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

Band: 8 (1968)

Rubrik: Free discussion

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In view of the contents of Section 3 of the general report by Professors O. Steinhardt and H. Beer, the two papers (1) and (2) by Ryo Tanabashi and Tsuneyoshi Nakamura should also be referred to as a possible approach to the plastic design of tall multi-story frames. In Ref. (1), the linear minimum weight design of a broad class of tall multi-story frames of practical interest has been established in a simple and explicit analytical form by introducing a new concept of "frame moment". The general solution for comparatively large lateral forces has been obtained due to the particular circumstance in Japan where equivalent static lateral forces due to earthquake disturbances are comparatively larger than those in other countries. The solution may, however, be readily modified for a more general case where the vertical forces are dominant compared to lateral forces in several stories from the top. This design is regarded as the preliminary design.

When a rigid-plastic preliminary design is constructed for a design problem, one may readily find the axial force distribution corresponding to the bending moment distribution at the collapse state of the simple plastic theory. Hence the secondary design may be accomplished by assigning the plastic moment to a column in such a way that the known axial force and bending moment acting upon its end sections would not violate the corresponding bending moment-axial force-interaction yield conditions.

The last step is to modify the above secondary design against the unfavorable effect of the additional moments induced by the sidesway deflections under large axial forces in the last hinge point state. It should be noted that the last hinge point load factor must be equal to or less than the true failure load factor and may be used as the base of the design. The last hinge point state may be constructed iteratively starting from the above secondary design. The crucial point here is that the iterative process is to be carried out not with respect to the moments as an analysis but with respect to the cross-sectional dimensions as a design problem. An example of a 30-story frame treated in Ref. (2) has shown a rapid convergence of the present procedure.

This last hinge point design is regarded as a standard design for the problem with which any actual design may be compared. Since any augmentation in stiffnesses and plastic strengths would not decrease the elastic critical load factor and the rigid-plastic collapse load factor, any actual design may be accomplished in reference to this standard design by appropriate augmentations such that the actual design is guaranteed to possess a greater failure load factor than the last hinge point load factor of the standard design satisfying other various practical requirements.

(1) Ryo Tanabashi and Tsuneyoshi Nakamura, "The Minimum Weight Design of a Class of Tall Multi-story Frames Subjected to Large Lateral Forces", Proc. 15th Japan National Congress for Appl. Mech., pp 72-81, 1965.

(2) Ryo Tanabashi and Tsuneyoshi Nakamura, "An Approach to the Last Hinge Point Design of Tall Multi-story Frames", Proc. Symposium on the External Forces and Structural Design of High-rise and Long-span Structures, pp 169-179, Tokyo, Sept. 1965. (Japan Society for the Promotion of Science)

IIIa

Elasticity or Plasticity?

Élasticité ou plasticité?

Elastizität oder Plastizität?

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A very interesting discussion is going on on elasticity and plasticity. I should like to contribute to it some further remarks.

A reversible (or elastic) deformation, as you all know, is the response of a material in the first stage of the loading process. It may be linear or non-linear. It is not accompanied by energy dissipation. (We confine ourselves to discussing isothermal processes).

Viscous flow is observed when the body is maintained for a long period under the action of external forces. This may be either reversible or irreversible; however, it is always connected with energy dissipation.

A plastic deformation is a kind of defence (self-defence) of the material against overloading. It is always irreversible and is always connected with energy dissipation.

Thus it may be seen that there is not only a quantitative, but, essentially, also a qualitative difference between elastic, plastic, and time-dependent phenomena.

The above remarks hold, as a rule, for any material; they are also true for our engineering materials from which our structures are made.

In consequence, the response of our engineering structures to various kinds of external agents depends (1) on the duration of the application of loads and (2) on their intensity.

The Theory of Elasticity deals with reversible phenomena, and is not interested in and, therefore, cannot account for such effects as the time-dependent deformation processes which are generally called the rheological (or viscous) phenomena as, e.g., creep, relaxation etc.; but it also cannot account for plastic effects.

On the other hand, the designer - a conscientious designer - wants to know what really is going to happen to his structure in the course of its existence, let us say, in a year, or two, or five; and perhaps also, what is going to happen if the structure - by accident or purposely - is overloaded, overloaded in comparison with the originally planned design load.

Thus, there is no contradiction and, of course, no competition between the "elastic" and "inelastic" approaches. Consequently, there is also no competition or clash between the Theory of Elasticity and the Theory of Plasticity: these theories simply cover different questions. Thus, they are complementary.

The Theory of Plasticity is, if I may put it in a somewhat simplified way, a kind of extension of the Theory of Elasticity.

It is to-day quite obvious that the Theory of Elasticity is a well developed and logically built up discipline. It has been worked on for about three centuries since Robert Hooke's famous statement "Ut tensio, sic vis" has been published*). Thus, he formulated one of the basic assumptions of the (physically) linear Theory of Elasticity (law of proportionality between strains and stresses). The other assumption is that the deformations and strains are small (geometrical linearity). With these two fundamental assumptions the elegant and impressive structure of the classical Theory of Elasticity with all the required basic principles, variational theorems, methods of solutions, comprising countless effective applications, has been established.

The Theory of Plasticity is not less important, however quite different, somewhat more complex and, moreover, far younger. The foundations of the mathematical theory of perfectly plastic materials were laid in two splendid papers by Barré de Saint-Venant and Maurice Lévy (C.R. Acad. Sci., Paris 1870). But then, for about 30 or 40 years, nothing happened in this domain. Only in 1904 M.T. Huber, and later independently R.v.Mises (1913) and H. Hencky (1924) established the "energetic" yield criterion for the onset of plastic deformations in three-diemnsional states of stress. So the age of the Theory of Plasticity is to-day not even a hundred years, from which only the last 50 or even 40 years are of importance. It is quite clear that, under such circumstances, some questions are still open, especially for assessing the theoretical treatment of phenomena of work-hardening, finite deformations and some others. Anyhow, constant progress is being made in all basic and applied aspects and it is fair to state that the results achieved so far have already widened our basic knowledge and have well served numerous engineering branches.

In conclusion I should like to remark that man has always been and is very inquisitive creature: we examine everything, starting with ourselves, down to bacteria and virus, we reach out - at the other extreme - to the moons and galaxies. So I think it is quite natural that we cannot prevent people from being curious and having a penetrating mind in connection with the properties, life and reliability of our materials and structures in all the circumstances they have to face and also after they have exceeded the elastic range of response.

I also think that - so far - scientific research seems to constitute the only way of satisfying one's own personal curiosity being at the same time instrumental towards solving numerous social and public problems and needs; it likewise seems it will continue to be so in the field of structural engineering.

*) R.Hooke, De potentia restitutiva, London 1678. As a matter of fact Hooke's principle of his balance spring was first expressed in a Latin anagram "ceiiinosssttuu" (1676), a form which commonly was used in scientific circles of the time to establish priority of discivery without actually disclosing anything that might be of use for possibly jealous collegues.

IIIa

Plastic Design of Tall Buildings

Dimensionnement plastique de bâtiments élancés

Plastische Bemessung von Hochhäusern

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The conference topic, Plastic Design of Tall Buildings, has been particularly timely in connection with a current project of the American Society of Civil Engineers. An ad hoc committee of ASCE is currently (1968) nearing completion of its work in revising ASCE Manual No. 41, "Plastic Design in Steel". Included in the committee are many members from abroad, and their attendance at this meeting has made possible a number of valuable informal discussions.

Much additional information is now available on the status of plastic design, new research, new applications, and problems requiring further study. The second edition of ASCE Manual No. 41 is being revised on a modest basis to include this information, to incorporate braced multi-story frames, and to encompass modifications to simple plastic theory where necessary to extend its applicability. It will cover steels with yield points up to 65 ksi, and additional attention is given to repeated loading effects. It is hoped that the second edition of the Manual will be available early in 1969.

Discussion by Professor Hrennikoff

With respect to the prior discussion by Professor Hrennikoff, two comments are pertinent. In the first place, so-called elastic design would have the same inadequacies that he attributes to plastic design. If what Professor Hrennikoff says is true, then most of the buildings designed in the last two decades would either be unsafe or would be uneconomical--and that can scarcely be the case. It was in 1945 that the American Institute of Steel Construction first incorporated a provision to allow a 20% increase in stress at points of interior support in continuous beams. This amounted to a direct use, albeit on a somewhat arbitrary basis, of the plastic strength of steel structures. It is a provision that has been used in design ever since. In Europe plastic design has been used for decades in proportioning continuous beams. Thus one cannot in any way understand why Professor Hrennikoff continues to be concerned.

In the second place, as engineers we tend to be interested in stress. But the user and the owner are concerned about safety (that the structure has adequate strength) and with performance (that it doesn't deform too much). These latter are the truly important criteria: strength and deformation. Where stress is a logical basis for design it is only so because it assures that one or the other of these two design requirements will be met.

Therefore, we reject Professor Hrennikoff's thesis.

Contributors to the Plastic Theory of Structures

Earlier in the discussion of this theme, Professor Massonnet mentioned a conference on engineering plasticity at Cambridge University, England. It was the writers privilege to be able to attend this conference which honored Sir John Baker on the occasion of his completing his service to Cambridge. This honor to Sir John (Fig. 1) was particularly appropriate because he put into motion a new era in structural design. As a pioneer into new areas of structural design, he understood the weaknesses of past design techniques and the significant opportunities for improvement. Not only was he able to set forth the new concept, but he made that essential next step: to stimulate in a dramatic way the application of research findings to design. It is indeed fortunate that the engineering profession continues to benefit from his active contributions.

Fig. 1

The Conference on Engineering Plasticity was also important, as are all conferences, because of the people who attended. A special group are the four shown in Fig. 2--individuals who were true pioneers in various aspects of maximum load design*. Commencing from the right, Professor Prager headed a most important team at Brown University; their studies and writings are the major contributions to the mathematical theory of plasticity. It was Professor Baker's genius that made plastic design a practical, useful technique for the structural engineer. Professor Johansen gave the profession the

Fig. 2

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*Regretably, the photograph does not include M. Massonnet, also present at the Conference, and in Europe a leader in plastic design developments.

yield line theory. Finally, Dr. Stüssi, honorary president of the IABSE, gave us searching and challenging questions; and it is only the fact that it has been possible to answer these questions that plastic design has become the practical and useful tool that it is today.

Not included in the photograph, but active in this current New York IABSE conference (and pictured in Fig. 3) is one who, more than any other, has made possible the rapid advances in all aspects of steel design in the United States: T. R. Higgins, Director of Engineering and Research of the American Institute of Steel Construction. He is an integral member of the pioneering group. His grasp of the essence of new concepts, his untiring participation in the work of research councils, and his leadership in transferring research to practice have contributed significantly to the remarkable advances in design techniques that are available to the practicing engineer in the world today.

Fig. 3

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