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Studies on predictive virtual models based on finite element analysis of the behaviour of geomembranes

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Abstract. The study shown in this paper presents the behaviour of geomembranes used at the ecological landfills. For this goal was used a method designed to elaborate the virtual models of 3D geomembrane with one ply or 2 plies disposed at 30°, 45° and 90° and based on this model there were developed a number of 20 particular cases. For each situation it was realized the nonlinear analyses for all the developed cases with different vertical pressures representing different loads for the waste layer (1m, 2m, 10m, 15m, 20m). The main results are obtained in graphical form and represent the Maximum tensions Von Mises and total displacements of the geomembrane.

1 Introduction

The apparition and evolution of the computing system allowed the automation of the conception, designing and research processes.

In this context, the FEA Concept (Finite Elements Analysis) was born from the necessity to develop some strong computing systems of resistance and data stream or fields met in engineering.

Generally, the steps of approaching a simulation based on the method of finite elements are [11]:
• Generating the tridimensional model using its own 3D modulus of definition or importing it in a CAD specialized program.
• Defining the restraints, the forces, the pressures, the sources of heat, the radiations and the laws that govern them when the analysis is ruled dynamically.
• Dividing the initial model in finite elements using different techniques in order to obtain the wanted model in the Mesh structure.
• Ruling the analysis with the aim to obtain the statistic maps of tensions, siftings and temperatures and so on.

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Generally, the resulted maps regarding the static analysis and the films and the dynamic analysis express [11]:

• The stress obtains by the algorithm von Mises offering information on the charging of finite elements compared to the outside force.

• The strain of the mechanical system which reveals the lengths.

• The strain energy which offers information on the energetic consume needed to obtain the deformation status.

• The displacement which offers information on the variation of the defined nods.

In Romania the use of geosyntetic materials for construction works is regulated by MTCTNP 075/2002. The works of storage of waste and the use of geomembranes and geocomposits is regulated by Governmental Decision 162/2002 and the Technical Norms of the MAPM approved by Order 1147/2002.

In the entire world a lot of tests and studies were realized [1, 2, 3, 6, 9, 10] on the subject of the use of geomembranes. In a work [4] the use of protection materials installed on the geomembrane trough the experimental study was described.

In another study presented in the paper [5] the tension of encounter made in the system of the ecological deposit was analysed. The tension of encounter is due mainly to the weight of the body part elements of the ecological deposit and it varies. The phenomena of encounter between layers was also studied.

Another direction was given in a paper [7], which presented the classical lab tests analysing the puncturing effect which appears due to the sand layer currently placed on top of the geomembrane. In the tests, the liquid pressure was also taken into consideration.

In a paper [8], it was evaluated what was the mechanical answer of two polymeric geomembranes of PVC and polyethylene of 1,5 mm of high density, describing the phenomena in a proper mathematics model.

After analysing this worldwide published studies, it resulted the need to study the geomembrane actions when assembling and developing an ecological storage.

In this context, the current paper presents different studies using the finite element method which synthesizes the behaviour of the geomembrane submitted to different charges given by different thickness of waste pushing on it. A special attention has been offered to the plies that inevitably occur when mounting the geomembrane. These plies could have important consequences regarding the functioning and impermeability of the ecological landfill.

2 Virtual shaping and analysis with solid element of the geomembrane

The virtual model of the geomembrane was conceived in the Design Modeller Application, application that is a predecessor of the AnysWorkbench Application.

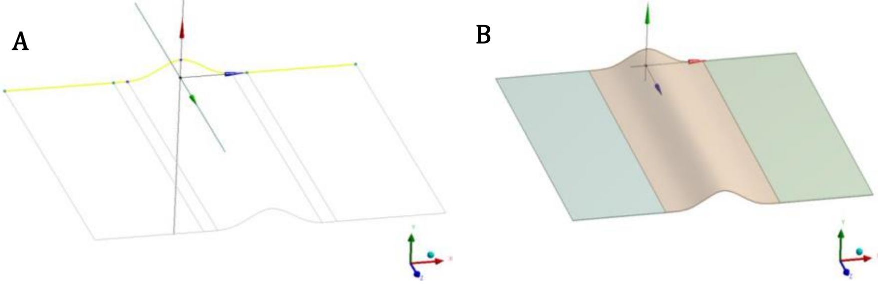

Fig. 1. A - Making the membrane surface; B - Making solid model of the membrane with a single ply.

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In order to realize the geomembrane model with one ply, it was used a sketch and then every 2 plies models used different realization methods.

In order to achieve the 3D model, the first step is to draw in the coordinates system XY the 2D model Sketch, a curve line with a height of 57 mm (height of the ply). The sketch (figure 1A) realized in the pre-processor Design Modeller represents the contouring shape of the geomembrane ply.

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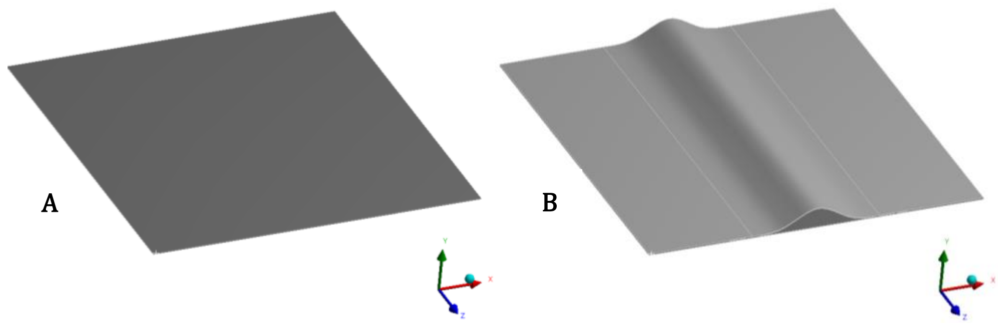

Fig. 2. A - *„Ground"* component; B- Virtual model geomembran1 (1ply) – *„Ground*".

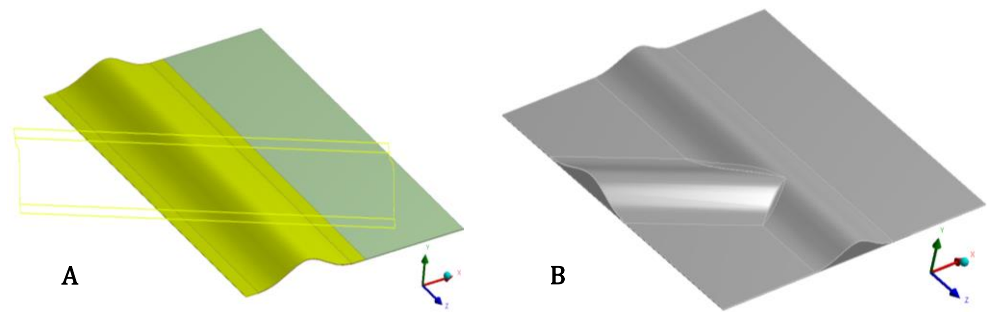

Fig. 3. A – The rotation of the ply at - 30°; B - The model of the geomembrane with 2 plies arranged at 30° and "Ground".

The surface of the geomembrane was conceived using the commands Line from Sketch and Extrude and then defining in solid by extrusion at 2 mm (figure 1.B). A contact on the surface of the geomembrane was imposed in order to make the analysis in such a manner that it won't go in one Direction-Y. This component, which was a simple plate with the same exterior dimensions like geomembrane, will be called Ground (figure 2A). The 2 components can be distinguished by their colour and position in figure 2.B. It is important to mention that the surface of the model is $1m^2$ (1m x 1m) and the thickness both of the geomembrane and of the Ground component is 2 mm. In this way the surface of the ply geomembrane solid model was realised (figure 2B).

For achieving the virtual models for the geomembranes with 2 plies arranged at 30°, 45° and 90°, special functions were used:

• Move – for rotation of the plies at different angle.
• Substract – Boolean operation.
• Fblend – for rounded of the new components.
• Repair – for a detailed checking of the consistence of the components.

In figure 3.A the rotation of the ply at the 30° is shown and in figure 3.B it is presented the model of the geomembrane with 2 plies together with "Ground" element.

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In the same way, the others 3D models of the geomembranes with 2 plies disposed at 30°, 45° and 90° were achieved. In order to achieve a nonlinear static analysis with shell elements these 3D models used were suitable.

3 Nonlinear analysis of the geomembrane with 2 plies

In the following, the elaboration of the nonlinear static analysis for the geometric model of the 2 plies 30˚ geomembrane with shell elements will be presented. The 2 components were placed in a global XYZ system in order to correctly place the degrees of freedom of the 2 components.

The discretization of the geometric model in nods and elements was realized with 186 Solid hexahedric elements and 187 Solid tetraedic elements, both solid elements with middle nods. The middle nods are necessary in order to better approximate the results.

The Sweep method was used in order to discretize the elements for the Ground component, automatically controlling the formation direction of the source elements to the interest area.

For the encounter zones of ply surfaces, due to the fact that they are hard to discretize, advanced discretization methods were used, like HexDominant and PatchConforming, those being methods used to encounter the hexaedric and tetraedic elements. In order to obtain an efficient discretization the 10 mm and 20 mm dimensions were used.

Following the solving of the nods and elements network, 42. 731 nods and 15. 125 elements resulted (figure 4).

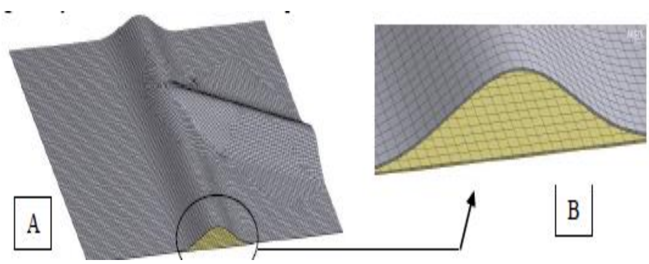

Fig. 4. A - Network modes and items obtained for model membrane 2 folds arranged at 30° – "Ground"; B - Picture fold local area.

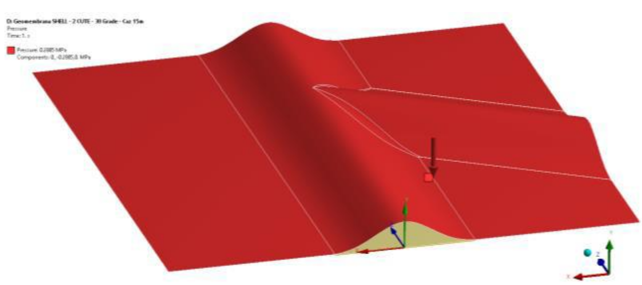

Fig. 5. Applying pressure evenly distributed on the upper surface of the membrane 2 folds arranged at 30⁰.

In order to realize this analysis, the limit conditions used were:

• Virtual time for run of the analysis was set at 1 sec.

• The solver was set as one being the iterative type using PCG method („Preconditioned Conjugate Gradient") level 2.

• Constraining the "ground component" using the commands „Fixed Support" on the bases surfaces, DOF = 0 (degree of freedom).

•Applying a Normal uniform distributed pressure on the superior surfaces of the geomembrane with a value dependent of the height of the waste (1m, 2m, 10m, 15m, 20m) (figure 5).

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• Constraining the geomembrane on the exterior lines (parallel with the ply) using also the command Fixed Support.
• Constraining the lateral surfaces of the geomembrane with the support „Frictionless Support", blocking in this way the movement on the perpendicular direction.

The characteristics of the isotropic material used for the geomembrane are shown in Figure 6. The image is the caption from simulation module „Data Engineering".

Properties of Outline Row 3: Polyethylene

	A	B	C
1	Property	Value	Unit
2	Density	1020	kg m^-3
3	Isotropic Secant Coefficient of Thermal Expansion		
4	Coefficient of Thermal Expansion	0.00176	C^-1
5	Reference Temperature	22	C
6	Isotropic Elasticity		
7	Derive from	Young's Modulus and Poisson's Ratio	
8	Young's Modulus	2000	MPa
9	Poisson's Ratio	0.394	
10	Bulk Modulus	3.1447E+09	Pa
11	Shear Modulus	7.1736E+08	Pa
12	Tensile Yield Strength	63	MPa
13	Compressive Yield Strength	0	MPa
14	Tensile Ultimate Strength	33	MPa
15	Compressive Ultimate Strength	0	MPa
16	Isotropic Thermal Conductivity	0.2256	W m^-1 C^-1
17	Specific Heat	1386	J kg^-1 C^-1

Fig. 6. The characteristics of the isotropic material used for the geomembrane.

For the results set the following values were extracted: Total displacement, Equivalent total strain, Maximum equivalent Von Mises Stress, Maximum principal stress, Minimum principal stress.

In figure 7 it is shown the map of the Maximum equivalent Von Mises Stress.

The area of interest and importance is the maximum stress Von Mises and total displacement of the membrane. Due to the pressure imposed by 0.0192 MPa, total displacement is 25.38 mm and the maximum value calculated for maximum tension membrane is equivalent to 29.82 MPa.

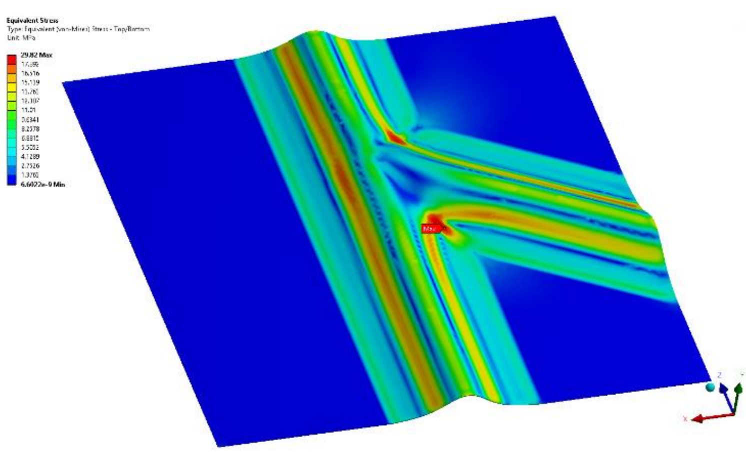

Fig. 7. Maximum equivalent Von Mises Stress.

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These values were obtained at the analysis of the 30°, 2 plies geomembrane model with Shell elements for the application of the tension given by the waste layer with the 1m length. The 0.192 MPa tension is applied on a 1m^2 surface of the geomembrane. The values obtained for the 5 analyses with the respective tensions and waste layers of 1m, 5m, 10m, 15m, and 20m for the total deformation, Equivalent Total Strain and the Equivalent Total Strain can be found in Table 1.

Table 1. Values obtained for the 5 cases developed membrane with 2 plies arranged at 30° analysed with shell element.

H *[m]*	**PESD** *[MPa]*	**DT** *[mm]*	**DET** *[mm/mm]*	**TME** *[MPa]*
1	0,0192	25,38	0,0375	29,82
5	0,0961	35,99	0,0599	39,73
10	0,1923	41,13	0,9973	57,01
15	0,2885	45,78	0,1279	60,14
20	0,3846	47,69	0,1413	66,14

H - height layer of waste;
ESDP - pressure from the layer of waste;
DT - total displacement;
DET - total equivalent strain;
TME - the maximum stress equivalent von Mises

Table 2. Values obtained for the 20 cases developed membrane analysed with shell elements.

H *[m]*	**PESD** *[MPa]*	**Geomembrane 1 PLY – Shell**			**Geomembrane 2 PLIES – 30° - Shell**		
		DT *[mm]*	**DET** *[mm/mm]*	**TME** *[MPa]*	**DT** *[mm]*	**DET** *[mm/mm]*	**TME** *[MPa]*
1	0,0192	29,44	0,0249	23,68	25,38	0,0375	29,82
5	0,0961	41,78	0,0450	32,05	35,99	0,0599	39,73
10	0,1923	45,64	0,0672	50,54	41,13	0,9973	57,01
15	0,2885	47,35	0,0775	59,23	45,78	0,1279	60,14
20	0,3846	49,72	0,0963	64,18	47,69	0,1413	66,14
—		**Geomembrane 2 PLIES – 45°- Shell**			**Geomembrane 2 PLIES – 90° - Shell**		
1	0,0192	27,14	0,0379	31,11	32,81	0,0384	32,10
5	0,0961	37,03	0,0507	43,19	38,17	0,0406	45,12
10	0,1923	42,15	0,0671	59,02	41,71	0,0852	59,43
15	0,2885	46,22	0,0993	63,79	45,61	0,0929	64,11
20	0,3846	51,31	0,1129	68,23	49,17	0,1213	68,63

Using the same approach, the virtual models of 3D geomembrane with one ply or 2 plies disposed at 30°, 45° and 90° were achieved (20 particular cases).

The obtained values for different tensions from the waste layers are presented in table 2. The abbreviations used in Table 2 are the same as those used in Table 1.

It can be observed that by applying a pressure of 0.0192 MPa (1 meter height layer waste), the maximum total displacement is 32.81mm and the maximum stress equivalent von Mises is 32.10 MPa. This values were obtained for the geomembrane with 2 plies disposed at 90°. By applying a maximum pressure of 0.0348 MPa (20 meter height layer waste), the maximum total displacement is 51.31mm obtained for the geomembrane with 2 plies disposed at 45°, whereas the maximum stress equivalent von Mises was reached for the geomembrane with 2 plies disposed at 90°.

4 Conclusions

The main goal of this paper is to analyse the geomembrane behaviour, using the finite element method, in different situations. The main original contributions are the following. It was realised a numerical simulation of the geomembrane by the 4 developed models each and every one with 5 different loading cases. It was realized a static nonlinear analysis for all the developed cases with different vertical tensions representing different heights for the waste layer (1m, 2m, 10m, 15m, and 20m). In the paper are presented the analysis conditions for the simulations, the limit conditions and the material characteristics. There were extracted images for the maximum tensions Von Mises and for the total deformations of the geomembrane. By undergoing a comparative analysis with these cases, it resulted that:

• All evaluated parameters in all cases increase with the height of waste layer.

• For the maximum value of the waste layer (20 m), the total displacement is minimum for 2 plies disposed at 30° and maximum for 2 plies disposed at 45°, the total equivalent strain is minimum for 1 ply and maximum for 2 plies disposed at 30° and the maximum stress equivalent von Mises is minimum for 1 ply and maximum for 2 plies disposed at 90°

Because the appearance of the plies is inevitable at the mounting of the geomembrane it would be better to manage the disposition of these plies. According with this study it's important to avoid the situations when the values of the studied parameters are maximal because in these positions of the plies it is possible to damage the geomembrane with bad consequences on the good functioning and on the non-permeability of the ecological landfill.

We consider that the study is very important in order to achieve a good and correct mounting of the geomembrane.

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