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MEMORANDUM RE PROPOSED ELASTIC-WAVE METHOD OF UNDERGROUND ANALYSIS AS APPLIED TO THE DETERMINATION OF THE DEPTH OF OVERBURDEN IN PROSPECTIVE DAM SITES

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I. PREVIOUS METHODS MAKING USE OF ELASTIC WAVES: The previous elastic-wave methods for determining the nature of underground structure have been known as sonic or seismic methods.

With the exception of a few experiments using sound waves of one frequency, generated by a "buzzer" and received after an underground excursion by means of a sensitive microphone, little has been done in the way of sonic depth finding on land. The sonic method has been brought to a high degree of perfection in measuring the depth of the ocean, but the procedure does not, so far as the writer has been able to learn, parallel the method about to be outlined for use in probing earth depths.

The seismic method makes use of elastic waves generated by an explosion and received, after an underground excursion, by means of a "geophone" recording through a galvanometer. The method has not been used to any extent in this country for determining the depth of overburden in dam site work because of the unwieldy nature of the procedure and the high cost due to the many expensive dynamite charges or to the many equally expensive geophone parties. The method has been, in general, used to determine the existence of "salt domes" (on the flanks or tops of which oil may presumably be located) and to detail their shape, size, and depth.

An explosion releases a great store of energy. To reach a geophone, say eight or nine miles away from the shot, from four to five hundred pounds of explosive must be used in a single shot. Much of the released energy is lost in the air. Only a part enters the earth. That which reaches the wave front and which is thenceforth to be propagated by the elastic properties of the terrain is probably but a small fraction of the released energy. The waves generated are of fortuitous periods. The records received show that the registered vibrations are from 3/100 to 5/100 of a second in period. They penetrate to a maximum depth which is variously estimated to be from 3000 to 5000 feet. Using this method upwards of a hundred salt domes have been located in the Gulf-States region.

II. THEORETICAL CONSIDERATIONS UNDERLYING THE NEW ELASTIC-WAVE METHOD:

(a) Elastic waves are propagated in the earth with the period with which, as such, they set out. Dispersion may require a modification of this statement for prospecting work where great depth is to be probed, as in an oil field. In the case of a dam site it may be taken as rigorously true within the limits of the errors of observation.

(b) The velocity of propagation of elastic waves is determined by the elasticity and density of the medium transmitting them, and on the type of vibration propagated - longitudinal or transverse. In the absence of evidence to the contrary it is assumed

that the various types of overburden about a dam site would give about the same velocity of propagation for elastic waves of one given type, down to the rock, at which an abrupt and effective change of properties would be met. Experiment alone would determine the extent to which the wave velocity of propagation would vary with, say, sand, clay, or gravel in the overburden.
(c) The velocity of propagation of elastic waves is essentially independent of the amplitude or period of the impressed vibration: a shorter period is propagated with a correspondingly shorter wave length, but the velocity is, for the purposes of the proposed method, the same.
(d) The wave length is determined by the relation L = V/T where L is the wave length, V the velocity, and T the period of the vibration.
(e) The amplitude of the vibration is a function of the energy introduced and will, of course, diminish with distance.
(f) The elastic waves meeting a substance of markedly different elastic properties will either be refracted into it or be reflected from the face separating the two media, provided that the thickness of the second substance is an appreciable fraction of a wave length of the elastic vibration. For the sake of argument let us say that if the second substance is one in which the velocity of propagation of the wave is greater, and that reflection takes place, then the second substance must be a quarter wave-length or more in thickness.
(g) It is not known whether the elastic waves in the earth obey, even approximately, the laws of reflection and refraction determined for optical paths. If we confine ourselves to <u>pure sinusoidal</u> elastic waves, of longitudinal type only, of <u>simple regular period</u>, propagated in the essentially homogeneous (?) medium of the overburden of a dam site, we deal with a greatly simplified case and can probably safely assume the laws of <u>reflection</u> as developed for optical paths.

We may conclude then that sustained sinusoidal elastic waves of regular known period, generated at a point on the surface of a proposed dam site, will be propagated with a velocity (and hence with a wave length) definitely determined by the elastic properties of the overburden: that they will be reflected at the rock surface, approximately according to the laws of reflection as developed for optics and that they will reach the surface at a point determined by these laws, appearing as elastic vibrations of the same period, but diminished amplitude, as compared with the initial vibrations.

III. SOME ASSUMPTIONS WHICH REQUIRE EXPERIMENTAL VERIFICATION:
It is known that soldiers crossing a bridge in step can generate a vibration of the structure which may prove disastrous. In a somewhat similar way it is believed by some seismologists (there is strong evidence in its favour and the idea has never been disproved) that the regular, rhythmic beating of the waves on the coast is the cause of the microseisms or earth tremors which are recorded from time to time on sensitive seismographs at distances

up to more than a thousand miles inland.

Be this as it may, it is probable that a regular, rhythmic pulsation imparted to the earth can be propagated to very considerable distances and depths. Unlike the great energy of the blast which is largely dissipated and which imparts to the earth vibrations of fortuitous amplitudes, periods, and nature (longitudinal or transverse), we can control the energy employed so that a considerable part of it will be imparted to the ground in the form of a regular purely-longitudinal sinusoidal vibration of unchanging period, of amplitude gradually waning with distance, and of determinable velocity and wave length.

Whether or not the proposed method would succeed in so doing for depths such as are required in geophysical prospecting of oil fields, experiment alone can say. It would seem, however, highly probable that it would succeed in the conditions to be encountered in probing the depth of overburden of a dam site.

IV. A GENERAL OUTLINE OF THE PROPOSED ELASTIC-WAVE METHOD.

(a) Regular sinusoidal vibrations are to be imparted to the ground by a method which can be outlined later. The equipment for generation and control of the input can not be purchased but must be developed in a machine shop. For dam sites, experiment will probably show that a very simple modification will suffice, rather than the complete equipment which has been carefully projected in some detail for geophysical work. To demonstrate the feasibility of the assumptions outlined in section III, it should be possible to develop the energy by means of an electric motor in a region where the current is readily available and where the depth and contours of the rock subsurface are known to some extent. Preliminary experimentation could probably be carried out in the vicinity of La Gabelle, for example. In practice the method would require a level piece of ground in which one could readily dig of a size say twenty feet square. We shall, for convenience, refer to the equipment designed to generate and control the vibrations as the "vibrator".

The vibrator must provide means of continuously and gradually varying the period of the vibration imparted to the ground. The amplitude should be determinable at will, within fairly wide limits, but need not be gradually and continuously variable. It is probable that in the course of experimentation it will be found possible, also, to impart a certain amount of direction to the impressed vibrations.

(b) The vibrations, after their subsurface excursion (which is to include reflection at the rock surface), are to be received by a specially-designed seismograph. The part of this instrument which must be purchased is a sensitive microphone. The remainder of the instrument, which, when completed, we may call the "geophone", can be made up in the machine shop. It should be adjustable as to period over the range to be made available in the vibrator. The complete instrument can not be purchased anywhere but could be constructed quite easily, provided the microphone of required sensitivity be secured. The microphones used in the geophones developed for geophysical prospecting would be ideal, but their complete geophones would have to be re-designed for the new uses to which they would be put.

(c) The microphone currents are to be passed through a recording galvanometer. This will require to have a high recording speed, something like an oscillograph. The periods to be used will probably be of the order of sound vibrations for the purpose of obtaining short wave lengths. Experiment would be required to determine the best type of equipment. The recorder must be provided with two mirrors in order that the vibrator phases can be recorded side-by-side with those transmitted through the earth. With this extra feature provided for, the recording equipment developed for geophysical prospecting would best serve. The recording equipment will be referred to simply as the "recorder".

V. OBSERVATION ROUTINE BY ELASTIC WAVE METHOD: The observation routine will vary somewhat as experience will indicate. The following are but some of the possible methods of attack which seem best adapted for such work as that with which we are here dealing.

(al) Steady-period Method: The vibrator is set to introduce a continuous vibration of constant period to the earth. The amplitude is adjusted to introduce sufficient energy to reach the geophone, which is to be set up several hundred feet away. The beam of vibration is to be directed downward, so that very little energy will be propagated along the surface. The vibrator is directly connected to one recorder mirror by cable to register the phases as generated. (In geophysical prospecting work this connection could be by radio.) The geophone is moved about until a point is found where the earth-transmitted vibrations are in phase with the vibrator, i.e. such that the path down to the rock and up to the geophone is an exact number of wave lengths. It will be necessary to move the geophone about in order to determine this position for the period involved.

Then, all being in readiness, a single cycle is to be omitted by a means to be indicated. It is not known whether this will appear as missing at the recorder. It is possible that it may; if so, it will be possible to make, quite readily, a series of observations showing the number of wave lengths from vibrator to recorder, provided we know the velocity of propagation in the overburden.

To secure this definitely for any given case one bore hole will be required, from which we can proceed by gradual steps. It may be possible to choose a point where this one hole does not need to be at maximum depth. For preliminary work a velocity could be assumed, the resulting values giving the contours in terms of an approximately correct wave length. If conditions were indicated as favourable for more extended work the entire set of observations could be calibrated by a subsequent boring.

In all probability the method would permit of a sufficiently accurate determination of conditions for all reconnaissance work in connection with prospective dam sites without any bore hole especially where the geological conditions are known and are taken into consideration in conjunction with the seismic data.

True we should not know whether the path were a simple symmetrical reflection from a horizontal rock surface, or whether it were from a surface inclined in one of an infinite number of possible directions. However, by choosing various wave lengths, and setting up at different points with the geophone as experience would indicate, the uncertainties could be eliminated, since we should have an exact measured length and the points of input and recorder.

(a2) If the single omitted vibration will not carry through, a total cessation might. The equipment, as designed, would provide for an abrupt total cessation of energy input. The procedure would then be as indicated in al above.

(a3) If the first two methods will not give a signal to carry through then a sudden abrupt change of period should. This can also be arranged for if necessary. The procedure would then be as in al above.

(b) Gradual-period-variation Method: The equipment is to be set up as indicated in the first paragraph of al.

All being in order the period is to be gradually increased until the recorder again just shows synchronism with the vibrator. The total path can now be determined as follows:-

Assuming that the velocity of propagation is the same for all wave lengths then we have:

$$D/L_1 - D/L_2 = 1$$

i.e.

$$D = \frac{L_1 L_2}{L_2 - L_1}$$

where D is the total path distance, L_1 is the initial period-determined wave length, and L_2 the final period-determined wave length.

Again it is true that we should have to carry on further work to determine whether the subsurface rock were horizontal or inclined.

(c) Penetration Test: By gradually increasing the period according to the method outlined in subsection (b) we should pass successive coincident points which would serve to check our determination. By carrying this process further and further we should perhaps come to a point where reflection suddenly failed. This should, calibrated by boring tests, permit a measure of the depth of an underlying layer of finite thickness.

Other methods of observation applicable to dam site surveys would, no doubt, be indicated in practice. Others have been planned with respect to oil-field work.

VI. COST OF METHOD AND TIME REQUIRED TO PERFECT:

It is difficult to estimate the cost of developing this method or of the time required to perfect it. It appears, however, that the method could be brought to a state suitable for use in the Company's own problems in three months' time. The cost would depend largely upon whether all the instruments would have to be purchased or whether use could be made for experimental purposes of instruments already owned by the company for other purposes. It is probable that the cost would range from a few thousand dollars in the first case down to a few hundred dollars in the second case.

If the company has portable oscillographs and sensitive galvanometers available it is probable that preliminary tests could be completed for a few hundred dollars or so for equipment assembly, making use of instruments already in their possession for other purposes.

When the preliminary experimenting is completed, it will be possible to estimate with much greater accuracy the cost and the time required to perfect the method for general use.

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