Chapter Ten

Trends

John D. McNeal

Prophecy is seldom wise for the prophet who can expect to live to see its fulfillment or failure. On the other hand, no one can afford to ignore the indications of the future as these are revealed in the conditions and trends of the present. Neither can one be content with the tools of today for the task of tomorrow.

There are factors and trends of today which indicate that landslides will be of even greater significance in engineering practice in the future than they are now. These same signs appear to point to a shift in emphasis in landslide treatment from correction to prevention. What are these signs?

The first is the tremendous expansion in traffic. A second is the change in thinking in regard to financial responsibility of governing bodies; a gradual change away from the precept of the sovereign right of a state to refuse to be sued. A third and related indication of the future is seen in the decline of the concept of a landslide as an "act of God" and the growing realization that many landslides are initiated by "acts of man."

In spite of the scientific methods and great effort devoted to traffic prediction today, the volume increase continues to exceed expectation. At the same time the demand for greater safety, shorter routes, wider pavement, and improved grades combines with the volume increase to require ever higher design standards. As a result, the engineer is faced with more and deeper cuts, higher fills, and alignments which must overcome rather than avoid obstacles. In each case the chances for landslides are increased. Urban expansion; the increase in irrigation use; and the growth, both in volume and complexity, of other civil works, are also increasing the number of locations where landslides must be anticipated.

The remarkable growth in urbanization, so apparent across the entire country, is causing man to make even greater demands on nature. As cities become larger and more congested, and as land values increase, land that was once considered too waterlogged or too steep or otherwise unfit for use is developed for industrial or residential construction. With such construction comes an increase in the number of potential and actual landslides that is out of all proportion to the relative area of the land that is so used.

The engineer is faced not only with the increased possibility of landslides, but also with greater economic losses and greater chances for injuries and deaths when landslides occur. For example, the probability of an accident caused by a rockfall increases in direct proportion to traffic density. In addition, in heavy traffic other vehicles may collide with the car actually hit by a rockfall, thus multiplying the damage and injuries. Property damages also will increase out of proportion to those which can be expected today. Higher design standards require higher priced roads and structures. Failures, thus, involve more cost. Greater losses chargeable to traffic delays and detours result from increased traffic density. Higher land values and urban expansion

lead to increased right-of-way costs. Under the conditions described, economics and public safety will dictate the expenditure of money for the detailed investigations needed to effect prevention of landslides.

Although every engineer and highway department is keenly aware of public safety and property rights, the increasing extension of liability to Federal, State, and municipal governments can scarcely fail to increase the emphasis on these basic engineering considerations. Neither is it to be expected that the establishment of courts of claim and the passage of tort claim acts will reduce the number of demands for damages.

The number of damage claims (and the number of awards made) will probably also increase with the growth of public and legal awareness of the true nature of landslides. It was shown in Chapter Two that the courts have at least on occasion been influenced by the "act of God" concept of landslides. It is logical to assume that at least a part of the public has held and still holds a view similar to that of the courts. The growing realization that some slides are caused or at least triggered by the activities of men, combined with the extended rights of legal action, will cause many more claims, just and unjust, to be filed. More awards will be made and, inevitably, blame will be assessed in some cases where no blame exists. The result must be that engineers will turn more and more to prevention. For self-protection, they may even be tempted toward uneconomic decisions.

Faced with the necessity for preventing landslides, the engineer and all those who work with him on the problem will find it necessary to re-evaluate and improve their present knowledge and procedures and to develop new or better methods of study and control. The remainder of this chapter is devoted to a consideration of some of the changes and improvements that may be expected or that at least are needed. The organization of the discussion in general follows the order of chapters in the book.

Economic and Legal Aspects

The probable future in regard to economic and legal aspects has been discussed in the preceding paragraphs. However, one additional point deserves consideration. The legislation passed by the City of Los Angeles concerning grading, excavation, and foundations (Chapter Two) probably will be followed by similar regulations for other cities, and perhaps even for counties and states. For example, while this book was in preparation, a fatal accident involving a foundation excavation in New York City resulted in a demand for increased regulation of such operations. Legislation of the general nature of that passed in Los Angeles is undoubtedly needed in the interest of public safety. In view of the present state of public knowledge of slope stability, however, engineers, geologists, and soils engineers should take an active part in the drafting of such legislation. They must also assume the responsibility for keeping the laws in step with changing conditions or knowledge. Otherwise, regulations of this type may become either inadequate or unduly restrictive, and thus uneconomic.

Landslide Types and Processes

The multiplicity of existing classification systems of landslides (Chapter Three), each based on somewhat different factors, would seem to rule out either the need for or the probabilities for significant improvement. Many more classification schemes will no doubt appear and each one will have some usefulness or appeal to certain groups or individuals. Some additional landslide subtypes will probably be discovered and will need to be assigned a proper classification.

The anticipated increase in emphasis on prevention of slides, the interest of the public in their cause, and particularly the expected demand of the legal profession for better, more exact, and more inelastic definitions, will lead to a need for more general agreement on a single system of classification which would be fur-

ther subdivided than existing schemes. It might well be based on several interacting factors, including cause and materials involved. It must be remembered, however, that lawsuits are decided on the basis of evidence and that classification of a slide is likely to be less important than is quantitative evidence based on field and laboratory analyses.

Increased emphasis in classification on the description of materials involved and the correlation of materials to slide types and motions offers some possibilities for a system of use in the prediction of slides. Data (Table 6) from the replies to the landslide questionnaire show some interesting, apparent correlations between occurrence and lithologic type. For example, the Pierre, Bearpaw, and Graneros shales are all superficially similar to each other and, in lesser degree, to the Maquoketa shale of a very different age. Each of these formations is associated with landslides in a number of different climatic environments and reliefs.

Much more research into the basic properties of different materials as related to different environments is needed before data like those in the table can be used safely. Certainly, on the basis of information now available, one cannot make a blanket condemnation of any one of the formations or rock types listed, nor can one make any useful statement correlating rock or material type with slide type.

Field Recognition and Airphoto Interpretation

The characteristics by which landslides and dangerous ground may be recognized in the field are rather well known and it is doubtful that many new features of importance will be described in the future. Emphasis on recognition of potential landslides is a necessary prelude, however, to an increase in the use of preventive measures.

The greatly increased use of aerial photogrammetry in the location and surveying of highways is already in evidence. The preliminary survey of some highway projects, as well as the final cross-sectioning, is now being done entirely by photogrammetry with a field survey only for control. With the expanded highway program recently authorized, use of slower field methods of survey will tend to lose ground to the newer technique. This trend, of course, will restrict the opportunity for field investigation and recognition. Airphoto interpretation is a logical substitute, but in its best application it should supplement and guide rather than substitute for field study.

Rapid advances are being made in aerial photographic techniques and equipment. Aerial photographs in color and at much larger scales than currently used, while not now in general engineering use, offer many advantages in landslide studies and should increase in application. In many areas the relatively new techniques of airphoto interpretation can provide a fairly complete and accurate picture of geologic features of importance in landslide studies with a saving in time and, often, money.

Field and Laboratory Investigations and Stability Analyses

The most fertile fields of the landslide problem for future research and development are those of field and laboratory investigations and quantitative analyses of stability. For both field and laboratory studies the immediate need is for better and more complete application of present techniques and knowledge. There is a wealth of geologic and soils data which could and should be more generally applied to landslide problems. Unfortunately, engineers and others working with landslides in the field are too often unfamiliar with such material.

Information on availability of basic geologic maps and reports, as well as some help in interpreting them in engineering terms, can commonly be obtained from the U.S. Geological Survey, from the appropriate State Geological Survey, or from the geology department of the

TABLE 6

STRATIGRAPHIC UNITS SUSCEPTIBLE TO LANDSLIDING

(Data compiled from replies to H.R.B. landslide questionnaires)

Region and State	Geologic Series or Formation	Description
Northeast	Glauconite beds in Cretaceous sediments	
Vermont		Pervious material beneath clay or soil
Maine		Soft clays
Middle East		
New Jersey	Upper Cretaceous clays such as Merchantville and Woodbury	Sand or gravel overlying clay strata
Delaware	Talbot/Wicomico; Wissahickon	
West Virginia	Conemaugh; Monongahela; Dunkard	
Ohio	Ordovician shales and limestones Conemaugh; Monongahela; Dunkard	Fire clays
Illinois		Shales
Pennsylvania	Conemaugh; Monongahela; Catskill; Wissahickon	
Southeast		
No. Carolina	Blue Ridge Province	Jointed surfaces filled with manganese
Florida	Miocene-Hawthorne	Fullers earth type clay
North Central		
Iowa	Des Moines series (Pennsylvanian) Maquoketa (Ordovician)	
Kansas	Pierre shale, Graneros shale, Dakota formation	
South Central		
Texas	Tertiary lava, tuffs and agglomerates Animas sediments	
Mountain	Pierre shale; Bearpaw shale; Graneros shale; top Dakota sandstone	
Montana	Precambrian Belt sediments	Clay shales, bentonite, serpentine
Idaho	Payette; Triassic sediments	
Colorado	Fort Union; Denver, Arapahoe	Glacial till; ground moraine
New Mexico	Dakota on Morrison	
Pacific		
California	Franciscan; Pico; Rincon	Serpentine; clay shale, Quaternary alluvium
Oregon	Eagle Creek volcanic breccia	Basalt talus resting on breccia
Washington	Nespelem silts; Astoria siltstone; Eocene shales	

nearby colleges or universities. The Bureau of Soil Survey, U.S. Department of Agriculture, the State Agricultural Surveys, and the agriculture departments of universities or colleges are equally good sources of information on soils and soil maps. Perhaps the easiest way for the engineer to obtain help in seeking available source material, however, is to enlist the friendly services of a professional in the special field of interest. Such an expert also can be expected to help in translating the basic data into terms of strength or other engineering characteristics.

However, the need exists for new and improved testing and investigative procedures. In this respect, attention is called to the mapping techniques being used in terrain intelligence and other military geology reports (Hunt, 1950). Refinement and extension of this type of mapping could be very beneficial to landslide investigations. Some of the recently published U.S. Geological Survey maps, such as those of Crandell (1955), Hansen and Bonilla (1956), and Lindvall (1956) represent an important step toward correlation of geologic and engineering data.

Opportunities exist for extension of basic research, both in fields now being studied in connection with landslides and into fields not now receiving proper attention. One new field for research has been mentioned in connection with the discussion of Table 6. Few rock types have received as little study as have shales, yet they are of vast significance both to landslide problems and to many other phases of engineering and the general economy. There is widely recognized association of many engineering problems and specific shales, yet little is known of the cause of troublesome properties of these rocks. For the solution of landslide problems perhaps it would be sufficient to develop methods of determining cohesion and internal friction for shales, such that the laboratory values would be indicative of field performance. Again, the engineering significance of the changes which occur during weathering in physical and other properties of shales and other rocks needs much study.

Current knowledge of both the role and the occurence of subsurface water in relation to landslides is highly inadequate. The influence of hydrostatic pressures on slope stability is very little known, as are the quantitative effects of water on the mechanics of failure. A part of the study needed should be directed to the physicochemical changes which result from the interaction of subsurface water and various minerals. Much is known of the occurrence and movement of subsurface water below the ground water table and studies of soil water have received much attention in recent years. Between the water table and the soil water zone, however, all too little is known about either the occurrence or movement of water.

The use of stability analyses often furnishes the only quantitative evaluation of a landslide, and in many cases offers a reliable means of comparing alternate designs. With constantly improving techniques and equipment for sampling and testing, the application of stability analyses and other tools of soil mechanics should have even greater application in the future. The numerous assumptions and simplifications referred to in Chapter Nine as necessary for any stability analysis in themselves condemn our lack of knowledge of basic soil information. The engineering profession will not be satisfied to allow these assumptions to remain unchallenged, for, although the assumptions are well understood and to some degree can be evaluated by the soil engineer, he must continue to seek replacement of assumption by fact.

Laboratory soil tests of all types give results which have meaning principally in relation to their correlation with field behavior. Among other things, case histories are needed that compare actual field behavior with that predicted from laboratory tests and stability analyses. No doubt many of the difficulties encountered in applying test results in the field result from inadequate sampling techniques and procedures. Engineers, including soil engineers, and geologists

have too long ignored the fundamental properties of soils, including soil structure, mineralogy and genesis. Fortunately, the field has not been entirely ignored. The soil scientist and the clay mineralogist, among others, have available much of the basic information which is needed, but it remains for the engineer to interpret the information and to put it to work.

Prevention and Correction

The major prediction of a shift in the future from emphasis on correction to prevention has been discussed previously in this chapter. This emphasis on prevention is not meant to imply that correction will be no problem in the future. Landslides will continue to occur, and it will never be economically feasible to prevent slides completely. This applies particularly, perhaps, to relatively small landslides, many of which occur in mantle soil or weathered material. These are far more numerous, and more troublesome to many agencies, than are larger and more spectacular slides, yet it is both technically and economically infeasible to predict and to prevent many of them.

Several other less inclusive predictions can be made. Many are dependent for fulfillment on the developments which are predicted or indicated as needed in the discussions of previous sections of this chapter. Most are related to the expected increased interest in prevention.

The prediction of sliding as to time remains one of the most difficult problems. It will not always be possible or economically feasible to prevent a landslide, even when its occurrence can be predicted. For some areas of anticipated slides it will be sufficient and advisable to be able to predict the time of their occurrence. A start has been made on solution of this problem, but far more research is needed. Some railroads and other agencies have maintained repeated checks of the positions of reference points on an area subject to sliding and are able to predict the time of any catastrophic movement. The Japanese have made real progress in time prediction of landslides by the use of strain gage data correlated with the results of laboratory tests (Fukuoka, 1953).

Related to the time prediction of sliding is the use of automatic devices to warn the traveling public that a slide has occurred. Railroads have led in the use of warning devices. These usually consist of signal wires which when broken or moved actuate block signals to halt traffic. Highway departments have been slow in adopting automatic warning signals and have relied on permanent signs warning that an area is potentially dangerous. It is reasonable to assume that both railroads and highways will increase and improve the use of automatic warning systems.

Fundamental to accomplishment of prevention is prediction. Several of the chapters of this book have discussed methods of predictions. Field and air-photo recognition of the characteristic surface indicators of dangerous ground has been discussed. The recognition of dangerous situations which are not evident on the surface are less well understood. There is a trend, however, which will help in the identification of subsurface danger spots. There has been a rapid growth since 1940 in the use of engineering geologists in highway departments. Their use has been restricted in many states to functions which are not connected with landslides. However, the geologists in a few states now prepare a complete, three-dimensional view of subsurface conditions by showing detailed soil and geologic conditions in both plan-profile and cross-section. With this information, dangerous situations that will arise entirely from construction and that are not visible on the original ground can be readily seen. Provision for correcting such locations in the design (prevention) stage can often be handled in a balanced design with very little additional cost.

It is not to be expected that many really new preventive or corrective measures will be developed. The increasing knowledge of the physico-chemical prop-

erties of clays, soils and shales, however, may make the use of electro-osmosis, electro-chemical hardening of clays, and chemical injections more economical and effective than they are today.

The principal development in prevention and correction measures will probably come from better understanding and use of present-day methods. A better understanding of the forces involved in a landslide should eliminate some of the failures which have occurred in the past through misuse of piling and restraining structures, or indeed of every other known method of treatment.

With all of the refinements and advances that are expected in investigation, testing, and mathematical analyses of slides, experience will no doubt remain a most important guide for field use. The experience which has been gained and is recorded in the files of many highway departments and other agencies needs to be organized and analyzed and the results published for all to use. Eckel (1956) has summarized this need, as follows:

> We need many, many more studies of actual slides — not simply descriptions of their size and shape and the damage they did. To get much further with our understanding of slides these descriptions must include detailed records of the physical properties of the soils or rocks that were involved, detailed histories of the movements that took place, and enlightened inquiries into the causes of movement. With this kind of facts we can go a long way in comparing slides and in extrapolating the knowledge thus gained to the solution of new slide problems.
>
> Finally, we need to record many more of our failures as engineers or geologists. The literature is full of descriptions of preventive or corrective methods that were successful. On the other hand, records of installations that failed to do the job expected of them are notably lacking. Nobody enjoys publicizing his mistakes, of course — but just the same there is little hope of improving our knowledge of how to handle landslides until we are able to study and compare the case histories of methods that have failed with those that have been successful.

References

Crandell, D. R., "Geology of the Oahe Quadrangle, South Dakota." U. S. Geol. Survey Geol. Quadrangle Map GQ 53, 1955.

Eckel, E. B., Proc. 55th Ann. Conf., *Proc. Am. Railway Eng. Assoc.*, v. 57, p. 1081-1085, 1956.

Fukuoka, Masami, "Landslides in Japan." Proc. 3d Internat. Conf. on Soil Mechanics and Foundation Engrg., v. 2, p. 234-238, Zurich, 1953.

Hansen, W. R., and Bonilla, M. G., "Geology of the Manila Quadrangle, Utah-Wyoming." U. S. Geol. Survey Misc. Inv. Map I-156, 1956.

Hunt, C. B., "Military Geology." In "Application of Geology to Engineering Practice." Berkey Volume, Sidney Paige, Chairman; Geol. Soc. America, p. 295-327, 1950. (See also "Interpreting Geologic Maps for Engineering Purposes." Hollidaysburg Quadrangle, Penna., 1953, U. S. Geol. Survey.)

Lindvall, R. M., "Geology of the Big Sandy Quadrangle, Montana." U. S. Geol. Survey Misc. Inv. Map 1-130, 1956.

Appendix

Questionnaire on Landslides and Engineering Practice

The questionnaire whose results formed the basis of this book, and which is described in Chapter One, is here reproduced in full as to contents, but condensed as to format. In its original form the questions were preceded by a two-page statement of the objectives of the questionnaire and a solicitation for help from the many engineers and geologists to whom it was sent. It was also accompanied by an early version of the classification chart that appears as Plate 1 in this volume.

The questionnaire is included here mainly because it gives in succinct form a guide to the thinking and observations that the Committee feels must go into the investigation, solution and description of any landslide problem. It may also have some value in giving the reader an idea of the kind of data that are contained in the completed questionnaires as filed with the Highway Research Board Library. These questionnaires contain an abundance of basic facts that will be useful, it is hoped, to future students of landslide problems. They also contain many excellent photographs and drawings of actual slides and of methods used for combating them.

General Questions

Please indicate restrictions as to use of the information you supply.

(a) No restrictions.

(b) Permission granted to publish with due credit.

(c) Permission granted to publish if identity of organization and location are withheld on all items marked "X."[8]

(d) Permission granted to publish all information furnished except those marked "C" (*i.e.*, C VI) which are supplied as confidential information to the committee.[8]

If exact figures are not readily available, the committee would appreciate approximate figures or informed guesses throughout this questionnaire rather than no answer. Wherever possible, the following questions have been designed for objective answers for your convenience. More detailed remarks will, of course, be appreciated.

I. What is the approximate yearly cost to your organization of all landslides (include construction, relocation, and maintenance costs)?

(a) Less than $25,000

(b) $25,000 to $100,000

8 Editor's note: Questionnaires that contained confidential material have been returned to the authors and are not on file with the Highway Research Board.

(c) $100,000 to $250,000
(d) $250,000 to $500,000
(e) $500,000 to $1,000,000
(f) In excess of $1,000,000
(g) ______________________

II. Please cite figures for an unusually troublesome year under the following headings.
(a) Loss of life (number).
(b) Number of persons injured.
(c) Cost of relocations to avoid landslides.
(d) Cost of all preventive and corrective (maintenance) measures other than relocation.
(e) Direct damages not included under a, b, or c (*i.e.*, damage to rolling stock, damages awarded in lawsuits as a result of encroachment of slide on other property, estimated damages resulting from traffic delays including construction of temporary detours, etc.)
(f) ______________________
(g) Year for which above figures are given.

III. Was the year cited under II above one of:
(Indicate yes or no)
(a) Particularly heavy precipitation?
(b) Unusually severe winter?
(c) Unusual drouth?
(d) Had the previous season been one of particularly heavy construction on new alignments?
(e) Other unusual aspects? (Please cite) ______________________

IV. In the year cited, which type of landslide (see enclosed classification chart) caused most of your problems?
(a) Falls
(b) Slides
(c) Flows

V. Which of these types is most frequent in a normal year?
(a) Falls
(b) Slides
(c) Flows

VI. Do most of your landslide problems occur in:
(a) Bedrock
(b) Unconsolidated material (including soils)

VII. Please indicate on a standard base map, highway planning map, or railway system map, the location of all slides with which your organization has been troubled or of which you have knowledge. Please assign an index number to each slide.* This number may be used in referring to the slide on the detailed description sheets which have been enclosed. We are particularly desirous of obtaining detailed information on at least one slide of each type (see enclosed classifica-

* If the number of slides to be plotted makes impractical the assignment of an index number to each slide, use a black dot for each slide location and assign index numbers only to those slides for which you complete the enclosed data sheets or supply additional information.

tion charts) which your organization has encountered. In addition, for other representative slides of each type which you have shown by number on the map, we would appreciate at least the following information:

1. Slide type as indicated by a figure number selected from the enclosed charts.
2. Location (*e.g.*, route, direction, and distance from city or town).
3. Volume of slide.

We can plot this information on large geologic, physiographic, and climatic maps of the area and thus obtain considerable additional information.

VIII. What existing texts or books have you found most satisfactory?
For example:

Ladd, G. E., "Landslides, Subsidences and Rockfalls as Problems for the Railroad Engineer." Proceedings, American Railway Engineering Association, v. 36, p. 1091-1162, 1935.

Sharpe, C. F. S., "Landslides and Related Phenomena." 125 p. New York, Columbia University Press, 1938.

Heim, A., "Ueber Bergsturge." Naturf. Gesell. Zurich, Neujahrsblatt 84, 1882.

Terzaghi, K., "Erdbaumechanik." Franz Deuticke, Wien, 399 p., 1925.

Terzaghi, K., "Mechanism of Landslides:" (chapter in) "Application of Geology to Engineering Practice." Berkey Volume, Geol. Soc. of America, p. 181-194, 1950.

IX. Why do you prefer the book or article cited, or what features of the book have you found most satisfactory?

X. If you have developed a classification of landslides within your organization, or favor one of the standard classifications such as those included in the references cited under Question IX above, please give details on the back of this page.

XI. Have you had experience with any landslide which you feel does not fit into one of the classifications (figures) shown on the enclosed chart? If so, please sketch below and/or on the following blank sheet. Please assign a type name to each sketch.

XII. Of the types of landslides shown on the enclosed chart or in your sketches, which has most frequently been a problem to you?
List by figure number (enclosed chart) or type name in order of frequency.

XIII. One state has reported that a majority of the landslides on the highway system has resulted from undercutting of the toe of a slope by stream action; another, faced chiefly with the problem of rockfalls, attributes the problems to frost wedging in strongly jointed rock. *What single factor do you consider most important in causing each of following major landslide types in your state or on your system?* If applicable,

qualify your answer for a particular section (physiographic or geologic provinces).

1. Falls; 2. Slides; 3. Flows.

XIV. What percentage of your landslides occur under the listed conditions?

1. In undisturbed natural slopes above the construction.
2. Above the roadway but on slopes cut by the construction.
3. Below construction but apparently "triggered" by natural causes, such as undercutting of the downhill slope by streams.
4. Below construction and apparently "triggered" by the construction.
5. Entirely within the cut section of construction.
6. Entirely within constructed fills.
7. In ancient slides reactivated by construction.
8. Other ____

XV. In general, what relationship have you found between ground water and landslide occurence?

XVI. Many of the landslides of southwestern Colorado occur in the Mancos shale where overlain by the Mesaverde formation, and many landslides occur in the Conemaugh formation in Pennsylvania and adjacent states. What formations or stratigraphic sequences have you found to be particularly susceptible to landsliding?

XVII. What is the flattest original slope on which you have observed each of the following?

(a) Rockfall (Fig. 1)
(b) Soil fall (Fig. 2)
(c) Bedrock slump (Figs. 3, 4)
(d) Block glide (Fig. 5)
(e) Soil slump (Figs. 6, 7, 8)
(f) Rockslide (Fig. 9)
(g) Debris slide (Fig. 10)
(h) Failure by lateral spreading (Fig. 11)
(i) Debris flow (Fig. 19)
(j) Other flows

XVIII. Rate the methods listed below (plus any additions which you may make) in the order of their effectiveness in prediction of "troublesome ground."

(a) Study of aerial photographs.
(b) Interviews with local citizens along proposed line.
(c) Predictions based on geologic formations to be encountered.
(d) Predictions based on soil types to be encountered.
(e) Soil mechanics studies.
(f) Ground reconnaissance by experienced personnel.
(g) ____
(h) ____

XIX. In the recognition of old slide areas, every engineer or geologist has his "pet" signs (hummocky ground, bent trees, etc.) What are your favorite signs for recognizing such ancient or potential trouble areas?

XX. Some organizations use laboratory identification of the various clay minerals to determine the probability of slides. If you have used such methods, can you summarize your experience with examples?

XXI. We can all profit by knowing how the other fellow goes about his work. Supply, if you can, a copy of a representative field study of a slide indicating the field methods used and the recommendations drawn from observations.

XXII. Supply a copy of a typical soils laboratory report on a landslide problem that indicates the methods of testing and analysis used in your organization.

XXIII. Describe briefly any special methods of field or laboratory investigations that you have tried other than those exemplified in the examples asked for above.

XXIV. In your organization are landslide problems considered principally the concern of: (underline one)
(a) The location engineer
(b) The soils engineer
(c) The staff engineering geologist
(d) The design engineer
(e) The maintenance engineer
(f) ____

XXV. The Swedish Geotechnical Commission has devised an automatic, electrically-operated, warning system which operates a block signal at the ends of a railroad cut when a slide occurs in the cut; other organizations take regular readings of observation stakes driven in suspected slide areas in order to detect a movement in its earliest stage. Have you used either of these methods? __________ What other methods for predicting or warning of the occurrence of landslides in known dangerous areas have you used or encountered?

XXVI. If you have made any studies using observation wells or pore-pressure gauges to determine the subsurface water conditions in suspected slide areas, please give brief description.

XXVII. The State of Washington has recently installed strong, wire mesh blankets over the face of deep rock cuts to prevent damage from rockfalls. Other states often use a series of berms on high backslopes to form catchment shelves for rockfalls. Have you used either method for controlling rockfalls? __________ With what success? _______________ ______________________________ What other methods have you used in preventing or controlling rockfalls?

XXVIII. What method or methods of correction have you found most successful in correcting or controlling slides (Types II, A and B of classification chart)?
What methods have you found to be unsuccessful or of doubtful worth? Use back of this page for further details.

XXIX. What method or methods have you found successful in controlling or correcting flows (Type III of classification chart)?
What methods have you found to be of doubtful or no worth?

XXX. The courts have held (*Boskovich* vs. *King County, Wash.*, 1936) that where warning of the danger of landslides would not promote the safety of those using the highway, there is no duty to give it. At the location in question slides had occurred in the past, but the court felt that since no slide actually blocked the road, no warning would have been suitable or required. What do the laws of your state have to say about the necessity of warning signs in areas susceptible to landslides or rockfalls?
Specifically, does the establishment of such things as "Danger, Falling Rock" relieve the state of liability if a motorist hits a fallen rock in the road?

XXXI. In a number of cases landslides onto a highway or railroad right-of-way have been attributed to irrigation canals or detention dams constructed at some point above the right-of-way. If you know of such a case, where have the courts placed responsibility and to what extent were damages awarded?

XXXII. Describe briefly other types of legal problems which may have arisen in connection with landslides.
Citations of specific suits or details of specific litigation will be greatly appreciated. Please indicate restrictions upon publication of such material.

Description of Individual Slides

It is desired that you complete one of these sheets for at least one representative of each type of slide with which you are troubled. Data for any additional slides listed on the location map would be greatly appreciated. Space is provided on the back of these sheets for additional remarks, sketches, photographs, etc., any of which would be extremely valuable. If you prefer, substitute a narrative description of each slide for this information sheet. The questions listed below cover the principal points in which we are interested, but a description in your own words will undoubtedly furnish us more information on the important points of slide characteristics and corrective measures.

Slide Reference Number (from location map) ______________________
Location: __________ miles ______________ (direction) from __________ (town, city, etc.) on Route No. ______________.
Landslide type (figure number from enclosed classification chart).
Landslide type (your classification or nomenclature).
Date of Occurrence ______________________
Estimated quantity of material involved in slide:

__________Less than 5,000 cu yd
__________5,000 - 50,000 cu yd
__________50,000 - 500,000 cu yd
__________500,000 - 1,000,000 cu yd
__________Greater than 1,000,000 cu yd

Approximate dimensions of slide block or flow
Width (along scarp): ______
Length (normal to scarp): ______
Depth (maximum): ______
Greatest distance through which material moved: ______
Approximate original slope on which slide occurred: ______
Estimated rate of movement (select one or indicate measured movement under (e):
______(a) Slow (less than 5 ft per month)
______(b) Moderate (5 ft per month to 5 ft per day)
______(c) Rapid (5 ft per day to 1 ft per minute)
______(d) Very rapid (in excess of 1 ft per minute)
______(e) Measured rate was ______ feet per ______
Precipitation conditions preceding slide were:
______(a) Dry
______(b) Moderate rainfall
______(c) Heavy and/or prolonged rains
______(d) Rapidly melting snow cover
______(e) Fast spring warmup
______(f) ______
Was subsurface water involved? ______ Remarks: ______
Estimated monetary damage: ______
Number of persons injured ______ Killed ______.
For what period of time was traffic blocked or delayed until slide could be cleared or detour route established ______

TYPE OR TYPES OF MATERIAL INVOLVED IN SLIDE (Underline): If preferred, by sketch of slide show types of material involved.

A. Slide entirely in unconsolidated material: Yes______No______
  I. Material was: (a) Residual (b) Non-residual
  II. Material was (a) Relatively homogeneous (b) Non-homogeneous.
  III. Material was:
    (a) Waterlaid:
      1. Floodplain alluvium 2. Terrace deposits
      3. Alluvial fan deposits 4. Other ______
    (b) Glacial deposits:
      1. Till 2. Stratified drift 3. Other ______
    (c) Wind deposit:
      1. Dune sand 2. Loess 3. Adobe
    (d) Other:
      1. Talus material 2. Old landslide material
      3. Manmade fill 4. Mine tailings
      5. Other ______
    (e) Agricultural soil type was (*e.g.*, Putnam clay) ______
    (f) Please give available B.P.R. soil classification and other available pertinent soil mechanics data under remarks where applicable.
      Remarks ______

B. Slide involved chiefly consolidated material. Yes______No______
  1. Sedimentary:
    (a) Shale (b) Sandstone (c) Limestone

(d) Interbedded limestone or sandstone and shale.
(e) Other ______________________________
(f) Stratigraphic unit(s) involved (*e.g.*, Pottsville fm.) ______

2. Metamorphic:
   (a) Schists (b) Phyllite (c) Marble
   (d) Serpentine (e) Gneiss
   (f) Other ______________________________

3. Igneous
   (a) Volcanic:
      1. Volcanic ash.
      2. Tuffs and breccias.
      3. Interbedded lava flows of composite cones.
   (b) Lava flows:
      1. Movement entirely in the lava.
      2. Lava flow underlain by weaker rock.
   (c) Acid igneous rocks
   (d) Basic igneous rocks
   (e) ______________________________

CAUSE OR CAUSES OF THE SLIDE: If several causes or factors are involved check as many as necessary, indicating, if possible, their relative importance.

(a) Gravity primarily.
(b) Rounded sand and pebbles.
(c) Clay materials.
(d) Micaceous minerals.
(e) Serpentine.
(f) Water, free, capillary.
(g) Raising water content through increase of supply.
(h) Raising water content through blocking natural flow outlets.
(i) Prevention of evaporation by blanketing with earth, cinders.
(j) Rapid drawdown of water table.
(k) Rise of water table in distant aquifer.
(l) Seepage from artificial source (reservoir or canal).
(m) Removal of toe, natural causes.
(n) Removal of toe, construction.
(o) Earthquakes.
(p) Blasting.
(q) Temperature changes.
(r) Frost action.
(s) Dipping joint planes.
(t) Shrinkage cracking.
(u) Increase of load, construction.
(v) Increased load, ice and snow.
(w) Increased load, talus and slide accumulation.
(x) Dipping bedding planes.
(y) Dipping schistosity and cleavage.
(z) Fault planes.
(aa) Chemical decomposition of rocks (particularly volcanic).
(ab) ______________________________

TYPE OF TREATMENT: (after Baker, R. F., "Determining Corrective Action for Highway Landslide Problems." Highway Research Board Bull. 49, p. 6, 1952.)

I. Elimination methods
  A. Relocation of structure, complete
  B. Removal of the landslide
    1. Entire
    2. Partial at toe
  C. Bridging
  D. Cementation of loose material, entire

II. Control methods
  A. Retaining devices
    1. Buttresses
      a. Rock
      b. Cementation of loose material at toe
      c. Chemical treatment, flocculation, at toe
      d. Excavate, drain and backfill at toe
      e. Relocation, raise grade at toe
      f. Drainage of the toe
    2. Cribbing — concrete, steel, or timber
    3. Retaining wall — masonry or concrete
    4. Piling — steel, concrete, or timber
      a. Floating
      b. Fixed, no provision for preventing extrusion
      c. Fixed, provision for preventing extrusion
    5. Tie-rodding slopes
  B. Direct rebalance of the ratio between resistance and force
    1. Drainage
      a. Surface
        (1) Reshaping landslide surface
        (2) Slope treatment
      b. Subsurface (French drain type)
      c. Jacked-in-place or drilled-in-place pipe
      d. Tunneling
      e. Blasting
      f. Sealing joint planes and open fissures.
    2. Removal of material, partially at top
    3. Lightweight fill
    4. Relocation, lower grade at top
    5. Excavate, drain, and backfill, entire
    6. Chemical treatment, flocculation, entire

III. Other ____

____

____

Has the above listed treatment been successful? ____________________
Were any previous treatments unsuccessful? ____________ What was the type of treatment?
Sketches, photographs and written reports or descriptions from your files will be appreciated.

TYPE OF MOVEMENT

I. FALLS

Mass in motion travels most of the distance through the air. Includes free fall, movement by leaps and bounds, and rolling of rock and debris fragments without much interaction of one fragment with another.

II. SLIDES

Movement caused by finite shear failure along one or several surfaces which are visible or whose presence may reasonably be inferred.

A. Material in motion not greatly deformed.
Moving mass consists of one or a few units. Maximum dimension of units is greater than displacement between units. Movement may be controlled by surfaces of weakness such as faults, bedding planes or joints.
1) SLUMP: Movement only along internal slip surfaces, which are usually concave upward. Backward tilting of units is common. 2) BLOCK GLIDE: Movement of a single unit out and down along a more or less planar surface of weakness, generally a bedding plane. Block may glide far out on original ground surface.

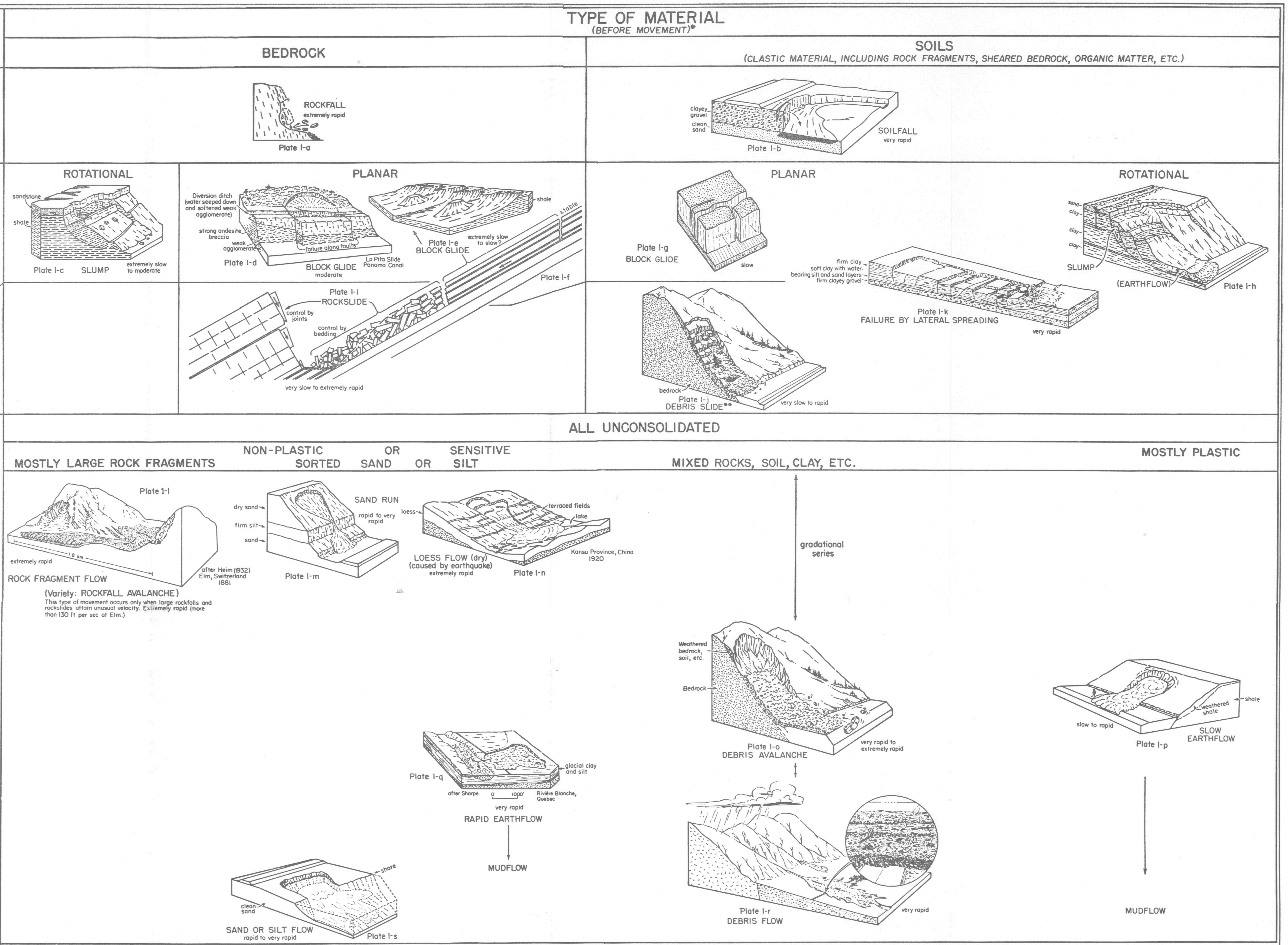
B. Material in motion is greatly deformed or consists of many semi-independent units.
Movement frequently is structurally controlled by surfaces of weakness such as faults, joints, bedding planes, variations in shear strength between layers of bedded deposits, or by the contact between firm bedrock and overlying detritus. Maximum dimension of units is comparable to or less than displacement between units, and generally much smaller than displacement of center of gravity of the whole mass. Movement may progress beyond original slip surface so that parts of mass slide over the ground surface.

III. FLOWS

Movement within displaced mass such that the form taken by moving material or the apparent distribution of velocities and displacements resemble those of viscous fluids. Slip surfaces within moving material are usually not visible or are short-lived. Boundary between moving mass and material in place may be sharp or a zone of distributed shear.

IV. COMPLEX LANDSLIDES

Movement is by a combination of one or more of the three principal types of movement described above. Many landslides are complex, although, as illustrated in Pls. 1-k and 1-l, one type of movement generally dominates over the others at certain areas within a slide or at a particular time in the evolution of a slide.



Nomenclature of the parts of a landslide
(see drawing at right)

MAIN SCARP – A steep surface on the undisturbed ground around the periphery of the slide, caused by movement of slide material away from the undisturbed ground. The projection of the scarp surface under the disturbed material becomes the surface of rupture.

MINOR SCARP – A steep surface on the disturbed material produced by differential movements within the sliding mass.

HEAD – The upper parts of the slide material along the contact between the disturbed material and the main scarp.

TOP – The highest point of contact between the disturbed material and the main scarp.

FOOT – The line of intersection (sometimes buried) between the lower part of the surface of rupture and the original ground surface.

TOE – The margin of disturbed material most distant from the main scarp.

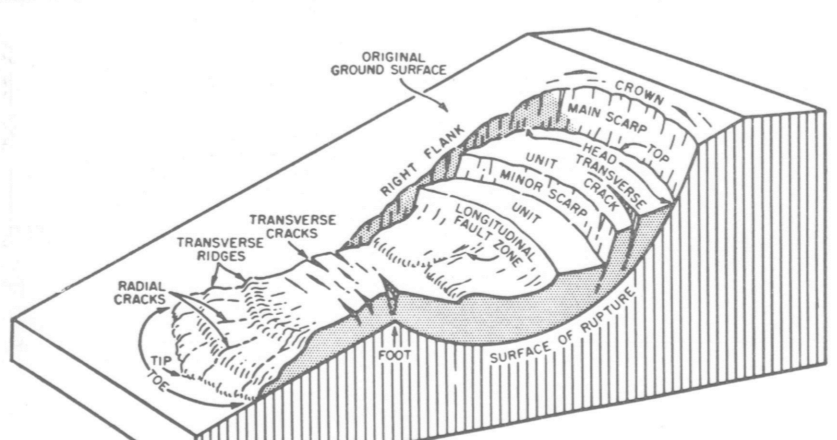


Plate I-t

TIP – The point on the toe most distant from the top of the slide.

FLANK – The side of the landslide.

CROWN – The material that is still in place, practically undisturbed, and adjacent to the highest parts of the main scarp.

ORIGINAL GROUND SURFACE – The slope that existed before the movement which is being considered took place. If this is the surface of an older landslide, that fact should be stated.

LEFT AND RIGHT – Compass directions are preferable in describing a slide, but if right and left are used they refer to the slide as viewed from the crown.

The following definition of a landslide has been adopted for use in this book:

Landslide – The term "landslide" denotes downward and outward movement of slope-forming materials composed of natural rock, soils, artificial fills, or combinations thereof.

Landslides move along surfaces of separation by falling, sliding, and by flowing. Parts of a landslide may move upward while other parts move downward. The lower limit of the rate of movement of landslide material is restricted in this book by the economic aspect to that actual or potential rate of movement which provokes correction or maintenance.

* The type of material involved is classified according to its state prior to initial movement or, if the type of movement changes, according to its state at the time of the change in movement. Thus, the Elm slide (Pl. 1-l) began as a rock slide and rock fall in bedrock, but at the time a flowing type of movement started the material was an "unconsolidated" mass of extremely rapidly moving rock fragments.

** By debris is meant natural soil and rock detritus.

Approximate ranges of rates of movement are according to the scale below

Plate I-u

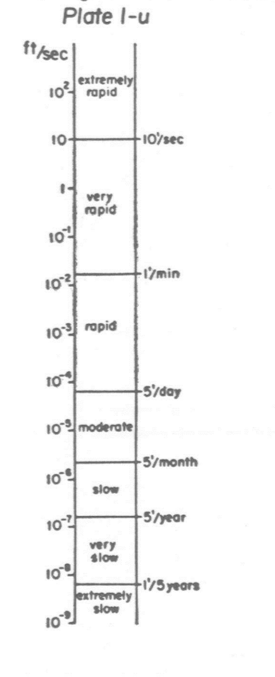


PLATE I
CLASSIFICATION OF LANDSLIDES
Highway Research Board Landslide Committee

HIGHWAY RESEARCH BOARD

NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL
DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH

2101 Constitution Avenue | Washington 25, D. C.

EXecutive 3-8100

BOOK ANNOUNCEMENT

LANDSLIDES AND ENGINEERING PRACTICE

HRB Special Report 29

Prepared by the Committee on Landslide Investigations

Edited by Edwin B. Eckel, Chairman

Publication date: January 1958 | Price: $6.00

126 illus., 6 tables, 1 plate | 232 pp.

The Highway Research Board, a unit of the National Academy of Sciences—National Research Council, announces publication of its Special Report 29, entitled "Landslides and Engineering Practice." The result of several years of effort by the Board's Committee on Landslide Investigations, this book may well become a standard reference work for those ~~concerned with this important field of~~ engineering.

It is the purpose of this volume to bring together in coherent form and from a wide range of experience such information as may be useful to any engineer who must recognize, avoid, control, design for, or correct the more important types of landslide movement.

Because the book is designed for practical use, theoretical discussions are minimized, whereas those phases held to be of greater interest to the practicing engineer are emphasized over others.

The book is divided into two parts. Part I, called "Definition of the Problem," is intended to provide the engineer with the tools and methods he needs to solve an actual or potential landslide problem.

Part II, called "Solution of the Problem," summarizes the methods known to have been applied to the prevention and control of landslides; it also discusses the methods of making stability analyses and of using them in the solution of design problems. In this part every effort has been made to distinguish between those methods that have proved successful under given circumstances and those that

have not. The brief closing chapter points out the kinds of information on landslides and their control that are still lacking and suggests methods by which such information may be obtained.

In its attempt to cover the entire field of landslides, from causes to cures, the volume is, to the authors' knowledge, unique in the English language.

There is no expectation that the reader of this book will become an expert on all phases of the investigation and treatment of landslides. Rather it has been the aim of the compilers to provide an introduction to all of the main factors that go into the solution of a given landslide problem. The average engineer, to whom a landslide is only one of many different problems that he encounters in his work, should be able to use the tools presented here himself or else should be able to determine from the facts given here when it is time to call in a specialist on one or another phase of his investigation. On the other hand, the specialist in some phase of landslide studies should gain an appreciation of the many facets of a landslide problem and of how his specialized knowledge of one facet can best be applied toward solution of the total problem.

Normal surficial creep is arbitrarily excluded from consideration, as are subsidence without downslope movement and most types of movement due to freezing and thawing of water. Similarly, landslide phenomena in tropic and arctic climates, and their treatment, are almost entirely neglected here. A few examples are drawn from other countries, but as the writers and their informants are largely experienced in the United States, most of the descriptions of landslides and of engineering techniques are drawn from this country.

It was perhaps inevitable, considering the makeup of the committee that compiled the book and the sources of information easily available to it, that the volume should seem to stress the landslide problem related to highways and railroads almost to the exclusion of many other landslide problems, such as those of shorelines and waterways, of city, suburban, and resort developments, and of farmlands. This apparent neglect has not been intentional—nor should it necessarily detract from the applicability of the facts contained herein to the solution of landslide problems other than those encountered by highway and railroad engineers. The factors of geology, topography, and climate that interact to cause landslides are the same regardless of the use to which man puts a given piece of land.