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REPORT ON THE

PERCEPTION OF SUBTERRANEAN SOUNDS

AND THE

PLOTTING OF SUBTERRANEAN WORK BY SOUND.

Methods and Instruments Prescribed by the Military Telegraph Service.

[Translation of a French official document of June, 1916.]

SECRET AND CONFIDENTIAL—FOR OFFICIAL USE ONLY—NOT TO BE TAKEN INTO FIRST-LINE TRENCHES.

REPORT ON PERCEPTION OF SUBTERRANEAN SOUNDS.

The present report is divided into three parts—

I. Sound perception proper, comprising (1) Natural and makeshift methods of sound observation; (2) Description of the instruments for sound observation actually in use and their method of employment.

II. Methods for determining the direction or position of a subterranean sound and the critical examination of the results, anomalies, etc.

III. Concise account of instruments now antedated, the types of which may still be found in the armies.

PART FIRST.

PERCEPTION OF SUBTERRANEAN SOUNDS.

NATURAL METHODS—MAKESHIFT METHODS.

Sounds transmitted through the earth and heard in the air generally have slight intensity. This comes from the fact that the density and rapidity of the diffusion of sound in the earth and in the air being very different, the sound waves are largely reflected on the surface of separation of the two media, which are therefore acoustically almost entirely separated.

In certain cases, however, subterranean sounds can be perceived by placing the ear close to the ground. In this case the sound perception is due to the fact that the vibrations of the earth are transmitted by contact to the little air space between the surface of the soil and the tympanum.

The instruments ought not to be applied to plank linings or foreign bodies (old sandbags masked under a thin layer of earth, etc.). The results can only be successful if the instruments rest on the natural ground, carefully smoothed and cleared with the spade of the detritus of every kind which may be found there. It is evidently wrong to place the instruments on planking, which is only in contact with the earth at unknown points. When a shock is produced on a plank lining, it is impossible to determine the direction of the impact, because the entire planking, by its many points of contact with the earth, produces a great many points of sound emission scattered along its surface. When a direction is sought in these conditions, no result is obtained; the direction remains vague and confused.

Consequently, sound perception ought to be practiced only on the natural ground, and only those results ought to be accepted as valid which are perfectly clear and obtained without hesitation; others should not be preserved.

The same rules must be followed when two instruments are placed on the same vertical line against the walls of a shaft. It will be very convenient to prepare a series of little platforms with niches on a vertical line and to install the instruments there.

The perception of the sound may also be improved by burying any large receptacle in the ground, filling it with water, and completely immersing one's ear in the water of this vessel far enough to cover part of the face and the cranium. Instead of placing the head in the water, a soldier's canteen may be used, after removing the cloth covering. It is placed on the ground and filled with water, except that a small air space is left in the upper part of the neck. By fitting onto the small neck of the canteen a rubber tube terminating in a suitable metal tip placed in the ear the subterranean sounds will be heard. The little air space imprisoned in the upper part of the canteen will serve the same purpose as the air confined in the ear in box and cover by two tubes of rubber, the sections of which appear in the figure as C_1 and C_2.

To make sound observations, a rubber tube thick enough to avoid obturation from bending is fitted to the knob with the opening O. Its length is 90 centimeters. To listen with both ears, a second stethoscope exactly like the first is used, having a similar rubber tube 90 centimeters long.

For the convenient transmission of the sound to the ears, either an elastic earpiece (fig. 2) or two single earpieces

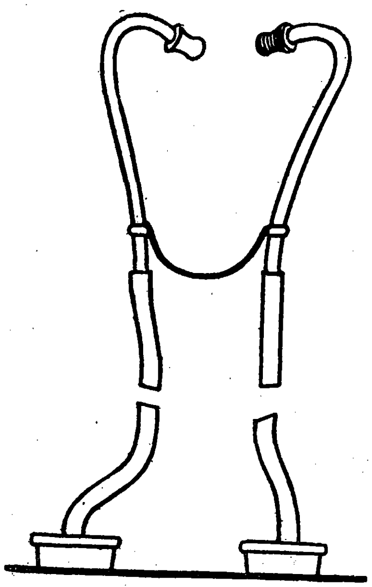


Fig. 2.

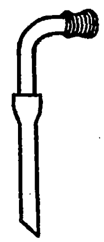


Fig. 3.

(fig. 3) to be held in the hand, are fastened to the free ends of the two rubber tubes.

The extremities of the tubes of the elastic earpieces are curved from the front backward, so as to penetrate more conveniently into the ears. The tips are distinguished by means of different colors. The white tip should be inserted in the left ear, the black tip in the right. In this way the earpiece is properly adjusted.

The seismostethoscopes are kept in pairs in a box containing the rubber tubes and the earpieces.

These instruments reproduce with great fidelity all the subterranean sounds. They will not get out of adjustment, but

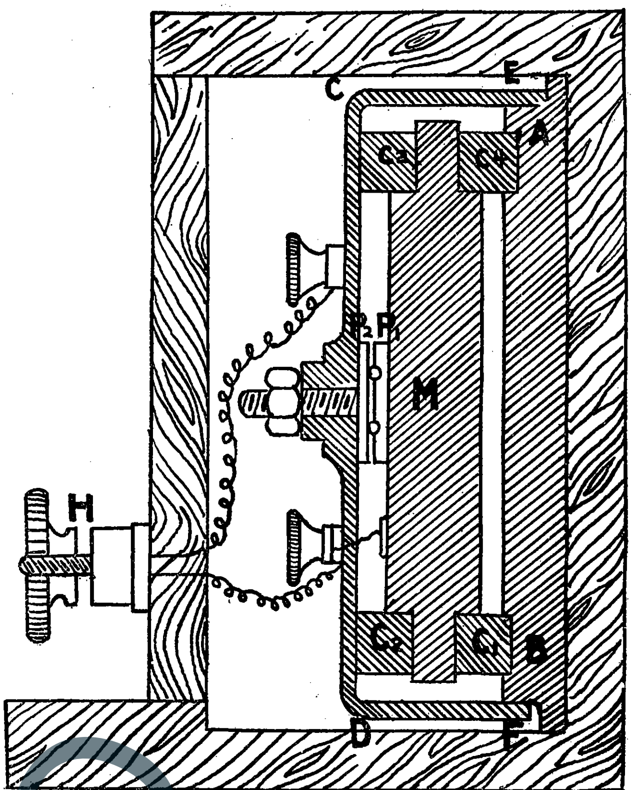


Fig. 4

the introduction of any sand into the interior destroys their efficacy. Keeping the rubber tubes constantly attached will prevent this difficulty.

left for a long time in galleries or mine chambers partly flooded, where the binding posts might become short-circuited. This consists in a steel box closed by a lid. The lid is pierced by an aperture surmounted by a long brass tube (fig. 8).

This tube affords a means for inserting the cable (lead-sheathed duplex cable) to connect with the binding posts of the microphone inclosed in the metallic case. The microphone fits snugly into the case.

A coat of black varnish applied to the lid and case makes it possible to mark the corresponding faces and properly fit the lid to the case.

To insure perfect impermeability at the mouth of the brass tube, a thick binding of Chatterton will be laid over the lead sheath of the cable and the tube of the lid. To insure perfect impermeability between the lid and the box the former will be soldered to the latter.

The properties of the microphone thus inclosed are not perceptibly altered.

Listening station with central.—It is important that a single observer should be able to control several microphones; thus an economy in time and personnel will be effected. The use of a central makes it possible also, as will appear later, to determine the position of a hostile work. (See Part Second, Microphonic method.)

The equipment comprises:

(1) A central case with six keys, containing batteries and telephone, enabling the operator to listen to the microphones successively.

(2) Six microphones of equal sensitiveness.

(1) THE CENTRAL FOR SIX DIRECTIONS. The spring keys C_1 C_2 ——— C_6 are mounted side by side (fig. 9). By their agency each of the six microphones M_1 M_2 ——— M_6 can be connected successively with a telephone by means of two battery cells (Military telegraph, model zero) contained in the interior of the case (not represented on figure 9 but in the cut 10). The line wires are attached to the binding posts as in the figure. Provision has really been made for the use of two telephones, which can be deposited in the compartments A_1 A_2. One or both telephones, as desired, can be attached to the binding posts T_1 T_1 and T_2 T_2. If one person wishes to listen alone, he will connect the bands of the headpiece B_1 to the binding posts T_1 T_1 while the second headpiece B_2 remains unattached to the binding posts T_2 T_2 (as

in fig. 9). To listen to any one of the microphones, it will only be necessary to lower the key corresponding to this microphone while the five other keys remain raised. To pass to one of the other microphones the key previously lowered is raised with one hand, and the new key is lowered with the other. In this way one can run over the entire series instantly.

If a second person wishes to listen at the same time, to check the observations of the first, he will attach to the binding posts T_2 T_2 the second headpiece B_2, which will thus be mounted parallel with the first. We should note, however, that simultaneous listening diminishes somewhat the intensity of the sound perception.

Two attachment clamps P_1 P_2 provide for hanging the central on a vertical surface, and in this position the lid hangs vertically beneath the case. Furthermore, the lid may be removed, since it is fitted with pin hinges (fig. 9). Notes on the sound observations may be registered on little plates of celluloid fastened by the side of the keys.

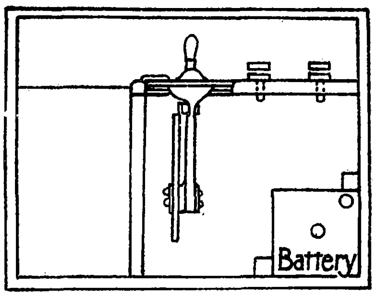


Fig. 10.

Precautions to be observed. By tapping near each microphone, when in place, make sure that the microphones are in working order and that there is no error in the connections.

Avoid the short-circuiting of the different binding posts of the wires of the microphones. When not listening, do not forget to raise the keys so as to save the batteries.

To replace exhausted batteries, unscrew and remove the surface board which supports the keys.

(2) Case with compartments for microphones. Six microphones, as nearly alike as possible, are placed for transportation or convenience of arrangement in a box provided with six compartments lined with felt.

way between A and B will therefore give the direction of the source of the sound, or, more accurately, the projection of this direction on the horizontal plane passing through A and B.

2. *Position.*—Another line of direction of the propagation of the sound may be obtained by the repetition of the same operations as above in another place (whether or not situated on the same level as the first point). These two lines of direction are

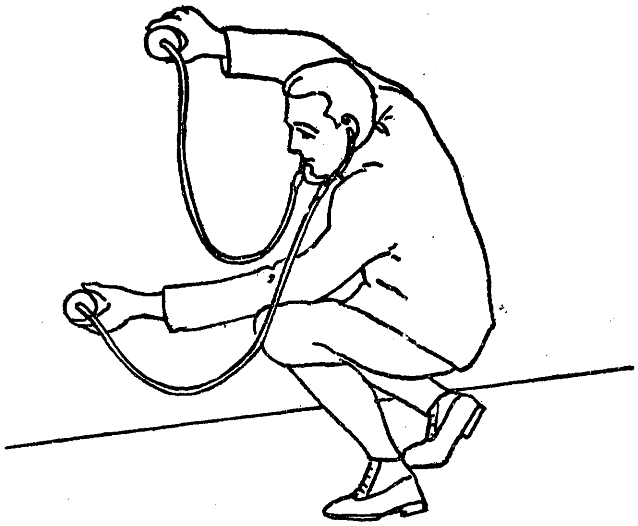


Fig. 12.

projected on the plane of the mines. Their intersection gives at once the source of the sound, if the two successive listening points and the point of impact are on the same horizontal plane.

If the latter condition is not realized, the projection M of the point of impact on any given plane (the plane of the mines, for instance), is thus determined.

If it is desired to find the position in space of the point of impact—that is, to discover the vertical level of this point—it is only necessary to make an additional test analogous to the two preceding, but this time on a vertical surface (fig. 12).

Let P P^1 (fig. 13) be the line of the vertical surface, O the position of the observer, and M the inaccessible projection of the point of impact M (in space) on the plane of the mines. To trace the direction obtained by the observer in the vertical plane, it is only necessary to let this plane revolve in a horizontal sense on P P^1 as axis, letting P O Z be the angle between the direction found and the horizon. By dropping the perpendicular Mh from m on P P^1, and by prolonging it to its junction N with the ascertained direction O Z, it is evident that the distance hN (equal to Mm) represents the unknown level of the point of impact of the sound M, reckoned from the horizontal plane passing through the point O.

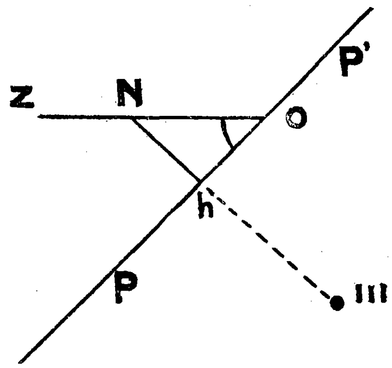


Fig. 13.

Details of the operations.—The principle of the determinations being thus exposed, it remains to enter into the details of the operations.

Suppose a determination is to be made at the head of a mine gallery R_1 R_2; the seismostethoscopes S_1 and S_2 are placed on the ground at A and B (fig. 14). The observer is not represented in the figure, but the double earpiece E will represent his position conventionally. With the instruments in the position A B, if the observer hears sounds on the right he may, to face these sounds, either revolve the position of both instruments, or, more conveniently, move one only, the other remaining stationary. In the present case the stethoscope S_2 must be moved far enough from the direction of the source of the sound, which is on the right, for the sound to pass definitely to the left, so as to bracket at once the position facing the sound. The instrument S_2 should therefore be moved from B to B^1.

We are then confronted with two possible situations: Either the removal from B to B^1 is sufficient for the sound to be heard on the left, or it is insufficient, and the observer still hears on the right. In the first case the correct position of S_2 is included between B and B^1 on the arc of the circle described (fig. 14): The point of impact is situated in the angle xOy. In the second case, to make the sound pass to the left, S_2 must be drawn farther back, or, what amounts to the same thing, the stethoscope S_1

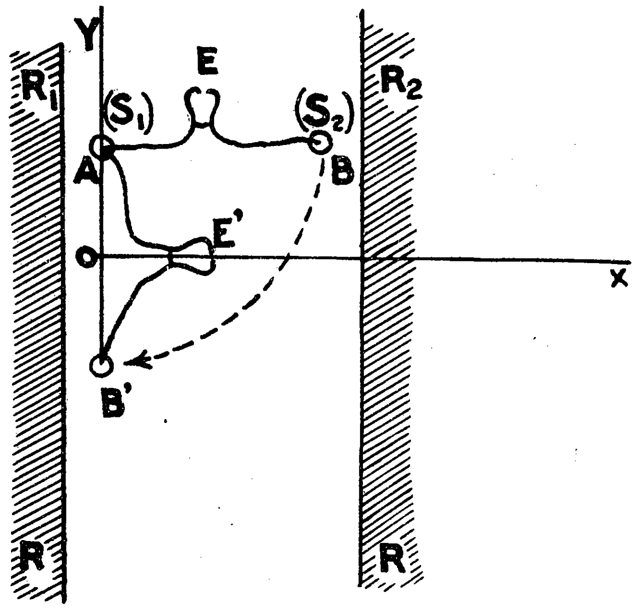


Fig. 14.

must be advanced from A. The instrument S_2 will then be left in place at B^1, and S_1 will be moved from A to A^1 (fig. 15). The observer will then have his back to the end of the mine gallery and will obviously, this time, hear the sound on his left. The correct position for S_1 will be included between A and A^1 on the arc of the circle described. The point of impact will be situated in the angle xOy^1.

To complete the determination, in the first case, for instance (fig. 14), the method of operation is as follows:

Since in the position A B, the sound is heard on the right, while in the position A B[1] it is heard on the left, the instrument S_2 should be moved to and fro in such a way that the sound will

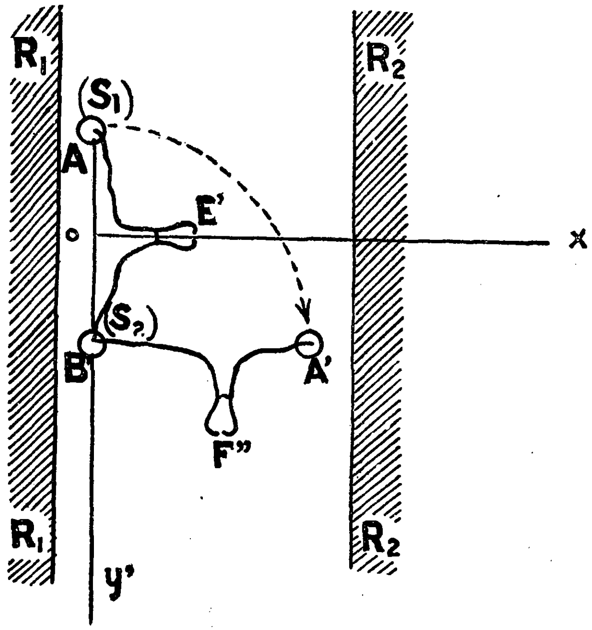


Fig. 15.

pass from one ear to the other with a constant reduction of the range of the displacements.

Consequently, the instrument S_2 is placed successively in the positions marked 1, 2, 3, 4 (fig. 16), selected in such a manner that the sounds are heard alternately on right and left: In positions 1, 3, 5 the sound is on the right, and in positions 2, 4, 6 the sound is on the left. These positions are immediately marked on the terrain by successive lines scratched with any pointed object. These lines are represented on figure 16.[1] Thus two groups of lines are developed confining ever more closely the correct position.

There comes a moment in this series of tests when the distinction between the sensation on the right and left becomes imperceptible as one approaches the desired position,[2] as, for instance, when the position 7 is tested after 5 and 6. It is advisable, then, to ignore the doubtful position 7, and only to register the posi-

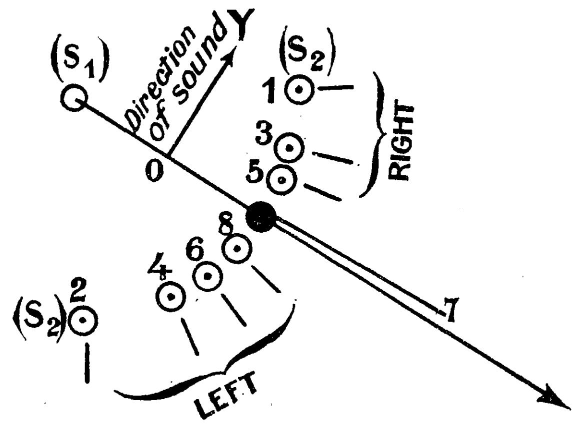


Fig. 16.

tions where the distinction of the sound as coming from right or left was clearly defined (positions 5 and 6); the line marked 7 should therefore be obliterated.

To consummate the determination, the instrument S_2 should be replaced in position 5 (the last one where the position of the

---

[1] The practice of marking lines on the ground is convenient for preserving a record of the successive positions occupied by the movable instrument, and thus avoiding a return to positions already observed.

[2] If the movements are too short, it may happen that the side of the perception was not reversed.

sound was still clearly discernible as on the right), then moved to 8, for instance, to see whether the sound passes clearly from one ear to the other. If this is so, the position 8 will be marked on the ground. As the positions 5 and 8 are near enough, one may, without committing a serious error, assume that the position sought is halfway between the marks 5 and 8. In actual practice it will often happen that the positions 5 and 8 of the seismostethoscope almost coincide. After the desired position has been found it remains to erect the perpendicular OY on OX, O being the center of the space between the two stethoscopes.

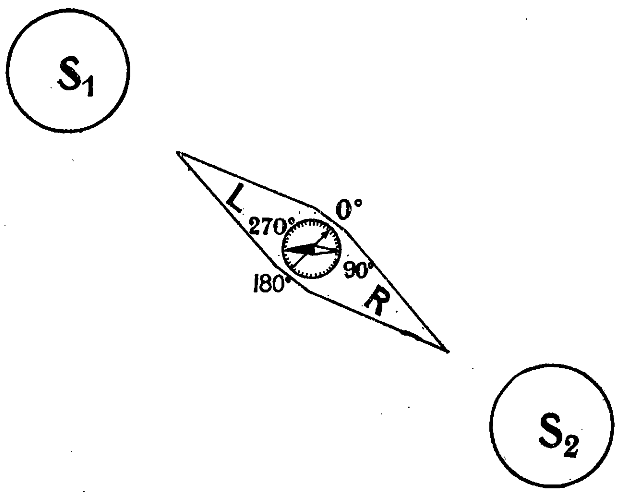


Fig. 17.

If the operator is skillful, the complete determination can be made very quickly without the necessity of marking the successive positions of the instrument S_2 on the ground.

Use of the compass.—It is necessary to determine the ascertained direction OY in respect to some known direction, as, for instance, that of the magnetic north.

For this purpose the points of the board on which the compass rests are set toward the stethoscopes S_1 and S_2 (fig. 17) in such a way that the letter L painted on the board is toward the left *perpendicular erected at the center of the straight line connecting these two microphones.*

Example: We find the following order of classification for the six microphones:

IV
V and VI
II
III
I

By shading (fig. 23) the perpendiculars in the way indicated we readily discover that the sound must be situated on the section AB of the perpendicular erected at the center of the interval V VI. To fix more closely the position on this section we must

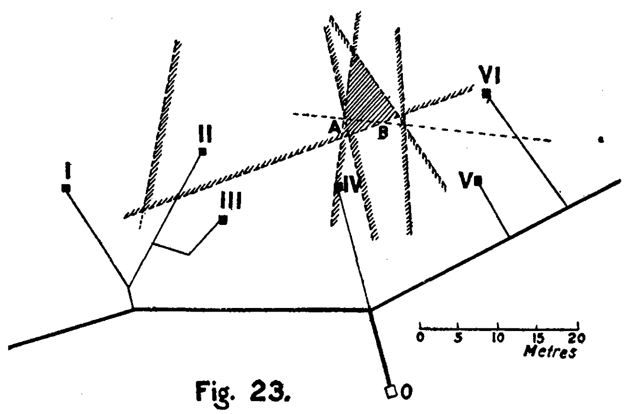


Fig. 23.

consider the qualifying circumstances involved in the order of the microphones. For the sake of brevity no mention has been made of these.

2. Three microphones register the same intensity. This case will be quite rare. The point of impact is then situated at the center of the circle passing through the three points.

3. Several microphones register no intensity at all.

First example: Assume that the order of classification is as follows:

IV
II
III
I, V, VI (no intensity).

We readily get the triangle ABC as the only possible region (fig. 24). Thanks to microphone VI, this region is bounded by the side AC. Since, moreover, the microphone VI gives no perceptible sound, we may be sure that if II, III, and IV give a sufficiently intense sound the unknown point of impact can not be near the side AC. The possible region will thus be reduced to the doubly-shaded triangle aBc. To determine the position of the unknown point with greater accuracy it would be necessary to ascribe certain qualifying data to the microphones IV, II, and III. If the silent microphones had not existed we should have been reduced to the unlimited region DBE.

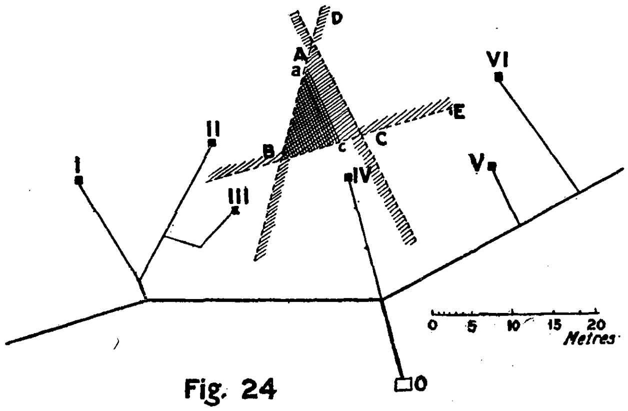


Fig. 24

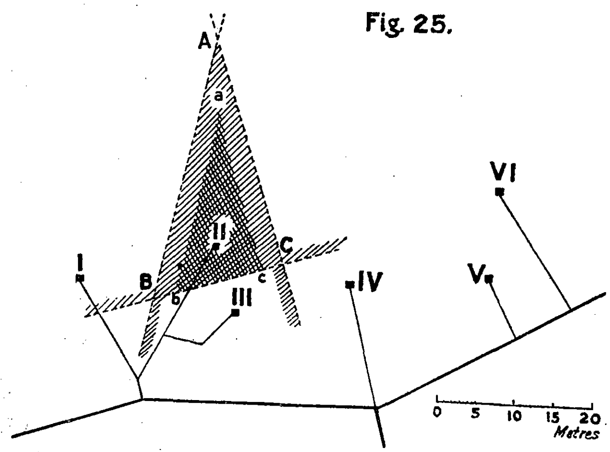
Second example: All the microphones are silent except two. We then have:

II
III
I, IV, V, VI (zero).

If the microphones I, IV, V, VI did not exist we would have as possible region the whole region situated above the unlimited line BC (shaded side of this line) (fig. 25). Thanks to the existence of the silent microphones I and IV, we can confine this region to the triangle ABC, and, if the sound registered by microphones II and III is not feeble, to a smaller triangle (doubly shaded) such as abc. By this example we perceive clearly the evidence furnished even by microphones that are silent by reason of their remoteness. It would naturally be much better if they were near enough to furnish positive data capable of defining more closely the point of impact. If the microphones II and III are both quite clearly heard the point of impact is included between the straight line bc and the microphone II; but if the microphones II and III render only a feeble sound the point of impact is situated on the other side of microphone II toward the summit a.

Practical remarks.—From the practical point of view it is expedient to consider the remarks already made in respect to the seismostethoscopes.[1] The instruments should rest solidly on the earth with the handle up. They ought not to be placed on a timber lining.

Fig. 25.



When the instruments are not installed at the head of the mine galleries, other places may be used by removing the timber lining from the vicinity of the point selected. It is advisable to hollow out a nitch of some depth, so as to remove the microphone from the remaining timber lining and to protect it from the laborers. Completely finished mine galleries will naturally be used as far as possible. But since others will also be used it will be advisable to take every precaution against the laborers up-

[1] The remarks made on the seismomicrophones in Part First will also be consulted. Air-tight cases may also be employed in cases of necessity, any tension of the cable likely to make the microphone unsteady being carefully avoided.

setting the microphones or injuring the cables. Prudence would suggest that the electric lines be hung by cleats along the ceiling of the mine galleries. Special care in respect to electrical insulation ought to be observed in the installation of the cables.

It is absolutely necessary to verify the perfect working condition of each microphone after its installation, and particularly the exact correspondence of each microphone with the corresponding key of the central, as mentioned in Part First. The operator should speak into the microphone or tap it with the finger. It is convenient to arrange the connections so that the order at the central will be the same as that of the microphones on the terrain.

Inasmuch as the six microphones have been grouped with care, it is not advisable to substitute any microphone for one of them. Whenever, in consequence of an accident, certain of them are out of order, it is best to provide oneself with a new case of six and to reserve the instruments which are still serviceable for other uses, such as the supervision of a loaded mine. But if it is desired to complete a partial set with other microphones, the equivalence of the new microphones with the old ones must be established by placing all the microphones side by side in a restricted space and comparing them by means of the central with six directions. Regular blows with a pick handle delivered at a great distance should be heard in an identical manner, whichever microphone is used.

Of the six instruments, it is advisable to place at least two in a direction roughly perpendicular to the front (for example, the microphones II and III or IV and VI of fig. 20.) These barrage microphones make it possible to detect immediately a hostile penetration into the network of the mines. The perpendiculars erected at the center of the Groups II and III or V and VI divide the terrain into an exterior and interior zone.

As for the disposition of the six microphones, it is often imposed by the arrangement of the mine galleries. Yet one should avoid, as far as possible, symmetrical dispositions which reduce the number of the sectors. The number of the sectors is 101 in the general case. It is reduced considerably in the case of symmetrical dispositions. For instance, if the six microphones occupied the points of a regular hexagon, there would be only 12 sectors. The most irregular dispositions possible ought therefore to be adopted. Avoid especially placing several microphones on the same straight line.

Method of making determinations.—It has already been explained in Part First how one or two observers can use the central of six directions. Thanks to the rapidity with which one can listen to the six microphones successively, it is easy to tell whether work is in progress in an excavation chamber or in several simultaneously. In fact, there is generally a certain rhythm in the handling of a tool, and, since it takes only a few seconds to run over the six microphones, if the same rhythm is noticed on all the instruments it will be concluded that there is only one excavation chamber.

The observations made will be noted rapidly. It is of the greatest importance to repeat several times, for, however rapidly the observation may have been made, the different blows heard may not have been delivered with the same force. In this case the microphone which has registered the greatest intensity is not the closest to the point of impact. But this cause of error will be eliminated if the number of observations is great enough.

When the microphones have been classed in the order of their intensity, the qualitative indications resulting from the average intensity of the strokes heard will be placed opposite. By means of this information the point of impact can be located at leisure on the plan of the mines.

COMPARISON OF THE STETHOSCOPIC AND MICROPHONIC METHODS.

It remains for us to explain the advantages and disadvantages of the two methods for the solution of one of the three following problems: (1) To determine the existence of an excavation chamber; (2) to determine the direction of the chamber; (3) to determine the exact position of the chamber.

(1) *Stethoscopic method.*—The seismostethoscopes are easily handled and permit the taking of observations without any previous installation. Their trustworthiness is greater than that of any microphone, and their sensitiveness, although somewhat inferior, is still very satisfactory. Their use is therefore especially appropriate for determining the existence of an excavation chamber.

The same advantages exist in the determination of the direction of an excavation chamber, except that in this case the observer should have special instruction.

But if it is desired to fix the exact position of the point of impact, we have seen that two skilled observers are needed, In mounting the rod it is necessary to be sure that there is no lack of contact between any two consecutive sticks. Such a gap would be as harmful as the interruption of a telephone line.

The ordinary case of listening sticks contains 12 sticks, each about a meter long; but several sets may be used to reach the desired length.

CHAPTER II.

In the preceding chapter the use of the methods in the case of supposedly homogeneous terrains has been described, but the situation is not always of this character. The causes of heterogeneity are many,—the existence of mine galleries (lined or not), layers of rock, areas disturbed by explosions, subterranean

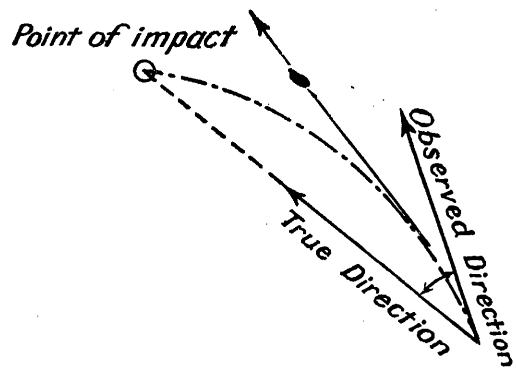


Fig. 26.

foundations, etc. The strict application of the methods heretofore described would expose one to mistakes or impossible situations. It is clear that the ear alone would also commit errors, since they would be due to the nature of the terrain.

No universal method for the solution of the problems of heterogeneous terrain can be given, but it is often easy in each individual case to determine a region containing the point of impact restricted enough to serve as useful information.

General observations.—When a terrain is not homogeneous, the acoustic waves which are propagated through it undergo modifications manifested in changes of velocity, of direction, and of intensity. It follows that the listener will be deceived in his estimations, whether he receives the sounds directly or uses the listening instruments. In particular the seismostethoscopes will render erroneous directions and the seismomicrophones will give abnormal intensities. Such irregularities have actually been observed.

1. *Stethoscopic method.*—It is often observed that the direction, although clearly marked, is inexact. This is due to the fact that there is a constant variation in the sound direction from the point of impact to the point of listening (fig. 26).

Evidently the position of the point of impact can not in this case be found by an intersection.

It is therefore first necessary to determine more than two directions for the same point of impact, so as to have several intersections. If the different points found are grouped in the same region, the point of impact will probably be located there also.

Sometimes it has been found impossible to obtain any direction at a selected point. The only remedy, if the cause of the impossibility is not connected with the source of the sound itself, is to undertake the determination at another point. (See in this connection the above remarks concerning shocks derived from an enemy plank lining.)

2. *Microphonic method.*—It has been assumed that, after the classification of the microphones in the order of their intensity, it was only necessary to trace the sector of the impact bounded by the perpendiculars erected at the centers of the straight lines joining the suitable pairs of microphones. But the abnormal conditions of the terrain often complicate the results. In actual experience the place of equal intensity for two microphones is rarely a straight line; it is a band, more or less straight, but not rectilinear. The sector of impact is therefore limited otherwise than on the theoretical design, and the point sought may lie outside the given sector. In theory, furthermore, one is generally apprised of the heterogeneity of the terrain by the impossibility of obtaining a sector corresponding to the classification of the microphones. In fact, the six microphones can be arranged in order of intensity in the 720 possible permutations in the order of the six microphones, supposing that all the intensities are different. But as there are only 101 sectors, therefore the number of impossible cases is 720—101, or 619. When one of these cases is observed, one may be certain that the terrain is hetero-

geneous,[1] but it does not follow that the terrain is homogeneous if one chances to fall upon one of the 101 possible permutations.

Example: It will be shown by a simple example that, even in certain cases theoretically impossible, a sufficiently exact solution can often be found, *provided the terrain is not heterogeneous in all parts,* a situation in which no conclusion would be possible.

Example:	Data.
V	Very loud.
III	Rather loud.
II, IV	Medium.
VI	Feeble.
I	Zero.

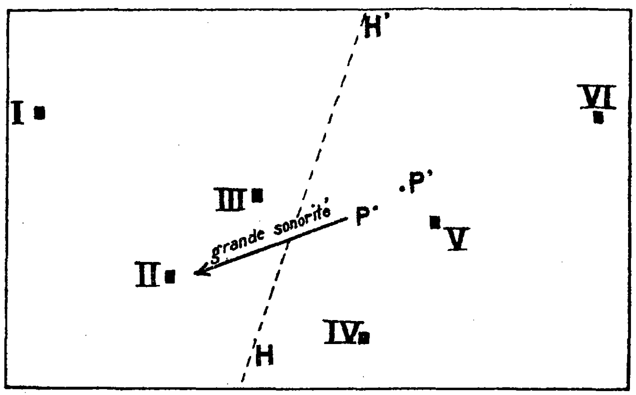


Fig. 27.

Figure 27 shows that the data is incompatible. In fact, there can not be identity in the intensity of microphones II and IV and at the same time a greater intensity in V than in III. There is a glaring abnormity.

[1] Other circumstances, not ascribable to the terrain, may lead to erroneous conclusions, and one should make sure that none of these are involved. These are (1) the disparity in the sensitiveness of the microphones, (2) the fact that the microphones do not rest firmly on the ground, (3) errors of perception (errors arising from different blows heard not having been delivered with the same force), (4) the existence of more than one excavation chamber. These different causes of disturbance may be eliminated.

But it ought to be possible to correct data that can not be satisfied (if the terrain is not entirely heterogeneous) by considering all the conditions to be fulfilled.

If we consider the simplest (but not the only) method of making the data compatible, it will appear that it is only necessary to change the equality given by the microphones II and IV to an inequality, with the microphone IV giving the greater intensity. This inequality suggests itself if one considers all the other data, namely, the very great intensity of V and greater intensity of VI than of I.

The point P will be adopted, although not on the perpendicular HH^1 erected at the center of the interval (II–IV), because this point is sufficiently in accord with the other data.

The corrected order of the microphones is then as follows:

V	Very loud.
III	Rather loud.
IV	Medium.
II, VI	Feeble.
I	Zero.

Experience has shown that, in reality, the point of impact (P^1) is near the point P^1 selected. It follows that the terrain displays a special sonority between P and the point occupied by the microphone II. If the point of impact had been in another region, the microphone II might have given normal results, for the abnormity observed is the result of a special character of the ground between P and the microphone II.

This manner of procedure, which aims to make the best of a combination of incompatible data, must be made only with great circumspection.

To sum up, the geometrical construction of the perpendiculars described in Chapter I gives the complete solution in cases which are practically normal, but its inflexibility is an obstacle to the location; in the case of heterogeneous terrains, of the situation of the point of impact. It is better, then, not to adhere too closely to the construction, but to be guided rather by the aim of making all the data furnished by the sound of all the microphones as compatible as possible.

Conclusion.—Given the complications due to the possible heterogeneity of the terrains, it is advisable to have recourse to all means at one's disposal; in other words, to the combination of the two methods described, and to the use of them in the most critical spirit.

The principles on which the two methods are based are quite different. In the microphonic method, only the intensity of the sounds is involved, and each instrument is heard separately. In the stethoscopic method, on the contrary, while the two instruments are heard simultaneously, the impressions produced are not absolutely simultaneous, and this gives rise to a certain delay which undoubtedly exercises an important influence in the sensation of distinction between right and left.

The two methods will therefore be mutually helpful, and will exercise a mutual control.

CHAPTER III.

INSTRUCTION OF THE MINE LISTENERS.

The mine listeners should be trained as often as possible at the rear, because only there can direct verification of the directions and the situations of the impact be obtained. It is at the rear, also, that imperfectly trained listeners should be developed by progressive exercises, and that the faults committed by listeners already trained should be corrected.

The use of seismostethoscopes or similar instruments requires a sustained training. The periods of instruction should be short and frequent.

The use of the seismomicrophones is simpler and does not require the same degree of skill. It is advisable, however, that some lessons be given at the rear, to familiarize the listeners with the instruments and show them the results that may be expected.

1. *Seismostethoscopes.*—The methods and remarks set forth in Part First and in the first chapter of Part Second will be used as guides. The exercises can be performed either on the surface of any terrain (as far as possible homogeneous, so that the exercises may not be complicated at first), or in a listening shaft with a circle of impact used in the listening schools. (See the provisional instruction for the listening schools.)

When the operations are conducted on the surface of the ground without special preparations, a natural terrain may be chosen. The grass and its roots will be removed on a space of a square meter, and the ground will be worked to a perfectly level surface. The seismostethoscopes will be installed on this surface.

COURSE OF INSTRUCTION.

Exercise I: The two seismostethoscopes S_1 and S_2 remain in the same position, the eyes of the listener being closed. The ground is tapped with the finger between the two instruments, the finger moving several times from S_1 to S_2 and from S_2 to S_1 along the straight line connecting S_1 and S_2. The listener should sense the passage of the sound from right to left and from left to right. He should be able to discern the moment when the finger passes the center of the space. The listener can practice alone by closing his eyes and then observing whether he has succeeded in discovering by the sound the center of the interval S_1 S_2.

Exercise II: With the listener in the same position, an assistant strikes the ground with a pick handle along a line parallel with the straight line connecting S_1 and S_2. This exercise is similar to the former, except that the ground is struck beyond the instruments instead of between them. At first a parallel line will be taken 5 meters from the instruments, then successively lines at 10 meters, 15 meters, 20 meters, etc. The listener should stop the man who strikes the blows whenever the point of delivery seems to be directly in front of him. At this moment the position of the pick should be on the perpendicular erected at the center of the straight line S_1 S_2. This exercise becomes increasingly difficult with the greater distance of the parallel on which the blows are struck.

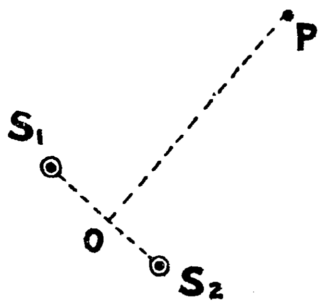


Fig. 28.

Exercise III: Practice determinations in a listening pit two meters deep and a meter and a half in diameter with blows delivered at a number of points in a striking circle traced or dug with the pit as center and a radius of 8 or 10 meters. The man will handle the instrument as previously explained. When the listener thinks that he has suitably arranged his instruments S_1 and S_2 (fig. 28), he will often be able to improve and correct their position by striking with his finger at O, at an equal distance from S_1 and S_2, and timing the blows of his finger with the blows of the pick in the enemy's work. Directly after each blow heard the listener will tap with his finger at O with an intensity calculated to render the same impression on his ears as the blow of the pick. If the instruments are suitably placed, the finger taps will seem to have the same origin as the strokes of the pick. If the instruments are not suitably placed, the strokes of the pick will at once seem to be on the right or on the left of the center, and the listener will be led to correct the position of the two instruments. One may find on the straight line S_1 S_2, to right or left of the point O, some point where the finger strokes seem to be delivered in the same position as the blows of the pick. If this point, m, is somewhat to the right of O, S_2 must be moved back a little; if the point is somewhat to the left of O, S_2 must be moved forward. Then by striking at the center of the space S_1 S_2 a sensation similar to that of the blow of the pick should be produced.

Remark.—By operating methodically, as has been described, and by tracing all the positions "right" and "left" on the ground, it is impossible to make a mistake in the choice of the field for the determined direction. The observer will always face the sound. Yet experience has shown that listeners left to themselves do not always proceed systematically, and that, having found a position in which the sound is "in front," they really have their backs to its source. To avoid such serious mistakes, it may be serviceable to accustom the listeners to recognize the direction of the sound on the line determined. For this purpose, the line S_1 S_2 is traced on the ground, and at its center a perpendicular is erected on both sides representing the direction of the enemy sound. The two instruments are placed on this perpendicular—that is to say, across the former position of the two seismostethoscopes. The sound will then be heard indubitably on the right or left, and this will determine the direction of the enemy work.

Exercise IV: Use of the compass (see above). To avoid all confusion, the compass is graduated from zero to 360. To any direction there corresponds but a single degree on the scale.

Exercise V: Determination of the level of the impact (see discussion concerning fig. 18). Repeat along a slope the experiment described (fig. 18).

Repeat Exercise III on varied terrains.

2. *Seismomicrophones.—Exercise I:* Install six seismomicrophones on a homogeneous terrain. Remove the grass on the six emplacements selected on a surface 20 cm. square, and make it as level as possible.

The microphones should be placed at intervals of from 12 to 20 meters from one another. Any plan of arrangement may be adopted, as, for instance, that of figure 20.

Begin by plotting the emplacement of the microphones on a sheet of paper. Measurements are made with a double decameter and transferred to the paper, according to scale, by means of the compass. This map will serve eventually to locate the point of impact.

The microphones will be installed on the emplacements chosen, perfect contact with the soil being assured. The different instruments will be connected in the order in which they are situated with a central masked behind a wood. The ground will be struck as hard as possible with the pick, so that the blows will be heard in as many microphones as possible.

When the listener has made the plan of the intensities, leave the pick in place and measure the distances from the pick to the two nearest microphones. The location of the pick will be plotted on the map as soon as the listener shall have determined it. The error involved will be calculated by the distance from the point chosen by the observer to the true point (the location of the pick).

Remarks.—The central includes two telephones: One of them will be used by the instructor to control the observations of the listeners being trained. Be sure to connect the positive pole of the batteries as marked on the central with the band of the headpiece painted white at its extremity.

When any microphone has a tendency to whistle, lift the instrument and set it down firmly on the ground, giving it a shock; all whistling will then cease. Never fail to raise a key that has been lowered before lowering another.

Exercise II (Graphic exercises): 1. With the locations of the six seismomicrophones plotted on the paper, trace the 15 possible perpendiculars erected at the center of each pair of instruments, using every possible combination, so as to obtain a division of the terrain in sectors. The 101 sectors will, of course, not be obtained within the limits of the sheet of paper, but, nevertheless, a considerable number will be obtained.

2. Try to modify the emplacements of the microphones on the paper so as to realize, in a region arbitrarily chosen, a division of the terrain into a large number of sectors of small surface.

Remark.—To simplify these graphic exercises, we may begin with a smaller number of microphones; as four, for instance.

PART THIRD.

The first two parts of the present edition aimed to describe the listening instruments of the military telegraph of the latest models, and their employment.

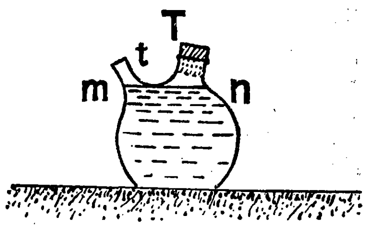


Fig. 29.

As there are still in the armies different types of listening instruments of former models, it is advisable to mention them in this Part Third. They have been described, together with the methods for obtaining the direction and location of subterranean sounds, in the first edition of this report (May, 1915). We shall confine ourselves, therefore, to a brief résumé of their nomenclature.

1. *Water stethoscope* (*canteen*).—This makeshift instrument may be used for lack of others. It acts either buried or simply placed on the ground.

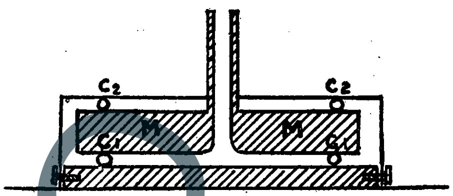


Fig. 30.

When the canteen has been entirely filled with water and placed on the ground, the operator blows very gently through the small mouth t, to which a rubber tube is attached, so as to expel a certain quantity of water, which passes through the large mouth T (fig. 29) until bubbles of air appear at T. T is then corked. At this moment the level m n of the water is properly adjusted. A Y-shaped earpiece is then attached to the rubber tube so that both ears can be used.

2. *Air stethoscope.*—Two types of air stethoscopes have been employed for ascertaining the direction (fig. 30 and fig. 31). In the first, the inert mass M was mechanically insulated from the rest of the instrument by two rubber rings, C_1 and C_2 (fig. 30). In the second, a thin brass plate f (fig. 31) insulated the mass M. This second type was the more common, and is still found in the armies.

3. *Microphones.*—Two former types are still in use, the water-tight microphone and the simplified microphone.

I. *Water-tight microphone.*—This microphone consists of a metallic case absolutely water-tight, one of the sides of which is a vibratory plate 12 cm. in diameter and three-tenths mm. thick, protected against shock by a metallic screen (fig. 32).

The microphonic contacts in carbon are borne by the vibratory plate and the rigid pieces of the metallic case respectively. The water-tight microphone is used by being immersed vertically in a steel vessel full of water, which is buried in the ground up to its upper part, the ground being heaped up around it.

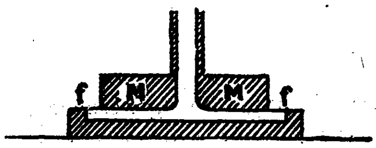


Fig. 31.

The vibrations of the earth act through the medium of the water on the vibratory plate.

With each microphone are issued a receiving box containing two batteries, a little transformer with sliding primary (used to make the sensitiveness vary), and a headpiece with earpieces of 2,000 ohms (sic. probably means 20 ohms). The headpiece has two independent bands, mounted in parallel when only one water-tight microphone is used. When two water-tight microphones are available the bands are used separately, each telephone of the headpiece being connected with one of the microphones. This arrangement makes it possible to determine whether a sound is projected from a point nearer one or the other of the two microphones.

Simplified microphones (fig. 33).—This microphone, intended for the perception of sounds produced near a charged mine chamber, consists of a microtelephonic disk (the model used in the microphones of the military telegraph) deprived of a part of its protecting metal plate. A curved steel wire, forming a spring, is soldered to one of the sides of a parallelopipedic can-

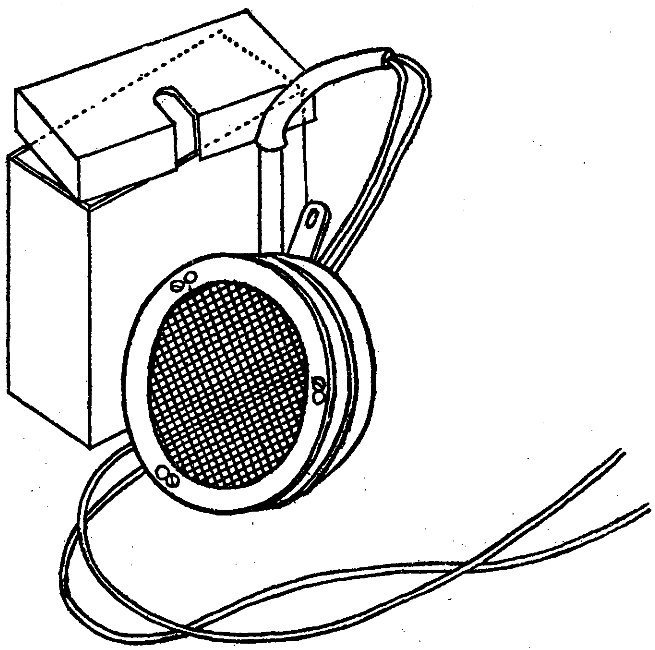


Fig. 32

teen of thin steel. This wire rests on the center of the carbon plate of the microphonic disk.

The canteen is filled with water when the microphone is to be used. It simply rests on the ground.

A reception box accompanies each microphone. This box contains two compartments, one reserved for two battery cells in a series, the other for the telephonic headpiece formed of two earpieces of 10 ohms mounted in series.

This receiving box, like that of the seismomicrophones, may be used alike for the simplified microphone, the water-tight microphone, and the seismomicrophones. It does not contain a transformer.

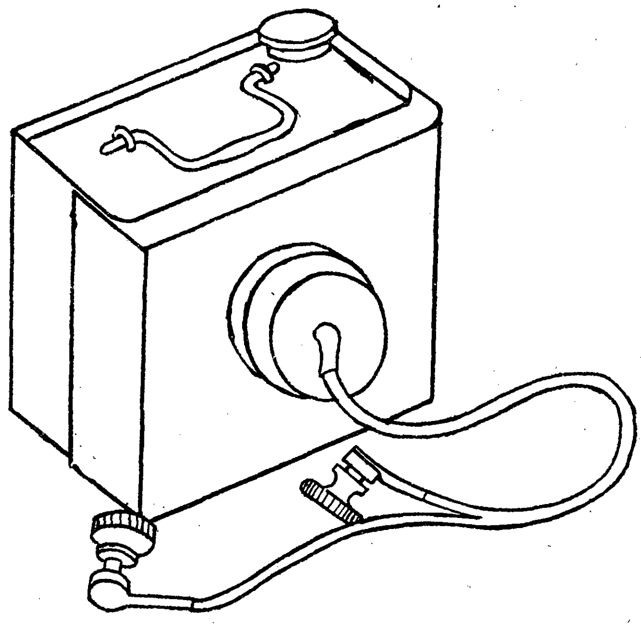


Fig. 33.

Remarks.—The instruments just described may still be found in the armies, as well as in certain engineer parks or reserve stores, where they can be procured.

To simplify as far as possible both the manufacture and use of the material, the only instruments constructed by the military telegraph are the seismostethoscopes and seismomicrophones of which the characteristics and advantages have been presented in Part First of this report.

APPENDIX I.

MILITARY TELEGRAPH SOUND PERCEPTION INSTRUMENTS FOR MINES—DESCRIPTIVE CATALOGUE OF THE INSTRUMENTS AT PRESENT MANUFACTURED.

Shipments include, according to the orders, (1) complete packages; (2) separate instruments.

1. Complete packages of material.

There are three categories of complete packages. (See I, II, III.)

Fig I.

I.

Nonelectric Instruments.

Case of seismostethoscopes (fig. 1).
This case contains:
- 2 seismostethoscopes.
- 2 rubber tubes, 90 cm. long.
- 1 double elastic earpiece.
- 2 simple earpieces.
- 1 compass with graduated scale 0°–360°.

II.

Electric Instruments.

Case of seismomicrophones (fig. 2).

This case of three compartments contains:

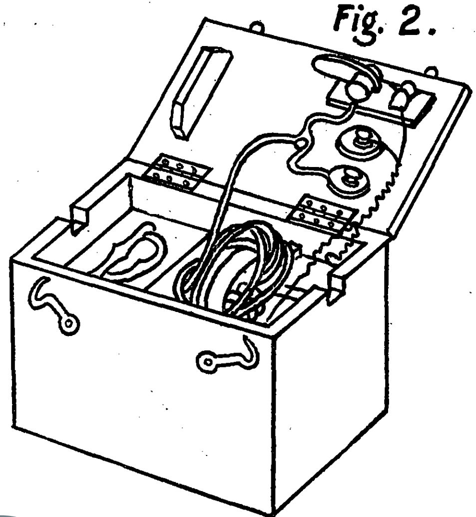
1 seismomicrophone (see also fig. 5).

1 telephone headpiece, with 2 earpieces, each of 10 ohms mounted in series.

2 batteries of the Military Telegraph, model O.

There is also sent (1) a water-tight case for the seismomicrophone (see fig. 6), serviceable when the seismomicrophone has

Fig. 2.



to remain long in water; (2) 75 meters of secondary duplex cable and Chatterton.

III.

Complete microphonic central station (figs. 3 and 4). The central station includes:

1 central of six directions (fig. 3), including 2 batteries and 2 telephones of 20 ohms.

1 compartment case of 6 seismomicrophones (fig. 4).

6 rolls of secondary duplex cable of 150 meters each.

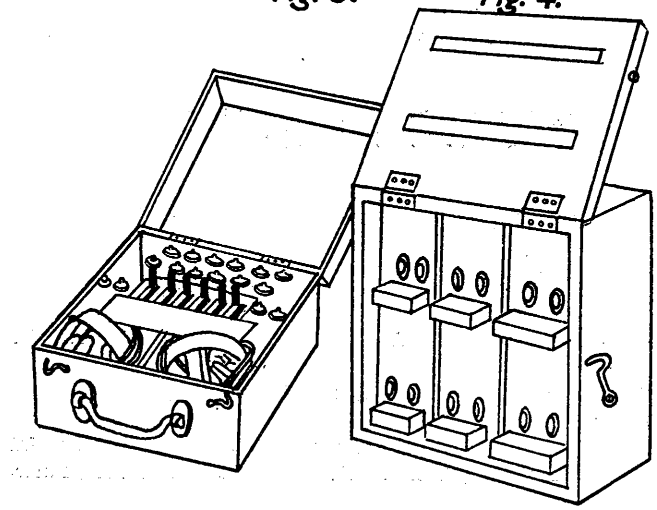
6 water-tight cases (fig. 6), Chatterton.

2. Packages of separate instruments.

Certain separate articles forming a part of the above equipments can be supplied. These articles are the following:

1. Compass with scale graduated from 0° to 360°.
2. Rubber tubes 90 cm. long.
3. Double elastic earpiece.
4. Simple earpieces.
5. Seismomicrophone: The seismomicrophones ordered separately ought to be used only to replace those of the cases represented in figure 2 and not those of the cases in figure 4. In fact,

Fig. 3. Fig. 4.



the latter have been selected with a view to all six possessing the same sensitiveness, and any seismomicrophone chosen at random can not replace one of them. If one or more seismomicrophones of the case (fig. 4) are destroyed, order a new case (see 7), and use the remaining microphones for the same purpose as those of figure 2.

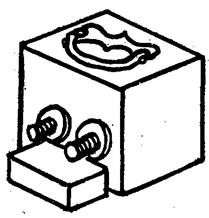
6. Water-tight case for the seismomicrophone (fig. 6).
7. Compartment case of 6 seismomicrophones (fig. 4).
8. Central of six directions (fig. 3).

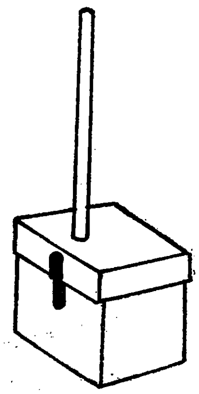
9. Telephones of 20 ohms (2 earpieces of 10 ohms in series). This telephone suits the seismomicrophone case as well as the central of six directions.

10. Substitute batteries of the Military Telegraph No. 0. These batteries suit the seismomicrophone case as well as the central of six directions.

Fig. 6.

Fig. 5.





11. Double secondary cable (rolls of 150 meters). Give the number of rolls.

12. Double lead-sheathed cable. Give the length.

13. Chatterton.

Orders are filled by the Central Establishment for Special Engineers Material (E. C. M. S.), 39, Rue de Bellechasse, Paris.