58. *Damage on Window-panes by the Air-waves of Explosion of Volcano Asama on Sept. 23, 1950.*

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1. Introduction.

The activities of Asama have been typically Vulcanian in recent years. A large amount of bombs and other volcanic materials is hurled out in an instantaneous explosion with the velocity of 150–200 m/s, accompanied by strong detonations which are often audible as far as 200 km from the volcano. In addition, such violent explosions sometimes cause damage to windows, doors and walls of wooden houses at the foot of the volcano by their strong air-shocks.

As to the propagation of audible air-waves, detailed descriptions of the sound-areas of the detonations of the volcano were given by the late F. Omori[1], and the phenomenon was treated by S. Fujiwara[2] from the meteorological standpoint. The air-waves of longer period, however, have hitherto scarcely been recorded or studied, with the exception of barographic observations by F. Omori[1], on the basis of which T. Matuzawa[3] discussed the pressure at the instant of explosion.

The explosion of Asama on 4 h 37.5 m of Sept. 23, 1950 was one of the most violent in recent years[4]. A number of large incandescent lava blocks were thrown out in an instant together with gases, vapour, ash and other volcanic materials, and some of the bombs fell to the ground even at a distance of 3 km from the crater. The initial velocity of the bombs was estimated at about 200 m/s on the basis of the distance of their flight[5]. The total kinetic energy for the ejection of volcanic bombs was estimated at about 10^{20} ergs. The volcanic smoke was blown off eastward by the west wind which prevailed in

1) F. OMORI, *Bull. Earthq. Inv. Comm.*, **6**; **7** (1914).

2) S. FUJIWARA, *Bull. Centr. Meteor. Obs.*, **2** (1912), 1.

3) T. MATUZAWA, *Zisin*, **6** (1934), 588; **7** (1935), 47. (In Japanese).

4) T. MINAKAMI, Reported to International Association of Vulcanology, I.U.G.G., Brussells Assembly, August, 1951.

5) T. MINAKAMI, *Bull. Earthq. Res. Inst.*, **20** (1942), 65.

the upper atmosphere at that time, and ash fell to the east of the volcano. Detonations were heard as far as 200 km skipping over a non-audible region from about 100 km to 150 km. The damage done to window-panes by the present explosion was the most remarkable in these thirty years since glass-windows came into common use in the district around Volcano Asama. As no instrumental observation was carried out at that time except those by barographs for meteorological purposes, the writer planned to study the character of the air-shock from the damage.

2. Collected Data and Method of Investigation.

As 29 primary, junior high and senior high schools kindly accepted the writer's request to ask their pupils to report on the numbers of both broken and total window-panes in the respective directions of their own houses, several results could be obtained about the nature of the air-shock according to the reports. Reports were sent from 2,582 families around the volcano, with the exception of the north-western quadrant and close neighbours of the volcano. The total of the broken panes reported amounted to 5,520. In dealing with them, the following points were noticed and taken into consideration.

(1) Since some of the reports include the number of panes inside their houses while some do not, the "total number" of window-panes cannot hold one definite meaning and a kind of error is introduced here. Fortunately, pupils belonging to the same family gave their reports independently, and 327 such cases could be examined. As the result, we could infer that the errors in the total number might probably be about 10% including the errors due to miscounting. It must also be added that the "broken number" of window-panes reported independently by those of the same family showed satisfactory coincidence.

(2) The number of window-panes was given for the four directions in most of the reports. Some were given in N, E, S and W, and others in NE, SE, SW and NW, according to the aspect of each house. In dealing with these data statistically, the writer rearranged the directions in the four directions of "craterward", "anticraterward" and "lateral" (left and right seen from the crater) in the following way. At first, the nearest direction towards the crater among the eight directions is adopted as the "craterward" direction. When

none of the reported directions of a house coincides with the above defined craterward direction and differs 45° in arc, the average value of both broken and total number of the two neighbouring directions is supposed, for convenience sake, to represent the state of matters in case the directions of the house should coincide with the above defined ones. Functional relations between the angle of impact of the air-waves and breaking of panes are not yet made clear, so the error which might be introduced into the results through the above procedure cannot be estimated quantitatively. Qualitatively, however, it may be said that the damage obtained thus is slightly increased in the anticraterward direction and slightly diminished in the craterward direction in comparison with the houses facing exactly to the crater.

When we consider the characters of the collected materials, it is to be noticed that the situation we face is quite similar to that when we attempt to infer the nature of earthquake-motions quantitatively from the damage caused by the earthquake. Though not impossible the work is quite difficult.

As the first step for studying the intensity of air-waves, the percentage of damage in every house and every village is adopted as a measure and is discussed in this paper.

Even in one village where azimuth and distance from the crater

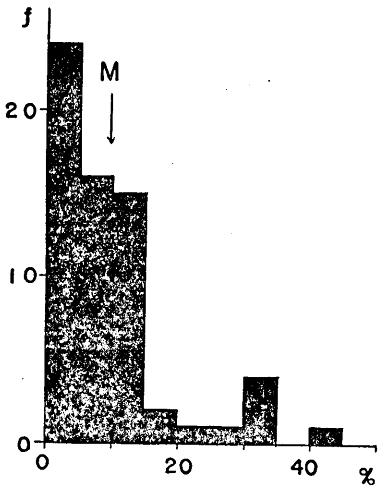

Fig. 1. Frequency of occurrence of damage-percentage M for every house at Komoro. (craterward)
M: average broken percentage

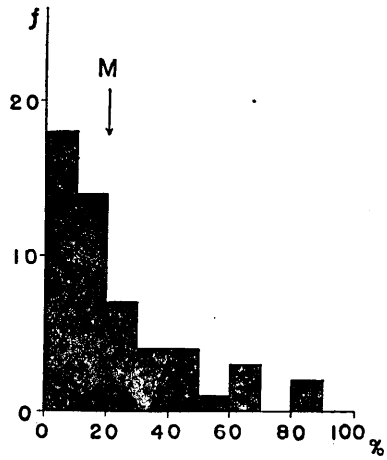

Fig. 2. Frequency of occurrence of damage-percentage M for every house at Kutukake. (craterward)
M: average broken percentage

are nearly the same, the damage percentage differs very much from one another. Examples are given in Figs. 1 & 2 for two villages in order to show how much the percentages for windows of every house differ from one another, by taking the damage-percentage in abscissa and its frequency of occurrence in the village in ordinate. This disparity was caused more by the existence of obstacles in the path of air-waves such as trees, houses and sometimes outer wooden sliding doors than by differences in the strength of window-glasses. For this reason, those houses whose windows were not damaged were omitted from the following calculation of percentages. The writer adopted an average percentage (M) in the four directions as representing the damage as follows:

$$M=\frac{\text{sum of the number of broken window-panes in one direction}}{\text{sum of the number of total window-panes in the same direction.}}$$

The value of M are tabulated in Table I and illustrated in Figs. 3 & 4.

Table I. Average broken percentage M for villages.

Location	From the crater		Damage in M (%)			
	Distance (km)	Azimuth	Craterward	Anticraterward	Lateral Left	Lateral Right
Sengataki	7.2	E34°S	9.0	0.2	4.4	2.1
Oiwake	7.6	E72°S	9.9	1.2	3.5	2.9
Kariyado	8.2	E59°S	12.2	1.7	11.9	0.9
Kose	8.8	E14°S	1.4	0.0	2.4	0.0
Kutukake	9.0	E44°S	20.3	2.6	16.1	5.8
Toriibara	10.0	E51°S	15.0	0.3	17.7	3.7
Mikasa	10.0	E20°S	0.0	0.0	0.0	0.0
Hanareyama, Minamihara	10.4	E39°S	7.6	1.6	9.9	5.0
Yui	10.6	E56°S	12.9	4.2	9.9	3.8
Siozawa	11.3	E47°S	10.1	9.7	12.8	10.1
Kyū-Karuizawa	11.6	E26°S	5.9	0.3	2.2	0.9
Sin-Karuizawa	12.2	E32°S	3.3	2.2	1.1	2.6
Hotti	12.2	E58°S	12.3	1.8	14.5	1.1
Kami-Hotti	14.0	E57°S	12.1	2.3	3.3	3.4
Minami-Karuizawa	14.1	E46°S	4.3	1.7	6.1	0.9
Siono	8.4	S18°W	36.0	3.3	19.4	10.9
Norise	9.6	S24°W	41.0	3.8	9.8	1.6
Maseguti	9.8	S13°W	11.9	2.6	7.2	0.8
Miyota	11.0	S 8°W	9.0	2.8	4.8	3.2
Hatiman	11.0	S28°W	20.4	2.7	3.0	16.6

(to be continued)

(continued)

Location	From the crater		Damage in M (%)			
	Distance (km)	Azimuth	Craterward	Anticraterward	Lateral Left	Lateral Right
Kasiwagi	11.4	S31°W	22.5	0.9	5.1	16.7
Hirahara	11.6	S24°W	13.7	1.6	3.7	2.5
Ōsato	11	S55°W	12.0	0.0	0.0	5.7
Komoro	12.3	S43°W	8.8	0.7	2.0	3.9
Mikage	12.4	S20°W	8.4	0.0	0.0	0.0
Yotuya, Otome	12.8	S35°W	9.7	1.5	0.7	7.2
Obara	13.8	S38°W	10.0	1.1	0.7	17.6
Sibauda	14.4	S61°W	7.2	0.0	0.0	0.0
Moriyama, Mimitori	14.6	S32°W	4.5	0.0	0.5	7.5
Kawabe	14	S41°W	2.8	2.1	1.8	3.3
Mitui	16	S 5°W	very slight			
Nakatu	18	S31°W	1.1	0.2	0.6	1.3
Minamiomaki	19	S41°W	no damage			
Kitaomaki	19	S60°W	no damage			
Gorobeesinden	19	S33°W	no damage			
Motomaki	21	S42°W	no damage			
Mituwa	21	S54°W	no damage			
Yokodori	24	S51°W	no damage			
Kyōwa	24	S43°W	very slight			
Agata	18	S70°W	no damage			
Kanou	18	S80°W	no damage			
Hosimata	14.2	N 6°W	5.7	0.6	—	—
Kita-Karuizawa	9.0	E43°N	11.5	1.6	5.5	7.3
Ōmae, Kambara, Ōzasa	12.0	E83°N	14.6	13.0	3.9	0.0
Ōkuwa	13.0	E59°N	13.3	2.5	4.0	14.1
Mihara	14.4	E80°N	3.1	0·0	0.9	0.6
Naganohara	19	E55°N	no damage			

3. Discussion.

A glance at the geographical distribution of M will show that the value of M is remarkably diminished here and there even within a short distance from the crater as at Oiwake and Sengataki. These anomalies can be explained mostly by obstacles in the course of the

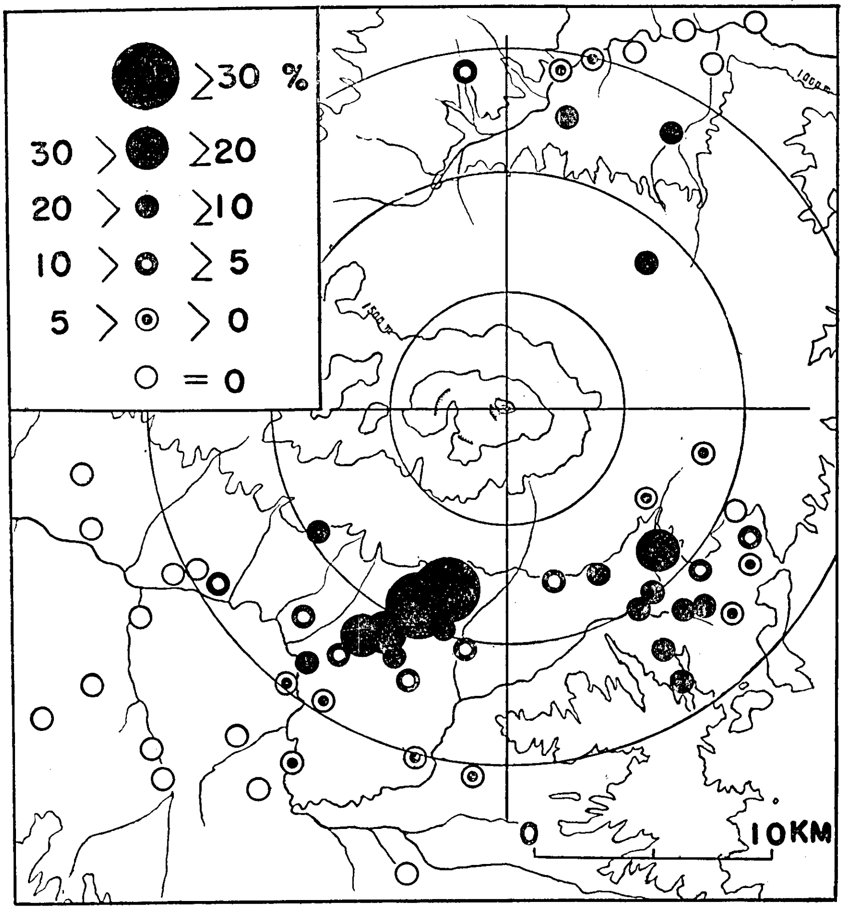

Fig. 3. Geographical distribution of average damage-percentage M for every village. (magnitude in craterward direction)

air-waves from Asama. Almost all the villas in Sengataki, for example, are surrounded by trees and were protected from air-shocks at that time. In contrast to that, percentages were high at those villages where the houses faced directly to the volcano. It is also remarkable that the breaking of window-panes was not restricted to the craterward direction but occurred, to some extent, also in the lateral and anticraterward sides. This phenomenon may be ascribed to the reflection and refraction by the neighbouring obstacles of high reflective power such as houses. Neither the errors due to the procedures in arranging the original data nor the effect of topographies of large scale can explain this phenomenon which was experienced in almost all villages.

The effects of those obstacles which existed near the villages were so great that problems concerning azimuthal distribution of intensity of air-waves at the instant of burst, and those of reflection and refraction due to such large topographies as sommas cannot be treated with ease. In this connection, though tentatively and qualitatively, it may be pointed out that the main direction of damage was not exactly craterwards in most of the villages in the SE and SW quadrants of Fig. 4, but the damage seemed to be caused by air-waves coming from a somewhat northern direction.

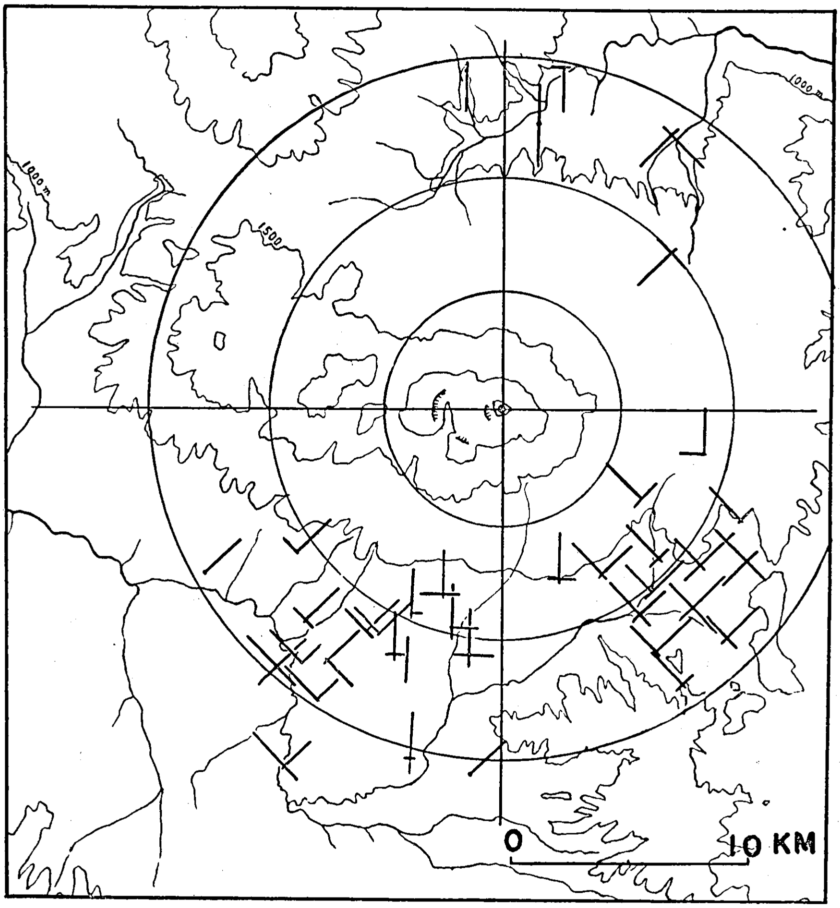

Fig. 4. Geographical distribution of average damage-percentage M for every village. (Ratio of magnitude in four directions, taking the largest M as unity)

In order to study the relations between the intensity of air-waves and distance, such local effects should be excluded by adopting maximum values of M for respective distances. The curve with full line in Fig. 5 was thus drawn and it became clear that the average percentage for the craterward direction decreased in proportion to r^{-4} from 8 to 20 km. The value, of course, should draw close to 100% nearer the crater.

Maximum percentages in respective villages were also studied in place of the average percentage M. It would rather be going too far to adopt maximum percentages, especially when the number of window-panes is very small. If only those houses, of which the total number of window-panes is not less than twenty, are taken into account, the maximum percentage is nearly proportional to M and also diminishes almost in proportion to r^{-4} as will be seen in Fig. 6.

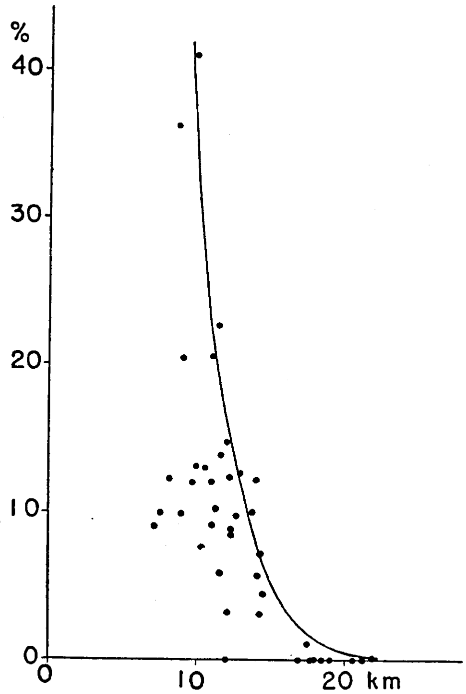

Fig. 5. Average damage-percentage M in the craterward direction and distance from the crater.

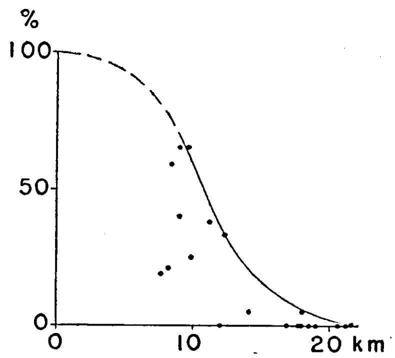

Fig. 6. Maximum damage-percentage in the craterward direction in every village and distance from the crater.

Since our purpose is to clarify the character of the air-shock itself, it is desirable to find the relations between those percentages and the intensity or period of the air-shock. The breaking strength of glass-plate has been treated both mathematically and experimentally by many authors[6]. Changes undergone by glass-plates under various kind of loads are known in detail. Experiments on breaking glass-plates by impact of impulsive air-waves were also carried out[7]. Most of them, however, are concerned with a plate clamped or supported by a sufficiently rigid frame. The mode of causation of strains in the actual window-panes is not so simple as that in perfectly clamped or perfectly supported plate but differs from one another in boundary conditions. The wooden frames and besels of windows which could be deformed easily by the air-waves might have caused localization and concentration of stress in the glass plate in a haphazard manner, in addition to heterogeneities in the glass-plate itself. The size and thickness of glass-plate also differ from one another. In addition, some of the panes were reported to have come off the weak frames and been smashed to pieces on the ground. The phenomenon is so complicated as described above that the writer gave up the attempt to find the exact relation between the intensity of air-shock and the percentages on the basis of those experiments.

Damage on actual window-panes, however, is caused also by explosions of powders and bombs. The writer compares here the present results with the effects of the atomic bomb which fell on Hirosima. According to K. Muto[8], the glass-windows were damaged as far as 16 km from the centre, though the distribution of this kind of damage was not described. Comparing this result with theoretical and field studies by American and Japanese physicists and engineers[8][9] we obtain $1\text{–}2\times 10^{-2}$ atm. press. as a probable value of the lower limit of intensity for air-blast from the atomic bomb to cause slight damage on actual window-panes. If we neglect the difference in period of waves between the two kinds of explosions and discuss the apparent intensity of the shock-wave, the intensity of $1\text{–}2\times 10^{-2}$ atm. press. may be regarded as the value at about 18 km from the crater at the time of the present volcanic explosion. More words must be spent here lest the result should lead immediately to the conclusion that the energy of the air-waves of the present volcanic manifestations should have been comparable with that of the atomic bomb. The periods of air-waves of

6) "Glass in Architecture and Decoration" (1937), London.

7) G. SHINKAI and others, *Trans. Inst. Japan Arch.*, **5** (1937), 45.

8) Japan Science Council, "Report on the Damage Caused by Atomic Bombs" (1951), (in Japanese).

9) "The Effects of Atomic Weapons" (1950).

explosion of Volcano Asama and its difference from that of the atomic bomb is known to some extent. The initial positive phase of air-waves of explosions of Asama which were observed in 1913 and 1914 by F. Omori[10] was nearly 2–3 sec. at the distance of 3 km from the crater, and the greater the eruption was, the longer the duration became. The duration of the initial positive phase of the atomic bomb can be estimated by calculation at 1.8 sec. at the distance of 16 km from the centre[11]. As the volcanic explosion in 1950 was on a greater scale than those in 1913 and 1914, the air-waves might have contained waves of much longer periods. Besides the above-mentioned differences in the character of waves, the differences in the mechanism and mode of both explosion and propagation must be taken into consideration. Consequently, our comparison of the two phenomena should be limited to the intensity of air-waves that could cause damage to window-panes.

Trace-amplitudes on barograms at the weather stations are tabulated in Table II for reference. It must be remembered that these records have been obtained through Stevenson screens and thus the air-waves may have been much reduced.

Table II. Amplitude of barographic disturbance.

(After weather stations).

Station	From the crater	Amplitude in mm Hg	
		Increase	Decrease
Kutukake	9 km SW	3.1	2.2
Nagano	43 km NW	0.4	—
Maebasi	50 km E	1.6	1.0
Matumoto	54 km SWW	—	—
Kumagaya	87 km SE	—	—

4. Resumé.

The damage caused to window-panes by the air-shock in the 1950 explosion of Asama was confined to the region within nearly 18 km distant from the crater.

Air-waves were reflected and refracted by various obstacles in

10) F. OMORI, *loc. cit.*, 1).

11) *loc. cit.*, 9).

their path of propagation, and consequently, the resultant effect became complex.

The degree of damage was expressed by percentages. Though this expression is still imperfect, several problems concerning the air-wave could be discussed to some degree, as may be seen in Figs. 3 & 4.

It is also interesting and useful to compare the present result with effects of explosion of the atomic bomb.

In concluding, the writer wishes to express his cordial thanks to Dr. T. Minakami by virtue of whose guidance and encouragement the present research was made possible, and to those schools which supplied the writer with the reports on damage. The expense for this study was defrayed from the Funds for Scientific Research of the Ministry of Education.

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58. 1950年9月23日の淺間火山爆發の空氣波による窓ガラス被害

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表記の爆發は，最近の淺間火山の爆發の中で最大級に屬し，山麓の窓ガラスに生じた被害は甚しかつた。火山周邊の各學校の協力により，各學童の家についての方位別の窓ガラス總數及び破壞數の報告を得，これを整理して次の結果を得た。

1) 被害は火口からの距離が大きくなるにつれて急にへり，火口から大約 18 粁が有被害の限界であつた。

2) 被害は家屋や部落の立地條件に著しく左右され，火口に直面する位置では被害が大きい一方，樹木其他の小地物の遮蔽效果が著しいらしく，火口から 10 粁以内でも被害の輕かつた部落もある。

3) 被害は家屋の方向の中では火口に直面する方向は著しいが，それ以外の方向にも被害のある例が多い。これは家屋附近の地物による空氣波の反射や回折を考へれば大體說明出來る。又，もつと大きい地形又は噴出時の條件によるとも思われる樣な，廣い範圍にわたつての被害方位の偏りがある。

4) 被害から直ちに空氣波の性質を量的に論ずることは難かしいが，原子爆彈被害の類推から有被害の限界地附近では大約 $1\sim2\times10^{-2}$ 氣壓程度の壓力振幅であつたと推定される。
