Material behaviour and stability in aluminium-construction (E DIN 4113)

MATERIAL BEHAVIOUR AND STABILITY IN ALUMINIUM-CONSTRUCTION (E DIN 4113)

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ABSTRACT

KEY WORDS:

Alloy-Materials, General Buckling of Struts, Standardisation

Overall buckling by bending and torsional flexural buckling of aluminium alloys can be understood by a set of two formulae, beyond this frame-buckling is cleared up.

Introduction

The up-to-date standard-specifications for compressed members in aluminiumconstruction should reasonably follow the example of s t e e l - construction standardisations. There, the correlations and interrelations between material, section-groups and "imperfections" lead to relastistic general definitions and formulations for "planned-centrical" (but not yet expressly for "excentrical") loaded struts - as H e r m a n n B e e r , his collaborators and others demonstrated in a clear and remarkable manner. The fundametal buckling-curves (fig. 1, overall buckling with excessive bending) offer the collape-stress σ_S (basic-column-stress) for a given slenderness ratio (probable values, each with a tolerance limit equal 2,3 % of collapse load F_S, found by more than one thousand special tests). -

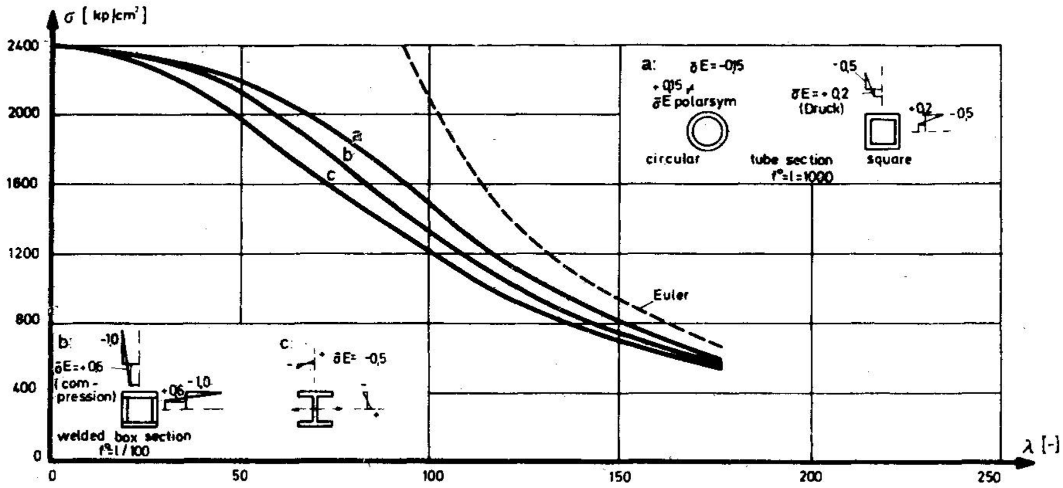


Fig. 1 European Curves of the Basic-Column-Strength included initial imperfections and residual stresses (Steel St37)

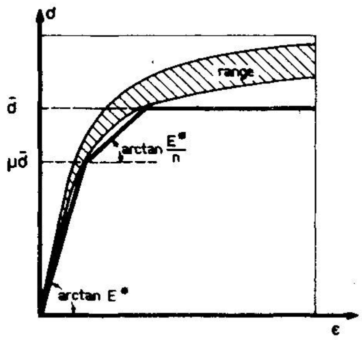
Here, with regard to aluminiumconstructions (and specially to the E DIN 4113, 1973) one should differentiate (according to six basic alloys), on the one hand between peculiar and disproportionate σ,ϵ-curves (each of them very sufficiently described as a tripartite-polygon); on the other hand there are no residual stresses in not-welded and matrix-pressed sections (fig. 2). -

Additionally, it may be noted that it seems possible to conceive the behaviour of compressed steel-struts, even with residual stresses, by a method which will be explained in the following: For instance, a s t e e l - strut with only geometrical imperfections according to $u = i(\lambda/320)^2$ (material St. 37, $\sigma_y = 2{,}4$ Mp/cm^2, $n = 3{,}15$, $\mu = 0{,}575$) is computable very accurately (for the case fig. 1.a) if the formula of fig. 3 is taken as a basis; hereby the greatest deviation from the Beer-curve may be only 2 to 4 %. -

The Standardisation

In the new E DIN 4113 (in chapter 8.1) the σ-ϵ-(compression) diagram of each alloy will be replaced by a tripartite polygon: At first for flexural buckling it turned out that the exact (computer-)analysis of the elastic-plastic collapse stress σ_S, for single and double symmetrical cross sections over the whole range of slenderness up to $\lambda = l/i = 250$ produces results not more than 2 or 3 percent higher than given by the formulae (a) and (b) (see figure 3). -

a.



b.

Legierung (DIN 1725) (Blatt 1)	$\bar{\sigma}$ (Mp/cm^2)	E^* (Mp/cm^2)	μ (-)	n (-)	ungewollte Außermittigkeit Rohre+I-Profile	JL-Profile
AlZnMg1F36	2,9	680	0,85	4,0	$i[(\frac{\lambda}{160})^2+(\frac{\lambda}{160})^3]$	$i[(\frac{\lambda}{240})^2+(\frac{\lambda}{120})^3]$
AlMgSi1F32	2,7	680	0,85	4,0	$i(\frac{\lambda}{120})^2$	$i(\frac{\lambda}{110})^2$
AlMg3F18	0,8	550	0,75	5,0	$i\frac{\lambda}{500}$	$i\frac{\lambda}{580}$
AlMg4,5Mn	1,7	650	0,85	4,5	$i(\frac{\lambda}{190})^2$	$i(\frac{\lambda}{200})^2$
AlMgMnF20	1,1	600	0,80	5,0	$i\frac{\lambda}{400}$	$i\frac{\lambda}{500}$
AlMg3F23	1,5	650	0,85	5,0	$i(\frac{\lambda}{210})^2$	$i(\frac{\lambda}{220})^2$

Fig. 2 a. Tripartite σ,ϵ-Polygon (Aluminium)
b. Characteristic alloy values

$$\frac{N_v}{\mu \bar{N}} + \frac{M_v}{(1-\frac{N_v}{N^*})\mu M^*} \leq 1 \qquad (a)$$

$$\psi \frac{N_v}{\bar{N}} + \frac{M_v}{(1-\frac{N_v}{N^*}) \cdot M^*} \leq 1 \qquad (b)$$

$$\frac{n+1}{2} \qquad \frac{N_v}{N^*}\begin{cases} >1 \text{ formula (a)} \\ <1 \text{ formula (b)} \end{cases} \qquad (c)$$

$$\psi = 1 + \frac{n-1}{2}(1-\mu) \quad \frac{\bar{N}}{N^* - N_v}$$

N^* = the smaller value of $\frac{\pi^2 E^* F}{\lambda^2}$ (Euler) / $\frac{\pi^2 E^* F}{\lambda_{v_i}^2}$ (DIN 4114, Ri 10.13)

M^* = the smaller value of $M_{pl} = \gamma \bar{\sigma} W_d$ (plastic bending moment) / M_{Ki} (Lit. Kollbrunner - Meister)

$N_v = v \cdot N$, $M_v = v \cdot [A_m |M_2| + |N_{vorh}| \cdot u]$

$A_m = 0{,}6 + 0{,}4\, M_2/M_1 \geq 0{,}4$ fixed bearing
$(0{,}85$ not fixed bearing)

v = safety factor

Fig. 3 Formulas (a)(b)and(c) for the Design of Compressed Columns

For the six most important aluminium-alloys, the decisive polygon was shown above in figure 2, (their characteristic dimensions E, $\bar{\sigma}$, n and μ are tabulated). The tripartite polygon is found as the lower limitation of a "bunchy despersion" of many experimentally determined σ-ϵ diagrams).

The new standard will contain additionally (in chapter 8.2) a series of ω -tables; therefore it will also be possible in future to use (selectively) the so called "ω-procedure". Those ω -tables (according to the DIN 4114, 1952) consider - for the case of the exactly planned-centrical loaded strut - only partly the unavoidable geometric imperfections $u = i/20 + l/500$; therefore, the greater range of slenderness is determined by an eigen-value analysis and here the buckling factor grows up to $\nu_{Ki} = 2{,}5$.

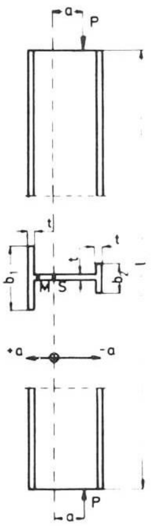
The new E DIN 4113 is principally based on the excentrically loaded strut; by the way, it is connected in parallel to the "ω-procedure" by functions $u = f(\lambda)$ (found by attempting) which result in such collapse stresses $\sigma_S = P_u/F$ that $\sigma_S / \nu_S = \sigma_{d\,zul}$. Now it is essential to state that ν_K is constant over all slenderness ratios. That means that "safety factors" (know from the DIN 4114) ν_{Ki}, ν_K and ν_{Kr} can be replaced by only o n e value. -

How far does it seem possible for each case in point to start exclusively from the determined geometric "imperfections" and from the σ-ε- polygon? In addition to this the following may be declared up to the present: In causes of flexural bending, there is not only the simple "ω-procedure" to be replaced (for the planned-centrical strut!) by the formulae given in figure 3, but there result clear σ_S-values also for the excentrically loaded ones; more presicely, there result the relations regulating the forces and moments N and M, according to the formulae (a) to (c). -

The main advantage of the new thinking (not at all an international one, but in view of the German DIN 4114) seems to be given by the fact that one may succeed in integrating also the t o r s i o n a l flexural buckling (besides the "over turning" and the "torsional buckling"). Therefore,the "Karlsruher Formeln" were applied to some limiting cases, partly delivering very clear deviations in comparison with the "theoretical" values of the DIN 4114. On the basis of many calculations and also in borderline cases (this is done in the dissertation of F. Labib, 1972/73), the above mentioned formulae could be estimated as very useful; but additionally a suitable series of tests should verify the real circumstances.

Some aluminium-specimens (fig. 4) were carefully produced (partly with stress relieving by annealing), and the σ-ε-compression-diagrams (as well as generally the σ-ε tension-diagrams) were registered. Though (see specimen No. 1 to No. 3) a relatively weak aluminium alloy lying outside the new standard, was investigated, it seems to be suited for recording sensitively the aim which should be followed here.

Specimen Nr.	l mm	a mm	b_1 mm	b_2 mm	h mm	t mm	Material
1	650	- 30	45	25	85	25	AlMgCuPb
2	650	- 30					
3	400	+ 70					
4	500	0	56	28	76	5	AlMgSi 1
5	500	0					
6	500	+ 6,5					
7	500	+ 20,8					



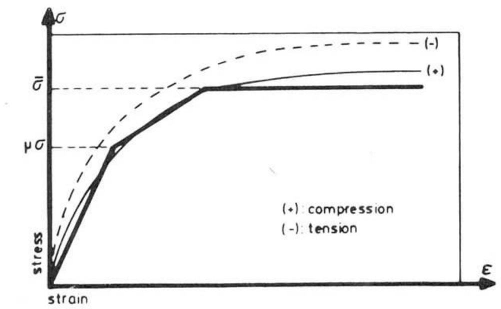


Fig. 4 Investigations on Torsional Flexural Buckling Specimens

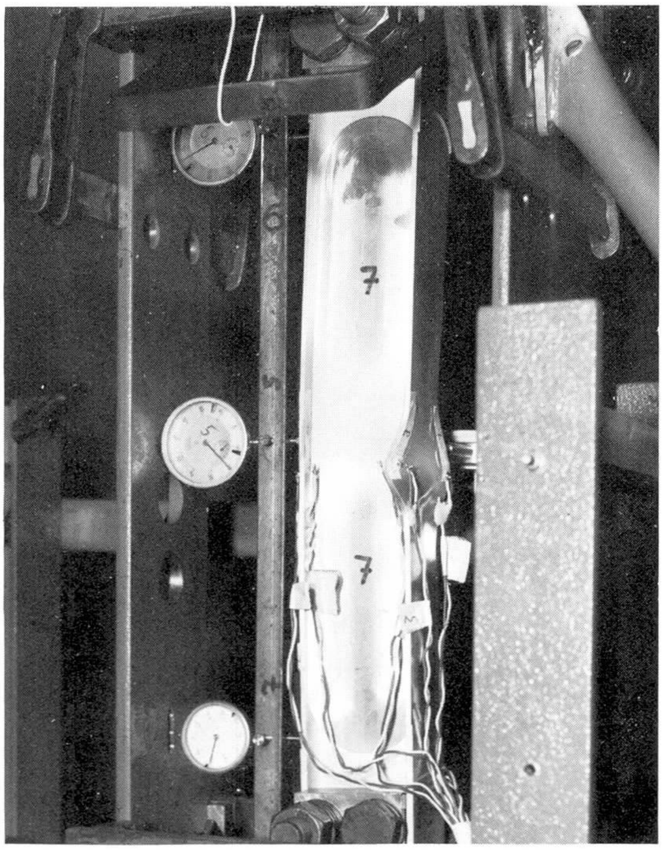
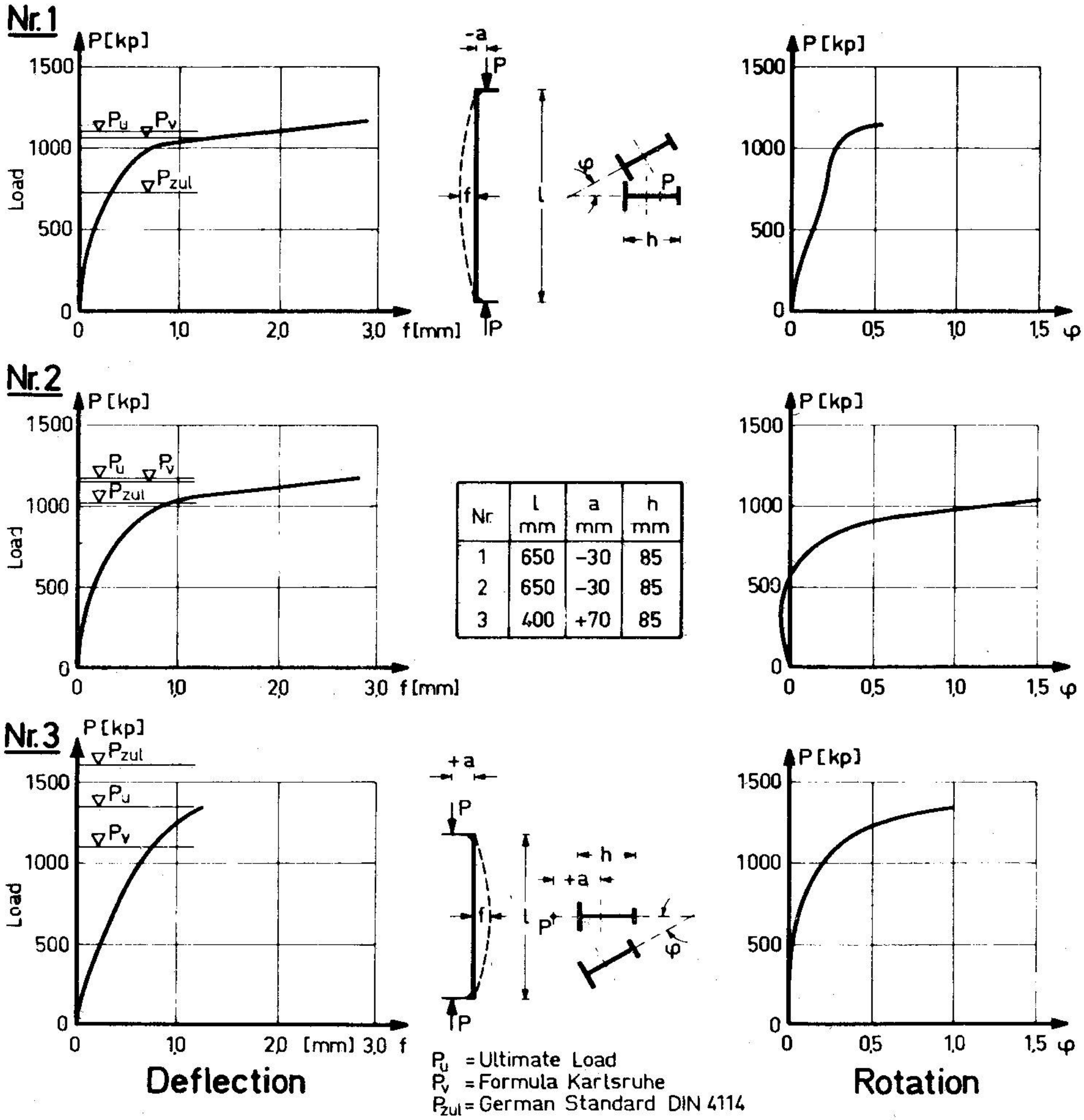


Fig. 5 Setup for Buckling Tests

A photograph (fig. 5) shows the total mode of the test procedure as well as the normally used measuring instruments.

It was possible to watch permanently not only the strains but also the total and part torsions of the medium cross section of the strut and also the lateral deflections.

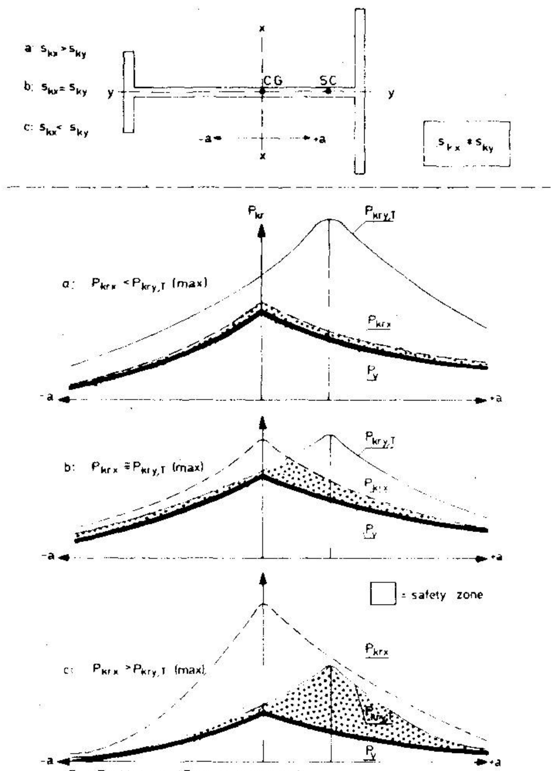
The ultimate loads of the tests No. 1 to No. 3 are compiled in figure 6. They are compared with the values appropriate



Nr	l mm	a mm	h mm
1	650	-30	85
2	650	-30	85
3	400	+70	85

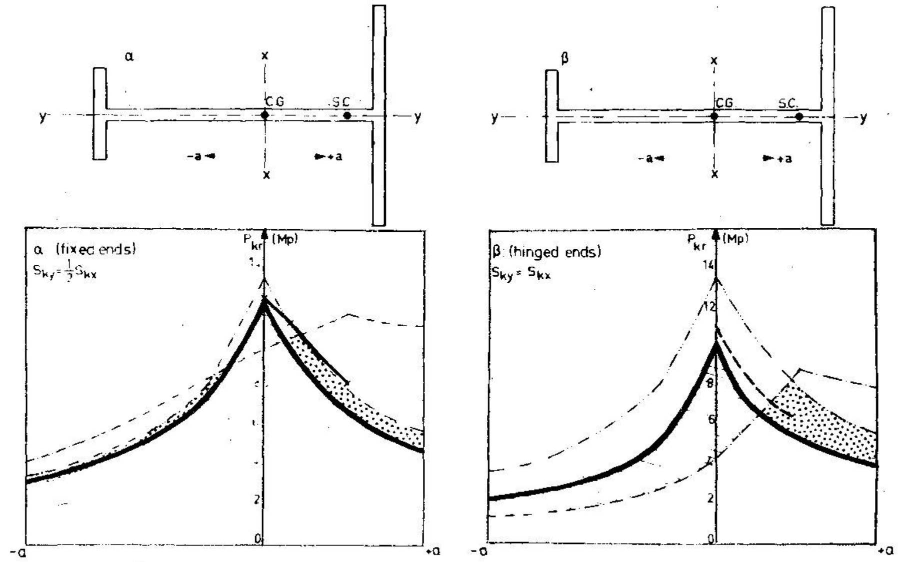
Fig. 6 Load-Deformation-Curves of Aluminium Columns (Ultimat-Loads and Calculated-Forces)

to the "formulae" (in figure 3) and with the results according to DIN 4114 and they recommend these formulae as most realistic and accurate! At any rate they are very useful(for



P_y : Buckling load (Formula Karlsruhe)
P_{krx}: Flexural buckling load
$P_{kry,T}$: Torsional flexural buckling load
} Theoretical exact values

Fig.7 Qualitative buckling load plots according to Formula Karlsruhe and theoretical values



Torsional flexural buckling loads
—— Test results
▬▬ Calculated buckling load (Formula Karlsruhe)
–··– Calculated flexural buckling load
– – – Calculated torsional flexural buckling load
(German Standard DIN 4114)

Fig. 8 Comparison of test results with buckling loads due to Formula Karlruhe and German Standard DIN 4114 horizontally supported or) for braced frames; for unbraced frames, and this holds not only for the "Elastic-Design"but also for the "Plastic-Design" (th.i. german "Traglast-Verfahren"), only the "Nonlinear-Theory" can deliver accurate results. In this connection we maintain that the equilibrium must be considered for the displaced system, not only in the simplified plastic configuration but also in the elastic situation.

Figure 6 shows:

1. The collapse results by way of "torsional flexural buckling"!
2. The deformation curves by flexure and also by torsion, indicate clearly the ultimate load - and not the bifurcation load; but all deformations start directly from initial-values (= geometrical imperfections).
3. The limit-loads can be found to a very good approximation by the formulae (fig. 3); on the other hand roughly estimated values for the "allowable strength" (as in the German standard DIN 4114) are not sufficiently accurate. By the tests No. 1 and No. 2 it was shown that (instead of $\nu_K = 2{,}5$) the security-factors were only 1.49 and 1.16 respectively; test No. 3 would have been only 0,84, but here simple stress-calculation $N/F \pm M/W < \text{zul}\,\sigma$ gives protection - but not clearness.

The next series of tests had to clear up the usefulness of the formulae (fig. 3), if the load is piled up within the small area of section between the center of gravity and the shear-center.

The "Classical-Theory" gives us, for this interesting special sphere, the curves of fig. 7; depending on the different effective buckling lenght in the x- or y-direction, and as a function of the load-point. For practical designing each of the lowest side-branches of these curves should be taken as basis.
The formulae (fig. 3) revale and demonstrate a good and safe adaption, although related to the center of gravity of the cross-section. What's more, the "Classical-Theory" would not be applicable in the elastic-plastic-range.

Left in fig. 8 experimental values can be offered; in this figure, by the way, it is the arithmetical values according to the German-Standard-DIN 4114, which are shown, Not only left but also right one can recognize the weakness of the standardized procedure; on the other hand the formulae of fig. 3 describe the reality in a satisfactory manner (Probably, on the left side the ultimate loads would have been some what higher, if as a result of entering the elastic-plastic range, buckling of the flanges had not occured (fig. 9).)

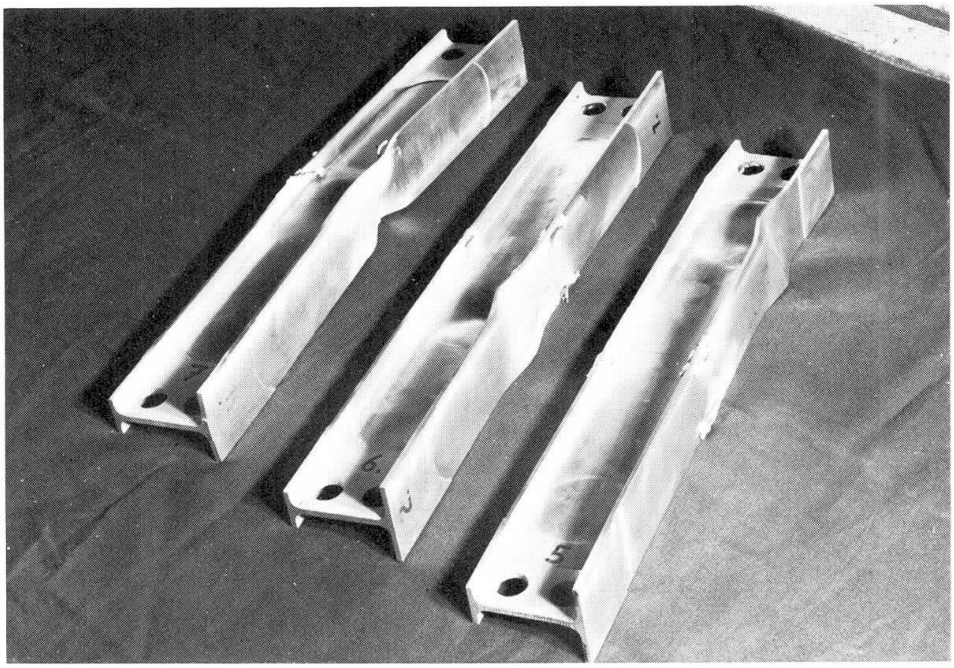


Fig. 9 Specimens after Testing

Summary

In regard to the instability of (single) members in a aluminium-structure (i.e. of columns) - and also of members in frames, loaded in a manner which does not produce transverse displacements at the floor levels -, it seems possible to propose a calculating method (see fig. 3) which covers "overall buckling with excessive bending" as well as the "lateral torsional flexural buckling"; this is valid so far as the cross section of the strut has a I-form and is loaded within the web-plane.

For practise design it seems alternatively possible to use tabulated "ω-values" (for planned-centrical loading) and, as a rough estimate, the "0.9 formula" (DIN 4114) for excentrical loading. -

In both cases knowledge primarily of P_{cr} (that is the bifurcation-load, which is always greater than the stability-limit-load P_S) is an important tool for assessing the strength, also of (braced) systems (see lit. Andelfinger, Der Stahlbau 1964). -

At last the problem of <u>frame-buckling</u> (= general system buckling) with lateral <u>free</u> joints is to be discussed. Here in every case an (elastic) secondary order analysis seems useful (1. Klöppel-Friemann, Der Stahlbau, 1964; 2. H.Rubin, Dissertation, University Karlsruhe, 1971; 3. P. Dubas T.C. 17, Planning and Design of Tall Buildings, S.O.A. Report Nr. 5, 1972). If there are not lateral loads, then initial displacements for the joint levels should be assumed.

In as far as the mentioned (lateral free) frames are only <u>one or two storeys</u> high numerous tabulated values are available for the ideal effective length (S_{ki}); in this connection, the generally known "0.9-formula" (DIN 4114) is indeed being applied, but as regards this important sphere of application investigations are being conducted covering a more realistic and accurate use of the formulae of figure 3.—