SOFiSTiK

Benchmark Example No. 46

Material Nonlinear Analysis of Reinforced Concrete Beam

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VERiFiCATiON
BE46 Material Nonlinear Analysis of Reinforced Concrete Beam

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Front Cover

6th Street Viaduct, Los Angeles Photo: Tobias Petschke

Overview	
Element Type(s):	B3D, SH3D
Analysis Type(s):	STAT, MNL
Procedure(s):	
Topic(s):	
Module(s):	STAR2, ASE
Input file(s):	nonl_rein_conc.dat

1 Problem Description

The problem consists of a single span beam of reinforced concrete, subjected to a single load P in the middle of the span, as shown in Fig. 1. The material nonlinear behaviour of the beam is examined and compared to test results.

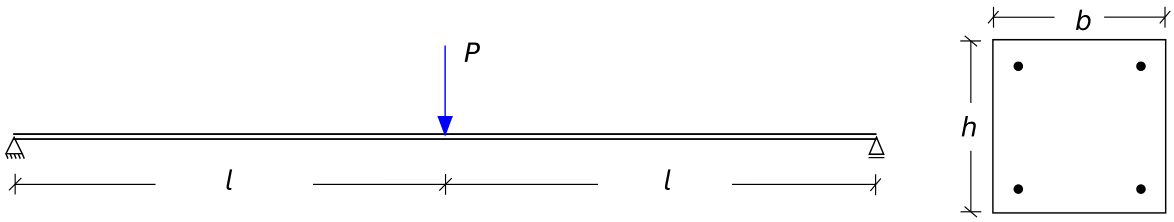

Figure 1: Problem Description

2 Reference Solution

Materially nonlinear analysis is utilised more and more for the structural design in concrete construction. It is often overlooked that for such analysis, both in-depth knowledge of the computational algorithms as well as the behavior of the concrete in cracked condition, are required. The following simple example will serve for verification of material nonlinear calculations of reinforced concrete beams. It will also highlight the unavoidable variations in practice. Therefore, the individual test results are given below and not only the mean values. The load-displacement curves of seven identical concrete beams, which were prefabricated almost at the same time and under the same controlled conditions, are graphed below. As a reference solution, these load-displacement curves of the test beams are used.

3 Model and Results

The properties of the model [1] are defined in Table 1. The simply supported beam is shown in Fig. 1, as well as the dimensions and the reinforcement of the beams. The total length of the span is $l_{total} = 3.0\ m$. The square rectangular cross-section with edge lengths of $20\ cm$ is reinforced by four longitudinal bars of $\oslash\ 10\ mm$ and stirrups of $\oslash\ 6\text{-}15\ cm$. For this example the stirrups are not influential and can be neglected. The load is applied at the midspan and the beam is loaded to failure. Self weight is accounted for. The material properties of the concrete, $B\ 35$ or equivalently a $C\ 35$, were determined on a total of twelve cylinders $\oslash\ 150/300$, and are given in Table 1. The concrete cover of the longitudinal reinforcement is $c_{v,l} = 2.4\ cm$. The reinforcing steel is a $BST\ 500\ S$, following a stress-strain law, as shown in Fig. 2.
The results are presented in Fig. 4. The deflection in the middlespan is recorded and plotted versus the load. The expectance is for the numerical calculations to fall into the gray shaded area, which bounds the curves of seven tests beams. Of particular importance, are the onset of cracking, the slope after the completion of the cracking and by the yielding of the reinforcement, as well as the limit load.
SOFiSTiK results are presented by the three additional curves included in the original figure.

For beam elements: (a) yellow color with triangles for concrete C 35, (b) red color with circles for concrete B 35. For quad elements: (c) green color with squares for concrete C 35.

Strain mm/m	Stress N/mm²
0.00	0.0
1.07	213.0
2.00	395.9
3.04	517.0
4.04	539.4
5.00	551.7
6.10	560.9
7.10	566.2
10.07	574.9
20.01	589.4
40.09	604.1
50.06	605.6
55.05	604.4
58.19	512.2

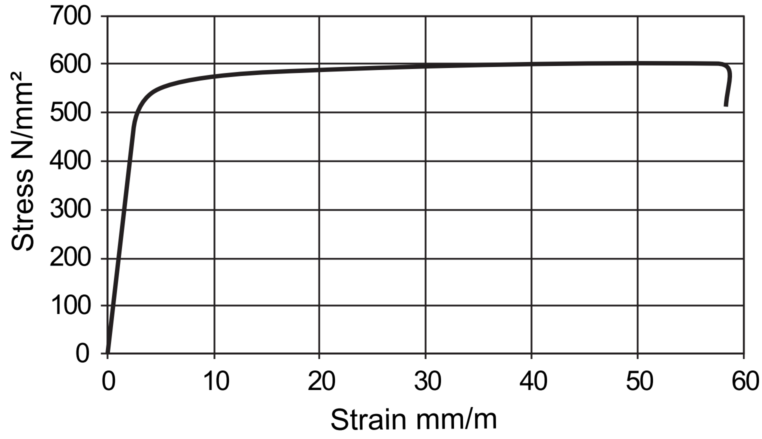

Figure 2: Stress-Strain Curve for Reinforcing Steel

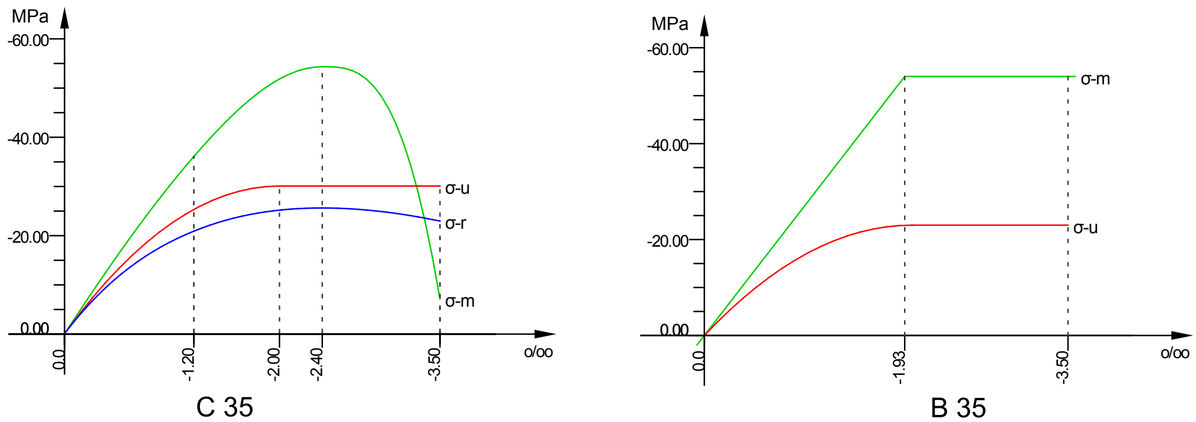

Figure 3: Stress-Strain Curve for Concrete

Table 1: Model Properties

Material Properties		Geometric Properties	Loading
Concrete	Steel	$b = h = 20.0\ cm$	$P = 1\ kN$
B 35 or C 35	$BST\ 500S$	$l = 3.0\ m$	until failure
$\rho = 2320\ kg/m^3$		$c_{v,l} = 2.4\ cm$	
$f_{cm} = 54.0\ MN/m^2$		4 bars ⌀ $10\ mm$	
$E = 28000\ MN/m^2$			

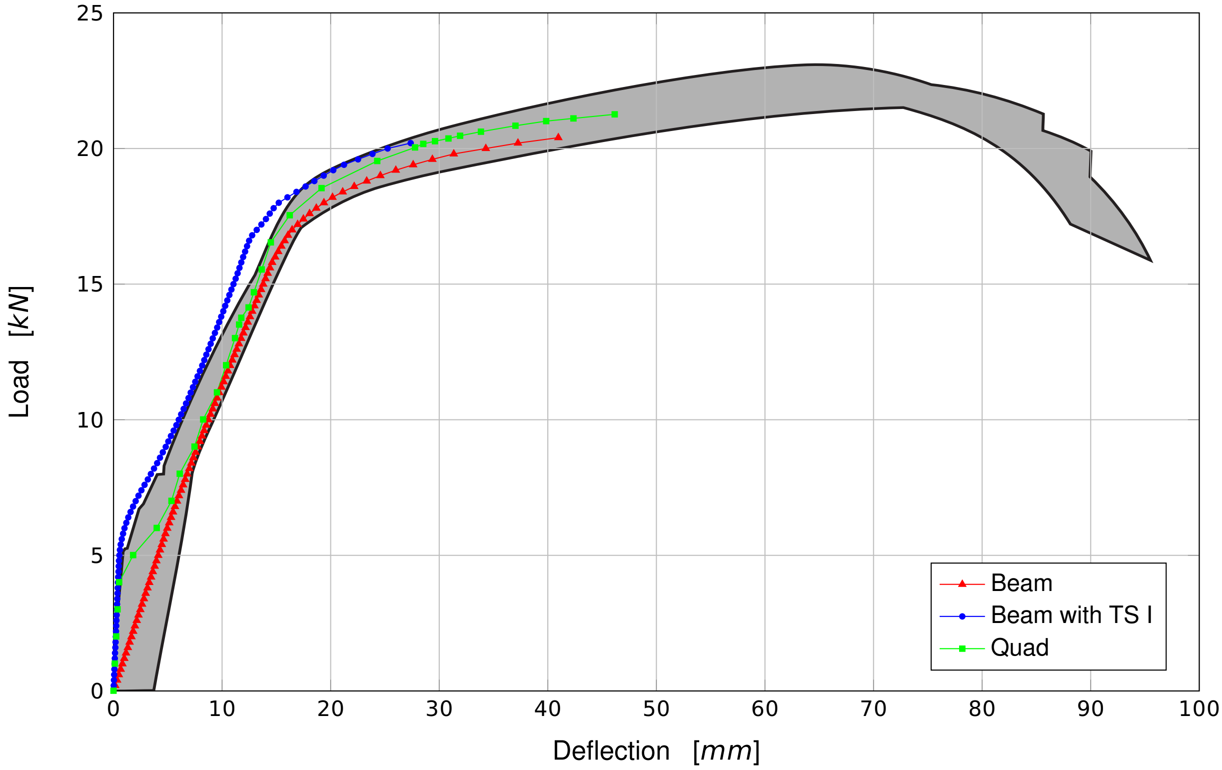

Figure 4: Load-Displacement Curves

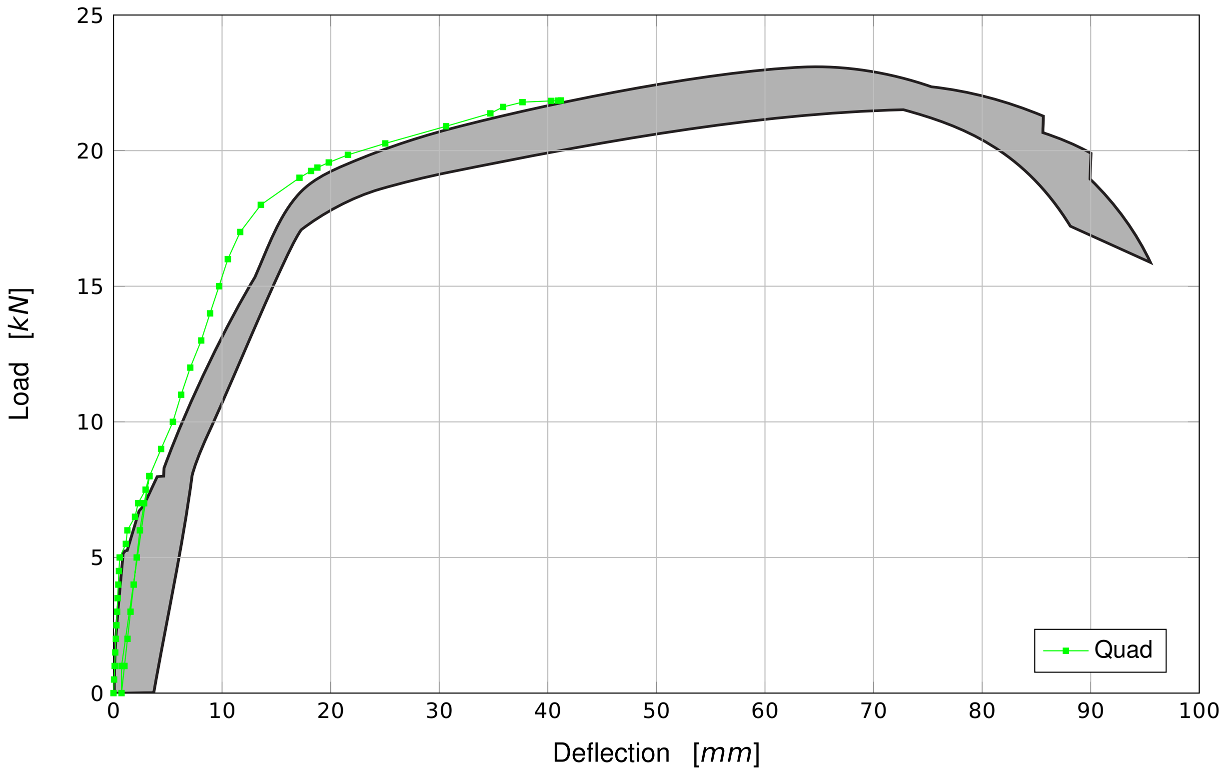

Figure 5: Load-Displacement Curves with reloading

4 Conclusion

This example examines the material nonlinear analysis of reinforced concrete beams. It has been shown that the behaviour is captured accurately.

5 Literature

[1] *VDI 6201 Beispiel: Softwaregestütze Tragwerksberechnung - Beispiel Stofflich nichtlineare Berechnung von Stahlbetonbalken, Kategorie 1: Mechanische Grundlagen*. Verein Deutscher Ingenieure e. V.