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Newtonian Mechanics in the Routine of Civil Construction

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***Abstract*— *The role played by General Mechanics education on the advancement of scientific and technical knowledge in our society is vitally important. In Brazil, this education is increasingly relevant due to the great boost in civil construction that our society has been attending. Particularly, we would like to highlight that this research aimed to apply the theory and exploration of friction concept, from a constructive criticism in the context of civil construction, for example: surfaces with friction, inclined planes with friction, in wedges and screw or the screw thread. To better understand the concept of friction, we instrumentalized it in a didactic context, respecting the existing knowledge with regard to the study of forces in some problems regarding to analysis of structures with friction, as we mentioned before. We understand that this is the most adaptable to the conception of a textbook in Mechanics, because it allows the exploration of the concepts in a hierarchical manner, as well it enables the deliberate manipulation of this universe to proper a meaningful learning.*

Keywords*— Concept and Applications of Friction, General Mechanics, Meaningful Learning, Types of Friction.

I. INTRODUCTION

This article is a result of theoretical studies that seek to succinctly introduce the themes of friction in the analysis of mechanical vibration in structures and structural analysis. In the implementation of the research, its phases are organized in a temporal order, being, therefore, differentiated by its main features, being thus explored in parallel.

In daily, it is common to us disregarding the friction presents on surfaces, in other words, the force exerted by a surface on another is the normal to the surface and both surfaces can freely move across each other. This model would be the ideal. Nonetheless, actually, there is no perfectly smooth surface, in other words, frictionless. The friction, for a didactic purpose, can be defined as the resistance between two bodies in contact when they tend to slide or roll one over another. Then, the relative motion of two bodies in contact is always followed by a force opposed to the displacement, generically called friction force or friction.

In the course of the study it is presented a vision of the main properties about the friction. In addition, we speak in detail on the development that lead to the expansion of friction concept and its types. We develop and represent, according to the mathematical system, the concept of friction presents in some problems in civil construction, like on surfaces, inclined planes, wedges and threaded bolts.

II. DEVELOPMENT

To better understand the concept of friction, we are going to apply it in a didactic way, respecting the previous knowledge regarding to the study of forces into some problems affecting structural analysis, for example: sliding friction, friction on wedges, friction on inclined plane and screw lift.

Friction in sliding situations

Let’s consider a block W that is placed on a horizontal surface with friction and that is under action of a horizontal force F. As the weight W has not a horizontal component, the surface reaction does not present a horizontal component, then the reaction is the normal to the surface and is presented by N, as represented in figure 01. For didactical purpose, let’s consider that the body slides in a

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uniformly movement along a straight line. Thus, the sum of the acting forces and momentums on it are null. [1]

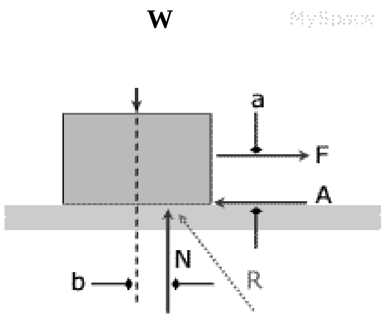

Fig.1: Slinding friction

We can observe through the figure above that if F has a low magnitude, the block will not move, in other words, another horizontal force should exist to balance F. This another force is called static friction force f, that is the net of many forces that acts above all the surface between the block and the plane. However, if the force F gets stronger, the friction force will increase too to a maximum value fm, in other words, when two bodies in contact are on the verge of sliding one over another. But if F continues to increase, the friction force will not be able to balance it anymore and the block will start to move, reducing this force fm to a force fk. So the block will keep its speed, and the force represented by fk is called kinetic friction force. It is important to highlight that it is proved, through experimental results, that the static friction force fm as well the kinetic friction force fk are proportional to the vectosdrial component N from the surface reaction. Represented by equations 01 and 02 [1]

$$\vec{f}_m = \mu_s \,.\, \vec{N} \qquad (01)$$

$$\vec{f}_k = \mu_k \,.\, \vec{N} \qquad (02)$$

μs is a constant so-called coefficient of static friction and μk so-called coefficient of kinetic friction. These static friction coefficients are parameters that depend from the nature of surface and other factors as temperature and presence of other elements on the surface such as water, oil. However, to the same material and same conditions, proportionality is valid. It is important to highlight that the friction force that exists when two bodies in contact are on the verge of sliding one over another is usually bigger than the friction force when they are sliding, that is to say, μs > μk. [2]

Wedges

Other example very common in constructions are the wedges, that are simple machines used do lift big stone blocks and other heavy loads, for example, the wedges are used to split logs. In other words, the wedge is used to move up or move down a load or to separate two parts of a system. Knowing that, these loads can be moved up by applying a force to the wedge, in general considerably smaller than the weight of the load. Furthermore, due to the friction between the surfaces, a wedge of a proper shape remains in place after been pushed to under the load. In other words, we can use the wedges as we want to make little position adjustments of machines' heavy pieces. A wedge is represented in Figure 02.

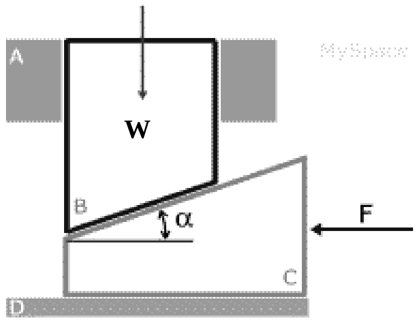

Fig.2: Wedge

In Figure 02, a horizontal force F applied on wedge C tends to lift the column B. Despising the parts' weights and considering the same friction angle φ to all the surfaces, it is desired to know the magnitude of force F that lifts a load P above column B at a constant velocity.

As the bodies are in mechanical equilibrium, the sum of parts B and C forces has to be zero, in other words, ∑ F = 0, and it is represented in Figure 03.

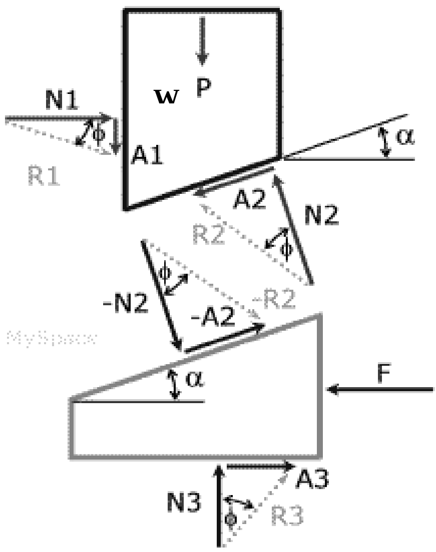

Fig.3: Representation of acting forces on the blocks

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In B: $\vec{W}+\vec{R}_2+\vec{R}_1=0$ (03)

In C: $\vec{F}+\vec{R}_3-\vec{R}_2=0$ (04)

The vector diagram can be seen in Figure 04. Considering triangle properties,

$$\vec{F}\,/\,sen\,c=\vec{R}_2\,/\,sen\,b \quad (05)$$

$$\vec{W}\,/\,sen\,c=\vec{R}_2\,/\,sen\,e \quad (06)$$

$$\vec{F}=\vec{R}_2\;sen\,c\,/\,sen\,b \quad (07)$$

$$\vec{R}_2=\vec{W}\;sen\,e\,/\,sen\,d \quad (08)$$

$$\vec{F}=\vec{W}\,(sen\,c\;\;sen\,e)\,/\,(sen\,b\;sen\,d) \quad (09)$$

To the angles:

$$a=90^0-\varphi-\alpha \quad (10)$$

$$b=90^0-\varphi \quad (11)$$

Therefore,

$$sen\,b=\cos\varphi \quad c=\alpha+2\varphi \quad (12)$$

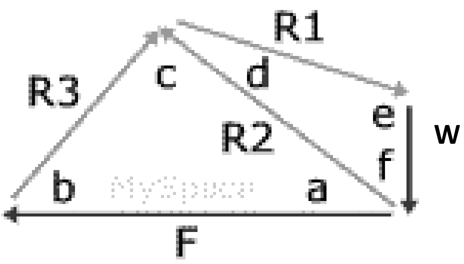

Fig.4: Representation of vector diagram

$$d=90^0-2\varphi-\alpha \quad (13)$$

Therefore,

$$sen\,d=\cos\,(2\varphi+\alpha) \quad (14)$$

$$e=90^0+\varphi \quad (15)$$

Therefore,

$$Sen\,e=\cos\varphi \quad (16)$$

$$f=\varphi+\alpha \quad (17)$$

Replacing, $\vec{F}=\vec{W}\,sen\,(\alpha+2\varphi)\cos\varphi\,/\,(\cos\varphi\cos(2\varphi+\alpha))$.

The simplification of this equation results in:

$$\vec{F}=\vec{W}\tan\,(2\varphi+\alpha) \quad (18)$$

Jack screw

It is a screw with a rectangular threaded (Figure 06) and it is used to raise certain load. They are usually used for jacks, presses and other engines. In other words, the screw thread behaves like an inclined plane rolled up to form a screw. To better understand this concept, let's observe the Figure 05 that represents a block on an inclined plane that makes an angle α with the horizontal and is under action of its own weight, according to Figure 05, and has a friction angle φ with the surface.

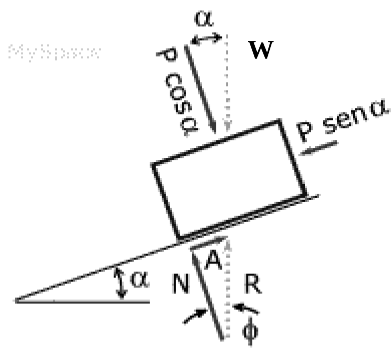

Fig.5: Inclined plane

Thereby, we are able to conclude that the body remains at rest if,

$\alpha \leq \varphi$. (19)

For this purpose, we can find the momentum M of Figure 06, for which it will be necessary to apply in function of this load, the thread's internal (Di) and external diameter (De), the thread's angle α and the friction angle φ.

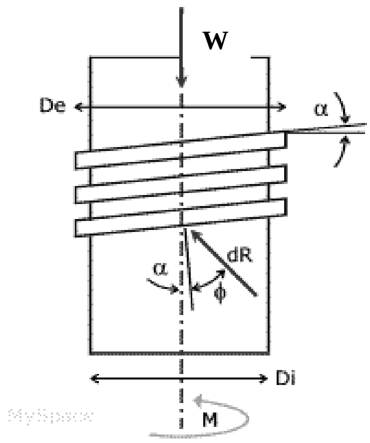

Fig.6: Rectangular thread screw

Considering that each thread screw supports the load W uniformly distributed along an average radius r, given by (De + Di)/4. So, in each infinitesimal portion of r it will occur a reaction dR that makes an angle (α + φ) with the vertical. In other words, in equilibrium condition:

$$\sum \vec{F}_y = 0 = \vec{W} - \int dR\cos(\alpha+\varphi) \quad (20)$$

or

$$\vec{W} = \cos(\alpha+\varphi)\int dR \quad (21)$$

As we have

$$\sum \vec{M} = 0 = \vec{M} - ((D_e + D_i)/4\int dR\, sen(\alpha+\varphi) \quad (22)$$

Thus,

$$\vec{M} = \vec{W}\tan(\alpha+\varphi)(D_e + D_i)/4 \quad (23)$$

III. FIGURES AND EQUATIONS

The following is the representation of the figures used in this article, present in the development of this paper.

a) Sliding friction

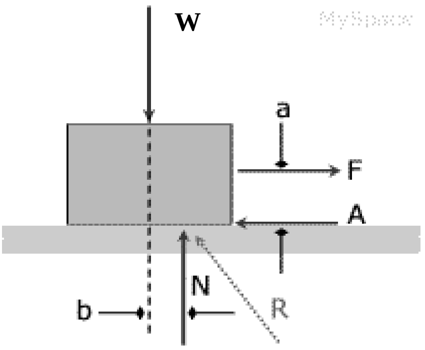

Fig.7: Sliding friction
Image source: Google images

b) Wedge

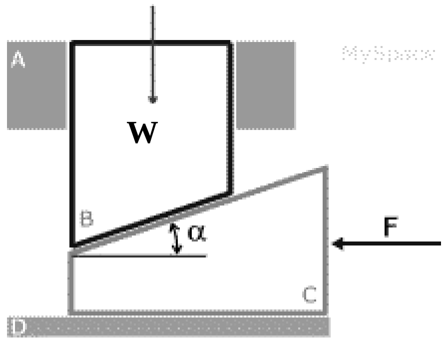

Fig.8: Wedge
Image source: Google Images

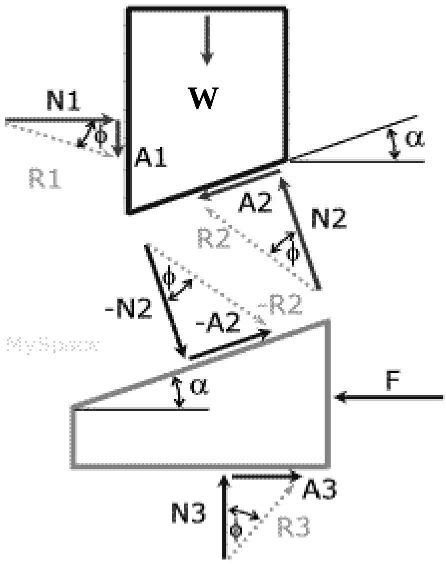

Fig.9: Representation of forces acting on the blocks

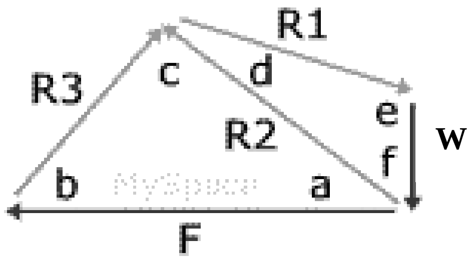

Fig.10: Representation of vector diagram
Image source: Google images

c) Jack screw

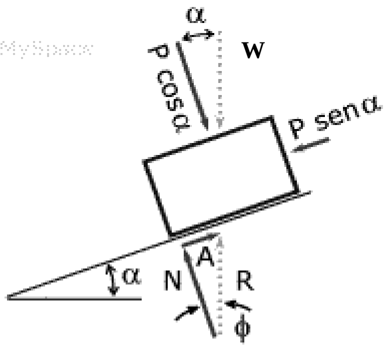

Fig.11: Inclined plane

Image source: Google images

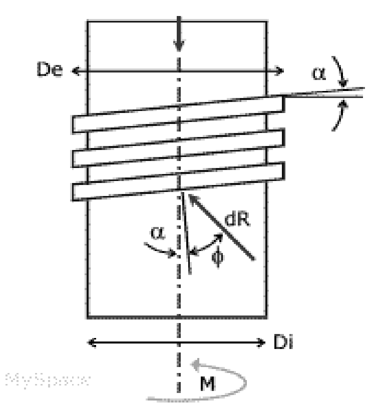

Fig.12: Rectangular thread screw

Image source: Google images

Equations

a) Sliding friction

1) $\vec{f}_m$ → Static frictional force

2) $\vec{f}_k$ → Kinetic frictional force

3) μ_s → Coefficient of static friction

4) μ_k → Coefficient of kinetic friction

$$\vec{f}_m = \mu_S . \vec{N} \qquad (01)$$

$$\vec{f}_k = \mu_k . \vec{N} \qquad (02)$$

b) Wedges

The vector components are represented below in bold and are named as: [3]

1) $\vec{W}$ → Weight force

2) $\vec{R}$ → Net force

3) c, b, d, e → Angles relative to Figure 04.

4) φ, α → Angles of triangle.

5) $\vec{f}$ → Friction force

$$\vec{W} + \vec{R}_2 + \vec{R}_1 = 0 \qquad (03)$$

$$\vec{F} + \vec{R}_3 - \vec{R}_2 = 0 \qquad (04)$$

$$\vec{F} \,/\, sen\, c = \vec{R}_2 \,/\, sen\, b \qquad (05)$$

$$\vec{W} \,/\, sen\, c = \vec{R}_2 \,/\, sen\, e \qquad (06)$$

$$\vec{F} = \vec{R}_2 \, sen\, c \,/\, sen\, b \qquad (07)$$

$$\vec{R}_2 = \vec{W} \, sen\, e \,/\, sen\, d \qquad (08)$$

$$\vec{F} = \vec{W}\,(sen\, c \;\; sen\, e) \,/\, (sen\, b\, sen\, d) \qquad (09)$$

$$a = 90^0 - \varphi - \alpha \qquad (10)$$

$$b = 90^0 - \varphi \qquad (11)$$

$$sen\, b = \cos\varphi \quad c = \alpha + 2\varphi \qquad (12)$$

$$d = 90^0 - 2\varphi - \alpha \qquad (13)$$

$$sen\, d = \cos\,(2\varphi + \alpha) \qquad (14)$$

$$e = 90^0 + \varphi \qquad (15)$$

$$Sen\, e = \cos\varphi \qquad (16)$$

$$f = \varphi + \alpha \qquad (17)$$

$$\vec{F} = \vec{W}\,\tan\,(2\varphi + \alpha) \qquad (18)$$

c) Jack screw

1) $\vec{M}$ → Momentum of a force

2) $\vec{R}$ → Net force

3) c, b, d, e → Angles relative to Figure 04.

4) φ, α → Angles of triangle

5) φ → Angles of friction

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$$\alpha \leq \varphi. \tag{19}$$

$$\sum \vec{F}_y = 0 = \vec{W} - \int dR \cos(\alpha + \varphi) \tag{20}$$

$$\vec{W} = \cos(\alpha + \varphi) \int dR \tag{21}$$

$$\sum \vec{M} = 0 = \vec{M} - ((D_e + D_i)/4 \int dR\, sen(\alpha + \varphi) \tag{22}$$

$$\vec{M} = \vec{W} \tan(\alpha + \varphi)(D_e + D_i)/4 \tag{23}$$

IV. CONCLUSION

This work aimed to develop a didactic material in the field of Newtonian Mechanics, geared for the meaningful learning of generators concepts attributed to the study of problems involving the friction force applied to sliding bodies, on wedges, on inclined planes and on screw or screw thread.

From this analysis, we intended to demonstrate and represent the friction force present in several structures associated with civil construction. In other words, it results in the expansion of friction concept, which conception and application in the practical context reflects the physical concepts' representational ability in various situations. Furthermore, its wide range of actions allows the gradual deepening exploitation of this physics concept, being unnecessary a systematic introduction of mathematical formalism.

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