Engineering Geophysics - A New Concept

A. E. Scheidegger *

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Summary. — In analogy to "engineering physics", "engineering geophysics" is defined as the engineering applications of geophysical phenomena. These include processes occurring anywhere from the Earth's core to the upper atmosphere: thus, there is a vast range of possible applications. In this paper a discussion is given of engineering applications of the physics of the solid Earth (including seismology, volcanology and geomechanics), of the physics of the hydrosphere (including hydrology) and of the physics of the atmosphere (including tornadoes and lightning).

Riassunto. — Analogamente al termine "fisica ingegneristica", "geofisica ingegneristica" si definisce come applicazione all'ingegneria di fenomeni geofisici. Questi comprendono i processi che avvengono in un qualunque punto dal nucleo della Terra all'alta armosfera; di qui l'enorme campo di possibili applicazioni. In questo lavoro viene fatta una discussione sull'applicazione all'ingegneria della fisica della Terra solida (comprendente sismologia vulcanologia e geomeccanica), della fisica dell'idrosfera (includendo l'idrologia) e infine della fisica dell'atmosfera (includente i tornado e i fulmini).

1. - Introduction.

If one translates the word "geophysics" from Greek into English, it signifies "the nature of the Earth". Meant is of course the *study* of the nature of the Earth. In the modern connotation, the word "physics" does not mean "nature" in general any more, but the workings of the materials involved excluding changes in composition.

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* Technische Hochschule Wien, Institut für Geophysik A – 1040 Wien Karlsplatz 13, Austria.

By its definition, "geophysics" is therefore the study of the physics of the Earth. Commonly, this includes now the gamut from the Earth's core to the solar-terrestrial relationships. *Applications* of geophysics to the economic field have, thus far, mostly been confined to geophysical exploration. It is clear, however, that these applications could be vastly extended, inasmuch as many aspects of geophysics lend themselves to engineering uses. In analogy with "engineering physics", I like to designate the systematic study of engineering applications of geophysics as "engineering geophysics". Some engineering applications of geophysics are, of course, well known, such as engineering seismology, but on the whole, geophysics has not as systematically been applied to engineering as it might have been.

In this paper, I only plan to discuss some of the engineering applications of geophysics that might be useful in practical work. To give a comprehensive review would be quite impossible as the subject is vast.

The physics of the Earth is commonly divided into the physics of the solid earth, the physics of the hydrosphere and the physics of the atmosphere. In what follows, I will keep the same division.

2. – Engineering geophysics of the solid earth

For man, the surface of the solid earth is probably the most important region of the Universe because he lives thereon. In this connection, the fast or slow changes of this surface are of particular significance, since they represent an alteration in his habitat. These changes are generally caused by "geo"–physical processes within and without the Earth.

Fast changes can occur as veritable catastrophes. Slow changes, however, can be just as serious although they may lack the particularly spectacular aspects of a suddenly occurring disaster.

If one thinks of disasters, some of the most feared ones are earthquakes. Earthquakes are shocks that usually occur without warning; they engender sudden displacements on the Earth's surface that can cause buildings to collapse. The study of earthquakes is called "seismology"; "engineering seismology" is one of the few branches of engineering geophysics which has already received some attention. Thus far, what triggers an earthquake is not known. It has been found that earthquakes cluster spacially in certain regions (notably the circum-Pacific belt), but what actually causes an earthquake to occur, is not known. Thus, the general seismic risk can be determined for a certain area, but a *prediction* of earthquakes has not yet been achieved. Incidentally, this is a rather "hot" subject just now.

Earthquakes are geodynamic phenomena; i.e. phenomena basically caused by processes taking place in the Earth's interior. Of a similar origin are volcanic eruptions. Such eruptions have caused spectacular disasters in historical times; one need only think of the disasters at Herculaneum and Pompeii and of Mt. Pelée. Thus, many countries could make good engineering use of geophysical observations on volcanoes and from an understanding of their mechanism.

Of direct applicability to engineering are geophysical events occuring quite generally on "slopes". I mean any kind of slopes: excavations, mountain sides, embankments etc. Questions of the stability of such slopes have been studied extensively by civil engineers; the geophysicist, however, wishes to go further, inasmuch as the entire physics of the motion, including the physics of the very collapse, is of interest to him. Contrariwise, the engineer is not concerned with the latter, because his main aim is to *prevent* such an occurrence. Nevertheless, the mechanics of a landslide, if known, could also be put to engineering use, e.g. for the evaluation of the safety of a site or in the design of protective measures. Stability estimates on slopes often depend on a knowledge of the physics of a potential slide. Strangely enough, the physics of a major slide is still largely a matter of speculation. The ordinary friction between the rocks is simply too great for a major slide to occur at all. One stands here before a great puzzle. Famous cases are the slides at Frank, Alberta in 1903 and the slide at Vajont in Upper Italy in 1963. The latter was a particularly disastrous event. A dam was built across a deep valley to create a lake behind it for a hydroelectric power development. When the lake was filling up, the pore pressure rise caused thereby apparently made one of the slopes unstable. It started to creep: — this in itself was no cause of concern to the engineers, because all slopes creep everywhere anyway. The creeping motion accelerated eventually to 20 centimeters per day on the day before the catastrophe, but nobody forsaw the disaster that then followed inside of a short time: 200 million cubic meters of rock material slid into the lake, with a velocity of about 25 m/sec, causing a tremendous floodwave (the dam held!) to spill into the valley below with a death toll of some 2000 people.

Similarly large speeds have been observed in other catastrophic land slides. By all standard physical theory, such events should be mechanically impossible. The sliding surfaces are not steep, perhaps around 20°, well below the angle of repose of the material in question and the rock friction should cause any moving mass to stop rather quickly. How then can the almost total loss of friction be explained? Pore water pressure and thixotropy has certainly something to do with it, but alone it is hardly sufficient to reduce the friction to almost zero. The latest conjectures are that the slide moves on an air or steam cushion, perhaps caused by the evaporation of the pore water due to the heat created by the initial friction. The accurate following up of such conjectures is, however, a difficult thermodynamic problem which has by no means been solved. Evidently, the simple laws of mechanics are no longer sufficient and other fields of physics, like thermodynamics, have to be introduced.

Who was at fault in the Vajont disaster? The engineers can hardly be blamed, because the event could not be foreseen. However, a bit more "engineering geophysical" research of the behavior (and not just of the *stability*) of slopes *before* the event might have provided the insight that could have given the engineers the means to foresee the possible implications of his actions, and to modifyis designs accordingly.

Great disasters with many casualties tend to make news, because they are spectacular. Minor events, like rock falls, the motions of single boulders down a slope etc. are just as serious for those affected by it as a great disaster to the victims of it. A motorist killed by a rock rolling onto the highway is just as dead as any of those people killed by the Vajont flood wave, although he will scarcely make the papers. Similarly, many slow phenomena may not cause death, but great porperty damage. One only has to think of the city of Venice sinking into the sea. As noted above, all slopes creep, with sometimes serious effects on bridge abutments etc. Much of the mechanics of such events is only imperfectly known, in spite of many studies by civil engineers.

3. – Engineering geophysics of the hydrosphere

Engineering applications of hydrology are numerous. I only need to recall the physics of flow through porous media with its application to groundwater studies. In the undersaturated zone, again not only mechanics, but also thermodynamics and the molecular behaviour of air and moisture has to be used.

As on the solid earth, the hydrosphere also may give rise to spectacular disasters: floodwaves, tidal waves, tsunamis. Such events lead to difficult mathematical problems, since all the differential equations are nonlinear.

Floods may occur by a combination of meteorological conditions. Attempts have been made to predict the occurrence of such floods. Thus far, only statistical prognostications can be made. One treats the "hydrograph", that is the temporal sequence of water level readings, as a "time series". The statistical properties of such time series can be analysed and described. From this, predictions of the general frequency of the occurrence of a particular size flood, if not the time thereof, can be made.

Less spectacular, but of great importance, is the mechanics of erosion: the near-shore circulation system on a coast is responsible for the evolution of beaches etc., meanders create river terraces, and gullying the degradation of a slope.

Glaciers are also part of the hydrosphere. For engineering purposes, they have recently gained more and more importance, because developments are pushed to the limits of the habitable areas. Thus, near Mattmark in the Canton of Wallis in Switzerland, a workman's camp (in connection with the building of a dam) was located below a glacier. One afternoon in 1965 a large mass of ice, 1.6 to $2.0 \cdot 10^6$ m^3, broke off that glacier and killed 88 men. An unexpected "surge" in the ice had taken place which led to the break-off when it reached the glacier tongue. Needless to say, the accident gave some impetus to the study of the thermodynamics of glacier surges; but this was like locking the barn after the horse had been stolen.

Many more examples of engineering glaciology and engineering hydrology could be cited, but the above will have to suffice.

4. – ENGINEERING GEOPHYSICS OF THE ATMOSPHERE.

Finally, a few words about the physics of the atmosphere. Engineering applications thereof are mostly concerned with wind stress. The wind stress can be substantial, as is evidenced by the destruction caused by tornadoes. Much research needs still to be done to understand this phenomenon, to predict it and to arrive at design criteria for constructing houses wich will not collapse when hit by a tornado. Up to the present, very little is done in this regard. In tornado areas, one simply trusts God. Perhaps one has proceeded to provide a warning system of imminent tornadoes, but this is not of too much use if one does not really have a safe place in an ordinarily built house to go to.

In connection with atmospheric phenomena, one should also mention the physics of lightning as possibly leading to some engineering applications for the protection of lives and property. One might perhaps think that lightning causes only minor distress, but at the end of August 1972, an oil tanker blew up when struck. Much minor damage is also caused by lightning which reflects itself in insurance rates and such like.

5. – Conclusion

The above remarks were intended to present a few typical applications of geophysics to engineering problems. I like to call this "engineering geophysics". The engineer needs to know the basic physics of the phenomena occuring on the Earth's surface with which he has to deal. The required values of the expected stresses, frequencies, velocities etc. can be provided by the geophysicist who, as a fundamental scientist, is perhaps best qualified to study the pertinent phenomena *per se* without being under the pressure to finish job after job.