

WIRE ROPE SLINGS FOR LIFTING PURPOSES - CRITICAL ANALYSIS OF NBR 13541

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Abstract. *Brazil experiences a strong growing in industries of petroleum, shipbuilding, infrastructure, construction, mining, among others. With the growing demand for faster, more modular, heavier fabrication and construction, lifting operations are becoming increasingly important for the effectiveness of the projects. Therefore, the use of wire rope slings is becoming increasingly more important for the lifting operations.*

In 1995, ABNT issued NBR 13541 – Lifting purposes – Wire rope slings – Specification, which specifies the characteristics of wire rope slings used to raise, lower or suspend loads. Since its publication, there was considerable progress in research and practical experience in the use of slings, in addition to the updating of standards referenced by NBR 13541 and international standards like ISO 19901-6, ASME B30.9, EN 13414 and others.

This paper is a critical analysis of NBR 13541 standard, aiming at preparing its updating and revision, mainly regarding strength, durability and safety of slings.

Proposes to generalize the equation for calculating the working load limit (or safe working load) of slings, as well as the consideration of how many legs effectively participate in the sling strength.

It is considered the loss of strength of steel wire rope due to bending, both in the body and in the region of sling eye.

It also proposes the inclusion of grommets and cable-laid slings, which are very useful in heavy lift operations, indicating the equations for calculating the working load limit of these slings.

Keywords: *slings; wire rope; lifting; rigging.*

1. INTRODUCTION

Brazil, as well as other developing countries, experiences a strong growing in industries of petroleum, shipbuilding, infrastructure, construction, mining, ports among others. In all these industries, lifting operations are essential and the demand for these services is continued growth, since constructions and loads are becoming more complex, prefabricated and modular. Also, the major projects are demanding shorter deadlines that only can be efficiently achieved with lift engineering.

Inevitably, the weight and size of the loads to be lifted are getting greater than ever, increasing the risk of accidents and demanding stronger slings. All this requires up to date standards that cover the major types of slings and present a reliable method for calculating slings strength.

The growing of lift services can be illustrated by some recent cases in Brazil. Odebrecht (2006) reports the construction of three offshore platform modules for PRA-1, owned by PETROBRAS, weighing 13.650 kN, 38.700 kN and 71.490 kN (Fig. 1). The lightest one was lifted and placed onto the module of 38.700 kN, forming a single module weighing 52.350 kN. The two modules were taken to Campos Basin, lifted and placed onto the jacket by a dual crane vessel.

Odebrecht (2007) also reports the lifting operation to upend a large pressure vessel, considered the first of this kind in Latin America's refineries (Fig. 2). The equipment weighs 7.500 kN, has a diameter of 5 m and is 96 m high. Two cranes were used, the main crane, with a capacity of 16.000 kN and the tail crane, a crawler crane model, with a capacity of 7.500 kN.

In another recent lifting operation, considered the heaviest lifting operation of the kind performed in Latin America (EAS, 2010), Atlântico Sul Shipyard lifted a block weighting 25.000 kN that makes part of the P-55, an offshore platform owned by PETROBRAS. The shipyard used two synchronized gantry cranes to move the block to the dry dock (Fig. 3).

Preparing for a worldwide growing demand, global manufacturers of lifting equipment are also improving the technology and increasing the capacities. Recently, Liebherr released the strongest conventional crawler crane in the world, with capacity of 30.000 kN (AC&T, 2011).

These and other facts show that an urgent revision of NBR 13541 is extremely necessary, so Brazilian engineers can design effective and safe slings for next lifting challenges.



Figure 1. Construction of three modules for PRA-1 Offshore Platform. Photo courtesy of Odebrecht, Luciano Andrade.

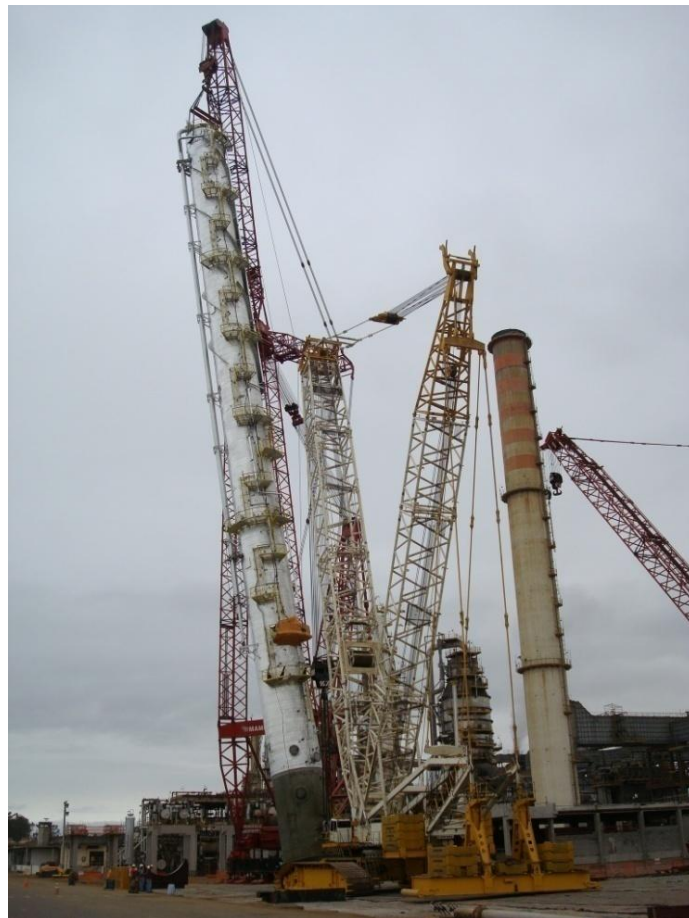


Figure 2. Lifting a 7.500 kN pressure vessel at REVAP, PETROBRAS. Photo courtesy of Odebrecht, Luciano Andrade.



Figure 3. A 25.000 kN block for P-55 offshore platform being lifted at *Atlântico Sul* shipyard. Photo courtesy of *Estaleiro Atlântico Sul*.

2. OVERVIEW OF NBR 13541 AND NBR 13543

ABNT, Brazilian organization for standardization, issued NBR 13541, "Lifting purposes - Wire rope slings - Specification", published in December 1995 and valid from January 1996, remaining in effect after fourteen years, without revisions, amendments or errata. The scope is defined as "This Standard specifies the characteristics of wire rope slings used to raise, lower or suspend load." (ABNT, 1995a). It was based on ISO 7531, first edition, 1987, which remains in effect today, also without receiving reviews since its publication (ISO, 1987).

As the only Brazilian standard that deals with the determination of the working load limit of wire rope slings, it is widely used by most slings manufacturers in Brazil, which sell for the various sectors that require this type of slings for lifting, without distinction, from the industry of petroleum to the electronic industry.

NBR 13543, "Lifting purposes - Wire rope slings - Use and inspection", was published at the same date and was valid with the NBR 13541, remaining in effect nowadays, without revisions, amendments or errata. The scope is defined as "This Standard provides guidelines for the use and inspection in operation of wire rope slings for general purposes." (ABNT, 1995b). It was based on ISO 8792 (1986), published in 1986, which remains in effect.

These two Brazilian standards, although complementary, do not mutually reference each other or gives any indication to use or query each other.

NBR 13541 has items of normative references, definitions, characteristics, and the latter item involves most of the content, comprising: classification, material, manufacturing, forms and dimensions, working load limit, terminal fittings, proof force, minimum ultimate strength, fatigue test and conditions for usage of slings. The remaining items include sampling and criteria of conformity, test methods, designation, identification and prototype certification check.

NBR 13543 includes items for normative references, slinging method, use of wire rope slings and inspection.

NBR 13541 classifies the slings according to the number of legs that are used and may be one, two or four legs, noticing the absence of three-legged sling, which is present in ISO 7531 (1987).

There is also a classification by the type of termination, that is, the type of the eye, allowing the four types listed in NBR 11900 (ABNT, 1991).

The classification regarding flexibility is considered by choosing the class, 6x19 or 6x37. Class 6x37 is no longer covered by NBR ISO 2048 (ABNT, 2008), and shall be replaced by 6x36 class. The Ordinance Number 242 published by INMETRO (2008) prohibits the sale of 6x19M and 6x37M classes, therefore prohibited for manufacture of slings.

Lastly, it classifies the sling according the core of the wire rope used to fabricate it, allowing the use of fibre core or steel core (independent wire rope core - IWRC) and the adoption of slings with steel core demands the use of wire ropes fabricated with steel having minimum strength of 1960 MPa.

NBR 13541 (ABNT, 1995a) covers only single-part slings, with an eye on at least one end, neglecting grommets, cable-laid grommets, cable-laid slings and braided slings, which are even more used, especially for heavy lifting.

3. FACTORS THAT REDUCE THE STRENGTH OF SLINGS

3.1. Eye termination

The presence of eye terminations reduces the strength of the sling which is considered by NBR 13541 (ABNT, 1995a) through the coefficient K_e , efficiency of termination, and has the value depending on the type of eye: 0,9 for eye terminations types 1, 2 and 4 and 0,7 for eye termination type 3, values consistent with the minimum values required by NBR 11900 (ABNT, 1991). Table 1 shows efficiency of wire rope eye terminations stated by some standards.

Table 1. Efficiency of wire rope terminations according to sling design standards.

Standard	Hand-tucked Splice	Mechanical Splice (ferrule-secured)	Socket
EN 13414-1	0,8	0,9	-
ISO 19901-6	0,75	0,9 ¹ or 0,75 ²	1,0 ³
ISO 7531	0,8	0,8	-
NBR 13541 / NBR 11900	0,7	0,9	-

⁽¹⁾: For swage fittings on Flemish eyes.

⁽²⁾: For steel ferrules (mechanical termination).

⁽³⁾: For resin sockets.

3.2. Bending

According to ISO 19901-6 (2009), when a wire rope sling is bent around a shackle, trunnion, padeye, hook and others, the strength of the sling is locally reduced by bending. This reduction must be taken in account when designing the sling, using a bending efficiency factor, K_B .

Other publications also state the requirement of reducing sling strength due to bending: IMCA M 179 (2005), Noble Denton (2010), Liang (2004) and Milwee (1995).

ISO 19901-6 (2009), IMCA M 179 (2005), Noble Denton 0027/ND (2010) and Liang (2004) use the same experimental equation for K_B , expressed by Eq. (1), which is valid for wire ropes of 6x19 and 6x36 classes.

$$K_B = 1 - \frac{0,5}{\sqrt{\frac{D}{d}}} \quad (1)$$

D is the minimum diameter over which the sling body or eye is bent and d is the sling diameter, as shown in Fig. 4. The graphical representation of the values for coefficient K_B is shown in Fig. 5, based on Eq. (1).

NBR 13541 (ABNT, 1995a) does not consider this loss of strength due to bending, although NBR 13543 (ABNT, 1995b) recognizes this loss, indicating that a wire rope bent on its own diameter loses 50% of its strength. This loss value is compatible with Eq. (1), whereas a unitary value of D/d conducts a K_B value equal to 0,5.

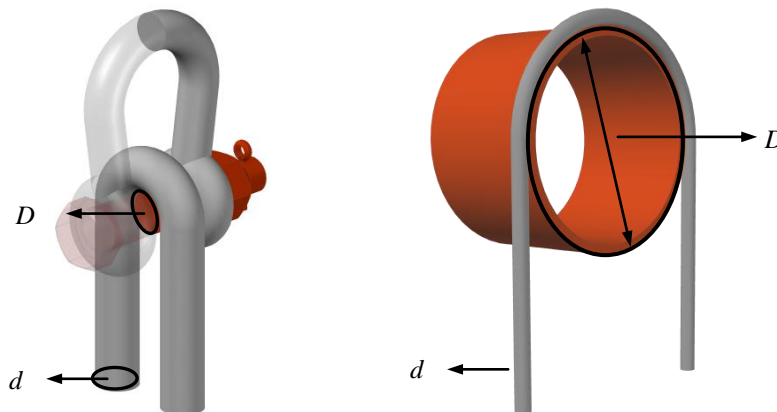


Figure 4. Examples showing sling diameter (d) and bending diameter (D).

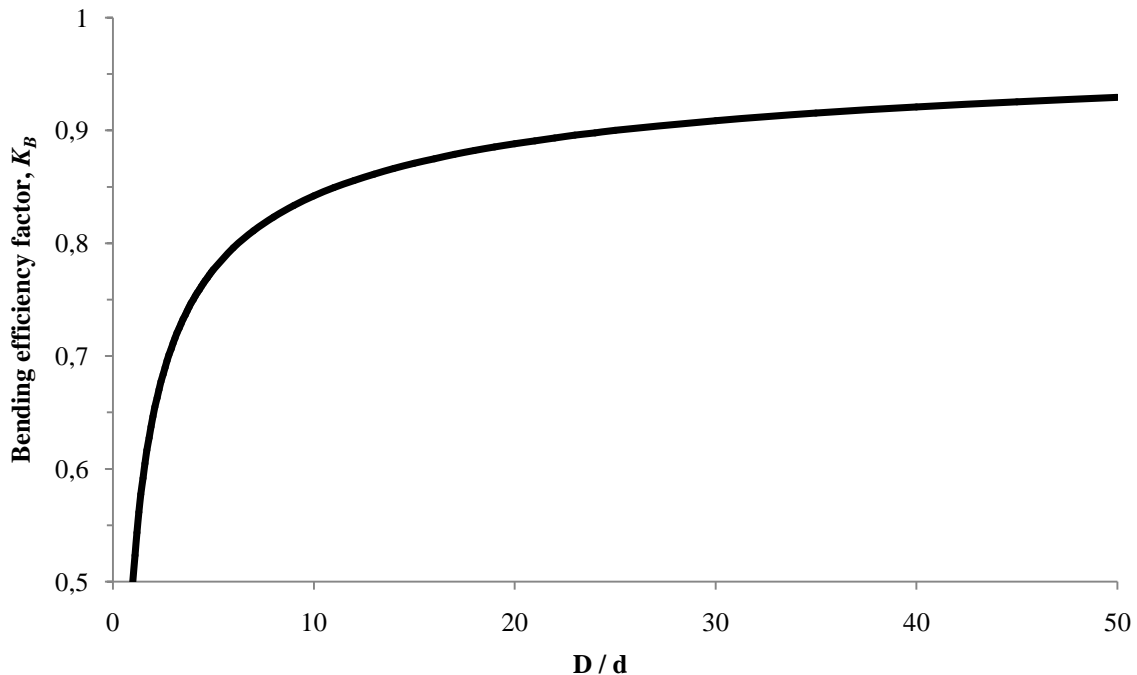


Figure 5. Bending efficiency factor, K_B , in function of D/d ratio.

The both factors that reduce strength, efficiency of termination (K_T) and bending efficiency (K_B), are not cumulative, as stated by ISO 19901-6 (2009), EN 13414-1 (2008) and IMCA M 179 (2005), and the smallest of the two shall be used in the calculation of the working load limit (WLL) of the sling. The factor K_B shall be calculated for bending in sling eye and bending in sling body, if applicable and the smallest value shall be taken. Typically, bending in sling body governs as loads in sling eyes are divided by two legs (IMCA M 179, 2005).

ISO 19901-6 (2009) does not allow the use of K_B factors lower than 0,50, recommending at least 4,0 to avoid even limited permanent deformation of the sling. Moreover, the body of the sling shall not be bent around a diameter less than $2,5d$. D/d ratios smaller than 2,5 are applicable only to the sling eyes. Revision of NBR 13541 shall limit bending ratios aiming at a limited reduction of strength and a limited permanent deformation, consequently improving durability.

4. WORKING LOAD LIMIT OF SINGLE PART SLINGS

To calculate the working load limit of a sling (WLL), NBR 13541 (ABNT, 1995a) uses the Eq. (2), adapted to express the value in kN:

$$WLL = \frac{Cr Ke}{5} f \quad (2)$$

Where:

Cr is the minimum actual ultimate strength of wire rope, in kN, according to NBR 6327, (superseded by NBR ISO 2408, in 2008).

Ke is the efficiency of termination, according to Tab. 1 for NBR 13541.

f is a factor for load calculation, as described below.

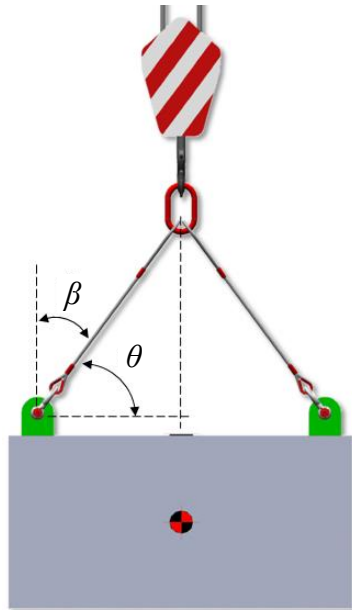


Figure 6. Two-legged sling.

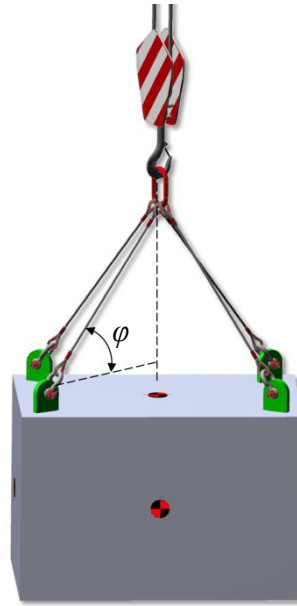


Figure 7. Four-legged sling.

Equation (2) considers an angle β (Fig. 6) equal to 45° . Hence, the *WLL* shall be recalculated for an angle of 60° , if the angle is greater than 45° . Angles greater than 60° shall not be used. NBR 13541 does not allow any other values for β angle but 45° and 60° .

The factor f takes into account the amount of legs effectively contributing to strength, and in the case of a four-legged sling, only three legs are considered, the other one is just to balance the load. Slings with three legs are not covered and shall be treated as two-legged slings.

The factor f has the following values: for single-leg 1,0, for two-legged 1,4 and four-legged sling 2,1, which are the same used by EN 13414-1 (2008) and ISO 7531 (1987).

For single part slings, this paper suggests the following equations, to be used in the revision of NBR 13541.

For single-leg slings the working load limit (WLL_1), in kN, shall be calculated by Eq. (3), based on Eq. (2).

$$WLL_1 = \frac{F_{min} K_R}{Z_p} \quad (3)$$

Where:

F_{min} is the minimum breaking force of the rope, in kN, according to NBR ISO 2048 (ABNT, 2008).

K_R is the factor of strength reduction, taken as the minimum value between the efficiency of termination, K_T and the bending efficiency factor, K_B . K_B shall be calculated using Eq. (1) for eye and body. K_T shall have value according to Tab. 2.

Z_p is the coefficient of utilization, not less than 5.

This paper proposes general equations to calculate the working load limit of a multi-legged sling, using the θ or φ angles instead of β (Fig. 6), using a minimum value of 30° . The preference for θ or φ is the easiness to check it on field.

For two-legged slings (Fig. 6) and three-legged slings the working load limit (*WLL*), in kN, is deduced by Eq. (4) to Eq. (9).

As forces must be in equilibrium at point A, we have, according to Fig. 8:

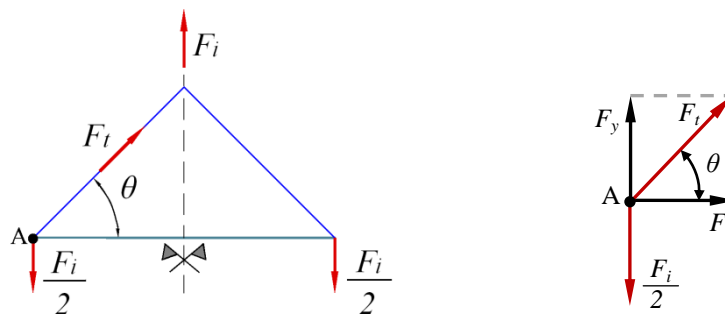


Figure 8. Forces acting on a two-legged sling.

$$F_y = \frac{F_i}{2} \quad (4)$$

$$\sin \theta = \frac{F_y}{F_i} \quad (5)$$

Replacing F_y in Eq. (5):

$$F_i = \frac{F_i}{2 \sin \theta} \quad (6)$$

F_i cannot have a value greater than the WLL_i for a single-leg sling, expressed by Eq. (3), therefore:

$$F_i \leq WLL_i \therefore \frac{F_i}{2 \sin \theta} \leq \frac{F_{min} K_R}{Z_p} \quad (7)$$

$$F_i \leq \frac{2 F_{min} K_R \sin \theta}{Z_p} \quad (8)$$

The WLL for two-legged sling is the maximum value for F_i , therefore:

$$WLL = \frac{2 F_{min} K_R \sin \theta}{Z_p} \quad (9)$$

For a four-legged sling, theoretically with absolutely the same length and the same strain for the four legs, we have the equilibrium of forces at point B, according to Fig. 9:

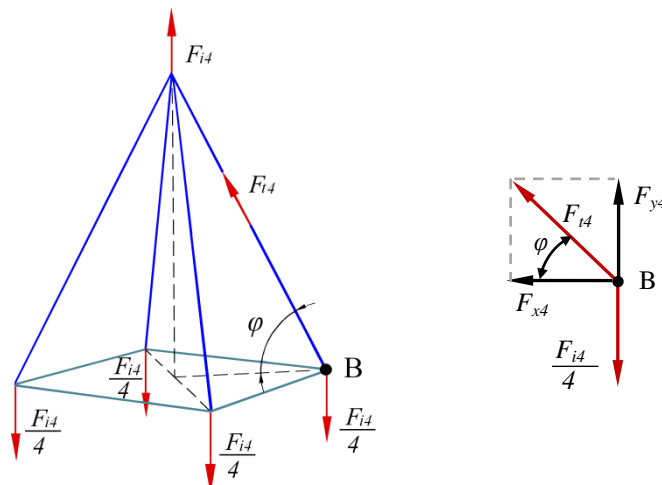


Figure 9. Forces acting on a four-legged sling.

$$F_{y4} = \frac{F_{i4}}{4} \quad (10)$$

$$\sin \varphi = \frac{F_{y4}}{F_{i4}} \quad (11)$$

Replacing F_{y4} in Eq. (11):

$$F_{i4} = \frac{F_{i4}}{4 \sin \varphi} \quad (12)$$

F_{i4} cannot have a value greater than the WLL_1 for a single-leg sling, expressed by Eq. (3), therefore:

$$F_{i4} \leq WLL_1 \therefore \frac{F_i}{4 \sin \varphi} \leq \frac{F_{min} K_R}{Z_P} \quad (13)$$

$$F_{i4} \leq \frac{4 F_{min} K_R \sin \varphi}{Z_P} \quad (14)$$

As in practice we never have sling legs with the same length and it is a hyperstatic structure, the load will not be distributed equally to the four legs. To solve this, most design codes (ABNT, 1995a; ISO, 1987; EN, 2008) consider that only 3 legs are supporting the load. Therefore, the factor “4” of Eq. (14) shall be replaced by “3”. So, the WLL for for-legged sling is:

$$WLL = \frac{3 F_{min} K_R \sin \varphi}{Z_P} \quad (15)$$

If the four-legged sling is lifting a rigid load and a structural analysis is not conducted to assess forces distribution thru legs, Eq. (9) shall be used for WLL , that is, only two legs are considered loaded and the other two are balancing the load. A rigid load can be defined as that not allowing a redistribution of forces in legs due to no deformation of the load. NBR 15637-1 (ABNT, 2008) deals briefly about distribution of forces in slings legs due to stiffness of load.

The presented method is also known as “trigonometric”, once WLL is calculated for any sling angle θ or φ above 30° and has the advantage of use all the allowable strength of the sling when this angle is above 45° .

Table 2. Suggested efficiency of wire rope terminations for revision of NBR 13541 based on Tab. 1.

Termination	K_T
Resin sockets	1,0
Ferrule secured	0,9
hand-tucked, wire rope diameter ≤ 50 mm	0,8
hand-tucked, wire rope diameter > 50 mm	0,75

5. WIRE ROPE GROMMETS

EN 13414-3 (2008) defines a wire rope grommet as an endless sling made from one continuous length of strand, formed to make a body composed of six strands around a strand core.

A cable-laid grommet, by the same Code, is defined as an endless wire rope sling made from one or two continuous lengths of rope, formed to make a body composed of six ropes around a rope core.

Grommets are not covered by NBR 13541 (ABNT, 1995a) although NBR 13543 (ABNT, 1995b) provides some slinging methods for endless slings.

As grommets are very versatile and are used worldwide, the revision of NBR 13541 shall incorporate this type of sling, including subtypes like cable-laid grommets and braided grommets.

The working load limit (WLL), in kN, of a wire rope grommet is deduced by Eq. (16) to Eq. (19), based on Fig. 10:

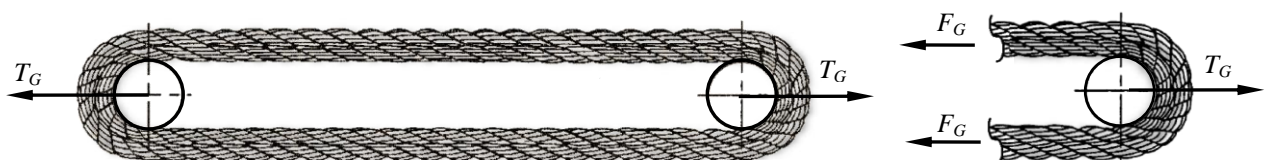


Figure 10. Forces acting on a wire rope grommet. Adapted from EN 13414-3 (2008).

$$F_G = \frac{T_G}{2} \quad (16)$$

As F_G cannot have a value greater than the WLL_1 for a single leg, Eq. (3), we have:

$$F_G \leq \frac{F_{min2} K_B}{Z_P} \quad (17)$$

$$\frac{T_G}{2} \leq \frac{F_{min2} K_B}{Z_P} \therefore T_G \leq \frac{2F_{min2} K_B}{Z_P} \quad (18)$$

The *WLL* for grommets is the maximum value for T_G , therefore:

$$WLL = \frac{2 F_{min2} K_B}{Z_P} \quad (19)$$

Where:

F_{min2} is the minimum breaking force, in kN, of the fibre core rope from which the strand is used to form the wire rope grommet, according to NBR ISO 2048 (ABNT, 2008).

K_B is the bending efficiency factor.

As cable-laid grommets have six effective ropes at any cross section (ASME, 2010), the working load limit (*WLL*), in kN, shall be calculated by Eq. (20), which is six times the value given by Eq. (19), multiplied by a factor k , defined below.

$$WLL = \frac{12 F_{min1} K_B k}{Z_P} \quad (20)$$

Where:

F_{min1} is the minimum breaking force, in kN, according to NBR ISO 2048 (ABNT, 2008), of the unit of rope which is used to form a cable-laid grommet. F_{min1} can be used because the six ropes are continuous.

K_B is the bending efficiency factor.

k is an experimental factor which allows for the spinning losses in cabling the ropes, taken as 0,9 according to EN 13414-3 (2008).

Z_P is the coefficient of utilization, not less than 5 for rope diameters (d) less than 60 mm, for diameters up to 150 mm, Z_P shall be calculated using Eq. (21), according to EN 13414-3 (2008), and for diameters greater than 150 mm, Z_P shall be equal or greater than 3.

$$Z_P = 6,33 - 0,022 d \quad (21)$$

6. CABLE-LAID SLINGS

According to EN 13414-3 (2008), a cable-laid sling is the one formed from a wire rope constructed of six unit ropes laid as outers over one core unit rope, with a termination at each end, usually in the form of a spliced eye. ISO 19901-6 (2009) defines a cable-laid sling as an assembly of several, usually six, round stranded steel wire ropes (referred to as unit ropes), laid helically around a core (usually a seventh rope).

NBR 13541 (ABNT, 1995a) does not cover the use of cable-laid slings. As single part slings have limited diameter hence limited strength, it is necessary that revision of NBR 13541 incorporates cable-laid slings.

The working load limit (*WLL*), in kN, of a cable-laid sling, expressed by Eq. (22), can be deduced from Eq. (3) multiplied by the sum of strength of outer ropes and by k . This equation is equivalent to those presented by EN 13414-3 (2008) and ISO 19901-6 (2009).

$$WLL = \frac{\sum F_{min} k K_R}{Z_P} \quad (22)$$

Where:

$\sum F_{min}$ is the sum of the individual minimum breaking forces of the outer ropes, in kN, as specified in NBR ISO 2048 (ABNT, 2008).

k and Z_P as defined for Eq. (20).

K_R as defined for Eq. (3).

7. CONCLUSIONS

It is concluded that due to the improvement of lifting research and technology, increase of loads weights, complexity of loads geometry and quantity of lifting operations, an urgent revision of NBR 13541 is necessary. It shall include other types of slings, besides single-part slings, such as cable-laid slings, grommets and cable-laid grommets.

Other configurations shall be allowed but these slings shall comply with all other requirements of the proposed reviewed code.

The reduction factors presented in this paper for termination and bending shall be used to reduce the calculated *WLL* value, increasing reliability, strength and durability of the slings.

The revision of NBR 13541 shall use the “trigonometric method” to calculate the *WLL* of the slings with more than one leg and the presented formulation for each type of sling.

The new equation proposed for *WLL* of single-leg sling, Eq. (3), leads to the same result of Eq. (2) from NBR 13541 if no bending in the body is made. If there is a bending, the situation is not covered by the Code and the new equation is the most appropriate.

Comparing Eq. (9) and Eq. (15) with Eq. (2), the proposed ones are more general, allowing a wide range of leg angles, optimizing the use of the wire rope.

As NBR 13541 does not cover grommets and cable-laid slings, the proposed equations for these types, Eq. (19), Eq. (20) and Eq. (22) shall be adopted for *WLL*.

The revision shall also modify some values of efficiency of wire rope terminations, using those suggested by Tab. 2, allowing the employment of other types of terminations, since manufacturer attests results by experimental methods.

Finally, it is necessary to revise NBR 13543 and NBR 11900 to reflect NBR 13541 modifications.

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