On the Methodology of Landslide Investigations in Soviet Russia

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The present paper is based on Russian information concerning the landslide investigations done by special field stations located either in the regions with abundant slides or in the vicinity of a large slide in a state of slow motion in which final failure may or may not take place. Slides only, as distinct from falls and flows, are considered in this paper. Russian approaches to the slide classification are discussed first, after which cracks and fissures in the sliding body are considered in detail. Methods of measurement of the displacements at the surface and of those at a depth are described. The paper ends with the methodology of computing the balance of sliding masses at a given slope, the negative balance being generally an indicator of the tendency of the slide to stabilize.

● SLIDES ONLY as distinct from falls and flow are considered in this paper. The writer became interested in the information concerning the methods of slide study as used at the present time by Russian engineering geologists and engineers. Because these simple, but rather efficient methods are not well known outside of Russia, this paper has been prepared for information only. Basically it represents an outline of several chapters of a book written by a Russian woman engineering geologist (1) with information from other sources and some writer's comments.

FIELD SLIDE STATIONS

The slide research in Russia is done by field slide stations located at different parts of the country. The first station of this kind was organized in 1930 at the Koutchouk-Koy slide in the Crimea; and in the same year the first instructions for long-term observations were published. Methodology of making investigations of slides at field stations was afterwards gradually developed and discussed in the special press; and in 1934 the first All-Union slide conference took place.

Natural slides generally are not isolated phenomena but are spread over a territory characterized by certain geologic and geohydrologic conditions, and similarity in the development of the slopes. A slide is just a step in the process of denudation or gradual slope formation of a region. Therefore, a field slide station should be located within a certain region characterized by the abundance of slides. It may be also located in the neighborhood of a huge slide as in the example of the Crimean slide already quoted.

Stages of a Sliding Process

A field slide station has to classify local slides and establish the stages of the slide development in different slide types. Schematically speaking, if the sequence of slide stages in the slides of a given type is known, the present stage of the slide may be determined, for instance, from visual inspection and the next probable stage forecast. Slavianov (2) gives, for instance, the following example of stage sequence. A river starts to undermine a bank which becomes steeper, and in which fissures appear. A new factor takes place, namely penetration of water into the body of the slope through fissures with activation of the whole process. The next stage will be separation of the sliding mass and its translation. At the lower, flatter portions of the natural slope the sliding masses are arrested and the forepart of the slide ("tongue" in Russian terminology) enters the water. This is the stage of temporary equilibrium. In the natural state the ground water within the slope has outlets for discharge that may be covered or closed by sliding masses. Consequently the ground water may change its course and wet portions of the slope, heretofore dry. In this connection fissures and pools appear at the surface of the sliding mass. This stage is characterized by alternate periods of motion and rest. In connection with described phenomena, the relief of the locality gradually smooths out and the position of the sliding mass is stabilized on the slope. The sliding body is finally gradually covered up with soil coming from the inland or may be eroded and disappear.

Generally, the stage sequence observations should last a considerable time and encompass a large number of slides. Excessive automatization in the use of stage-sequence schemes should be avoided, however, and in each particular case the environment conditions properly appraised.

Activities of a Field Slide Station

In order to obtain a sufficient number of observations in the most economical way, simple sets of observations are done on a great number of objects spread through the region assigned to the station; and the more complicated the observations the fewer the number of individual objects of study. Finally, such complicated long-term observations as soil or water balances (discussed at the end of this paper) are done on a few objects only.

The region assigned to a station may be from several tenths of a mile to several hundred miles long (e.g., along a river canyon). On a portion of the region with especially intense slides (perhaps 12 to 30 mi long), regular visual observations are done from one to four times a year; additional observations are done after heavy displacements of existing slides; after new slides have started; after heavy rainstorms; after earthquakes; during construction, etc. On some individual slides where instrumental survey is done (e.g., systematic displacement measurement or ground water study), observations are done every two to five days, and sometimes every day.

More specifically, the following types of observation sections may be distinguished:

1. Sections containing slides at the stages when they threaten or may threaten the stability of existing or planned structures or facilities. The objective of the observations is the elaboration of measures tending to decrease the activity of the slide and stabilize it. The observations are short-termed and generally coincide with the period of preliminary or final engineering investigations for a given structure.
2. Sections on which the anti-sliding structures already exist and their effectiveness is studied. In the majority of cases the observa-

tions have to confirm complete stability of the section or show the rate of stabilization. The observations are rare, but may last decades.

3. Sections with typical slides in progress for obtaining information on the sliding law. Such sections may serve as field laboratories (for instance, by observing the stability of experimentally excavated slopes under variable conditions). These are usually long-term observations. The full-size experiments are combined with the work of the indoors laboratory where the experiments on smaller scale are done. In comparing the results the similitude laws may or may not be used. In the latter case the experiments are purely demonstrative, but may be sometimes helpful in the solution of some particular problems.

Mapping of the Region

The slide observations should be preceded by the mapping in of the whole region under the station jurisdiction using 1:25,000 to 1:100,000 scales. The contours of large slides are shown on such maps, and smaller slides are indicated by conventional signs.

The basic portion of the region under the constant observation by the station is usually mapped on a 1:5,000 to 1:10,000 scale, seldom larger. The mapping is supposed to (a) give the characteristics of each individual slide; (b) establish the dependence of the slide morphology on the petrography, genetics, location of the slope making formations, and on the plentifulness of the aquifers; (c) record the presence and intensity of other physico-geologic phenomena; (d) record all structures, particularly those designed for slide arresting purposes, and all artificial factors that may possibly affect the slope stability.

Individual slides are mapped on 1:500 to 1:2,000 scale, and very large ones on 1:5,000 scale. In this case geologic sections are shown. In this connection all available data should be utilized concerning the magnitude and direction of the displacements of the formations, their tippings and twists and other data obtained from the study of fissures and other deformations at the surface of the slide and from observations on reference points. Large-scale mapping is accompanied by boring and sampling of soils and rocks, and sometimes by the determination of the direction and velocity of the ground water flow, including pumping. Geophysical investigations are sometimes used. The boring logs should indicate not only the sequence of strata, but also their lithology, and technically important physical properties; presence, characteristics and orientation of cracks and fissures, sliding surfaces and slickensides (and scratches on them), also collapsed and smashed zones. Data from bore holes have to be checked against those from trenches and test pits. All basic bore holes must be sunk from 3 to 7 ft into the natural ground and one or two holes go to a deeper horizon whose immobility during the sliding process is above doubt. When the strata are horizontal, at least one bore hole on the slope must reach the elevation of the bottom of the deepest hole sunk through the sliding body itself.

Slope History

A purely geological problem of great importance is the history of a given slope considered as a whole. For a competent geologist, this is the basis of the understanding of the present day slides and possible prognosis of coming ones. Often the history of the slope is connected to the history of a water basin or a river canyon of which the slope is a part.

In addition to the history of the slope in remote times the station gathers all possible information concerning the present historical period (old maps, newspapers, questioning of the neighbors, etc.).

SLIDE TERMINOLOGY AND CLASSIFICATION

The Russian term for the slide is "ópolzen." The sliding body proper is the "body of the ópolzen." The visible vertical cliff-like scarp where the sliding body separates from the rest of the earth mass is "pull-off-wall." The sliding surface on which the sliding body reposes, if practically immobilized, is its "bed." The sliding body is limited by the right and left "flanks" or "sides," right and left being considered in the direction of sliding. The foremost portion of the slide is its "tongue" (not "toe").

A new slide changes the appearance of the slope. The relief changes, fissures and steps appear near the top of the slide, rock formation may become visible, there are new ground water outlets and swampy spots. If the displaced masses keep the new position for a certain time, the slope appearance changes again: the fissures are gradually filled up, their edges smoothen, and the newly exposed surfaces are covered with vegetation. This is the transformation of the slide into an "old slide." The duration of this transformation depends on the climate. It may be of the order of several hundreds of years in dry climate, whereas in the presence of considerable rainfall and rich vegetation two and even one year may suffice. It is necessary to distinguish between "old" and "ancient" slides. The latter are healed up slides (scars) formed in past geological times.

As may be concluded from Emel'ianova (1), the terms "new" or "modern," "old," and "ancient" slide are used by the stations' personnel. There are also slide classifications by Popov and Maslov, discussed later.

The slopes with old or ancient slides or slopes without slides at all may be similar to those on which new or modern slides are developed so far as the conditions of slope formation and existence are concerned. All such slopes deserve attentive study in order to clarify the reasons why under apparently identical conditions the slides may or may not develop; why the slides may be active or completely healed up.

Slide Classification

Popov's Slide Classification (3) is in reality an adaption of F. P. Savarensky's (3a) classification "somewhat developed and made preciser." Savarensky, a well-known Russian geologist, working mostly in engineering geology and seismology, was the first in Russia to introduce into the slide classification the time of manifestation of the slide and its state (stage). His classification, modified by Popov, is given in Table 1. On the basis of Table 1, Popov elaborated another table (Table 2) which in reality contains a small list of features on which a regional slide classification should be based and a small list of measures for the control of landslides. Table 2 is formulated in general terms and has no immediate practical value for a field engineer or geologist. It is not presented here.

Maslov's (4) slide classification considers four characteristics of the loss of slope stability, namely: (a) form, whether fall, slump with shear and rotation, shear at settlement, sliding, creep-displacement, creep, flows, plastic and viscous deformation, secular reworking of the

TABLE 1

CLASSIFICATION OF SLIDES ACCORDING TO AGE AND STAGE

Age	Stage	Characteristics	
		Of Age	Of Stage
Recent	Moving	With recent base level of erosion, and level of abrasion	Process tending to establishment of equilibrium
	Suspended		Action of cause temporarily balanced by some "security agent"
	Arrested		Cause temporarily eliminated
	Completed		Action of cause discontinued
Ancient	Exposed	With a different position of erosion and abrasion	Only soil and eluvium at the surface
	Buried		Slide covered with later deposits

slope; in total seven forms if fall and flow are not considered; (b) character of deformation, e.g., understanding under "sliding" a displacement along the planes of stratification, breaks, ancient movements, etc.; under "creep-displacement" almost horizontal displacement along a weak layer of cementing material between two strata caused by lateral pressure; (c) velocity of deformation expressed quantitatively only, e.g., "small and exceedingly small" in cm or mm per year; (d) natural environment (mostly geology of the site).

Cracks and Fissures

In the Russian originals discussed here no distinction is made between "crack" and "fissures." The general term used there is equivalent to English "fissure." In this paper the term "crack" is generally used; the term "fissure" is also used when real closed fissures are described.

Cracks and fissures at the slide surface are caused by stresses and displacements within the slide body. In the case of an elementary (simple) slide in clayey material there are tensile stresses and tensile cracks and fissures at the top of the slide; whereas at the tongue there may be bulging and, hence, compression cracks and fissuring. This is true in the case of non-sensitive clay. If the clay is sensitive, or if there is a sudden increase in the bed gradient close to the tongue, clay may move or flow down and spread on the terrain. There may be also fissures in the natural ground above the slide and below its tongue.

The portion of the simple slide between the upper (extended) and the lower (compressed) zones is a "displacement zone." If the curvature of the slide bed (shearing surface) is constant, e.g., as in the case of a perfect circular or plane shearing surface, the body of the slide is not stressed and no fissures are formed on it during the sliding process. If, in such a case, there are engineering structures built at the "displacement zone," they will be simply translated and may be tipped one way or the other according to their relative position with respect to the shear surface.

Figure 1 shows the crack classification by Ter-Stepanian (4) who subdivides all cracks on the sliding body into surface cracks and deep cracks or fissures. In their turn, the surface cracks constitute four large groups indicated on plan (Fig. 1, bottom).

Group I. Upper Cracks (Figs. 1a and 1b), open at top, more or less vertical, edges not smashed. Cracks (Fig. 1b) are in reality faults (or shear) surfaces. May be covered by the dry material falling from the upper "shoulder." Cracks (Fig. 1a) are tear (or tensile) cracks, not very long, dying out at the ends; both shoulders are at the same level.

Group II. Side Cracks (Figs. 1c, 1d, 1e and 1f), along sides of sliding body, right and left, considered along direction of movement. Each crack has two "shoulders," one movable on the sliding body, the other unmovable on the rest of the mass. At the beginning of the sliding process both shoulders have equal elevations but not so afterward, when the shoulders move relatively up and down, because of horizontal (and not vertical) displacements. However, at the end of the process there is a tendency for the movable shoulder to be lower than the unmovable at the top portions of the slide, and higher at the lower ones. This is explained by the erosional action at the cirques of the slide and the accumulative action of its tongue.

There may be four types of cracks along the sides of the sliding body. "Pushing" cracks (Fig. 1c) are formed when the direction of motion makes an acute angle with the edge of the sliding body, and both compression and shear stresses are acting. Basic pushing cracks (Fig. 1c) are accompanied by secondary curvilinear secondary crack probably caused by torsion. The presence of a moment in this case has been indicated in the United States by A. M. Ritchie (5, p. 55), and by the Russian investigators themselves (1, p. 40). "Squeezing" cracks (Fig. 1d) are of the same origin as cracks (Fig. 1c), only the acute angle is larger in this case. Also the secondary cracks are heavier; and there is a longitudinal roll of earth material squeezed up from below.

Figure 1. Types of cracks on a slide.

If the longitudinal sides of the sliding body are parallel to each other and to the general direction of sliding (Fig. 1e), the fissures separating the sliding body from the rest of the mass, are typical shear failure fissures covered with "lines" that probably are portions of the shear pattern and traces of wearing. In such cases slickensides may develop at the vertical or almost vertical sides of the sliding body. If the sliding body tends to widen in the direction of impending motion, "separation" cracks (Fig. 1f) are observed. Roughly such cracks approach a straight line, the shoulders are often torn and there are no "lines" and no signs of friction on them.

Group III. Central Cracks, are conventionally termed "compression cracks," though in their formation tensile stresses also participate. "Smashing cracks" (Fig. 1g) are in reality transverse closed fissures with one or more transverse earth rolls. The shoulders of the fissures are level. These cracks are formed at the place where the movement of the sliding body is decelerated by some obstacle, e.g., a heave in the bed of the slide.

"Opening" cracks are formed especially in the zone between the middle and the lower portion of the sliding body (Fig. 1h). These are transverse vertical cracks, formed by tensile stresses, e.g., in the case when the earth material accumulated in the lower portion of the slide, creeps over some obstacle (e.g., a heave in the bed) and breaks. The shoulders of these cracks are level.

Group IV. Lower Cracks. The fissures formed at the end of the tongue (Fig. 1i) are joints connecting the slide with the surrounding soil mass. These fissures are closed, their upper shoulder is high, sometimes tipped and even overturned; their lower shoulder is often hidden by the earth material.

This particular classification does not cover all kinds of cracks and fissures that may appear at the surface of a sliding body, e.g., dessication fissures; tectonic cracks, e.g., caused by faults; weathering fissures, etc. Besides cracks and fissures there may be other deformations of the sliding body such as folds, decrease and increase in thickness and other phenomena known as "slide tectonics."

The importance and general significance of cracks at the sliding body is well known (5, p. 54); here the methodology of crack study on the typical slides only as practiced by the Russian field slide stations, will be briefly discussed. In describing a crack in a report or a paper the following items are considered: (a) whether the crack is individual or belongs to a series; (b) shape in plan (straight, curved, wavy, broken, etc.), its length and its orientation and position on the sliding body; (c) width, max, min, average; (d) depth and state of the visible bottom; (e) walls of the crack (whether smooth, with "friction mirrors," scratches or "lines," or rough, notched, smashed; (f) state of the shoulder edges, whether sharp, fallen off, rounded; straight in plan torn, indented; (g) difference in level of the shoulders; (h) horizontal translations along the crack; (i) possible relation of the crack to geologic conditions, e.g., changes in the character of the crack when intersecting different rocks; (j) material filling the crack; (k) geohydrological significance of the crack; (l) possible causes of the crack. In certain cases pits and trenches are used for the detailed survey of a crack. Sometimes detailed instrumental mapping of cracks for individual sections of a large slide is advisable. An American example of such mapping should be recalled (7).

DEFORMATION OF STRUCTURES

A slide may occur under, or close to, an existing structure. In this case the structure may be heavily damaged or, under certain circumstances, may continue its service. Finally a structure (e.g., a road) may be constructed on a slowly progressing slide. In all these cases observations on the state of the structure are needed. The primary objective of these observations is to establish the relationship of the actual or possible damage of the structure with its position on the slide. It already has been suggested in this paper that the structures located at the central portion of an elementary slide are only slightly damaged, if at all. Obviously, the construction and depth of the foundation and the general condition of the structure prior to sliding are of importance.

Tipping and displacement of parts of structures are measured in three mutually perpendicular directions and shown schematically on the plans of the structure. Cracks and fissures are given special attention. Particularly, to establish whether a crack is widening or not, rectangular pieces of thin glass 1 to 3 cm wide are often fixed with gypsum or cement on the shoulders of the crack. Gypsum and cement overlays across the fissure are also used.

DEFORMATION OF VEGETATION

Plants may resist sliding or be entrained by the slide according to where their roots are fixed. In huge slides the whole root system is generally located within the sliding body. In a cylindrical slide an isolated vertical tree tips up slope; and moves forward, i.e., down slope, in the case of plastic flow. Young trees rotated by an early slide grow vertically afterwards, a growth which permits one to estimate how much time has transpired since the slide. It should be realized that bent trees are also found in windy regions.

DISPLACEMENTS OF SLIDING BODIES

Magnitude, direction and rate are to be recorded in the study of sliding body displacements. Regular surveying operations are performed on a system of "monuments" (Russian "reper") placed on and outside the slide. Besides determining whether or not there is a displacement of the sliding body, the boundaries of "active" slides or those of secondary slides (cirques) within huge old slides may be determined using such observations. It may also be found whether the sliding process is still progressing and, if so, what kind of movement is taking place: either displacement of the sliding body as a monolith; or differential displacement of its parts; or, finally, a plastic flow. It may be disclosed whether there is a lateral or an upward growth of the sliding body. Data for the stress distribution study within the sliding body may be collected. So far as the anti-sliding structures are concerned, data for the design of such structures may be collected, and when the structures themselves are constructed their efficiency checked.

Observations on "monuments" are referred to three mutually perpendicular axes. Displacements of a point along the axes and full displacement in space, velocities of displacement and increase or decrease of the true distance between the monuments are determined. Changes in the true distance between the monuments indicate tension or compression close to the slide's surface. Rotation of the sliding body about a horizontal or vertical axis is found from the angles of rotation of line AB connecting the two monuments A and B in the vertical or horizontal plane, respectively. In their turn, the values of these angles are computed from the coordinates of points A and B.

Monument observations may be used for determining the depth of the sliding body and the configuration of the sliding (shear) surface. The method proposed by Buckingham (8) is described by Emel'ianova (1, p. 59). During a displacement of the sliding body volume A_1 and ABB_1 (Fig. 2), may be assumed equal to the volume of soil passed through section BC. If the horizontal displacement of point B is Δ and assuming a uniform distribution of the velocities of the moving soil along vertical BC,

$$\text{depth BC} = \frac{\text{area } A_1ABB_1}{\Delta} \qquad (1)$$

If the sliding body is severely broken during the displacement, Eq. 1 may lead to considerable errors.

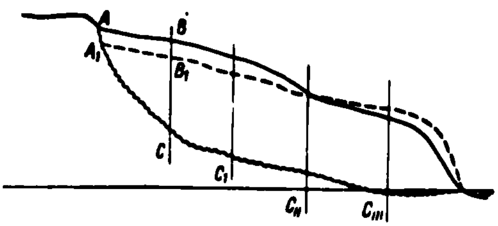

Figure 2. Approximate determination of the depth of a slide (8).

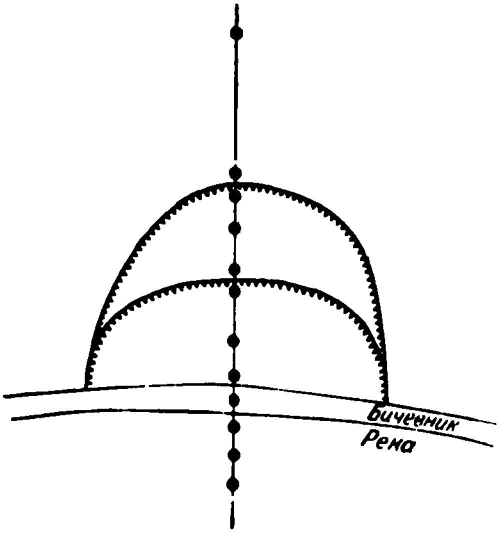

Figure 3. Location of monuments on a medium size two-step slide (schematic sketch).

Location of Monuments. The monuments are located in longitudinal and transverse, mutually perpendicular rows. The longitudinal rows are usually parallel to the general direction of sliding. Some monuments should be placed beyond the perimeter of the sliding body proper. If there is a water basin at the foot of the slope, there should be monuments placed in water with at least one monument unmovable. Additional longitudinal monument rows are needed (a) on complex slides with secondary cirques (Figs. 3 and 4); (b) on frontal slides of considerable length along the slope; and (c) when besides translation also rotation may be expected. Figure 5 shows a case when monolithic sliding takes place along a plane dipping obliquely to the slope. It should be noted, however, that in many cases one good longitudinal monument row may suffice.

Sometimes monuments are located in triangles as for a diminutive triangulation. Practice has shown, however, that the readings obtained from a sufficient number of mutually perpendicular monument rows are easier to analyze and are more illustrative than those obtained from triangular sets.

Location of monuments following a rectangular grid may be useful in

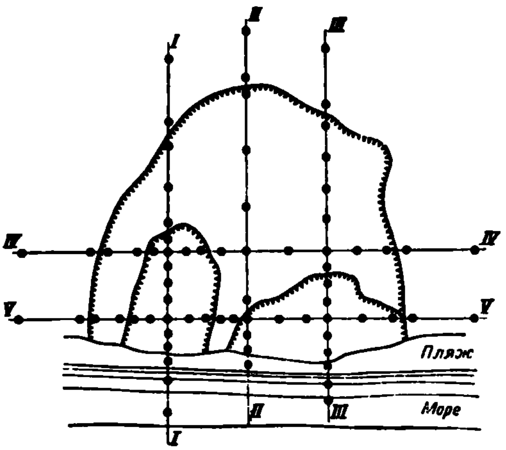

Figure 4. Location of monuments on a huge old slide with secondary cirques (schematic sketch).

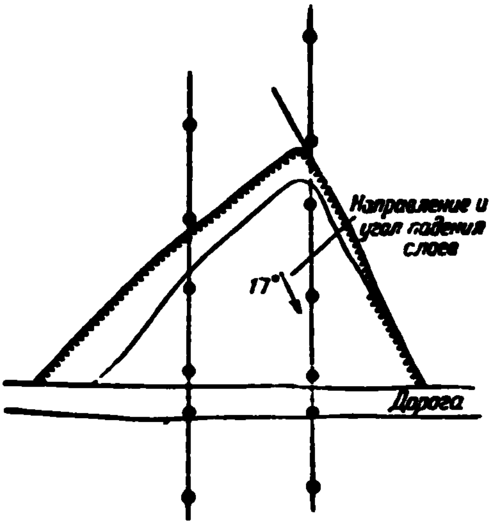

Figure 5. Location of monuments in the case of an oblique slide. Arrow shows direction and angle of dip of the sliding plane (schematic sketch).

the case of plastic flow and creep when the soil mass moves like a stream of viscous liquid.

Location of monument rows should be first planned on a large-scale topographic map according to available geomorphological information. The plot should be then corrected in the field by a geologist and an engineer together, according to the presence of cracks and shear steps, conditions of visibility, etc.

Monument Types. Monuments may be basic, for long-term observations, and working, for short duration use. Monuments of either type may be exposed or covered with earth. The monuments of the latter type are better so far as preservation of the monument is concerned but often are difficult to find in the field. It is advisable to make all monuments exposed and to cover them only if their safety is threatened.

The base of a monument should be placed below the freezing depth except for that case when the displacements of the mantle only are considered.

Figure 6 shows one covered monument (a) and two exposed. There are many types of working monuments; concrete is used in most of them for stability. A very common type is shown in Figure 7, left. In this case the monument of a metallic rod or pipe segment driven from the bottom of a shallow excavation filled afterwards with concrete. In the soils subject to swelling this type of monument is replaced by a concrete slab with a vertical rod placed at the bottom of a relatively deep pit and filled with compacted clay (Fig. 7, right).

Duration of Monument Observations. Practically always, observations on a slide, even in the areas served by field stations, start after the slide has already moved so that information on a very initial stage of sliding is missing. The sliding process develops non-uniformly and there may be periods of quiet between the displacements, lasting sometimes for years. Again, the history of some slides is limited to one displacement

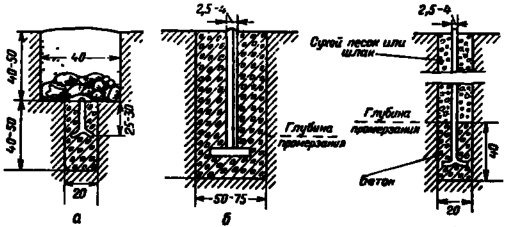

Figure 6. Types of basic monuments for long-term observation.

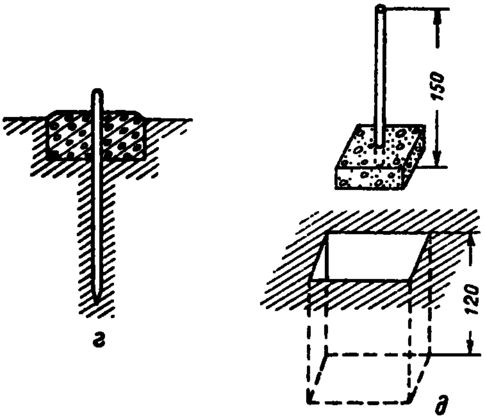

Figure 7. Typical monuments for short-term observations (the right one is used in frost-expansive soils).

only. Therefore, it is not necessary very often to perform full surveying operations, i.e., determination of the three coordinates x, y, z of all monuments. For instance, for intermediate observations of a slide, done 4 to 6 times per year, a systematic determination of one or two coordinates may suffice. The vertical coordinate z may be determined by simple leveling. The coordinate x may be found from the longitudinal monument rows, often by simple measurement of the distances between the monuments. The immobility of basic monuments should be checked once in awhile, however.

Measurement of any of the coordinates x, y, z should be done in dry weather or during a freezing spell. Obviously no coordinate measurement should be done during visible slide movement.

Simplified Observations. Regular surveying operations are expensive and require considerable time for their completion. Simplified observations between regular surveying operations are performed in order to investigate whether or not there are displacements during a certain time interval and what is the nature of these displacements. Temporary "marks" are placed or made at the surface of the sliding body for this purpose. Placing one mark at each side of a fissure and measuring distance between these marks may indicate the pressure or tension in the sliding body. Both of these marks may be located at the surface of the sliding body, or one on it, and the other outside, i.e., at the unmovable section of the earth surface. A great number of mark pairs may operate simultaneously at different sections of the slide. Marks may be located along the estimated direction of sliding and distances between them measured. To study a rapid sliding motion, a long graduated rod is fixed at the surface of the sliding body along the direction of sliding. Outside the edge of the slide, i.e., on the unmovable earth surface, a telescope tube is fixed perpendicular to the rod. Readings of the rod are then plotted against times of observation.

Obviously the marks should be simple, inexpensive and conveniently located. A pair of monuments from an existing longitudinal monument row located on both sides of a fissure or crack may work as marks. Boulders, trees, buildings and structures of all kinds may also be utilized for the purpose.

DISPLACEMENTS AT A DEPTH

Russian technical literature (9) advances the idea of existence of a "landslide nidus," or that region of the slope where the local concentration of tangential stresses occurs. The complete sliding cycle caused by these stresses consists of a phase of deep creep which may last for years, and a phase of shear in the form of quick displacement. An old slide may be healed up and become active again, and this may be repeated several times during the long geological history of the slope. Thus in one slide there may be traces of sliding surfaces at different levels. It is difficult to locate the shearing surface from a bore hole even in a recent slide; more correct data are obtained from pits and trenches. Russian field slide stations use deep monuments for the purpose.

Practically all methods of the field deep displacement-study are based on the consideration of deformation of a straight line (usually vertical) within the sliding body. When intersecting a sliding surface or a break the experimental straight line is displaced and the displacement of the sliding body equals the distance between the ends of the segments of the experimental vertical line. Within a displaced but monolithic block, the experimental line is still straight, but may be tipped. In the case of a plastic flow, the experimental line is curved and may be broken. Generally the shape of the curve in this case depends on the law of velocity changes along the vertical.

In one type of deep monuments their deformation is determined by carefully excavating the earth material around the monument which in this case may be used for one observation only. A simple type of such monuments consists of a bore hole filled in by wooden cylinders 4 to 10 in. in length, freely standing on each other and filling the bore hole. In another type the bore hole is filled with some loose material, e.g., gravel, sand, fine coal, etc. The color of this material obviously should differ from that of the slope materials. Very important in this case is the determination of the original deviation of the bore hole from the vertical which can be determined by placing into the hole a glass cylinder filled with appropriate liquid, e.g., acid affecting glass or some dye. In the latter case the walls of the glass cylinder should be lined inside with paper. The difference between the highest and the lowest level of liquid in the glass cylinder and its diameter furnish the data for computation of the slope of the bore hole at the level where the experimental glass cylinder is placed.

The excavation of a monument is costly and time consuming and is generally done when the monument is displaced horizontally 3 to 5 ft. Figure 8 represents a sketch of the wall of an excavation showing the displacement of a monument consisting of wooden cylinders. The monument is sheared, displaced vertically 120 cm and tipped 42 cm. Symbols on the sketch mean: (1) loose yellowish-brownish clay, slightly plastic; (2) grey sticky clays; (3) sandstone fragments and inclusions; (4) shearing (sliding) surface; (5) original position of monument.

A method permitting constant observations of the slide displacements consists in the excavation of special pits and trenches with non-rigid timber bracing. Bracing of a cylindrical pit (hole of large diameter) may consist of concrete rings 15 to 25 cm (6 to 10 in.) high, lying freely on each other. Horizontal displacements are well recorded by such installations but the vertical component of the sliding displacement cannot be correctly measured until the installation is completely sheared.

BALANCE OF SLIDING MASSES

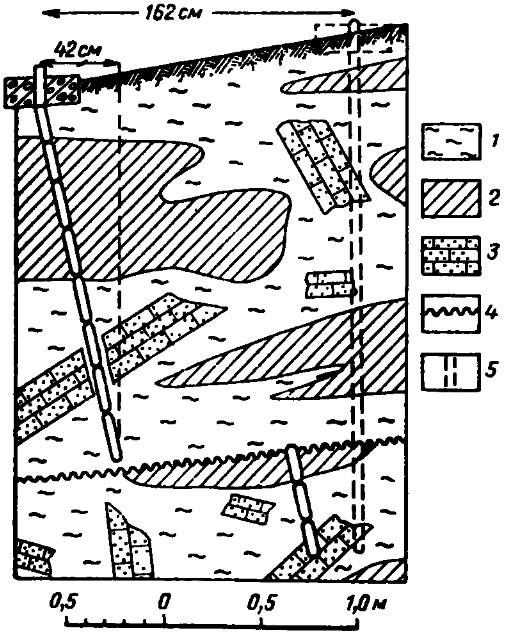

Figure 8. Idealized page from the field book of a slide observer showing translation and rotation of a deep monument.

A sliding mass may or may not vary in weight during the sliding process. Increase in weight is due to (a) active participation in the sliding process of the masses usually located at the top and at the sides of the slide; (b) deepening of the sliding body; (c) gradual arriving of earth material from the areas above the top of slide, because of falls (e.g., as with the Crimean slides), and because of erosion of these areas; (d) artificial additions to the sliding mass (e.g., because of the earthwork on railroads and highways located on the sliding body); (e) deposition of sediments on the slide's tongue and at the foot of the slope (e.g., in the case of formation of a sea or river terrace). Decrease in weight of the sliding body may take place because of (a) the slope's foot abrasion, erosion, flattening of slopes; (b) erosion of the slope with formation of ravines and gullies; (c) surficial soil removal (ablation); (d) artificial removal of earth masses in grading, building of cuts and excavations, removal of slides or heaves on the railroads and highways; (e) subsurface erosion. What is meant under the terms "balance of sliding masses" is the difference, positive or negative, of the increase and decrease of the weight of the masses constituting the sliding body.

Displaced soils are more or less saturated; and besides water may be displaced independently from the soil. Hence, strictly speaking, the balance of earth masses and the balance of water should be prepared independently, both of them being the components of the general balance of displaced masses. Hereafter, the water balance on the slope is not considered separately from the earth-mass balance.

With circular-cylindrical sliding surface the conditions of equilibrium of the sliding body depend on the position of its center of gravity. When the center of gravity is lowered, stability of the sliding body increases and vice-versa. Therefore, when considering a slide with circular-cylindrical sliding surface, it is necessary to consider separately the portions of the slide separated by a vertical plane passing through its center of gravity (determined at a certain initial time moment) and parallel to the strike of the slope. The position of this vertical plane in space is considered constant and the displaced masses are visualized as passing through that plane. In this way, the center of gravity of the slide is visualized as moving in space, and not within the earth mass. The negative balance of the upper portion of the sliding mass, and the positive balance of its lower portion mean the downward displacement of

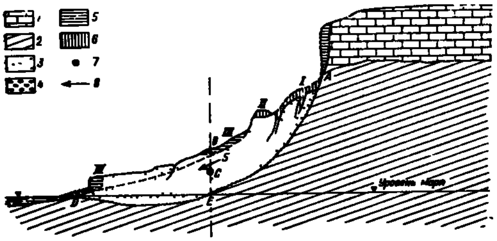

Figure 9. Balance of sliding masses: (1) limestone; (2) clay; (3) body of ópolzen; (4) beach gravel; (5) removed material; (6) added material; (7) center of gravity; (8) direction and length of displacement.

the center of gravity and increase in stability. The positive balance of the upper portion and the negative balance of the lower portion correspond to decrease in stability. If the sign of the two balances is the same, their absolute values are to be compared:

Example: The solid line AED in Figure 9 shows the position of the sliding body in 1947, with its center of gravity at C.

Before 1952 the following occurred (for symbols I, II, III, IV, see Fig. 9):

I. There was a limestone outfall, 340 m3 in volume.
II. Because of gradual settling, 180 m3 of imported gravel were placed on the existing highway.
III. As a result of the ravine and gullies, growth 170 m3 of earth were washed off.
IV. As a result of abrasion, the volume of the tongue decreased by 1,850 m3, whereas the volume and the regime of sediments in the shore portion of the sea did not change substantially. No suffosion in the slope was reported. Suffosion (term used by some Russian engineering geologists) is the internal erosion and removal of the eroded material at the base of a slope.

The average displacement of the sliding body for 5 yr, 1947-1952, as measured along a monument row passing through the center of gravity C was 95 cm horizontally and 24 cm vertically.

Assume the following unit weights of the materials: limestone, 2.35 tons per m3; gravel, 1.85 tons per m3; earth materials of the sliding body ravines and gullies, 1.75 tons per m3. Then:

1. Balance of the upper portion of the slide ABE.

The increase in weight consists of the weight of the limestone outfall (2.35 x 340 = 799 tons) and the weight of imported gravel (1.85 x 180 = 333 tons). Total increase = 799 + 333 = 1,132 tons.

The volume of the material lost by erosion in the ravines (170 m3) should be broken into two parts. Assume that 130 m3 have been eroded in the upper portion of the slide and 40 m3 in the lower. This gives a loss in weight in the upper portion of the slide equal to 1.75 x 130 = 227 tons.

Assume, furthermore, the average depth of the sliding body at 18 m and its front width (parallel to the strike of the slope) at 100 m, the volume of earth materials that passed through section BE is 0.95 x 18 x 100 = 1,710 m3 and its weight 1.75 x 1,710 = 2,992 tons. Hence, the total soil balance of the upper part of the slide ABE is + 1,132 - 227 - 2,992 = - 2,087 tons.

2. Balance of the lower portion of the slide BDE.

There is no addition of new material in this portion. The loss in weight equals the weight of the abraded material (1.75 x 1,850 = 3,237 tons) and that loss by abrasion in the ravines (1.75 x 40 = 70 tons), total 3,307 tons. The weight of the material passed through section BE (2,992 tons) is an increase in weight of the lower portion of the slide. Thus the total balance of the slide is:

$$- 3,307 + 2,992 = - 315 \text{ tons.}$$

Both the upper and the lower portion of the slide have negative soil balance. However, because the decrease in weight of the upper portion of the slide is larger than that in the lower portion, the center of gravity has moved down during the 5-yr interval which shows a tendency for stabilization of the slide. The balance of the slide as a whole is - 2,087 - 315 = - 2,402 tons, which means that the total weight of the sliding body is decreasing with time. Again, strictly speaking, the weight of the outfall (799 tons) should not be considered because this is a displacement of the material inside the slope. Under this assumption the negative balance of the slope as a whole would be - 2,402 - 799 = -3,201 tons and the average denudation intensity 3,201 ÷ 500 = 6.4 tons per lin ft of the slope per year.

OTHER ACTIVITIES OF FIELD STATIONS

Besides the continuous measurement of the displacements connected with the sliding process, as described, the field slide stations are conducting studies of (a) the sliding factors and (b) the effectiveness of the anti-sliding measures. Study of sliding factors in a given environment encompasses seismicity, meteorology, hydrology (including both surface and subsurface water, and water content regime of the slope), weathering, etc. An important sliding factor is the undermining of slopes by both stagnant and current water, and particularly by waves.

The anti-sliding measures studies are regulation of the run-off, drainage, mechanical stopping of sliding masses, modification of soil properties, stabilization of slopes, etc.

The Russian field slide stations belong to different "ministries" or Government repartitions. Most of the stations are under the jurisdiction of the Ministry of Geology, though some are in the Transportation Ministry, in the Ministry of Coal Industry (1), etc. The stations have to submit periodical reports and prepare recommendations when requested. Prognosis of sliding possibilities is also their responsibility.

CONCLUSIONS

The writer wishes to emphasize the purely informative character of this paper. No definite suggestions are made, but the writer believes that the idea of stationary (or rather regional) landslides observations deserves attention. Besides a thorough discussion of the subject matter—a discussion the writer thinks very desirable—it seems advisable to start a few field slide stations, not necessarily exactly of the Russian type, in zones affected by landslides that are produced as a natural step in the denudation process of a given region. Another proper location of such field stations would be next to river canyons in which several dams are planned. Quite a few facts became known when, after the construction of a reservoir and local collapse of its shores, expensive relocation of threatened highways and railroads running parallel to those canyons was necessary. States and counties, and in pertinent cases the railroad companies, should be interested in the idea.

REFERENCES

1. Emel'ianova, E. P., "Methodical Manual for Stationary Study of Landslides." Govt. Geologo-Tech. Pub. House, Moscow (1956). (in Russian)

2. Slavianov, V. N., "Some Problems of Slide Development by Stages." Doklady Acad. Sci. U.S.S.R., Vol. 79 (1951). (in Russian).

3. Popov, I. V., "A Scheme for the Natural Classification of Landslides." Doklady Acad. Sci. U.S.S.R., Vol. 54 (1946). (in English); also

3(a). Savarensky, F. P., "Proc. First All-Union Slide Conference." Moscow (1935). (in Russian).

4. Maslov, N. N., "Engineering Geology." P. 232. Govt. Pub. House of Const. and Arch. Lit., Moscow (1957). (in Russian).

5. "Landslides and Engineering Practice." HRB Special Report 29, Washington, D. C. (1958).

6. Ter-Stepanian, G. I., "On the Classification of Slide Cracks." Proc. Acad. Sci. Armenian U.S.S.R., No. 10 (1946). (in Russian).

7. Krauskopf, K. B., et al., "Structural Features of a Landslide Near Gilroy, California." J. Geology, Vol. 47, No. 7 (1939).

8. Buckingham, Earl M., Discussion of the paper by Hyde Forbes, "Landslides Investigation and Correction." Trans. ASCE, Vol. 112 (1947); also

8(a). Hrennikov, N. A., "Studies of Slide Phenomena According to the Data of the Photopolar Survey." Govt. Geolog. Pub. House, Moscow (1951). (in Russian).

9. Goldstein, M., and Ter-Stepanian, G., "The Long-Term Strength of Clays and Depth Creep of Slopes." Proc. 4th Conference on Soil Mechanics and Foundation Engineering, Vol. 2, Paper 6/11, London (1957).