SAFETY FACTORS IN SOIL MECHANICS

COEFFICIENTS DE SEGURITE EN MECANIQUE DES SOLS

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When the originator of this Session, Professor J. Brinch Hansen, had unfortunately to withdraw, the Author accepted his personal invitation to continue the organization. At the beginning of the Session the Author paid a tribute to Professor Brinch Hansen, who had died on 27 May, 1969.

TRIBUTE TO PROF. J. BRINCH HANSEN

By Prof. G. G. Meyerhof, Canada

JORGEN BRINCH HANSEN was born in Copenhagen and obtained his Civil Engineering degree from the Technical University of Denmark in 1935. Later, in 1953, he was awarded by the same University the degree of Doctor of Science for his dissertation on "Earth Pressure Calculation", and in 1954 he was elected a member of the Danish Academy of Technical Science.

From 1935 until 1955 he was employed by the well-known contracting and consulting firm of Christiani and Nielsen, and became their Chief Engineer in 1940 and Technical Director in 1953. During this period, he took part and supervised the design of numerous civil engineering projects in many different countries. Some of these projects, like the Maas Tunnel in Rotterdam, belong to the most outstanding civil engineering achievements of this period.

In 1955 he accepted the position of Professor of Soil Mechanics and Foundation Engineering at the Technical University of Denmark and was appointed Director of the Danish Geotechnical Institute at Copenhagen. In addition, he continued his practice as private consultant to Christiani and Nielsen and various other organizations.

In 1960 Prof. Brinch Hansen was Knighted by the King of Denmark, and in 1965 the University of Ghent, Belgium, conferred upon him the honorary degree of Doctor of Science.

Since 1965, he has been Chairman of the Danish Geotechnical Society and Vice-President for Europe of the International Society for Soil Mechanics and Foundation Engineering. He is the author of numerous important research papers and a co-author of two widely known books on soil mechanics.

On 27 May, 1969, Prof. Brinch Hansen died in Copenhagen after a long illness.

This brief biography will give you an idea of his outstanding contributions which have received world-wide recognition. He was dedicated to doing research in his chosen field, which he pursued painstakingly and with absolute integrity. He was a great personal friend to many of us and will be warmly remembered for his sincerity and helpfulness throughout his life.

I should now like to ask you to stand in silence for a moment in his memory.

As introduction to this Session the Author had propared a paper on "Safety Factors in Soil Mechanics" (Meyerhof, 1969) for presentation. To ensure reasonable safety in earthwork and foundation engineering, the design is usually carried out by introducing into the structural analysis a safety factor, which may be defined as the ratio of the resistance of the structure to the applied loads. It was shown that the customary overall safety factors used in stability analyses relating to shearing failure and seepage considerations (Table 1) depend mainly on the uncertainties and variability of the soil conditions and to a smaller extent on the variability of the applied loads and approximations in the analyses. Partial safety factors on the soil resistance and applied loads (Brinch Hansen, 1956) (Table 2) may lead to a more uniform margin of safety.

TABLE I

VALUES OF MINIMUM OVERALL SAFETY FACTORS

Failure Type	Item	Safety Factor
Shearing	Earthworks	1.3 to 1.5
	Earth Retaining	1.5 to 2
	Structures Foundations	2 to 3
Seepage	Uplift, Heave	1.5 to 2.5
	Exit Gradient, Piping	3 to 5

TABLE II

VALUES OF MINIMUM PARTIAL SAFETY FACTORS

Item	Shearing Strength Parameter	Safety Factor
Earthworks and Earth Retaining Structures	Cohesion (c)	1.5
	Friction (tan Ø)	1.2
	Cohesion and Friction	1.3 to 1.5
Foundations	Cohesion (c)	2 to 2.5
	Friction (tan Ø)	1.2 to 1.3
Dead Loads	-	1.0
Water Pressures	-	1.0 to 1.2
Live Loads	-	1.2 to 1.5

The results of the Author's safety analyses indicate that earth dams designed for a minimum overall safety factor of about 1.5 have a probability of sliding failure of roughly one-half per cent during the first few years of reservoir operation; further, the conventional overall safety factors of about 1.5 to 2 in the design of large earth retaining structures and the safety factors of about 2 to 3 used in foundation designs correspond perhaps to a probability of failure of the order of 10^{-3} and 10^{-4}, as shown in Fig. 1. A semi-probabilistic approach to these analyses shows that the customary safety factors are consistent with overall coefficients of variation in the range of about 0.1 to 0.3. The lower limit of these coefficients governs the stability of earthworks and the upper limit governs that of foundations, as would be expected. Although more field data are required, it is of interest to note that the range of the overall coefficients of variation indicated by these safety analyses is supported by the range of observed coefficients of variation of the soil resistance, applied loads and stability analyses.

There were three invited speakers to present state-of-the-art papers on safety factors relating to earthworks, earth retaining structures and foundations.

The probability of failure in earthworks and probability distribuitions of shearing strength parameters have been discussed by Mr. P. Lumb. He had determined these parameters for a number of soils, which showed a random variation of strength about a mean or linear trend. He also presented an outline of methods by which probability distributions can be used in design and illustrated the basic principles of this approach to stability problems using partial safety factors. His previous analyses of conventional overall safety factors (Lumb,1966) suggested that a suitable value of probability or risk of failure for the design of earth retaining structures is of the order of 10^{-2} to 10^{-4}, and for the stability of foundations it is of the order of 10^{-3} to 10^{-5}, which is in reasonable agreement with the Author's safety analyses.

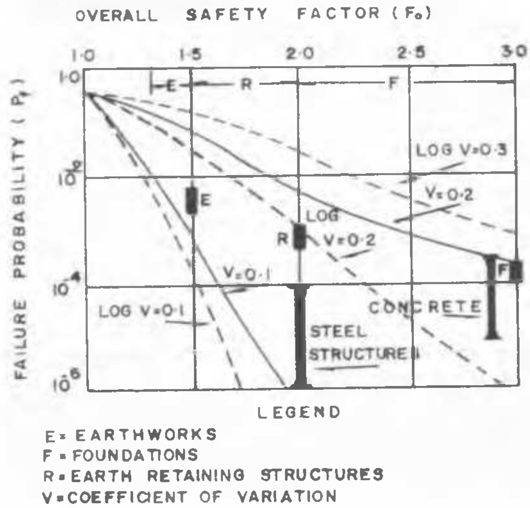

FIG. - COMPARISON BETWEEN SAFETY FACTOR AND PROBABILITY OF STABILITY FAILURE

The safety factors used in the design of earth retaining structures have been discussed by Prof. E. Schultze who summarized the values of conventional factors in various European standard specifications and codes of practice. He discussed in some detail the partial safety factors recommended by the German Committee for Waterfront Structures. These factors are similar to those suggested by Brinch Hansen (1956) and contained in the Danish Code of Practice for Foundation Engineering. However, the German partial factors on shearing strength are based on the characteristic strength parameters, which are obtained from a conservative assessment of the shearing strength. The partial safety factors on the applied loads vary with the type of loading and design considerations.

The problem of safety factors of foundations has been treated by Mr. P. Demonsablon with special reference to pile foundations. He considered the case of pile groups beneath a rigid superstructure and distinguished several cases of limit states.

Two methods of calculation are proposed, the first one relating to the case of progressive failure of the pile group under increasing loads, and the second method is based on the parameters of the rupture state. It was shown that the bearing capacity of a pile group under a system of loading can be defined in terms of a safety factor associated with the resultant of the applied loads. For a given geometry of the pile group the variation of the safety factor can then be related to the position of the load resultant.

The presentation of the above-mentioned papers was followed by an informal discussion to exchange information on safety factors in soil mechanics. The following main topics were discussed:

(a) Customary safety factors in design of earthworks, earth retaining structures and foundations.

(b) Safety factors on loads, strength and hydraulic parameters.

(c) Probability concepts in soil mechanics.

In connection with the customary safety factors in soil mechanics, several speakers referred to various stages of failure and unserviceability of earthworks and foundations. Thus, methods were outlined to estimate the safety factor for incipient stability failure in elasto-plactic analyses, progressive failure using the state of stress along a potential slip surface and creep deformation of slopes on the basis of velocity field equations. A number of discussors mentioned the need to relate safety factors to the total cost of structures and their economic or service life.

Partial safety factors on load, strength and hydraulic parameters were considered with respect to the accuracy of stability analyses, uncertainties of laboratory and field test data, performance observations and time effects on stability. Considerable discussion took place on probability concepts in soil mechanics using statistical and decision theories. Safety analyses of structures based on an acceptable risk of failure can be improved by estimating the frequency distribution of safety factors in a given case. The need to determine allowable coefficients of variation of loads, strength and other design parameters was emphasized for both permanent and temporary engineering works. Many practical examples and case histories given by the speakers made this specialty session particularly interesting.

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P. Lumb.	"Probability of Failure in Earthworks"
G. G. Meyerhof.	"Safety Factors in Soil Mechanics"
E. Schultze.	"Safety Factors in Design of Earth Retaining Structures"