TRANSPORT PROBLEMS 2011
PROBLEMY TRANSPORTU Volume 6 Issue 1

stabilizer bars, calculation, model

Adam-Markus WITTEK*, Hans-Christian RICHTER
ThyssenKrupp Bilstein Suspension GmbH
Oeger St. 85, 58095 Hagen, Germany
Bogusław ŁAZARZ
Silesian University of Technology, Faculty of Transport
Krasińskiego St. 8, 40-019 Katowice, Poland
**Corresponding author*. E-mail: adam.wittek@thyssenkrupp.com

STABILIZER BARS: Part 2. CALCULATIONS - EXAMPLE

Summary. The article contains the further outline of the calculation methods for stabilizer bars. Modern technological and structural solutions in contemporary cars are reflected also in the construction and manufacture of stabilizer bars. A proper construction and the selection of parameters influence the strength properties, the weight, durability and reliability as well as the selection of an appropriate production method.

STABILIZATORY SAMOCHODOWE: Część 2. OBLICZENIA - PRZYKŁAD

Streszczenie. W artykule przedstawiono dalszą część zarysu metod obliczeniowych stabilizatorów samochodowych. Nowoczesne rozwiązania technologiczno–konstrukcyjne we współczesnych samochodach znajdują również odzwierciedlenie w konstrukcji i produkcji stabilizatorów. Prawidłowa konstrukcja i dobór parametrów mają wpływ na cechy wytrzymałościowe, ciężar, trwałość oraz niezawodność jak i wybór właściwej metody produkcyjnej.

1. INTRODUCTION

The stabilizer bars in vehicles have the following functions:

1. Pure rolling motion (cornering) without stimulating the wheels. The reduction of rolling motion during cornering is achieved that way.
2. Stimulation of the wheels in the same direction.
   The secondary spring rates occurring in practice in the bearings lead to stiffening of the body suspension (mechanical parallel connection of secondary spring rate and body rigidity)
3. One-sided stimulation.
   Due to the stabilizer bar occurs one-sided stiffening of the body (comfort deterioration). Additionally, the stabilizer bar strengthens the waddling motion of the body (waddling: rolling caused by the road surface).

One of the most important criteria when calculating a stabilizer bar (function test) is the spring rate of the stabilizer bar – the stabilizer bar rate. The stabilizer bar rate results from the sum of deflections at the ends (axle articulation) and the stabilizer bar force. Only the vertical portions of the displacement and the force are considered. The rate is stated in the N/mm unit.

2. CALCULATION OF THE STABILIZER BAR RATE

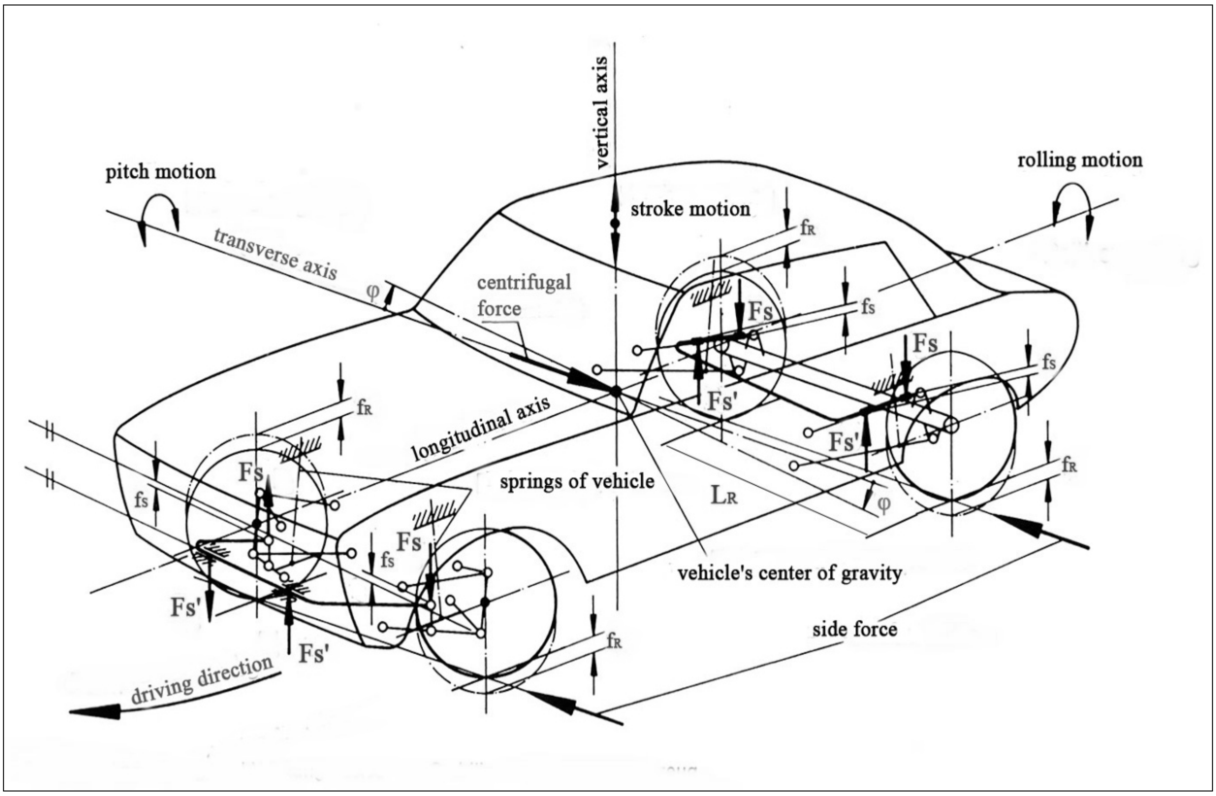


Fig. 1. Arrangement and principle of operation of stabilizer bars in a motor vehicle
Rys. 1. Rozwiązania i funkcje stabilizatorów w pojazdach samochodowych

In case of the calculation of cornering ability, the transmission ratios i_F and i_S from wheel to spring or stabilizer bar are specified [1]. They are understood as quotients from the spring travel of the wheel and from the spring or stabilizer bar end [1, 10]:

$$i_F = \frac{f_R}{f_F} \quad \text{and} \quad i_S = \frac{f_R}{f_S} \tag{1}$$

Whereas the forces are transmitted in the reversed ratio as compared to the travels from wheel to spring or to stabilizer bar, i_F and i_S are adopted square in the transmission ratio of the spring or stabilizer bar rate which are indeed quotients from force and spring travel:

$$c_{FR} = \frac{c_F}{i_F^2} \quad \text{and} \quad c_{SR} = \frac{c_S}{i_S^2} \tag{2}$$

The stresses σ and τ in the stabilizer bar can be calculated with the given dimensions as a function of forces F acting on the arm ends:

$$F_s = c_S f_S = c_S \frac{f_R}{i_S} = c_{SR} i_S f_R = \frac{1}{2} c_S \frac{L_R}{i_s} \varphi = \frac{1}{2} c_{SR} i_S L_R \varphi \quad [\text{N}] \tag{3}$$

Characterizing feature of the typical stabilizer bar (fig. 2) is the double mounting of its back on the vehicle frame or body, or on the axle or the wheel suspension arms, respectively, and fastening of its arm ends on the axle or the wheel suspension arms, or on the vehicle frame or body, respectively. These stabilizer bars can be designed for all wheel suspensions.

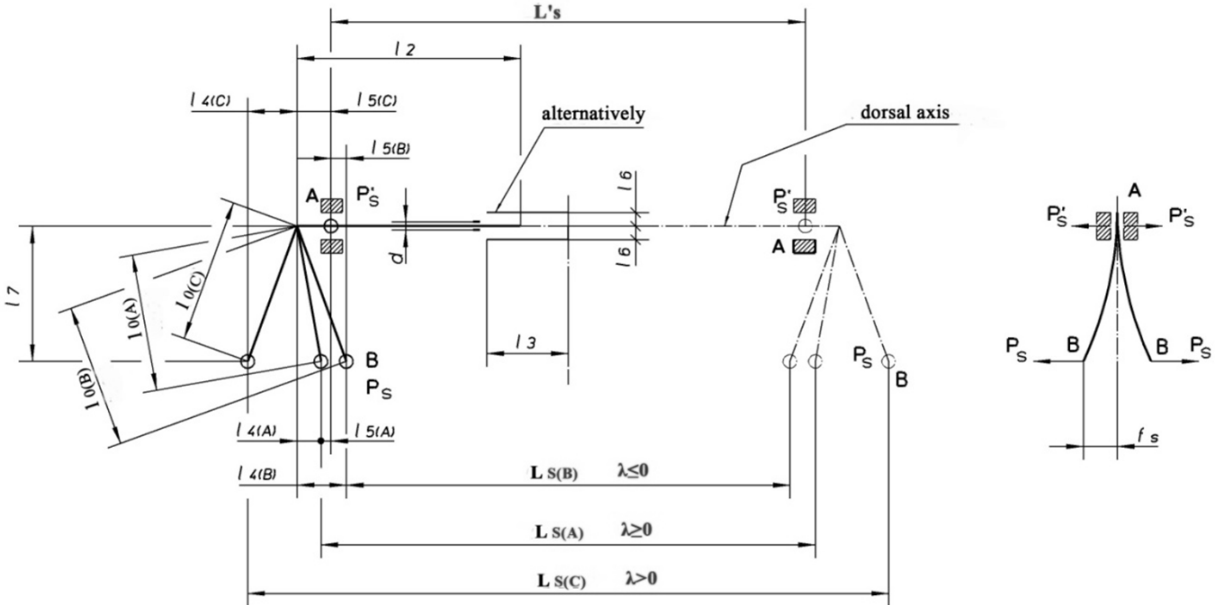


Fig. 2. Equivalent system for stabilizer bar calculation
Rys. 2. Model zastępczy – obliczeniowy stabilizatora

$$\lambda = \frac{L_S}{L'_S} - 1 \tag{4}$$

$$c_S = \frac{F_S}{f_S} = \frac{3E\pi d^4}{32\left\{2kl^3{}_0 + l^2{}_5 L_S \pm 2l^3{}_4 + 3\frac{E}{G}\left[l_2 + l^2{}_7 + l_3(l_7 \pm \lambda l_6)^2\right]\right\}} \tag{5}$$

With the given longitudinal dimensions, the bar diameter may be calculated [1, 7, 8, 10]:

$$d = 2\sqrt[4]{\frac{2c_s}{3E\pi}\left\{2kl^3{}_0 + l^2{}_5 L_S \pm 2l^3{}_4 + 3\frac{E}{G}\left[l_2 + l^2{}_7 + l_3(l_7 \pm \lambda l_6)^2\right]\right\}} \tag{6}$$

where $k = 1$ for U–shaped, full–length round stabilizer bar (constant diameter)

Calculation of a stabilizer bar with circular cross–section and pure torsional strain [5–10]:

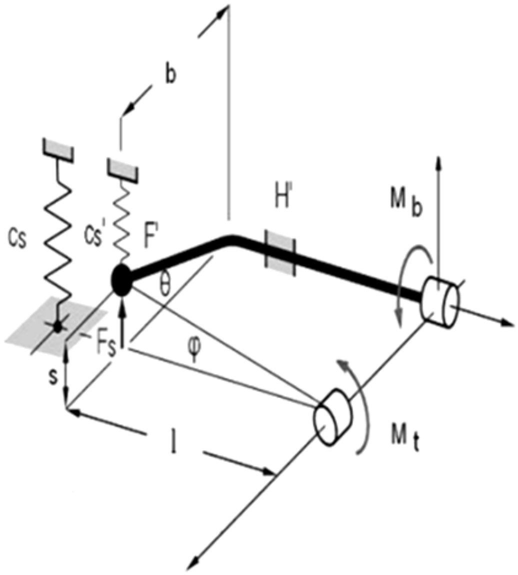


Fig. 3. Equivalent system for stabilizer bar calculation
Rys. 3. Model obliczeniowy stabilizatora

Twisting moment of the stabilizer bar:

$$M_t = \frac{\varphi G}{l} I_p \qquad \text{[MPa]} \qquad (7)$$

where

$$I_p = \frac{\pi d^4}{32}, \qquad \varphi = \frac{M_t l}{G I_p} = \frac{32 M_t l}{\pi G d^4} \qquad [°] \qquad (8)$$

$$\tau = \frac{M_t}{W_p} = \frac{16 M_t}{\pi d^3} \qquad \text{[MPa]} \qquad (9)$$

The stabilizer bar rate is then:

$$c_\varphi = \frac{M}{\varphi} = \frac{G I_p}{l} = \frac{\pi G d^4}{32 l} \qquad \text{[N/mm]} \qquad (10)$$

3. INFLUENCE OF THE FLEXIBLE STABILIZER BAR BEARING

Each stabilizer bar has either four or, when the longitudinal displaceability of the back or the arm ends over connecting links is achieved, six bearing surfaces which in general are flexible and as a result reduce the stabilizer bar rate. The extent of this bearing–related rate decrease depends, apart from the flexible bearing surfaces, also on their position on the stabilizer bar as well as the shore hardness and the volume of bearing material used [1, 11]. Back bearing – function and requirements:

- connection / fixing of the stabilizer bar to the vehicle body,
- transmission of forces and moments,
- Realization of the degree of torsional freedom
  - frictionless/low–friction,
  - generation of a defined twisting rigidity (secondary spring rate),
- Axial protection during shear force transmission.

Considering that the resilient rubber bearings are connected in series with the stabilizer bar, the calculation of the rate of complete system and consequently of the stabilizer bar with resilient rubber bearing gives [1, 7, 8, 10]:

$$\frac{1}{C_{SG}} = \frac{f_{SG}}{F_S} = \frac{1}{C_S} + \left(\frac{L_S}{L'_S}\right)^2 \left(\frac{1}{C_{GA1}} + \frac{1}{C_{GA2}}\right) + \frac{1}{C_{GB1}} + \frac{1}{C_{GB2}} \qquad (11)$$

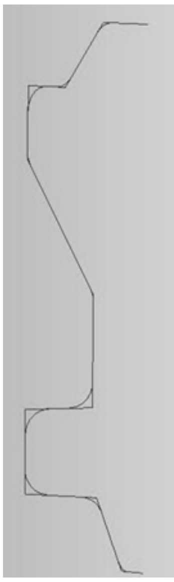
4. STRENGTH TEST AND FUNCTION TEST (EXAMPLE)

4.1. Drawings and general design data

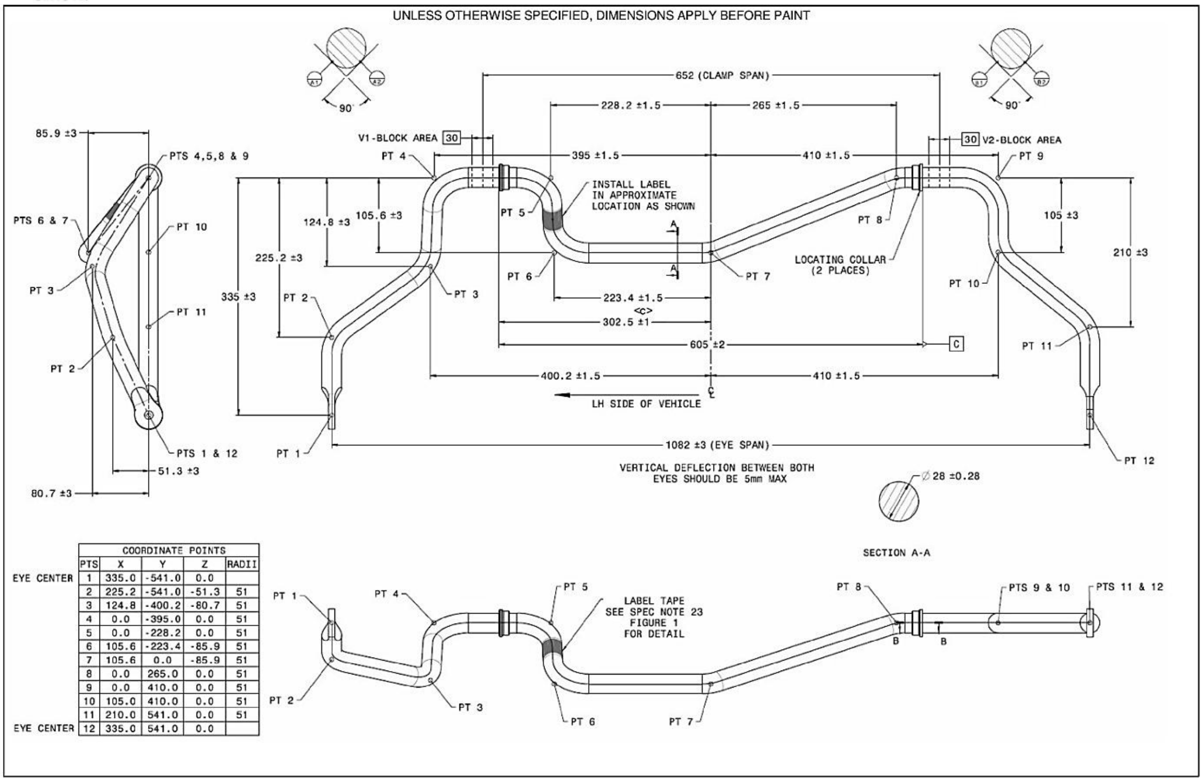
Table 1

stabilizer geometry (points of intersection)

point [-]	X [mm]	Y [mm]	Z [mm]	radius [mm]
1	335,000	-541,000	0,000	
2	225,000	-541,000	-51,300	51,000
3	124,800	-400,200	-80,700	51,000
4	0,000	-395,000	0,000	51,000
5	0,000	-228,200	0,000	51,000
6	105,600	-223,400	-85,900	51,000
7	105,600	0,000	-85,900	51,000
8	0,000	265,000	0,000	51,000
9	0,000	410,000	0,000	51,000
10	105,000	410,000	0,000	51,000
11	210,000	541,000	0,000	51,000
12	335,000	541,000	0,000	



Bar geometry:
bar diameter d [mm]: 28.000
lenght [mm]: 1711.490



	COORDINATE POINTS				
	PTS	X	Y	Z	RADII
EYE CENTER	1	335.0	-541.0	0.0	
	2	225.2	-541.0	-51.3	51
	3	124.8	-400.2	-80.7	51
	4	0.0	-395.0	0.0	51
	5	0.0	-228.2	0.0	51
	6	105.6	-223.4	-85.9	51
	7	105.6	0.0	-85.9	51
	8	0.0	265.0	0.0	51
	9	0.0	410.0	0.0	51
	10	105.0	410.0	0.0	51
	11	210.0	541.0	0.0	51
EYE CENTER	12	335.0	541.0	0.0	

Fig. 4. Stabilizer bar / production drawing / bar geometry
Rys. 4. Rysunek wykonawczy stabilizatora prętowego, współrzędne

4.2. Warehousing, forces and tensions:

Table 2

stabilizer with back bearings:

bearing	X [mm]	Y [mm]	Z [mm]	F_x [N]	F_y [N]	F_z [N]	point No.: [-]
1	335,000	-541,000	0,000	0	0	2127	1
2	0,000	-326,147	0,000	0	0	-3528,5	2415
3	0,000	326,093	0,000	0	0	3528,5	6291
4	335,000	541,000	0,000	0	0	-2127	8557

deflection (wanted) 2s[mm]: 77.000
tangent force [N]: not defined

Table 3

bearing spacing

bearing	X [mm]	Y [mm]	Z [mm]	distance
3-2	0,000	652,240	0,000	632,24
4-1	0,000	1082,000	0,000	1082
2-1	-335,000	214,853	0,000	
3-4	-335,000	-214,907	0,000	

lenght of leg [mm] : 335.0 ±3
leg distance [mm] : 1082.0 ±3
bearings distance [mm] : 326.0

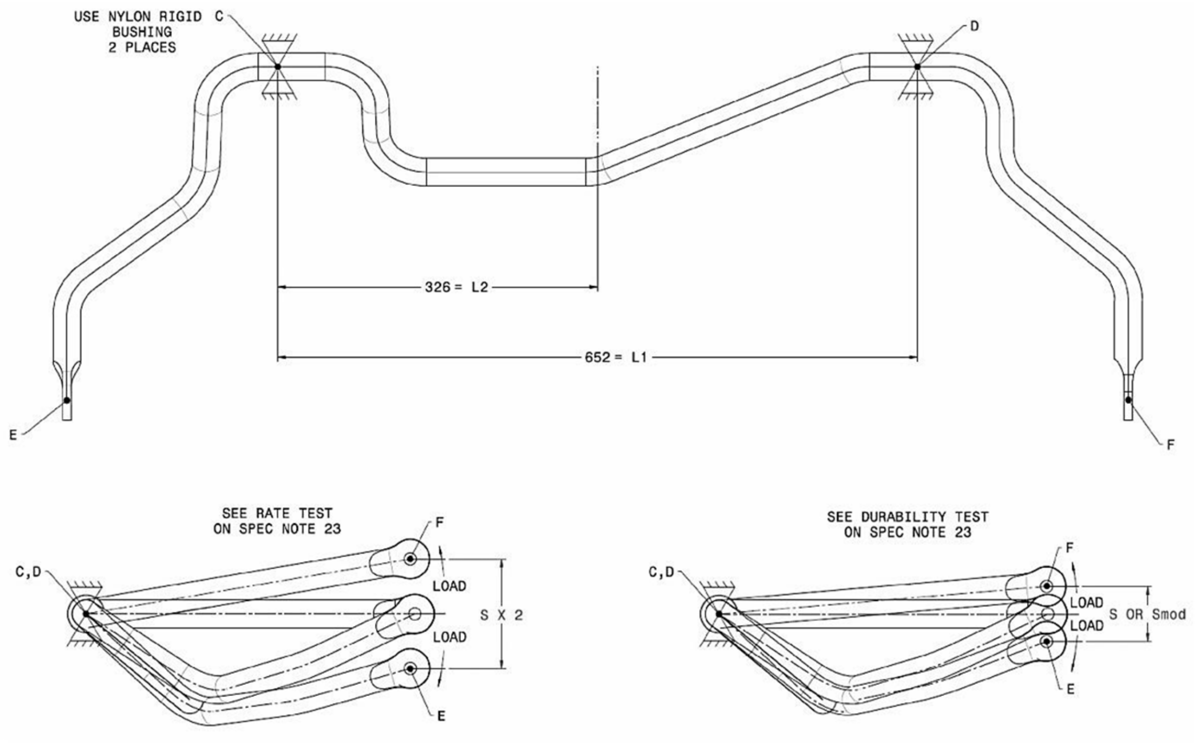


Fig. 5. Stabilizer bar – spring travel / warehousing
Rys. 5. Droga sprężysta stabilizatora, łożyskowanie - mocowanie

maximum equivalent stress at 0°	[MPa]:	390 at length	631.9mm
maximum corrected equivalent stress	[MPa]:	465 at length	713.1mm Pos. 0°

4.3. Results of calculation

Maximum bar diameter	[mm]:	28.00
lenght theor. (for pipe stabilizers)	[mm]:	1711.5
lenght theor. (for rod stabilizers)	[mm]:	1728.2
lenght before / after	[mm]:	0.00
mass theor. / actual	[kg]:	8.27
calculated deflection	[mm]:	71.30
rate	[N/mm]:	29.83
roll angle	[°] :	3.77
leg angle (bearing 1-4)	[°] :	12.15
stress / roll angle	[MPa/°] :	103.42

4.4. End configuration

		left	**right**
inner eye diameter	[mm]:	12.3 ±3	12.3 ±3
outer eye diameter	[mm]:	40.0 ±1	40.0 ±1
thickness at eye	[mm]:	9.0 ±0.5	9.0 ±0.5

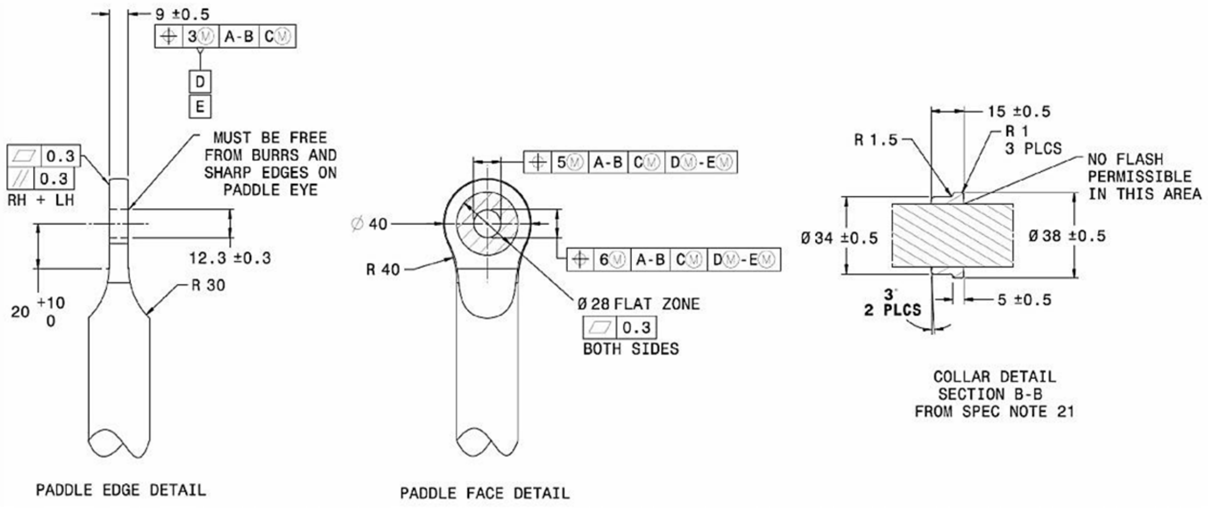
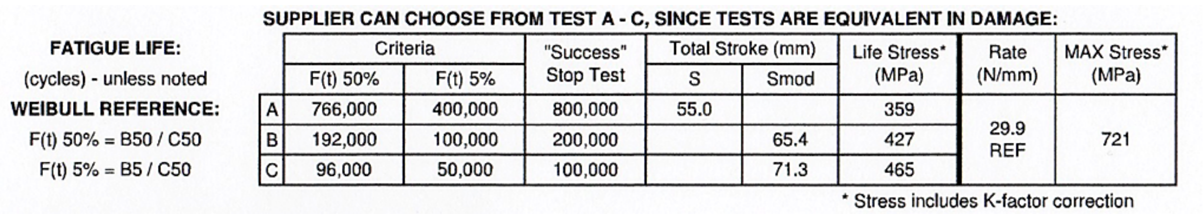


Fig. 6. Stabilizer bar - end configuration

Rys. 6.Końcówki stabilizatora

4.5. Aterial and production requirements

Table 4



SUPPLIER CAN CHOOSE FROM TEST A - C, SINCE TESTS ARE EQUIVALENT IN DAMAGE:

FATIGUE LIFE:
(cycles) - unless noted
WEIBULL REFERENCE:
F(t) 50% = B50 / C50
F(t) 5% = B5 / C50

	Criteria		"Success" Stop Test	Total Stroke (mm)		Life Stress* (MPa)	Rate (N/mm)	MAX Stress* (MPa)
	F(t) 50%	F(t) 5%		S	Smod			
A	766,000	400,000	800,000	55.0		359	29.9 REF	721
B	192,000	100,000	200,000		65.4	427		
C	96,000	50,000	100,000		71.3	465		

* Stress includes K-factor correction

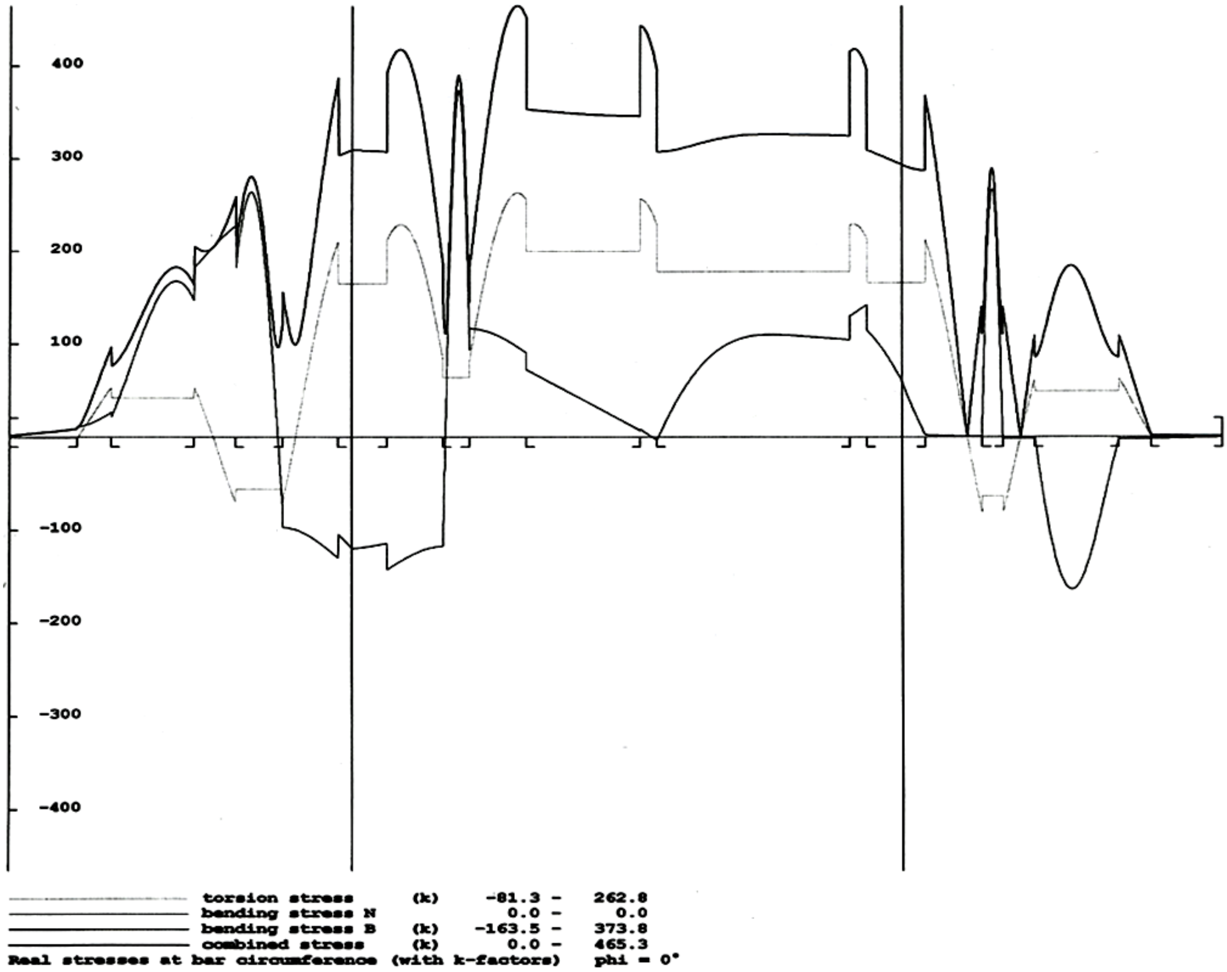


Fig. 7. Stabilizer bar - stress distribution
Rys. 7. Wykresy naprężeń w stabilizatorze

material: SAE 5160 or DIN 55Cr3
E-modulus, G-modulus [MPa]: 206000, 78500
spec. gravity [MPa]: 7.85 kg/m³
surface condition: black bar bar diameter [mm]: 28.00±0.28
bar lenght (pipe) [mm]: 1711.00 bar lenght (rod) [mm]: 1728.00
temper strength: HB- diameter [mm] 0.00 – 0.00 hardness (Rockwell) [HR] 45.0 – 49.0
tensile strength: [MPa] 1444 – 1625

5. CONCLUSIONS

The described calculation methods should be instrumental in designing the stabilizer bars. If the calculated stresses in the bearing / bend are too high ($\sigma > \sigma_{zul}$), there are two ways to solve it when constructing the stabilizer bar [11]:

1. Use of a steel of higher strength (possibilities limited).
2. Stabilizer bar with variable diameter:

- If the maximum permissible stress is exceeded even using high-strength steel, a transfer of the deformation work to less stressed areas must follow. Consequence – stabilizer bar with non-constant diameter / wall thickness (rotary swaging).
- Large diameters / wall thicknesses in critical areas (e.g. bends, bearing surfaces).
- Thinner diameters / wall thicknesses at the back / arms.
- The required rate may be achieved only by reducing the diameter/wall thickness in the less stressed areas may.

Refeferences

1. von Estorff H.-E.:*Technische Daten Fahrzeugfedern Teil:3 Stabilisatoren.* Stahlwerke Brüninghaus GmbH, Werk Werdohl, Hang Druck KG, Köln, 1969.
2. *Technische Daten Fahrzeugfedern.* Stahlwerke Brüninghaus GmbH, Werk Werdohl, E.Anding KG, Herborn, 1965.
3. Ulbricht J., Vondracek H., Kindermann S.; *Warm geformte Federn – Leitfaden für Konstruktion und Fertigung.* Hoesch Werke, Hohenlimburg Schwerte AG, W.Stumpf KG, Bochum, 1973.
4. Fischer F., H.Vondracek H.: *Warm geformte Federn – Konstruktion und Fertigung.* Hoesch Werke, Hoesch Hohenlimburg AG, W.Stumpf KG, Bochum, 1987.
5. Mitschke M.: *Teoria samochodu – Dynamika samochodu tom 2/ Drgania.* Wydanie 2 Wydawnictwa Komunikacji i Łączności, Warszawa, 1989.
6. Meissner M.,.Schorcht H.-J.: *Metallfedern – Grundlagen, Werkstoffe, Berechnung, Gestaltung und Rechnereinsatz.* 2. Auflage, Springer Verlag, Ilmenau, 2007.
7. Muhs D., Wittel H., Jannasch D., Voßiek J.: *Roloff / Matek Maschinenelemente – Normung, Berechnung, Gestaltung.* 18. Auflage, Viewegs Fachbücher der Technik, Wiesbaden, 2007.
8. Jakubowicz A. Orloś Z.: *Wytrzymałość materiałów.* Wydanie 6, Wydawnictwa Naukowo-Techniczne, Warszawa, 1984.
9. Reimpell J., Betzler J.W.: *Fahrwerktechnik – Grundlagen.* 5. Auflage, Vogel Verlag, Würzburg, 2005.
10. Topac M., Kuralay N.S.: *Computer aided design of an anti–roll bar for a passenger bus.* http://www.turkcadcam.net/rapor/otobus-stab-cae/index.html, 23.10.2010.
11. Brendecke T., Götz O., Schneider F., Brust B.: *Präsentation Wissenmanagment Stabilisatoren* ThyssenKrupp Bilstein Suspension GmbH, Hagen, Dezember, 2006.

Received 11.10.2009; accepted in revised form 20.03.2011