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Design of an adjustable prop made of Polymeric material

Diseño de un puntal ajustable elaborado de material Polimérico

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Abstract

In this work, an adjustable prop made of polymeric material was designed. To do this, standards that refer to this element were consulted and which specify that the load that the prop must support is 6000 N including live loads and dead loads. Consequently, the selection of the appropriate polymer for this application was carried out through a comparison of the mechanical properties of these materials, with acetal proving to be better. With this information, a buckling analysis was carried out using the analytical method considering an adjustable prop length of 3 m. In addition, supported by the Solidworks® software, a simulation of the critical load and contact stress was also carried out, resulting in the fixed part of the adjustable prop being a tube with an internal diameter of 80 mm and an external diameter of 95 mm. The adjustable part must be solid with a diameter of 80 mm.

Adjustable prop, Falsework, Buckling, Acetal

Resumen

En este trabajo se diseñó un puntal ajustable en altura elaborado de material polimérico. Para ello, se consultaron normas que hacen referencia a este elemento y donde se especifica que la carga que debe soportar el puntal es de 6000 N incluyendo cargas vivas y cargas muertas. En consecuencia, la selección del polímero adecuado para esta aplicación se realizó mediante una comparación de las propiedades mecánicas de estos materiales resultando ser mejor el acetal. Con esta información se procedió a realizar un análisis de pandeo por el método analítico considerando una longitud del puntal de 3 m. Además, apoyados en el software de solidworks®, se realizó tambien una simulacion de la carga crítica y de esfuerzos de contacto dando como resultado que la parte fija del puntal debe ser un tubo con diámetro interior de 80 mm y 95 mm el diámetro exterior. La parte ajustable debe ser sólida con un diámetro de 80 mm.

Puntal telescópico, Cimbra, Pandeo, Acetal

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Introduction

The construction industry uses large quantities of standard-sized wooden poles for shoring, which are generally 2.5 m long and 76 mm square in cross-section. Nowadays, concern for forest conservation has led to a search for options in terms of the materials used for the production of these elements. For example, telescopic props made of steel can be found on the market with lengths ranging from 1.75 m to 3.5 m and load capacities ranging from 23 KN to 8.44 KN [1] [3]. Plastic dunnage with the above mentioned standard dimensions for wooden dunnage is also available on the internet. As a consequence, in this work, the structural feasibility of a telescopic prop made of polymeric material is analysed.

General objective

To determine, by means of the analytical method and the finite element method, the dimensions and geometries of a telescopic prop made of polymeric material capable of supporting a load of 6 KN.

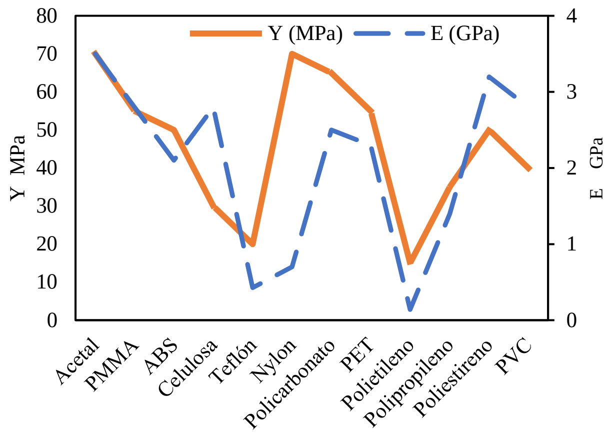
Methodology

According to the ACI-347-04 guide, the design of a shoring system must be dimensioned to withstand the live and dead loads, whose value reaches 6 KPa with a safety factor of 2 [1]. The length of the prop, proposed for this analysis, was 3 m; and the selection of the plastic to be used was a function of its modulus of elasticity and its tensile strength since, in the buckling analysis using Euler's formula, the critical load is a function of the mechanical properties mentioned above. With respect to the tensile strength Y and modulus of elasticity E, table 1 shows the values for some of the most common plastics on the market and also shows the main applications.

Material	E (GPa)	Y (MPa)	Applications
Acetal	3.5	70	Automotive components
PMMA	2.8	55	Light lenses, aircraft windows.
ABS	2.1	50	Tubes, office machines.
Cellulose	2.8	30	Clothing, cellophane paper.
Teflon	0.425	20	Bearings, kitchen utensils.
Nylon	0.7	70	Mats, clothing, tyre cords.
Polycarbonate	2.5	65	Safety helmets, glass.
PET	2.3	55	Beverage containers, fabrics.
Polyethylene	.14	15	Bottles and tubes.
Polypropylene	1.4	35	Injection moulded parts.
Polystyrene	3.2	50	Toys, foams.
PVC	2.8	40	Rigid tubes for drainage and irrigation.

Table 1 Mechanical properties of plastics and their applications
Source: Own Elaboration with data obtained from [4]

In order to select the material in an objective way, graph 1 was made where the values of tensile strength Y, as well as Young's modulus E of different plastics are compared. In this graph, it could be seen that acetal is the plastic with the highest values in both properties.



Graph 1 Tensile strength and modulus of elasticity values for different polymers
Source: Own Elaboration with information from [4]

Other properties of acetal, whose technical name is polyoxymethylene thermoplastic material (POM), are shown in table 2. Its high melting point allows it to be used up to temperatures of 100°C, competing with some metallic materials such as zinc and brass.

Property	Valor
Yield strength MPa	71.5
Poisson's modulus	0.3859
Maximum working temperature °C	100
Density g/cm^3	1.41
Melting point °C	170
Density kg/m^3	1410

Table 2 Mechanical properties of acetal.
Source: Own Elaboration with data obtained from [9]

As for the props, they must be erected in such a way that they do not tilt and must be firmly supported by a square-shaped termination at the end. For adjustable models, the load values depend on their length and can be seen in table 3.

Prop height in m	Carrying capacity in KN	
	Strut of 1.75 m-3.10 m	Strut of 2.10 m-3.50 m
1.75	23	
1.9	23	
2	23	
2.3	20.43	22.14
25	17.64	20.5
2.7	14.21	16.5
3	9.83	12.17
3.3		9.72
3.5		8.44

Table 3 Load-bearing capacity of telescopic metal props.
Source: Adapted from [9]

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Strut dimensioning using the analytical method

As a starting point, a length of 3 m and an outer pipe diameter of three inches (76 mm) was considered. With this information we proceeded to calculate the inner diameter of this tube to avoid buckling failure using the Euler's critical load equation.

The critical Euler load on an element before buckling occurs is given by equation (1) where one end is considered embedded and the other sliding (Figure 1).

$$P_{cr} = \frac{\pi^2 EI}{L^2} \quad (1)$$

And the critical stress is expressed by equation (2) as being inversely proportional to the cross-sectional area.

$$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{\pi^2 EI}{AL^2} \quad (2)$$

In equations (1) and (2), E is the modulus of elasticity of the material in Pa, A is the cross-sectional area of the column in m^2, I is the moment of inertia in m^4 and L is the length of the element in m.

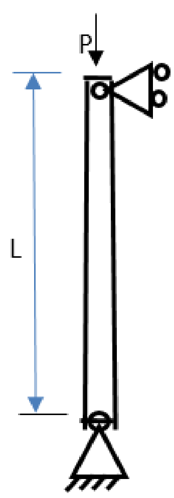

Figure 1 Parameters involved in the buckling of an element
Source: Own elaboration adapted from [6]

For a tube, the equation (1) is expressed as (3).

$$P_{cr} = \frac{\pi^2 E\left(\frac{\pi\left(d_{ext}^4 - d_{int}^4\right)}{64}\right)}{L^2} \quad (3)$$

In proposing the value of dext, the unknown is the value of dint, which can be removed from equation (3).

$$d_{int} = \sqrt[4]{d_{ext}^4 - \frac{64 * P_{cr} * L^2}{\pi^2 * E * \pi}} \quad (4)$$

Given the above conditions and using the properties of acetal, the values used in equation (4) were: Pcr=6000 N, E=3.5 GPa, L=3 m, dext=76 mm resulting in dint=35 mm. Then, different values of dext were analysed to find the minimum value that complies with the load condition since a smaller diameter will be easier to handle and also represents a lower weight. The results obtained are shown in table 4.

d_{ext} mm	d_{int} mm
100	90.8
90	76
80	54
76	35
75	There is no value

Table 4 Outer diameter and inner diameter values for a tubular section required for a critical load of 6000 N
Source: Own Elaboration

Now that the inner dimensions of the fixed tube are known, the diameter of the telescopic element was determined using equation (5).

$$d_{ext} = \sqrt[4]{\frac{P_{cr} * L^2 * 64}{\pi^3 * E}} \quad (5)$$

$$d_{ext} = \sqrt[4]{\frac{6000 * 3^2 * 64}{\pi^3 * 3.5x10^9}}$$

$$d_{ext} = .0751\, m = 75 \text{ mm}$$

Dimensionamiento del puntal mediante el método de elemento finito

Se utilizó el programa de cómputo SolidWorks® para realizar el modelado y el análisis de pandeo por elemento finito. En cuanto al pandeo, el análisis se realizó con las piezas de forma individual y el análisis de esfuerzos de contacto y factor de seguridad se realizó con las piezas ensambladas las cuales consisten de un tubo fijo, un redondo y un pasador. Este ultimo se le agregaron las propiedades del acero SAE 1015 tomadas de [5] y loas otras piezas con las propiedades del material acetal tomadas de [4].

Results

From the application of the analytical method it was determined that the telescopic part should be a round bar with a diameter of 76 mm and length of 1.5 m. As a consequence, the inner diameter of the fixed tube should be 76 mm with a fit H7 [7] and a thickness of 7.5 mm.

The finite element analysis allowed to take into account the holes in the tube that serve to adjust the height of the strut. After sufficient simulations, it was determined that the dimensions of the telescopic strut should be as shown in figure 2.

The mentioned dimensions result in a load factor of 6355 N and 6531 N for the two elements.

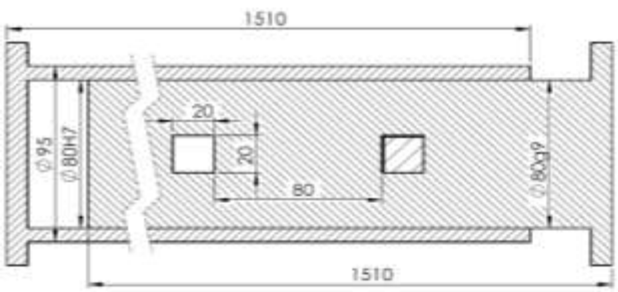

Figure 2 Dimensions of the elements that make up the telescopic prop
Source: Own Elaboration [SolidWorks]. Mass = 10.5 Kg

In the contact stress analysis with SolidWorks, using a load of 6000 N applied to the assembled model, the Von Mises stresses were 34.8 MPa and thus a minimum safety factor of 2.1 was obtained as shown in Figure 3.

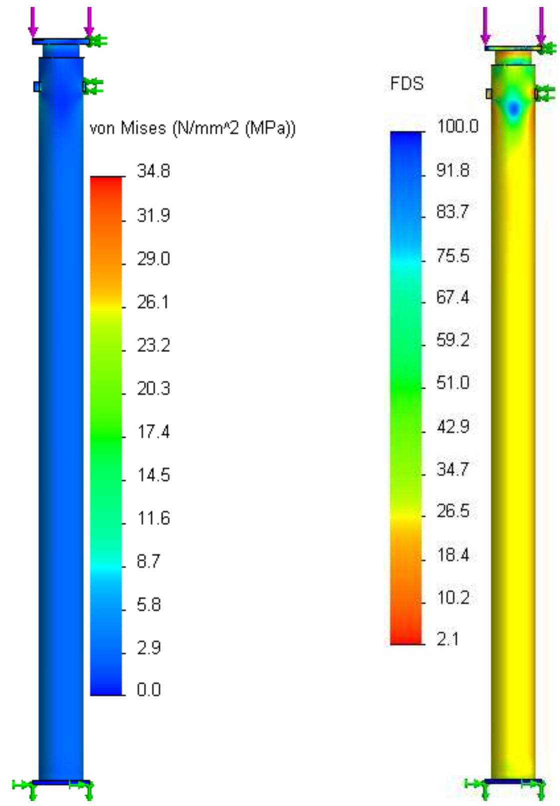

Figure 3 Von Mises stress in MPa and factor of safety
Source: Own Elaboration [SolidWorks]

Therefore, if we consider a solid element, the diameter must be larger than 75 mm since we are working with a telescopic strut composed of two pieces where one slides inside the other, and the proposed dimensions, based on the calculations made, will be as shown in figure 2.

Acknowledgements

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Conclusions

From the results obtained from the buckling analysis and the simulations for the determination of contact forces, it is concluded that it is possible to use acetal as a material for the fabrication of adjustable props used in construction for a load of 6 KN. For a prop length of 3 m, the appropriate external diameter is 95 mm with a thickness of 7.5 mm, resulting in a factor of safety of 2.1 and a von mises stress of 34.8 MPa.

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