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Abstract of Test Report for Research Project

Ultimate Load-Bearing Capacity of Full-Scale Composite Columns

by

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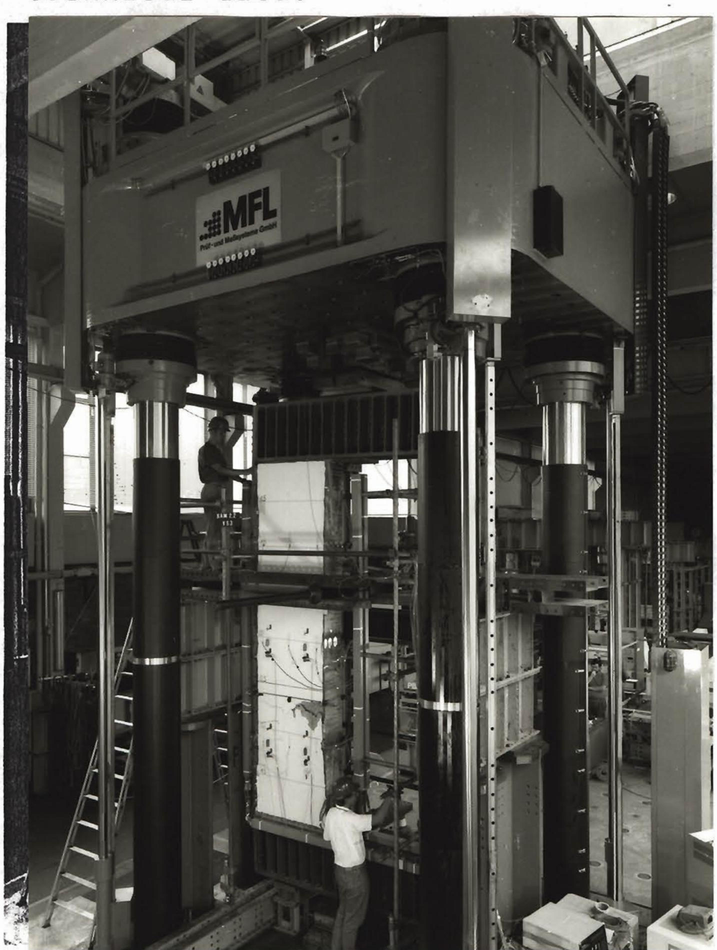
1. Introduction

More than 50 years ago, the Federal Institute for Materials Research and Testing (BAM) carried out first tests on steel-concrete composite columns. In those early days the bearing behaviour of such columns was unknown, while today various test results, calculation models and standards are available and allow the dimensioning of such load-bearing elements. Nowadays, the research projects mainly focus on "fire protection", "high-strength materials" and "special shapes of cross-sections". The Department "Building" of the BAM is engaged in all of the three fields mentioned above.

The research project "Ultimate Load-Bearing Capacity of Full-Scale Composite Columns" focused on the investigation of four test specimens of HE 1000 AA steel sections which were concreted between the flanges. The experimental verification of the ultimate load-bearing capacity of such columns with full-scale cross-sections requires testing units available only at few institutions in the Federal Republic of Germany. Since the beginning of this year, BAM is in possession of such a 25-MN universal testing unit. Figure 1 gives the most important technical data:



Test load:	± 25 MN
Clearance height:	1.60 to 7.00 m
Stroke:	± 200 mm
Frequency:	≤ 2 Hz
Control mechanisms:	load, displacement, strain
Crosshead dimensions:	3.85 m x 4.85 m
Control system:	Schenck
Design and construction:	MFL; Schenk

Figure 1:
The new BAM 25-MN universal testing unit

2. Problem definition and aim of research

Calculation methods for composite columns are laid down in numerous National Standards. In general, these Standards also contain data for composite columns with rolled H-profiles concreted between the flanges which are, however, almost exclusively based on theoretical assumptions. Up to now, only few experimental investigations have been carried out on such columns and tests on full-scale specimens have not been conducted at all. For reasons of comparison it is desirable to have at least some results gained by testing of full-sized specimens. The purpose of the present research project was to clarify by tests of full-scale specimens whether it is possible to make not only correct but also safe predictions for composite columns with rolled H-profiles concreted between the flanges by using the method outlined in DIN 18 806, part 1, "Composite columns".

3. Dimensions

3 columns with bending about the major axis and 1 column with bending about the minor axis were tested. The M/N-interaction diagrams (Figure 2) show the load combination at which failure of the specimens was intended to take place.

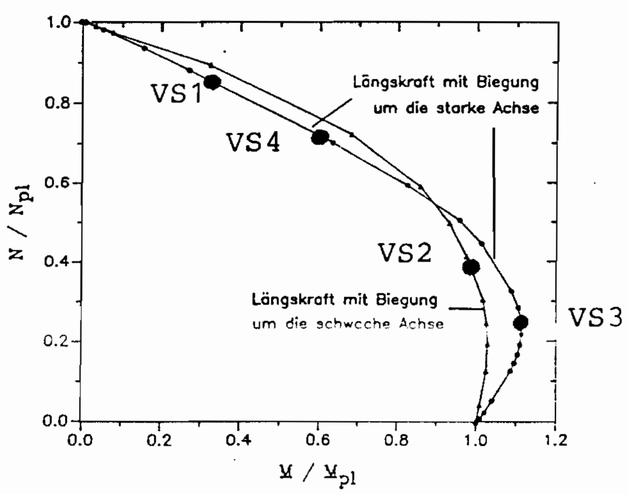
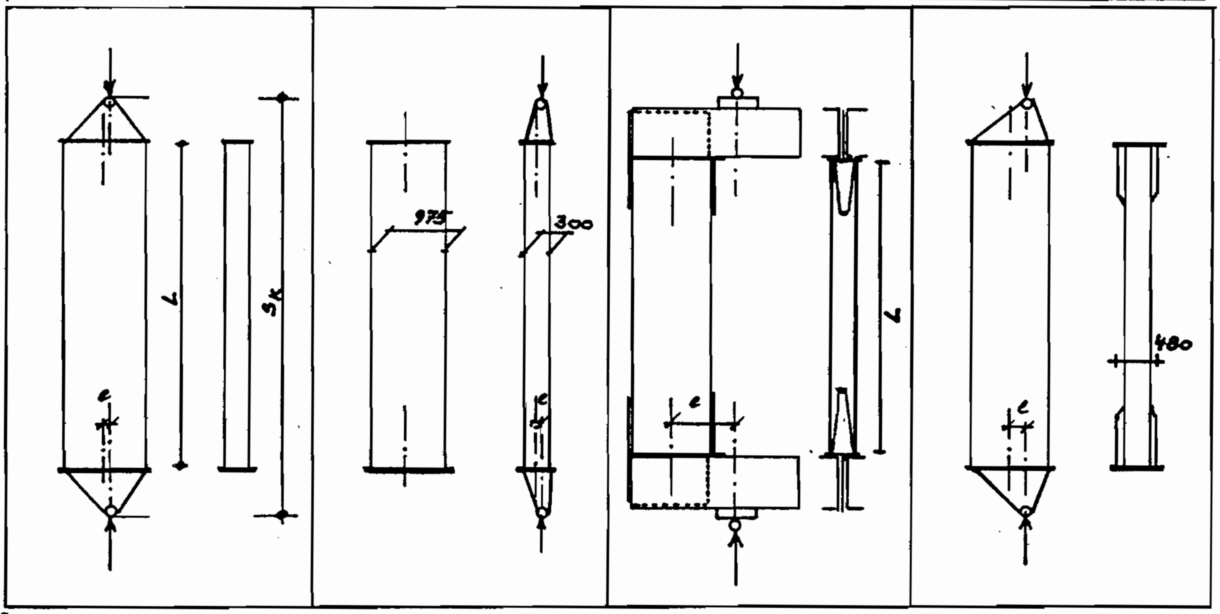


Figure 2: Interaction diagrams for longitudinal load with bending about the major and minor axis

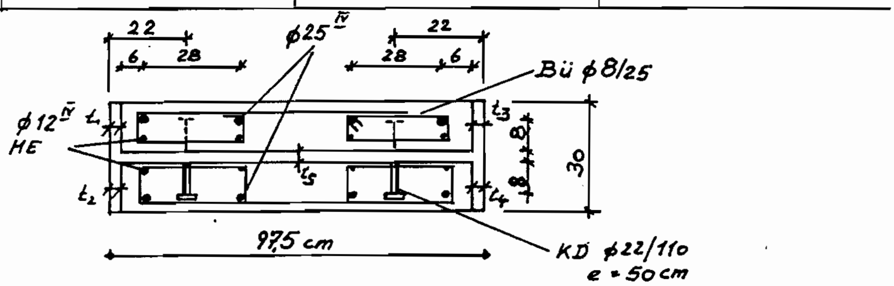
The dimensions, cross-sectional values and determined material parameters are given in Figure 3.

VS1	VS2	VS3	VS4
major axis e = 80 mm	minor axis e = 30 mm	major axis e = 800 mm	major axis e = 160 mm



	VS1	VS2	VS3	VS4
l	= 4,32 m	4,32 m	3,84 m	4,32 m
s_k	= 5,45 m	5,45 m	5,55 m	5,45 m

t_5 = 17,1 mm
t_1 = 21,3 mm
t_2 = 21,5 mm
t_3 = 23,0 mm
t_4 = 21,1 mm



Concrete:			
β_p = 43.6 N/mm²	44.0 N/mm²	43.8 N/mm²	42.2 N/mm²

Steel:
Reinforcing steel: β_S = 611 N/mm²;
Rolled steel section: β_S web = 287 N/mm², β_S flange = 269 N/mm²

Figure 3: Dimensions and material parameters of specimens VS1 to VS4

Except for specimen VS3, it was possible to accomplish load eccentricity by an eccentric arrangement of the column support. In order to apply load to VS3, cantilevers were bolted onto the extended web. Steel butt straps, which were attached by welding, transferred the girder tensile forces. The compression girder was reinforced in the load application area, too.

The reinforcements added to the head and base point of VS4 seemed advisable, especially after failure in the load application area of VS1 had already taken place before the theoretical ultimate load-bearing capacity was reached. However, the particular problems arising due to load application were not the actual subject-matter of this research study.

4. Test performance

The test performance was always carried out according to the following procedure:

- step-wise load increase until the service load F_G was reached - 1000 load cycles with 0.15 Hz and $0.4 \cdot F_G \leq F \leq 0.8 \cdot F_G$	load controlled
- step-wise load increase until failure	displacement controlled

After each loading step the load was kept constant for 2 minutes and then, at constant deformation, the measurements were carried out.

5. Measurement performance

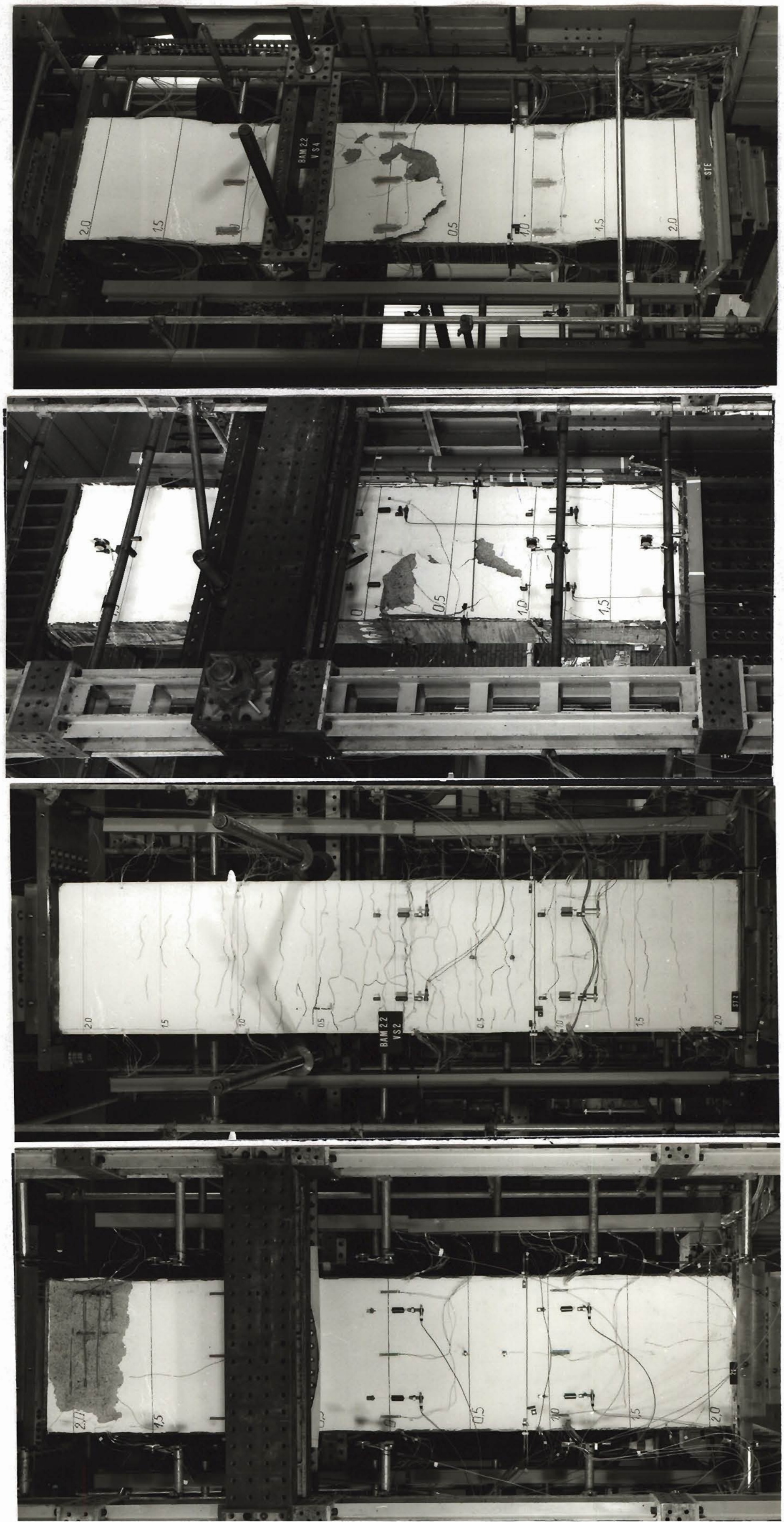
During the tests the following measurements were taken and recorded by means of a multi-channel measuring unit:

a) load and displacement of testing unit
b) horizontal displacement of the column at 5 levels with rotary potentiometers
c) rotation of the support with inductive gauges
d) strains at 5 levels with strain gauges: at the steel section
   at the longitudinal reinforcement
   on the concrete surface
e) deformations of the column cross-section in transvers direction (e.g. relative displacement girder-concrete) with inductive gauges

6. Test results

6.1 Ultimate loads and damage patterns of failure

Figure 4 gives a survey of the ultimate loads and the maximum horizontal displacements and shows a photography of each of the four columns.



VS1, major axis
e = 80 mm
failure of load application at head

failure load F_u=15.4 MN
corresp. displacement

VS2, minor axis
e = 30 mm
concrete compression failure in column centre
(back view)
F_u = 9.47 MN
w_x = 45 mm

VS3, major axis
e = 800 mm
concrete compression failure in medium third

F_u = 5.2 MN
w_y = 30 mm

VS4, major axis
e = 160 mm
concrete compression failure in column centre

F_u = 14.8 MN
w_y = 10 mm

6.2 Strains in the centre of the column

The strain distribution in the column centre at each loading stage can be determined by means of attached strain gauges. The measured values thus received serve as basis for a linear regression analysis, the results of which deliver information used to determine the strain gradient of the column. Figure 5 shows the single measurement values of column VS3 as well as the regression line of some load steps.

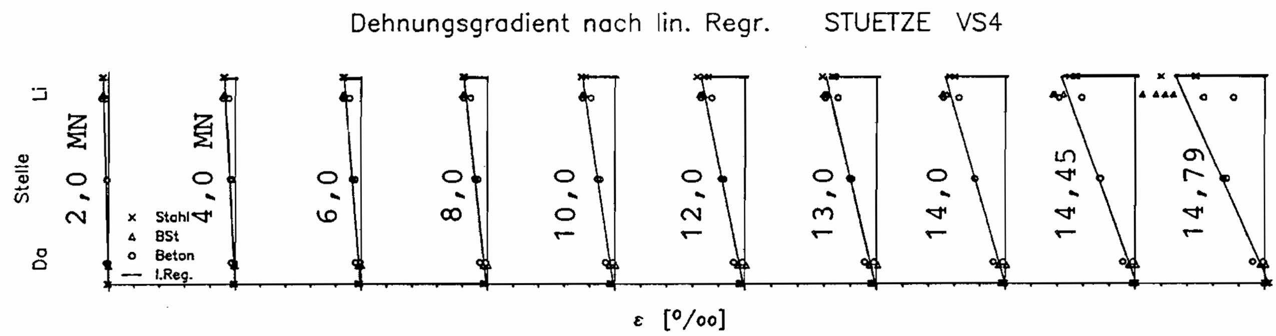


Figure 5: Strains in column centre at different load steps

The strains at the edges of the composite column cross-sections can be given in a load-strain diagram, see Figure 6.

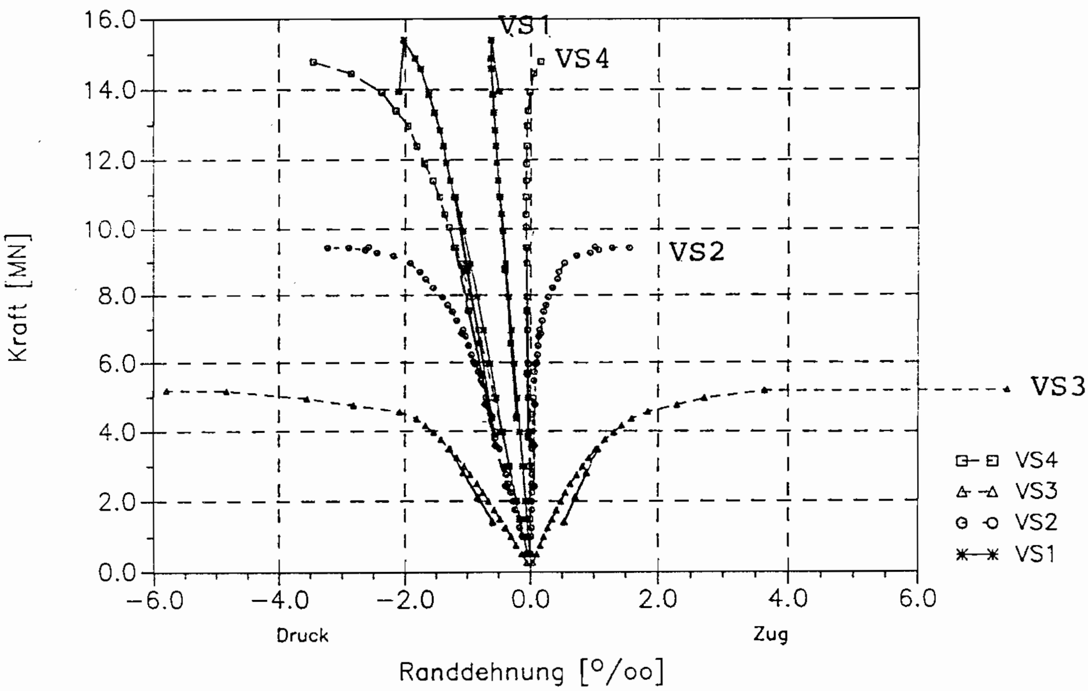


Figure 6: Strains at the outer fibres [o/oo]

7. Comparison with calculations according to DIN 18 806, part 1

The following two approaches are investigated:

a) local: Is the measurement point (M_{test}/N_{test}) located on the interaction curve? If this is the case, this confirms that the preconditions assumed for the MN-interaction diagrams correspond to those actually existing.

b) global: Does DIN 18 806 give results which are on the safe side as far as the influences according to the 2nd order theory are concerned?

To a)

As the concrete strengths of the single columns differed only slightly at the time of the test performance it was possible to enter the test results of columns VS1, VS3 and VS4 in the same diagram.

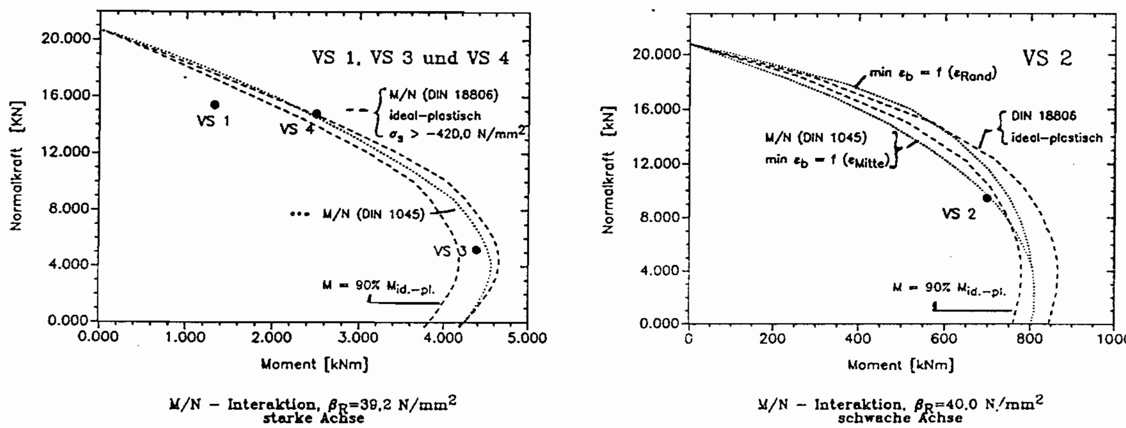


Figure 7: M/N-diagrams for bending about the major and minor axis

The curves given in Figure 7 differ as follows:

Curve a: M/N-interaction diagram based on data given in DIN 18 806; ideal plastic material behaviour.

Curve b: according to DIN 18 806 the bending moments determined by curve a have to be reduced by 10 % to make allowance for the real material behaviour.

Curve c: M/N-interaction diagram according to DIN 1045, i.e. the cross-section is regarded as an ordinary reinforced concrete element.

Curve d: assumption: each concrete column between the flanges is regarded as a single column and is not allowed to exceed the concrete boundary strains given in DIN 1045.

In addition to the determined dimensions of the cross-sectional areas the following material parameters were applied:

- design strength of concrete

  $\beta_R = 0.9 \cdot \beta_P = 39.2\ N/mm^2$ and $40.0\ N/mm^2$ resp.

- yield point of reinforcing steel

  $\beta_{S,s} = 611\ N/mm^2$ and $-420\ N/mm^2$ resp.

- yield point of rolled steel sections

  $\beta_{S,web} = 286\ N/mm^2;\ \beta_{S,girder} = 269\ N/mm^2$

Apart from the results obtained for VS1, which cannot be used here due to the fact that failure already took place before the theoretical ultimate load was reached, the theoretical ultimate loads of the 3 other columns are in good agreement with the ultimate loads determined by experiments.

To b)

If a modulus of elasticity of the concrete of $E_b = 500\ \beta_{WN} = 21\ 000\ N/mm^2$ is taken into account the following characteristic values result according to DIN 18 806, part 1:

cross-sectional parameter $\delta = \frac{N_{pl,a}}{N_{pl}} = \frac{8262}{20780} = 0.40$

slenderness ratio $\bar{\lambda}_1 = \sqrt{\frac{N_{pl}}{N_{Ki}}}$

major axis $\bar{\lambda}_1 = \sqrt{\frac{20.8}{463}} = 0.21 \rightarrow \varkappa \approx 1.0 \quad N_{Kr} = \varkappa \cdot N_{pl} = 20.8\ MN$

minor axis $\bar{\lambda}_2 = \sqrt{\frac{20.8}{23.7}} = 0.94 \quad \varkappa = 0.578 \quad N_{Kr} = \varkappa \cdot N_{pl} = 12.0\ MN$

The simplified dimensioning method given in DIN 18 806, part 1, as well as the standard dimensioning method deliver results for the 3 columns VS2 to VS4 which are on the safe side. The results of VS1 cannot be included due to the above mentioned failure in the load application area.

8. Summary

By means of 4 full-scale composite columns with rolled H-profiles which were concreted between the flanges tests were to be carried out in order to investigate whether the dimensioning suggestions given in DIN 18 806, part 1, are correct as far as the behaviour of such composite structures under failure is concerned. The test results show that the theoretical and the experimentally determined ultimate load-bearing capacity are in good agreement. The tests thus demonstrate that the dimensioning specifications based on theoretical assumptions give the actual bearing behaviour of composite columns with good approximation. However, further research is required especially in the field of the load application areas of such columns.

9. Acknowledgement

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