11. A Model Experiment on the Mechanism of Seismic Sea Wave Generation. Part I.

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1. Since the dawn of our history, the Pacific coast of the Sanriku District, in the north-eastern part of the main island of Japan, has frequently been visited by severe seismic sea waves or *tunami*. According to A. Imamura[1], records are extant of at least fifteen occurrences of tunami in this district, including the recent one which occurred on March 3, 1933. They are tabulated in chronological order as follows:

No	Date			No	Date		
1	869	VII	13	9	1835	VII	20
2	1611	XII	2	10	1843	IV	25
3	1616	IX	9	11	1856	VIII	23
4	1640	VII	31	12	1894	III	22
5	1677	IV	13	13	1896	VI	15
6	1689	—	—	14	1897	VIII	5
7	1763	I	29	15	1933	III	3
8	1793	II	17				

No investigations by modern scientific methods were made however until the tunami of 1896, of which there is a report by T. Iki[2] regarding the height of the waves and the extent of the inundated areas, but the investigation was by no means exhaustive, owing to the insufficient number of investigators that participated.

In the recent tunami of March 3, 1933, careful and thorough investigations were made from every possible angle by a number of investigators who were despatched from various institutions. Some of the reports of these investigations have already been published. It is evident,

1) *Jap. Journ. Astr. Geophys.*, **11** (1934), 79.

2) *Rep. Imp. Earthq. Inv. Comm.*, **11** (1897).

however, that there are many problems relating to tunami phenomena which cannot be solved by a mere study of the result of these investigations, such as heights of waves, extent of the damage to structures, etc. The behaviour of the tunami wave, as it approaches the coast, the motion of the sea water after it reaches land, and the mechanism of tunami generation at its origin, etc., all these may be just such problems. In simple and restricted cases, some of these problems may yield to mathematical treatment, but the advantages to be gained by experimetal studies with the help of models are self-evident.

The present experiment is mainly concerned with the problem as to what waves are generated and what is the motion of the sea surface near the origin when a dislocation of the sea-bed occurs.

When the sea-bed vibrates violently, tunami of some magnitude will be generated, even if no dislocation had occurred. Whenever a sea bed upheaves or sinks or both, tunamis of various magnitudes must of neccessity be generated. Tunami waves will also be produced when a land-slide takes place in the sea floor. The wave form, wave length, period, etc. will depend in these cases upon the character, velocity, and magnitude of the dislocation. If we could ascertain the relations that connect these factors of submarine dislocation to the magnitude, wave form, etc., of the tunami waves, then conversely it would be possible to learn something of the submarine dislocation from mareograms that record the tunami waves. Should dislocation occur at a great depth, say over 5000 m., as in the recent case, we could then obtain more satisfactory and accurate knowledge regarding it by experimenting with models than by resorting to soundings of depths.

K. Sano and K. Hasegawa[3], and later K. Sezawa[4], have already made mathematical studies of the waves produced by submarine dislocation. The former treated the case in which a cylindrical area of the sea bottom subsides suddenly, and the latter the case in which there is an expansion or contraction nucleus at the sea bottom, but neither of them dealt with conditions near the origin. K. Sezawa[5] also discussed a continuous progressive circular wave-train generated when there are stationary oscillations of water surface at the origin, but he did not fully treat the case of a solitary wave or a group of two or three waves.

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3) *Proc. Tokyo Phys-Math. Soc.*, 2 (1915), 8.
4) *Bull. Erthq. Res. Inst.*, 7 (1929), 15.
5) *Bull. Earthq. Res. Inst.*, 9 (1931), 291.

2. In beginning a model experiment, it is important that we consider the law of similitude. We shall suppose that a circular area of radius D of the sea bottom, where the depth is H, upheaves by amount S in time interval T, and also that the form of the dislocation is always the same; that is, if we denote by s the amount of dislocation at time t, the instant when the dislocation began being taken as $t=0$, then the function F in the expression

$$s=S\cdot F\left(\frac{t}{T}\right)$$

is always the same.

The wave length λ, wave height η, velocity of the wave v, etc., of the waves thus generated are then governed by the relation

$$\phi\left(\frac{\lambda}{H}, \frac{\eta}{H}, \frac{v}{\sqrt{gH}}; \frac{D}{H}, \frac{S}{H}, \sqrt{\frac{g}{H}}T; \frac{d}{H}, \sqrt{\frac{g}{H}}t\right)=0,$$

in which g is the acceleration of gravity, d the distance taken from the origin of the point at which λ, η, etc. are observed. Should the viscosity of the water affect the phenomena considered, it must be introduced in the above relation in the form $\frac{\mu}{\rho}\frac{T}{H^2}$, $\frac{\mu}{\rho}$ being the specific viscosity.

As is obvious from the above expression, if we use in a model, quantities of dimension $[L]$ in the reduced scale of $1/l$ of the actual dimensions, the time scale in the model will have to be $1/\sqrt{l}$ of that of the actual, so that the motion of the bottom of the model must be very much quicker than that of the actual. Should we, in addition to the conditions $[L]$ and $[T]$ just mentioned, desire to satisfy the condition of viscosity, we must use with the model a fluid whose μ/ρ is very small, that is, $1/l^{2\cdot5}$ of that of sea water. For this purpose, mercury is most suitable, but the reducing factor will then become as small as $l=2\cdot58$, resulting in the necessity of an enormous model.

In these circumstances we abandoned the idea of satisfying the condition of viscosity and fell back on water, since viscosity is not so important as to entirely change the character of the generated wave.

3. In the present experiment we used a wooden tank 2 m long, 1·5 m. wide and 0·3 m. deep. As the first step in the experiment, we took up the case of upheaval of a circular piston fitted to the centre of the bottom of the tank, to simulate upheaval of the sea bottom. The arrangement of the various apparatus used in the experiment is shown schematically in Fig. 1. Details of the arrangement will be seen in Fig. 2 and Fig. 3 (Plate).

In Fig. 1, *V* is the tank and *P* the piston fitted to a cylinder, 10 cm. inner diameter. Both piston and cylinder are of phosphor bronze to avoid rust, while leather packing prevents leakage of water. The piston, of maximum stroke 6 cm., is connected to a lever *R* by a connecting rod *C* and two joints, and moves up and down in the cylinder with the movement of the lever. The lever, which is of wood, is 15 cm. wide and 4 cm. thick. A scale *E* provided near the movable end of the lever shows the position of the piston. A helical spring *F*, attached to the movable end of the lever, and which is held taut at the beginning of an experiment, pulls up the piston the moment it is relaxed. In order to regulate the speed of the piston, an air damper with regulating valve *D* was at first used, but having proved unsatisfactory, was replaced later by a special device *B*. One end of a strong Koto (Japanese musical instrument) string is fixed to the movable end of the lever *R*, while the other end is wound on the shaft of device *B*. With this arrangement the contraction of spring *F* rotates this shaft of device *B*, as well as the inertia bar *J*, which is coupled to the shaft by a step-up gear *G*. The velocity of the piston motion is regulated either by attaching heavy bobs to or removing them from the inertia bar or by changing the position of the bobs. At the extreme left of the device a ratchet-wheel and stopper are provided. When the stopper is pushed down, the spring (which is stretched), the lever and the other parts are all set free and the piston begins to move upward. The motion of the piston is recorded by a device (shown in the figure) on a motor-driven drum *W*, simultaneously with the vibration (84·3 cycle/sec.) of an electrically maintained tuning fork *T*.

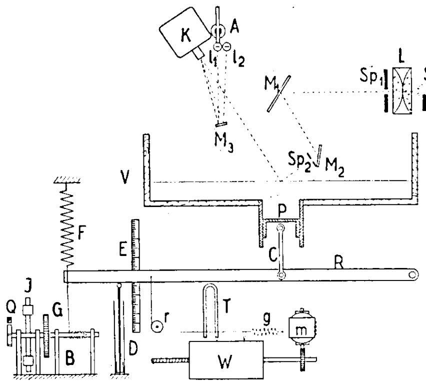

Fig. 1. Schematic diagram of the apparatus.

We shall now describe the optical system of the apparatus. *S* is an A. C. arc lamp provided with carbon bars of 7 mm. diam., and *L* a condenser, 20 cm. in diameter, having a slit Sp_1 of 5 cm. width in front of it. This slit serves to pick out the middle part of the pencil of light rays, which is made nearly parallel after passing through L. The sheet of light thus obtained is then reflected by a mirror M_1 (size: 30 cm. × 30 cm.) on to a second mirror M_2 (size: 3 cm. × 30 cm.), situated 6 cm. above the water surface with its longer side parallel to the water surface. The mirror M_2 has, in front of it, a slit Sp_2 3 mm. wide and 30 cm. long, which reflects the light on to the water surface through the slit. For adjusting the light direction, each of the two mirrors M_1 and M_2 is made to rotate about a horizontal axis.

On the water surface is thinly scattered some very finely pulverised rosin. As the fine powder of rosin is much lighter than water and does not become damp, it always floats on the water; it has proved very satisfactory for the present purpose, though it has a drawback in that it is not white but of a creamy colour. The sheet of light that is sent through the slit Sp_2 is made to fall on this thin film of powdered rosin at an angle of 30°, producing a bright straight strip of light, 6 cm. wide and 30 cm. long, on the water surface. The bright strip begins from a point 1 cm. distant from the center of the piston P, and after passing through the centre of the piston, ends at a point 29 cm. away from it.

At a distance of 1 m. from this illuminated portion of the water surface, and in the direction of 60° from it (see figure), a 16 m/m kineto-camera K, provided with an anastigmat $F=2{\cdot}8$ and $f=2{\cdot}0$ cm. and a portrait attachment, is installed. Under these conitions, if the water surface rises 1 cm., the bright strip, seen from the position of the camera, will be shifted 2 cm., as will easily be understood from Fig. 4. Therefore the form of the bright strip at any instant shows the magnified profile of the water surface through the centre of the piston. The form of the bright strip is recorded on the film in the reduced scale of 1/48·6.

In front of camera K is an elastic pendulum with a small lamp l_1 at its free end. Attached to the support of this pendulum, are also two small lamps l_2 and an electromagnet A. When beginning the experiment, the elastic pendulum is held at a deflected position by the electromagnet A. When the stopper is pushed down and the piston begins to move, the electric circuit of magnet A, being connected to the stopper and ratchet-wheel, is opened, and the pendulum is free to oscillate. This oscillation is recorded on the film by means of mirror M_3, simultaneously with the motion of the water surface, and serves as the time mark. The period of the oscillation of the pendulum is 0·230 sec.

Thus, on the film we get such an image as shown in Fig. 5, in which a is the image of the slit Sp_2, b the image of the bright strip described above, c the fixed lamp, and d the lamp attached to the pendulum. Since the pendulum is oscillating rapidly, it moves considerably during an exposure, so that d is generally of line form. The cinematograph was always operated at a speed of 16 exposures per second. The "Agfa Feinkorn Negative Film" was used.

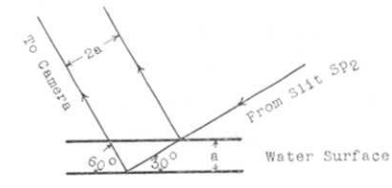

Fig. 4.

A calibration proved that the speed of the kineto-camera keeps to the constant value of exactly 16 exposures per second after the first three or four exposures. At this speed the time interval of an exposure was found to be 0·29 sec. For reading the position and form of the images of the bright strip on the film, we used a coordinate comparator, utilizing the image of the slit (a in Fig. 5) as the datum line. The time t of each exposure, measured in seconds from the instant when the piston began to move, was deduced from the position of the image d (Fig. 5) at the successive exposures.

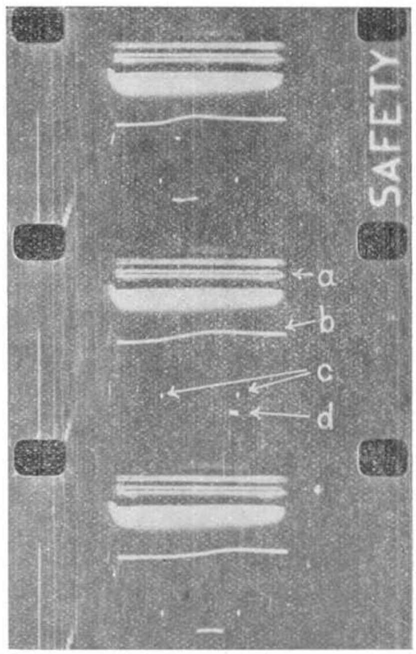

Fig. 5. Images on the film. (magnified. ×3·6)

The thickness of the water layer in the tank was measured before each experiment by a spherometer. The amount S and the velocity of stroke of piston, and also the time interval T in which the piston completed its stroke, were read off from the record made on a sheet of smoked paper wound around drum W.

4. In the experiment the piston was caused to move upwards from a depressed position to the level of the tank bottom where it stayed.

Altogether forty-five experiments were made, always varying the thickness of the water layer in the tank, the stroke of the piston, and the velocity of the piston, in various combinations.

The motion of the water surface thus obtained in these forty-five experiments are plotted in Figs. 6-21. In these Figures, H is the thickness in cm. of the water layer in the tank, S the length of the stroke in cm. of the piston, T the time interval in sec. between the beginning and end of the motion of the piston, and t the time measured in sec. from the beginning of the motion of the piston. The centre of the piston in the Figure corresponds to a point distant 1/30 the total length of the curve from the left end of that curve. In the Figure are also given two scales, one for the wave height (vertical) and the other for the extent of the level surface.

As will be understood from these Figures, the water surface just above the piston heaps up with the upward motion of the piston into a sort of long cone. As this cone becomes higher its base spreads. When a certain height is reached the peak or apex of the cone falls in, leaving at the margin an elevated circular bank of water. The water surface just above the piston falls in still further and to such an extent that it is now a truncated cone with a hollow in its middle. The water then begins to heap up again, and the whole process is repeated, only that this time the cone is not so high as in the preceding case.

In other words, the water surface above the piston oscillates above and below the level of the undisturbed water with a rapidly damping amplitude. The thinner the water layer in the tank, the quicker, it seems, is the decrease in the amplitude of the oscillation, which is probably due to the viscosity of water and also to the friction at the bottom of the tank, both of which act in an exaggerated way in the model experiment. In the case of an actual tsunami, the sea surface at the origin will probably continue to oscillate for a much longer time.

The circular bank of water that was produced around the piston goes to the right hand side of the curves in Figs. 6-21, that is, recedes from the piston, gradually changing its form. With each oscillation of the water surface above the piston, similar progressive circular waves are produced around the piston, but the wave height becomes smaller and smaller. On the whole therefore a train of waves is produced of which the first wave has the greatest height.

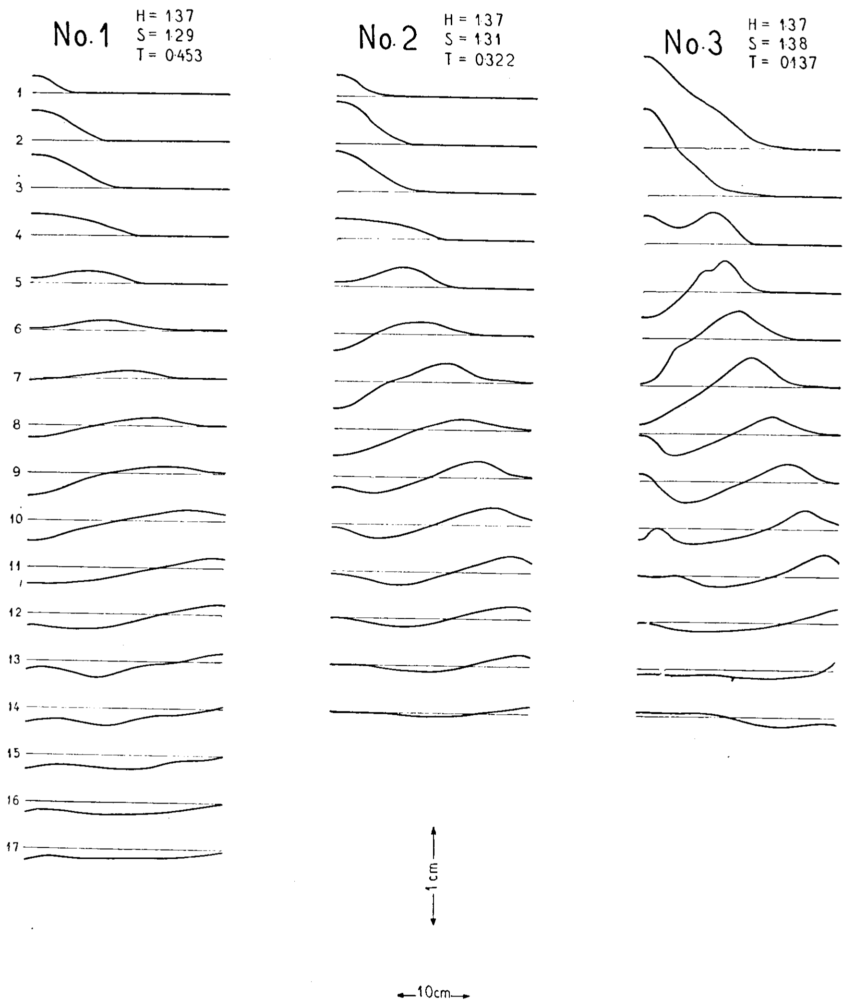

Fig. 6. Profile of the water surface through the centre of the piston.

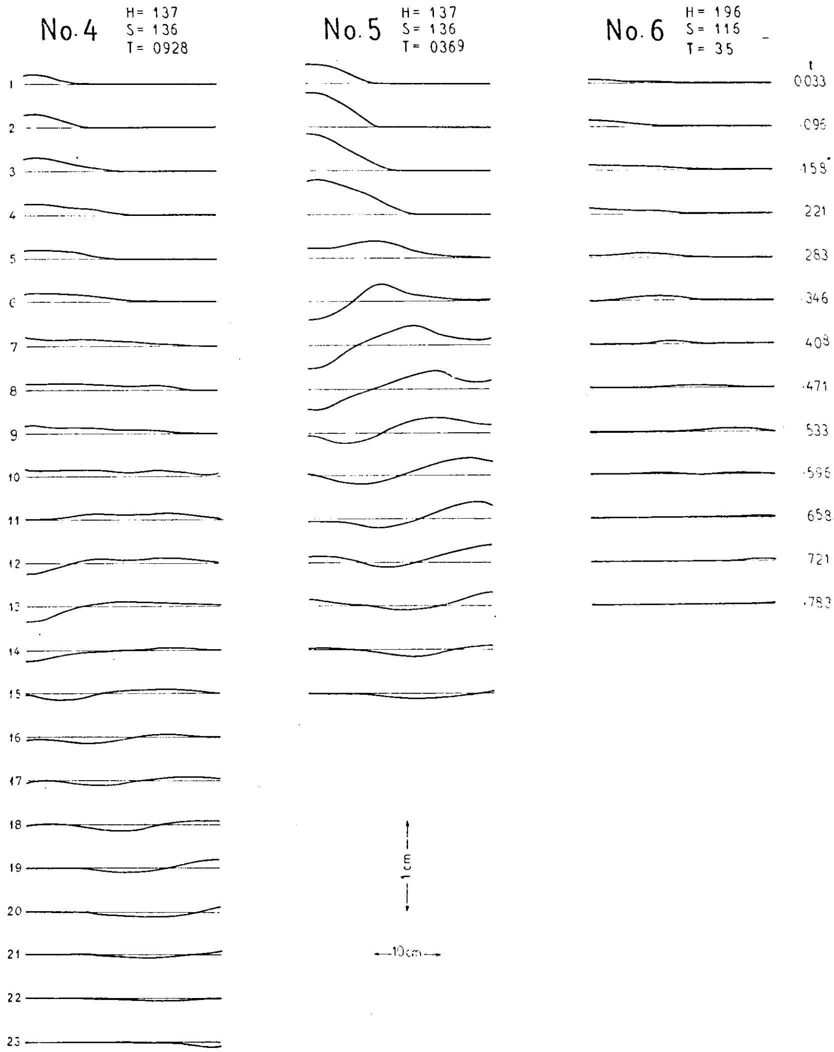

Fig. 7. Profile of the water surface through the centre of the piston.

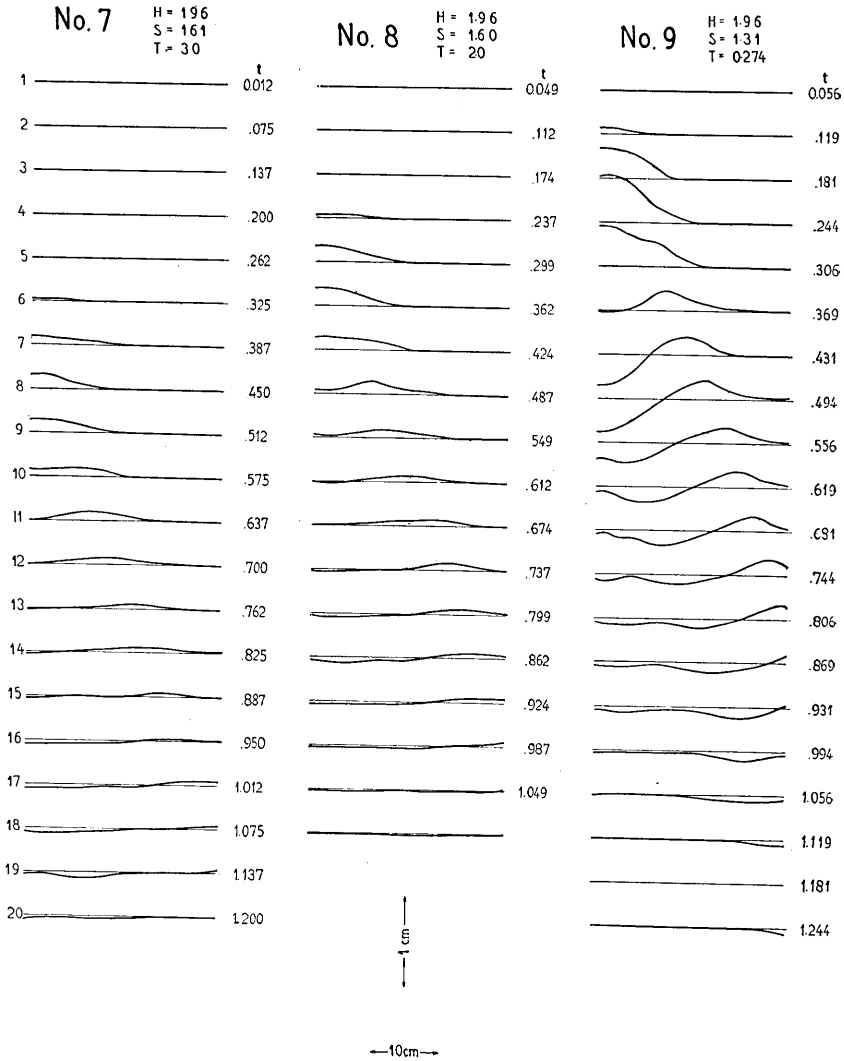

Fig. 8. Profile of the water surface through the centre of the piston.

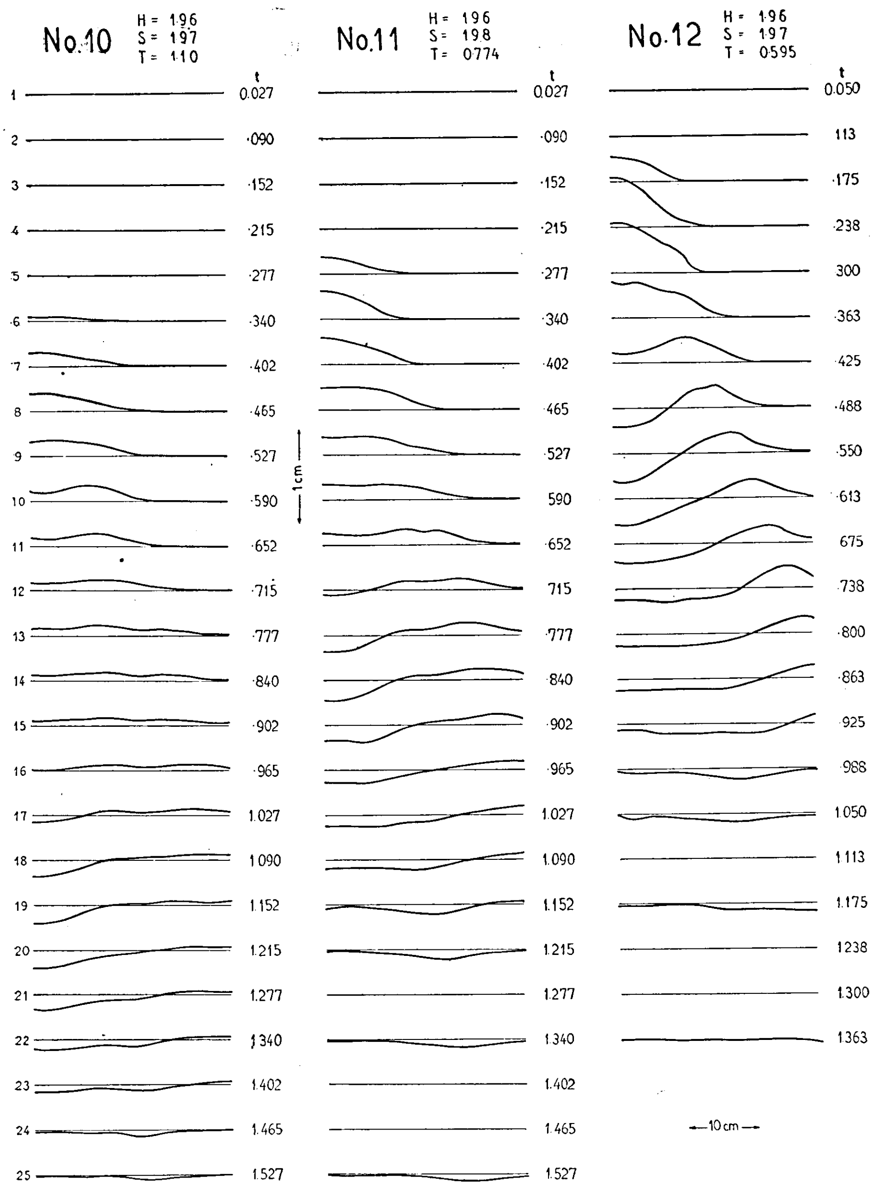

Fig. 9. Profile of the water surface through the centre of the piston.

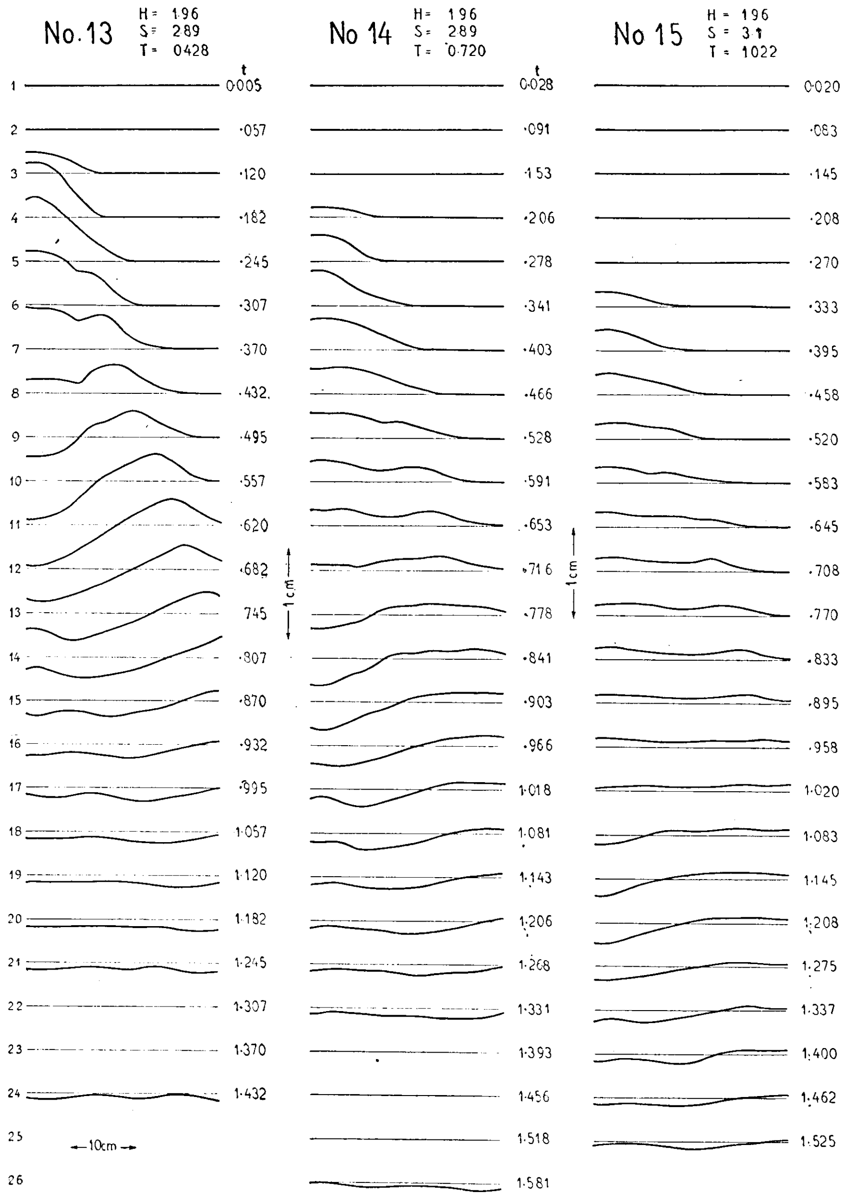

Fig. 10. Profile of the water surface through the centre of the piston.

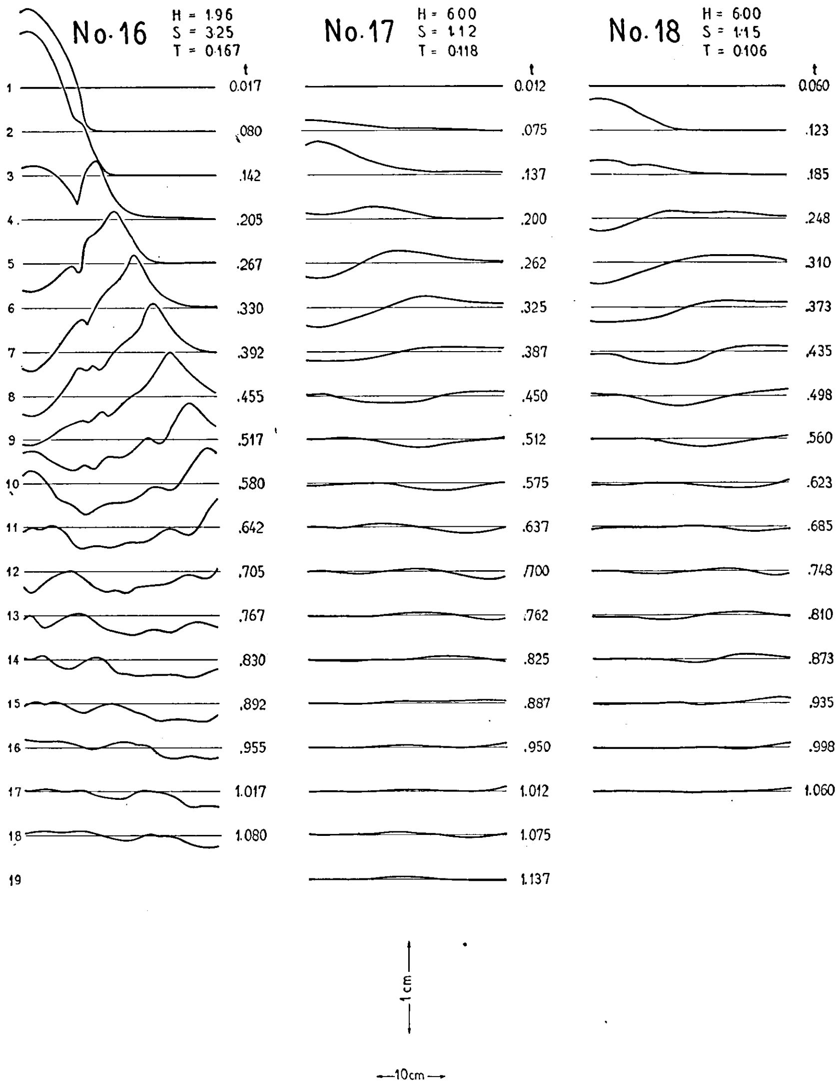

Fig. 11. Profile of the water surface through the centre of the piston.

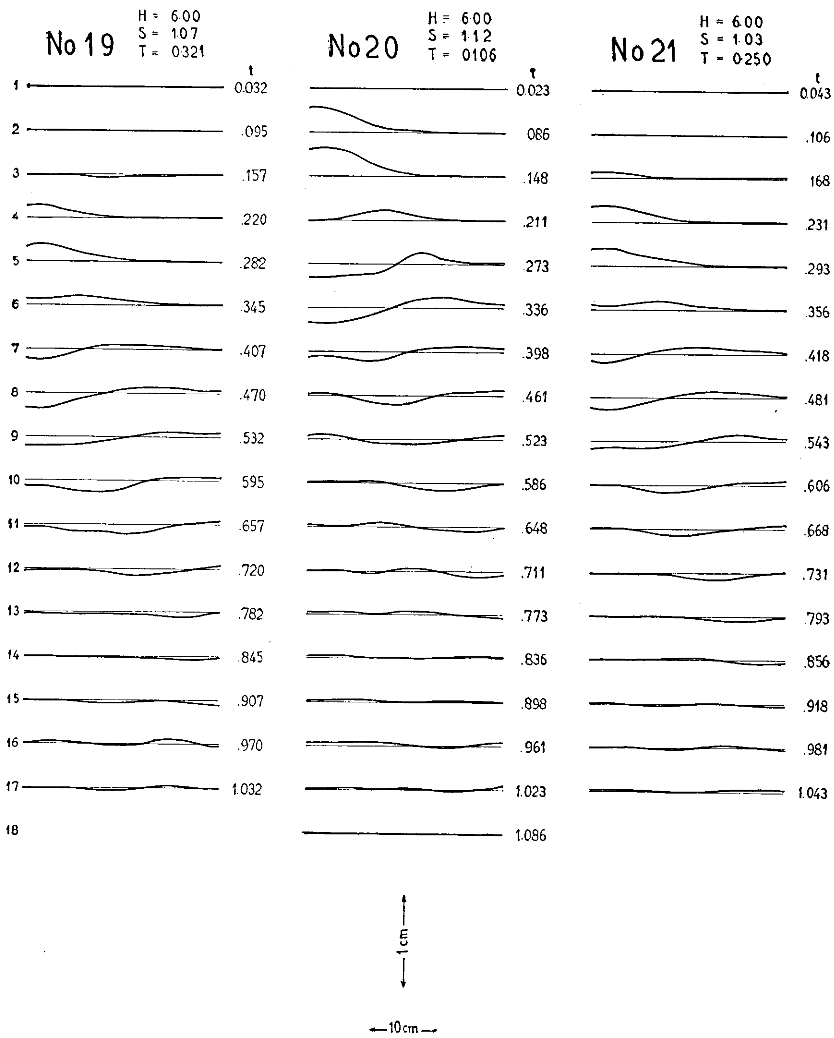

Fig. 12. Profile of the water surface through the centre of the piston.

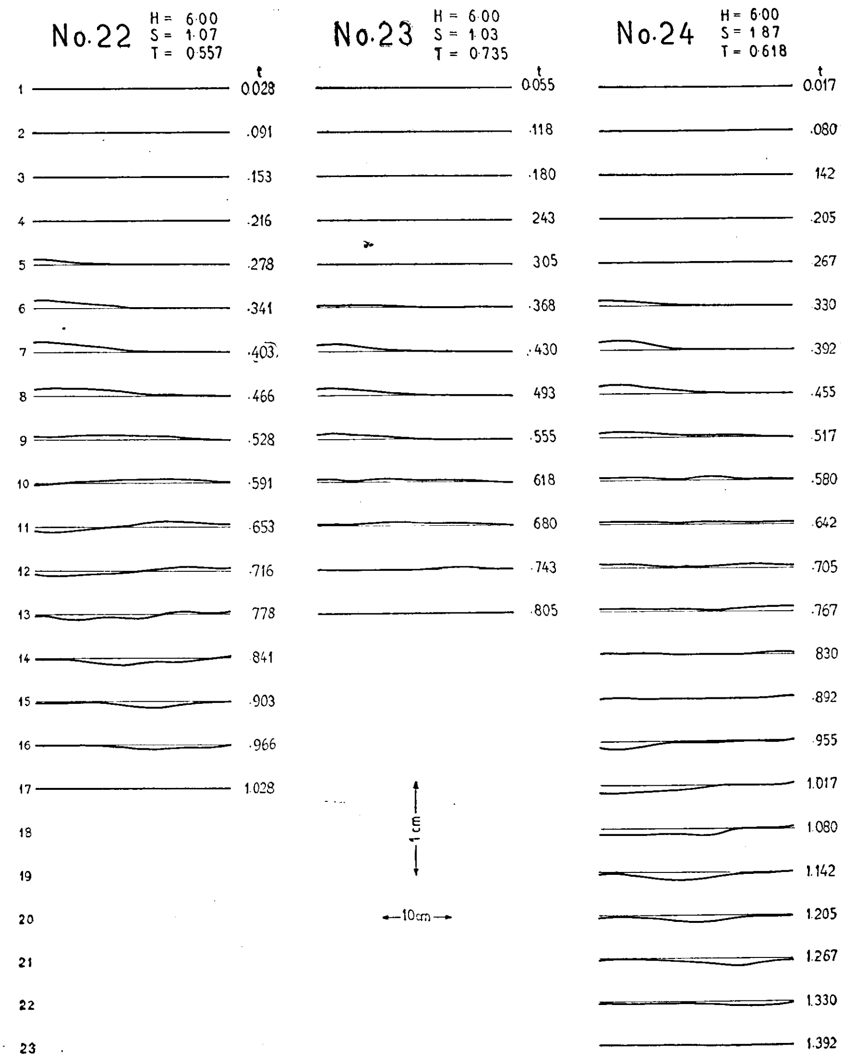

Fig. 13. Profile of the water surface through the centre of the piston.

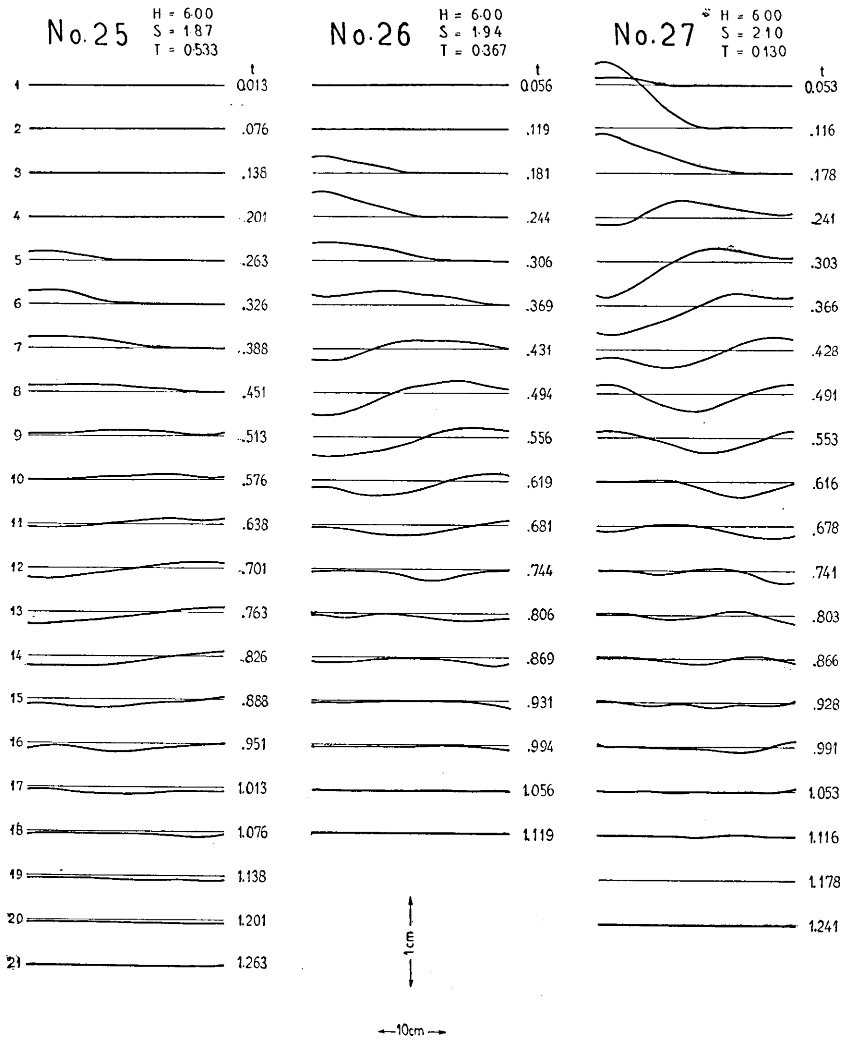

Fig. 14. Profile of the water surface through the centre of the piston.

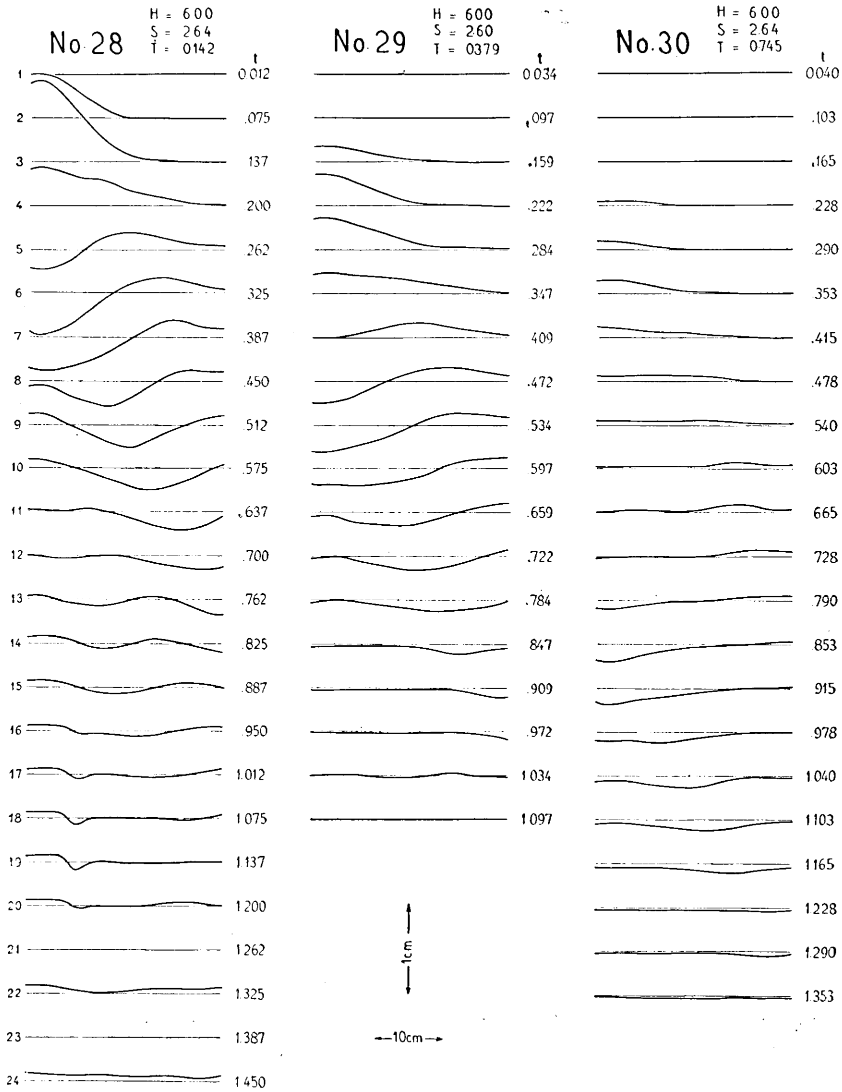

Fig. 15. Profile of the water surface through the centre of the piston.

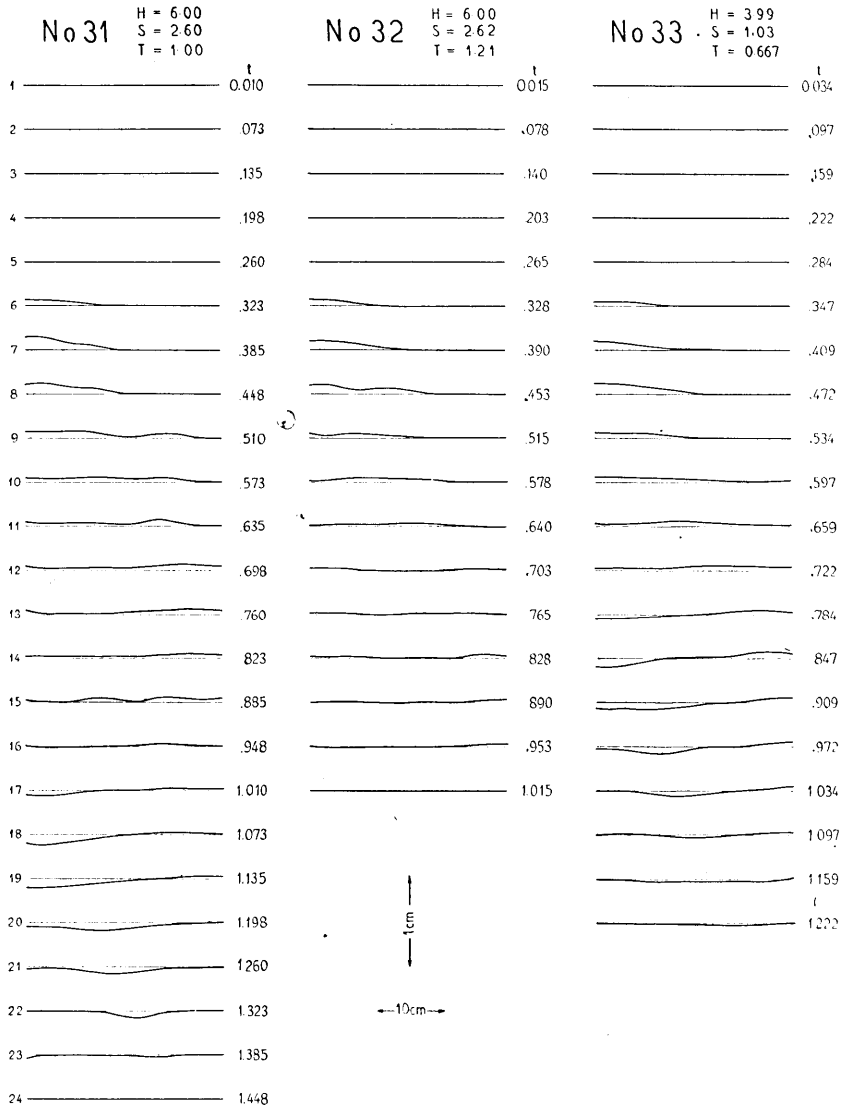

Fig. 16. Profile of the water surface through the centre of the piston.

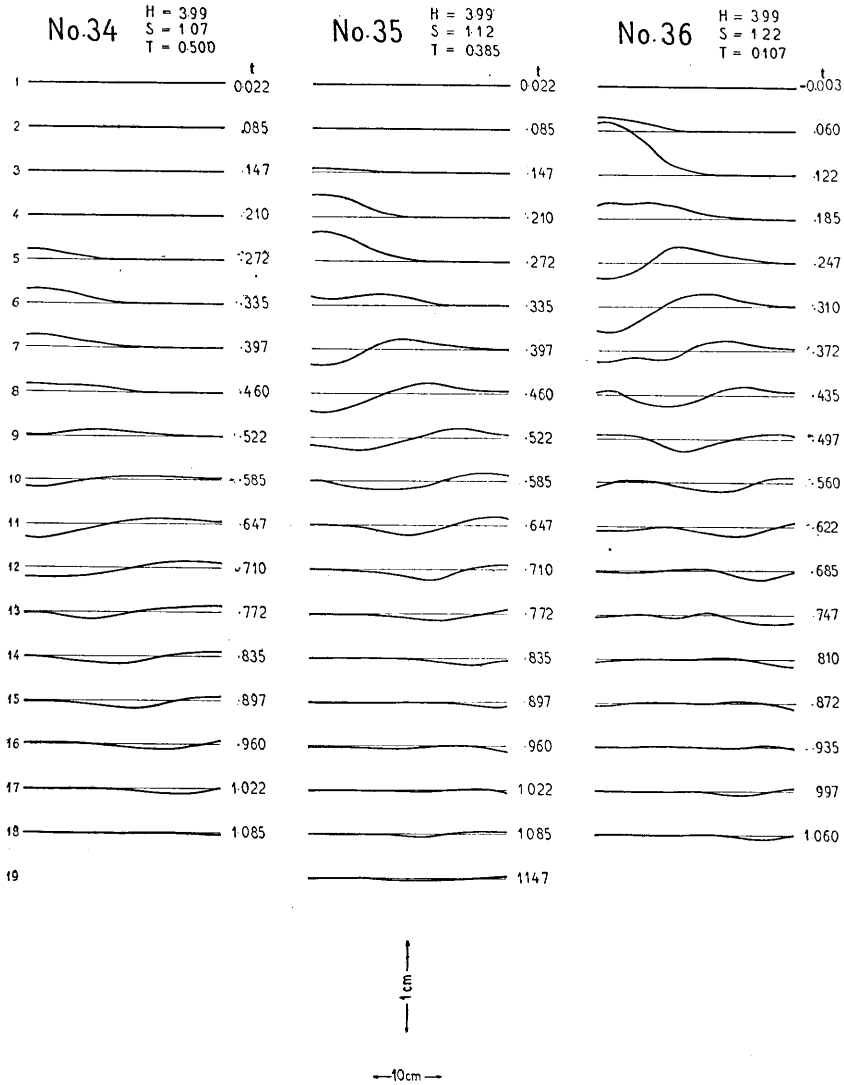

Fig. 17. Profile of the water surface through the centre of the piston.

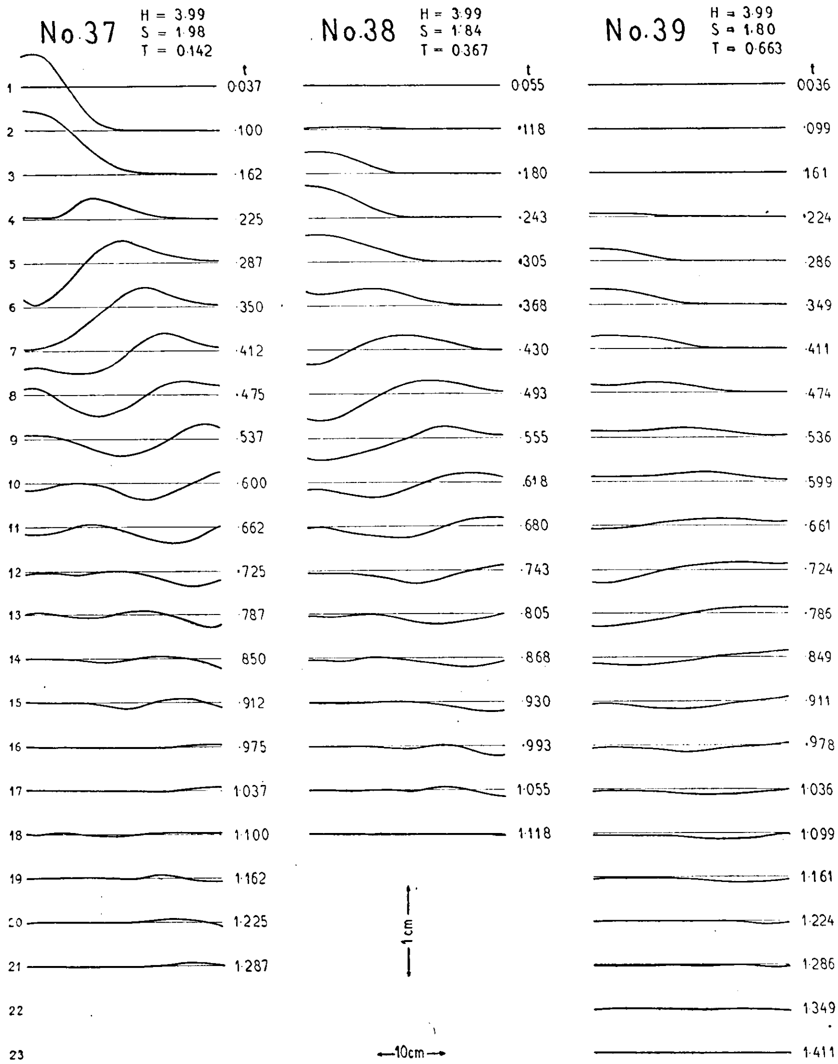

Fig. 18. Profile of the water surface through the centre of the piston.

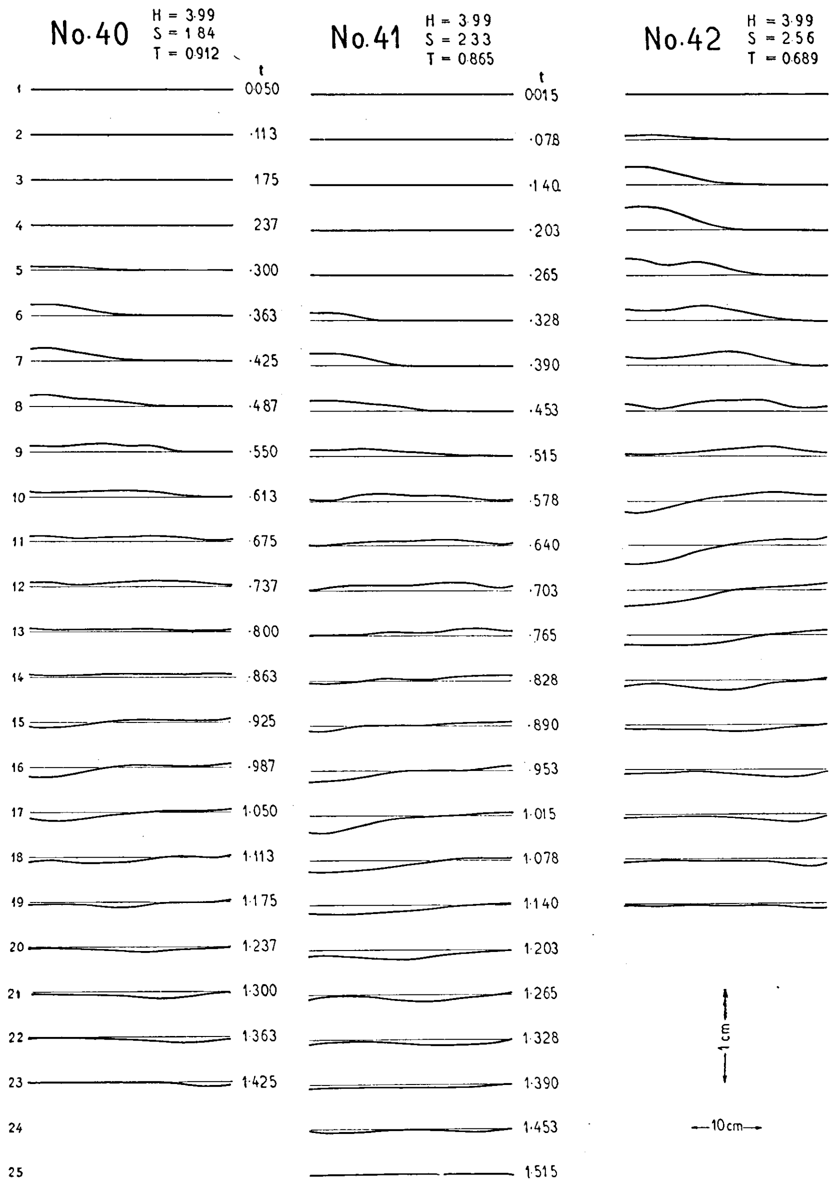

Fig. 19. Profile of the water surface through the centre of the piston.

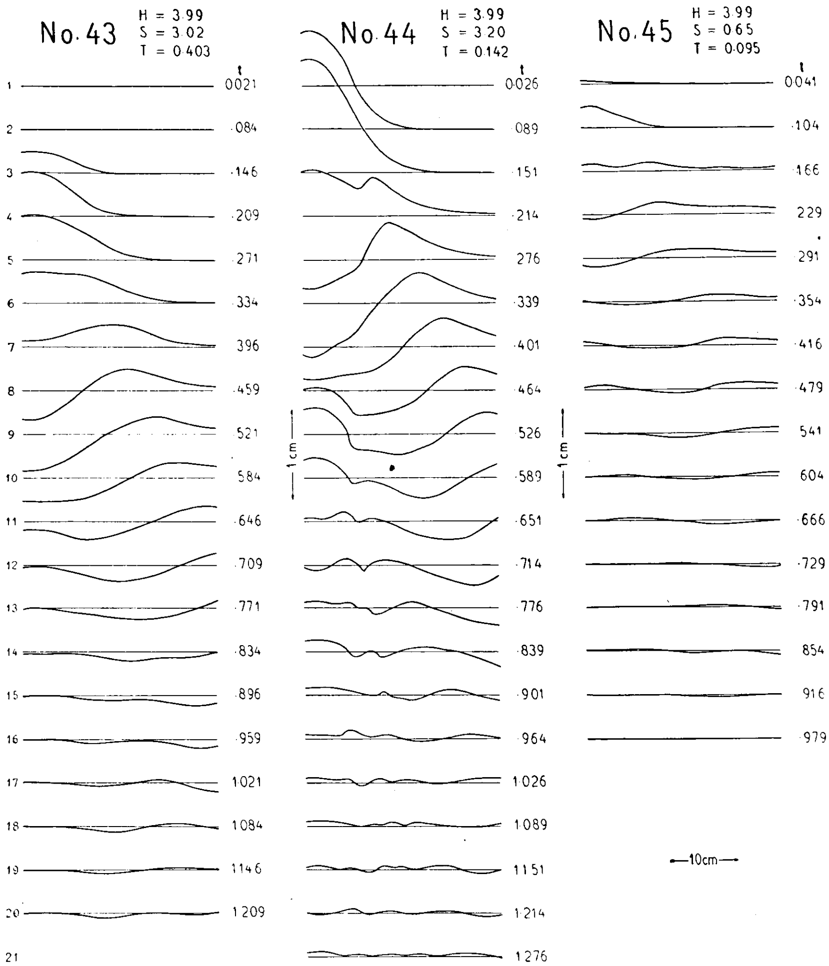

Fig. 20. Profile of the water surface through the centre of the piston.

In the region observed in the present experiment, the front part of the wave train, the so-called wave front, has a velocity of propagation markedly greater than that of the crest of the first wave. Consequently the form of the first wave becomes gradually elongated, and the slope of the front part of the wave train becomes gentle. The same may be said of other parts of the wave train, although the dispersion is not so pronounced as at the wave front. The wave train as a whole increases

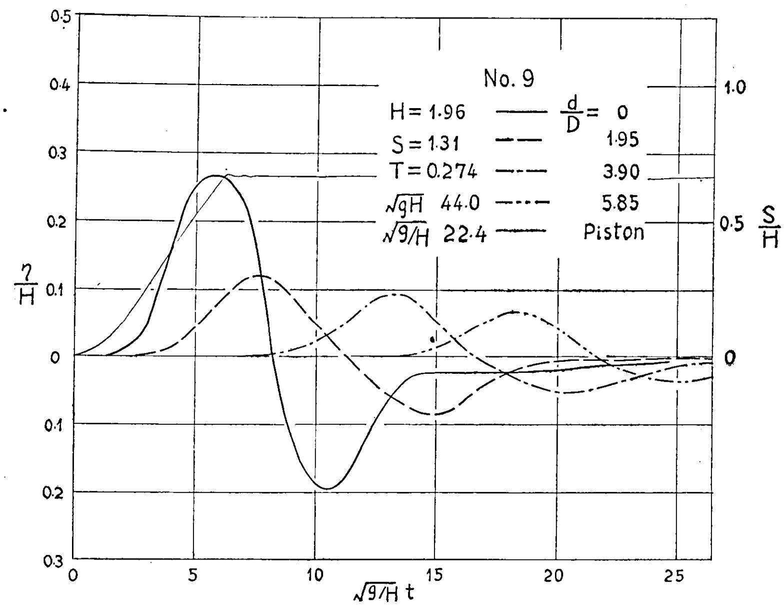

Fig. 21.

in length with the distance travelled.

The velocity of the crest of the first wave in the immediate neighbourhood of the piston is considerably larger than that given by the formula $\sqrt{gH}$, but approaches asymptotically to $\sqrt{gH}$ with increasing distance from the piston. The velocity of each point of the slope following the first crest has the same tendency as the first crest, although its departure from the formula $\sqrt{gH}$ is much less.

The water surface above the piston moves almost simultaneously with the point just above the centre of the piston. In other words, the waves here are of the stationary type and progressive waves are formed apparently for the first time at the distance that is twice the radius of the piston. In the region of the stationary wave the wave velocity is infinitely large.

The height of the progressive circular wave apparently decreases as $d^{-0.6}$ within the 'region' (extent of the water representing the sea) observed in the present experiment.

These wave features may be understood from a glance at Figs. 22–27. These figures were plotted on the basis of Figs. 6-21, and represent the motions of the four points whose distances from the centre of the piston are respectively 0 mm., 96 mm., 192 mm. and 288 mm. as well as the motion of the piston. In the figures, D is the radius of the piston and d the distance as measured from it.

From the idea of the law of similitude, these figures were drawn by taking the ordinate to scale $\frac{\eta}{H}$ (η being the height of the water surface above the undisturbed level) and the abcissa to scale $\sqrt{\frac{g}{H}}t$. The parameters of the curves in these figures must then be the functions of $\sqrt{\frac{g}{H}}T$ and $\frac{S}{H}$ only, provided that the viscosity of water and the friction of the bottom of the tank satisfies the law of similitude.

As it is very difficult however to ascertain what functions of $\sqrt{\frac{g}{H}}T$ and $\frac{S}{H}$ are the paramenters of these curves, we shall, as the first step

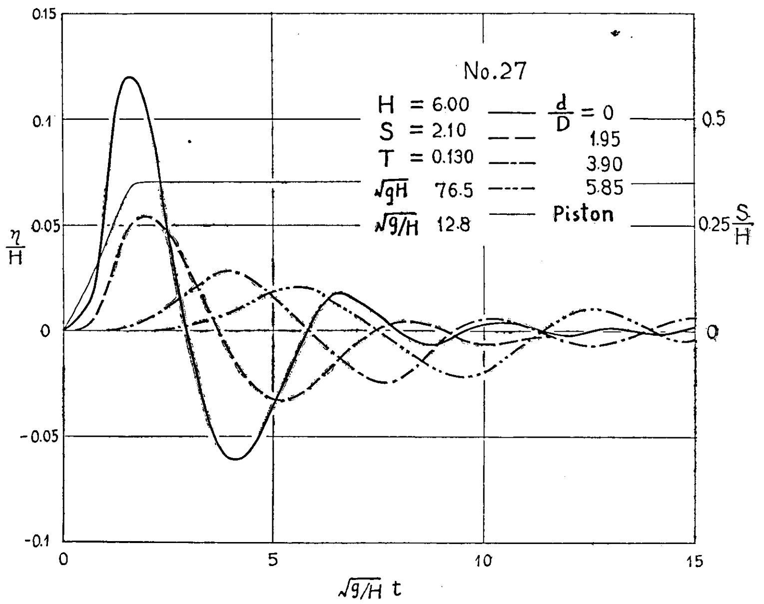

Fig. 22.

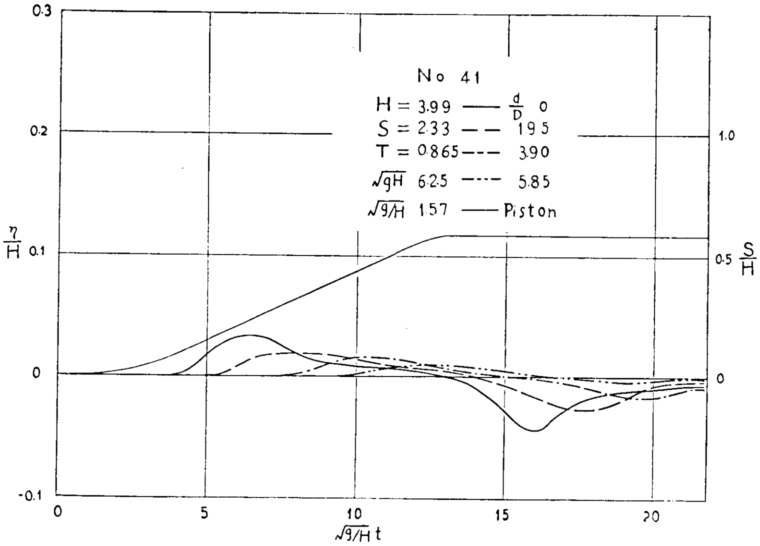
No 41
H = 3.99 —— d/D 0
S = 2.33 — — 1.95
T = 0.865 --- 3.90
√gH 6.25 -··- 5.85
√g/H 1.57 —— Piston
η/H
S/H
√g/H t
0.3
0.2
0.1
0
-0.1
1.0
0.5
0
5
10
15
20

Fig. 23

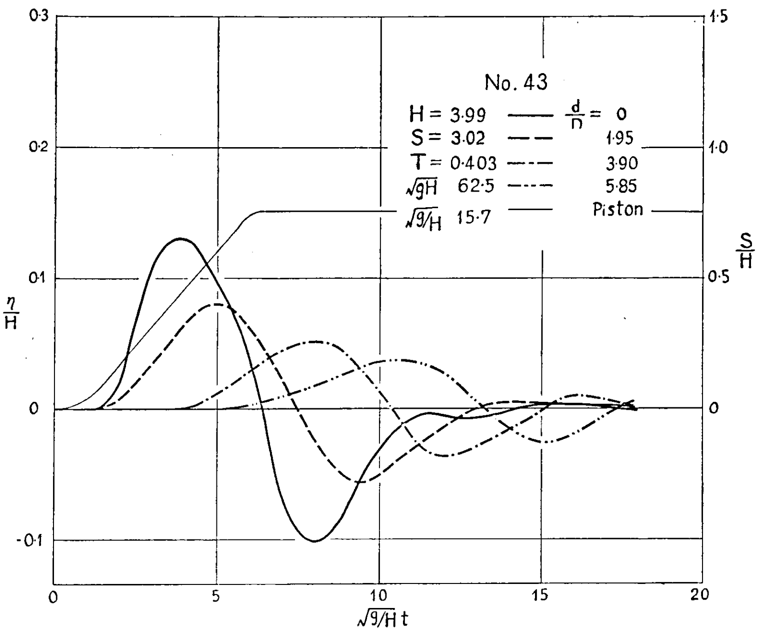
No. 43
H = 3.99 —— d/D = 0
S = 3.02 — — 1.95
T = 0.403 -·- 3.90
√gH 62.5 -··- 5.85
√g/H 15.7 —— Piston
η/H
S/H
√g/H t
0.3
0.2
0.1
0
-0.1
1.5
1.0
0.5
0
5
10
15
20

Fig. 24.

in this direction, attempt to find how the height η_0 of the truncated cone above the piston is related to $\sqrt{\frac{g}{H}}T$ and $\frac{S}{H}$. Plotting the values of $\frac{\eta_0}{H}$ against $\sqrt{\frac{g}{H}}T$ and $\frac{S}{H}$, the ordinate and abcissa, we obtain Fig. 26.

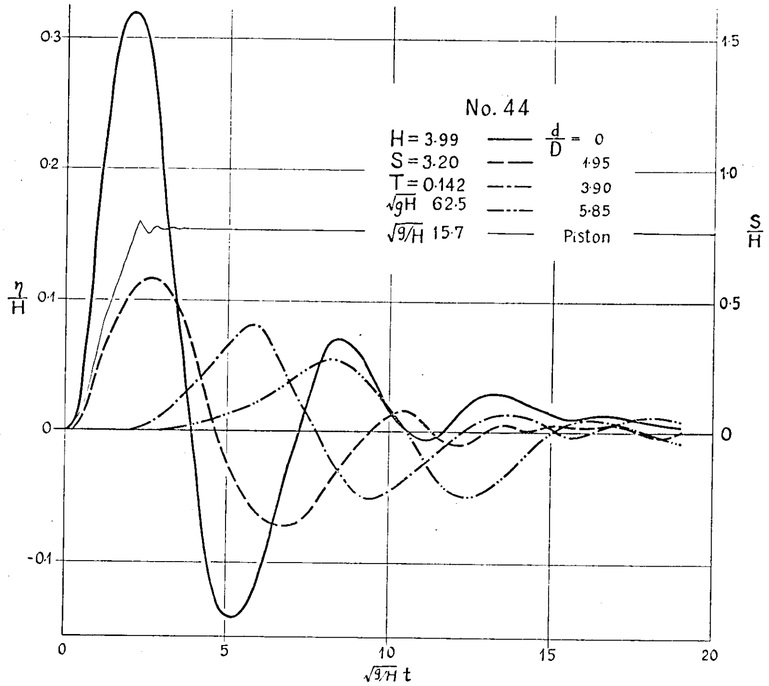

Fig. 25.

Each black dot in the figure corresponds to one experiment while the numeral alongside it is the value of $\frac{\eta_0}{H}$ obtained from that experiment.

The contour line in the figure, which then represents the relations of $\frac{\eta_0}{H}$, $\frac{S}{H}$ and $\sqrt{\frac{g}{H}}T$, may approxmately be expressed by

$$961\,(S-\eta_0)^2H^3=g\eta_0{}^2T^2\{0{\cdot}9\,H^2+(H+\eta_0-S^2).$$

From this Figure we can see that there is an optimal value in S for obtaining the maximum η_0 when the value of T is given. Generally speaking, a large S and small T, that is, a large piston velocity gives a large η_0.

As to the wave length of the generated wave, owing to limitations to the scope of the experiment, we can say nothing definite, the 'region' observed in the present experiment being too small in area, although in every experiment it seemed that the wave length was almost constant, except for the case of very slow motion of the piston. In the last-mentioned case the wave length became markedly long.

This experiment is now being continued for such cases as when the piston sinks downwards, for the upheaval or depression of elliptic or rectangular area, etc., the results of which will be published in due course.

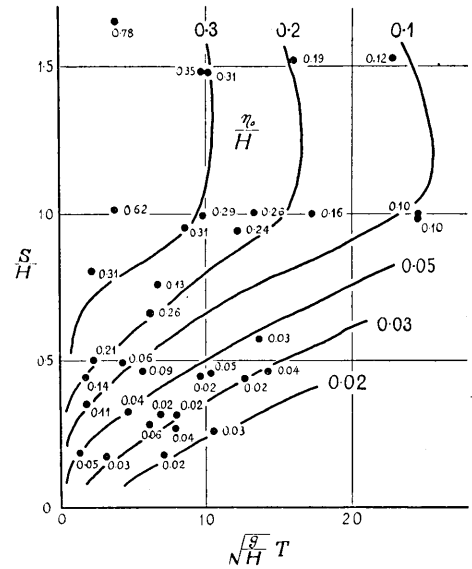

Fig. 26. Diagram showing the relation of $\frac{S}{H}$, $\sqrt{\frac{g}{H}}T$ to $\frac{\eta_0}{H}$.

11. 津浪發生の機巧に關する模型實驗（第1報）

地震研究所 高橋龍太郎

a) 海底に地形變動を生じた場合には必ず津浪の發生を伴ふであらう．只其の津浪の波形，波高等は地形變動の種類，大きさ及び其の速度等によつて決められるものであらう．若し吾々が地形變動の諸要素と，生じた津浪の諸要素との間にある關係を知り得たならば，檢潮儀による實際の津波の記錄から逆に海底に起つたであらう地形變動に就て何者かを推知する事も全然不可能ではないであらう．本實驗は海底の如何なる運動に因つて如何なる波動が發生するか，變動を爲した海底附近の海面は如何なる運動を爲すかを明にしやうとするものである．

b) 模型實驗に於て當然問題となるのは相似律である．今 H なる深さの海底の R なる半徑の圓形面積が S なる衝程を T 時間内に爲したと考へ，且 t なる時刻に於ける變動量 s は

$$\frac{s}{S}=F\left(\frac{t}{T}\right)$$

であつて何時も同じ函數 F で表されるとする．然る時は生成する波の波長 λ，波高 η，速度 v 等は次の形で結ばれてゐる筈である．

$$\phi\left(\frac{\eta}{H},\ \frac{\lambda}{H},\ \frac{v}{\sqrt{gH}},\ \frac{R}{H},\ \frac{S}{H},\ \sqrt{\frac{g}{H}}T,\ \frac{\mu}{\rho}\frac{T}{H^2},\ \frac{d}{H},\ \sqrt{\frac{g}{H}}t\right)=0.$$

但し g は重力，d は浪源からの距離，μ/ρ は海水の比粘性である．此の式から判明する通り，模型に於ける底の變動速度は實際のものより餘程早くなければ同じ割合の波は出來ぬのである．又粘性の關係から模型に於ては海水の粘性が非常に誇張されて影響して居る事が判る．

c) 實驗裝置としては本文第1圖，第2圖，第3圖に示した樣なものを用ゐた．弧光燈 S から出た光は集光レンズ L，細隙 Sp_1，鏡 M_1 及 M_2，及び第2の細隙 Sp_2 を經て水面に 30° の角度を以て放射される．水面上には松脂の微粉が薄く散布してある．從つて水面上には輝いた眞直な線條が現れるのである．此の輝いた線條の斜上方1米の距離に，水面と 60° 方向に 16 ミリ活動寫眞の撮影機が据付けてある．今水面が假に1糎昇つたとすると第4圖に示した樣に撮影機の位置から見れば輝いた線條は2糎變位する事になる．從つて或る時刻に於ける輝條の形狀は其の時の水面の斷面を示すものである．

V は實驗水槽であつて長8尺，巾4尺，深1尺，木製である．水槽の底の中央，輝く條線の眞下にピストン筒及ピストンがある．ピストンは直徑 10 糎であつて最大 6 糎の衝程を爲しうる．ピストンとピストン筒との間には革パツキングが用ひてある．ピストンは連結棒 C によつて杆桿 R に連つてゐて，R の一端は固定されてゐるから，杆桿の他端が上下するとピストンも上下する．杆桿の動端近くにはピストンの位置を讀取る爲に目盛 E がある．

桿杆 R の動く端には螺旋狀スプリング F が取附けてある．實驗の初めに於て此のスプリングは引伸されてゐるが，此の收縮する力でピストンを押上げるのである．ピストンの運動速度を加減する爲には B なる仕掛を用ひた．桿杆 R の動く一端に結んだ琴絲の他端は B の軸に卷付けてある；從つてピストンの上昇は B の軸を廻轉させ乍ら行はれる事になる．B 軸の廻轉は增大して慣性棒 J の廻轉になる．ピストンの運動の遲速は此の慣性棒へ重錘の附け脫しと重錘の位置の變化によつて加減された．B の一番左側にはガンギ車と爪がある．B の軸に琴絲を卷取る事に依つて發條 F を引伸しておいて爪を脫せば，B は廻轉を初めてピストンは上り初めるのである．ピスト

ンの運動は圖示の如き裝置によつて電動機 m に依つて回轉する圓筒 W の上に音叉の振動と同時に書込まれる.

活動寫眞機 K の前には一端に豆電球 l_1 を付けた彈性振子がある. 實驗の初まる時は彈性振子は電磁石 A によつて引寄せられてゐるが, ガンギ車の爪が脱れてピストンが動き出すと同時に電磁石の電路が切られて彈性振子が振動し出す樣になつてゐる. 此の振動は, 鏡 M_3 に依つて, 水面の動きと同時にフイルム上に記錄され, 時刻標として役立つのである.

活動寫眞フイルム上に映つたものは本文第5圖に示す樣なものである. a は細隙 Sp_2, b は輝く線條, c は固定の豆電球, d は彈性振子の一端についた豆電球である. b の形は卽ち水面の斷面の形を示すものであるが此は坐標コンパレーターを用ひ, a の細隙の像を零線として讀取つた. 又ピストンが運動を初めてからの時間は次々の駒の d の位置を讀取る事に依つて知り得た.

各實驗に於て水層の厚さはマイクロメーターを用ひて測つた. ピストンの衝程と速度は圓筒 W 上の記錄から讀取つた.

d) 此の樣にして知り得た波の斷面を順次に列べたものが第6圖—第 20 圖である. 同圖中 t はピストンが動き初めてからの時間 (秒), H は水層の厚さ (糎), S はピストン衝程 (糎), T はピストンが動き初めてから止るまでの時間 (秒) である. 此等の圖の曲線の左端がピストンの略ゝ中心に當つてゐる. ピストンの半徑は 5 糎であるから, 各曲線の左端から測つて全長の 1/6 の所がピストンの緣になる. 此の圖は皆ピストンが凹んだ位置から上に動いて, 水槽底と同一平面に到つて止つた場合のものであつて, H, S. T を色々に變へて實驗したものである.

圖に依つて知り得る如く, ピストンが上昇するとピストン眞上の水面は高まつて山になり, 山の底面積はピストンの面積よりも大きくなる. 次にピストン上の部分丈凹んで來る. 卽ちピストンの周圍には環狀の水の堤が出來る. ピストン直上の水面は更に凹んで平衡の位置よりも低くなるのが普通である.

ピストンの周圍に出來た水の堤は其の形を多少變化しながら圖の右端, 卽ちピストンから外方へ進行する. 平衡位置を越して凹んだピストン上の水面はやがて又上方に運動を初めて又前と同じ事を繰返し, 再び環狀の水の堤が出來る.

かくしてピストン直上の水面は數回平衡位置の上下に振動し, 其の振動が次第に小さくなつて靜止する. 而て其の度毎に環狀の水の堤を生じ, 此が圓形のピストンから外方へ進行する波となる. 振動の回數は水深の大きい程多い樣である. 從つて單なるピストンの上昇によつて出來る波も數個の波より成る波群である事は注意を要する.

波群の最先端卽ち所謂ウェーヴフロントの速度は第1波の山の速度よりも著しく速いから, 波の形は次第に伸びて, 最初の斜面は段々に緩になつて來る. 次に第1波の山の速度はピストンの極近所では $\sqrt{gH}$ で與へられる長波の速度よりも著しく速く, ピストンからの距離と共に $\sqrt{gH}$ に近づく. 尤も進行する波はピストンの中心からピストン半徑の2倍位距つた所で初めて出現するのであつて, ピストン直上では各點共同時に昇降する; 卽ち定常數の形を爲すから, 速度は非常に大きいのである.

第1波の山より後の部分, 卽ち第1波の谷, 第2波の山等の速度は, 大體に於て第1波の山の速度と大差はなく, 幾分其よりも遲いかの樣に見える.

波の高さは距離の $-0{\cdot}6$ 乘に比例して減少する樣であるが確かではない.

此等の事柄を更に見易すくする爲に第6圖—第 20 圖中の代表的なるものを取つて第 21 圖—第

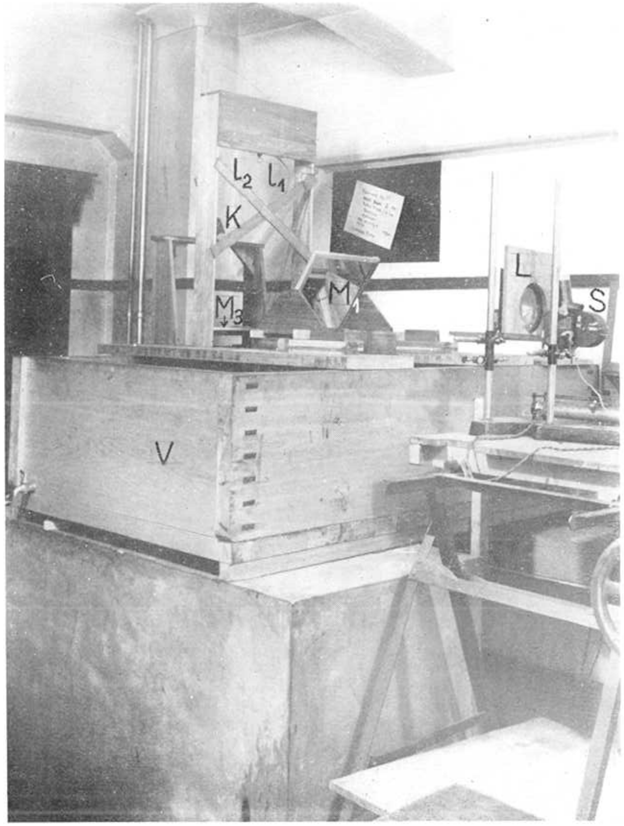

Fig. 2.

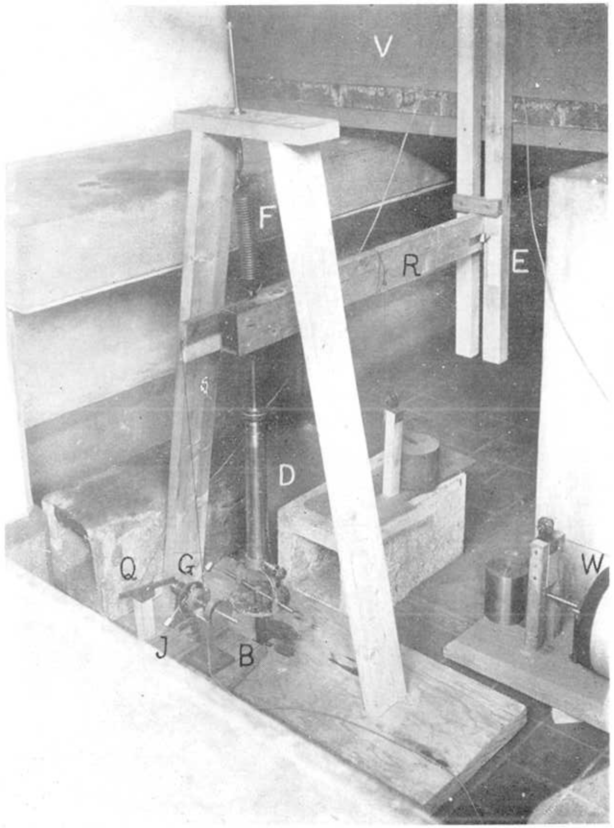

Fig. 3.

25 圖を作つた．此の圖はピストン中心から異なつた距離にある4つの點の運動を時間に對して畫いたものであつて，圖には相似律の考から橫軸に $\sqrt{\frac{g}{H}}t$ を取り，縱軸に $\frac{\eta}{H}$ 又は $\frac{S}{H}$ を取つてある．

次に第 26 圖は S, T, 及ピストン直上の水面の上昇の極大値 η_0 の間に如何なる關係があるかを示す圖であつて，縱軸に $\frac{S}{H}$, 橫軸に $\sqrt{\frac{g}{H}}T$ を取つた場合の $\frac{\eta_0}{H}$ を表すコントルである．圖中黑點は1回の實驗を表し，側に書いた數字は $\frac{\eta_0}{H}$ を表す．

此圖に依つて見られる如く，或る與へられた T の値に對して，最大の η_0 を得る爲には丁度適當な S の値があつて，ピストンの衝程は餘り大きくても，又餘り小さくても不可なる樣に見える．一般には T の少さい程，又 S の大きい程，即ちピストン速度の大きい程大きな η_0 を得る樣である．

尙此實驗はピストンの沈降する場合，ピストンが楕圓形又は矩形の場合等に就て續いて行ふ豫定である．