# Summary report on theme III

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Objekttyp: **Article**

Zeitschrift: **IABSE reports of the working commissions = Rapports des commissions de travail AIPC = IVBH Berichte der Arbeitskommissionen**

Band (Jahr): **14 (1973)**

PDF erstellt am: **22.09.2024**

Persistenter Link: https://doi.org/10.5169/seals-14475

**Summary Report on Theme III**

Rapport sommaire au thème III

Zusammenfassender Bericht zum Thema III

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The primary results to be extracted from the discussions to Theme III are to obtain a method to predict the deformation response of steel structures and their elements against well-defined,nonstationary repeated and reversed loading and to find the maximum strength and deformation for such loading, rather than the evaluation of fatigue strength and phenomenological description of cyclic behaviour.

In the analysis of frames and members for which buckling is not critical,it seems to be best,as Dr.Popov pointed out,to start with a stress-strain diagram obtained for cyclic loading. This is then integrated to obtain the moment-curvature relation for a given member section. Finally,using the latter information, calculation of the load-deflexion response due to cyclic loading is made. Dr.Akiyama presented such a method for construction of stress-strain diagram of steel material under nonstationary cyclic loading directly from a monotonic stress-strain curve. Using this basic relation,Kato presented in the session of Theme I a method to obtain the load-deflexion response of members and frames under cyclic loading. Dr.Nakamura's remarks were also in the same direction. Each smooth piece of hysteresis loops was approximated by a Ramberg-Osgood eqation,and the moment-curvature relation was calculated for a simplified two-parallel flange section. Dr.Popov,in his research,started with the moment-curvature relation obtained from experiments. Dr.Yamada et al. carried out repeated and reversed horizontal loading tests of unit rectangular steel rigid frames. Dr.Igarashi et al. presented test results of beam-columns subjected to repeated and reversed loading under a constant axial thrust. The former assumed a tri-linear and the latter assumed a bi-linear type of stress-strain relationship in their analyses.
   Dr.Johansson carried out shake down tests on two span beams. The shake down loads were found to be approximately 15% greater than the calculated loads due to strain-hardening. It was also shown that the shake down behaviour was time dependent.

Six papers dealt with the topics of incremental collapse,repeated loads were applied in post buckling state.
Dr.Davies carried out tests of axially loaded continuous beams subjected to both static and cyclic transverse loading. He pointed out that for a structure which

exhibits instability,an incremental collapse would be caused by cyclic loading.
Balancing between strain-hardening effect and P-$\Delta$ effect is a most critical
factor in the response to cycles of load. Dr.Morino presented test results of
centrally and eccentrically loaded struts. Alternate compressive force and tensile
force were applied,while axial displacements were controlled to keep a constant
magnitude from each load-free state. In these tests,buckling took place during
the compressive loading phase. It was shown that residual lateral deflexion inc-
reased and load carrying capacity decreased in each cycle of loading.

Dr.Novák et al. carried out local web crippling tests subjected to repeated
concentrated load,and concluded that the cyclic loading and incremental collapse
did not lead to any significant reduction in ultimate strength,and consequently,
to any premature failure of the girder. Similar tests with rather long cyclic
loading period were performed by Dr.Bergfelt. His test results agreed,in principle,
with those of Dr.Novák. The most important result in his investigation was that
for girders of high strength steel the increase of failure load was not directly
proportional to the yield stress but was approximately proportional to the square
root of the yield stress.

Dr.Popov demonstrated that beams subjected to cyclic loading can maintain
stable loops even after local buckling of flanges has taken place if the beams
were sufficiently braced laterally. On the contrary,Dr.Takanashi et al. carried
out beam tests without any lateral supports. Due to the occurence of lateral
buckling,reduction of beam stiffness was observed in each cycle of bending,and
loops could not attain a stable state. Rotation capacity of a beam under such a
cyclic loading condition is considerably lower than that for monotonic loading
condition.

Concerning with structural connexions,Dr.Igarashi et al. carried out cyclic
bending tests of a beam spliced by high strength bolts. Behaviour of beam-to-column
joint panels was reported by Dr.Popov.

Mr.Takahashi et al. investigated the cyclic behaviour of steel shear walls
stiffened transversely as well as longitudinally to form a grid shape. Stable
hysteresis loops were obtained when stiffeners were strong enough to allow the
wall plate to form a tension field in the post buckling region.

The objective of experimental studies is that the results obtained from
those experiments should be digested and integrated into unified formulations
which are simple enough for the practical design use. Toward this purpose,the
following subjects should be kept in mind:
- The experiments should be planned and carried out in a well coordinated way.
- A prevailing rule derived from experimental results should be checked by the
  theory pertaining to the phenomenon. In this sense,contents involved in
  Theme III and those involved in Thems I should be examined and criticized
  each other. A good example of this can be given. For the behaviour of frames
  subjected to repeated and reversed horizontal loading,the above figures
  were obtained experimentally(1),while the figures below were obtained from
  theoretical basis(2). In the experimental phase,it is difficult to cover all
  relevant parameters and conclusions might have been drawn from results of a
  limited number of test specimens.
- Application of the numerical analysis is coming up to follow the experimental
  behaviour of structures. However this approach does not seem as effective for
  obtaining general information on the behaviour of structures for a specified
  loading condition,thus,for the derivation of a practical design formula. In
  the experimental and theoretical approaches as well,more effort should be made
  to have an insight into fundamental characteristics of the structural system.

(REFERENCES)    (1) Fujimoto,M. and Naka,T.,Introductory Report,III,Experimental
Studies concerning Steel Structures,their Elements and their Connections, P.56.
(2) Kato,B. and Akiyama,H.,Preliminary Report,I,Theoretical Prediction of the
Load-Deflexion Relationship ·of Steel Members and Frames, p.27.(SYMPOSIUM,1973)
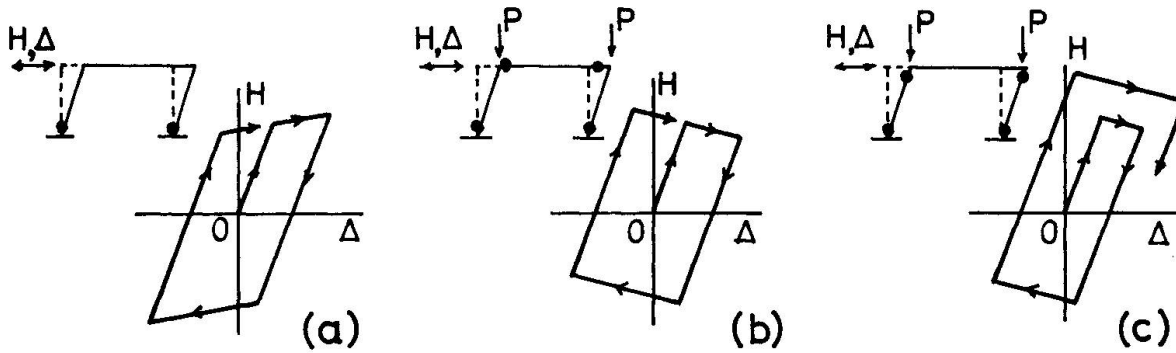
(a) Vertical load P does not exist or are small. The positive range of H-$\Delta$ curve are parallel to $\Delta$-axis,neglecting strain-hardening.

(b) Vertical load P is large and hinges form at beam ends. H-$\Delta$ curve is modeled by closed loop with negative gradient in plastic range.

(c) Vertical load P is large and hinges form in columns. H-$\Delta$ curve is modeled by helically expanding loops due to the accumulated compressive strains and strain hardening,with negative gradient in plastic range.

(FROM INTRODUCTORY REPORT ,THEME III,p.56,Fig.21)

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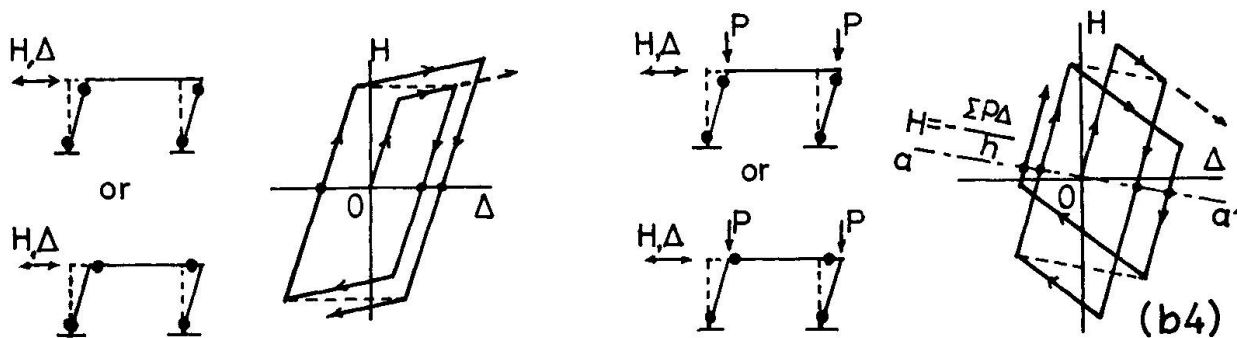


(a) NO AXIAL LOAD               (b) WITH AXIAL LOAD
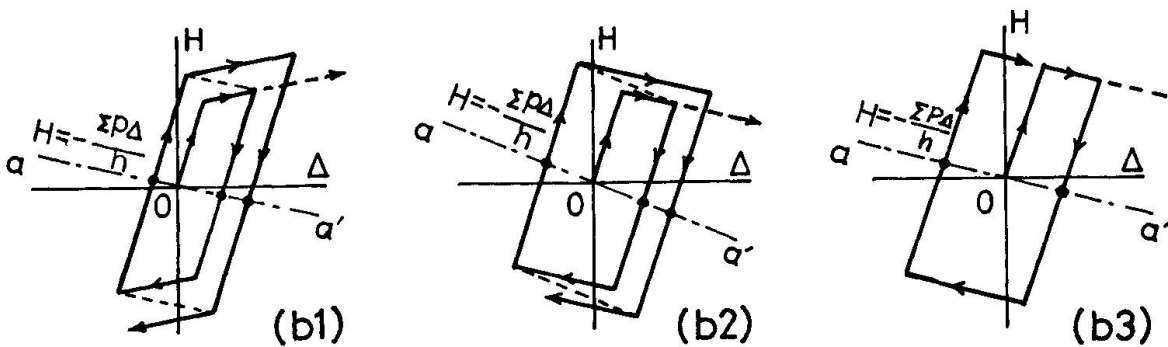


(b1),(b2)---Moment capacity increases over $M_p$ due to strain-hardening,and
            (b1),increasing rate overcomes P-$\Delta$ effect.
            (b2),P -$\Delta$ effect overcomes increasing rate.
(b3)--------Moment capacity keeps $M_p$ (no strain-hardening)
(b4)--------Moment capacity decreases from $M_p$ due to buckling etc..

(FROM PRELIMINARY REPORT,THEME I,p.27,Fig.9)

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