FEM MODELLING OF WIND LOAD ON INDUSTRIAL FILTER

Snežana Vulović[1,a], Rodoljub Vujanac[2,b], Miroslav Živković[2,c], Marko Topalović[1,d] , Aleksandar Dišić[1,e]

[1]Institute for Information Technologies, University of Kragujevac, Kragujevac, Serbia

[2]Faculty of Engineering, University of Kragujevac, Kragujevac, Serbia

[a]vsneza@kg.ac.rs, [b]vujanac@kg.ac.rs, [c]zile@kg.ac.rs, [d]topalovic@kg.ac.rs, [e]aleksandardisic@uni.kg.ac.rs

Abstract The industrial filter was analyzed by the Finite Element Method (FEM). Strength calculations are made according to the European Eurocode standard EN 13445-3 which prescribes the loads that pressurized vessels must withstand during their lifetime. This paper presents the setting of wind load that depends on the geometry of the filter, its location as well as the terrain configuration. The wind load is done according to standard EN 1991-1-4. FEMAP software with a built-in NX Nastran solver was used for FEM modelling and analysis. Load assignment is performed using a Visual Basic script, which accesses the model via the FEMAP API and assigns wind pressure. Based on the FEM calculation, the static strength of the filter according to the standards was verified.

Keywords: Industrial filter; FEM analysis; Visual Basic; FEMAP API; wind load.

1. INTRODUCTION

The gravitational backwashed industrial filter is a large thin-walled pressurized structure used for waste water treatment [1]. Gravity pushes service water through multilayered filter that contains anthracite coal and several layers of sand with different granulation [2]. Coal and sand grains retain suspended particles while the water flows through. However, the accumulation of these filtered-out particles can obstruct the flow of water through the filter, and when the pressure drop due to clogging reaches a certain threshold, the filter needs to be cleaned by the backwash flow. Figure 1 illustrates the filter in the both modes of operation, normal service and during the backwash cleaning.
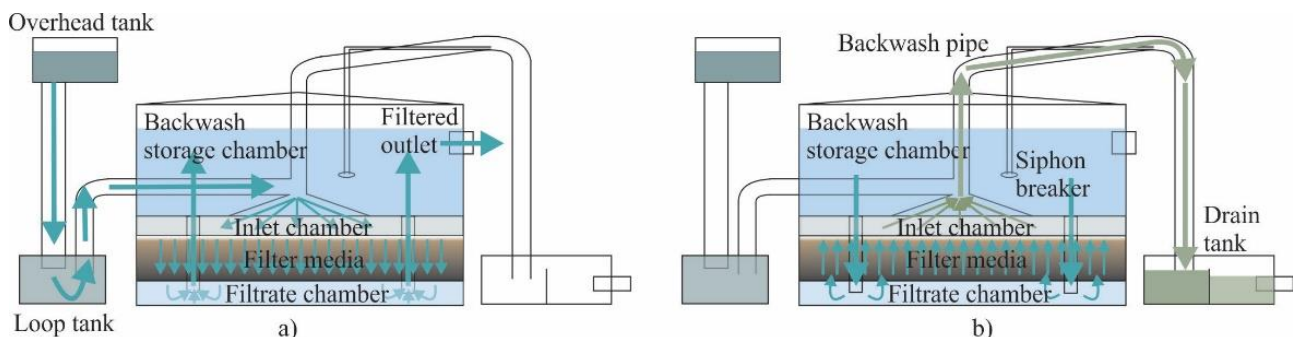

Figure 1. Industrial gravity filter a) normal operation, b) backwash cleaning.

As the filtered water passes through the last layer of filter, it is collected beneath it and transferred via a pipe into the backwash storage chamber above the filter. This chamber store water needed for the backwash cycle, and once it is full, the filtered water begins to overflow through service outlet.

Filtered water in the backwash chamber is the main cause of the service loads (hydrostatic pressure), however, since the filter exposed to nature influence, these loads must be taken into account as well. According to the EN13445-3 standard [3], static strength must be analyzed for the following cases:

- Normal regime loads due to its own weight and hydrostatic pressure,
- Backwash rinsing,
- Normal regime + snow pressure,
- Normal regime + wind pressure,
- Normal regime + snow and wind pressure,
- Normal regime + earthquake (quasistatic analysis).

For numerical analysis we use FEMAP with NX Nastran solver [4] which uses the Finite Element Method [5]. This numerical method is used to determine stress state in the construction [6] and to verify that during the exploitation cracks will not occur [7]. In the next sections we will discuss the calculation of wind loads according to EN 1991-1-4 standard [8], and developed Visual Basic script [9] for application of pressure on FEM shell elements which are used to model the filter.

2. CALCULATION OF WIND LOAD ACCORDING TO EUROCODE

Wind load on cylindrical filter is represented by a simplified group of pressures or forces whose influence is equivalent to the extreme influence of the turbulent wind. Besides, when the large surfaces are exposed to wind, friction forces can be significant. Wind load is calculated according to Eurocode EN 1991-1-1-4 [8].

For wind load determination, we used a fundamental value of basic wind velocity $v_{b,0}$, which are

given in the National Annex SRPS EN 1991-1-4, and for the region near where the filter will be placed it has value of $v_{b,0} = 19\ m/s$. The filter will be placed on flat ground with regular vegetation

classified as terrain category III according to Table 4.1 in [8].
The same table gives us the values of the roughness length $z_0 = 0.3\ m$ and the minimum height

$z_{min} = 5\ m$. Terrain factor k_r is calculated based on roughness length z_0 and reference roughness

length $z_{0,II} = 0.05\ m$ for terrain catogory II:

$$k_r = 0.19 \cdot \left(\frac{z_0}{z_{0,II}}\right)^{0.07} = 0.215. \tag{1}$$

The roughness factor c_r for $z_{min} \leq z \leq z_{max}$ is calculated using:

$$c_r = k_r \cdot \ln\left(\frac{z}{z_0}\right) = 0.605 \,. \tag{2}$$

The mean wind velocity at height $z = 5\,m$ is given as:

$$v_m = c_r(z) \cdot c_o(z) \cdot v_{b,0} = 11.495 \text{ m/s}, \tag{3}$$

with the value of topography coefficient $c_o = 1$ obtained from the National Annex. According to [8] the turbulence intensity at $z = 5\,m$ is:

$$I_v = \frac{k_I}{c_o(z) \cdot \ln(z/z_0)} = 0.355 \,, \tag{4}$$

where the value of turbulence factor $k_I = 1$ is also found in the [8].

The peak velocity pressure $q_p(z)$ at $(z = 5\,m)$ accounts for turbulence intensity I_v and the mean wind velocity v_m is:

$$q_p = (1 + 7 \cdot I_v) \cdot 0.5 \cdot \rho \cdot v(z)_m^2 = 288 \, kN/m^2. \tag{5}$$

The recommended value of density according to the National Annex is $\rho = 1.25 \, kg/m^3$. For the reference height we take the maximum height of the observed section $z_e = 5\,m$, [8] and use it for the calculation of the peak wind velocity:

$$v(z_e) = \sqrt{\frac{2 \cdot q_p(z_e)}{\rho}} = 21.466 \, m/s. \tag{6}$$

We use the peak wind velocity $v(z_e)$, kinematic viscosity of the air $v = 15 \cdot 10^{-6} m^2/s$ and tank diameter $b = 3.9\,m$ to calculate the Reynolds number:

$$R_e = \frac{b \cdot v(z_e)}{v} = 5.58 \cdot 10^6. \tag{7}$$

Reynolds number characterizes wind load distribution over a cylinder surface. The positions of the minimum pressure $\alpha_{min} = 77.5°$ and the flow separation $\alpha_A = 112.5°$ are obtained from the table 7.12 in [8] for $R_e = 5.58 \cdot 10^6$. The distribution of load changes with the angle in regards to wind direction according to the end-effect factor $\psi_{\lambda\alpha}$:

$$
\begin{aligned}
\psi_{\lambda\alpha} &= 1 & \text{for} \quad && 0° \leq \alpha \leq \alpha_{min} \\
\psi_{\lambda\alpha} &= \psi_\lambda \cdot (1 - \psi_\lambda) \cdot \cos\left(\frac{\pi}{2} \cdot \left(\frac{\alpha - \alpha_{min}}{\alpha_A - \alpha_{min}}\right)\right) & \text{for} \quad && \alpha_{min} \leq \alpha \leq \alpha_A \\
\psi_{\lambda\alpha} &= \psi_\lambda & \text{for} \quad && \alpha_A \leq \alpha \leq 180°,
\end{aligned} \tag{8}
$$

where ψ_λ is the indicative value of end-effect factor which must be determined from the diagram (7.36) in [8] using the solidity ratio φ (which is for cylinder equal to 1) and slenderness λ which can be found in table (7.16) in [8]. For $l \leq 15\ m$ we calculate slenderness as:

$$\lambda = 2 \cdot \frac{l}{b} = 2.56. \tag{9}$$

Now we can calculate wind pressure on external surfaces w_e as:

$$w_e = q_p\left(z_e\right) \cdot c_{p,0} \cdot \psi_{\lambda\alpha}, \tag{10}$$

where $c_{p,0}$ is the external pressure coefficient without free-end flow, which is given in figure (7.27)

[8] for various Reynolds numbers as a function of angle α. In the Figure 2 we have illustrated the

pressure distribution on the cylindrical filter according (7), (9).
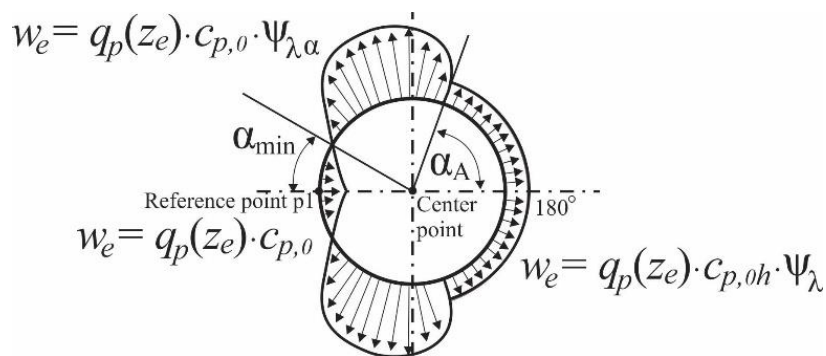

Figure 2. Pressure distribution illustration.

In the next section we will present FEMAP API in which we implemented previously described equations, and in the results and discussion section we will show real calculated pressure values and equivalent (Von Mises) stress that they cause.

3. FEMAP API FOR LOAD DEFINITION

FEMAP is the most versatile software for pre-processing [4] i.e. FEM model preparation, which includes generation of finite element mesh and prescription of loads and boundary conditions. After the FEM analysis in built in NX-Nastran solver [4] for all of the required load cases listed in the introduction, FEMAP is again used to load and to display results. In order to apply wind pressure on the tank wall modelled with shell elements and according to Equation 9., and Figure 2., we have developed FEMAP API script in Visual Basic (API stands for Application Programming Interface).

More details on the FEMAP API script application is given in [9]. Here we will focus on the most important sections of code that are used for load definition.

First, to access current model we use:

Dim App As femap.model
Set App = feFemap( )

Next, we declare and set element object, which is used to obtain element faces on which to apply pressure from the list of selected elements, which we will explain later.

Dim e As femap.Elem
Set e = App.feElem

We also need a point object to select the centre of the filter and a reference point (according to Figure 2.) which are needed to measure the angle of the wind direction.

Dim n As femap.Point
Set n = App.fePoint

To prescribe wind load, we must first declare and later create a new load set.

Dim newldset As femap.LoadSet
Set newldset = App.feLoadSet

Particular load (pressure on elements) also first needs to be declared in order for us to use it later when wind load is calculated.

Dim neweload As femap.LoadMesh
Set neweload = App.feLoadMesh

IDs of center and reference point, load set, element and its face are declared.

Dim centarid, p1id, ldsetiD, ipress, eFace As Long

All coefficients obtained from the Eurocode and previously given equation are declared. These coefficients are entered into an API generated dialog box (Figure 3.)

Dim cp0_h, alfa_min, cp0_min, alfa_A,qprit, ksi_l As Double

Calculated pressure with some supplemental variables is declared.

Dim prez, k1, k2, n1, n2 As Double

Dialog for entering parameters is generated using the following code snippet:

Begin Dialog UserDialog 600,200,"Parametri"
OKButton 150,140,120,42

CancelButton 400,140,120,42
TextBox 150,14,120,21,.Val1
TextBox 150,42,120,21,.Val2
…
Text 30,21,100,14,"cp0,min ",.Stiff1
Text 30,49,100,14,"alfa min",.Stiff2
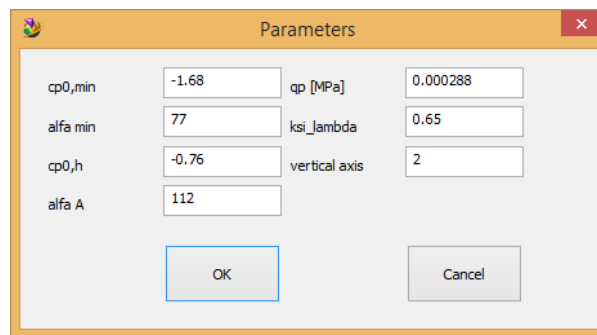*…*
End Dialog
Dim dlg As UserDialog

Figure 3. FEMAP API dialog for pressure coefficients.

After the users click on OK button coefficients are cast from the textbox values.

cp0_min = Val (dlg.Val1)
alfa_min = Val (dlg.Val2)
…

Supplemental variables are calculated to keep equation implementation concise.

n1=1.0
k1=(cp0_min-n1)/alfa_min
k2=(cp0_h-cp0_min)/(alfa_A-alfa_min)
*n2=cp0_min-k2*alfa_min*

To select elements for wind load prescription we create a selection dialog from the FEMAP API as shown on Figure 4. This collection we named *pressSet*.

rc=pressSet.Select(FT_ELEM, True, " Select the elements on which the pressure is applied ")
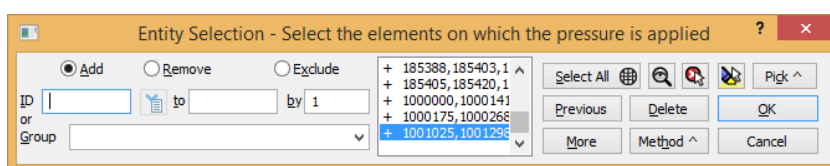

Figure 4. FEMAP API dialog for element selection.

After the elements for pressure load are selected, API generates dialog boxes for selection of center and the reference point which define wind direction (see Figure 2).
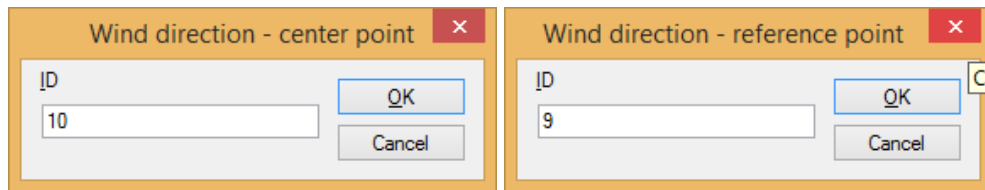
Figure 5. FEMAP API dialogs for point selection.

The counter that is used to loop through all selected elements is *ipress*.

ipress=pressSet.First
While ipress>0
rc = e.Get(ipress)
eFace=2
rc= e.GetFaceCentroid(eFace,cgXYZ)
centar(iosa) = cgXYZ(iosa)
p1(iosa) =cgXYZ(iosa)
rc=App.feMeasureAngle(centar,p1,cgXYZ,angle)

Initially we assumed that for every element on which we apply pressure external face is face number 2, and that the wind blows in the x direction. The vertical axis (y, i.e. 2) is selected in the first dialog (Figure 3.) and stored as variable *iosa*. First, we get the coordinates of element center of gravity using API method *GetFaceCentroid* and store it in *cgXYZ* vector. Then we need to elevate center and reference point to be at the same height as the element center of gravity, and finally we use API method *feMeasureAngle* to get the angle α.

Now we can calculate pressure (*prez*) if we combine equations 8 and 10 using previously calculated supplemental variables:

If (angle<= alfa_min) Then
prez=qprit*(k1*angle+n1)
ElseIf (alfa_min <angle) And (angle<= alfa_A) Then
prez=qprit*(k2*angle+n2)
prez=prez*(ksi_l+(1.0-ksi_l)*Cos(pi/2*((angle-alfa_min)/(alfa_A-angle))))
ElseIf (alfa_A<=angle) And (angle <180) Then
prez=qprit*ksi_l*cp0_h
End If

Finally, we apply the calculated pressure on the element face, move to the next element from the selected collection, and refresh the FEMAP view.

neweload.Type=FLT_EPRESSURE
neweload.meshID=ipress
neweload.FaceNumber=eFace
neweload.Pressure=prez
rc = neweload.Put(neweload.NextEmptyID)
ipress=pressSet.Next
Wend
rc = App.feViewRegenerate (0)

4. RESULTS AND DISCUSSION

Figure 6. shows wind pressure distribution on the filter. This distribution is obtained from previously shown equations and applied via described FEMAP API script. We can see similarity between Figure 2. which is an illustration of different pressure zones and Figure 6. which gives us real results, but has far less emphasized the difference between the pressure along the rim of the filter.
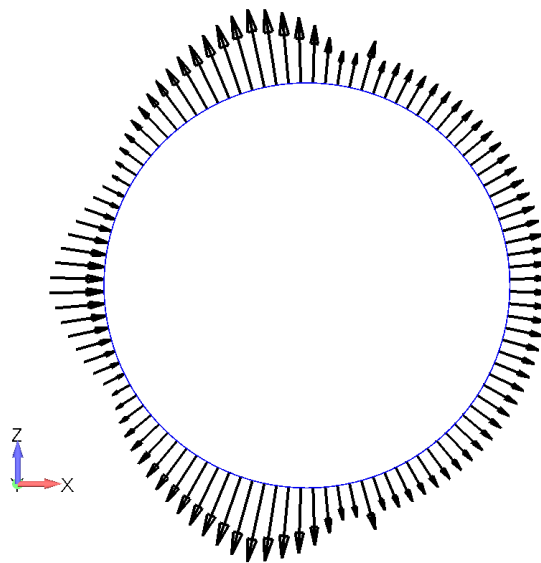

Figure 6. Wind pressure distribution on filter surface.

This pressure is combined with a hydrostatic pressure caused by the waste water in the normal regime of operation, and stress and strains are calculated using NX Nastran. Based on the results shown on Figure 7., we can conclude that Von Misses stress in below permissible stress for the steel used in the construction of the filter, and that the filter is safe for operation. From the results shown in Figure 7., it can be seen that the influence of wind pressure on the filter load is not large.
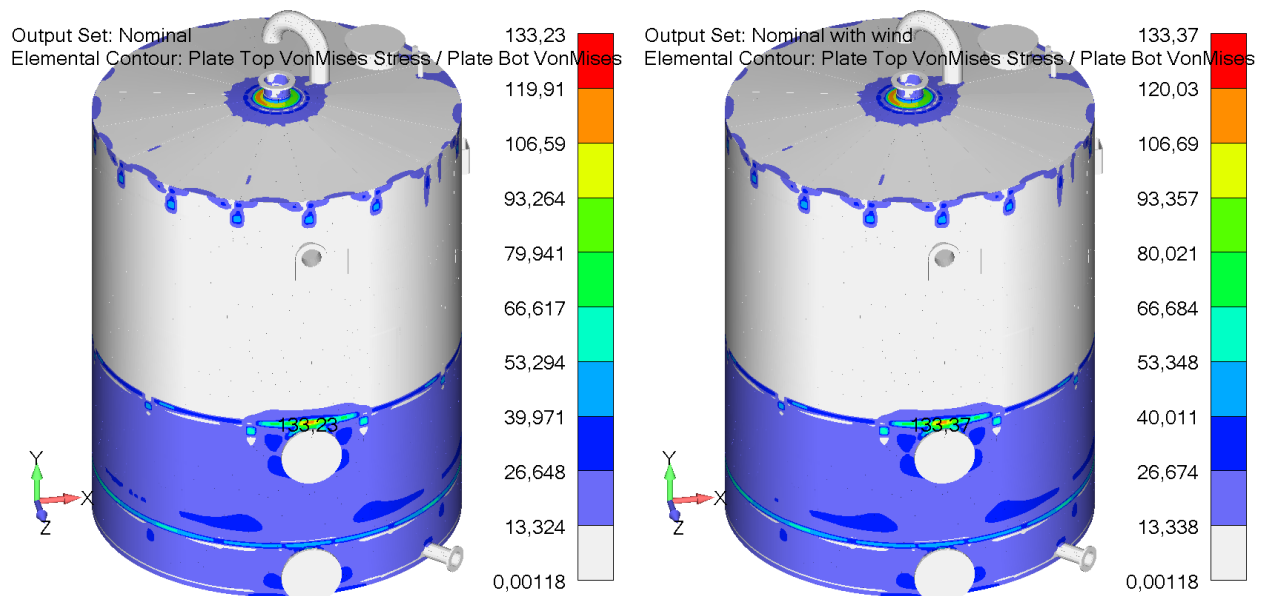
Figure 7. Von Misses stress in the industrial filter: a) without wind, b) with wind.

5. CONCLUSION

Prediction of industrial waste water filter response to the external load requires calculation of wind pressure, which must take into account geographical position of the filter, its shape, and its surroundings. In order to validate structural strength, we used European Eurocode standards, and their localized variants for the Republic of Serbia. In order to implement the equations from Eurocode into FEM analysis, we developed a specialized FEMAP API script, in which users can input coefficients obtained for Eurocode, and as a script output, a new load case is created with appropriate wind pressure on every selected element. Finally, FEM analysis confirms the validity of the initial design, with maximum stress in the critical areas not exceeding the permissible stress. Presented methodology with some modifications can be used on all outdoor thin walled pressurized structures, such gas and oil tanks, grain storage etc.

Acknowledgements

References

[1] Efeovbokhan V., Olurotimi O., Yusuf E., Abatan O., and Edith, A., 2019, Production of Clay Filters for Waste Water Treatment, *Journal of Physics: Conference Series*, 1378(3), pp. 032028.
[2] Topalović M., 2016. Numerical modelling of granular materials, PhD thesis, Faculty of Engineering, University of Kragujevac, Kragujevac, Serbia.
[3] EN 13445-3:2014, Posude pod pritiskom koje nisu izložene plamenu – Deo 3. (in Serbian).
[4] Femap with NX Nastran - user manual.

[5] Kojić M., Slavković R., Živković M., and Grujović, N., 1998, *Metod konačnih elemenata I, Linearna analiza*, Mašinski fakultet, Univerzitet u Kragujevcu, Kragujevac.

[6] Kojić M., 2012, An extension of 3-D procedure to large strain analysis of shells, *Computer methods in applied mechanics and engineering*, 191, pp. 2247-2462.

[7] Jovičić G., Živković M., and Vulović S., 2011, *Proračunska mehanika loma i Zamora*, Mašinski fakultet, Univerzitet u Kragujevcu, Kragujevac.

[8] EN 1991-1-4:2003, Dejstva na konstrukcije, Deo 1-4 Dejstva vetra (in Serbian).

[9] Vulović S., Bojović M., and Topalović, M., 2020, Automation of FEM Analysis Report Generation using Visual Basic FEMAP API, *ICIST 2020 Proceedings*, (1), pp. 10-15.