VERTICAL CRUSTAL MOVEMENTS AND THE GEOKINETIC MAP

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The most effective method to investigate vertical crustal movements is, at present, the repeated, precise levelling. In many countries investigations have been carried out to deduce the rate of vertical crustal movements on the basis of the differences of survey levellings of the same bench marks at different times. The last phase of such investigations is usually the graphic representation of the observed displacements, i.e. to construct the so-called geokinetic map.

A geokinetic map of adequate scale has several uses; it being not merely a suitable means of representation, but also a graphic continuation of the numerical evaluation. Such a map is more informative of the movements of the investigated territory than numerical data are.

It would be an undue simplification to suppose that the geokinetic map represents clearly the *vertical crustal movements* of the territory in question, in the investigated period. Namely vertical crustal movements have to be considered the vertical component of displacements in any direction of *all* the rock masses between the earth surface and the Mohorovičič discontinuity (two limiting surfaces of the earth crust).

Between these limiting surfaces, however, simultaneous movements of different directions and velocities occur. These are the different *forms of appearence* of the crustal movements (such as that of the fundamental rock, of the sediments, etc.).

On the other hand, geodetic observations like precise levellings as well pertain to the surface of the Earth, i.e. to one limiting surface of the crust. Hence, the geokinetic map shows only the *joint* effect of these movements appearing on the earth surface (the surface-forming effect of the crust movements).

By geodetic means, however, even this joint effect cannot be registered *directly*, but only by observation of the displacement of the bench marks. Therefore, the bench marks are supposed to absolutely follow every displacement of the earth surface.

As bench marks cannot be placed at every point of the investigated territory, the inevitable intermediative character of the bench marks has also the disadvantage of reducing the geokinetic map to a function of the arrangement of the bench marks in space.

It has also to be noted that the data underlying the construction of the geokinetic map are by no means homogeneous, because displacement of almost any bench mark represents a different kind of movement.

This is clearly seen from Fig. 1 schematically showing the following current bench mark types: wall pin embedded in rock (1), deep foundation point (2, 3, 4), bored concrete pile (5), stone bench mark (6) and wall pin in a building (7).

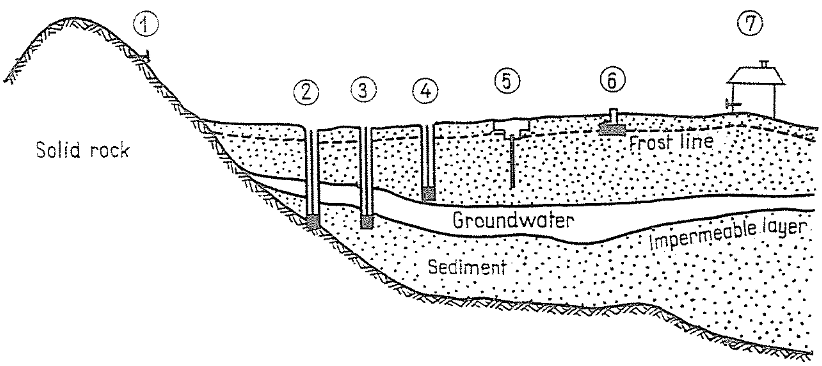

Fig. 1

Displacement of datum mark No. 1 can only be caused by displacement of the corresponding block of the coherent rock (substratum).

Bench mark No. 2 breaks through the sediment layer and is supported by the coherent rock. Because of its special design it is not in contact with the overlying soil, displacement of its highest point is only caused by movement of the supporting rock and the variable thermal expansion of the material of the mark.

Beside the above, bench mark No. 3 may also be moved by compaction (or consolidation) of the sediment layer between the lower end of the mark and the coherent rock.

Beside the causes enumerated for 3, forces due to the ground-water level fluctuations may contribute to the movement of mark No. 4. A movement of the bored concrete pile No. 5, sunk under the frost line, contacting the surrounding soil along its full length, can be caused jointly by all effects mentioned above, and the yearly temperature oscillation.

In case of the standard reference rock No. 6, the above enumerated causes may be joined by the effect of frost and by the soaking (swelling) or drying out (shrinkage) of the top soil.

Finally, displacement of bench mark No. 7 may theoretically arise, beside all effects mentioned so far, from local soil compaction caused by the weight of the building.

In addition to all the enumerated effects, cosmic phenomena (e.g. tidal motion of the crust), earthquakes and other transitory, periodical movements, as well as effects of human activity, may affect the displacement of any bench mark.

Generalization of the above leads to the following conclusions:

1. In general, crustal movements in their different forms affect differently the displacement of bench marks.

2. The same form of crustal movement may have differential effect on bench marks (e.g. compaction of a sediment layer of variable thickness or structure, movement of different rate of the ground-water level in function of place and time, differential rate of movement of separate blocks of the coherent rock, etc.)

3. The altitude of one and the same bench mark is in general subject to the simultaneous effects of several forms of the crustal movement. It is rather difficult to isolate these effects and cannot be done by purely geodetic means because the simultaneous forces may also weaken or annullate each other.

If the geokinetic map is only intended to represent the displacements of the *earth surface*, theoretically it is indifferent, what the forms of crustal movement inducing the observed surface displacements are.

In practice, however, this problem is of interest because the effects of certain movements *have to be eliminated* of the measurement results, such as:

a) surface fluctuation due to frost action;

b) periodical movements due to daily and yearly temperature changes;

c) the movements of the surface due to soaking or drying out of the upper soil layers;

d) consolidating effect of the weight of the building supporting the bench mark on the underlying soil layers, inducing surface displacement;

e) surface movements due to rapid cyclic dynamic effects (e.g. traffic);

f) surface fluctuation due to that of the ground-water level.

Though the enumerated movements are also classified as varieties of crustal movements, they have to be considered as "disturbing movements". They should be eliminated from the comprehensive investigation, the discussion of their effect being not comprised in the sphere of crustal movements but chiefly because of the following:

No crustal movement survey network of irrestricted utility can be realized. *Spatially* it is limited by the average density of points (linearly about max. 1.0 to 1.5 km), in the *time* by the intervals between repeated levellings (about 15 to 20 years).

Hence, our network (as measuring means) is even in linear sense unsuitable to unambiguously indicate movements occurring on territories of a diameter of 1.0 to 1.5 km or less, or within a period of 15 to 20 years or less.

Though, movements *a)* through *f)* are such that their unknown effect would impair the reliability of the geokinetic map, — as it often does — namely in certain cases they cannot be eliminated.

Reliability of the geokinetic map is known to be influenced by measurement errors, deficiencies of corrections to the observations and by forces of adjustment. These will not be treated in detail here.

The geokinetic map — besides its reliability depending to a great extent on the spatial distribution of bench marks — jointly represents:

a) the effect of persistent "disturbing movements";

b) measurement errors;

c) deficiencies of corrections to the observations and forces of adjustment;

d) map construction errors;

e) *real* displacements of the *earth surface* to be indicated by the crustal movement network (as means of measurement).

Our scope is, of course, that the map should represent displacements under *e)* only. *This is at the same time the maximum requirement to be set up for the geokinetic map constructed from geodetic data.*

There may be areas for which the map reflects also other movements, e.g. displacements of the substratum. In general, however, no exact knowledge in this respect is available and to get any exact information merely by geodetic observations is usually impossible.

Based on a lot of suppositions and neglections, mere surface data could be applied to construct maps, representing e.g. movement of deeply lying basin fonds or "regional movement conditions", though reliability of such maps is rather doubtful. This is clear as the geokinetic map based only on geodetic data is not able to truly reflect movement conditions for even the accessible earth surface.

Such attempts are, however, absolutely justified. Investigation of the crustal movements could be efficient if the effect of the different forms of crustal movements could be known, not only *jointly*, but also *separately* for the investigated territory, this being a precondition of clearing up causes and consequences of crustal movements.

This has to be taken into consideration, however, already at planning the alignment and choosing the types of bench marks.

Fig. 2 shows the most expedient locations and types of bench marks possible along a fictitious line-section. For this purpose the geological profile along the line has of course to be known. This is a condition sine qua non for *the suitable bench mark type to be put on the right spot.*

Provided the bench marks are placed according to the manner shown in the figure, there is already some possibility to separate the effect of each form of movement.

For the sake of illustration, a much simplified example is presented in Fig. 3, showing the bench marks of a levelling-section, its geological profile, and the displacement values of the bench marks (e.g. in mm).

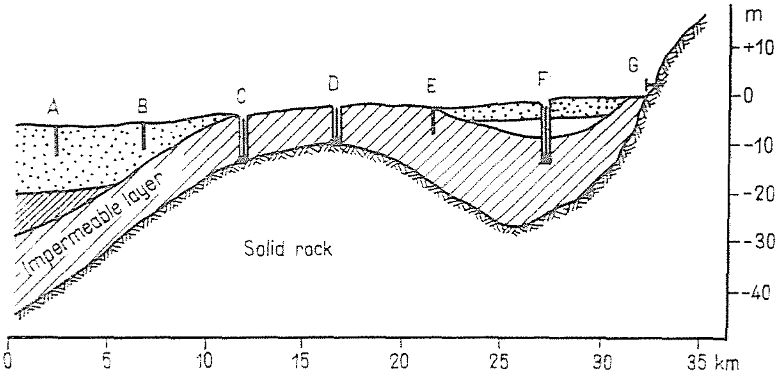

Fig. 2

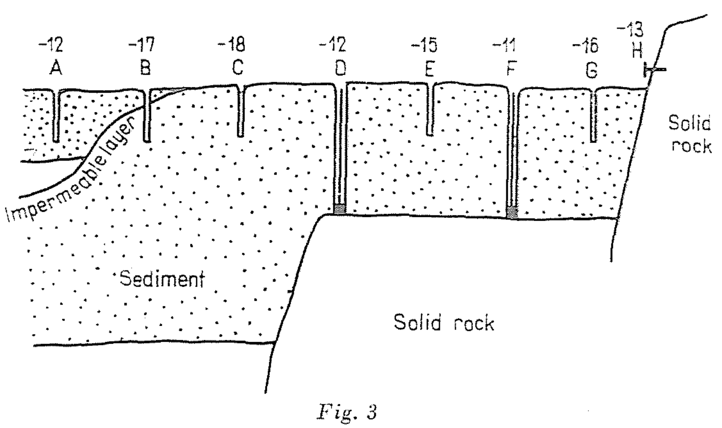

Fig. 3

The following are supposed to be known for the relevelled line-section:

a) relief of the substratum,

b) depth of the sediment layer,

c) relief of the watertight layer,

d) true to sign rate of groundwater level movement for the considered period.

As a first attempt of decomposing displacements manifest on the surface, the following table can be set up:

Table I

Bench mark	Measured movement	Movement of substratum	Sediment compaction	Groundwater-level fluctuation
		derived from surface displacement		
D	−12	−12*		
F	−11	−11*		
H	−13	−13*		
E	−15	−12	−3	
G	−16	−12	−4	
B	−17	−12	−5	
C	−18	−12	−6	
A	−12	−12	−5	+5

Direct observations have been denoted by an asterisk, the others were derived from the former and from known circumstances. Of course, so few data are insufficient even in the given, extremely simplified case for a reliable solution of the problem. For the knowledge of the environment of the section, further real data have absolutely to be collected, such as:

e) place of cracks and faults dividing the substratum;

f) average rate of consolidation of the sediment (based on experimental or empirical data, in function of age, of composition, of depth and of the inspected time interval);

g) average surface displacement for the given soil corresponding to the unit groundwater level movement (based on experimental or empirical data);

h) change of gravity in the given period (based on simultaneous measurements with the levellings);

i) results of horizontal movement investigations for the area (if available);

j) other data deemed necessary.

Sources for this information are results and partial results of geophysical, geological, geomorphological and hydrological basic and single purpose investigations, further, data of deep-borings carried out for any purpose in the immediate vicinity (or proximity) of the survey lines.

Collection of the data and their suitable fitting is a meticulous and lengthy work, lending itself, however, to separate the effect of movement forms causing surface displacements.

Subsequently, geokinetic maps could be constructed to represent each different form of vertical crustal movements, to define areas affected by movements of local character and to construct regional movement maps.

Summary

The end-product of vertical crustal movement investigations by precise levelling is the so-called geokinetic map. An analysis is given of content and use of geokinetic maps. It is pointed out that they reflect only the earth surface deformations with some exactitude, giving but little information about the causes of surface displacements.

Therefore, it is deemed necessary to construct geokinetic maps showing the effects of separate forms of crustal movements. Ideas about such possibilities are outlined.

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