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TEXAS HIGHWAY DEPARTMENT

COOPERATIVE RESEARCH

# STABILITY ANALYSIS OF SLOPES AND EMBANKMENT FOUNDATIONS

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## STABILITY ANALYSIS OF SLOPES AND EMBANKMENT FOUNDATIONS

1. A. J. da Costa Nunes - SLOPE STABILIZATION-IMPROVEMENTS IN THE TECHNIQUES OF PRESTRESSED ANCHORAGES IN ROCKS AND SOILS. Proceedings of the First Congress of the International Society of Rock Mechanics, Lisbon, 1966 (Laboratorio Nacional de Engenharia Civil, Lisbon, Portugal), Vol. 2, pp 141-146, 1966. Highway Research Abstracts, Aug. 1967.

   Prestressed anchorages in rocks and residual soils, as well as in secondary soils, have been developed in Brazil, since 1947, permitting safe economical solutions to slope and foundation problems. The paper describes the techniques used and furnishes results of job behavior observations. It points out the versatility through different applications that this method has and discusses the problem of prestressing of soils and rocks and its future importance.

2. Schumm, S. A. RATES OF SURFICIAL ROCK CREEP ON HILLSLOPES IN WESTERN COLORADO. Science (1515 Massachusetts Ave., N. W., Washington, D.C. 20005), Vol. 155, No. 3762, pp 560-61, Feb 3, 1967. Highway Research Abstracts, Aug. 1967.

   The average rate of downslope movement of rock fragments on shale hillslopes is directly proportional to the sine of the slope angle or that component of the gravitational force which acts parallel to the hillslope. The rates of surficial rock creep range from a few millimeters per year on a 3-deg slope to almost 70 millimeters per year on a 4-deg slope, but these rates vary with natural variations in soil characteristics and microclimate, as well as with accidental disturbances.

3. TerStepanian, George TYPES OF DEPTH OF CREEP OF SLOPES IN ROCK MASSES. Proc. of the First Cngress of the International Society of Rock Mechanics, Lisbon, 1966, (Laboratorio Nacional de Engeharia Civil, Lisbon, Portugal), Vol. 2, pp 157-160. 1966. Highway Research Abstracts, August 1967.

   Depth creep of slopes is a widespread pheonomenon which occurs not only in soils but in rock masses as well. Deformation of rock masses proceeds extremely slowly and the process is of a secular nature. Different types of depth creep are distinguished depending on the geological structure and rheological characteristics of rock strata. Planar depth creep occurs on long slopes when the strata dip parallel to the slope and rocks have different rheological characteristics. Rotational depth creep occurs on short slopes when the slope body consists of homogenous rock masses. General depth creep is a common type of slope deformation which occurs in different geological conditions.

4. Finn, W. D. Liam, STATIC AND DYNAMIC STRESSES IN SLOPES. Proc of the First Congress of the International Society of Rock Mechanics, Lisbon, 1966 (Laboratorio Nacional de Engenharia Civil, Lisbon, Portugal), Vol. 2, pp 167-169, 1966. Highway Research Abstracts, Aug. 1967.

The change in the initial stress pattern in rock due to loading or excavating is investigated by the finite element method of analysis. A method is also presented for evaluating the dynamic stresses caused by an earthquake. The method of analysis is not restricted to the solution of stresses in slopes: it can also be used to determine the stresses and strains due to underground excavation or the drilling of boreholes.

Research is under way at the University of British Columbia on two possible extensions of this method which are of interest in rock mechanics: the extension of the dynamic analysis to inelastic material and the development of a creep-stiffness matrix for the solution of flow problems. If a suitable creep-stiffness matrix can be obtained, then not only the continuing creep deformations of rock can be estimated but also the changing stress patterns during such deformations.

5. Esu, F. SHORT-TERM STABILITY OF SLOPES IN UNWEATHERED JOINTED CLAYS. Geotechnique (Inst. of Civil Engineers, Great George St., London, S.W.1) Vol. 16, No. 4, pp 321-28, 1966. Highway Research Abstracts, June 1967.

The short-term stability of the slopes in fissured and jointed stiff clays is analyzed. The author examines the behavior of some typical Italian clays and points out the factors influencing the stability of cuts. Considering some failures which occurred immediately after the end of excavations, it is concluded that jointed clays are more similar to jointed rocks than to soils. The behavior of these clays depends on the resistance to sliding along the discontinuities, and the usual methods of stability analysis cannot be applied. Since water can seep through the discontinuities, jointed clays can be considered as permeable media and the hydrostatic pressure of the water contained in the discontinuities controls the stability of the slopes.

6. Mencl, V. MECHANICS OF LANDSLIDES WITH NON-CIRCULAR SLIP SURFACES WITH SPECIAL REFERENCE TO THE VAIONT SLIDE. Geotechnique (Institution of Civil Engineers, Great George St., London, S.W.1), Vol. 16, No. 4, pp 329-337, Dec. 1966. Highway Research Abstracts, June 1967.

After a summary of the data relating to the Monte Toc (Vaiont) landslide, some hypotheses of its development are presented. First its limit equilibrium is analyzed. Then the transformation of the rock body into a mechanism in the course of plastic flow is explained by supposing a gap or cavity to have developed along the curved section of the slip surface. The occurrence of such a gap at another site is reported. The assumption of the gap helps to explain the sudden unexpected collapse of the slope.

If the hypotheses as presented hold true there would be only one way of treating the landslide in the given case: to detect the location of the cavity (using a model test as a guide) to bore pumping holes and seal them to prevent the inflow from the other elevations, to install deep well pumps and to exhaust water from the cavity as completely as possible and probably for the entire lifetime of the reservoir.

7. Jones, Walter V. GROUNDWATER MOVEMENT IN LANDSLIDES, Engineering Experiment Station, University of Idaho (Moscow, Idaho), June 1966. 160 pp. Highway Research Abstracts, June 1967.

Many landslides could be prevented if groundwater could be diverted or drained from potential slide areas. Therefore, an investigation was conducted to determine if tracer materials could be used satisfactorily to delineate groundwater movement in or near active or potential slide areas.
Laboratory experiments utilizing soil columns were run to compare the effectiveness of eight chemical dye tracers. Two dyes, fluorescin and pontacyl, were found to be less absorbed or filtered out of solution than other dyes. Field tests were run in which these two dyes were tested and compared. It was found that either dye was satisfactory as a delineator of Groundwater movement. Analysis of the samples by a fluorometer is necessary. Graphical presentation of the fluoremeter readings is essential before definite conclusions can be made. Augur-hole methods of hydraulic activity determination are an aid in planning the tracer program.

8. Barnett, A. P. EVALUATION OF MULCHING METHODS FOR EROSION CONTROL ON NEWLY PREPARED AND SEEDED HIGHWAY BACKSLOPES. Agronomy Journal (677 S. Segoe Rd., Madison, Wis. 53711), Vol. 59, No. 1, pp 83-5. Jan.-Feb. 1967. Highway Res. Abstracts, July 1967.

Evaluation of several mulching methods used by different highway departments showed that 2 tons of grain straw per acre provided adequate protection to newly prepared and seeded 2½:1 backslopes when subjected to 1-year frequency storms, 1.3 inches of rain in 30 minutes. However, when subjected to a 10-year frequency, storm, 2.7 inches of rain in 60 minutes, two treatments stood out as superior. These were "shisker dams," called the Florida method, which permitted 41 percent runoff and 10 tons per acre soil loss; and surface mulch, called the Cartersville method, which permitted 40 percent runoff and 11 tons per acre soil loss. In all cases where asphalt spray was a part of the treatment, the effectiveness of mulch was decreased when tested by the 10-yr frequency storm. Mulches, both mixed and unmixed, when combined with asphalt, allowed a runoff of 1.3 inches, with a soil loss of 27-32 tons per acre, indicating that the asphalt had no beneficial effect. Bare, unprotected backslopes eroded at the rate of 97 tons per acre and permitted 62 percent runoff.

9. Spangler, M. G. LATERAL PRESSURES ON RETAINING WALLS DUE TO BACKFILL SURFACE LOADS, Highway Research Abstracts, December 1955.

For many decades the traditional method of evaluating the lateral pressure on a retaining wall due to a load applied at the surface of the soil backfill has been to substitute a uniformly distributed load for the actual load, and then calculate the pressure by either the Rankine or the Coulomb classical theory. This method of approach to the problem has several shortcomings and disadvantages. First, there is no logical or scientific basis for determining the magnitude of the uniformly distributed load in relation to the actual load. Judgement and intuition are the only guides for this substitution. Second, the lateral pressure on the wall resulting from the substitution is of uniform intensity throughout the entire height of the structure, whereas the intensity of pressure due to the actual load may vary considerably throughout the height of the wall.

10. Brice, J. C. EROSION BY TERRACETTES ON LOESS-MANTLED SLOPES, Transactions, American Geophysical Union (1513 Massachusetts Ave., N. W., Washington 5, D. C.), Vol. 37, No. 3, pp 337-38, June 1956. Highway Research Abstracts, October 1956.

Terracettes that consist of sod-covered treads and bare risers appear in many places on the loess-mantled slopes of southern Nebraska. Such terracettes have been attributed to slump movement resulting from slippage of individual blocks along deep-seated surfaces or along vertical joint planes. Field evidence in the Medicine Creek drainage basin in dicates that the terracettes there have originated from breaks in the sod cover that initiated upslope scarp retreat. Abundance and growth of terracettes are related to thickness of the sod cover and to the slope angle on which they are developed. An understanding of the origin of terracettes is necessary for their prevention and control and for making quantitative estimates of their sediment contribution.

11. Idriss, I. M. THE RESPONSE OF EARTH BANKS DURING EARTHQUAKES, Soil Mechanics and Bituminous Materials Research Laboratory, Univ. of Calif. (Berkeley, Calif.), April 1966. Variously paged. Highway Research Abstracts, April 1967.

A method is presented for investigation of the response of earth banks to earthquake ground motions. Using this approach, it is possible to make an assessment of the influence of the bank on the ground surface response, the stresses developed in the bank by a given base motion induced by an earthquake, and the stability of the bank during the earthquake. It has been shown that the overall response of an earth bank may vary widely depending on the nature of the soils involved, the height of the bank, and the depth of the foundation of the soil. Although the assumption that the soil behaves as a linear-elastic material is a limitation of the analysis, the results obtained provide a useful guide in assessing the behavior of an earth bank. Compensating corrections for this limitations can be included by selecting appropriate material properties to be used in the analysis of any given case.

12. Williams, P. J. DOWNSLOPE SOIL MOVEMENT AT A SUBARTIC LOCATION WITH REGARD TO VARIATIONS WITH DEPTH. Canadian Geotechnical Journal (Civil Engineering Dept., Univ. of Toronto, Toronto 5, Canada), Vol. 3, No. 4, pp 191-203. Nov. 1966, Highway Research Abstracts, May 1967.

An investigation of soil movements resulting from solifluction or similar processes at Schefferville, P.Q., Canada, gave special consideration of the variation of movement with depth below the surface. Tubes up to 2 meters long were inserted vertically in the ground and their subsequent deformation (if any) measured with special probes, which passed down the tubes in situ. The distribution of movement with depth produced a typically concave downslope form in the tubes. The movements varied in intensity and from year to year; they decreased with depth and were not measurable below about 1 meter. Analysis shows that consolidation following frost heave is probably not the sole cause. A stability calculation of the type commonly used for engineering purposes would have given no indication of the occurrence of movements of the magnitude observed.

13. UNIQUE APPLICATION OF PRESTRESSING USED IN BANK SLOPE STABILIZATION, Modern Concrete (431 S. Dearborn St., Chicago 5, Ill.), Vol. 24, No. 5, pp 46-49, Sept. 1960, Highway Research Abstracts, Nov. 1960.

Slope stabilization in deep earth cuts has always been a problem in the construction of highways and railroads. Normally, if cuts are not excessive depth, the selection of a suitable angle of repose for the type of material being excavated may suffice. For deeper cuts, involving loose soil and moisture, it may be necessary to report to additional measures, for example, extremely flat slopes, systems of terracing to remove more weight of material, or elaborate systems of drainage in order to maintain the stability of the slopes.

In the construction of one California Highway even more drastic means had to be adopted. In this case, an area on one side of a long slope (which later would be called upon to support the columns of a bridge) had to be stabilized by the installation of concrete beams anchored to pile footings by means of high-tensile alloy steel rods stressed to 50 tons per rod. This is probably the first time such an application of the features of prestressed concrete has been used in slope stabilization.

The main problem in the actual construction of the bridge was presented by the combination of a 15½ percent grade and the 1½ percent grade cross slope required for drainage. The bents and bbutments are skewed 17.2 ft from the centerline of the freeway below, and vary in height from 26 to 36 ft. The bridge proper did not present any serious problems.

The area involved has a soil of known poor reliability with respect to sliding.

Escavation was started in the late fall of 1957. When about 35 ft of earth had been removed, damp spots were noticed in the cut slope in the vicinity of the bridge site. Several small slides followed.

The instability of the cut was due mainly to a generally circular slip plane accompanined by aggravated wet conditions.

The slope, approximately 150 ft long, could not be terraced because of the private property adjacent to the top of the cut, and draining would not provide the required level of stability. It was therefore decided to stabilize the soil by reloading it to the stress which existed prior to excavation. Although this idea is often used, the method that was adopted to supply the required load in this instance is unique.

The load was applied to the slope through 3 reinforced concrete beams 15 in. thick by 5 ft wide, which were anchored to the top abutment and to a tie beam at the toe of the slope. The load was applied to the beams through high-strength alloy steel 1 1/8 in. diameter Stressrods and transferred to the soil from the rods through 24-in. diameter 75-ft long piles, which were of the cast-in-drilled-hole type.

The resulting load of 100 tons on each anchor pile provided a stabilizing force of 3 tons per sq ft where the piles were on 7-ft centers, and 1½ tons per sq ft where the piles were placed on 15-ft centers.

At the point of connection with the piles the beams were provided with a very strong step, a level 25 ft sq bearing area directly beneath the concentrated loads. The lower 40 ft of the anchor piles is of poured-in-place concrete, placed against undisturbed soil.

It was decided that if any shifting of the soil were to occur, the footings of the upper bent would probably become unstable and would probably cause the bridge to fail. Therefore, steps were taken to prevent movement in the horizontal direction, which would not interfere with the vertical movement of the beam when the load from the anchors was applied.

Stressing was started as soon as the concrete was considered strong enough to take the loads. The rods were loaded by means of 100-ton hydraulic rams which butted against the tops of the beams. Loads were applied in 10-ton increments (up to the total load of 50 tons) in order to determine the elongation of the rods and the settlement of the beams.

Since its completion, this California installation has functioned successfully, accomplishing all that it was designed to do to load up the side of the slope by compressing the soil to the extent that slides were eliminated, and to provide firm material to support the column footings for the overhead crossing. Without the drastic measures, that were taken, the bridge undoubtedly could not have been built safely at the site chosen.

14. Deere, Don U. SEEPAGE AND STABILITY PROBLEMS IN DEEP CUTS IN RESIDUAL SOILS, American Railway Engineering Association (59 East Van Buren St., Chicago 5, Ill.) Bulletin, Vol. 58, No. 535, pp 738-745, February 1957. Highway Research Abstracts, May 1957.

Construction was begun in the summer of 1955 of a new cross line approximately 2 to 3 miles south and west of Charlotte, N. C.

This report deals with those aspects of the subsurface conditions which were primarily responsible for the slope failures, the construction methods adopted for combating the adverse conditions, the results of the construction methods used, and a summary of the experience gained from this series of deep cuts in residual soil.

A study of a series of deep cuts in residual soils of this type has shown that there are several inherent conditions likely to be present in these soils that may result in slope failures. The residual soils may be quite clayey and cohesive in the upper few feet of the soil profile. However, the clay content decreases below a depth of 15 ft or so, and the soils are essentially cohesionless silts or fine silty sands. If a high water table is present, seepage at the base of the cuts may cause backward or subsurface erosion which tends to undermine the slope. In addition, the presence of joints, possibly with coating of manganese dioxide, introduces planes of weakness in the soil mass which further results in a lower stability. Predrainage by open ditches, by gravel-filled trenches, or possibly by well-points should be considered. Working the cut from one side only at approximate grade elevation would perhaps result in sufficient drainage to allow construction to progress at a normal rate. Rather than work at flatter slopes, it would appear advisable to consider the use of a 10 or 12-ft beam at midheight of the slope where cuts are greater than about 20 ft.

15. Akai, K. ON THE STRESS ANALYSIS AND THE STABILITY COMPUTATION OF EARTH EMBANKMENTS, Kyoto University, Disaster Prevention Research Inst. (Kyoto, Japan), Bulletin No. 17, 1957, (In English) Road Abstracts, Vol. 25, No. 2, p 28, February 1958. Highway Research Abstracts, June 1958.

The first part of this paper discusses stress distribution in earth embankments, taking into account the residual strength in the embankment in its natural state, externally applied forces and internal pore pressure. In the second part of the paper, consideration is given to the effect of pore pressure on the stability of embankments.

16. Shepard, C. H. SOLUTION OF A PROBLEM IN HIGHWAY SLOPE STABILITY, Highway Research Abstracts, December 1960.

This paper describes the application of soils engineering to the correction of an unstable highway slope.

During construction of a highway cut through clays, silts and sands of glacial outwash origin, the cut slope became very unstable. Extensive sloughing and erosion, with some slope movement, developed as excavation of the cut proceeded. A heavy flow of ground-water seepage developed in the cut slope. Drainage methods used to control this seepage are described.

After excavation of the cut area was complete, further slow movement of the slope face was observed. Successive cross-sections showing rate and nature of movement are presented. Additional field explorations, employing continuous sampling techniques, were made to determine cause of movement. Methods of sampling and testing were described. Investigation revealed slickensides, resulting in low-strength zones, in a soil mass which had general high shear strength. Also, a zone of soft, slow-strength elastic clay was disclosed at a critical location below subgrade.

Observations indicated movement on failure plane approaching the shape of a circular arc. Analyses by the Swedish circular arc method and the critical height of slope method are dicussed. Results of further study to determine the slope section required to attain stability are presented. Corrective treatment used is described, and principles and techniques used in this solution which are considered to have general application to other similar problems are summarized.

Pictures illustrate conditions from the beginning of construction to final completion of corrective work in September 1960.

17. Long, Albert, STABILITY OF ROCK SLOPES, Paper Presented at the January 1966 Annual Meeting of the Highway Research Board.

Described and discussed are the instruments and data analysis procedures used by the U. S. Bureau of Mines in the early stages of a continuing study of the method of predicting the steepness of the angle and height at which a rock slope will safely stand.

The described instruments and procedures represent the beginning of a scientific effort to quantify experimentally the engineering and general significance of the character of gravity and tectonic induced stresses in rock slopes with and without berms, slope geometry, groundwater, overblasting, and the attitude of rock joints, bedding planes and faults as they affect the stability of a rock slope. Also discussed is the use of the presplitting technique of blasting to form a smooth and tight slope face relatively free of rockfalls.

The reporting of these mining research studies may provide highway engineers with information regarding some new rock slope design tools. However, this segment of rock excavation science is in its infancy, and much costly and time consuming work must yet be done before the various rock slope stability factors can be assigned numbers. Ultimately, technically sound and rational rock slope design criteria and procedures will be developed.

18. Goodman, Louis J. SOIL ADDITIVES FOR EROSION CONTROL, Paper Presented at the January 1953 Annual Meeting of the Highway Research Board, Highway Research Abstract, Dec. 1952, p 62.

Erosion is one of the more serious problems encountered by engineers and soil conservationists. Highway cut and fill sections, upstream faces of earth dams, and other types of earth slopes must be protected against erosion. Current control methods are either too expensive or detrimental to vegetation, which is the simpliest means for protection of most slopes. Many fine-grained soils, which are not conducive to vegetation, are highly susceptible to erosional damage.

19. Krusekopf, H. H. EFFECT OF SLOPE ON SOIL EROSION, Missouri Ag Experiment Station, Research Bulletin 363, Brit. Abs., B. III., 1949, (October ), 406. Building Science Abstracts, Vol. XXII (New Series), No. 12, December 1949, London. Highway Research Abstracts, June 1961.

An increase in slope from 6 to 8.48 percent increased run-off by about 35 percent and approximately doubled the amount of erosion. The cropping system was the most important factor affecting run-off and erosion. The degree of slope and the amount, and intensity of rainfall also affected erosion, but to a variable extent, and their influence was greatly modified by the cover. Vegetation was more effective in reducing erosion than in reducing run-off. Under good cover the length of slope was the least significant factor affecting run-off and errosion.

20. SEE NEW SEEDING PROCESS FOR HIGHWAY EMBANKMENTS, Michigan Contractor and Builder, (Contractor Publishing Co., 642 Beaubien St., Detroit 26, Mich.) Vol. 54, No. 10, p 52. June 1960. HR Abstracts, September 1960.

Michigan State Highway Department engineers witnessed a demonstration of a newly developed process for seeding highway embankments and interchange areas.

The demonstration was held at the intersection of Interstate 94 (US 12) freeway and M-78 just south of Battle Creek.

The new process, developed by a paper company, calls for a specially-prepared solution of woodpulp, fertilizer, grass seed and other additives to be air sprayed over the ground.

The mixture forms a coating like a blotter paper over the ground when it dries and and is designed to protect the new seed beds against erosion until grass starts growing.

Highway Department officials said that if the new process is acceptable, it would be included in future contracts and the work would be done by contractors.

One of the big advantages of the new method is that the seeding, fertilizer and protective coating is done in one operation.

At the present time, embankments and interchange areas on Michigan's new highways are seeded and then fertilizer and a coating of straw mulch is spread over the seeded area in separate operations.

21. Dunich, J. M. THE ESTABLISHMENT OF CROWN VETCH AND BIRDSFOOT TREFOIL ON HIGHWAY SLOPES WITH VARIOUS COMPANION GRASSES AND RATES OF SEEDING, Report of Committee on Roadside Development, 34th Meeting, pp 55-59, 1955.

Previous experiments and practical experience have demonstrated the high value of crown vetch for use as a permanent herbaceous protective cover on the slopes of highway cut and fill sections. However, crown vetch seeded along did not provide satisfactory early slope protection because of its slow rate of establishment. These trials showed also that certain grasses were effective in providing quick slope protection. Best results were secured with tall fescue (variety Ky. 31) red fescue, and domestic rye grass.

Studies reported in this paper was undertaken to determine the rates of seeding of these grasses with crown vetch and birdsfoot trefoil that would provide immediate slope protection without suppressing the legumes to such an extent that their development into a permanent cover was prevented or seriously checked.

Field plot trials were established in July 1952, using 3 rates of seeding of the above grasses (25, 40, 60 pounds per acre) and 2 rates for the lugumes (20 and 30 pounds and 15 and 25 pounds respectively for crown vetch and birdsfoot trefoil). The seeding rates for grasses and legumes were in all possible combinations. Plots were 5 feet wide and 20 feet on the slope. They were located on a cut section of a highway that had an average gradient of 1½ on 1. All treatments were completely randomized in 3 replications.

Data is submitted showing the quality of the grass cover and initial legume stand in the fall of 1952 and through the 1953 and 1954 seasons.

Results to data show material differences in survival of crown vetch and birdsfoot trefoil at the various seeding rates of the grasses.

22. Skempton, A. W. EARTH PRESSURE, RETAINING WALLS, TUNNELS AND STRUTTED EXCAVATIONS. General Report. Proc 3rd International Conf. Soil Mech. 1953, 2, 353-61. Road Abstracts (England), Vol. 21, No. 10, October 1954, Highway Research Abstracts, January 1955.

This report for Session 7 deals with papers presented at the conference and other papers published since 1948. The various aspects of earth pressure are considered under the following headings: General theory and experiments, anchored sheet pile walls, strutted excavations in clay tunnels, rock tunnels and abutment pressure due to soil creep. Proposals for discussion are: (1) evidence, if any, that disagrees with observations in model tests on sheet pile walls which show that the elastic extension of tie rods and the usual small forward movement of the anchor are sufficient to prevent any "arching" in sand and the pressure distribution is of classical form; (2) comparison of methods of design of sheet pile walls; (3) additional field data on the center of pressure in clay; (4) pressures developed on a tunnel by a clay overburden; (5) the measurement of Young's modulus of rocks in-situ; and (6) pressures on bridge abutments due to soil creep.

23. Helenelund, K. V. STABILITY AND FAILURE OF THE SUBSOIL WITH SPECIAL REFERENCE TO RAILWAY EMBANKMENTS IN FINLAND, Report No. 4, Geotechnical Department of the Finish State Railways, Helsingfors, 1953. Highway Research Abstracts, January 1954.

In case of a distributed strip load on a homogenous cohesive soil, the author holds that it is possible to compute the bearing capacity of the soil with a high degree of reliability by means of circular slip surfaces. The shearing stress in the critical slip surface can be calculated as the product of an influence value and a load factor, the influence factor being a function of the depth factor. The author provides equations and graphical relationships for determining the shearing stress in the critical slip surface. Similarly, he provides graphical and formulated means for determining the effect of strengthening the soil by means of timber beds, or by means of loading berms. Consideration is also given to the solution of cases involving soft foundation soils. Separate discussions of 21 different failures are included.

The report consists of 148 pages, 80 figures and a list of references. Text is in Swedish followed by a 21-page summary in English and a list of references.

24. EROSION CONTRAL ON CALIFORNIA STATE HIGHWAYS, Reprint of a Series of Articles Published in "California Highways and Public Works". Highway Research Abstracts, February, 1951.

The most successful erosion control methods have proved to be those which reproduce most closely conditions which are to be found on natural slopes. Mechanical or unnatural methods of control, which sometimes immediately effective, deteriorate with time and show up poorly in the long run as compared with methods that follow natural vegetative processes. If we work with Nature, erosion control problems are simplified and the probability of success becomes more certain than if we disregard the examples of successful natural stabilization to be found on every hillside and proceed to attack the problem from a mechanical angle.

By artifically speeding up the stabilization process, thereby creating conditions in one season which Nature could not duplicate in several years, we find that we can shorten the time required for complete control.

Much of the value of slope stabilization treatment is lost unless proper maintenance can be given during the all-important first and second years after installation, and as required thereafter. Cost of timely maintenance is not high, but neglect can bring about increased and unnecessary expenditures due to the necessity of cleaning gutters and repairing gullies which threaten the traveled way, and of frequently rebuilding portions of roadways at fill locations.

Highway construction standards now encourage the use of flatter slopes in erosion-prone soils. Flatter slopes allow the use of thicker blankets of topsoil which can support a more vigorous growth of vegetation without tending to slump when saturated. Control problems are eased considerably, and the need for maintenance reduced.

As new successful erosion control projects are completed and the consequent reduction in maintenance cost for repair of erosion-caused damage becomes more evident, highway employees are taking a greater interest in the program. Highway engineers have been particularly cooperative in developing methods which would be both practical and effective and highway maintenance forces have become more conscious of the value of prevention. There is still a decided need for continued educational work, however, especially in regard to effective methods for repair of old eroded slopes, and it is believed that eventually this work will be done as a matter of course.

Experimental work will be continued. Even though it is felt that considerable progress has been made, too many questions remain unanswered and too many partial failures result from high-intensity rains to allow us to believe that the most effective methods have yet been developed.

25. Muller, Leopold THE EUROPEAN APPROACH TO SLOPE STABILITY PROBLEMS IN OPEN-PIT MINES, In Third Symposium on Rock Mechanics. Colorado School of Mines Quarterly (Golden, Colo.), Vol. 54, No. 3, pp 115-133. July 1959, GeoScience Abstracts, Vol. 1, No. 12, pp 52. December 1959. HR Abstracts, May 1960.

Arithmetical calculations of permissible slope angles, while cumbersome, are the most practical means of assuring safety with maximum slope. Rock stability and permissible angle are determined by the type of rock, the strength of rock, stratification and foliation, mechanical fragmentation, chemical defects, positional relations between slope plane and structural elements, a time factor, water in rock joints, and vibrations.

26. Murphy, V. A. A NEW TECHNIQUE FOR INVESTIGATING THE STABILITY OF SLOPES AND FOUNDATIONS, Proceedings, The New Zealand Inst. of Engineers, Vol. 37, pp. 222-285, 1951. Highway Research Abstracts, September 1952.

The author describes the development of a vane apparatus for determining the inplace shearing resistance of soils in the investigation of the stability of slopes and foundations.

The vane consists of a steel rod having, at one end, four small projecting blades or vanes parallel to its axis and situated at 90-deg. intervals around the rod. An auger is used to excavate to the required depth, and the vane is pushed or driven into the ground. At the other end of the rod above the ground surface, a torsion head is used to apply a horizontal torque, which is steadily applied until the soil fails, thus generating a cylinder of soil. The area sheared consists of the peripheral surface of the cylinder and the two round ends. The first moment of these areas divided into the applied moment gives the unit shear value of the soil.

The torsion head scale was attached 10 in. from the center so the turning moment was equal to 10 times the scale reading. The turning moment is equal to the resisting moment of the soil cylinder to shear.

$$\text{Therefore 10 times scale reading} = 2\,r^2 \,.\, L \,.\, c + r^2 \,.\, 2/3r.\, c$$
$$= 2\,r^2\, c\,(L + 2/3r)$$

If L the length of the cylinder is 4½ in. and r the radius is 1½ in., then

10 times scale reading = 77.8c

$$\text{or the shear strength} = \frac{\text{turning moment psi.}}{7.78}$$

Using a factor of safety of 3, the author arrives at a safe bearing capacity of a square footing equal to dial reading in pounds divided by 54.4

The author made several tests between the vane and unconfined compression tests and found good correlation. He shows typical examples of analysis of slides by means of data obtained from vane tests.

The paper and discussion contains 53 pages of text, 26 figures and a list of 13 references.

27. Gould, James P. Dr. COMPRESSION CHARACTERISTICS OF ROLLED FILL MATERIAL IN EARTH DAMS, Tech. Memo. 648, U. S. Department of the Interior. Bureau of Reclamation, Denver, March 1954, Highway Research Abstracts, March 1955.

Apparatus designed to measure consolidation within the embankment have been placed in 25 Bureau of Reclamation earth dams in the past 14 years. Horizontal crossarms, connected in a system of telescoping riser pipes, are placed in the fill at 5-foot vertical intervals as construction of the embankments proceeds. Observed shortening of the vertical distance between crossarms in the telescoping pipe system is caused by (1) primary consolidation, (2) secondary compression, and (3) shear strain.

This analysis utilizes the measurements (from embankment settlement apparatus) in an investigation of the following stress strain characteristics (1) primary compressibility in one-dimensional consolidation which influences magnitude of pore pressures built up during construction; (2) secondary compression and settlement on saturation, factors which threaten loss of freeboard and cracking of embankment in periods of reservoir operation; and (3) recompression characteristics that influence pore pressures residual from drawdown.

The conclusions obtained from the analysis are, in the main, as follows:

Primary compressibility compression curves of observed strain versus effective stress were described from 33 impervious materials from crossarm-settlement observations of 22 earth dams. Values of strain obtained from these curves at 100 psi. effective stress were tabulated with the soils grouped according to the new Unified Soil Classification.

Compressibility increases in the following order: gravels and sands with silty fines; silts of low plasticity; gravels and sands with slightly plastic fines; sands with clayey fines; mixtures of gravels, sands, and silts with clay; and clays of low to medium plasticity. This sequence emphasizes the importance to compressibility of the plasticity of the fine fraction compared to gradation or grain size characteristics. Values of compression, expressed in percent, at 100 psi. effective stress were of the approximate order given below for the appropriate soil groups.

| Soil Group | Approximate compression, at 100 psi. effective stress |
|---|---|
| GM and GM-GP | 0.9 - 1.1 |
| GM - SM | 1.1 - 1.4 |
| SM | 1.5 - 1.8 |
| MC | 1.9 - 2.1 |
| SC - GC | 1.9* |
| SC - SM | 1.9 - 2.6 |
| SC | 2.0 - 3.3 |
| CL - GC | 2.7* |
| CL - MC | 2.9 - 3.6 |
| CL - SC | 4.2* |
| CL | 2.8 - 4.6 |

* only one dam represented

A study of two major structures shows that the deviation of compaction moisture from optimum moisture content has marked influence on compressibility increases with placement moisture of the fine fraction in the range of stress to at least 100 psi. Materials placed wetter than 0.5 percent below optimum exhibited compression curves convex upward in logarithmic plots with high initial strain and progressively decreasing compressibility, so that consolidation strain per unit of effective stress had become small by the end of construction. Soils compacted drier than about 2 percent below optimum have concave curves with low initial strain and constant or slightly increasing compressibility, so that in some instances compressibility is maximum at the end of construction. (Placement moisture is in part responsible for the wide range in compression given for CL soils).

Loss of freeboard cumulative post-construction consolidation of the embankments under observation generally has been less than 0.2 percent of the original height in 3 years and 0.4 percent in periods as long as 14 years. The longer records apply to dense broadly graded materials. Observations are not yet complete to demonstrate effects of reservoir load, seepage and drawdown on embankments built of CL clays.

Settlement on Saturation. In no case do the crossarm-settlement observations show an important increment of compression accompanying penetration of the seepage into the impervious zones.

Effect of Compressibility on Drawdown Pore Pressures. A limited number of observations indicate that broadly graded impervious materials and fine-grained soils of little plasticity are insensitive to recompression and, therefore, can be considered incompressible during drawdown.

This technical memorandum is the first of a series on general performance of Bureau of Reclamation earth dams. Two memoranda of this series now in preparation will report on the pore fluid pressures which developed in fine grained materials during construction. This technical memorandum contains 31 pages of text, 30 figures, and a bibliography.

28. USC SCIENTISTS HALT SLIDES BY ELECTRIC SHOCK TREATMENT, Southwest Builder and Contractor (1660 Beverly Blvd., Los Angeles 26, Calif.) Vol. 142, No. 19, p 67. Nov. 8, 1963, Highway Research Abstracts, June 1964.

"Electric Shock Treatment" for slipping soil could prevent disastrous landslides in the Los Angeles area, according to a research team at the University of Southern California School of Engineering.

Even small amounts of direct current will dry out moist soil, change its molecular structure, and form cementing material in the ground.

The strength or cohesiveness of certain soil, particularly clay, can be increased from five to ten times by electricity.

Use of electricity to control or prevent land slippage first came to the attention of the USC engineers when they were successful in using electrical energy to get the last drop of petroleum out of oil wells after they had stopped flowing naturally.

In the laboratory and in oil fields the research team found that "shocked soil" became more compact and drier the longer it was exposed to electricity and that the process is irreversible.

Engineers in the Soviet Union, Germany, Sweden and Mexico have used electricity successfully to control or prevent landslides particularly where railroad tracks or highways have been cut through soft ground.

During World War II, the Germans electrified river banks to keep them from slipping and filling up channels dredged to hide submarines.

Professors working on the research at USC are Carrol M. Beeson, Chairmain of the Petroleum Engineering Department, and George V. Chilingar, Associate Professor.

29. Roland, Harry L. A RAPID METHOD FOR SOIL CEMENT DESIGN: LOUISIANA SLOPE VALUE METHODS, Res. Rept. No. 11, Louisiana Dept. of Highways (Baton Rouge 4, La.) March 1964, 33 pp., 64 tables. HR Abstracts, Sept. 1964.

This report is concerned primarily with the development of a laboratory design procedure calculated to reduce the testing time for determination of minimum cement content for soil cement construction.

The testing program covered some 274 different soil samples representing a major portion of the state. The samples selected were those materials which would be suitable for construction purposes without any previous treatment.

A minimum compressive strength requirement could be established for various AASHO soil groups that would meet the PCA criteria. However, this method would not be economically desirable in that it would lead to the use of excessive cement on a large portion of the samples tested.

Consequently, a method which would take maximum use of compressive strength criteria as correlated with the Wetting-Drying Test (AASHO T 135-57) was devised. The Louisiana "Slope Value Method" as it is called, is based on the premise that there is a relationship between the durability of soil cement mixtures at selected cement contents and the slope of the unconfined compressive strength line at identical cement contents. A procedure for this method is given in the Appendix.

This method, in addition to reducing the testing time by approximately 70 percent, is at least as accurate as the Wetting-Drying Test and incorporates many of the virtues of the latter.

The Louisiana "Slope Value Method" shall be evaluated with respect to the Wetting-Drying Method for a period of approximately one year in order to further observe its practicality.

30. Hardy, R. M. STABILITY OF SLOPES IN SOFT SHALES, Highway Research Board Paper Presented at the January 1963 Annual Meeting.

The paper deals with the stability of slopes in shales that have been formed by the compression of alluvially deposited clays under the weight of glaciers. Geologically these are classed as soft rocks, but in many instances no cementation of the particles has occurred. In their geological history the only physical alteration to the original clays has been compression due to the consolidating pressure from glaciers during the Pleistocene period. They are presently in a state of rebound and on release of overburden pressure along with access to water they may revert to soft clays frequently having high-swelling characteristics. Such soils are of wide occurrence in the northwestern portion of the North American continent. The paper presents several case histories of the performance of such materials in engineering construction in Northwestern Canada, and points out the deficiencies of conventional methods of analysis for predicting their behavior. The swelling mechanism and its significance are discussed, and suggested improvements in concepts for analyzing the stability of slopes in these materials are presented.

31. O'Neill, A. L. SLOPE FAILURES IN FOLIATED ROCKS ON THE WESTERN SLOPE OF THE SIERRA NEVADA, Highway Research Board Record No. 17, pp 40-42.

The physical properties of rock and its weathered counterparts can today be determined in laboratories with a high degree of accuracy. Such determinations lead to predictions of the stability of these materials for construction purposes; however, in some cases the rock fails to behave as anticipated. One important consideration is the geologic setting and the geologic history of the area. In evaluation of the geologic setting, the effects of rebound or stress relief of the rock mass has often been overlooked or neglected. As modern techniques and efficiency for excavating very large cuts in rock increase, it is apparent knowledge of the effects of stress relief in the design of cut slopes must also be increased.

The slope failures discussed occurred during relocation of Highway 40-A and the Western Pacific Railroad around the proposed Oroville Dam and Reservoir near Oroville, Butte County, California. The relocations are routed along along the edge of the Sacramento Valley and through the rugged foothills of the Sierra Vevada, where 8½ mi if the relocations pass through metamorphic rock of the Calaveras group. Most slope failures occurred in a rock type called phyllite, which has been tightly compressed and intensely folded during metamorphism.

Design criteria called for numerous 3/4:1 cut slopes, some in excess of 100 ft in height. Benches were used in many of the deeper cuts, however, some cuts were constructed without benches. Slope stability problems were most serious when cuts were made in directions parallel or near parallel to the direction of foliation of the rock. Very little trouble was encountered when cuts were made at right angles to the foliation. The nature of the failures with respect to geologic structure, the type and consistency of cracking on planes of foliation, and the direction of the displacement along hhe planes of foliation suggest that stress relief was part of the mechanism contributing to ultimate failure of the slopes.

32. Trollope, D. H. STRESS SYSTEMS WITHIN SIMPLE SLOPES OF GRANULAR MATERIALS, Inst. of Engineers, Australia, Civil Engineering Trans. (Science House, Gloucester & Essex St., Sydney, Australia), Vol. CE 1, No. 1, pp 18-26, March 1959. HR Abstracts, July 1959.

The theoretical work described in this paper covers the extension of the Systematic Arching Theory to be the case of the simple slope. In particular a solution has been derived for this case which takes account of the redistribution of stresses following plastic yield behind the slope. It is thought that the experimental work on model slopes described in this paper adds further support to the application of the Systematic Arching Theory to problems of stress distribution in granular materials.

The solutions lead directly to a description of the stress distributions across the base of embankments and as far as the authors are aware this is the first attempt to describe these stresses for the simple slope and the wide embankment.

The solutions also permit examination of the stability conditions within a slope. The conclusions derived are that for deep seated slips:

(a) A Circular failure surface is only likely to be applicable if shear failure first occurs in the foundation of a slope.

(b) The most likely failure suface for a slope resting on a compressible foundation is one which consists of a convex upwards portion merging into a straight line as distinct from the usual concave upward circular arc assumption.

A new method of analyzing conditions outlined in (b) above is described. This method makes use of the assumption of a straight line failure surface but is thought to be of sufficient accuracy for practical purposes. The resulting method is easy and quick to use. Finally it is concluded that the problem of the long term stability of slopes in stiff-fissured clays is likely to involve consideration of the increase of shear stresses with time as well as the reduction in shear strength with time; whereas previously only this latter factor has been considered.

33. Miyakawa, Isamu ON THE STABILITY OF SOFT GROUND UNDER AN EARTH EMBANKMENT, Civil Eng. Research Inst., Hokkaido Development Bureau, Sapporo, Japan, March 1959, Highway Research Abstracts, Sept. 1959.

This paper was prepared to make available for field engineers the method based on elasticity as a practical approach to the study of the stability of the supporting layer under an earth embankment. The study was limited to the problems of plane strain.

The distribution of shearing stresses developed in the underlying layer below a symmetrical earth fill having equal side slopes and the top surface parallel to the ground surface, and the relation between the form-index of fill and the character of stress patterns in the underlying layer in reference to the stability of soft ground were investigated. The mechanism of failure in the peaty undersoil, considering the anisotropic character of shearing strength of the constituent fibrous peat, was clarified.

On the application of the sliding-circle-method to the stability analysis of homogenous ground with negligible internal friction, the case most often encountered on the soft deposits, a study of the way that the stability factor and the location of the critical sliding-circle correlated with the form-index of the surcharge fill was made.

A failure of the soft ground water under the road fill at Toyohoro District, Hokkaido has been experienced by the author. On the basis of the analysis of this case, the interpretation was considered as most reasonable at least in isotropic soil the equilibrium relation of the danger factor regarding the maximum shearing stress was decisive for the stability of the underground.

34. BANK AND SHORE PROTECTION IN CALIFORNIA HIGHWAY PRACTICE, Calif. Dept. of Public Works, Div. of Highways (Box 1499, Sacramento 7, Calif.) Nov. 1960. published in 1961. 423 pp. HR Abstracts, March 1962.

This critical review of methods protecting banks, embankments, and shores from erosion is the result of a 10-yr study by the Division's Joint Bank Protection Committee. A generalized summary of the committee's findings as to past practice and performance is followed by specific descriptions of use, location, design, construction and performance for each type of protection.

Though geology is not treated as such, recognition of geologic situations and materials is implicit throughout the text and illustrations. Appendix B is a good abbreviated glossary of geologic, hydrologic and engineering terms related to the field of bank protection. The volume is a rich source of case history material, with as much attention paid to failure as to success.

35. Hutchinson, J. N. A LANDSLIDE ON A THIN LAYER OF QUICK CLAY AT FURRE, CENTRAL NORWAY, Geotechnique (Great George St., London, S. W. 1), Vol. 11, No. 2, pp 69-94, June 1961. Highway Research Abstracts, Oct. 1962.

The large slide which took place on 14 April, 1959, at Furre, on the River Namsen, forms the subject of the paper.

The main part of the slide consists of a single flake of ground which slid out rapidly on a long, gently inclined surface formed by a thin layer of normally consolidated quick clay. The investigations, which are described in some detail, reveal the essential features of the slide.

The main slide failed under drained conditions and from an analysis of its stability in terms of effective stresses, an angle of shearing resistance of 7 degrees is obtained for the quick clay in the sliding surface. Using this value, the decay of the safety factor of the area during the past 80 years is traced.

This low phi value, which is about one-third of that given by triaxial tests, is confirmed by in-situ, drained shear box tests. These indicate that in the failure surface of the slide, mobilization of the shear strength was simultaneous and that the low value obtained results from a release of internal energy through contraction of the loose structure of the quick clay under shear.

36. Peters, N. TEST APPARATUS IN EARTH EMBANKMENTS, Engineering Institute of Canada (2050 Mansfield St., Montreal 2, Quebec, Canada), Transactions, Vol. 3, No. 3, pp 89-95, Nov. 1959. Canadian Bldg. Abstracts, Abstract No. 29, p. 10, June 1960. Highway Research Abstracts, January 1961.

Test apparatus used to measure movements in pore pressures in earth dams during and after construction is described. The author is a soil mechanics engineer with the Prairie Farm Rehabilitation Administration which is responsible for irrigation projects throughout Canada's three western provinces. Details are given of installations in ten typical earth dams ranging up to 195 ft high. The test apparatus described includes settlement gauges, slope indicators, alignment pins, brass reference screws for observing surface movements and the 2 types of piezometer, the porous tube standpipe and the double tube type connected to a pressure gauge in a terminal well.

37. Bishop, A. W. STABILITY COEFFICIENTS FOR EARTH SLOPES, Geotechnique (Inst. of Civil Engineers, Great George St., London, S. W. 1) Vol. 10, No. 4, pp. 129-150. December 1960. HR Abstracts, April 1961.

More general application of the effective stress analysis to routine work has been hindered by the lack of a general solution for the total stress analysis. To obviate this difficulty, a set of coefficients that can be used to investigate the stability, in terms of effective stress, of most simple sections encountered in earth dam and embankment problems has been presented. The application of these coefficients gives results that are correct for simple sections composed of only one material and whose pore-pressure distribution can be described by the pore-pressure ratio, $r_u$, being constant throughout the given section.

A method has been described for determining the average pore-pressure ratio when the pore-pressure ratio distribution is variable within the cross-section. This allows the application of the stability coefficients to the more usual type of design or analysis that the engineer faces and the several cases of this type investigated reveal that only a comparatively small error is incurred in estimating the factor of safety. Examples of the end of construction and steady seepage stability in earth dams as well as natural slopes have been given to illustrate this application.

38. Terzaghi, Karl STABILITY OF STEEP SLOPES ON HARD UNWEATHERED ROCK, Norwegian Geotechnical Inst. (Oslo, Norway), Publication No. 50, 1963. 20 pp. (In English). Highway Research Abstracts, October 1963.

This paper contains a discussion of the factors which determine the degree of stability of steep slopes on hard unweathered rock. These factors include the angle of shearing resistance of the jointed rock, the effective cohesion, and the seepage pressures exerted by the water percolating through the joints of the rock. The paper also deals with concealed sources of instability which may exist beneath slopes in deep valleys between high mountains.

The angle of shearing resistance can be estimated on the basis of the results of a joint survey. The effective cohesion cannot be determined by any of the presently available procedures of rock exploration, but its influence on the stability of slopes on jointed rock is commonly much less important than that of the angle of shearing resistance.

The most unpredictable factor determining slope stability is the hydrostatic pressure in the water flowing out of a reservoir of a leaking pressure tunnel through the joints towards a slope, because this pressure depends on the details of the pattern of seepage which is commonly very erratic. Hence, if the slope is located next to and downstream from the abutment of a storage dam, sound engineering requires the elimination of these pressures by radical drainage. If the slope is located near a pressure tunnel, a reliably watertight lining should be installed in those parts of the tunnel from which leakage could have a significant influence on the stability of a slope.

In some very deep valleys located between high mountains, the rocks underlying the slopes of the valley have been displaced and damaged by movemeny along deep-seated surfaces of sliding. Hence, no dam should be built in any deep valley unless a geological survey supplemented by borings has demonstrated conclusively that such movements have not taken place.

39. Jones, Fred O. LANDSLIDES ALONG THE COLUMBIA RIVER VALLEY, Northeastern Washington, Geological Survey Professional Paper 367, U. S. Geological Survey ( U. S. Govt. Print. Office, Washington 25, D. C.), 1961, 98 pp. HR Abstracts, July 1962.

Landslides occur so frequently in the surficial deposits along the upper valley of the Columbia River that they affect greatly engineering developments and land use. The area of study extends along the upper 200 miles of the Columbia River valley in Washington, reaching upstream from Grand Coulee Dam along Franklin D. Roosevelt Lake to Canada and downstream from Grand Coulee Dam along the Columbia River nearly to Chief Joseph Dam.

More than 300 landslides in the Pleistocene terrace deposits were examined Slides were classified into type groups, so that each type might be analyzed and compared with the others. The geological environment was subdivided into the classification factors-material, groundwater conditions, terrace height, drainage, original slope, submergence culture and material removal.

The key measurement of a landslide was taken to be the ratio HC:VC, where HC and VC are, respectively, the horizontal and vertical distances from the foot to the crown of the landslide taken at midsection normal to the slope. The HC:VC ratio was correlated with the classification units of the geologic environment. The most extensive statistical analysis was done on data from slump-earthflow landslides. Of the eight classification factors analyzed, only material, ground water, original slope, and submergence proved to be significantly related to the HC:VC ratio. A formula was developed for predicting the HC:VC ratio of slump-earthflow landslides.

The stability of natural slopes was investigated by comparing data from slopes on which slides have not occurred with data from slopes on which slides have occurred. The analysis included a consideration of material, ground water, terrace height, original slope and submergence. A formula was developed for predicting the stability of natural slopes.

The technique of geologic classification and statistical analysis described in this report will assist geologists and engineers in judging the stability of natural slopes and in estimating the extent of impending landslides action.

40. MANMADE RAINSTORMS: A NEW TOOL FOR EROSION RESEARCH, Georgia Ag. Research, University of Georgia, Agricultural Experiment Station, (Athens, Ga.) Vol. 2, No. 4, p 14, Spring 1961. Highway Research Abstracts, July 1961.

A new erosion research tool is now in use at the Southern Piedmont Soil Conservation Field Station, Watkinsville, Georgia. It is called a "Rainulator," short for Rainfall Simulator. This machine will be used to determine the relative erodibility of different soils and the erosion control effectiveness of various soils, slope, crop, and management practices.

The basis design of the Rainulator was developed by an Agricultural Engineer-Agronomist team of the Agricultural Research Service at Purdue Univ. It distributed water uniformly onto plots through a system of reciprocating overhead nozzle at rainfall intensities of 5 and 2½ in. per hour.

The Rainulator can operate simultaneously on three plots 12 to 14 ft wide and 75 ft long, or four plots if the length of at least two are reduced to 35 ft. Any combination of rainfall intensities of 1¼, 2½, or 5 in. per hour can be applied to the individual plot.

The water needed is pumped from nearby ponds or streams. The entire system is portable. It can be moved to the location of any soil, slope, crop, and management complex needing study. Runoff and soil loss rates can be determined as well as total rainfall, runoff, and soil loss.

Current efforts are directed toward the development of a "standard storm" through the correlatinn of rainfall simulator erosion data with erosion data from natural rainfall. This "standard storm," when developed, will be used to study the relative erodibility of soils and the erosion control effectiveness of cropping system and management practices in different combinations on various soils and slopes throughout the Southeast.

41. Senour, Charles ECONOMICS OF RIVER BANK STABILIZATION, Proc. American Society of Civil Engineers, (33 W. 39th St., New York, N.Y.) Vol. 87, No. WW2, Journal of Waterways and Harbors Div., pp. 17-26, May 1961. HR Abstracts, Oct. 1961.

Determination of costs pertaining to stabilization of the caving banks of an alluvial river is not particularly difficult but realistic appraisal of resultant benefits presents some interesting problems in both the physical and accounting fields. In the latter, comparison of total benefits during the life of a bank stabilization project with total costs during the same period is suggested as possibly a better criterion of economic merit than the ratio between annual "equivalent" benefits and annual costs if interest rates pertaining to benefits differ materially from those pertaining to costs. In the physical field, gradually changing patterns of land use, and growth in population and industrial development challenge the adequacy of losses experienced in past decades as a criterion of future benefits from prevention of continued bank recession. The existing or foreseeable engineering construction (particularly reservoirs) offer the same challenge. The role of accretion in restoration of revenues is somewhat controversial.

The use of estimated future bank lines as a basis for computing benefits eliminates certain of the objectionable aspects of sole reliance on historical bank recession and damages. The criterion of benefits from stabilization and correlation between river stage and rate of bank recession provides a means of adjusting estimates of future land loss to reflect the influence of existing or authorized reservoir construction. Comparison of aerial photographs of selected localities taken at intervals during a period of years affords a basis for appraisal of the compensating effects of accretion.

42. Muller, Leopold, THE EUROPEAN APPROACH TO SLOPE STABILITY PROBLEMS IN OPEN-PIT MINES, In Third Symposium on Rock Mechanics, Colorado School of Mines Quarterly (Golden, Colo.) Vol. 54, No. 3, pp 115-133, July 1959. GeoScience Abstracts, Vol. 1, No. 12, pp 52, December 1939. HR Abstracts, May 1960.

Arithmetical calculations of permissible slope angles, while cumbersome, are the most practical means of assuring safety with maximum slope. Rock stability and permissible angle are determined by the type of rock, the strength of rock, stratification and foliation, mechanical fragmentation, chemical defects, positional relations between slope plane and structural elements, a time factor, water in rock joints, and vibrations.

43. Inderbitzen, Anton L. AN EROSION TEST FOR SOILS, MATERIALS RESEARCH & STANDARDS (American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.), Vol. 1, No. 7, pp 553-554, July 1961, HR Abstracts, October 1961.

It is now possible to determine in the laboratory how much erosion will take place on a hillside fill for given storm conditions. An apparatus devised by the author allows the user to determine how erosional rates for a given soil are affected by: relative compaction of the soil, slope of the experimental "hillside," rate of water flow, and duration of water flow. Erosion medium for the experiment is sheet runoff, and duration of water flow. Erosive medium for the experiment is sheet runnoff, but the apparatus could be modified to introduce the action of raindrops. Erosion of the soil specimen is measured on a weight basis and calculated as a percentage of the original dry weight.

The equipment consists mainly of a wooden tray with sides, a tapered front end, and a large circular hole in the center. A piece of ¼-in. ID copper tubing is attached to the rear of the tray. Holes 1/16 in. diameter on 1-in. centers are punched the length of the tubing at the level of the tray bottom. One end of the tubing is clamped shut, and rubber tubing connects the other end to a water tap. Water from the copper tubing flows down the board as a laminar sheet as long as the water pressure is not too great. Rate of the flow is calibrated by marking straight lines on the board where the spouts of water strike the board and coalesce as sheet flow.

Relative compaction at which the specimen is prepared and slope angle of the board depend on the original field conditions. Rate of water flow and duration of the flow over the specimen will depend upon the intensity and concentration of the rainstorm that is being duplicated in the laboratory.

Owing to the lack of complete precision in this test, the result should be considered qualitatively rather than quantitatively. This test merely indicates how rapidly any given soil will erode under different conditions of compaction, slope angle, and storm intensity; it gives the soils engineer and geologist a good idea of how different soils will react to erosive forces when places in hillside fills.

44. Raymond, Stanley PULVERIZED FUEL ASH AS EMBANKMENT MATERIAL, Proc, Inst. of Civil Engineers (Great George St., Westminster, London, S. W. 1), Vol. 19 Paper 6538, pp 515-635, Aug. 1961, HR Abstracts, November 1961.

A considerable effort has been made during the past 20 years to find uses for the ash from power stations burning coal, and in particular, in the past 2 yr interest has been shown in its use in road embankments. This paper assesses those properties of pulverized fuel ash (P. F. ash) likely to affect its use as fill material, in the basis of laboratory investigations conducted on some typical ashes from power stations in northwest England and western Scotland, and also appraises the evidence from two recent field trials.

It deals briefly with the nature, production, and availability of P.F. ash and at some length with the increase in shear strength with time which occurs with moist compacted ash. Changes in strength with time are measured using the California Bearing Ratio (CBR) test and undrained triaxial tests and increases in strength are shown to take place with all the samples tested at all conditions of moisture and density, although the rate of increase varies. The nature of the reaction causing hardening is considered, and the suggestion is made that it is a pozzolanic one initiated by free lime present in freshly produced ash. The effect of ash variability on compaction characteristics is also considered, and a method of specifying supply moisture content for hopper ash is suggested which should tend to minimize the effects of these variations.

The handling characteristics of the material are shown to be such as to warrant its consideration in appropriate circumstances as fill material, particularly over weak sub-grades.

45. Swanson, N. P. PROTECTING STEEP CONSTRUCTION AGAINST WATER EROSION, Paper Presented at the January 1967 annual meeting of the Highway Research Board.

Mulching practices on a roadside cut (3:1 slope) were evaluated with respect to controlling soil erosion and minimizing grass seed and fertilizer loss prior to grass establishment. A field plot rainfall simulator and a device to introduce additional surface flow over a plot were used to evaluate the mulching practices.

Measurements of soil erosion and grass seed and fertilizer loss were made from run-off samples taken through a series of simulated rainstorms. The effectiveness in protecting soil surfaces against water erosion was determined for (a) wood cellulose, (b) fiberglass, (c) latex material, (d) asphalt emulsion, (e) nettings, and (f) a combination of asphalt emulsion used as an anchorage for woodchips, corncobs, wood cellulose, fiberglass, and prairie hay.

The best protection was provided by materials such as jute netting, wood excelsior and prairie hay (1 ton/acre) anchored with asphalt emulsion (150 gal/acre.) The least effective mulches were the latex (150 gal/acre) and a kraft paper netting. Anchoring a material with asphalt emulsion provided increased adherence to the soil surface and was generally beneficial.

46. Rutka, A. UNUSUAL CASE OF EMBANKMENT FAILURE, Paper Presented at the Jan. 1967 Annual Meeting of the Highway Research Board.

The paper describes a study of an unusual failure which occurred in a short section of a winter-placed rock fill embankment constructed over swampy terrain composed of muskeg followed by soft to firm sensitive clay overlying a highly irregular bedrock surface. The embankment was built by the partial excavation and displacement method.

The study included a detailed subsurface investigation and examination of climatological information, settlement which collapsed was originally "floating" in the clay and supported at either end on bedrock. The spacing between the supports on bedrock was found to be only about 6 times the overall depth of the fill. The evidence indicated that the rock fill must have remained frozen until thawing in the spring. It is concluded that the collapse of the roadway at failure, and the resulting downward displacement, of about 12 feet which occurred, was due to a rare combination of circumstances. It is believed that flat horizontal arching between bedrock supports had developed in the section of frozen rock fill and that thawing in the spring led to collapse of the arching and consequent failure of the roadway. This explanation is consistent with the geometry and delayed nature of the failure and other evidence obtained.

A brief discussion of published precedent relating to implications of the phenomenon of arching in granular materials in other civil engineering works is given. Methods of dealing with soil and bedrock conditions which might be potentially troublesome through arching in winter-placed rock fills constructed over soft ground are also discussed.

47. Lang, C. H. EARTH PRESSURES IN RETAINING WALL DESIGN, Eng News-Rec v 134 n 8 Feb 22, 1945, p 276-8.

Adaptation of Rankine formulas for earth pressures may be used for simplification of design; illustrative example given of conventional abutement retaining wall traversing sloping bank of earth at oblique angle and with backfill having broken slope.

48. Daniel, A. W. T. EXTENSION OF WEDGE THEORY OF EARTH PRESSURE, Engineering v 158, n 4112 Nov 3, 1944, p 341-3.

In wedge theory, it is assumed that earth is dry, granular and free from cohesion and weight and friction are only physical properties to be taken into account; problem often arises in which retained earth has variable slope, such as river banks and investigation of this problem has led to results cited.

49. Johnston, J. CONSOLIDATION OF ROCK EMBANKMENT TO PREVENT WAVE EROSION, Roads & Bridges v 83, No. 8, Sept. 1945, p 67-9, 112-4.

Causeway at Baie Comeau, Que, made stable against heavy seas by intrusion method.

50. Nash, A. M. HOW FLEXIBLE WIRE MATTRESS AND RIPRAP WAS PLACED ALONG SECTION OF REDWOOD HIGHWAY IN NORTHERN CALIFORNIA TO STOP BANK EROSION. Roads and Streets v 87, No. 12 Dec. 1944, p 85-8.

Use of wire link fencing to control erosion of river banks and fills; design details and construction of jetties, mattress and riprap; description of project and method of installation.

51. Holmes, A. E. STOPPING SERIOUS EROSION. Highway Mag v 35 Nov-Dec 1944, p 160-1.

Use of Kudzu to control bank erosion; methods of plating and maintenance necessary are discussed.

52. ICWA'S NEW EMBANKMENT SPECIFICATION. Roads and Streets v 89, n 5, May 1946, p 67-9.

Discussion of Iowa's new embankment specification including description and preparation of site, use of roller for compaction, and construction of embankment; principal change from old specification is requirement of sheepsfoot in place of smooth roller.

53. NEW DEVELOPMENTS IN USE OF ASPHALT IN EROSION CONTROL. Roads and Streets v 89 n 4 Apr 1946, pp 90-2.

Illustrated description of use of asphalt in control of embankment erosion either as asphaltic concrete mat for protection against wave where road follows lakeshore or as thin film of asphalt for general protection against wind or rain water erosion.

54. CONCRETE RIPRAP BRIDGE APPROACHES. Western Construction News v 22 n 4 Apr 1947, p 81.

Use of sacked concrete "rip-rap" as bank protection is being tried for first time in Niles Canyon, Calif. area where new highway is being built in former creek bed; construction includes new bridge over Western Pacific Railroad, approaches of which required bank protection; cement and aggregate were placed dry in sacks which were later wet to form concrete.

55. Bennett, E. F. DEVELOPMENTS IN SOIL MECHANICS, Roads and Streets v 90 n 4 Apr 1947, p 54-5.

Study of structural soil mechanics as it benefits highway engineering; correct construction of embankments, foundations, compaction, etc depends on knowledge of soil properties.

56. HIGHWAY FILL PUMPED INTO PLACE. Construction Methods v 30 n 8 Aug 1948, p 74-6.

Pictorial report on construction of embankment of Columbia River Highway by means of dredging; direction of flow of material through three dredge pipes can be quickly changed by large diam valve; as dredged material enters fill, it is terraced by bulldozer.

57. Jakobson, B. DESIGN OF EMBANKMENTS ON SOFT CLAYS, Geotechnique v 1 n 2 Dec 1948 p. 80-90.

Development of method of strengthening site and reduction of shearing by means of loading berms; computations based on assumption of cohesive material and on circular cylindrical slides; diagrams.

58. Hardy, R. M. COMPACTION OF SOILS AS APPLIED TO ROAD CONSTRUCTION, Roads & Bridges v 87 n 10 Oct 1949, p 78-80, 122, 124, 126, 128.

Fundamentals of soil consolidation as applied to road embankments; significance of laboratory and field tests on compacted soils and discussion of merits of various types of compacting equipment explained; typical moisture density relationships; comparison of moisture density curves. Before Canadian Good Roads Assn.

59. Juhren, G. SHRUBS REPLACE STEEL AND CONCRETE, Western Construction News v 24 n 9 Sept. 1949, p 79-80.

Steep fill slopes of Palamar observatory road, often damaged by heavy rail, have been protected successfully by shrubs; method proved better and cheaper than application of steel and concrete.

60. Wilson, A. INVESTIGATIONS INTO CAUSES OF SUBSIDENCE IN EARTH RESERVOIR EMBANKMENT. Instn Mun Engrs-J v 76 n 9 Mar 1950, p 610-9.

Causes of subsidence on earth embankment and remedial measures to safeguard stability; investigations were carried out through shaft 8 ft. square; reservoir situated in moorland has capacity of 163 m gal with maximum depth of 29 ft; embankment is earth work 470 ft long and 39 ft high with puddle clay core; weakness in structure lay in fissured character of upper rock layers.

61. Hallett, E. R. AIR IN EARTHFILLS ASSURES STABILITY, Eng News_Rec v 144 n 22 June 1, 1950, p 44-5.

Charts developed to predict pressure required to absorb air in fill; it depends on specific gravity of material and temperature; computation of charts involves ratio of moisture content to soil to its moisture content at full saturation.

62. Belt, R. M. VOLCANIC CLINKERS STABILIZE FILLS ON HAWAIIAN HIGHWAY, Civ Eng (NY) v 20 n 9 Sept 1950, p 30-1.

Area of Hawaii's Hamakua Coast highway is covered by deep deposit of fine volcanic ash which has consistency of axle grease where trucks and draglines were unable to place fills; final solution for embankments was liberal use of select volcanic clinker material for toe fills and 3 ft blanket; new highway designed for speed of 60 mph, with 4% max grades.