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Application of Simulation Technology in Analysis of the Influence of the Casing Hanger Length on the Stress and Deformations of Suspended Casing

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Abstract: *Conventional wells consist of several steel casings; a surface casing, a production casing and a tubing pipe (retrievable pipe placed within a well to conduct fluid from the well's producing formation into the christmas). The surface casing commonly reaches a depth of about 10-100 meters and the production casing a depth of about 800-2500 meters. The casing diameters vary with regard to the depth of the wells. For well drilling the casing column is suspended in the wellhead through the casing hanger. Their dimensioning is done analytically, considering the maximum weight of the column of casing. Design loads according to API 6A, are the weight of the column and the pressure in the system. The loads to which the casing will be exposed during the life of the well will depend on the operations to be conducted. Casing suspending on casing hanger will result in radial (burst and collapse) and axial (tensile and compressive) loads on the casing strings.*

In this paper, using finite element analysis (ANSYS), we studied the influence of pressure on the casing resistance suspended into the 9 5/8 " casing hanger for three slip lengths (170 - resulting from analytical calculation, 120 and 220 mm).

Keywords*: Casing hanger, Finite Element Analysis, ANSYS*

1. Introduction

The wellheads are used to suspend casings and tubing and to seal the annular space between them, from 2 3/8 in - 21 ¼ in and 2000-10000 psi work pressure, in any combination. The typical wellhead assembly is shown in figure 1.

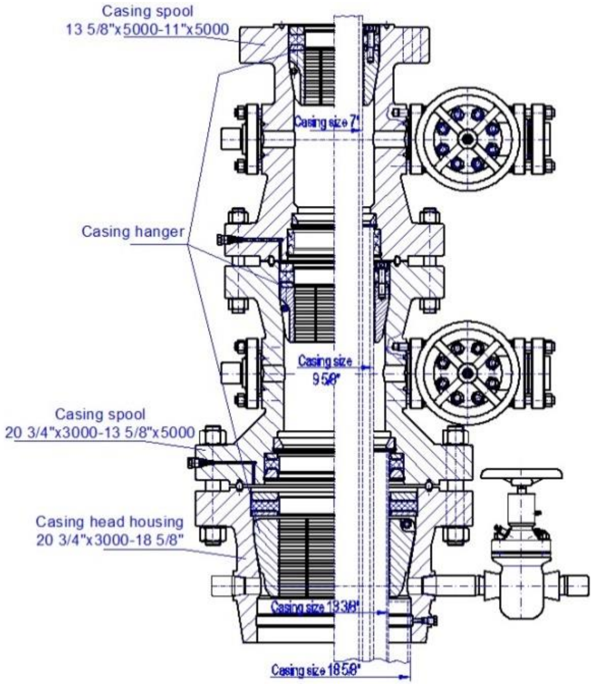

Fig. 1. Typical wellhead assembly

The Slip Type (SC) Casing Hangers (figure 2) has a medium capacity of suspension and includes a ring seal which works up to 10000 psi (68,9 MPa).

The seal energizing is performed by tightening the seals screws. This type of hanger is wrapped around the casing and then lowered until it sits inside the casing spool. The slips are automatically set when the casing is lowered (in a similar fashion to drillpipe slips) [1, 2]. These types of hanger are also used when tension has to be applied in order to avoid casing buckling when the well is brought into production.

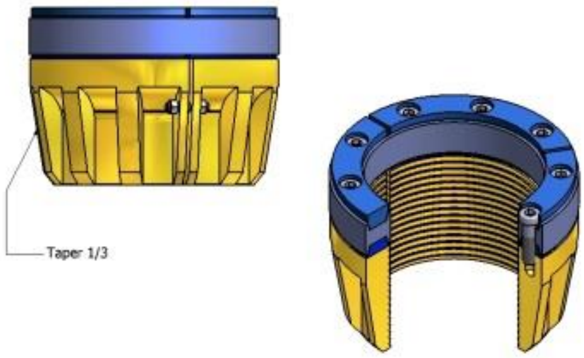

Fig. 2. SC Type- Casing hanger

2. Design methodology

2.1. Dimensioning of casing hanger SC 9 5/8 length

The load and pressure ratings for casing hanger are a function of the tubular grade of material and wall section.

According to API Specification 6A, casing hangers design will take into account [1]:

-radial load on hanger body due to settlement tapered surface;
-tensile loads directly distributed on hangers' body due to the weight of the suspended column of the casing;
-load distributed to casing hanger due the pressure test in field work.

For the suspension of the columns, the casing hanger slips lean on the internal tapering surface (1: 3) of casing spool (figure 3).

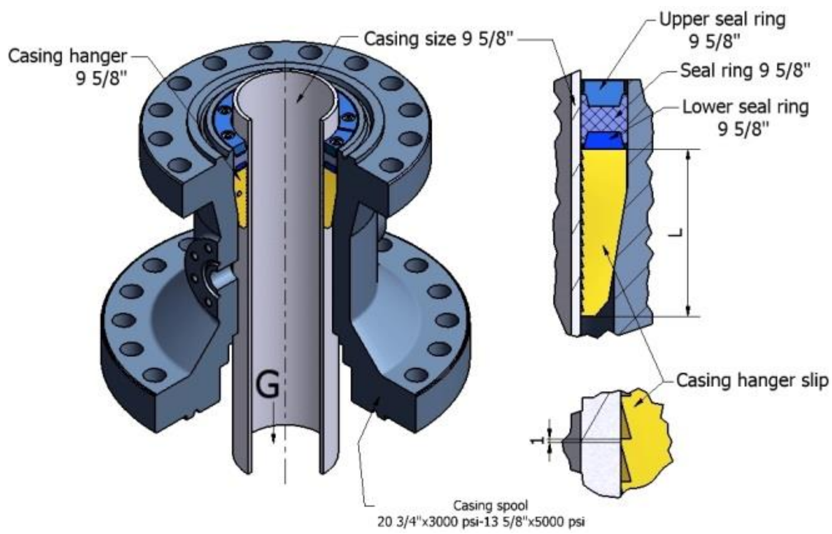

Fig. 3. Suspend and seal 9 5/8 in column on casing spool

To fulfil the role of supporting the weight of the column during tubing well works or in case of if hang off procedures during bad weather, it is necessary to (Figure 4).

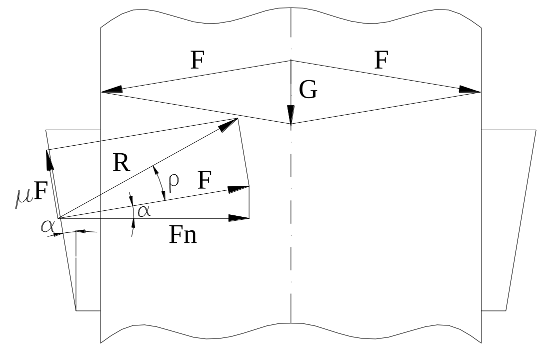

Fig. 4. The system of forces to hinge the column on casing spool

$$G = 2R\sin(\propto + \rho) \tag{1}$$

where: *G* - is the casing weight *(N);*

$\mu = tg\rho = 0{,}15$ -steel/steel friction coefficient

$(\rho = 8^o 32')$

$\propto$ - casing hanger tapering angle

The tapered rough backs control slip assembly movement and the radial component F_n acting on tubular material are:

$$2F_n = 2Rcos(\alpha + \rho) \tag{2}$$

But,

$$2R = \frac{G}{sin(\alpha + \rho)}$$

$$2F_n = \frac{G}{tg\ (\alpha+\rho)} \tag{3}$$

Specific pressure p_s which develops on tapered surfaces of the spool and the casing hanger are:

$$p_s = \frac{G}{S \cdot tg\ (\alpha+\rho)} \qquad (N/mm^2) \tag{4}$$

where: *S*- the real contact surface between casing spool and casing hanger *(mm²).*

The length of the slip of a casing hanger is given by the need to ensure the suspending weight column, avoiding the collapsing of the tube in the hanging zone [2, 3] is:

$$l = \frac{G}{2\pi \cdot D \cdot \sigma_c \left[\frac{t}{D} - \left(\frac{t}{D}\right)^2\right]\left[1 - \frac{4G}{\pi\left(D^2 - D_i^2\right)} \cdot \frac{1}{\sigma_c}\right] \cdot tg(\alpha+\rho)} \qquad (mm) \tag{5}$$

In which: $\sigma_c = 720MPa$ the casing material specified (N80) minimum yield strength;

t - casing wall thickness;

D - casing outside diameter;

D_i - casing inside diameter.

It is considered the variant N80 material with higher mechanical characteristics and the smallest wall thickness t = 10.05 mm.

Thus, the dimensions of casing are:

$$D = 244.5\ mm$$

$$Di = 222.4\ mm$$

$\frac{t}{D} = 0.045 > 0.040$– thick-walled tube

For weight G =1810 kN of the 9 5/8 in casing, the calculated slip length is $l = 170\ mm$

The maximum load *T* with which the casing can be loaded [3] is:

$$T_{max} = \frac{\sigma_c \cdot S_m}{C_z} \tag{6}$$

Where: $S_m = 8104\ mm^2$ -average section of the 9 5/8 in casing:

$C_z = 1.8$ – tensile safety factor.

$$T_{max} = \frac{720 \cdot 8104}{1{,}8} = 3241.7 \cdot 10^3 N > G = 1810\ kN$$

In order to fulfill its functional role, it is necessary that the maximum loading does not exceed 50% of the allowable stress of the material of the casing [1].

2.2. Specific contact pressure

Under the action of forces $2F_n$, between the peaks of the teeth of the casing of the head slip and the casing, the specific pressure which should not exceed the yield strength of the material casing is developed. In order not to print permanent deformation traces through casing body, we will consider:

$$p_s = (0.75 \div 0.85)\sigma_c \tag{7}$$

The contact surface between casing hanger and tube is:

$$S_c = \pi \cdot D \cdot h_1 \cdot n \tag{8}$$

where: n – number of teeth on the inner surface of casing hanger;

h_1 – contact width of a tooth ($h_1 = 1mm$) ;

$$p_s = \frac{2 \cdot F_n}{S_c} = \frac{\frac{G}{tg(\alpha+\rho)}}{S_c} \tag{9}$$

Thus, for $S_c = \pi \cdot D \cdot h_1 \cdot n = \pi \cdot 244.5 \cdot 1 \cdot 15 = 11522\ mm^2$ the specific contact pressure is:

$p_s = 483\ N/mm^2 < (540 \div 612)\ N/mm^2 = (0.75 \div 0.85)\sigma_c$ for casing material N80.

Hanger teeth will not leave permanent traces through casing deforming.

2.3. Total deformation for material on casing surface

Under the action of specific pressure that develops on the surface of contact with hangers' teeth, the casing material deforms in the elastic area.

The penetration of the teeth in the outer surface of the casing can be calculated using the equation [1,3]:

$$\Delta l = \frac{2F_n \cdot D}{E \cdot A} = \frac{\frac{G}{tg(\alpha+\rho)} \cdot D}{E \cdot \pi \cdot D \cdot h_1 \cdot n} \tag{10}$$

The radial forces $2F_n$ will cause a dent in the material, below the surface of the teeth peaks, namely an agglomeration of material around these areas (Figure 5).

In this application the penetration of the teeth in the outer surface of the casing is:

$$\Delta l = 0.562\ mm$$

As there is no relative motion between hanger slips and tube, friction adhesion appears. The coefficient of friction of adhesion μ_0 is slightly larger than the coefficient of sliding friction, in motion μ .

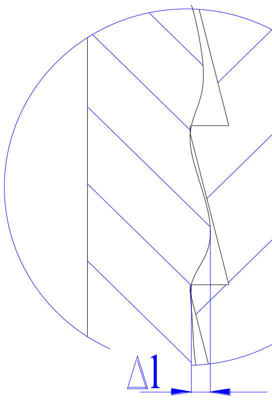

Fig. 5. Casing material deformation

For the steel / steel couple: $\mu = 0.15 \div 0.22$ and $\mu_0 = 0.25 \div 0.35$ [3]

Under the action of axial force G, the column of the casing tends to slip, which is opposed by friction adhesion and agglomeration of formed by deforming of the material.

$$G \le \mu_0 \cdot 2F \cdot cos(\alpha + \rho) + n \cdot \pi \cdot D \cdot \Delta l \cdot \sigma_c \quad (11)$$

If there were no friction, resistance that develops sill formed by deforming the material Δl will be:

$$\sigma_{ef} = \frac{G}{\pi \cdot D \cdot \Delta l \cdot n}$$

In this application: $\sigma_{ef} = 280 N/mm^2 < \sigma_c$

Since the yield strength of the material is not exceeded, the casing column do not slide down and the hanger teeth will not leave marks on the casing wall.

For the pipe not to slide on the casing hanger [6] it must be provided with teeth which achieves a higher coefficient of friction of 0.27. The configuration of this type of teeth generally provide $\mu_0 = 0.35$.

3. The length of the casing hanger FEM (ANSYS) verification and determination of the influence of the pressure (3000 psi) within the column

To validate the analytical calculation, in addition to experimental tests, we checked the behavior of the casing in the assembly (casing spool- casing hanger- casing column) loaded by the weight of the column, to which was added the system pressure (internal pressure) was added.

The program developed using ANSYS 14.5 [8] and the model was established from the conical part of flange (intermediate casing spool), slip type casing hanger assembly and 9 5/8 "casing of N-80 with a thickness of 10.05 mm.

Contacts, identified by the *program controlled*, between tapered surface of the flange and the casing hanger slips are defined *frictional type with 0.15 friction coefficient* and contacts between hanger inside and casing are defined *frictional type, with 0.35 coefficient.*

The meshing of the parts was done differently (in order to decrease the structural error to an acceptable level) [8, 9, 11].

- For casing hanger and flange - tetrahedrons method, patch conforming algorithm, element midside nodes- kept
- For casing - automatic method, element midside nodes- kept

Restraint and loads define the environment of the model. Fixed support was chosen on casing spool face and loads (weight force G=1810 kN for 9 5/8 in casing column).

The verifications were done in two stages (fig.6):

Stage 1: without pressure

Stage 2: with internal pressure - 3000 psi (20.684MPa)

for three hanger lengths (L =170, 120 and 220 mm)

To check the casing behavior, two patches length 400 mm, on two generators of outer surface of casing, in hanger area, were defined.

By solving the ANSYS static study the following solutions were calculated (especially on the two paths) as exemplified in Figure 7, 8 and 9 and centralized in Table 1.

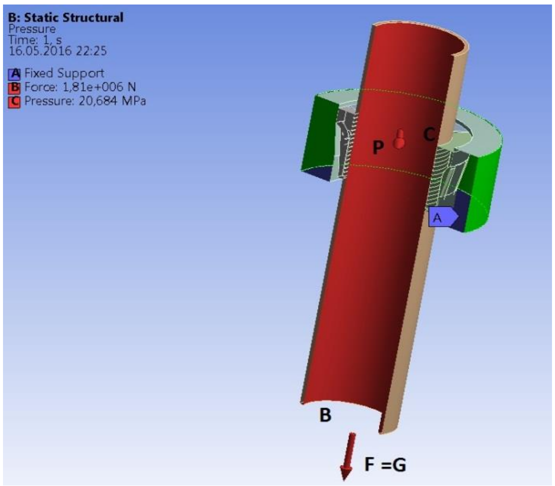

Fig. 6. Restraint and loads (stage 2) for static studies by ANSYS

- von-Mises Equivalent Stress (MPa)(fig.7, table 1);
- Directional deformation (X, Y and Z axis) on Path1 and Path 2 (table 1)
- von-Mises Equivalent Stress (MPa) on Path 1 and Path 2 (Figure 8, tabel 1)
- Total deformation (mm) on Path 1 and Path 2 (Figure 9, table 1)

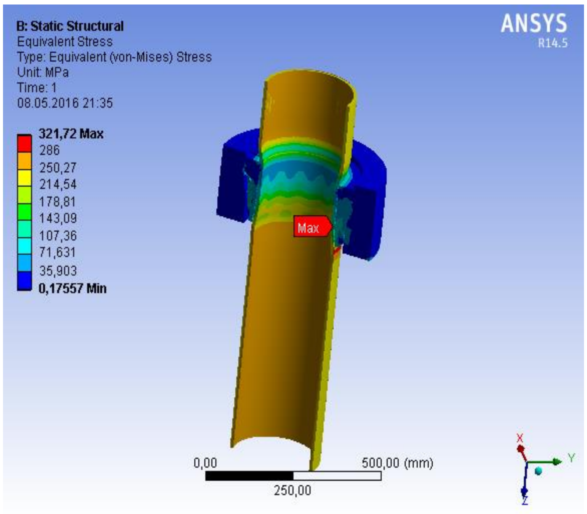

Fig. 7. Equivalent (vonMises) Stress

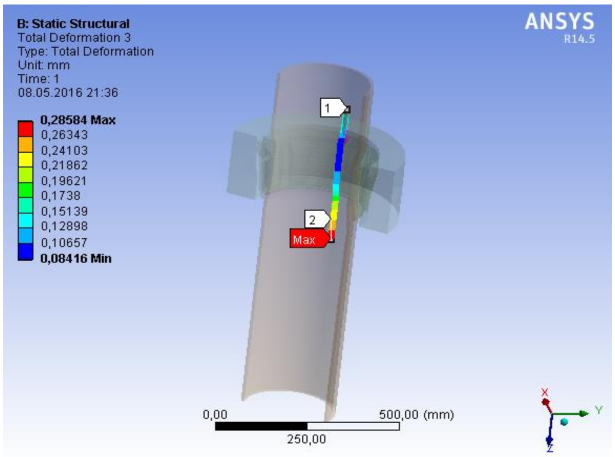

Fig. 8. Total deformation exemplification figure – cansing hanger node on Path 2(L=170 , stage 2)

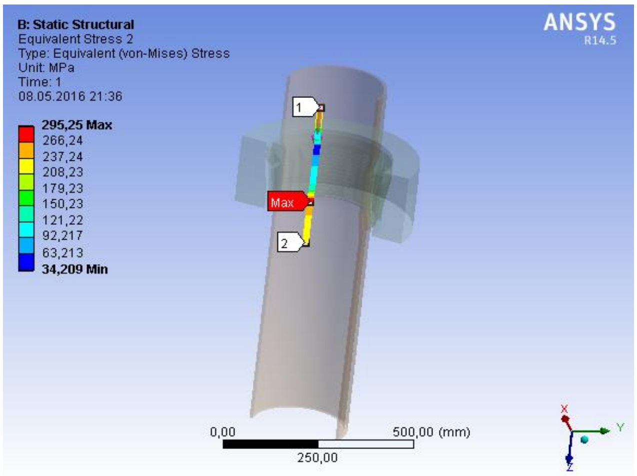

Fig. 9. Equivalent (vonMises) Stress exemplification figure – cansing hanger node on Path 2(L=170 , stage 2)

Table 1: The results of static analysis for three variants of casing hanger length and two load stage

Casing hanger dimension	Equivalent stress		Total deformation		Directional deformation (Path 2)		
	(Path1)	(Path2)	(Path1)	(Path2)	X axis	Y axis	Z axis
9 5/8 in	(N/mm2)		mm		mm		
L=170	293.91	296.34	0.3183	0.3186	0.0197	0.0096	0.31563
L=170 -internal pressure	295.25	290.49	0.2862	0.2858	0.0989	0.0997	0.2708
L=120	657.27	725.14	4.9349	4.9409	0.0093	0.0125	4.9407
L=120 -internal pressure	443.15	507.13	3.6526	3.6542	0.1043	0.1088	3.6532
L=220	474.76	538.64	3.0833	3.0868	0.0045	0.0082	3.0864
L=22 -internal pressure	299.77	330.12	1.8672	1.8711	0.0996	0.10389	1.869

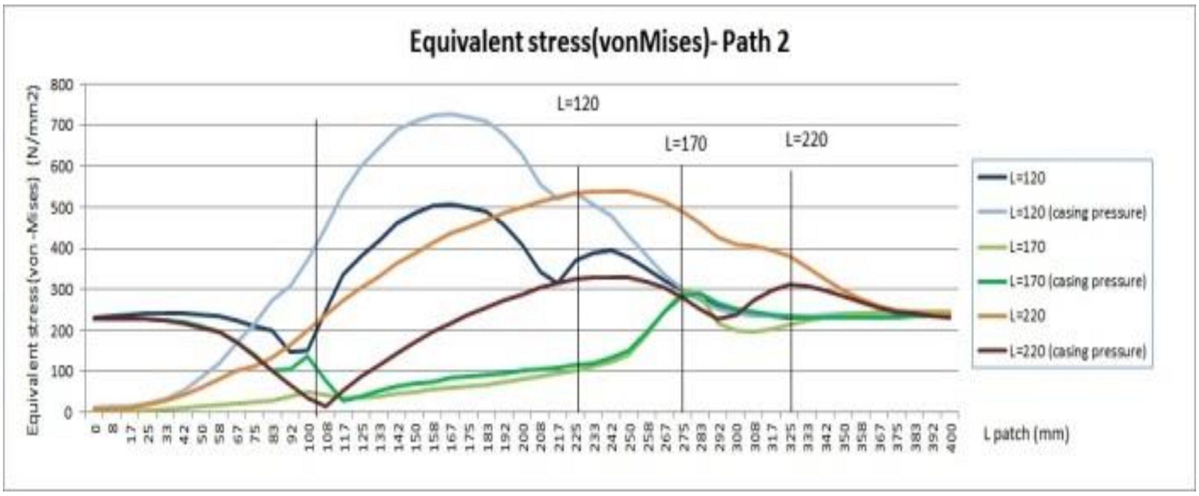

Fig. 10. Graph of Equivalent stress (von Mises) on path 2

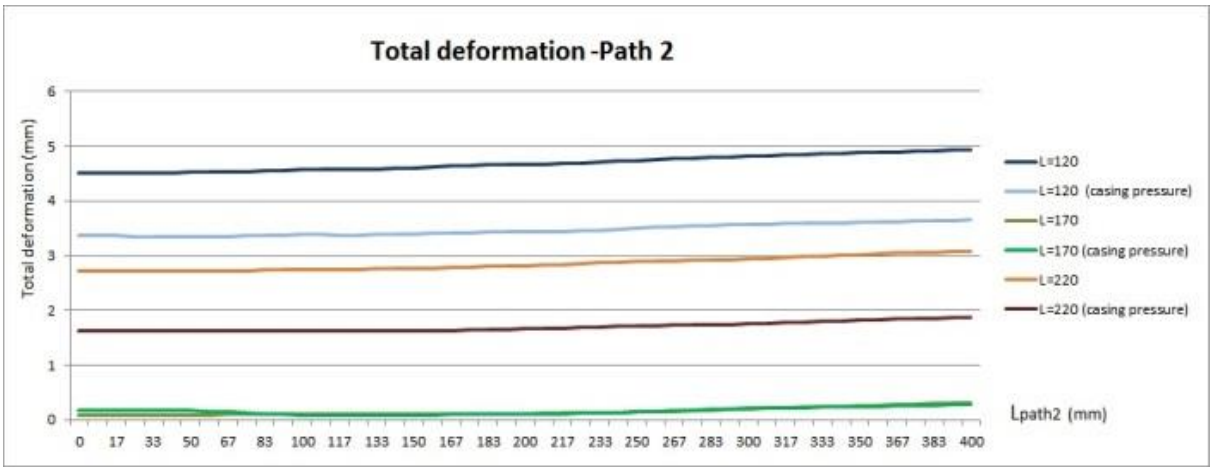

Fig. 11. Graph of total deformation on path 2

4. Conclusions

Trough the analysis of the values obtained for the equivalent stress (von Mises) for the casing hanger with length of 170 mm, we can observe that on a maximum load, with or without internal pressure, 50% of the yield strength of the material is not exceeded.

The equivalent stress calculated with to the distortion energy theory, also known as the Von Mises law, are compared to the yield strength of the material according to API Spec 6A [1 8.3.3.3] [1, 10].

For hangers with lower length (120 mm) or larger length (220 mm) an increase in equivalent stress is observed along the area of suspension, that exceed the yield strength of the casing material.

Total or axial deformation also certify analytical calculations, but also experimental observations (the approval tests of the product). The Casing hanger with 170 mm length produces a maximum of 0.3186 mm displacement for nodes located on the generating line of the casing, which is a coefficient of less than 3%, considered as an acceptance criterion of the slip performance [7].

The significant differences in the length of the casing hanger slips (± 30%) negatively affect its performance, while applying pressure to the interior, in the case of the hanger with 170 mm length, does not affect its performance.

So, the slips hangers length calculated from the condition to suspend the entire weight of the column of pipes, without permanent tube deformation in the mounting area, verified through the finite element method can reduce the risk of damage but also sliding of the tubular material.

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