The Scientific Bulletin of VALAHIA University
MATERIALS and MECHANICS –Vol. 21, No. 25

DOI 10.2478/bsmm-2025-0019

EXPERIMENTAL EVALUATION OF THE INSTABILITY THRESHOLD OF VERTICAL CYLINDRICAL VESSELS

Veronica DESPA

Valahia University of Targoviste, Faculty of Materials Engineering and Mechanics,
13 Aleea Sinaia Street,Targoviste, Romania

E-mail: dumiver@yahoo.com

Abstract: *The present paper presents an experimental analysis of the structural behavior of vertical cylindrical vessels subjected to increasing axial loads, with the aim of determining the critical instability threshold. The study focuses on identifying the conditions under which buckling or loss of stability phenomena occur, considering the influence of geometric parameters, material and support conditions. The experiments were performed on certain prototypes, using high-precision measuring equipment to monitor deformations and stress distribution. The obtained results were compared with theoretical predictions and numerical models, highlighting the differences between the idealized and real behavior. The conclusions of the study contribute to improving the design criteria for vertical cylindrical structures and provide recommendations for preventing instability in industrial applications*

Keywords: *stability, cylindrical vessels, static installations*

I. INTRODUCTION

Any structure (shell, plate, bar, etc.) can be loaded with loads of different nature or of the same nature but of different types. For example, mechanical loads can be: tension or compression, bending, shear, torsion. These can cause the structure to stretch or compress. In the compressed areas of the structure, loss of stability can occur. This loss of stability can be local or general. Loss of stability occurs only if the corresponding critical state is reached or exceeded.

Vertical cylindrical vessels are widely used in various industrial fields, such as petrochemical, food, pharmaceutical and energy, due to their ability to withstand internal and external pressures in an efficient manner. However, under the action of increased axial or lateral loads, these structures can become susceptible to loss of stability, a phenomenon known as buckling. Determining the instability threshold is essential for the safe and efficient design of these vessels, thus preventing the risks of structural failure.

Theoretical studies provide mathematical models for estimating critical loads, but the real behavior of vessels is influenced by a series of factors such as geometric imperfections, material variations, support conditions and the way of applying the load. In this context, the experimental approach becomes an indispensable tool for validating theoretical models and for a deep understanding of structural instability phenomena.

The present work aims to experimentally investigate the instability behavior of vertical cylindrical containers, by applying controlled loads and monitoring the structural response.

The results obtained will contribute to optimizing the design criteria and increasing the safety in the exploitation of these structures.

II. THEORETICAL DETERMINATION OF THE CRITICAL LOADS FOR A CYLINDRICAL VESSEL

Due to the fact that the complex dynamic testing machine can simultaneously stress a container in compression and torsion, the following problem arises: Consider a cylindrical container with a circular section (fig.1) subjected to an axial compressive force $F = 200$ daN and a torsional moment $M_t = 0{,}55$ daNm = 55 daNcm.

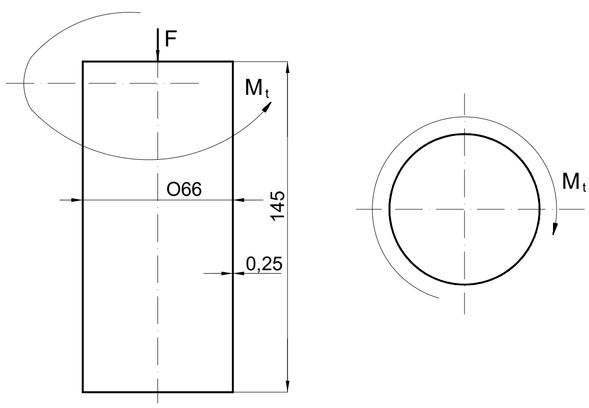

Figure 1. Container outline and dimensions

The dimensions of the vertical cylindrical container for which the verification calculations are performed for the grouping of critical loads are:

$L = 1450$ mm = 145 cm
$\delta = 0.25$ mm = 0.025 cm
$D_e = 66$ mm = 6.6 cm
$D_i = 65.5$ mm = 6.55 cm
$R = 0.5 \cdot (D_i + \delta) = 0.5 \cdot [(66 - 0.5) + 0.25] =$ 32.875 mm = 3.29 cm

The material from which the shell is constructed behaves linearly-elastically and is characterized by the yield strength $\sigma_c = 1200$ daN/cm^2 and the modulus of elasticity $M_e = 5.7 \cdot 10^5$ daN/cm^2.
It is checked whether the vessel maintains its stability by calculating the total contribution to the loss of stability, using the following expressions. For this purpose, the individual critical loads are first calculated.

Critical axial force:
$$F_{cr} = 2 \cdot \pi \cdot k \cdot M_e \cdot \delta^2$$
in which:
$$k = \frac{1}{\pi} \cdot \left(\frac{100 \cdot \delta}{R}\right)^{3/8}$$
where
$$R = 0.5 \cdot (D_i + \delta) = 0.5 \cdot [(66 - 0.5) + 0.25] = 32.875 \text{ mm}$$
result:
$$k = \frac{1}{\pi} \cdot \left(\frac{100 \cdot 0{,}25}{32{,}875}\right)^{3/8} = 0{,}287$$
That is:
$$F_{cr} = 2 \cdot \pi \cdot k \cdot M_e \cdot \delta^2 = 2 \cdot \pi \cdot 0.287 \cdot 5.7 \cdot 10^5 \cdot 0.025^2 = 642 \text{ daN}$$

Critical moment:
$$M_{t,cr.} = 2 \cdot \pi \cdot R^2 \cdot \delta \cdot \tau_{t,cr.}$$
in which:
$$\tau_{t,cr.} = \frac{M_e \cdot \delta^2}{L^2} \cdot \left[3{,}08 + \sqrt{3{,}14 + 0{,}556 \cdot \left(\frac{L}{R}\right)^3 \cdot \left(\frac{R}{\delta}\right)^{1,5}}\right]$$
$$\tau_{t,cr} = 459.40 \text{ daN/cm}^2$$
$$\boldsymbol{M_{t,cr} = 2 \cdot \pi \cdot R^2 \cdot \delta \cdot \tau_{t,cr} = 2 \cdot \pi \cdot 3.28^2 \cdot 0.025 \cdot 459.40 = 775.96} \text{ daNcm}$$

II. EXPERIMENTAL DETERMINATION OF CRITICAL LOADS FOR THE VERTICAL CYLINDRICAL VESSEL

%

Description of the installation and the system functions used to perform the experiments

The dynamic system represents an autonomous testing structure and is composed of the following elements:

1. Loading frame
2. Mobile crosshead lifting systems
3. Manifold
   - Actuators
   – Servo valves
   – Accumulators
4. Two or more transducers

1. Loading frame
The loading frame is the basic structure of the system. Two columns allow the vertical movement of a mobile crosshead to ensure the fitting of samples and accessories of different sizes. The mobile crosshead represents one of the two reaction masses within the force train, the other being represented by the base of the loading frame. An automatic control system allows the sample installation operations to be carried out.

2. Mobile crosshead
The actuator, servo valve, manifold and accumulators are mounted on the mobile crosshead. Typically, the actuator of the movable crosshead has a special clamping device or fixing accessories attached to it, for mounting one of the ends of the tested sample.
The movable crosshead can be positioned at any point along the columns of the loading frame, which allows the testing of samples of different lengths. The crosshead can be moved along the column manually or with the help of hydraulic lifting systems. When the movable crosshead reaches a suitable position for testing, it will be manually fixed in that position.

3. The Manifold
The manifold-actuator plays the role of hydraulic interface between the hydraulic power unit and the components mounted on the manifold of the test system (actuator, servovalves and accumulators). It contains the connections and installations necessary for the integration of the various hydraulically driven components. It also has the ability to control the hydraulic pressure of the dynamic test system.

- *Actuator:*

The linear actuator is positioned in the center of the movable crosshead, consisting of a hydraulically driven piston that imparts displacement to (or applies a force to) the specimen. It can apply equal tension and compression forces. One end of the specimen is inserted into a fixture mounted at the end of the piston rod. The rotary actuator is connected to the linear actuator. This is a hydraulically driven piston that imparts angular displacement to (or applies a torsional force to) the specimen.

- *Servovalves:*

The servovalves regulate the speed and direction of hydraulic fluid flow to and from the hydraulic actuator. Typically, the dynamic testing system consists of a Series 252 servovalve. One servovalve is required for each actuator.

- *Accumulators:*

Accumulators suppress pressure fluctuations in the pipeline. The dynamic test system is equipped with an accumulator connected to the pressure line, which allows the fluid to be stored so that a constant pressure can be maintained to ensure the servo valves operate at full capacity. The accumulator connected to the return line reduces pressure fluctuations on the return line.

4. Pressure Control
The dynamic test system can be adjusted in several ways, resulting in the following pressure configurations:

• Free low pressure scheme, in which the hydraulic pressure passes from the hydraulic power unit (or hydraulic manifold), through the manifold, to the hydraulically actuated components. This configuration does not involve any pressure control; the hydraulic pressure is controlled by the power unit.

• The on/off scheme starts or stops the supply of high-pressure hydraulic fluid to the dynamic system.

• The high-pressure/low-pressure/off scheme ensures the supply of high or low-pressure hydraulic fluid to the system.

• The proportional valve-based scheme ensures that the system is supplied with high- or low-pressure hydraulic fluid through a proportional valve that accelerates pressure changes.

III. EXPERIMENTAL METHODOLOGY AND PROCEDURE

To evaluate the instability threshold of vertical cylindrical containers, a series of tests were performed on an experimental stand specially designed for this type of analysis. The methodology was structured to allow the controlled application of axial loads and the monitoring of the structural behavior until the occurrence of instability phenomena.

III.1. Description of the experimental stand

The experimental stand (fig.2) is made up of the following main components:

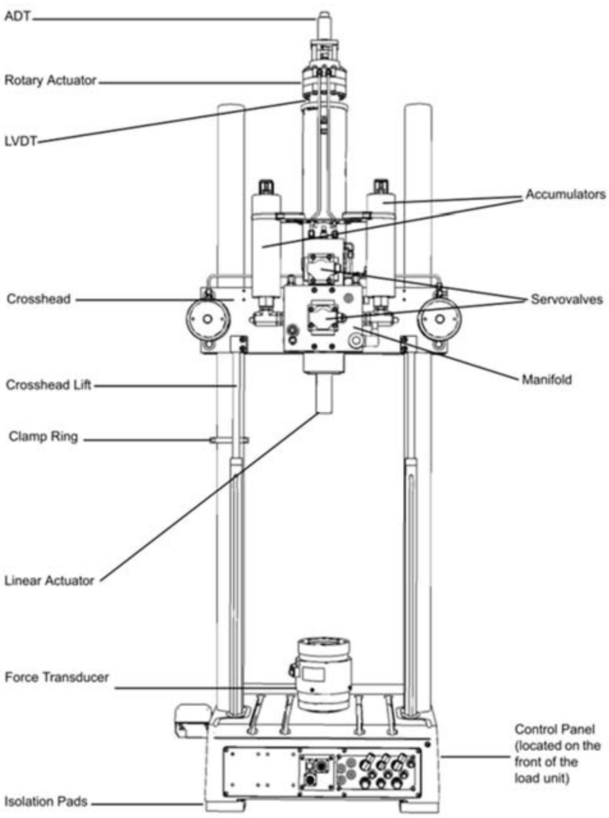

Figure 2. Experimental stand

- Rigid support frame, made of metal profiles, capable of supporting high loads without significant deformations.

- Load application system, consisting of a hydraulic actuator with precise force control, connected to an automated control system.

- Fixing devices for the cylindrical container, which ensure support conditions consistent with the real ones (for example, embedded at the base and free at the top).

- Displacement and extensometry sensors, strategically placed to measure local and global deformations of the container.

- Data acquisition system, which records in real time the evolution of the load, displacements and stresses.

III.2. Experimental procedure

- Sample preparation: The vertical cylindrical containers were made of standardized metallic materials, with controlled dimensions and preliminary geometric verification.

- Mounting on the stand: Each sample was fixed in the clamping device, ensuring correct axial alignment.

- Load application: The axial load was gradually increased, in well-defined steps, until the first signs of instability appeared (lateral deformations, loss of cylindrical shape).

- Data monitoring and recording: Deformations were continuously monitored, and the data were stored for later analysis.

- Identification of the critical threshold: The load at which instability occurred was considered the critical threshold for each sample.

To perform the experiments, proceed as follows:

- the installation is connected to the electrical network.

the computer and the pumping group included in the installation are put into operation.

- the container whose body is to be tested is placed on the force transducer plate.
- the linear actuator of the installation is turned on.

When its plate comes into contact with the upper surface of the container, the evolution of the axial force over time can be followed on the computer screen, both in value and graphically.

The vessel deformation is measured using a comparator placed on the installation table and whose probe is placed in contact with the linear actuator plate.

When the axial force F_c reaches the critical value, the container body deforms suddenly and the value of the axial force decreases very quickly.

At that moment $F_c = F_{critical}$.

The values of the forces and deformations are listed in Table 1.

Table 1

Value of applied force F_c [N]	0	100	200	300	400	500
Height of container, h [mm]	0	144.9	144.8	144.7	144.6	144.5
Height variation, Δh [μm]	0	100	200	300	400	500

a) Plotting the axial force - deformation graph

Using the values in Table 1, the graph of the function h=f(F) is drawn, according to Figure 3.
Both from table 1, and especially by following the graph in figure 3, one can easily observe the moment of loss of stability in the case of simple compression stress (axial force).

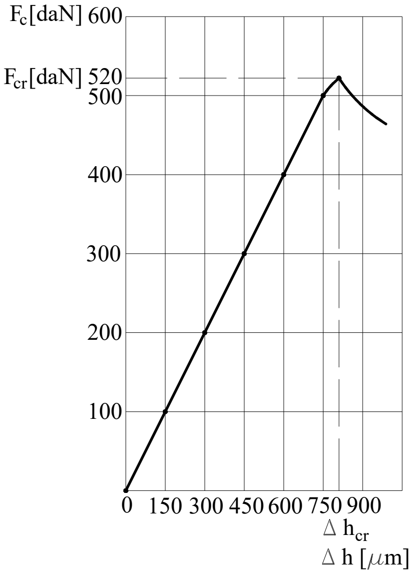

Figure 3. Experimental graph of the function Δh = f(F)

b) Plotting the torsional moment - angular deformation graph

At the moment when the torsional moment M_t reaches the critical value $M_{t,cr}$ the container body deforms suddenly and the value of the moment decreases very quickly. At that moment M = $M_{critical}$.
The values of the torsional moment and angular deformations are given in Table 2.

Table 2

Torsional moment M_t [daN·cm]	0	200	400	600	685.96
Rotation angle α[°]	0	1.25	1.76	2.2	2.6

In Figure 4 shows the variation graph for the deformation angular as a function of the torque applied to the container.
It can be observed that the value of the rotation angle, on the first portion of the graph, increases proportionally with the value of the torque applied to the container because when the value the torque reaches the critical value, the value of the same angle to increase greatly at a variation of the moment value that tends towards zero.
Another observation that can be made is that the value of the moment at which the vessel loses its stability is significantly lower than that determined theoretically.

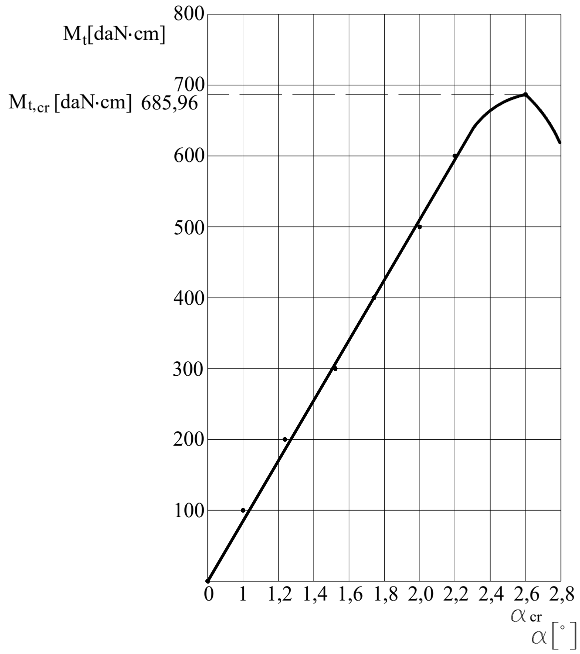

Figure 4. Experimental graph of the function α = f (M_t)

c) Plotting the theoretical and experimental graph of load grouping - linear deformation with slow application of loads

The values of the loads raised on the testing machine are listed in Table 3.

Table 3

Value of moment M_t [daN·cm]	0	20	40	46	50
Value of applied force F_c [N]	0	50	100	150	175
Height variation, Δh [μm]	0	150	300	450	480

These are used to plot experimental graphs of the function Δh = f(F_c, M_t) with slow application of the loads F_c and M_t (fig.5).

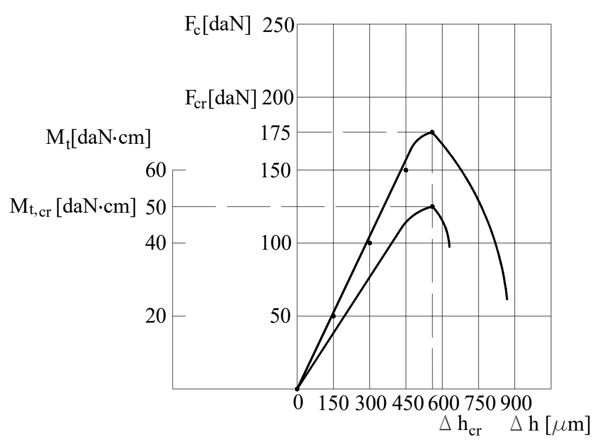

Figure 5. Experimental graph of the function Δh = f(F_c, M_t) with slow application of stresses

III.3. Validation and interpretation of results

The experimental results were compared with the theoretical values obtained from classical buckling formulas and with numerical simulations performed in structural analysis software. Discrepancies were analyzed according to geometric imperfections, material variations and support conditions.

IV. CONCLUSION

4.1. Conclusion

If the tables are followed and especially if the theoretical graphs are compared with the experimental ones, it can be easily observed that all the values raised on the stand are lower in value than the theoretical ones (in this case).
This may be the result of several causes, such as:

- incorrect values of the longitudinal elasticity coefficient which were not strictly determined for the material of the container subjected to the tests.
- approximate dimensions of the container subjected to the tests.
- possible deviations in the shape of the tested container which has walls of 0.25 mm (bumps, scratches etc.)

4.2 Motions

For realistic results, it is recommended:
The coefficient of longitudinal elasticity must be determined from samples taken from the material from which the container under test is manufactured.
The walls of the container must have an appropriate thickness that does not allow accidental deformation.
If the material from which the container is made undergoes specific treatments, then the samples for determining the coefficient of elasticity are taken after the treatments have been performed.

REFERENCES:

[1] Jerath S., Qiao W., *Dynamic Stability of Water Tanks*, ASCE-ASME-SES (American Society of Civil Engineers-American Society of Mechanical Engineers-Society of Engineering Science) Conference on Mechanics and Materials, Blacksburg, 2009, USA.

[2] Iturgaiz Elso M., *Finite Element Method studies on the stability behavior of cylindrical shells under axial and radial uniform and non-uniform loads*, 2012, UPNA.

[3] Heydarpou Y., Malekzadeh P., *Dynamic stability of cylindrical nanoshells under combined static and periodic axial loads,* Journal of the Brazilian Society of Mechanical Sciences and Engineering (2019) 41:184

[4] Ansari R., Gholami R., Sahmani S., Norouzzadeh A., Bazdid-Vahdati M., *Dynamic stability analysis of embedded multiwalled carbon nanotubes in thermal environment,* Acta Mech Solida Sin, (2015), 28:659–667

[5] Hosseini-Hashemi S., Ilkhani M.R. *Nonlocal modeling for dynamic stability of spinning nanotube under axial load.* Meccanica, (2017), 52:1107–1121

[6] Karličić D., Kozić P., Pavlović R., Nešić N., *Dynamic stability of single-walled carbon nanotube embedded in a viscoelastic medium under the influence of the axially harmonic load*, Compos Struct (2017), 162:227–243

[7] Saffari S., Hashemian M., Toghraie M., *Dynamic stability of functionally graded nanobeam based on nonlocal Timoshenko theory considering surface effects*. Phys B, (2017), 520:97–105