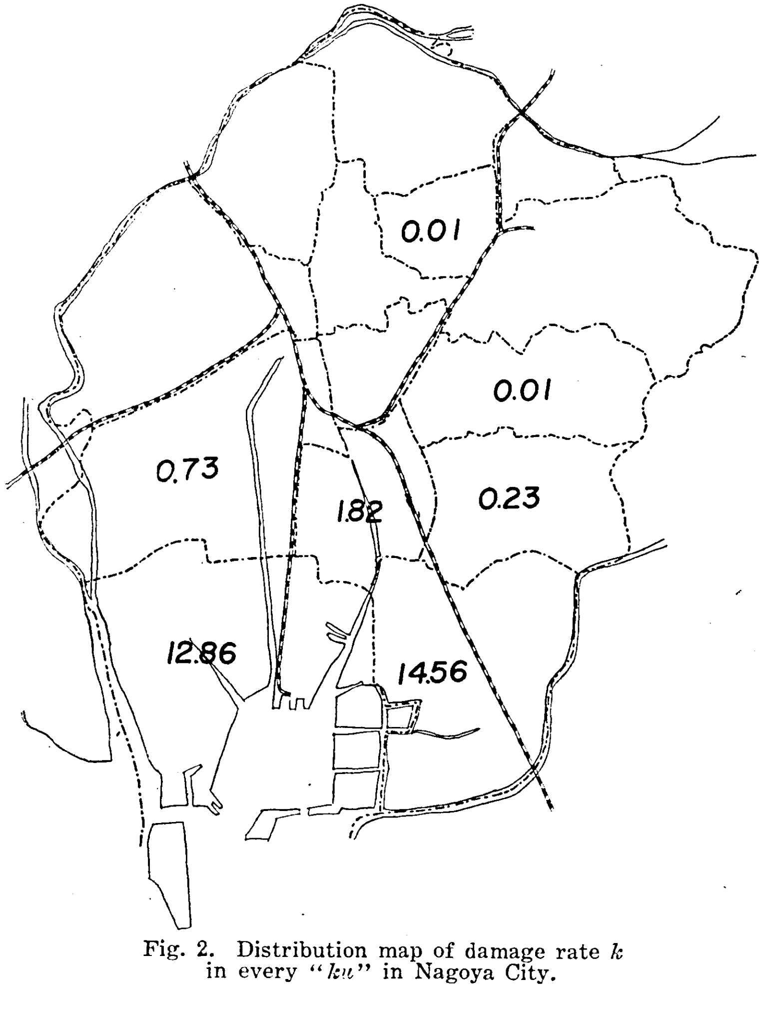


Fig. 2. Distribution map of damage rate k in every "*ku*" in Nagoya City.

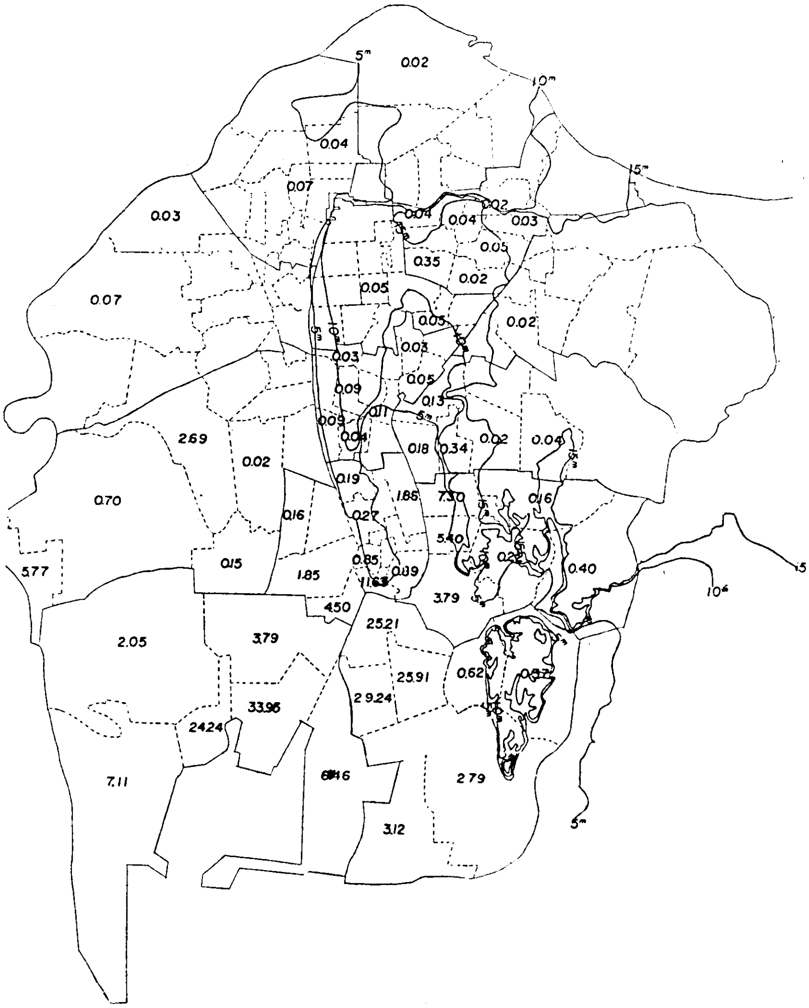
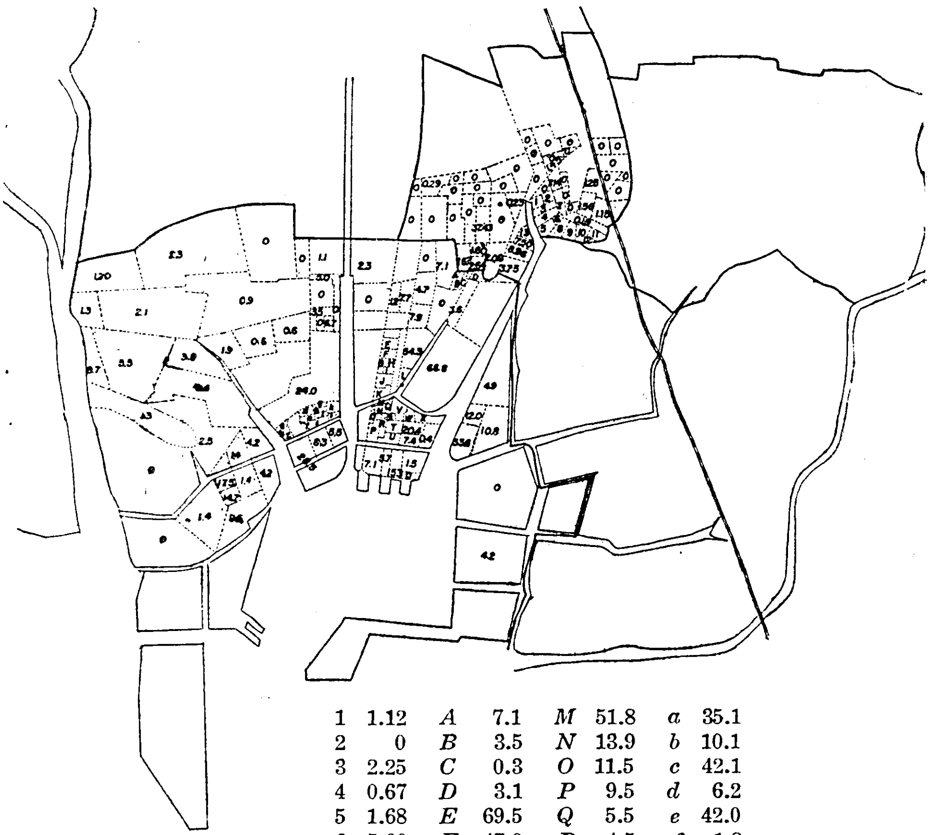


Fig. 3. Distribution map of damage rate k in every "*ren-ku*" in Nagoya City.

the hilly north-eastern part of the city is covered with a thick layer of alluvium. The thickness of the alluvium are deduced from the following source-materials :

i) The boring data. The columnar structures of the core borings carried out at 13 points in the city were available, but, to our great regrect, the description of the core samples was too inadequate to be useful to determine the boundary of geological formations.

Besides, since these borings were carried out to a depth of only 25 meters the base of the alluvium was not arrived at in the southwest part of the city. Thus these data could not be used for our present purpose.



1	1.12	*A*	7.1	*M*	51.8	*a*	35.1
2	0	*B*	3.5	*N*	13.9	*b*	10.1
3	2.25	*C*	0.3	*O*	11.5	*c*	42.1
4	0.67	*D*	3.1	*P*	9.5	*d*	6.2
5	1.68	*E*	69.5	*Q*	5.5	*e*	42.0
6	5.00	*F*	47.0	*R*	4.5	*f*	1.8
7	1.00	*G*	77.8	*S*	3.5	*g*	42.8
8	1.25	*H*	48.5	*T*	2.2	*h*	17.5
9	1.60	*I*	29.7	*U*	6.0	*i*	7.2
10	9.14	*J*	39.8	*V*	2.1	*j*	15.0
11	1.90	*K*	61.5	*W*	19.5	*k*	47.6
12	1.68	*L*	87.3	*X*	7.0	*l*	11.8
13	13.23						

Fig. 4. Distribution map of damage rate *k* in every "*tyo*" in Minato-*ku* and a part of Atuta-*ku*.

ii) The seismic data obtained by Prof. K. Sassa, Kyoto University. Seismic prospectings were carried out soon after the end of the World War II throughout the whole city by Prof. Sassa, Kyoto University. The results obtained afforded very useful materials concerning the subsurface structure of the city.

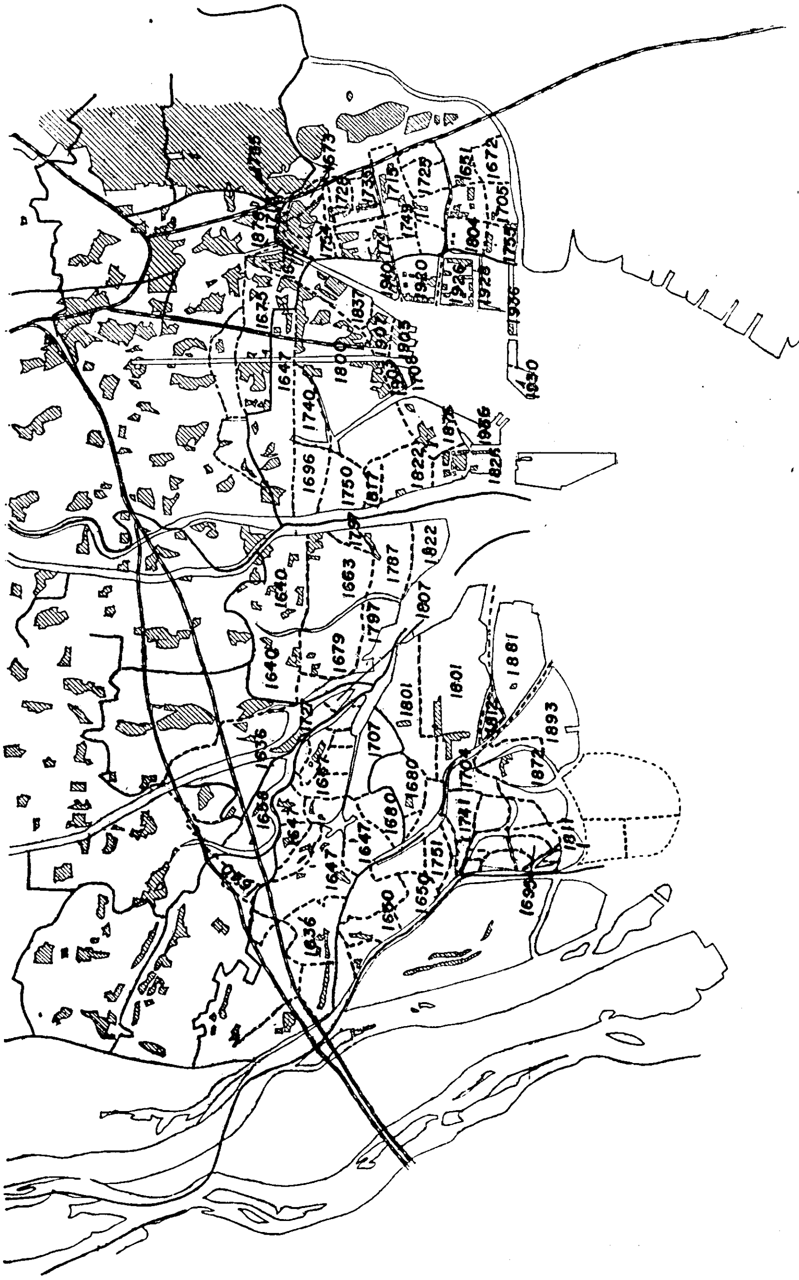


Fig. 5. Expanding history of reclaimed land in Nagoya and its vicinity.
(Compiled by Mr. Ota, Kinzyo Girls' College.)

iii) The seismic data by the Nippon Geophysical Prospecting Co. along the routes of the projected high speed railway lines. Seismic prospectings were carried out along the routes of the high speed railway lines which were projected to cover the city, and the geological structures thus revealed offer data, as to the subsurface structures of the city.

iv) The chronological study of reclamations. The area of the southwest part of the city has expanded gradually as the reclamations went on. Thanks to the studies made by Mr. Ota, the Kinzyo Girls' College, Nagoya, the chronological orders of these reclamations have been made clear, as stated above. (s. Fig. 5.)

Now taking advantage of these source materials the authors intended to get some informations concerning the subsurface structure of the city. Since these data were all furnished from independent sources, they are not without some contradictory points. In interpreting the results obtained by (ii) and (iii), the different characteristics of the respective strata were wholly attributed to the velocity difference of seismic waves in them. Consequently, the boundaries of layers as indicated by these data disagree with those geologically determined. The investigations of the materials (iii) showed the existence of upper alluvial layers, which furnished valuable data for the present study; but on the other hand they failed to reveal the depth of the deep boundaries of lower alluvial strata, and accordingly in some part in Minato -*ku*, the lower boundary of alluvium could not be decided clearly.

Looking at these data obtained from (ii) and (iii), we have become aware that the alluvium here is divided into two layers, the upper and the lower. The upper one has a thickness of a few meters or so and the velocity of seismic waves within it is about 200~500 m/s, while the lower one has much larger thickness and shows much higher value of the wave velocity. The upper one is considered to be made of reclaimed mud or sediments of very new ages and we shall call this "the upper alluvium". The lower layer has the velocity value of 1500 m/s, corresponding to the moderate value for the so-called alluvium and we shall call this "the lower alluvium".

The thickness of the upper alluvium. Consulting the geological sections derived from (ii) and (iii), the thickness of the upper alluvium differs very much at various places. Though the seismic prospectings covered the whole city with a fairly dense network, it could by no means be said that the data prepared are plenty enough for the contour map for the thickness of the upper alluvium to be drawn. Taking these points into account we prepared in Fig. 6 a map which shows the thickness of the upper alluvium.

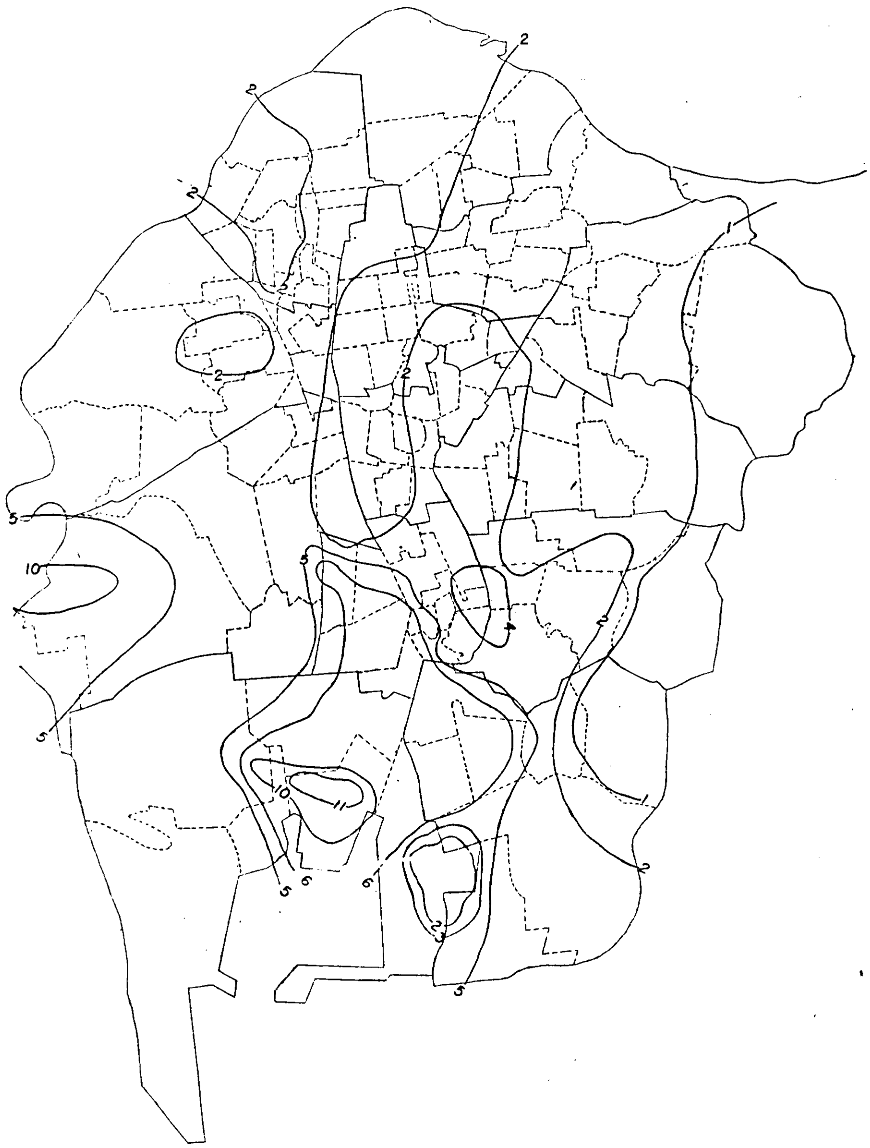


Fig. 6. Thickness of "the upper alluvium" in Nagoya City.

At first, the contour lines for every one meter were aimed at, but in some places this was not possible.

The thickness of the lower alluvium. Next, the thickness of the lower alluvium must be examined, because they have probably some close relationship to the earthquake damage. As was already stated, it was very difficult to correlate the layer succession, obtained by seismic prospectings, to that, defined from the geological point of view. As a rule, in the plain area of the southwest part of the city, the layer, in which the propagation velocity of P wave is higher than 2 km/sec. is as deep as 30~50 meters, while in the hilly regions the same velocity can be found even in the uppermost layer. From these reasons, the velocity of 2.0 km/sec. was attri-

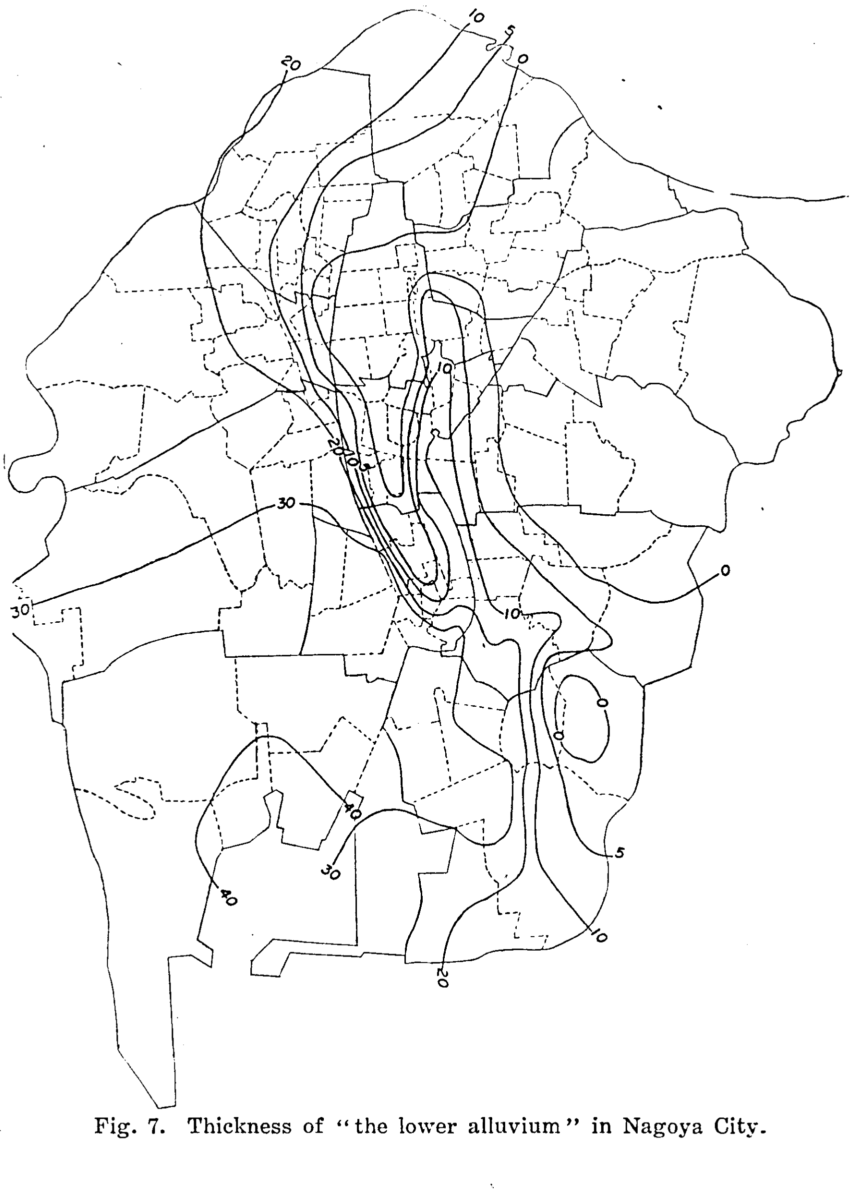


Fig. 7. Thickness of "the lower alluvium" in Nagoya City.

buted to the geological layer of the lower alluvium. The thickness of the lower alluvium within the whole city is shown in Fig. 7, by a family of contour lines.

From the above three figures (Figs. 5, 6 and 7) the general picture of the subsurface structure of the whole city may be obtained.

5. Relations between the earthquake damage and the structure of ground.

a) The earthquake damages and the topography. Comparing the topography and the earthquake damages shown in Figs. 1, 2 and 3, a close relation is found between them. On the hilly ground, the damage is very slight, while in the plain regions heavy damage is conspicuous. In Fig. 8 the mean topographic height of the respective *ren-ku* is plotted against the damage rate for the same *ren-ku* and from this diagram, it is quite clear, that on the hilly ground the damage is very slight, while in the low land the damage is conspicuous.

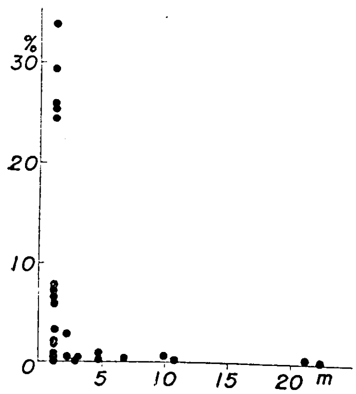


Fig. 8. Mean topographic hight and damage rate k in every *ren-ku* in Nagoya City.

b) The thickness of the upper alluvium and the earthquake damage. As is seen in Fig. 6 the thickness of the upper alluvium is known clearly, and the damage rates are plotted against the thickness of the layer in Figs. 9, 10. As will be seen from this diagram, large damage

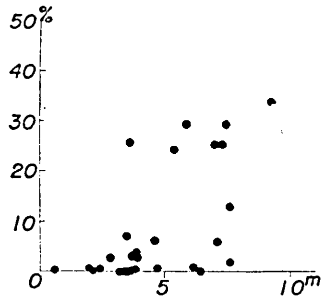


Fig. 9. Thickness of "the upper alluvium" (in m) and the damage rate k (%) in every *ren-ku* in Nagoya city.

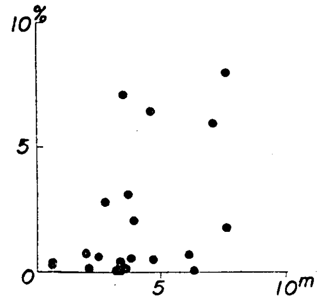


Fig. 10. Thickness of "the upper alluvium" (in m) and the damage rate k (%) in every *ren-ku*, whose k is smaller than 10%.

rates are seen only in the areas where the thickness of the upper alluvium are also large. But it must not be overlooked here that these simple relations are seen only when the unit area is taken as large as "*ren-ku*". This simple relation does not so clearly holds, if the unit area is taken smaller. As was already seen in Fig. 7, the thickness of the alluvium revealed from the seismic data, increases uniformely from north to south in Atuta-*ku* as well as in Minato-*ku*, but damage rate for each *tyo*, the subdivision of *ren-ku*, is not increasing so uniformly. With regards to these subdivisions *tyo*, the mean thickness of the upper alluvium were calculated and plotted against the respective damage rates, as shown in Fig. 11, which shows a close relation between them.

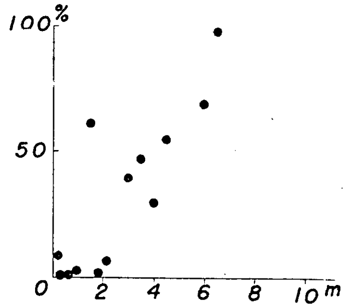


Fig. 11. Thickness of "the upper alluvium" (in m) and the damege rate k (%) in every *tyo* in Atuta and Minato-*ku*.

c) The thickness of the lower alluvium and the damage rate.

The relation between the damage rate and the mean thickness of the lower alluvium in each *ren-ku* is plotted in Fig. 12. By omitting the points for those *ren-ku*, whose mean heights are less than three meters, we immediately obtain Fig. 13, which shows a close linear relation between the damage rate and the thickness of the lower alluvium. In Fig. 14 the subsurface structures obtained from seismic prospecting data are compared with the earthquake damage in every *tyo* in Atuta-*ku* and in Minato-*ku*.

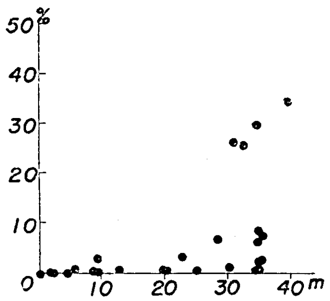


Fig. 12. Thickness of "the lower alluvium" (im m) and the damage rate k (%) in every *ren-ku* in Nagoya City.

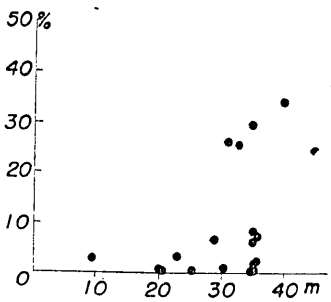


Fig. 13. Thickness of "the lower alluvium" (in m), and the damage rate k (%) in every *ren-ku*, whose mean height is less than 3 m.

In spite of the uniform increase of the thickness of the lower alluvium, the increase of damage is by no means parallel with it. The damage there may have probably rather closer relation to the thickness of the upper alluvium as already described in the preceding section b).

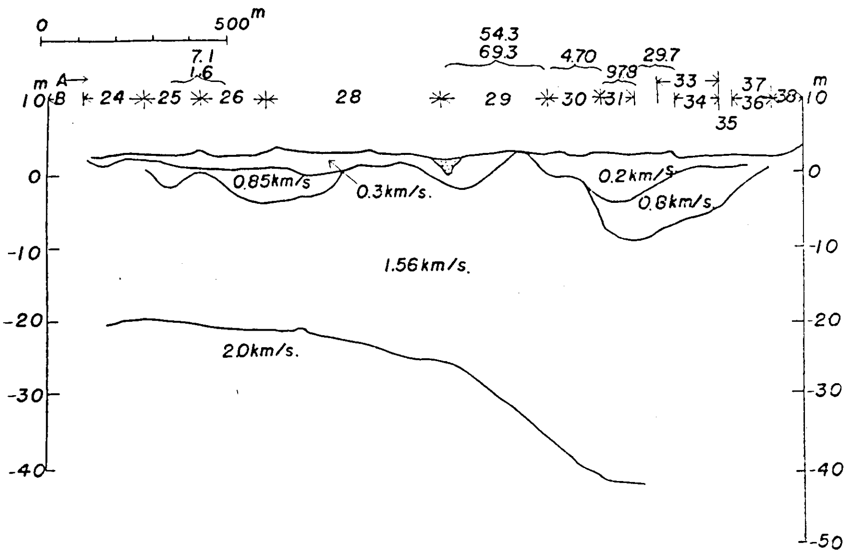


Fig. 14. Subsurface structure of ground, as indicated by seismic wave velocity (km/sec), and the damage rate k (%) in every *tyo* in Atuta- and Minato-*ku* along the route of the projected high speed railway.

d) The earthquake damage in the reclaimed land. Fig. 15 shows the relation of the earthquake damage and the age of reclaimed land in the

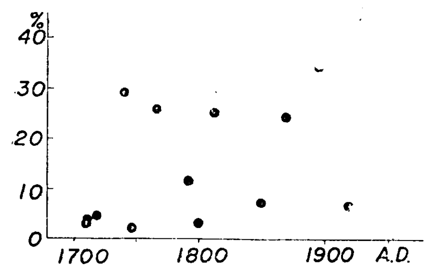


Fig. 15. The age of reclaimed land and the earthquake damage, represented by k in %, in the respective area.

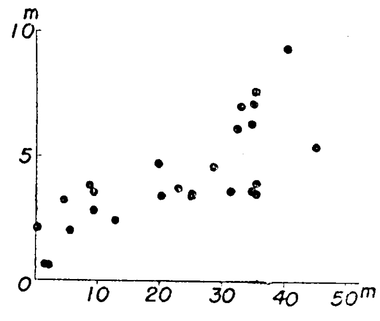


Fig. 16. The thickness of the upper alluvium (ordinate in m), and the lower alluvium (absisca in m) in Nagoya City, with respect to every *ren-ku*.

southern part of the city, and it can be said that there is at any rate a general tendency of a proportionality between them.

6. Concluding remarks.

From above considerations it may be said, at any rate, that where the alluvium is thick, the damage rate is also high. But, according to the investigations carried out in Atuta-*ku* and in Minato-*ku* more minutely with regards to each *tyo*, it was noticed that in spite of the uniform thickness of the lower alluvium, the damage rate due to the earthquake showed a very irregular distribution. The upper part of the alluvium was composed of soft muddy layer with a low propagation velocity of seismic wave. The thickness of this layer was very irregular. This part of the alluvium was called as "the upper alluvium" and we found that the thickness of the upper alluvium also play an important rôle upon the earthquake damage.

With all these considerations, however, it is still difficult to say to what extent the respective thickness of the upper and the lower alluvium affects to the damage rate. In Nagoya City the respective thickness of these layers is so closely related mutually as shown in Fig. 16, so that it will be almost impossible to know the separate influence of these two layers uppon the damage rate, provided only the data here reproduced were used.

In the northwestern part of the city, the lower alluvium is fairly thick, and the damages are very slight. This is very perplexing to us. With respect to these areas some more detailed investigations must be performed for making clear the particular conditions there. All the discussions above stated were restricted to the wooden houses. But, of course, it is quite probable, that the conditions of the wooden residental houses may not be uniform throughout the whole city and, consequently, it is very desirable that the fundamental statistical investigations concerning the conditions of houses be made prior to the occurence of earthquakes. No such investigations in Nagoya have been hitherto carried out and the uniform distribution of the conditions of the wooden houses had to be assumed. These assumptions, of course, are quite rough, so the detailed discussions can not be promoted further from these materials here given.

Though many questions are still left for furture investigations, we are convinced ourselves that the conclusions derived in this paper will furnish some new light to the relations between the earthquake damage and the structure of ground in Nagoya City.

7. Acknowledgments.

In conclusion the authors wish to express their hearty thanks to Dr. T. Tamaki, the Chief of the Architectural Section of the Provincial Office of Aiti, for his kind encouragements. Strong support of the Architectural Research Institute, Ministry of Construction, given to the present study is greatly acknowledged, too. Thanks are also due to Mr. Ota, Kinzyo Girls' College, Dr. K. Sassa, Kyoto University, and Dr. T. Watanabe, Nippon Geophysical Prospecting Co., for their kindness permitting us to use their valuable data.

The helpful cooperations of the provincial and municipal authorities of Nagoya in providing the necessary source materials must be here also gratefully acknowledged. Parts of the expense for the present study were defrayed from the fund of the Education Ministry, "Siken-Kenkyu-hi", and the grant from the Provincial Office of Aiti Prefecture.

---

15. 名古屋市における地盤と震害の關係

地震研究所 表　俊一郎
宮村攝三

名古屋市における地形，地下構造，埋立地の古さ等地盤の性質をしめす資料をあつめ，昭和19年12月7日の東海道地震による同市内の震害分布を調査し，これらの間の關係について考察した。

おもな結論として，一般に沖積層のあつさと震害の間に比例關係が見出されたが，こまかく區劃をわけ，町別位についてみると，かならずしもきれいに行かない。こゝに表土層の影響があらわれる。兩者はそれ自体第16圖にみるような關係をもつため，これらの影響を分離することはむつかしい。