General report

Autor(en): **Torroja, E.**

Objektttyp: **Article**

Zeitschrift: **IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht**

Band (Jahr): **4 (1952)**

PDF erstellt am: **13.09.2024**

Persistenter Link: https://doi.org/10.5169/seals-5016

A

General questions

Thèmes d'ordre général

Allgemeine Fragen

I

Bases of calculations; safety

Bases de dimensionnement et sécurité

Bemessungsgrundlagen und Sicherheit

General report — Rapport général — Generalbericht

PROF. DR. h.c. E. TORROJA
Madrid

The various subjects in the theme AI, although apparently quite independent, are none the less related by a common interest. This common link is the philosophical idea of safety, and it is interesting to notice how at present there is a growing tendency to focus these problems in a manner entirely disparate from that which served initially to establish the nominal concept of safety factor.

Whilst, according to classical theory, structures are designed so that extreme working stresses fall within the limiting permissible stresses, the modern tendency is to refer most definitely to the final breaking loads, or to loading conditions immediately prior to failure.

The idea of permissible stress derives from the supposition that, under a certain system of loading, the members behave in a certain way. Modern criteria on limiting conditions of loading are based on the system of externally applied forces that will cause the collapse of the structure.

According to the first of these two methods, the factor of safety is a number which divides certain yield or breaking stresses.

In the second method the external applied forces, or the set of forces acting on a section, are multiplied by the factor of safety, and the structure is then designed so that it will just fail at the resulting values.

Each procedure has its pros and cons. The first of these methods is widely accepted, and there are few codes that do not specify it in a more or less direct manner. The second method has the advantage of expressing the conditions of failure more rigorously. The first one is more easy to apply in most cases. The latter provides a more generalised description of the concept of safety. It can be applied both to problems of buckling and to modern prestressed structures.

If building materials exactly satisfied Hooke's Law, it would be satisfactory to apply either of the two methods. The exact linear correspondence between stress and strain implied by this law means a close proportionality between stresses and applied loads, and so both methods will be identical. Conversely, if this proportionality cannot be extended up to the point of failure, there is no longer a linear correlation between cause and effect, and the two concepts of safety mentioned will differ.

In strict rigour, the real solution has something of both criteria. To allow for the natural uncertainty in the mechanical properties of the material and inevitable defects in the process of manufacture, it is wise to rely on a yield or breaking stress that is lower than the estimated value. This will provide some margin of safety to cover the possibility of these aforementioned defects. Thus the limiting stress should be lowered, and it seems logical to divide this stress R by a partial safety factor C_r, so that the probability that the estimated design stress R' will not surpass the value R/C_r is sufficiently small.

Furthermore, any unforeseen increase in the overload, any error in the layout of the structures or in the sizes of the structural parts when actually made, any calculation mistakes, either in the arithmetical work or in the initial hypotheses, may result in actual or virtual increase of the estimated applied forces acting on a given section. This uncertainty necessitates that a factor of safety be accepted which, on multiplying the design forces by it, will give the structure the required measure of safety. By this means the chance that a set of sufficiently unfavourable circumstances shall coincide will be rendered small enough to meet the particular requirements of the case.

Often this distinction between factors of safety which multiply loads and those which divide top stresses is unnecessary, and it suffices to design the structure for a product of both factors. But in other cases it is necessary to make this distinction to reduce the cost without sacrificing safety.

Lack of sufficient experimental work has made it impossible to calculate the distribution of these two factors in metal structures. Tests on the change in strength of concrete if there is an excess of water or deficient proportioning of cement have made it possible to obtain a statistical law relating the magnitude of the defects and their probable incidence. In constructional work there will be several sources of error: variations in the quality of materials, mistakes in the actual construction, errors in dimensioning, arithmetical mistakes and faulty hypotheses, fluctuations in the overload, etc. These various sources of error have been expressed in the form of probability laws.

By means of successive compositions and eliminations of these laws, it was possible to obtain the relationship between the safety factor C_e by which loads should be multiplied and the total factor C.*

* This relation is, with fair approximation, equal to one plus the third of the total factor of safety, namely: $C_e=1+C/3$, and $C_r=C/C_e$ is the partial factor of safety by which maximum stresses should be divided.

These two partial factors of safety C_e and C_r provide a more precise description of the problem. The former describes the possibility that external loads should increase unforeseeably. The second describes the measure of confidence that can be placed on the materials selected for the work.

The paper submitted by B. G. Neal and P. S. Symonds on "The calculation of plastic collapse loads for plane frames" is a magnificent example of the diversity of these concepts. The authors advocate the adoption of a factor of safety of 1·75 as the factor by which dead-weight and foreseeable loads are to be multiplied; design calculations being based on the effect of such a system of externally applied loads. Having obtained their final results, they adopt the same procedure for external forces and wind load. For this set of forces they take a factor of safety of 1·4, as an indication of the lesser likelihood that the most adverse loading conditions shall operate simultaneously.

This manner of estimating maximum loads enables one to calculate stresses in hyperstatic structures, based on the elasto-plastic behaviour of the metal. Only under loadings that are 75% or 40%—according to the case—greater than those estimated will the structure begin to yield slowly. Such collapse occurs when a sufficient number of plastic hinges have formed to transform the statically indeterminate structure into a mechanism.

Thus the final condition of failure is clearly indicated by the previous "yielding" phase of the material. Apart from involving more laborious calculations, the method of permissible stresses enables one to describe only the distribution of stresses within the structure. It cannot correctly describe its safety against the danger of collapse with the vigour, clarity and simplicity of the theories initiated and developed under the direction of Prof. J. F. Baker.

This subject, novel and capable of rational analysis, involves the arduous, complex problem of the safety of hyperstatic structures. Both in the previously mentioned paper and also in the paper submitted by J. Heyman, "Plastic analysis and design of steel-framed structures," it is remarked how the initial measure of redundancy of the structure tends to impede the general movement of the system.

If these ideas are applied to the simple case of a pitched-roof portal frame, it will be noticed that the structure would collapse if the steel were to reach the point of yield prematurely. A defect in rolling, an internal air bubble or a defective weld would suffice for a given section to fail to withstand the forces for which it is designed. The section becomes plastic and a plastic hinge appears at a given point.

If the structure is statically determinate, failure will occur more or less suddenly. Conversely, if the system is highly redundant, the conditions of safety vary. Before a highly redundant multi-bay portal frame can collapse laterally, under the action of a horizontal force, all the vertical members have to become plastically hinged and rotate. A local defect in one of them implies a point of weakness, but the danger of collapse becomes notably reduced by the supporting strength of the other vertical members. Only at the final moment, when the externally applied forces are very severe, does the whole structure fail. Each member, fully strained under excessive loading, cannot render further assistance to its neighbours, and these, unable to withstand the load, subdivide and collapse.

In this sense, pin joints and other flexible joints seem to limit the capacity of the system to resist. They are veritable boundaries, or barriers, forcing adjacent members to depend only slightly on other members. This isolation and great autonomy are sometimes prejudicial, sometimes advantageous. Flexibility is an inestimable advantage in all those instances where it is to be anticipated that foundations will subside.

The fact that a structure may have to withstand a given set of loads effectively, as well as the strains arising from subsidences, makes it difficult to establish general conditions of safety for this dual form of loading.

Perhaps one of the most important points arising from the work inspired by Prof. J. F. Baker relates to the new concept of safety. The whole structure fails although at the instant when it begins to collapse the most loaded fibres have not reached their ultimate failing stress.

This new idea, this mutation of the concept of ultimate strength in order to substitute it for the critical instant at which the steel begins to yield, sets new problems. The nature of failure is shown, not as a sudden phenomenon but as a steady state of transition towards instability. In this situation the rheological behaviour of the material acquires a predominant importance. If failure requires that loads shall be kept applied for a certain time, i.e. if the collapse is not sudden, then damage due to accident will be less severe than in the case of a brittle collapse. If damage is less, the required factor of safety will diminish. The structure can be designed with a smaller margin of safety than if a sudden collapse is anticipated.

This effect of the time-variable leads to a new aspect of the behaviour of the material during the critical phase in which the creep phenomenon appears. In tests in which the load has been rapidly applied, it has been found that the moment at which plasticity begins may differ, according to the definition of J. F. Baker, from the critical moment at which, if the load is applied during a certain interval, the member yields. All will depend on the position within the stress–strain diagram of the theoretical or conventional creep limit.

Tests by Prof. Campus in which steel has been subjected to tensile stresses at ordinary temperatures have revealed the different behaviour of various kinds of steel and the influence of rolling or strain on the point of the limit of creep. This position does not seem to be directly related to the real, or conventional, yield point, nor to the arbitrary proportional limit.

This behaviour of the material under sustained loading sets two problems that so far have not been satisfactorily overcome, and which can be enunciated briefly as follows:

What is the bending moment which, if applied indefinitely, leads to considerably larger strains than those due to a slightly smaller moment? In tests in which loads are maintained over a long period, is there any indication of discontinuity, or is there a point at which steel suddenly begins to strain rapidly? In these circumstances has the previous history of cyclic loading any influence?

It cannot be overlooked that, rheologically, short-time tests only illustrate one facet, a partial aspect, of the strain problem. The loading processes which the structure will have to withstand involve conditions entirely different from those under which tests are often conducted. These begin with a rapidly increasing loading, until failure occurs. But the collapse of a structure is usually preceded by a long, uncertain history during which there may have been many unforeseeable loading cycles. Sometimes the collapse is due to the violent action of an external system of forces; these, acting statically or dynamically, sometimes after repeated cycles, are capable of causing failure either suddenly, or slowly or by successive steps. On other occasions some important defect in one or several sections of the structure imposes severe working conditions. The member, being stressed nearly to its ultimate capacity under normal loading, is strained to a point close to its creep or yield limit. Strains grow continuously under design loads, and failure may even occur for smaller strains than the maximum strains attained during a short-time test. The material, prematurely aged, is not able to resist any further. It withstood the initial loading, but time was the direct cause of its final failure.

In a sense, the effect of permanently applied loads is akin to the phenomenon of alternating or cyclic loading. A single cycle of loading and unloading does not suffice to break a structural member, but continuous repetition of loading cycles may lead to fatigue failure. The endurance limit seems to have some relationship with the critical load the material can withstand indefinitely. This critical load, according to tests on concretes by J. R. Shank, is 86% of the instantaneous ultimate strength.

For the present very little can be said about a possible correlation between fatigue and ageing phenomena due to loads permanently applied. The urgent problem faced by high-pressure-steam plant makers regarding the rheological behaviour of steel at high temperatures has been only partly classified, in spite of great efforts and advances made in this field. Nor is the similarity of the strain–time diagrams for constant stress, at various temperatures to the strain–time diagrams for various stresses at constant temperature of much help in formulating a satisfactory relationship between these two types of phenomena. There is a remote possibility that a relationship may exist between the behaviour of steel under sustained loading over a long period at a given temperature and a similar behaviour at a different temperature, by making some corresponding, but so far obscure, compensation in the time factor. But such a suggestion, for all its interest, cannot be formulated with any pretence to scientific rigour.

Only experimental research can clear up the complex strength behaviour of materials under permanently applied loads. New results on the behaviour of material under repeated loading can only be obtained by a systematic programme of tests.

All estimates about the future are tinged with uncertainty. As a first approximation the designer may guess intuitively, or may estimate the limiting value of certain loads to be statically applied. If he wants to get nearer the truth, he may take account of their effect on the structure when applied over a certain time span. Dead weights and permanent overloads constitute a system of forces which never cease to operate.

But additional to these, and concomitantly with accidental overloads which may operate over long periods, phenomena of the opposite type may supervene. Two examples of intermittent loading are the wind, with its gusts of capricious intensity, and the regular cadence of a train crossing a bridge. Its action endures hours or minutes, but in contrast to permanent loading which remains uniform, the magnitude of loading is modulated, varying according to arbitrary laws, and is always dependent on many variables which are difficult to estimate.

At times such intermittent loading may induce oscillations, which, if the structure is very flexible, will merely cause discomfort to users. A typical example of this is the Whitestone Suspension Bridge, near New York. The structure was capable of withstanding hurricanes and gusty winds, but when these attained a given intensity, the amplitude of oscillations at the centre of the main span was sufficiently large to cause justifiable qualms among those travelling over it. The magnitude of these displacements did not imply the slightest risk to the stability of the structure, but the heavy traffic and the adverse psychological condition induced in those who normally used it became an adequate motive for widening the deck as well as correcting its exaggerated flexibility, by increasing the depth of the stiffening beams. This is a complex matter, difficult to accommodate within normal safety criteria, though undoubtedly it requires attention for the sake of the peace of mind of those who use such a structure.

In this connection the paper submitted by Prof. Dr. E. Friedrich is very interesting.

The considerable oscillations caused by all types of traffic over the bridge at Villach necessitated the restriction of speed of wheeled traffic. The consequence of this, which from a functional aspect was logical, was an interference with the movement of traffic so that at certain times of day the difficulty became acute.

Starting from this particular case of statically determinate beams Prof. Friedrich has investigated the resonance of a simply supported beam, and has inferred that the best way to eliminate an unfavourable combination of oscillations is to suspend a longitudinal mass, like a beam, from the main stringers by means of springs and dash-pots. This will avoid resonance. The additional mass will only account for 10% of the total weight of the bridge, and the calculations for the design of this device are easy, using the formulae worked out by him.

In order to simplify calculations and arrive at practical results, Prof. E. Friedrich has substituted a somewhat equivalent mechanism for the actual system. Even in its most simple case, the investigation of the effects on a simply-supported girder over which a single load moves smoothly at a constant speed involves enormous difficulties of calculation. These difficulties have been pointed out by Dr. A. Hillerborg. The contribution he has submitted is a summary account of the results announced in the publication *Dynamic Influences of Smoothly Running Loads on Simply Supported Girders*. This work has been published by the Royal Institute of Technology of Stockholm, under the direction of Prof. Wästlund.

The theoretical merit of the work done by Dr. Hillerborg is evident. The mathematical work is developed with much ability and scientific rigour, but the practical consequences are disappointing due to the vast amount of work necessary to ascertain the dynamic factors applicable to even the most simple and elementary case.

The difficulties met in analysing a particular case are technically almost insurmountable. Actual conditions are such that for the time being they seem to defy direct calculation. The applied loads move with variable speeds. The hypothesis is made that effects are to be superimposed. The structure will consist of one or several spans, straight, or curved, independent, or not. The cross-section of the members changes frequently in accordance with functional requirements. The damping of the oscillations is closely linked with the rheological mechanism of the material.

But in spite of all this the engineer has to keep on constructing. It is not right to avoid the use of a particular type of structure, which intuition informs us to be adequate, simply because its dynamic behaviour is unknown. Theoretical research must continue, but until the desired aim is attained new resources have to be devised that will reveal the stability of the structure. It is not prudent to ignore the evidence of phenomena, even if they cannot be fully grasped by our reason.

In the present state of technology, it appears that only experimental work can lead to cogent results. Scale-model tests make it possible to study the most complex cases. By such means the influence of given phenomena can be measured, and the structure can be subjected to systems of forces very similar to the actual anticipated overloads.

The experimental work by C. Scruton at the National Physical Laboratory, on behalf of the British Ministry of Transport, is an example of this kind of attempt to study the behaviour of a structure subjected to the dynamic action of wind operating continuously or in gusts. The model was placed in a wind tunnel suitable for this type of test. By turning it conveniently around, it was possible to observe the effects: first on the structure as a whole, then separately on the deck.

As it was practically impossible to reproduce the structure so that similarity would be maintained in density, elasticity modulus, damping and speed and viscosity of the wind, this last factor was ignored because of its negligible influence. The test on the full model served to compare results with tests on sectional models, suitably mounted. These latter tests also served to measure in a simple manner different types of decks, so that by a process of trial and error, the most satisfactory deck was evolved, careful account having been taken of the results obtained with some of these decks in relation to the full model.

As so often happens the experiment by-passes the obstacles of calculation and solves problems that lie beyond the reach of theory. Sometimes it serves to determine the effect of imposed loads. At other times it reveals the behaviour of the material employed and corrects or checks the truth of the hypotheses, which often are too idealised to be correct.

Model research and work on test-pieces performs two distinct functions, both most valuable. The former overcomes problems beyond the scope of mathematical computation, and the latter reveals properties and defines qualities that broaden or limit the strength and mechanical possibilities of a given material.

Both are most valuable aids to technical research. Methods of calculation based on the plastic behaviour of materials, when applied to the dimensioning of reinforced-concrete sections, and by Prof. F. Baker to metal structures, are the result of good observation of the mechanical properties of steel.

The advantages of this procedure are not only that it provides a method more simple to apply, but also that it corresponds more closely to the actual behaviour of the material.

But to solve the stress–strain laws, as well as their evolution in the course of time under different kinds of loading, it is necessary to return to the basic material and to observe all its changes, its elongations and contractions.

With this end in view, Prof. J. F. Baker has undertaken a series of tests. These have been done in the Engineering Laboratory of Cambridge University by M. R. Horne.

Simultaneously, A. Lazard has arranged another set of tests, also on mild steel full-web double-T girders, and has compiled valuable data from other experimental centres.

As A. Lazard points out, the interest of the subject is such that there appears to be justification for a vast systematic research programme, not only into the behaviour of beams under an increasing bending moment, but also on structural pieces subjected to cyclic loadings, either in the form of repeated loadings, or of alternating or oscillating forces.

Other interesting aspects of this subject are buckling phenomena of the compression flange, the influence of shear stresses, rivet holes, and internal stresses due to rolling or welding. Further, this investigation should include tests on simply-supported beams, fixed-ended girders, continuous beams over several supports, portal frames, etc., and it should include rolled and built-up sections. It will be realised how vast is the field that awaits systematic exploration. The synoptic table prepared by A. Lazard gives a clear idea of the magnitude of the problem, to which it would probably be necessary to add the series of tests on strains and failures due to the action of permanently applied loads.

The task is enormous, but the consequences and the advantages that would result in reduced cost would far outweigh the effort made. Firstly, sizes could be cut down, since the behaviour of the material would be better known. In the investigation presented by M. R. Horne on the most efficient shape of fixed-ended beams it is shown that a saving of 16% can be achieved. A study into the optimum values that should be given to the safety factors which multiply loads and divide limiting stresses could lead to an additional saving of between 10% and 20%.

If to these percentages is added the reduction in the value of the safety factor due to the extensive research into the behaviour of structural members under long-acting dynamic loads, and due to the better estimation and precise functional operation of the structure, it can be well understood that those figures can be increased even more. So the safety factor might be lowered even further, all this as a result of a better knowledge of the materials and more accurate design hypotheses.

For these reasons, based on the highly promising results implied by Prof. J. F. Baker's theory, as expounded by B. F. Neal, P. S. Symonds, J. Heyman and M. R Horne in its various aspects, the general reporter seconds the proposal of A. Lazard, and takes great pleasure in communicating this most interesting proposal to the Congress—a proposal that is full of difficulties, and that will involve many hours of hard work, but which leads him to hope for a technological evolution from which all engineers will benefit.

Summary

In the general report concerning the contributions to theme AI, the different criteria are first explained on which the conception of the safety of structures is based. For this purpose it is suggested that the factor of safety C should be split into two partial factors C_e and C_r whose product is C. With one partial factor, the calculated shearing forces are to be multiplied; with the other, the strengths or limiting stresses are to be divided. The relation between these two partial coefficients results also from mathematical-statistical considerations.

The general reporter describes the special points of the various papers submitted. According to the above considerations, these are divided into two groups. To the first belong the papers on the deduction of the shearing forces from the dynamic or static loadings. In the second group are summarised the papers for extending the knowledge of materials with the help of experimental research on the behaviour of materials under the influence of static and dynamic loads.

Finally, the economic advantages which would result from these studies are explained. The materials would be better utilised when one or other of the partial factors of safety is reduced, so that the fundamental assumptions underlying the calculations are improved and a more accurate knowledge is obtained of the mechanical properties of the materials that are used.

Résumé

Dans ce rapport général, qui sert d'introduction à la discussion des travaux présentés à la Section AI, le rapporteur général expose les différents critères sur lesquels est basé le concept de la sécurité des structures. A cet effet, il suggère la décomposition de la valeur numérique C du coefficient de sécurité, en deux coefficients partiaux C_e et C_r, dont le produit est égal à C. L'un d'eux est destiné à multiplier les moments fléchissants, les efforts tranchants et les efforts normaux prévus; et l'autre, à diviser les résistances ou contraintes limites. La relation entre ces deux coefficients partiaux est basée sur des considérations de mathématique statistique.

Ensuite, le rapporteur expose sommairement les particularités qu'offrent les différents travaux présentés. Conformément aux idées antérieures, il les classe en deux groupes. Le premier groupe est formé par les thèmes qui traitent de la déduction des efforts produits par les surcharges, soit dynamiques, soit de type statique. Dans le deuxième groupe, il inclut toutes les contributions destinées à compléter la connaissance des matériaux au moyen de l'étude expérimentale de leur comportement sous l'action de charges statiques, dynamiques et permanentes.

Enfin, le rapporteur indique les avantages économiques qui résultent de ces travaux et portent sur une meilleure mise en valeur des matériaux et sur la réduction de l'un et l'autre des coefficients de sécurité partiaux, par l'amélioration des hypothèses de base de calcul et par la connaissance plus exacte des caractéristiques mécaniques des matériaux employés.

Zusammenfassung

Im Generalbericht über die eingereichten Arbeiten der Abteilung AI werden zunächst die verschiedenen Kriterien dargelegt, auf die sich der Begriff der Sicherheit der Baukonstruktionen gründet. Zu diesem Zweck wird die Aufteilung des Sicherheitsfaktors C in zwei Teilfaktoren C_e und C_r, deren Produkt C ist, nahegelegt. Mit dem einen sind die berechneten Schnittkräfte zu multiplizieren, durch den andern die Festigkeiten oder Grenzspannungen zu dividieren. Die Beziehung zwischen diesen beiden Teil-Beiwerten ergibt sich aus mathematischstatistischen Betrachtungen.

Sodann beschreibt der Generalberichterstatter zusammenfassend die Besonderheiten der verschiedenen eingereichten Arbeiten. Gemäss den vorstehenden Ueberlegungen werden diese in zwei Gruppen eingeteilt. Zur ersten gehören die Beiträge über die Ableitung der Schnittkräfte aus den dynamischen oder statischen Belastungen. In der zweiten Gruppe sind die Beiträge zur Vervollkommnung der Materialkenntnisse mit Hilfe der Versuchsforschung über das Materialverhalten unter dem Einfluss statischer und dynamischer Lasten zusammengefasst.

Schliesslich werden die wirtschaftlichen Vorteile dargelegt, die sich aus diesen Arbeiten ergeben, welche erlauben, die Materialien um soviel besser auszunützen, als es gelingt, den einen oder den andern der Teilsicherheitsfaktoren zu verkleinern, indem die grundlegenden Rechnungsannahmen verbessert werden und eine genauere Kenntnis der mechanischen Eigenschaften der verwendeten Baustoffe erreicht wird.

Leere Seite
Blank page
Page vide