

THEORETICAL AND PRACTICAL CONSIDERATIONS IN DIAGNOSING DEFICIENCIES OF FLEXIBLE JOINT OF THE GLIDING STEEL TIMBERING AND SUGGESTS FOR THE IMPROVEMENT OF PERFORMANCES

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Abstract: Given the shortcomings discovered in practice for the proper functioning of the gliding steel timbering used in horizontal mine works, this study tells into consideration theoretical and practical facts in order to determine the causes of these deficiencies and suggests solutions for the improvement of performances.

Key words: the sliding steel mine timbering, mathematical model, flexible joint, new structural solutions.

1. INTRODUCTION

In order to ensure the best conditions of execution and subsequent stability for the small bent or horizontal excavation galleries or for those with a small angle of inclination, irrespective of their purposes (mine exploration works; hydro technical works; subway read or railway tunnels, etc.) sliding steel mine timbering is used almost exclusively. This can be temporarily used when its mode of operation is under alternating loads, case in which they subsequently require the assembling of the rigid timbering, or it can be constantly used when it works under given loads.

A sliding steel timbering is mode up of chute type heavy sections interweaved at the extremities by overlapping and tightened with screws through pieces called bridles.

Bridles are conceived so as to allow the gliding between them at some stress values which act on the heavy sections, narrowing in this way the radius of the mine work but maintaining the lifting power at an approximate constant value.

The operation of sliding steel timbering is a dynamic and throbbing phenomenon; the heavy sections and the bridles which tighten them are moving

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because of the frictional force.

As a result, the position of the bridles changes during sliding modifying the mechanic parameters of the mine timbering as well.

This system has been widely and satisfactorily used in the mines from Jiu Valley region at a moderate mine pressure with total distortions of the rocks of 250-300 mm.

Severe problems appear when the mine pressure increases, the distortions exceed these values and some phenomena which compromise the normal operation of the timbering appear in the joint systems.

The shape of SG 18, SG 23 and of those sections brought from the import implies jointing over the mating surfaces obtained between flanks, resulting free spaces of 3 and 5 mm between flanges which favors the emergence of the heavy sections structural change and the intermission of the sections through splitting (extension) of the underneath section (the iron prop) and the compression of the upper section (the bar). This produces the stress relieving of the bridles resulting in this way their uncontrolled gliding and the blockage of the sections alongside the transformation of the system into a rigid timbering type.

Numerous bridles present a contortion effect by exceeding the contact pressures between the lower clamp made from strip steel and the lower section or between the round bridle and the upper section together with the tension release of the bridles and the blocking obstruction.

Frequently enough permanent elongations of the round bridle, even its rupture because of the stretch or the rupture of the thread of the screw nuts appear and the bridles stop functioning.

Given the shortcomings discovered in practice, this study examines all the phenomena that occur and gives practical usability conclusions in order to fix all the problems.

2. THE CALCULATION OF THE FORCES IN THE BRIDLES

2.1. The calculation of the forces of reaction in the bridles during the mine timbering operation

In order to study sliding timbering, the following situation of a circular mine work propped up by a fastening ring made up of 4 segments partially stacked at their heads and tighten with two bridles should be taken into consideration.

This fastening ring is pressed by the mine pressure represented by two loads uniformly distributed (Fig. 1).

The following annotations are made: R - the radius of the transverse section of the mine work; L - the timbering field (the distance between two successive timbering rings); 2γ - the central angle for the area where the sections overlap, an area which is delimited by the position of the two bridles; the central angle varies during the gliding of the timbering; pL - the vertical component of the mine pressure; kpL - the horizontal

component of the mine pressure, where k coefficient takes the following values: $k = 0$ the pressure of the rocks will only push vertically, $k = 0,5$ the horizontal pressure is half the vertical pressure, $k = 1$ the pressure of the rocks will equally act vertically as well as horizontally, $k = 1,5$ the horizontal pressure will be once and a half bigger than the vertical pressure and $k = 2$ the horizontal pressure is two times bigger than the vertical one. Generally, $k > 1$ in areas with difficult geological mine conditions.

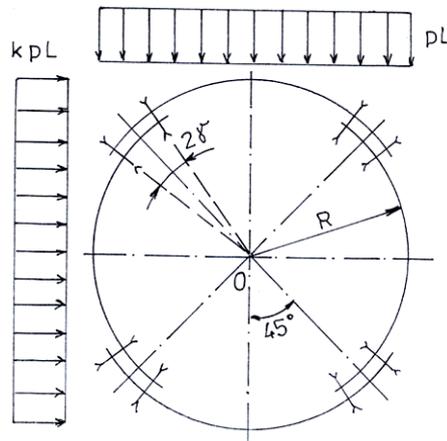


Fig.1. A circular mine work propped up by a fastening ring mode made up of 4 segments partially stacked at their heads

If we consider the timbering as an uninterrupted rigid ring with the symmetry of a circle we will take into consideration only a quarter of the work, which is statically indeterminate.

An imaginary section has a variable a central angle is drawn. The indetermination is lifted and calculating all the operations the stress from the steel timbering section is determined:

- axial load:

$$N = -pLR + (1 - k)pLR \sin^2 \theta$$

- shearing force:

$$T = (1 - k)pLR \sin^2 \theta \cos \theta \quad (1)$$

- moment of flexure:

$$M = -\frac{1 - k}{4} pLR^2 (1 - 2 \sin^2 \theta)$$

The steel timbering is actually mode up of 4 circle segments which are jointed

together through four bridle systems.

The remark to be made is that the upper segment of the ring is leaning on the other 2 lateral segments so that it seems like a curved bar on 4 points of support due to the binding forces which appear in the bridles.

The same happens to a lateral segment clung through 4 bridles on the superior the inferior segment.

Being under moments of flexure, the 2 segments which, at first, have contact on all the covering surface, tend to get to a two points contact because the bridle from the outside will be stressed to stretch and the bridle from the inside the superior section leaning in this way on the base of the lateral section. (Fig. 2)

As a consequence of all the counteracting forces which act on the bridles, the segments of the ring are differently stressed.

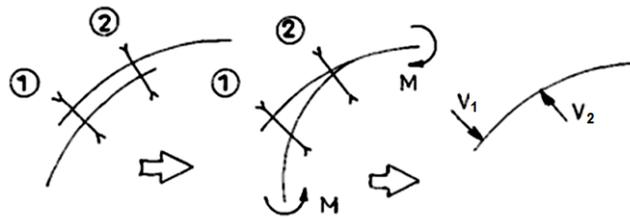


Fig. 2. Two segments tighten worth two bridles

Even though each segment looks like a curved bar on four piles, the problem involves only 2 unknowns, V_1 and V_2 reciprocal forces as a result of geometrical and physical symmetry of the ring.

To determine the values of the forces, the upper segment and the lateral one from the left pressed by the rock pressure and the interchangeable forces (Fig. 3) should be taken into consideration.

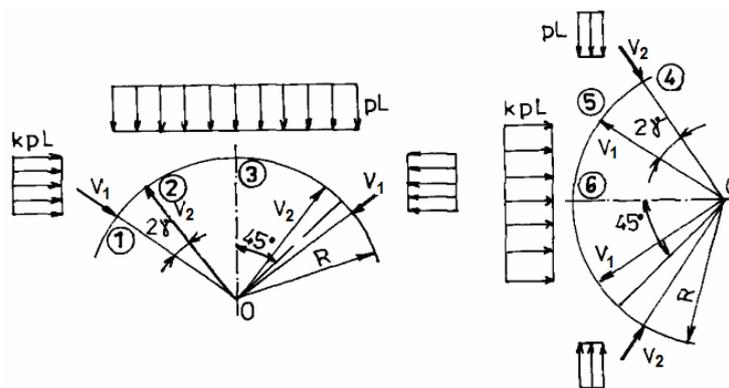


Fig. 3 Determining the values of the forces for the tightening of lateral segment with the upper segment

The condition for vertical projections $\sum F_y = 0$ for all the forces which press the upper segment is:

$$2V_1 \cos(45^\circ + \gamma) - 2V_2 \cos(45^\circ - \gamma) + pL \cdot 2R \sin(45^\circ + \gamma) = 0 \quad (2)$$

The condition for horizontal projections $\sum F_x = 0$ is:

$$2V_1 \cos(45^\circ - \gamma) - 2V_2 \cos(45^\circ + \gamma) - pL \cdot 2R \sin(45^\circ - \gamma) = 0 \quad (3)$$

Solving this system of equation allows us to discover the values of the forces:

$$V_1 = pLR \frac{1}{2} \cdot \left(\frac{\cos \gamma + k \cdot \cos 2\gamma}{\sin 2\gamma} \right) \quad (4)$$

$$V_2 = pLR \frac{1}{2} \cdot \frac{(1 + \sin 2\gamma) + k(1 - \sin 2\gamma)}{\sin 2\gamma}$$

It can be noticed that for some determined values for p , L and R , the values of the reacting forces depend on the overlap angle 2γ and the k pressure ratio.

Chart number 1 shows the values for the V_1 and V_2 notions (divided to pLR product) depending on the different values of the 2γ and k parameters. (Table 1, Fig. 4, Fig.5). The calculations were limited to the $2\gamma = 3^\circ$ value, an adequate value for the situation in which the overlapping is so small that the two bridles are brought together so that 2γ cannot increase anymore.

Table 1. Values for the V_1 and V_2 notions (divided to pLR product) depending on the different values of the 2γ and k parameters

$2\gamma^\circ$	V_1/pLR					V_2/pLR				
	K					k				
	0	0,5	1	1,5	2	0	0,5	1	1,5	2
3°	9,610	14,400	19,160	24,95	29,94	10,010	14,670	19,250	24,75	29,5
6°	4,780	7,180	9,550	11,9	14,33	5,310	7,470	9,620	11,76	13,92
10°	2,840	4,270	5,700	7,1	8,53	3,390	4,590	5,780	6,97	8,17
15°	1,860	2,790	3,730	4,67	5,61	2,430	3,140	3,860	4,59	5,3
20°	1,370	2,060	2,740	3,43	4,11	1,960	2,440	2,930	3,40	3,88
30°	0,866	1,300	1,730	2,165	2,59	1,500	1,500	2,000	2,25	2,5
45°	0,500	0,750	1,000	1,87	2,28	1,210	1,310	1,415	1,72	2,07

The main stress of the timbering structure is given by the action of the moments of flexure. That is why these shall be calculated for the most stressed sections of the ring (Table 2, Fig. 6, Fig. 7):

$$M_1 = 0 \quad (5)$$

$$M_2 = -V_1 \cdot R \sin 2\gamma - pL \cdot \frac{[R \sin(45^\circ + \gamma) - R \sin(45^\circ - \gamma)]^2}{2} - kP_y L \cdot \frac{[R \cos(45^\circ - \gamma) - R \cos(45^\circ + \gamma)]^2}{2} \quad (6)$$

$$M_3 = -V_1 \cdot R \sin(45^\circ + \gamma) + V_2 R \sin(45^\circ - \gamma) - pL \cdot \frac{[R \sin(45^\circ + \gamma)]^2}{2} - kP_y L \cdot \frac{[R - R \cos(45^\circ + \gamma)]^2}{2} \quad (7)$$

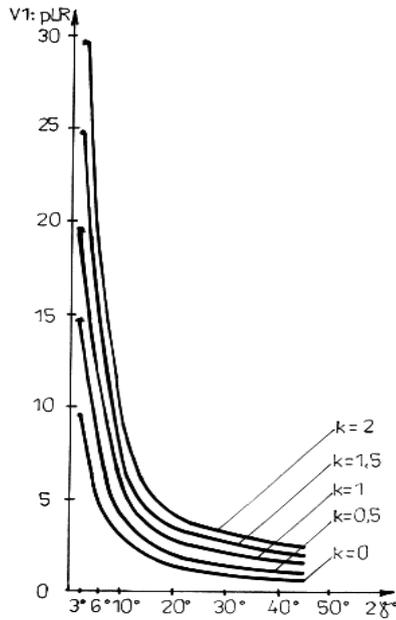


Fig. 4. The variation diagram for the V_1 force

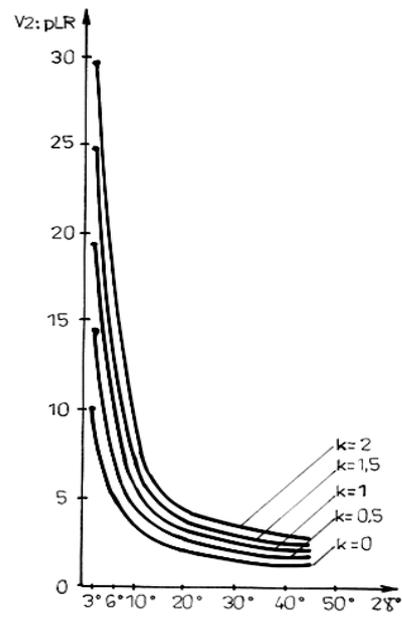


Fig. 5. The variation diagram for the V_2 force

And the calculation for the lateral segment is also done:

$$M_4 = 0 \quad (8)$$

$$M_5 = -V_2 \cdot R \sin 2\gamma \quad (9)$$

$$M_6 = -V_2 \cdot R \sin(45^\circ + \gamma) + V_1 R \sin(45^\circ - \gamma) - pL \cdot \frac{[R - R \cos(45^\circ - \gamma)]^2}{2} - kP_y L \cdot \frac{[R \sin(45^\circ - \gamma)]^2}{2} \quad (10)$$

Table 2. Values for the M_2, M_3, M_5 and M_6 notions (divided to pLR^2 product) depending on the different values of the 2γ and k parameters

$2\gamma^\circ$	M_2/pLR^2					M_3/pLR^2				
	K					k				
	0	0,5	1	1,5	2	0	0,5	1	1,5	2
3°	0,500	0,750	1,000	1,25	1,5	0,263	0,632	1,000	1,368	1,737
6°	0,500	0,750	1,000	1,25	1,5	0,276	0,638	1,000	1,36	1,725
10°	0,500	0,750	1,000	1,25	1,5	0,294	0,647	1,000	1,35	1,708
15°	0,500	0,750	1,000	1,25	1,5	0,315	0,658	1,000	1,342	1,685
20°	0,500	0,750	1,000	1,25	1,5	0,336	0,657	1,000	1,254	1,66
30°	0,500	0,750	1,000	1,25	1,5	0,375	0,688	1,000	1,06	1,37
45°	0,500	0,750	1,000	1,25	1,5	0,426	0,713	1,00	0,87	1,14
$2\gamma^\circ$	M_5/pLR^2					M_6/pLR^2				
	K					k				
	0	0,5	1	1,5	2	0	0,5	1	1,5	2
3°	0,526	0,763	1,000	1,237	1,47	0,763	0,881	1,000	1,11	1,237
6°	0,552	0,776	1,000	1,24	1,44	0,776	0,888	1,000	1,104	1,22
10°	0,586	0,793	1,000	1,20	1,41	0,793	0,896	1,000	1,10	1,206
15°	0,629	0,814	1,000	1,18	1,37	0,815	0,907	1,000	1,09	1,18
20°	0,671	0,835	1,000	1,16	1,35	0,835	0,918	1,000	1,08	1,16
30°	0,750	0,875	1,000	1,12	1,25	0,875	0,937	1,000	1,06	1,12
45°	0,853	0,926	1,00	0,98	1,14	0,928	0,963	1,00	0,84	0,98

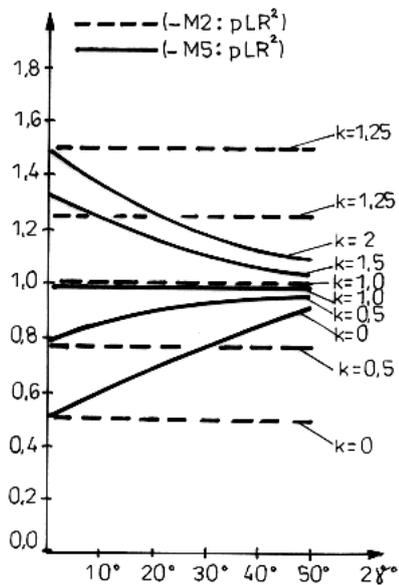


Fig. 6. The variation diagram for the M_2 and M_5

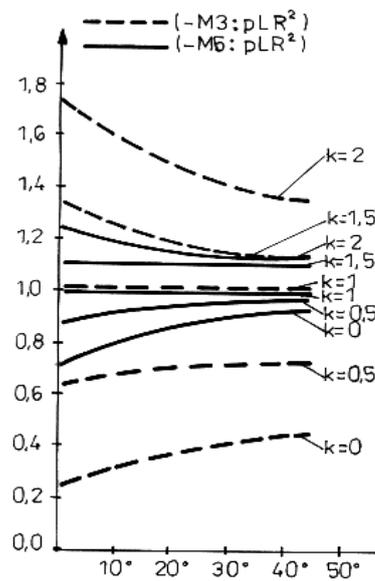


Fig. 7. The variation diagram for the M_3 and M_6

2.2. THE CALCULATION OF THE P_x FORCES IN THE BRIDLES

In figure 8 because the clamp of the bridle 1 is stressed to stretch and the gliding movement is intermittent, a new stress appears. This stress produces the sliding of the bridle 1 towards the bridle 2, shrinking in this way, during the gliding of the sections the distance between the bridles and also the central angle 2γ

During the gliding produced of the sliding of the bridles the V_1 and V_2 reacting forces present huge values which stop the steel timbering from functioning.

The technical solutions which maintain the initial distance between the bridles during the gliding of the timbering or which increase this distance because the bridles are clung to the extremities of the sections assure low values for the reacting forces in the bridles and a proper functioning of the steel timbering.

The moments of flexure have low variations depending on the 2γ angle and a maximum of 50% variations when the k coefficient increases from 1 to 2 which happens when the lateral mine pressure is twice the vertical mine pressure.

If the mine pressure which act on the contour of the steel timbering has asymmetrical concentrations of forces which produce sizeable moments of flexure in the joint surface, the stress from the bridles is removed, permanent distortions appear and the steel timbering stops functioning.

From the whole gliding steel timbering the most vulnerable parts are the joint surfaces of the bridles because the mechanical and functional characteristics of the bridles influence the performance of the steel timbering.

The bending moments M , normal forces N and peripheral forces T occur in all the sections of the arch of a sliding steel mine timbering including the median section of the bridle under the action of the external force.

Moreover, the bridles are tightened up with steel clamps and screw nuts (fig.8).

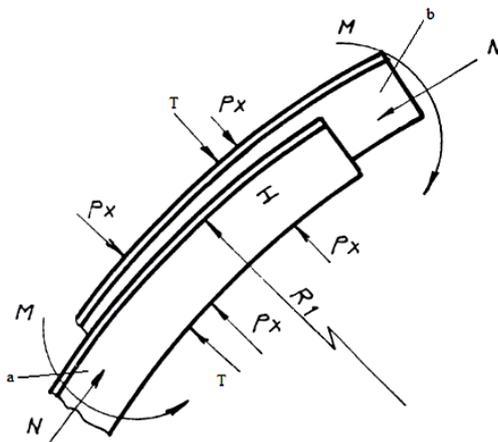


Fig. 8. The appearing forces in a flexible joint of two heavy sections with bridles

Until the sliding starts all the forces that operate in the flexible joint (the

external forces M, N, T, P_x and the frictional force F) are in balance. The forces that act upon the sections will be:

$$p = \sum P_x + T + \frac{3 \cdot M}{2(l_0 + l'_0)} \quad (11)$$

where $\sum P_x$ - represents the overall force of the bridles.

The sliding from the bridles can be expressed through the following relation:

$$N = \mu \cdot \left[\frac{\sum P_x + T + \frac{3M}{2(l_0 + l'_0)}}{\sin \alpha_0 - \mu \cdot \cos \alpha_0} + \sum P_x + \frac{3M}{2(l_0 + l'_0)} \right] \quad (12)$$

where: α_0 is the angle of inclination for the lateral edges from the section; μ - the coefficient of friction.

If we note:

$$A = 1 + \frac{1}{\sin \alpha_0 - \mu \cdot \cos \alpha_0} \quad (13)$$

and

$$B = 1 + \sin \alpha_0 - \mu \cdot \cos \alpha_0 \quad (14)$$

After calculations we get the pressure force from the bridles:

$$\sum P_x = \frac{N}{\mu \cdot A} - \frac{3M}{2(l_0 + l'_0)} - \frac{T}{B} \quad (15)$$

3. CONCLUSIONS AND PROPOSALS FOR IMPROVING THE HOLDING SYSTEMS OF THE HEAVY SECTIONS

From the previous studies it results that the bridles should be designed according to the geological mine conditions where the timbering will be used, estimating the values of the moments of flexure M generated by the asymmetrical mine pressure.

Because of the moment of flexure is the operating bridles tending to slide one towards the other and the mine timbering will malfunction.

The first condition that we should take into consideration for the fabrication of the holding systems of the sections is that the bridles maintain the same distance between them from the installation irrespective of the values of the stress or this distance way raise during the sliding through guidance.

The clamp of the bridles can be fabricated from round steel with threads at the

ends or from strip fixed with two screws.

Like the screws, the clamps stressed to stretch should be made from steel of superior quality because they are the most stressed components of the bridles.

The deformation within acceptable elastically limits of the screws as well as the joining (with elastic formulae) of the contact surfaces between the bridles and the sections will prevent the sections and the timbering from getting stuck the transformation of the timbering into a rigid support submitted to buckling phenomenon.

The strengthening of the sections with stand-ins should be considered where the geological mine conditions would be harsher than the estimated ones.

Figure 9 presents a bridle that assembles SG 18, SG 23 sections or equivalent sections brought from the import where the bottom clip 2 covers the bottom section decreasing the maximum mechanical stress from the section and reducing the distortion of the section.

The clamp (1) will be made from round steel Ø30 with M 30 threads and with one M 30 nut. The clip 2 will be assembled on the gripping section trough blockage or heat treatment so that it will not slide during the operation and maintain its initial position. The clamp 1 will be the part that will slide on the superior section during the sliding of the timbering, the friction coefficient of a cylindrical surface on a level surface is smaller than the friction coefficient between 2 level surfaces.

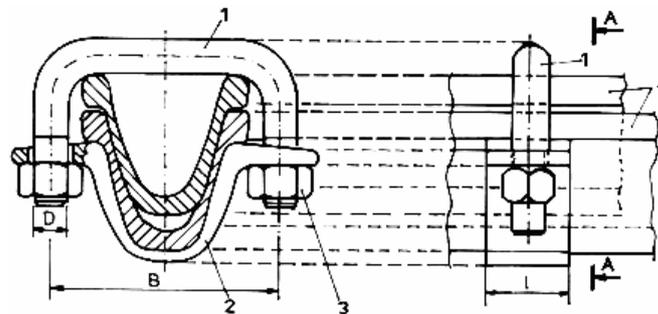


Fig. 9. Connecting bridle with lower clip assembled trough blockage or heat treatment

In figure 10 the represented bridle has the clamp 1 made from strip and joint with 2 screws of Ø30 mm in diameter. The 2 bridles drawn with adapter shoulders, the left one guided towards the abutment and the right one towards the light of the mine working separate from each other and the stresses from the bridles diminish. In this way the clip 2 is free and the shoulders have the role of controlling the bridles.

Figure 11 presents an attachment made up of 2 bridles connected by a spacer made up from spring steel and placed towards the light of the mine working. This will slide at the same time with the bottom section maintaining its position towards its end.

This attachment can be used for gripping the SG-18, SG-23 sections, figure 11.a or the SG-29 section, figure 11.b.

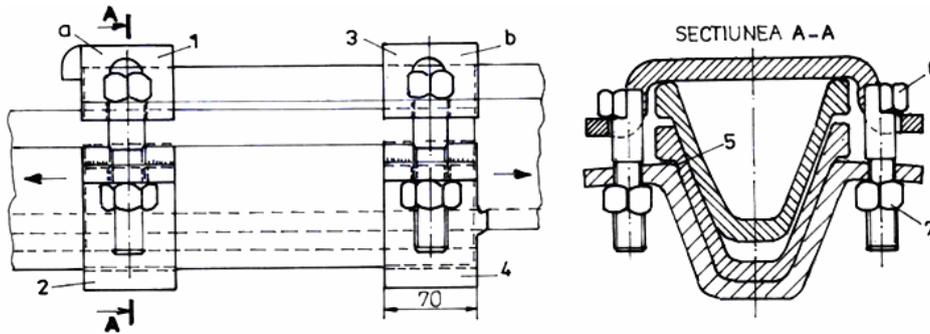


Fig. 10. Bridles with adapter shoulders

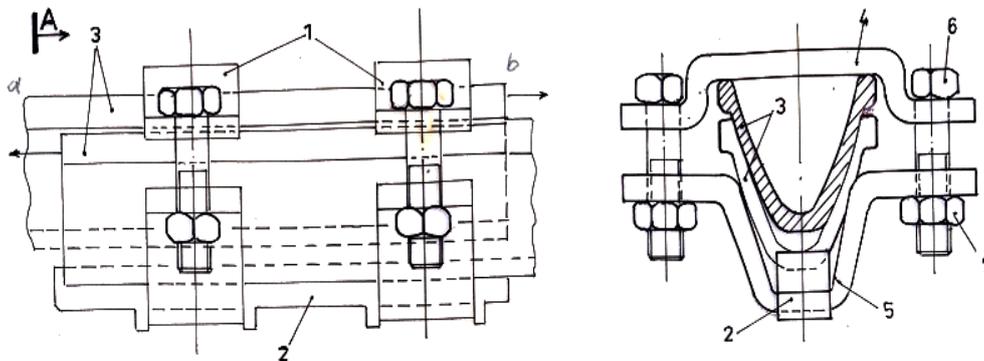


Fig. 11.a. Clamping device consist of two bridles guided by a spacer for gripping the SG-18, SG-23

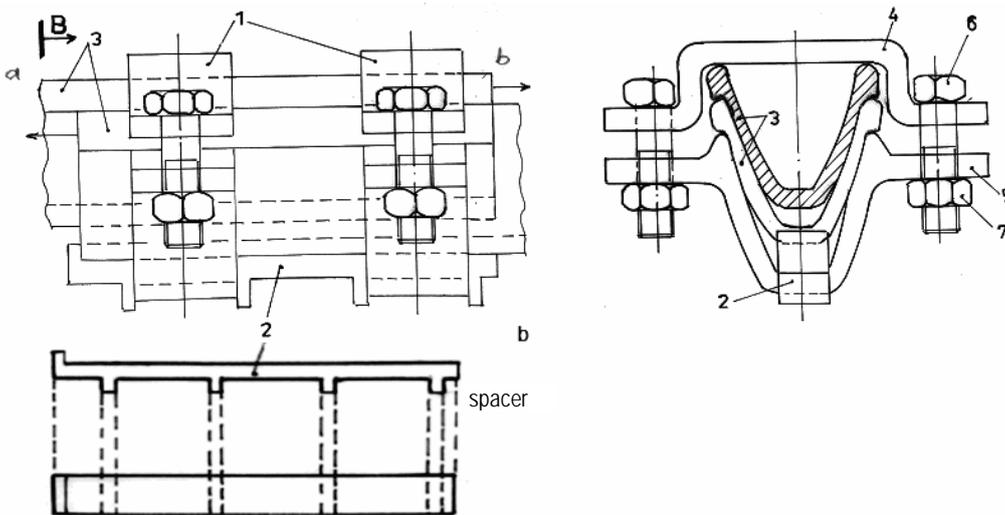


Fig.11.b. Clamping device consist of two bridles guided by a spacer for gripping the SG-29

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