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auf Wärmewirkungen und entspricht damit einem Bedürfnis der neueren Entwicklung des Bauwesens beim Reaktorbau.

B. Gilg skizziert die Entwicklung der Berechnung von Bogenstaumauern und weist darauf hin, daß bei der Kompliziertheit der hier vorliegenden Formen eine geschlossene analytische Lösung nicht möglich ist.

L. G. Booth und P. B. Morice zeigen, ausgehend von einer Darstellung der mathematischen Grundlagen, die Durchführung der Berechnung von Spannungen und Formänderungen einer zylindrischen Schale mit Hilfe einer elektronischen Rechenmaschine (Ferranti-Pegasus). Die Bedeutung dieses leistungsfähigen Hilfsmittels ist auch im Bauwesen steigend.

A. Ylinen und A. Eskola stellen die Anwendung der virtuellen Verschiebungen und des Prinzips vom Minimum der Ergänzungsenergie auf die Berechnung von statisch unbestimmten Fachwerken dar, wenn der Baustoff dem Hookeschen Gesetz nicht gehorcht. Für das Spannungsdehnungsdiagramm wird ein analytischer Ansatz vorgeschlagen.

A. Hillerborg unterscheidet bei der Plastizitätstheorie für Platten aus Stahlbeton zwischen der Fließlinientheorie und der Gleichgewichtstheorie, von denen die letztere die größere Sicherheit aufweist. Er weist auch auf die einschränkenden Bedingungen hin, die die schwedischen Bauvorschriften für die Anwendung solcher Berechnungen nach der Plastizitätstheorie enthalten.

L. A. Scipio untersucht das Verhalten von dünnen Rotationsschalen aus viscoelastischem Material unter konstantem Normaldruck. Unter bestimmten Voraussetzungen ergeben sich gleiche Beanspruchungen wie nach der Elastizitätstheorie, während sich die Verformungen um einen von der Zeit abhängigen Kriechfaktor unterscheiden.

General Report

In the first working sessions, basic problems are to be discussed which concern both structural steelwork and reinforced concrete structures, and which are consequently problems of decisive importance for the design of engineering works constructed on the one hand, of steel and light metals and, on the other, of reinforced concrete and prestressed concrete. In accordance with the resolution of the Permanent Committee of 2nd September 1958 at Istanbul, the discussion is to have reference to those characteristics of structural materials that are of decisive importance for design purposes; and here, in the first place, strength and deformation, as well as the development of methods of calculation, are to be considered. The Preliminary Publication comprises 16 contributions to Theme I. An examination of these contributions shows that it is not a simple matter to draw a clear line of demarcation between the two Themes I a and I b, and all the more so since close mutual relationships frequently exist between the properties of materials and design. The decision in regard to the classification of particular contributions was consequently a somewhat arbitrary expression of opinion; we have endeavoured to arrange the contributions in such a manner that a useful orientation for a fruitful discussion in the working session should be possible.

Theme I a: Properties of Materials

With a single exception, the contributions to this Theme in the "Preliminary Publication" are concerned with the behaviour of materials under repeated loads or under continuous loading of long duration; they show quite clearly the tendency that is prevalent at the present time for the design of structures to be based not only on the results of short-term laboratory tests, but on the actual behaviour of the structural material in long-term operation under variable loads. We are dealing here with long-time phenomena, and to elucidate them a long-time law is necessary. In particular, we are concerned with the following questions:

Fatigue under repeated loads
Strength under long-term loading
Stress development in course of time when deformation is impeded (relaxation)
Creep under constant load
Shrinkage of concrete or
combinations of these separate effects.

It is the function of a *generalised theory of long-time behaviour of materials* to deal with all these partial problems and to describe the behaviour of materials in a satisfactory manner by means of the smallest possible number of coefficients. Such a theory must be based upon a long-time law that is as generally applicable as possible.

This long-time law must satisfy the following requirements:

it must represent the behaviour of the material satisfactorily by means of the smallest possible number of coefficients, that is to say, it must, by its nature, conform to the basic course of the behaviour of the material; this implies, in particular, a steady and as far as possible "fluent" course from the initial value to the asymptotic ultimate value of the stress or deformation magnitudes to be represented. Furthermore, it is desirable that the expression should have as simple a form as possible, so that the evaluation of the experimental results may easily be made.

In principle, various expressions are conceivable for such a long-time law. As the result of the detailed consideration of such long-time phenomena, I have reached the conclusion that the expression I suggested some time ago for the determination of the so-called Wöhler stress-cycle diagram[1]) may be regarded as a general long-time law. The course of such a Wöhler curve σ_w is shown on the left-hand side of fig. 1 *) as a function of the number of stress cycles, n, and on the right-hand side with logarithmic abscissae $i = \log n$; for this curve the following expression holds good

$$\sigma = \frac{\sigma_0 + f\,\sigma_a}{1+f} \tag{1}$$

where σ_0 denotes the initial value, σ_a the asymptotic end value and f the "fatigue function" to be determined. From the evaluation of all the experimental results accessible to me, it is clearly and unmistakably evident that the value

$$\lambda = \log f = \log \frac{\sigma_0 - \sigma}{\sigma - \sigma_a}$$

when plotted against the abscissæ i gives a straight line, and hence we have

$$\lambda = p\,i + \lambda_0 \tag{2}$$

or

$$f = f_0 n^p = a^\lambda. \tag{2a}$$

Consequently, equation 1 can also be written in the form

$$\sigma = \frac{\sigma_0 + a^\lambda \sigma_a}{1+a^\lambda} = \frac{a^{-\lambda}\sigma_0 + \sigma_a}{1+a^{-\lambda}} \tag{1a}$$

The curve $-i$ is point-symmetrical for the turning point W with $\lambda = 0$, $\sigma = (\sigma_0 + \sigma_a)/2$.

In order fully to determine the fatigue strength of a material at constant temperature, we require to have, in addition to the strength as shown by the alternating stress test σ_w, the oscillation amplitudes $\Delta\sigma$ for a given mean stress σ_m, for which the notations

$$\Delta\sigma = \frac{\sigma_{max} - \sigma_{min}}{2}, \qquad \sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2}$$

hold good. The pair of values $\Delta\sigma$, σ_m is reduced, by means of the creep constant κ^2,

$$\kappa^2 = \frac{\sigma_{0Z}(\sigma_{0Z} - \sigma_m)(\sigma_w - \Delta\sigma) - \sigma_m \sigma_w \Delta\sigma}{\sigma_m - \sigma_w + \Delta\sigma}, \tag{3}$$

to the fatigue strength σ_w for the same number of stress cycles n[2]). Consequently, κ^2 is independent of the number of stress cycles and also of the

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[1]) F. Stüssi: Die Theorie der Dauerfestigkeit und die Versuche von August Wöhler. Mitteilungen der T.K.V.S.B., No. 13, Zurich 1955.

*) See Figures in German text.

[2]) F. Stüssi: Theory and Test results on the fatigue of metals. Journal of the Structural Division, Proceedings A.S.C.E., Oct. 1959. (Joint-meeting A.S.C.E.-I.A.B.S.E., New York, Oct. 1958.)

point of origin chosen for the abscissæ; it is therefore a material constant for a given temperature. For ordinary structural steel at room temperature κ^2 vanishes, $\kappa^2 = 0$; on the other hand, for the aluminium alloys that have been investigated so far, κ^2 ist >0, which means that the tensile strength σ_Z,

$$\sigma_Z = \sigma_m \quad \text{for} \quad \Delta\sigma = 0,$$

is dependent upon the number of cycles of stress or the duration of the load application. With the abbreviations

$$c_1 = \frac{\sigma_{0Z}\,\sigma_w + \kappa^2}{\sigma_{0Z}^2 + \kappa^2}, \qquad c_2 = \frac{\sigma_{0Z} - \sigma_w}{\sigma_{0Z}^2 + \kappa^2}$$

the relationship

$$\Delta\sigma = \frac{\sigma_w - c_1\,\sigma_m}{1 - c_2\,\sigma_m}. \tag{4}$$

follows from equation 3. It is interesting to note that the values of $\Delta\sigma$ at constant mean stress σ_m likewise obey the long-term law according to equations 1 and 2 with the same value of p as the alternating strength, so that the fatigue factor f_m has the value

$$f_m = f_w\left(1 - \frac{\sigma_{0Z} - \sigma_{aw}}{\sigma_{0Z}^2 + \kappa^2}\,\sigma_m\right) = f_w\,(1 - c_{2a}\,\sigma_m)$$

These basic features of a theory of fatigue strength for a smooth test specimen are compared in figure 2 with the fatigue strength values for the alloys 14S-T, 17S-T, 24S-T given in the Alcoa Structural Handbook, 1945. Special influences, such as notch effects, cold-working, etc., will be discussed later.

Attention is drawn elsewhere to the good agreement of the long-time law equations 1 and 2 with the long-time creep strength of steels at high temperature[3]) and with the relaxation of steel wires[4]); in the case of these phenomena the time t takes the place of the number of stress cycles n and consequently $i = \log t$. We shall return later to the comparison with creep tests.

* * *

It is out of the question to discuss and analyse individually, in this general report, the contributions in the Preliminary Publication. We shall therefore confine ourselves to indicating particular questions regarding which a discussion at the first working session appears to be specially desirable.

A. M. Freudenthal reaches the conclusion, from fatigue tests on a high-strength steel SAE 4340 with variable stress values, that a reliable fatigue

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[3]) W. Stauffer and A. Keller: Anwendung der Dauerfestigkeitstheorie von F. Stüssi auf die Ergebnisse von Zeitstandversuchen. Archiv Eisenhüttenwesen 1958, Number 7.

[4]) F. Stüssi: Zur Relaxation von Stahldrähten. Abh. I.V.B.H., Vol. 19, Zurich 1959.

limit σ_{aw} only exists for tests with constant stress amplitude, but not for variable stresses in a stress spectrum. The three series of tests were performed in accordance with a test programme that had been clearly and logically worked out, by means of a cyclic bending stress ("rotating beam"); the number of stress cycles, in the case of the higher stress values, could be increased three to five-fold by omission of one stress stage below the (estimated) fatigue strength limit.

This result is of great and fundamental significance for the conception of the fatigue strength problem with an asymptotic lower limit and before it can be regarded as generally applicable, it must be carefully verified. In this connection, the question arises, in the first place, as to whether, in the case of the tests reported, certain peculiarities or additional influences may not be the cause of the unexpected result, so that the claim to general validity could not be substantiated.

Such possible interference arises, however, in the case of high stresses due to cold working whose influence may manifest itself[2]) in an increase in the fatigue strength for small numbers of stress cycles (up to 100,000 stress cycles and above). Since in the determinations made by A. M. FREUDENTHAL the highest stress in the spectrum was at 85% of the static tensile strength, a cold-working effect of this kind is possible in tests with small numbers of stress cycles.

On account of these considerations, I carried out a few preliminary tests with drilled test-bars of the "alloy *Z*" (an experimental alloy based on Al and Zn) made by the Aluminium-Industrie-Aktiengesellschaft (Switzerland) (my collaborator was E. Peter), in which the lowest of the four stress stages practically coincided with the calculated lower limiting strength $\sigma_{aw} = 0.55$ t/cm^2, while the highest stage corresponded to the strength for at least 100,000 stress cycles. Figure 3 shows the results of the basic tests with constant stress σ_w, carried out with an Amsler-type high-frequency pulsator and the curve for the fatigue strength σ_w calculated from these results. In the Table*) given the results of the three programme tests with the minimum, the maximum and the mean value from four separate experiments are summarised. The result of the experimental work by A. M. FREUDENTHAL was not confirmed.

In the last column, the calculated stress-reversal numbers are given which would be expected according to the theorem of MILTON A. MINER[5]),

$$\sum \frac{\Delta n_i}{n_i} = 1,$$

where Δn_i denotes the number of stress cycles in the programme test for the stress stage σ_i, while the number of stress cycles which, for constant stress

*) See table in German text.

[5]) MILTON A. MINER: Cumulative Damage in Fatigue. Journal of Applied Mechanics, Sept. 1945.

limits σ_i, leads to fracture is designated by n_i. The agreement between the experimental and calculated values is quite good if the inevitable scattering is taken into consideration.

It is to be anticipated that the discussions during the Congress will bring this fundamentally important question nearer to a solution.

G. REHM has submitted a report dealing with fatigue tests on reinforcement steels. In order to approach as closely as possible, during the tests, to the actual working conditions, the steels were embedded in short concrete beams. The difference in the fatigue strengths for pulsating stress and $2 \cdot 10^6$ stress cycles between free, straight bars and bars embedded in concrete is surprisingly large; on the other hand, the difference in strength of ribbed bars as compared with smooth bars falls within the limits that were to be anticipated. The suggestion that the amplitude of oscillation $\Delta\sigma$ should be introduced as the material coefficient for the fatigue strength is, on the contrary, hardly acceptable, since the amplitude of oscillation $\Delta\sigma$ decreases with increasing mean stress σ_m; the behaviour of the material, on the contrary, is characterised by the fatigue strength σ_w as determined by alternating stress tests.

D. D. VASARHELYI has shown by his tests on notched bars that at low temperature, namely $-50°$ F. ($-46°$ C.), not only the yield point and the tensile strength, but also the fatigue strength (at least for notches of large radius) of standard structural steel ASTM A-7 is substantially higher than at a room temperature of 70° F. (21° C.). The systematic extension of these tests would be desirable.

T. C. HANSEN has investigated the influence of room humidity on the creep and shrinkage of concrete. For determining the creep, the deflections of test beams loaded by a constant moment were observed.

The curves for the creep deflections η at 50%, 60% and 70% room humidity and the same extreme fibre stress of 32 kg/cm², taken from diagram 2 of his paper, have been compared with the long-time law according to equation 1; this comparison is shown graphically in figure 4. It was an obvious step to compare these creep curves with the creep equation indicated by F. DISCHINGER[6])

$$\eta = \eta_a (1 - e^{-ct}).$$

The constants η_a and c were determined from the creep values after 10 and 100 days for room humidities of 50% and 70%. The curves calculated with these values are compared in figure 5 with the corresponding curves in figure 4 calculated according to our long-time law. It is clearly evident that a creep equation of this kind with $1 - e^{-\varphi}$ does not correspond to the character of the creep phenomenon. This is consequently of importance, because the

[6]) F. DISCHINGER: Massivbau; Taschenbuch für Bauingenieure, edited by F. Schleicher, 2nd Edition, 1955, page 766, Vol. I.

determination of the ultimate creep value η_a, by extrapolation beyond the test range, is no longer possible, if correct results are to be obtained, because it is markedly dependent upon the test values selected for the determination of the constants.

It is possible, of course, to write the Dischinger creep equation in the generalised form

$$\eta = \sum \eta_{ia}(1 - e^{-c_i t})$$

as is done, in principle, in the creep equation suggested by A. M. FREUDENTHAL and F. ROLL[7]). With this equation, it is possible to secure a more satisfactory fit of the creep curve to the test values within the test range; but whether the extrapolation to the end value η_a by this means is sufficiently reliable has yet to be investigated.

ST. SORETZ describes the effect of the hardening conditions on the deformations of concrete under long-time stressing. The effect of the bond between the reinforcement and the concrete on these deformations was also investigated.

The report by J. TAUB and A. M. NEVILLE on the shear strength of concrete beams under static load shows that the type of load transmission (direct or through cross-members embedded in the concrete) exerts little effect.

Theme Ib: Development of Methods of Calculation

By the choice of this sub-theme, it was anticipated that there would be a continuation of the discussion of those questions which our former General Secretary, Prof. Dr. Pierre Lardy, has dealt with in a most comprehensive manner in his General Report on Theme II for the Congress held in 1952 in Cambridge and London. The General Report he made at that time still retains its topical interest today; now as then, the object in view in the development of methods of calculation, both analytical and numerical, as well as the methods of experimental statics, continues to be the determination of the effects of forces in our structures with sufficient precision and reliability. In spite of the fact that no contribution to this series of interrelated questions (at least not in the sense of the above-mentioned General Report by Prof. Dr. P. Lardy), has been presented, a discussion at the Congress of the important major topics in the development of methods of calculation would be most desirable.

Within the purport of these considerations, the contributions to the "Preliminary Publication" constitute component parts of the Theme that has

[7]) A. M. FREUDENTHAL and F. ROLL: Creep and Creep Recovery of Concrete under High Compressive Stress. Journal of the American Concrete Institute, June 1958.

been fixed, in that they deal with particular questions as being basically interrelated.

The contribution by R. F. LEGGET and W. R. SCHRIEVER is an instructive example of the importance attaching to the correct determination of the external loads on structures. It should be of general interest to compare the investigations they describe into the regional differences in the snow loads in Canada with the corresponding values in other countries. The idea that yet another, although slight, possibility of a collapse exists for his structures is intolerable to a design engineer with his heavy responsibility for human lives and property. Collapse, with the few exceptions due to force majeure, is always caused by human shortcomings, that is to say by ignorance or by making mistakes. The probability curves given for loading and carrying capacity intersect in the "Zone of Human shortcomings" (figure 6), which must be avoided by the necessary care and attention in design and execution.

I. I. CASEÏ reports on the theoretical and experimental investigations of the dynamic effects of moving loads on railway bridges in the USSR which depend not only on the type of structure, but likewise on the rolling stock and the permanent way. These results are welcome as contributions to the international exchange of experience.

CH. MASSONNET and P. MOENAERT have compared about 1500 results of fracture tests on reinforced concrete beams with the values determined by calculation of the breaking moment with varying distribution of the compressive stress in the concrete. If this distribution is established in accordance with reality, there is good agreement, on the average, between the experimental and the calculated values.

W. WIERZBICKI applies his semi-probability method to the calculation of a railway bridge built of steel. The separate "uncertainty effects" are indicated. The aim of the investigation is to make it possible to combine an adequate margin of safety (for example, against reaching the yield point) with greater economy.

The contribution by G. HERRMANN shows the application of energy methods to thermal effects and hence meets a requirement of the recent developments in structural engineering for the construction of reactors.

B. GILG outlines the developments in the calculation of arch dams and points out that, owing to the complicated nature of the shapes that have to be considered in such cases, a purely analytical solution is impossible.

L. G. BOOTH and P. B. MORICE, after giving an exposition of the mathematical bases, describe the performance of the calculation of the stresses and deformations in a cylindrical shell by means of an electronic computor (Ferranti Pegasus). The importance of this serviceable device in constructional engineering is increasing.

A. YLINEN and A. ESKOLA describe the application of virtual displacements and the principle of least energy to the calculation of statically indeterminate structures, if the structural material does not obey Hooke's law. An analytical expression is proposed for the stress-strain diagram.

A. Hillerborg distinguishes, in regard to the plastic theory for reinforced concrete slabs, between the flow line theory and the equilibrium theory and indicates that the equilibrium theory exhibits greater safety. He also comments on the restrictive conditions which the Swedish building regulations impose on the application of such calculations in accordance with the plastic theory.

L. A. Scipio has investigated the behaviour of thin shells of revolution of viscoelastic materials under constant normal pressure. If certain assumptions are made, the same stresses follow as those resulting from the elastic theory, while the deformations differ by a time-dependent creep factor.

Rapport général

La première séance de travail est consacrée à des questions fondamentales, concernant aussi bien la construction métallique que celle en béton, des questions donc qui sont déterminantes pour le dimensionnement des ouvrages en acier et en alliages légers comme de ceux en béton armé et en béton précontraint. Selon les décisions prises à Istanbul par le Comité Permanent le 2 septembre 1958, la discussion aura pour sujet les propriétés des matériaux qui conditionnent le dimensionnement, c'est-à-dire principalement leur résistance et leurs caractéristiques de déformation, ainsi que le développement des méthodes de calcul. La Publication Préliminaire contient 16 contributions au Thème I; leur examen montre qu'il n'est pas aisé de séparer clairement les Thèmes Ia et Ib, car il existe souvent des corrélations étroites entre les propriétés des matériaux et le dimensionnement. Pour certaines contributions, la répartition adoptée a donc été une affaire d'opinion; nous avons tenté d'obtenir un classement qui conduise à une disposition favorisant une discussion féconde à la séance même.

Thème Ia: Propriétés des matériaux

A une exception près, les mémoires de la Publication Préliminaire relatifs à ce thème traitent le comportement des matériaux soumis à des efforts appliqués un grand nombre de fois ou pendant une longue durée; ils font donc ressortir la tendance moderne de fonder le dimensionnement des ouvrages, non seulement sur les résultats d'essais à court terme en laboratoire, mais aussi sur le comportement réel des matériaux soumis à des efforts variables,