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Theoretical investigation of a composite shell structure for a circular cross-section liquid containment wall

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Abstract: *In the present research, we investigated the application of flexible hose-like walls, typically with a plastic-fabric composite shell, filled with fluid (typically water), where the level and extent of a relatively large mass of fluid (primarily water) needs to be flexibly and temporarily controlled. Special cases such as expansion of storage capacity (surface and open reservoirs), water level regulation, prevention and prevention of ecological disasters, creation and preservation of water habitats are particularly relevant. The important parameters to be considered in the analysis of a hose-like wall are static and dynamic effects and elastic deformation effects, which together may cause the wall to move horizontally, or even to rise and underflow considerably. Conclusions on their applicability are established on the basis of the results of analytical and numerical studies.*

Keywords: *composite, buoyancy, water*

1. Introduction

Liquid-filled temporary walls with a composite shell structure are gaining interest because they are easy to install, construct, and operate. They are used for various purposes such as irrigation, flood protection, flood and tidal control, as well as for drainage, protection, recreation, and even prevention of ecological disasters [1]. Their storage is space-saving; they can be drained when not needed and then filled. The hydraulic behavior of the structure necessitates the study of fluid-structure interaction, which is the objective of the current research.

Structures with composite shell structures are relatively easy to install, do not corrode, require little maintenance, can be reused many times, and can withstand extreme temperatures. These types of structures are considered to be more economical than rigidly built-in control structures [2-4].

A few studies have focused on the cross-sectional static profile of hoses, both when these hoses stop the “attacking” waterflow and when there is overflow

[1, 2, 5, 6]. Several published papers have focused on experimentally modeling flow hydraulics for flow through a composite structure [2, 3, 7, 8, 9].

2. Hydraulic calculation

The analysis examines the expected in-service behavior of two connected mobile systems consisting of composite shell structures. This type of design is used to achieve greater stability.

In this study, we aim to demonstrate how the behavior and stability of the system can vary under different loads in real-life scenarios, depending on the height of the medium in contact with the structure, also known as the "attacking" medium.

The system utilizes a pump to fill the tubular composite shell structure, consisting of two separate shell structures, with water. The height at which the structure can effectively prevent the 'attacking' medium from entering the protected area without shifting or floating is determined by considering the weight of the water contained in the structure, the material of the structure itself, and the friction between the structure and the ground.

The analysis first examines the magnitude and direction of the force acting on the structure's wall under static conditions, based on the height of the medium.

After conducting these tests and running a numerical simulation in parallel, the calculations will be verified.

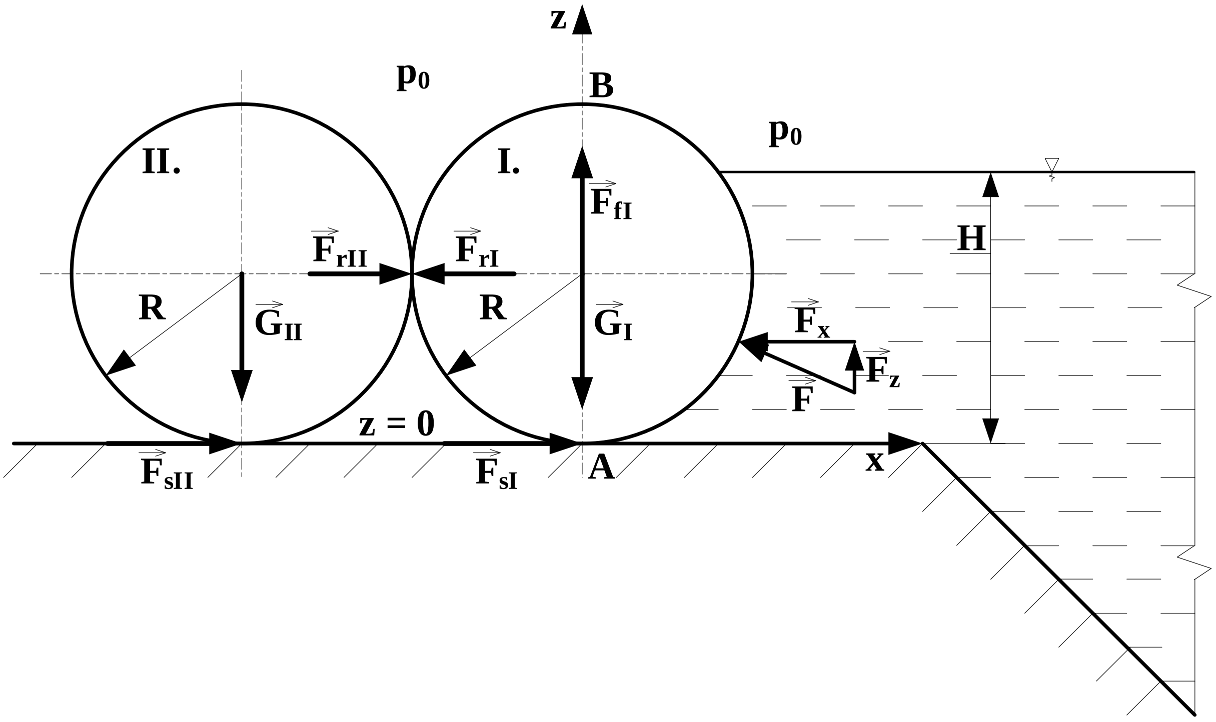

Figure 1: Theoretical cross-section of the structure and the forces acting on the wall

In the first stage of the test, the structure is fully filled with water and tested as rigid bodies. The cross-sections of the two structures are assumed to be regular circles. Friction is ignored. Hoses I and II are in contact during manufacture but form completely separate spaces. The medium only comes into contact with one side of hose I. Hose II only serves to support Hose I.

The designations shown in Figure 1:

H – the height of the liquid in contact with the hose is above the installation level of the wall;

p_0 – the atmospheric pressure;

R – the radius of the hose;

$\vec{G}_I$ – the weight of a hose filled with water in contact with the liquid;

$\vec{G}_{II}$ – total weight of the support hose when filled with water;

$\vec{F}_{fI}$ – buoyancy depends on the height of the liquid in contact with the hose;

$\vec{F}_{rI}$ – reaction force transferred from hose I to hose II;

$\vec{F}_{rII}$ – reaction force transferred from hose II to hose I;

$\vec{F}$ – the force is a function of the height H of the fluid. It represents the reduced resultant of the force system distributed over the surface of the hose in contact with the fluid at a specific point.;

$\vec{F}_x$ – the *x*-direction component of the force $\vec{F}$;

$\vec{F}_z$ – the *z*-direction component of the force;

$\vec{F}_{sI}$ – the friction force between hose I and the ground;

$\vec{F}_{sII}$ – the friction force between hose II and the ground.

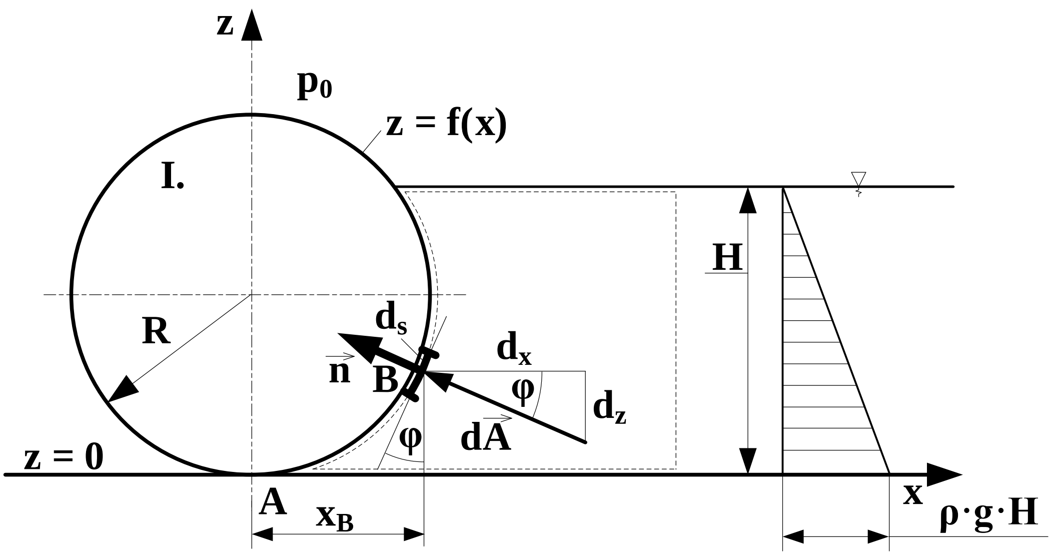

Figure 2: Resultant of the force system distributed from the height of the medium over the surface of the side wall of the structure

Force from the "attacking" fluid to the hose surface (Figure 2):

$$\vec{F} = \int\limits_{(A_{AB})} \left(p - p_0\right) \cdot d\vec{A}\,\textbf{.} \tag{1}$$

The basic equation of hydrostatics in a gravitational field for an incompressible medium:

$$\left.\begin{array}{l} \dfrac{p}{\rho} + g \cdot z = \text{constant} \\ \text{Boundary condition: } z = H \text{ on place } p = p_0 \end{array}\right\} \Rightarrow \tag{2}$$

$$\frac{p}{\rho} + g \cdot z = \frac{p_0}{\rho} + g \cdot H \quad \Rightarrow \quad p - p_0 = \rho \cdot g \cdot \left(H - z\right)\textbf{.} \tag{3}$$

$$\begin{aligned} d\vec{A} &= dA \cdot \vec{n} = dA \cdot \left(\underbrace{-\sin\varphi \cdot \vec{i} + \cos\varphi \cdot \vec{k}}_{\vec{n}} \right) = \left| dA = b \cdot ds \right| = b \cdot ds \cdot \left(-\sin\varphi \cdot \vec{i} + \cos\varphi \cdot \vec{k} \right) = \\ &= b \cdot \cancel{ds} \cdot \left(-\frac{dz}{\cancel{ds}} \cdot \vec{i} + \frac{dx}{\cancel{ds}} \cdot \vec{k} \right) = b \cdot \left(-dz \cdot \vec{i} + dx \cdot \vec{k} \right) \end{aligned} \tag{4}$$

Components of the force on the wall:

$$\vec{F} = \int\limits_{(A_{AB})} \left(p - p_0\right) \cdot d\vec{A} = \begin{array}{l} \nearrow \vec{F}_x \cdot \vec{i} \\ \searrow \vec{F}_z \cdot \vec{k} \end{array} \textbf{.} \tag{5}$$

The *x*-direction component equation:

$$F_x = \int_{z=0}^{H} -\left(p-p_0\right)\cdot b\cdot dz = \rho\cdot g\cdot b\cdot \int_{z=0}^{H} -\left(H-z\right)\cdot dz = -\rho\cdot g\cdot b\cdot\left[H\cdot z+\frac{z^2}{2}\right]_{z=0}^{H} = -\rho\cdot g\cdot b\cdot\left(H^2+\frac{H^2}{2}\right)$$

$$\underline{\underline{F_x = \frac{3}{2}\cdot\rho\cdot g\cdot b\cdot H^2}}\,. \tag{6}$$

Its value is independent of the shape of the sidewall. It is equal in magnitude to the force on the flat plate as a projection of the curved wall.

The *z*-direction component equation:

$$F_z = \int_{x=0}^{x_B} \left(p-p_0\right)\cdot b\cdot dx = \rho\cdot g\cdot b\cdot \int_{x=0}^{x_B} \left[H-f\left(x\right)\right]\cdot dx = \rho\cdot g\cdot b\cdot\left\{\left[H\cdot x\right]_{x=0}^{x_B} - \int_{x=0}^{x_B} f\left(x\right)\cdot dx\right\}$$

$$\underline{\underline{F_z = \rho\cdot g\cdot b\cdot\left[H\cdot x_B - \int_{x=0}^{x_B} f\left(x\right)\cdot dx\right]}}\,. \tag{7}$$

This component is equal to the weight of the fluid displaced by the curved wall.

Determination of the friction force -> if both structures are loaded, the magnitude of the friction force:

$$F_{sI}+F_{sII} = \mu\cdot\left(G_I+G_{II}-F_{fI}\right). \tag{8}$$

In Figure 3, the diagram below shows the absolute value of the force acting on the hose from the liquid (*F*[N]), the absolute value of the force acting on the hose from the liquid in the *x* direction (F_x[N]), the absolute value of the force acting on the hose (F_{sI}) in the filled state of the hose, as well as the I and II. When the hose is filled, the absolute value of the force acting on the hose (F_{sI} + F_{sII}) is a function of the liquid level.

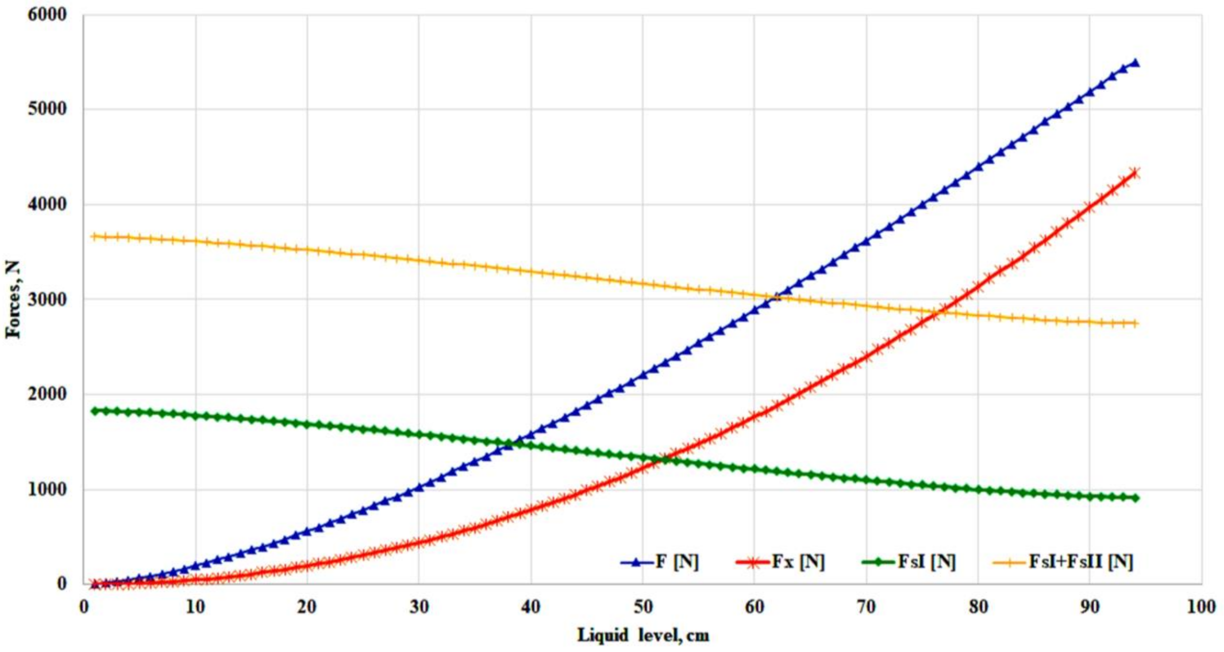

Figure 3: Variation of different forces as a function of the load medium level for a circular hose (ideal case)

3. Numerical simulation

An initial finite element analysis (FEA) was also conducted to examine the static behavior of the hose. The analysis yielded the following results for the deformations of the structure under various medium coverings. Due to the significant computational resource requirements, the simulation was conducted using a model with a width of 20 cm, considering the corresponding force effects. In order to better illustrate the relatively small deformation caused by the interstitial loading, Figure 4 shows the calculated displacements magnified 10 times compared to the enclosing frame of the base contour. The coloring of the surface elements in this case reflects the magnitude of their displacement, with green indicating the smallest displacement and red indicating the largest.

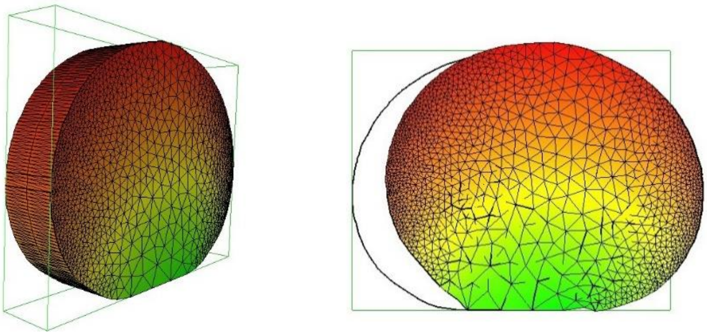

Figure 4: Deformation tested for the highest forces

4. CONCLUSIONS

The composite structure can be loaded with a significantly lower media height compared to its nominal diameter, which can be as low as 60-70% of its nominal diameter according to literature [9], and in practice even considerably less. In practice, this means that a hose with a nominal diameter of 90 cm will have a fluid height of only 30-60 cm. Because of the low dead weight and the associated buoyancy problem, water-filled structures cannot be used in places where higher quasi-regular dynamic loads, such as wave action, occur.

Preliminary calculations have shown that the 90 cm diameter twin-wall composite structure with an ideal circular cross-section, tested as a rigid body, will move at a medium height of about 50-52 cm if only one of the structures is filled, even if the friction between the structure and the soil is adequate. If both composite structures are filled with water, the interconnected hose wall will reach a height of 75-76 cm. If the conditions between the structure(s) and the soil are worse than those considered in the calculation, or dynamic wave action occurs, the still safely maintainable medium heights will be lower.

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