

THE EFFECT OF PLASTICITY ON THE STRUCTURAL BEHAVIOR OF LOCALLY SUPPORTED CYLINDERS

Wesley Vanlaere, Rudy Van Impe, Guy Lagae

Laboratory for Research on Structural Models,
Department of Structural Engineering, Ghent University,
Technologiepark-Zwijnaarde 904, B9052 Zwijnaarde, Belgium,
Wesley.Vanlaere@UGent.be, Rudy.VanImpe@UGent.be, Guy.Lagae@UGent.be

ABSTRACT- A parametrical study on stringer stiffened cylinders on local supports was performed. In this contribution, the results of the study and the design rule that was derived from the results are presented. The study shows that for a radius to thickness ratio equal to 250, the optimal design points for this type of structure correspond to plastic buckling.

INTRODUCTION: In an axially compressed cylindrical shell on local supports, compressive stress concentrations appear in the shell wall above the supports. These compressive stresses can lead to the local instability of the cylinder, entailing the failure of the entire structure. An effective way of preventing the instability is reinforcing the cylindrical wall by means of two longitudinal stiffeners above each support. These stringer stiffeners have a limited length and are placed in combination with two ring stiffeners. This configuration can be seen in Fig. 1. In our research, experiments on scale models and numerical simulations were performed in order to develop a design rule for this kind of structures. This design rule is presented in this paper and the effect of plasticity on the structural behavior is highlighted.

PROCEDURES, RESULTS AND DISCUSSION: In order to find the desired design rule, a parametrical study was performed with the numerical model in the finite element package ABAQUS. Because of symmetry reasons, this numerical model was restricted to a segment of 45° in circumferential direction (Fig. 2). The model was validated by means of experiments on scale models (see Vanlaere [2003]). The numerical model assumed a perfect elastic-plastic material behavior for the steel, with a Young's modulus equal to 200 GPa and a yield stress that was varied between 235 and 355 MPa in the parametrical study. For this study, the radius to thickness ratio of the cylinder is taken equal to 250. The variation of the other important parameters is given in Table 1. The simulations that were performed in this study led to two possible failure patterns. The first failure pattern is characterized by buckles in the stiffened part of the cylinder. This failure pattern is shown in Fig. 2(a) and is called *Stiffened Region*. For the second failure pattern, the buckles are forced outside the stiffened region and appear in the unstiffened part of the cylindrical shell. This failure pattern is shown in Fig. 2(b) and is called *Cylindrical Shell*. With the hundreds of simulations that were performed, multiple graphs similar to the one of Fig. 3 could be made. In this graph, the dimensionless failure stress σ_u/f_y is given as a

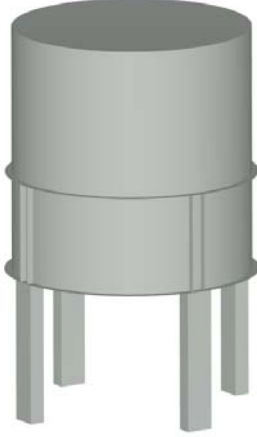


Figure 1. A model of a stringer stiffened cylinder on local supports.

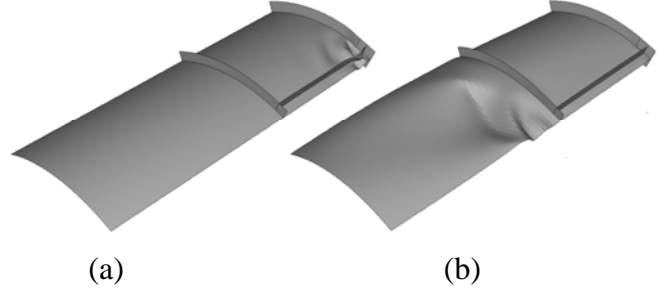


Figure 2. The two distinct failure patterns: (a) Stiffened Region and (b) Cylindrical Shell.

Table 1: Intervals for the Important Parameters of the Stiffened Cylinder on Local Supports

Parameter	Symbol	Starting value	End value
Dimensionless support width	w_{sup}/r [-]	0.029	0.200
Dimensionless stringer width	w_s/r [-]	0.071	0.143
Dimensionless stringer height	h_s/r [-]	0.286	0.857
Dimensionless stringer thickness	t_s/t [-]	1.000	3.250
Yield stress	f_y [MPa]	235	355

function of the dimensionless stringer height h_s/r for the different values of the dimensionless stringer width and for values $r/t = 250$, $w_{sup}/r = 0.029$, $f_y = 235$ MPa and $t_s/t = 1.75$. As can be seen, the curves in the graph are each formed by two almost straight lines. For small stringer heights, the corresponding straight line represents analyses with a failure pattern of the type *Cylindrical Shell*. The second – practically horizontal – straight line represents the analyses that led to a failure pattern of the type *Stiffened Region*. The optimal design point for the structure corresponds with the transition point between the two failure patterns. As can be seen in Fig. 3, this point corresponds for every curve to a failure stress σ_u that is larger than the yield stress, but lower than the maximum of the von Mises yield interaction envelope of plane stress, i.e. $1.155 \cdot f_y$. This clearly indicates that the transition point corresponds to a failure of the type plastic buckling. For other values of the parameters (see Table 1), similar conclusions can be made. This allows us to develop the following design rule for the stringer stiffened cylinders on local supports:

$$F_u = k_{imp} \cdot f_y \cdot n_{sup} \cdot (w_{sup} \cdot t + 2 \cdot w_s \cdot t_s) \text{ with } h_{s,crit} = \frac{0.029 \cdot w_{sup}^{0.16} \cdot f_y^{0.87} \cdot \left(\frac{t_s}{t}\right)^{1.45} \cdot w_s^{1.03}}{r^{0.19}} \quad (1)$$

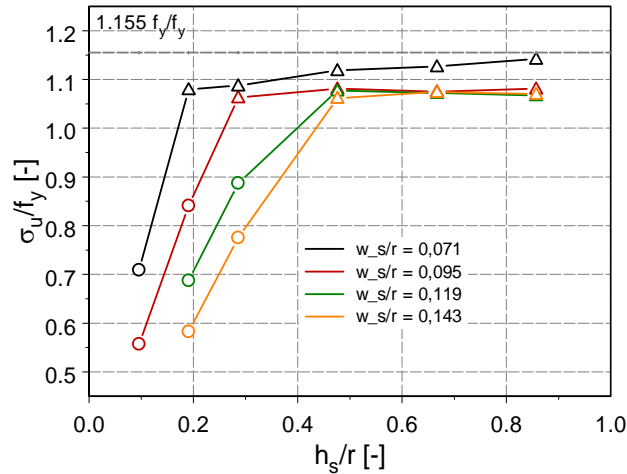


Figure 3. The relationship between the dimensionless stringer height and the dimensionless failure stress for the different values of the dimensionless stringer width and for values $r/t = 250$, $w_{sup}/r = 0.029$, $f_y = 235$ MPa and $t_s/t = 1.75$.

with f_y in MPa. The rule gives the failure load F_u as a function of the geometrical parameters, the number of local support n_{sup} , the yield stress and a knock-down factor k_{imp} that takes the effect of imperfections into account. This failure load can be reached if the height of the stringers is taken equal to $h_{s,crit}$. More information on these parameters and the range of applicability of the rule can be found in Vanlaere [2006].

CONCLUSIONS: The presented research of the stringer stiffened cylinders on local supports includes a large number of numerical simulations. These simulations lead to the conclusion that the optimal design points for the structure correspond with a plastic failure phenomenon. This allowed us to develop a design rule which is given in the paper.

ACKNOWLEDGEMENT: The first author is a Postdoctoral Fellow of the Research Foundation – Flanders (FWO). Therefore, the authors would like to express their gratitude for the financial support of the FWO.

REFERENCES:

- Guggenberger W., 1992, “Nichtlineares Beulverhalten von Kreiszyinderschalen unter lokaler Axialbelastung”, Ph.D. Dissertation (in German), Institute for Steel, Timber and Shell Structures, Technical University of Graz, Austria.
- Vanlaere W., Belis J., Buffel P., Lagae G. and Van Impe R., 2003, “The influence of plasticity on the local buckling behaviour of a cylinder with discrete stringer stiffeners above the local supports”, *Key Eng Mater*, **233-236**, 761.
- Vanlaere W., 2006, “Plooigedrag van verstijfde cylinders op lokale steunpunten”, Ph.D. Dissertation (in Dutch), Laboratory for Research on Structural Models, Ghent University, Belgium.