Dynamic analysis of biogas tank

Norbert Jendzelovsky, Lenka Uhlirova

STU Bratislava, Faculty of Civil Engineering, Radlinskeho 11, 81005 Bratislava, Slovakia

norbert.jendzelovsky@stuba.sk

Abstract. Global warming is a phenomenon that makes us increasingly aware of the importance of protecting nature. Lack of drinking water and waste disposal belong to today's biggest problem. This is the main reason why we try to recycle, use more renewable energy sources and treat waste ecologically. Drinking water tanks, sludge tanks for wastewater treatment and also tanks for biogas production, so-called fermenters, are becoming gradually more important. For built-up areas, respecting space usability, it is more appropriate to design tanks with a rectangular floor plan (so-called rectangular tanks). We can also use a system of rectangular tanks and thus achieve the most efficient use of space that is intended for them. In this article will be determined whether the proposed rectangular tank, intended for biogas production, has bearing capacity for dynamic loads. Construction of the tank itself must respect the design of the structure, as well as the building material, in order to prevent damage to its structure caused by the filling (it may also contain substances that could contaminate the environment and groundwater). This will ensure the integrity and load-bearing capacity of the tank and there is no risk of leakage.Selected tank is loaded with a standard response spectrum to see how it deforms, using finite element analysis in program ANSYS.

1. Introduction

Biogas is produced by natural processes in which methane is released during the decomposition of suitable material. The main components of biogas are methane, carbon dioxide and water vapor. It may also contain traces of nitrogen, oxygen, hydrogen, ammonia and hydrogen sulfide. It can be used as an alternative source of electricity, heat, but also as a fuel for vehicles. Biogas is obtained by capture in wastewater treatment plants, biogas plants and landfills. Biogas can contain substances that cause corrosion of metal parts, so the composition of biogas must always be taken into account. Biogas originating from wastewater treatment plants is also called sludge gas. Sludge from the wastewater treatment process serves as input material. It can be manure from livestock, manure (pig or beef), municipal biowaste, plant residues (e.g. grain, haylage, silage etc.), but also fresh meadow grass.

The volume weight of sludge needed for biogas production is in the range of 900 - 1200 kg / m³. In order to take into account the worst static effect of the filling on the structure, we chose a bulk density of 1200 kg / m³ in the calculation. Biogas as the result product has a lower density than air (1.2 kg / m³).

2. Response spectrum method

The method of response spectra is described in the basic literature dealing with the dynamics of building structures. It is currently the most used method for calculating the seismic load.
In modal analysis, when solving eigenvalues, we obtain the eigenfrequencies ($f_i$) and the corresponding eigenshapes. For a given direction of excitation ($x, y, z$), the participatory factor $\gamma_i$ of each eigenshape is calculated, which expresses how much the eigenshape contributes to the individual global directions. The participation factor is calculated according to the relationship:

$$\gamma_i = \Phi_i^T \cdot M \cdot d$$  \hspace{1cm} (1)

$\Phi_i$ - normed $i$-th form of oscillation
$M$ – weight matrix
$d$ – vector describing the direction of actuation

The following section describes the solution of a specific tank. In the example, 2 horizontal directions of actuation of the structure were used - in the direction of the $x$ and $y$ axis. The results from modal analysis as well as from spectral analysis are in the following chapters.

3. Rectangular tank model
The reinforced concrete tank (figure 1) was modeled as rectangular, with floor plan dimensions of 11 m x 7.5 m and a wall height of 2.0 m. The wall thickness is 200 mm and the tank bottom thickness is 500 mm. Filling of tank - sludge reaches a height of 1.5 m. The tank is above ground, placed on a flexible base. C25/30 concrete with modulus of elasticity $E = 30$ GPa was used.

![Figure 1. Structural model of the tank](image)

The static model of the structure was calculated in the Ansys system, where shell finite elements and fluid-type elements were used from the finite element library. With the aim of taking into account the interaction of the structure and its filling, an intermediate element (CONTAC52 - figure 2c) was inserted between the tank wall elements (SHELL181 - figure 2a) and the sludge elements (FLUID80 – figure 2b). This intermediate element is a contact element reckoning the influence of FSI (Fluid-Structure Interaction). Similar solutions for FSI theory are found in articles [1-7]
Figure 2. a) Rectangular 3D shell element SHELL181 [8], b) Liquid 3D element FUILD80 [8], c) Contact element CONTA52 [8]

The response spectrum used in the calculation is shown in figure 3. This is the response spectrum at the subsoil of category D and in the region with the value of seismic acceleration $a_{gR} = 1.10 \text{ m/s}^2$, created according to STN EN 1998-1 [9]

Figure 3. Response spectrum - Spectrum type 1 - subsoil of category D

4. Modal analysis
Eigenshapes and their frequencies were obtained from the modal analysis of the structure. It was necessary to separate the own shapes in which only the level of the filling oscillates from the own shapes in which also the structure of the tank itself oscillates. The frequency values of the first 6 eigenshapes are given in Table 1.
Table 1. Eigenshapes and frequencies of tank

| Eigenshape No. | Frequency [Hz] |
|----------------|----------------|
| 1              | 28,970         |
| 2              | 29,056         |
| 3              | 32,116         |
| 4              | 32,451         |
| 5              | 36,482         |
| 6              | 37,019         |

5. Result and discussions

After obtaining the results from the modal analysis, we solved the construction using spectral analysis. We used the above actuation spectrum - figure 3. The deformations of the tank and the specific moments in the tank walls for the area with the basic seismic acceleration $a_{GR} = 1.10 \text{ m/s}^2$ acting in the direction of the x-axis are shown in figures 4 – 7.

![Figure 4. Deformation along the x-axis from a seismic load acting in the x-axis direction with a maximum value of 0.293 mm](image)

![Figure 5. Deformation along the y-axis from the seismic load acting in the x-axis direction with a maximum value of 0.027 mm](image)

![Figure 6. Specific moments $m_x$ from the seismic load acting along the x-axis occur in the upper corner of the walls (max. value 1.445 kNm/m)](image)

![Figure 7. Specific moments $m_y$ from the seismic load acting along the x-axis arise in the middle of the lower edge of longer walls (max. value 5.981 kNm/m)](image)

It can be seen in the figures of deformations (figure 4 and figure 5) that if the load acts in the direction of the x-axis, then a half-wave showing the deformation is formed on the walls in the direction of this action (shorter walls). A wave with 10 times greater deformation value is created on walls perpendicular to the direction of the load (longer walls) than on a shorter wall.
For the area with the basic seismic acceleration $a_{gR} = 1.10 \text{ m/s}^2$ acting in the direction of the $y$-axis, the deformations of the tank and the specific moments in the tank walls are shown in figures 8-11.

**Figure 8.** Deformation along the $x$-axis from a seismic load acting in the direction of the $y$-axis with a maximum value of 0.058 mm

**Figure 9.** Deformation along the $y$-axis from a seismic load acting in the direction of the $y$-axis with a maximum value of 0.225 mm

**Figure 10.** Specific moments $m_x$ from the seismic load acting along the $y$-axis occur in the upper corner of the walls (max. value 1.478 kNm/m)

**Figure 11.** Specific moments $m_y$ from the seismic load acting along the $y$-axis arise in the middle of the lower edge of the shorter walls (max. value 4.83 kNm/m)

It can be seen in the figures of deformations (figure 8 and figure 9) that if the load acts in the direction of the $y$-axis, then a half-wave showing the deformation is formed on the walls in the direction of this action (longer walls). A wave is created on the walls perpendicular to the direction of the load (shorter walls) where the deformation is 5 times greater.

Figures 6 and 7 and also in figures 10 and 11 show the specific bending moments from which the resulting seismic combination is produced. These will be used in a seismic design situation which will be produced on the basis of standard regulations.

6. **Conclusions**
In situations where a liquid or other similar substance is used in the planned design (in our case sludge for biogas production), fluid itself must be taken into consideration in the calculations using 3D modeling and using the interaction of structure with fluid (FSI) and interaction of the structure with subsoil.
Acknowledgment(s)
This paper was written with the support of Slovak Grant Agency VEGA. Registration number is 1/0412/18 and 1/0453/20.

References
[1] K. Kotrasová, E. Kormaníková, „A case study on seismic behavior of rectangular tanks considering fluid Structure interaction,” In International Journal of Mechanics, Vol. 10, pp. 242-252, 2016.
[2] K. Kotrasová, E. Kormaníková, „Hydrodynamic analysis of fluid effect in rigid rectangular tank due to harmonic motion,“ 9th International Conference on Material in Engineering Practice 2014.
[3] L. Uhlířová, N. Jendzelovsky, „Analysis of a Tank Used for the Purposes of Ecological Purification of Water.“ In SGEM 2018., pp. 613-619, 2018
[4] R. L. C. Silva, G.B. Marques, E. N. Lages, S. P. C. Marques, „Analytical study of cylindrical tanks including soil-structure interaction,“ IBRACON Structures and Materials Journal, Vol. 12, pp.14-22, 2018.
[5] J. Kala, V. Salajka, P. Hradil, „Response of water tower on wind induced vibration considering interaction of fluid and structure.“ In ICETI 2012: 2nd International Conference on Engineering and Technology Innovation, Taiwan, pp 1269-1272, 2012
[6] K. Kotrasova, E. Kormanikova, „Effect of Fluid in the moving container.“ In Journal of Numerical analysis, Industrial and Applied Mathematics. Vol. 1, pp. 1-9, 2006.
[7] J. Vaskova, R. Cajka „Subsoil-structure interaction solved in different FEM programs. “ In SGEM 2017: 17th International Multidisciplinary Scientific GeoConference. Conference Proceedings, Vol. 17, pp.555-562, 2017.
[8] ANSYS Help, Theory Reference for the Mechanical APDL and Mechanical Applications (ANSYS manual).
[9] EN 1998-1 Eurocod 8, 1998.