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Pfafstetter, O.

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CALCULATION OF EARTH DAM STABILITY USING A UNIVAC - 1105 ELECTRONIC COMPUTER

BY

OTTO PFAFSTETTER

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D.G FREDLUND

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PREFACE

The high speed electronic computer can be applied very efficiently to the analysis of slopes using the Swedish slip circle method. This translation outlines a procedure for the application of a computer to stability problems with earth dam embankments and as such should prove useful to anyone concerned with the design of earth dams.

The Division of Building Research is grateful to Professor D. G. Fredlund, Dept. of Civil Engineering, University of Saskatchewan, Saskatoon, for making the translation and to the Translation Section of the National Science Library for their checking of the manuscript. The Division is pleased to have this translation included in the NRC series of Technical Translations.

Ottawa
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R. F. Legget
Director

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Author:	Otto Pfafstetter, Head of the Division of Planning Structures of the Department of National Works of Sanitation, Ministry of Transportation and Public Works, Rio de Janeiro, Brazil
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Translator:	D.G. Fredlund, University of Saskatchewan, Saskatoon, Saskatchewan

CALCULATION OF EARTH DAM STABILITY USING A UNIVAC-1105 ELECTRONIC COMPUTER*

ABSTRACT

The graphical stability computation of earth dam slopes with the Swedish slip circle method is very tedious. In order to improve these stability computations, considerable effort has been spent to give a solution with electronic computers (see references 1 through 4). This article discusses a programme for stability computations with the UNIVAC-1105 electronic digital computer.**

The proposed solution endeavours to cover all practical cases, from the simplest homogeneous sections to the most complex zoned embankments on heterogeneous foundations. The pore pressures developed in the impervious zones during construction, as well as the effect of percolating water for steady flow or draw-down conditions, may be considered in this computation. The stability of the upstream and the downstream slopes are investigated separately. The programme carries out the stability computations for each slope in two successive steps. The conditions right after construction are investigated first and then the conditions after the establishment of a flow net.

For each position of the slip circle centre, several circles with different radii are investigated. As output, the computer types the smallest safety factor found for each centre and the order number of the corresponding radius. With these results, contours of equal safety factor may be drawn and the slip circle of least stability located.

The last part of the article shows how to get the flow net potentials with the UNIVAC-1105 computer. It serves as a complement to the stability computation of dams. The potentials are obtained by the relaxation method, starting with an approximate flow net. The flow net and stability computation of Chapeu d'Uvas dam illustrates the application of the programme for a very general case of zoned embankments.

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* Abstract from a complete report published by the Department of National Works of Sanitation - M. V. O. P.

** In Brazil there is a UNIVAC-1105 computer in the Data Processing Centre of the National Census Service at the Brazilian Institute of Geography and Statistics, Pasteur Ave. No. 404, Rio de Janeiro.

Slope Stability Calculations

The outlines of the different materials comprising a dam and its foundation may be defined by a series of straight lines. The structure is assumed to consist of up to ten physically different materials, with each interface defined by polygonal lines, each one having no more than ten vertices. The form of a relatively complex structure can be described by providing the computer with the coordinates of up to one hundred vertices of the polygons that outline the different materials.

The physical properties that define the mechanical behaviour of the materials are the specific gravity, cohesion and the angle of internal friction. For clay soils the angle of internal friction can be determined by triaxial tests with pore pressure measurements. Using this method, the frictional component can be examined in conjunction with the anticipated pore pressures in the entire structure.

For the calculation of stability right after construction, a relationship between the pore pressure and the total pressure in impervious materials can be determined from consolidation tests on compacted samples allowing free drainage(5).

For each impervious material the computer is supplied with the coordinates of eight points on a curve outlining the relationship between the pore pressure and the total pressure.

Several numbers are supplied for each permeable material, one number to distinguish them from the impervious soils, another showing if the material is saturated and a third number indicating the phreatic water level.

From this data the computer calculates the intergranular pressure developed in the pervious and impervious materials immediately after construction.

To compute stability in conjunction with a flow net, the potentials are defined at the nodes of an orthogonal net with abscissae (xp) and ordinates (yp) (see Figure 1). Supplied with the potentials of 192 points, the computer determines the pore water pressure in any part of the structure along the slip circle by linear interpolation.

The stability analysis consists of determining the factor of safety against failure. This factor is defined as the ratio of the moments of the stabilizing forces and those tending to cause overturning. These moments obtained for each vertical slice of width dx are integrated along the slip circle (see Figure 1). The centres of these slip circles are located at the intersection of an oblique net with abscissae (xc) and ordinates (yc). The oblique net follows the general trend of equal factor of safety curves. This allows a better definition of the contours of equal factors of safety with a minimum number of trial centres.

For each trial centre, several slip circles with different radii are examined and the radius with the minimum factor of safety is selected. Only the minimum factor of safety and the corresponding radius are printed out for each centre. Using this method there is a minimum of computer time since the typing of the results requires more time than the processing of the data. The computations for one slip circle are done in approximately one second, whereas typing the results for one factor of safety requires approximately three seconds.

Figure 2 shows the results of stability computations on the downstream slope of the Chapeu d'Uvas dam.

The impervious zone of the dam is built of residual material taken from the right shoulder where its removal allows the construction of an emergency spillway. The residual material consists of approximately 53% sand, 39% silt and 8% clay*.

The liquid limit is 38.6% and the plastic index 15.3%. The average coefficient of vertical permeability is 1.1×10^{-6} cm/sec. Optimum water content and maximum density from the standard Proctor compaction test are 17.8% and 1.710 g/cm^3, (106.7 pounds per cubic foot), respectively.

The triaxial tests with pore pressure measurements showed an average cohesion of 0.10 kg/cm^2 (205 pounds per square foot) and an angle of internal friction of 34 degrees.

The consolidation tests with free drainage allow us to relate pore pressure and total pressure in the dam for the case of no pore water drainage(5). For the pressure range anticipated during construction, the pore pressures will be between 15% and 20% of the total pressure.

A three-metre-thick layer of the borrow area provided a well marked alteration since it was more clayey and impervious, and has a lower angle of internal friction and a higher compressibility. This material is less favourable from a strength standpoint and we suggested it be used only in a narrow middle zone. In this way the conditions of imperviousness can be improved without appreciably diminishing the stability of the structure.

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* The soil property tests (compaction, consolidation and triaxial tests with pore pressure measurements) were performed at the RODIO S/A laboratory.

The outside permeable zone of the downstream slope is built using sand from the river bottom. Besides improving stability (because it eliminates the pore pressures in this section) this zone allows the collection of seepage water from the impervious zone up to a level where another type of filter would be inefficient. The pervious sand is protected from surface erosion by a layer of riprap.

Figure 2 shows an oblique net with the intersections at the centres of slip circles examined. For each centre, ten slip circles, with the radius incremented by three metres each time, are examined. The minimum radius corresponds to circles whose horizontal tangent passes forty-two metres above the abscissa axis and the maximum radius corresponds to a horizontal tangent passing fifteen metres above the abscissa axis. The radius is therefore increased in three-metre increments from a minimum radius to a maximum radius by a process of iteration from 1 to 10.

Alongside and below each centre the minimum factor of safety is written and above each centre the iteration number corresponding to this factor of safety is written.

From these data, contours of equal factor of safety can be drawn which show the slip circle that will have a minimum factor of safety. After examining the results from the case of stability right after construction, the critical slip circle is drawn (Figure 2). Since the factors ofsafety at each centre are from circles of different radii, the contours of equal factors of safety are slightly irregular.

As this is a brief presentation, neither the stability analysis of the downstream slope using flow nets nor the upstream slope stability analysis is shown.

Calculation of the Flow Net

The method of relaxation used to calculate the potentials in the flow net consists of determining the potential at a point from the surrounding points in accordance with the law of seepage for porous media. The final results are obtained through several iterations of progressively computing the potentials at all nodes of an orthogonal net overlaying the structure under study. Applying the principle of continuity and Darcy's law of seepage through porous media, an equation expressing the potential at a node as a function of the four adjacent nodes can be written. The relationship between the horizontal and vertical dimensions of orthogonal mesh is equal to the square root of the ratio between the coefficients of permeability in the two directions. In this way, the above-mentioned expression is simplified because the potential at a node is the arithmetic mean of the potentials at adjacent nodes.

The method of relaxation is commenced using approximated values for the nodes of the orthogonal net. The better the initial estimates, the closer the final values are to the exact solution after a given number of iterations.

The distribution of the initial potentials in the impervious core is defined using linear variation laws. Outside the impervious core the potentials are equal to the limiting conditions, which are the upstream water level in the reservoir and the phreatic pore water level in the downstream pervious materials. The potentials in unsaturated permeable materials are equal to the elevations of the points under consideration. Along the base of the cutoff trench conditions of no drainage are assumed, making the potentials in the rock equal to the potentials in the impervious material after each relaxation process.

The computation of the shape of the phreatic line is performed automatically. Its position is controlled by keeping the potentials of points immediately below it higher, but as close as possible to their elevation.

The flow net results for the case of a constant level reservoir at the Chapeu d'Uvas dam is presented in Figure 3. In fifteen minutes, 200 relaxations on 724 nodes of the orthogonal net over the impervious core were performed. In order to reduce computer time, only the potentials of alternate points in both the horizontal and vertical directions were printed as output. The potentials from one quarter of the orthogonal net are used for Figure 2. Curves of equal potential have been drawn by interpolation between the furnished potentials. These potentials were used in the stability calculations described previously.

The phreatic line determined by the computer is shown in Figure 2. This line has a stepped form since the computer attempted to produce potentials closest to their elevation near that line, through the iteration process.

In this short presentation, the results obtained for the case of rapid draw-down in the reservoir are not shown, however, they were used for the stability computation on the upstream slope.

References

1. Little, A.L. and Price, V.E. The use of an electronic computer for slope stability analysis. Géotechnique, v.8, 1958.

2. John, Klaus. Über die Verwendung von Elektronenrechenmaschinen beim Entwurf von Erddämen. Die Bautechnik, (7), 1961.

3. Horn, John, A. Computer analysis of slope stability. Paper 2501, Volume 86, No. SM3, June 1960, Part 1. Journal of the Soil Mechanics and Foundations Division. Proceedings of the American Society of Civil Engineers.

4. Meyer, Otto H. Computation of the stability of slopes. Paper 1824, Volume 84, No. SM4, October 1958, Part 1. Journal of the Soil Mechanics and Foundations Division. Proceedings of the American Society of Civil Engineers.

5. Hilf, J. W. Estimating construction pore pressure in rolled earth dams. Proceedings of the Second International Conference on Soil Mechanics and Foundation Engineering, Volume III, 1948.

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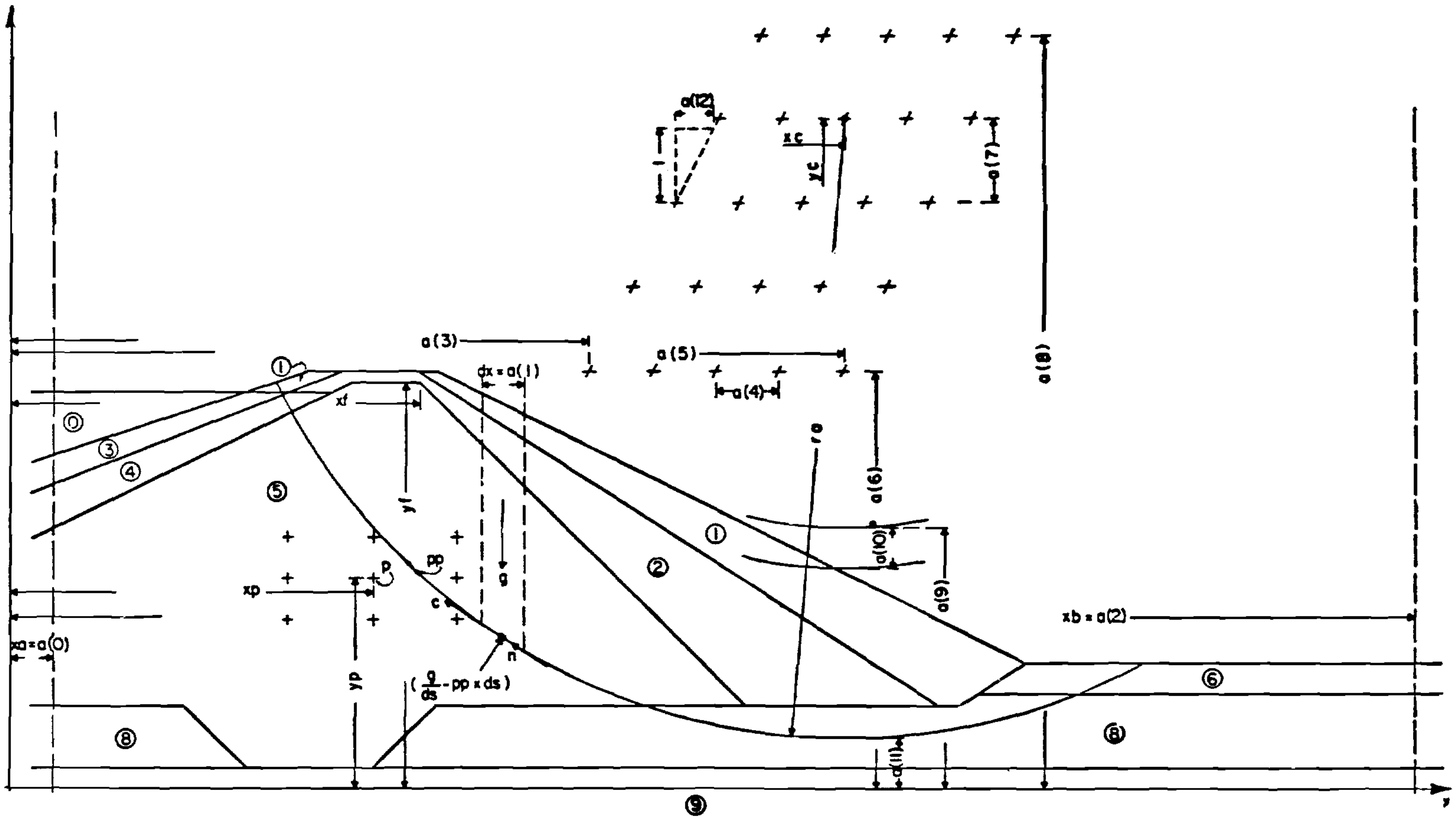

Fig. 1
Definition of the variables

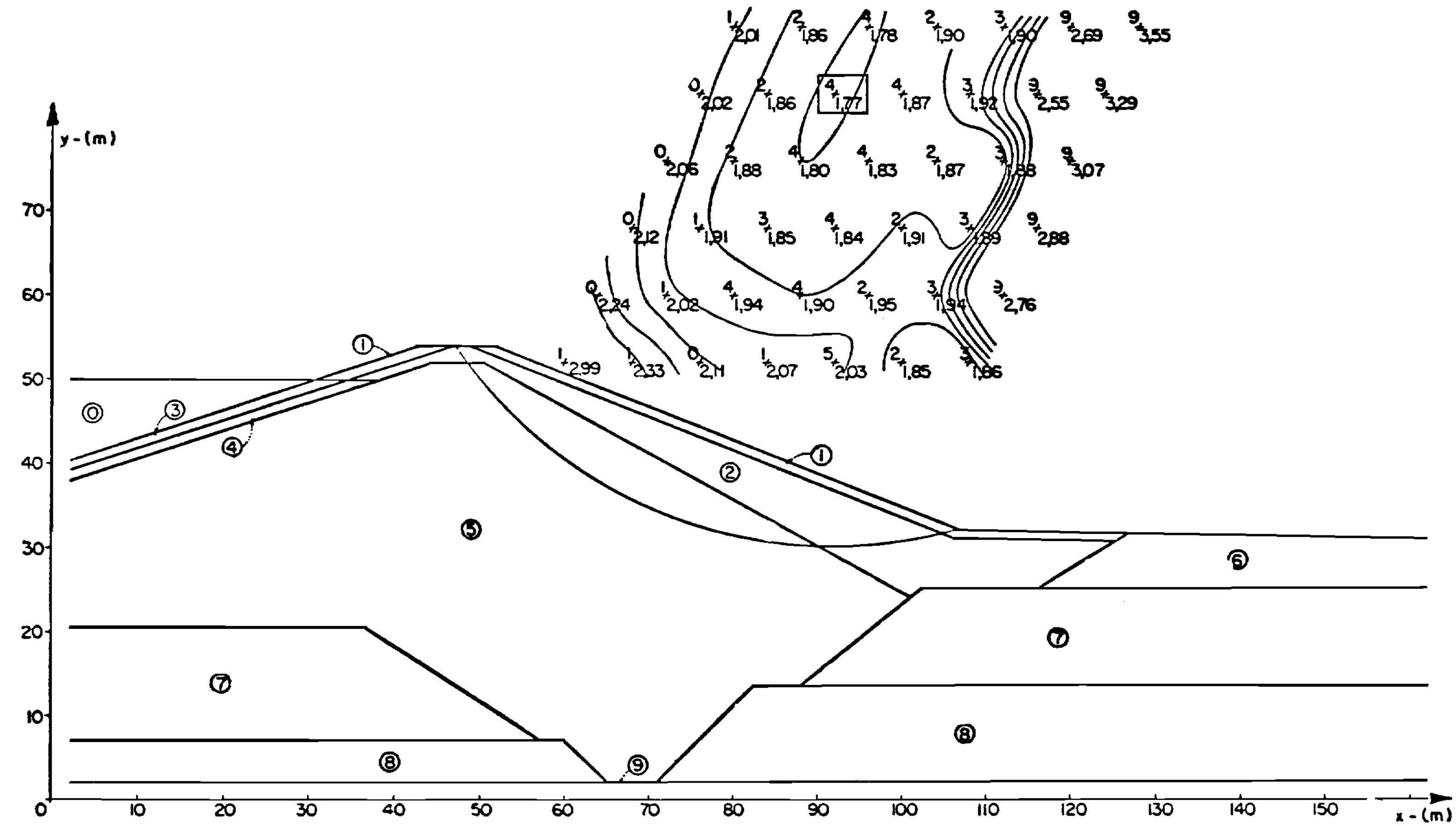

Fig. 2

Stability of the downstream slope right after construction

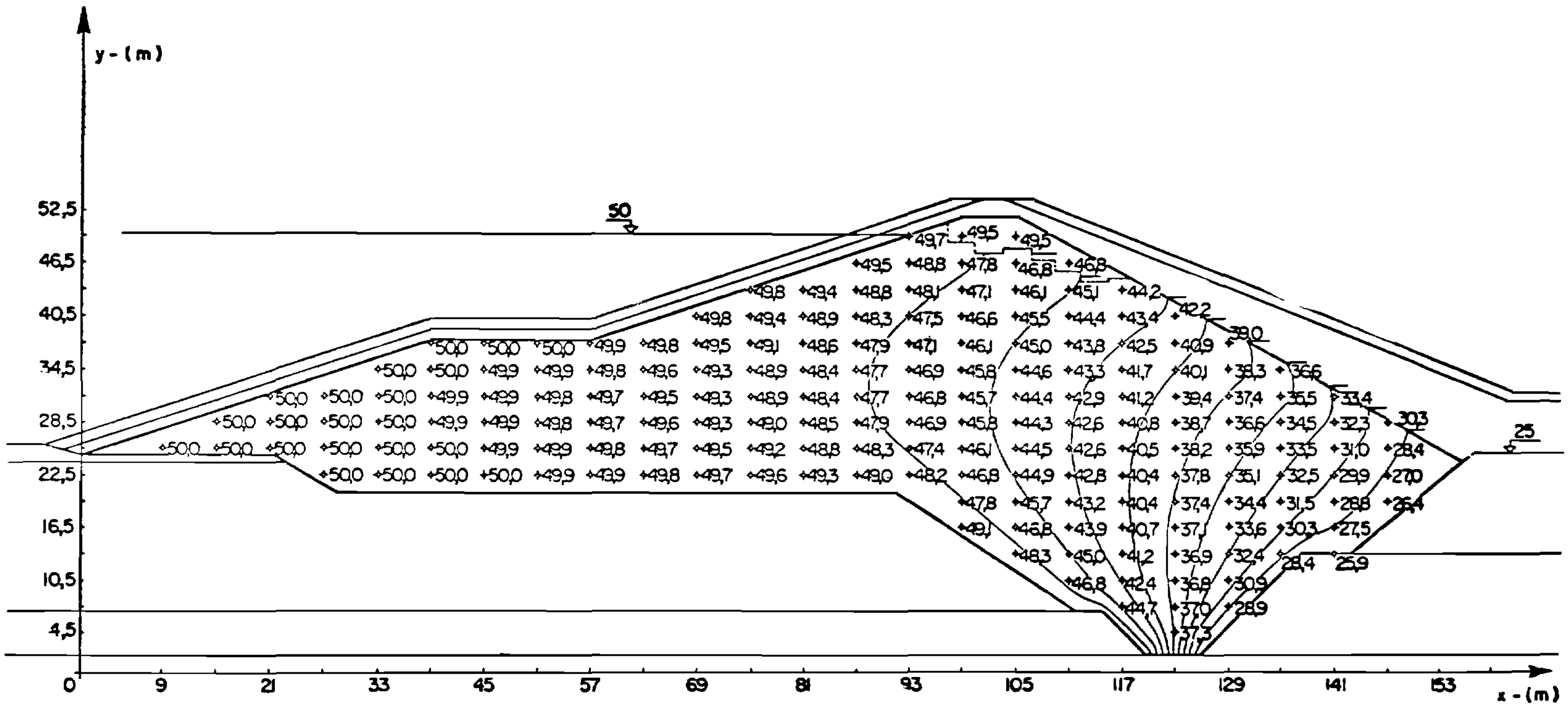

Fig. 3

Steady flow potentials