A DESIGN TOOL FOR REINFORCED NON-PRESSURIZED PIPES

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Abstract: Reinforced pipes are obtained winding a ribbed plate. The final product is a low-weight pipe with stiffness and strength determined according to its main application that is an underground duct for liquids flowing in open-channel conditions. During the winding process it is possible that the ribs will buckle. This instability makes the resulting pipe useless since it will not have the prescribed stiffness and strength. The objective of this paper is to present a design tool that provides the designer the capabilities to prevent this buckling. One model was proposed to be used on the design tool. The results show that the model can be employed on the design tool, using the maximum deformation as an indication of validation of the hypothesis used on the model, such as, linear elastic behavior for the material. The numerical results were compared to the practical occurrences described by a Brazilian pipe manufacturer.

Keywords: Buckling, plates, thin-wall sections, buried pipes

1. Introduction

In the nineties, the use of reinforced pipes made of PVC (Poly vinyl chloride) was introduced in Brazil. These pipes are an alternative to cast iron or concrete pipes and are used as underground duct for liquids flowing in open-channel condition, as seen on Fig. (1). They are obtained by winding ribbed blades made from extruded profiles.

Figure 1. Underground pipes in drainage works

Figure (2) shows a typical section of the ribbed blade. The number of ribbings (stiffeners) is function of the width of the blade. It can be noticed that the whole structure can be considered thin-walled. Thus, the rigidity of the pipe is increased by the inclusion of ribbings, without a substantial weight increase and on the amount of used material. This aspect is the main concept that makes this technology economically feasible.

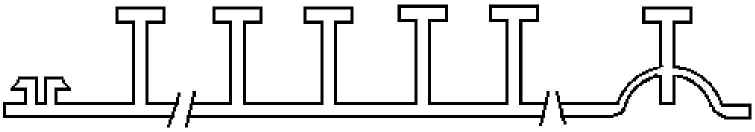

Figure 2. Typical cross-section of the ribbed profile.

During the pipe manufacturing, for determined profiles and pipe diameters, a sudden and extreme lateral deformation of the stiffener may happen. All the stiffeners on the profile may suffer this deformation or just one of them.

Some models are based on the theory of buckling of beams with open section and thin walls, under bending, summarized by Anderson & Trahair (1971), had been considered for application in this problem (Kaminski & Laterza, 2000). The great disadvantage of these models is the fact that the buckling load is dependent on the length considered for the beam. This length is of difficult determination if one considers the winding process. To obtain an alternative model to be used in a design tool for this type of pipe is the main objective of this work. This model is based on the web compression during the winding of the ribbed profile.

2. Web compression model

A possible way to consider the failure of the stiffener by instability is to consider that the plates are subject to bending during the winding process and that the compression of the web is due to the action of tension on superior flange as shown in Fig. (3). A more detailed description of this model can be found in Alves (2002).

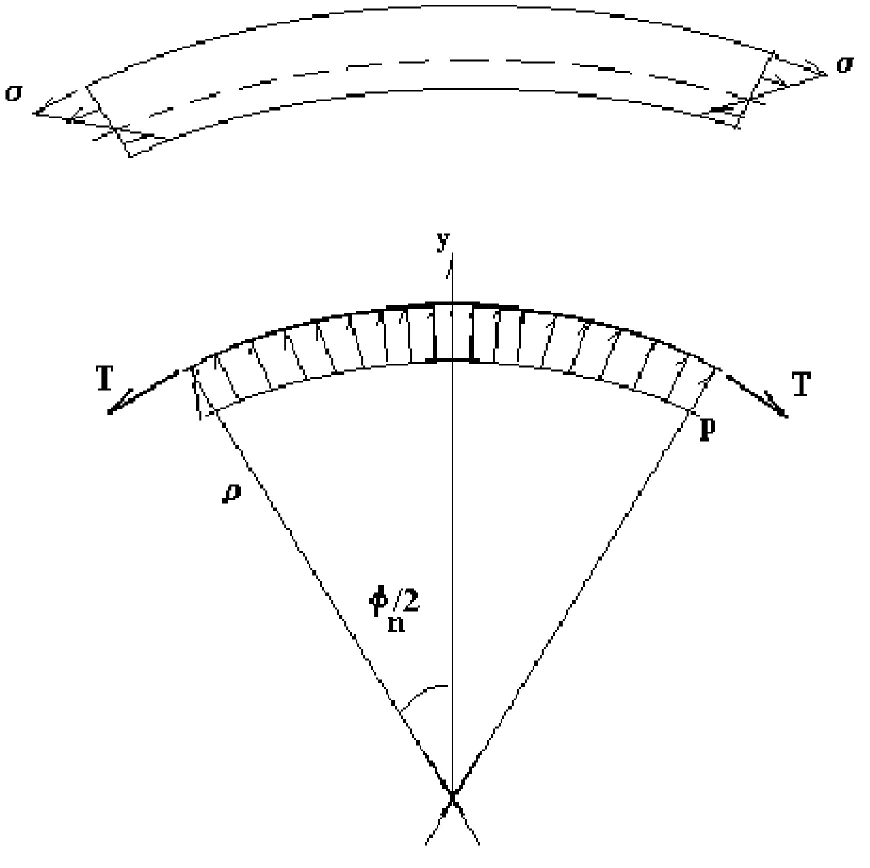

Figure 3. Ribbed profile under bending

The compressive stresses on the web are calculated from the normal stresses acting on the superior flange.

Figure (3) presents an element of the superior flange being winded up according to a radius of bending ρ. In this case, the stresses in the superior flange results in tractive forces T, that in turn are in equilibrium with compression p, acting at the junction of the flange with the web.

On Fig. (4) the main dimensions of the ribs are shown.

From the in the equilibrium y direction (fig. 3) the compression loading p can be determined as on the Eq. (1).

$$p = \frac{T}{t_h \cdot \rho} \tag{1}$$

It is interesting to notice that Eq. (1) is independent of the length that is considered.

For a section such as the one shown on Fig. (4), Eq. (1) can be rewritten as function of the winding diameter, d_e, and height, h, of the stiffener.

$$p = \frac{2T}{t_h \cdot (d_e + 2h)} \tag{2}$$

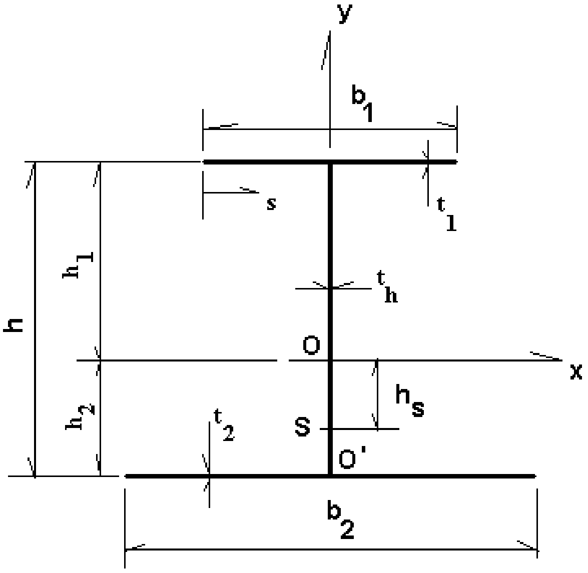

Figure 4. Main dimensions of the ribs

Load p is transformed into distributed load N, acting in the web, multiplying expression (2) by the thickness t_h of the web.

$$N = \frac{2T}{(d_e + 2h)} \tag{3}$$

The resulting force in the superior flange can be obtained from the acting stresses. Knowing the winding moment M_{en} and the properties of the cross section, it is possible to determine the stresses acting on the superior flange.

Considering a model of simple bending for the winding, as in Fig. 3, it is possible to write the maximum tractive stress as being:

$$\sigma = \frac{M_{en}}{I_x} \cdot h_1 \tag{4}$$

The tension load, T, acting on this part of the profile is given by:

$$T = \sigma \cdot b_1 \cdot t_1 \tag{5}$$

Substituting Eq. (4) in Eq. (5), the following equation is obtained:

$$T = b_1 \cdot t_1 \cdot \left(\frac{M_{en}}{I_x} \cdot h_1 \right) \tag{6}$$

The winding moment can be determined as a function of the diameter. Also in this case the theory of pure bending is applied. The bending radius, ρ, is calculated by:

$$\frac{1}{\rho} = \frac{M_{en}}{EI_x} \quad \text{or} \quad M_{en} = \frac{EI_x}{\rho} \tag{7}$$

This bending radius, ρ, is measured up to the neutral line. As the winding diameter is considered up to the profile base, the expression of the bending radius according to the geometry is:

$$\rho = \frac{d_e}{2} + \frac{2 \cdot h_2}{2} \tag{8}$$

Substituting Eq. (7) and Eq. (8) in Eq. (6), the expression of traction T is obtained as function of the winding diameter:

$$T = \frac{2 \cdot E \cdot b_1 \cdot t_1 \cdot h_1}{(d_e + 2h_2)} \tag{9}$$

Substituting Eq. (9) in Eq. (3) the expression of the load of compression is obtained in the web as function of the dimensions of the cross section of the profile and the winding diameter.

$$N = \frac{4}{(d_e + 2h)} \cdot \frac{E \cdot b_1 \cdot t_1 \cdot h_1}{(d_e + 2h_2)} \tag{10}$$

Distributed load N must be compared with the critical load for a plate in compression.
A possibility is load Nc for a plate with two built-in sides as shown on Fig. 5. (Allen & Boulson, 1980)

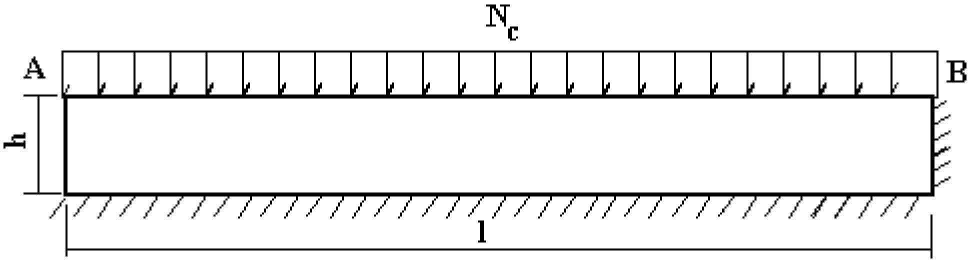

Figure 5. Web under compression with two built-in sides.

3. Plate buckling models

These models are based on the theory of bending plates (Timoshenko & Gere, 1961). They are obtained from the solution for the simply-supported plate with compressive loading acting on opposite sides. For this case the solution for the critical buckling load is given by Eq. (11).

$$N_c = \frac{\pi^2}{h^2} \cdot \frac{E \cdot t^3}{12(1-\upsilon^2)} \cdot \left(1 + \left(\frac{h}{l}\right)^2\right)^2 \tag{11}$$

It must be noticed that Eq. 11 depends on the length considered for the ribs. However, if the length, L, is far larger than the height, h, a more simple formula for the critical load can be found, that is dependent of the length.

For a plate with two free sides and a built-in side with the load acting on the opposite side, the critical load is (Alves, 2002):

$$N_c = \frac{\pi^2}{4 \cdot h^2} \cdot \frac{E \cdot t^3}{12(1-\upsilon^2)} \tag{12}$$

From Eq. (10), it is possible to determine load *N*, acting in the winding of the profile and to compare it with the critical load, N_c, obtained from Eq. (12).

$$\frac{N_c}{N} = \frac{\pi^2}{16} \cdot \frac{t_h^3}{12 \cdot (1-\upsilon^2)} \cdot \frac{(d_e + 2h) \cdot (d_e + 2h_2)}{b_1 \cdot t_1 \cdot h_1 \cdot h^2} \tag{13}$$

For instance, from Eq. (13), it is possible to find the diameter of the pipe, knowing the section of the stiffener, for which this failure mechanism starts to be critical. In this in case, it is enough to impose the condition:

$$\frac{N_c}{N} > 1 \tag{14}$$

4. Results evaluation

The proposed criterion will be compared for different stiffener sections and distinct of winding diameters of pipes. The sections considered are of the commercially available profiles in Brazil from a reinforced pipe manufacturer and the diameters also are those available from the same pipe manufacturer.

In this case, the objective is to validate the criteria using information obtained from the pipe manufacturers.

In Figure 4, the main dimensions of the profiles were shown. In table 1, the values of these dimensions are presented.

Table 1. Profile dimensions

	b_1 (mm)	t_1 (mm)	b_2 (mm)	t_2 (mm)	h (mm)	t_h (mm)
Profile 1	8	1,3	28	1,3	12,2	1,4
Profile 2	9	1,5	28	1,5	15,5	1,6
Profile 3	13	2,0	28	2,0	17,5	2,1
Profile 4	13	3,0	28	3,0	20	2,8

On table 2 the results obtained from the proposed criterion are show.

Table 2. Criterion results

		Criterion	Deformation
	d_e (mm)	Nc/N	ε
Profile 1	300	1.16	4,45
	400	2.02	3,08
Profile 2	400	1.20	3,73
	500	1.84	2,73
	600	2.61	2,05
	700	3.53	1,57
Profile 3	700	3.14	1,63
	800	4.07	1,25
	900	5.12	0,95
Profile 4	900	5.46	1,08
	1000	6.71	0,81
	1100	8.07	0,59
	1200	9.57	0,41

The material properties were determined experimentally according to the ASTM D790-00 Standard (ASTM, 2000), and the values are shown on table 3.

Table 3. Material properties

Property	Value
E	1100 N/mm^2
ν	0,3

The proposed criterion indicates that profile 1 winded at 300 mm and profile 2 winded at 400 mm are the most critical, although no calculated active load has exceeded the critical load. According to pipe manufactures both diameter are really critical and in most cases is impossible to obtain the pipe at all. According to the tensile test performed to determine the material properties the maximum deformation on the elastic range was 4,5%. Only the most critical case (profile 1 winded at 300mm) is close to this deformation being this value the limit of the proposed methodology that is based on linear elastic behavior for the material.

It must be noticed that in the design of any structure under possible instability it is always necessary to admit a safety margin between the active load and the calculated critical load based on a theoretical model or numerical model, always taking into account that the value and the nature of the active load in general are obtained by estimates, evaluations and that the models used in the calculation of the critical load have a series of simplifying hypothesis.

The less critical cases, where the criterion does not point to failure of the stiffeners are also compatible with what is observed in the practical cases with one manufacturer of this kind of pipe, that is, no occurrence of buckling was observed in its manufacturing process.

It is not possible to guarantee that in all the manufacturing situations the conditions are the same for the profile and the winding machine. However, it must be mentioned that the criterion did not present results opposed to what was observed on the manufacturing site.

5. Conclusions

The develop criterion can be used as an indicator for possible failures of the reinforcements during the winding process. The linear deformation is used as a crosscheck value in order to verify if the proposed criterion can be used. If the deformation is larger than the maximum linear elastic deformation then the criterion can not be used.

It is also possible to used the proposed criterion as an expedite design tool to verify if a new proposed reinforcement geometry can be used without the risk of buckling failure during winding. The criterion can also be used to determine minimum diameters for known profiles to be winded. It must be remembered that the only other tool available was "trial and error".

6. References

Allen, H. G.; Bulson, P. S. (1980) "Background to buckling". 1. ed. Londres: McGraw-Hill (UK), 582p.

Alves, M.A.L. (2002) "Um modelo para análise da instabilidade dos reforçadores no processo de fabricação de tubos estruturados", Tese de doutorado, EPUSP, São Paulo.

Anderson, J. M.; Trahair, N. S. (1971) "Stability of monosymmetric beams and cantilevers". Journal of the Structural Division Proceedings of the American Society of Civil Engineers, v. 98, n. ST1, p. 103-124.

ASTM - American Society of Testing Materials (2000) "D790 - 00 Standard Test Methods of Unreinforced and Reinforced Plastics and Eletrical Insulating Materials", ASTM, West Conshohocken.

Kaminski, P.C.; Laterza, L.B.M. (2000) "Buckling analysis of PVC sheets with Ribs". Journal of the Brazilian Society of Mechanical Science, vol.22, no.4, p.513-522.

Timoshenko, S.; Gere, J. M. (1961) "Theory of elastic stability". 2. ed. Nova Iorque: McGraw-Hill, 541p.

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