



Benchmark Example No. 4

## Tie Rod with Lateral Loading

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**VERiFiCATION**  
**BE4 Tie Rod with Lateral Loading**

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**SOFiSTiK AG**

HQ Nuremberg  
Flataustraße 14  
90411 Nürnberg  
Germany

T +49 (0)911 39901-0  
F +49(0)911 397904

Office Garching  
Parkring 2  
85748 Garching bei München  
Germany

T +49 (0)89 315878-0  
F +49 (0)89 315878-23

[info@sofistik.com](mailto:info@sofistik.com)  
[www.sofistik.com](http://www.sofistik.com)

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The manual and the program have been thoroughly checked for errors. However, SOFiSTiK does not claim that either one is completely error free. Errors and omissions are corrected as soon as they are detected.

The user of the program is solely responsible for the applications. We strongly encourage the user to test the correctness of all calculations at least by random sampling.

**Front Cover**

Volkstheater, Munich Photo: Florian Schreiber

## Overview

**Element Type(s):** B3D  
**Analysis Type(s):** STAT, GNL  
**Procedure(s):**  
**Topic(s):**  
**Module(s):** ASE  
**Input file(s):** [tie\\_rod.dat](#)

## 1 Problem Description

A tie rod is subjected to the action of a tensile force  $N$  and a lateral load  $P$  applied at the middle as shown in Fig. (1). Determine the maximum deflection  $\delta_{max}$ , the slope  $\theta$  at the left-hand end and the maximum bending moment  $M_{max}$ . In addition, compare these three quantities for the case of the unstiffened tie rod ( $N = 0$ ).

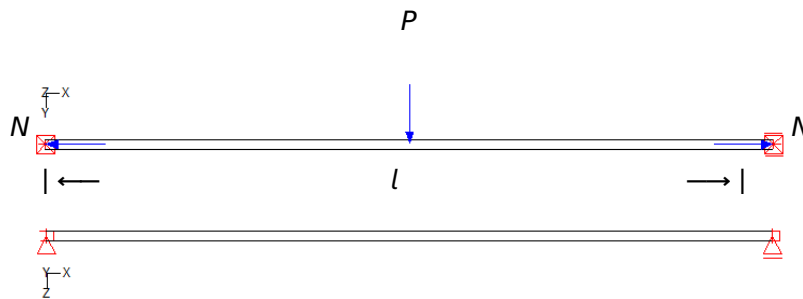


Figure 1: Tie Rod

## 2 Reference Solution

The combination of direct axial force and lateral load applied at a beam influences the reaction of the structure. Assuming that the lateral force acts in one of the principal planes of the beam and that the axial force is centrally applied by two equal and opposite forces, the expressions for the deflections can be derived from the differential equations of the deflection curve of the beam [1]. Under tension, the maximum deflections of a laterally loaded beam decrease whereas under compression they increase. The moments of the structure are influenced accordingly.

For the simple problem of a beam with hinged ends, loaded by a single force  $P$  at the middle, the maximum deflection at the middle is:

$$\delta_{max} = \frac{Pl^3}{48EI}, \quad (1)$$

where  $l$  is the length of the beam and  $EI$  its flexural rigidity. The slope  $\theta$  at both ends is:

$$\theta = \pm \frac{Pl^2}{16EI}. \quad (2)$$

The maximum value of the bending moment at the middle is:

$$M_{max} = \frac{Pl}{4}. \quad (3)$$

When now the structure (Fig. 1) is submitted to the action of tensile forces  $N$  in addition to the initial lateral load  $P$ , the deflection at the middle becomes [1]:

$$\delta_{max} = \frac{Pl^3}{48EI} \cdot \frac{u - \tanh u}{\frac{1}{3}u^3}, \quad (4)$$

where  $u^2 = Nl^2/4EI$ . The first factor in Eq. (4) represents the deflection produced by the lateral load  $P$  acting alone. The second factor indicates in what proportion the deflection produced by  $P$  is magnified by the axial tensile force  $N$ , respectively. When  $N$  is small, it approaches unity, which indicates that under this condition the effect on the deflection of the axial force is negligible. The expressions for the moment and the slopes can be derived accordingly [1].

### 3 Model and Results

The properties of the model are defined in Table 1 and the results are presented in Table 2. Fig. 2 shows the deformed structure under tension and lateral loading.

Table 1: Model Properties

Material Properties	Geometric Properties	Loading
$E = 30000 \text{ MPa}$	$l = 2 \text{ m}$	$P = 0.1 \text{ kN}$
	$h = 30 \text{ mm}$	$N = 0.1 \text{ kN}$
	$b = 30 \text{ mm}$	
	$I = 6.75 \times 10^{-8} \text{ m}^4$	

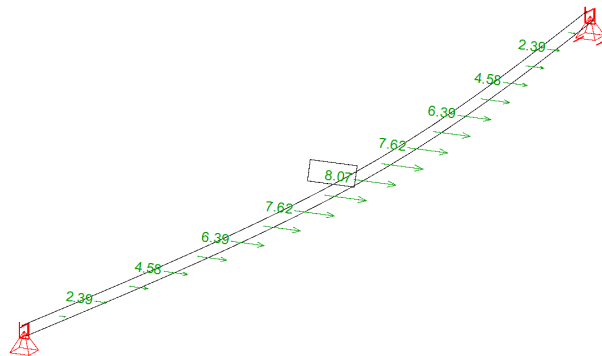


Figure 2: Deformed Structure [mm]:  $N \neq 0$

Table 2: Results

	$N = 0$	Ref.	$N \neq 0$	Ref.
$\delta_{max} [m]$	0.00823	0.00823	0.00807	0.00807
$M_{max} [kNm]$	0.05000	0.05000	0.04919	0.04919
$\theta [rad]$	0.01235	0.01235	0.01210	0.01210

## 4 Conclusion

This example presents the influence of axial forces applied at a laterally loaded beam. The case of a tie rod is examined and the maximum deflections and moment are derived. It has been shown that the behaviour of a beam under the combination of direct axial force and lateral load can be adequately captured.

## 5 Literature

- [1] S. Timoshenko. *Strength of Materials, Part II, Advanced Theory and Problems*. 2nd. D. Van Nostrand Co., Inc., 1940.