UNIUNEA EUROPEANĂ
GUVERNUL ROMÂNIEI MINISTERUL MUNCII, FAMILIEI, PROTECȚIEI SOCIALE ȘI PERSOANELOR VÂRSTNICE AMPOSDRU
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Axa prioritară: nr. 1: "Educaţia şi formarea profesională în sprijinul creşterii economice şi dezvoltării societăţii bazate pe cunoaştere"
Domeniul major de intervenţie: 1.5.: "Programe doctorale şi post-doctorale în sprijinul cercetării"
Titlul proiectului: "Armonizarea valenţelor academice româneşti cu cele ale Comunităţii Europene"
Cod contract: POSDRU/CPP107/DMI1.5/S/76851
Beneficiar: Universitatea "Lucian Blaga" din Sibiu

UNIVERSITY „LUCIAN BLAGA" SIBIU
FACULTY OF ENGINEERING

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Short summary

CONTRIBUTIONS TO THE STUDY OF MECHANICAL BEHAVIOR OF GEOMEMBRANE USED TO LINING ECOLOGICAL LANFILLS

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1. Introduction

Motivation in choosing the theme "Contributions to study the mechanical behavior of the geomembrane used to lining ecological landfills" derives from the desire of achieving new documentary and experimental research on the study of landfills.

Geomembranes are used mainly as part of the lining of landfills as a hydraulic barrier, their main function being prevented from passing contaminants through the liner into the soil below the foundation deposit. To ensure in good condition the waterproofing of landfills, the geomembranes must be well installed, protected by appearance of damage (holes, cracks).

The most common method was and still is in some countries, the landfill, despite the fact that it has the most negative effects. This thing can be attributed to the degree of development of countries, the behavior and attitudes of civil society and the authorities; as well the existence of legal instruments, political factors. For example, developing countries have the political strategy and general purpose the economic development, leaving environmental issues (impact of waste on the environment, in this case) at a lower position.

In this work will study the long-term behavior of geomembranes and also the effect of factors influencing this behavior, given the importance of protecting the environment that has geomembrane, used in waterproofing waste landfills. Also, a special attention will be paid to transport and collection systems of leachate.

The main objectives in achieving this these are: general presentation of a landfill, its structure, risk factors and impacts that result from the realization of a landfill, the geomembrane’s importance and its role in waterproofing the landfill.

For the development of the present work were studied a large number of works (more than 150) to achieve the current state of this field.

There were realized experimental research on the behavior of HDPE geomembrane by numerical simulation (analysis by finite element method) and also experimental research, related to the mechanical behavior of HDPE geomembrane, by testing for traction different specimens of HDPE geomembrane.

The present doctoral thesis entitled "Contributions to study the mechanical behavior of the membrane" is divided into 6 chapters.

Chapter 1, represent the introductory chapter, it defines the landfills, it shows the major risks and impacts of the construction of landfills.

The human population, considers deposits a source of air pollution, surface water, soil by decreasing soil fertility, changes in the biosphere lands near the deposits and not least unpleasant visual, olfactory. These visions must be evaluated before the construction of deposits by decision factors, to adopt the methods of waste management.

A landfill ecologic represent the place where is stored waste by burial, which is the oldest form of waste treatment. Due to the lack of planning and poor exploitation, landfills are among the recognized causes of impact and risk.

In terms of biodiversity, a landfill means the removal on the affected area this uses a number of species 30-300 / ha, without taking into account the microbiological population of soil biocoenosis.

The biocoenosis from the neighborhood store is modified in meaning that the plant associations become dominant species ruderal specific polluted areas, some mammals, birds, insects leave the area for the benefit of those who find their food in the garbage.

Trends in terms of waste management, promoted by the European Environment Agency and adopted by most EU member states are: minimizing and preventing waste generated, recycling, incineration, landfilling.

Figure 1.1 Ecological landfill transformed in park

2. The current stage of the field on mechanical behavior of geomembranes used on waterproofing landfills

In this thesis has been studying the long-term behavior of geomembranes and also the effect of factors that influence this behavior, given the importance of protecting the environment which has geomembrane, used for waterproofing ecological landfills.

Geomembranes are plane polymer products, thin, in sheets form, with very low permeability, sealing (waterproofing), in contact with in grounds and other materials in construction field.

Geomembranes are usually dark color because of additives based on carbon black, which protects against the harmful effects of UV rays. There are white geomembranes that reduce the heat absorption and thermal expansion.

Factors that may cause the membrane damage are:

- geomembrane wrinkles;
- Perforations caused by the drainage layer;
- Inappropriate choice of coating;
- Incorrect operation of the landfill.

Special requirements for HDPE geomembranes (polyethylene high quality) referred to "Technical norm on non-hazardous waste landfill 757/2004" are:

- Requirements on the physical properties of geomembranes;
- Requirements for mechanical resistance of geomembranes;
- Requirements for stability and durability of geomembranes;

Merging sheets are the main sensitive part of a seal, so should give special attention to this aspect. This is done by thermal welding dual hot wedge or extrusion Further testing of the weld is made with pressurized air to hot wedge welding double vacuum or with extruded high voltage welds.

Merging with thermal welding contact is made by warm bonding two sheets superimposed, simultaneously with passing them over a plinth (melting element) and pressing immediate with two pinch rollers.

Merging with extrusion welding consists in deposition of the additive material through a portable extruder which use electrode welding made from polyethylene, with a diameter of 4-5 mm. The process of merging geomembranes with welding added material extruded it is complementary to the contact thermal welding process.

Figure 2.1. Merging by weld

When is exposed to radiation due the installation and if a part of the geomembrane is not covered by the deposit during operation, geomembrane supports thermal expansion. If these expansions are prevented from developing side (due to friction with the layer below the geomembrane or geomembrane anchor) and dilation is large enough, geomembrane will fold.

Temperature is the main factor which cause wrinkling geomembrane. Infiltration through a hole in a geomembrane depends on: the hydraulic gradient, size and number of holes in the geomembrane, the permeability of the border between the geomembrane and the material where is placed the geomembrane, and also the thickness and the hydraulic conductivity of the foundation.

The problems that appear because of wrinkles are:

1. increasing potential damage because of traffic on installing and coverage;
2. disruption of drainage;
3. shortening time of welding and coating due to the formation wrinkles on the geomembranes exposed to the sun;
4. Long-term elongation in material which can be decisive for his life or cause localization efforts in inappropriate areas;
5. reducing the ability of electric monitoring system;
6. loss of contact with the layer below.

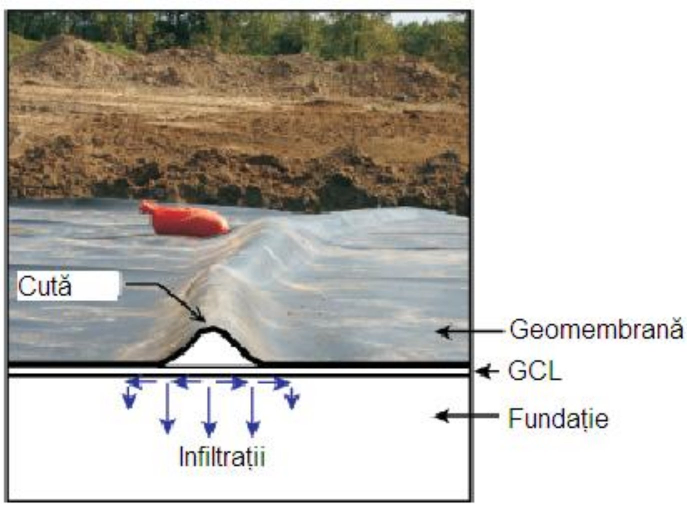

Figure 2.2 Implications of the wrinkles in waterproofing system

Absorption grade of solar energy is one of the major differences between white and black geomembranes. The black geomembrane textured had a surface temperature lower with 3°C than the fine black geomembrane. This leads to many comments about installing the ground and CQA (constructive quality assurance) of geomembranes and fine textured. Depending on the degree of bleaching, the fine white geomembrane was up to 24 ° C cooler than the fine black.

The temperature differences due to the different degrees of absorption of solar heat have a significant benefit and lasting consequences as discussed below.

Dilation / contraction of the geomembrane: the northern desert environments, where black geomembrane temperatures can reach at 80° C in summer and -30° C in winter, can appear temperature variations near 100° C or more. In temperate zones, differences can be 50-75 ° C. Geomembranes with white surface can reduce variations between 25-50%.

The geomembrane surface exposed during installation can exceed several hundred square meters. However, the information from field presented in the specialty literature indicate that the wrinkles that occur in the geomembrane are typically from about 0.2 to 0.3 m in width and height of 0.05m to 0.1m.

It presented a new method for quantification of geomembrane wrinkles in the field using low-altitude digital images and image processing techniques.

In idea to obtain images along the entire exposed surfaces of the geomembrane for use in quantifying the wrinkles of geomembrane, they must first be corrected for camera position and image coordinates transformed to be associated with real coordinates. These processes are addressed as geometric transformations and records of image. The need to achieve these processes can be seen in the image sample of HDPE geomembrane thickness of 1.5 mm abstracted from 60 m.

Geomembranes wrinkles appear in the image as linear projections, reflecting sunlight on the top of edge and shadows on the offset edges (wrinkles are visible when it is cloudy).

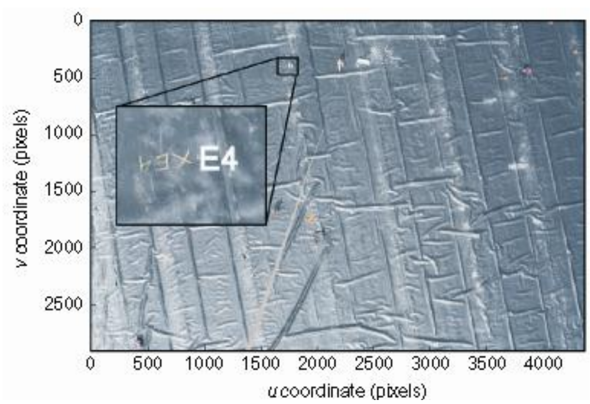

Figure 2.3 – Raw image [Tak07]

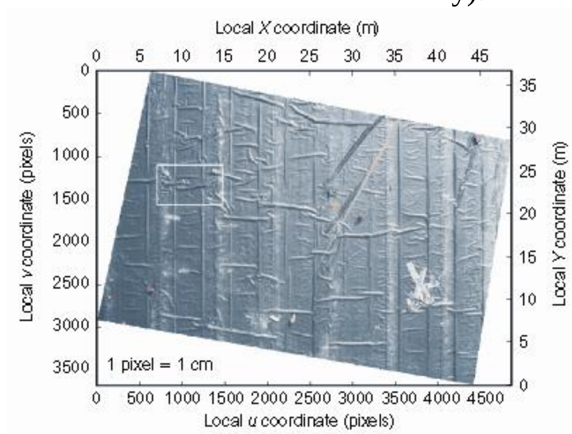

Figura 2.4 – Geometrically corrected image [Tak07]

The analysis results indicate that the date and time when the images were captured, geomembrane containing a hundred major wrinkles covering 13.9% of the total surface of the geomembrane. More importantly from the perspective of seepage, over 90% of these wrinkles have been found to be hydraulically connected with the entire field covered by geomembrane. A connected hydraulic wrinkle was found with a drain length of 520 m.

CONCLUSIONS

In this chapter has made an extensive study on the current state of knowledge of waterproofing systems, collection and transport of leachate from landfills green in world, European and national level in terms of mechanics.
An important part of this thesis was devoted to existing research in the field.

The research from the least years in the ecological landfills regarding waterproofing and leachate collection and transportation, have become an important theoretical and applied increasingly higher, because knowing the ways by which they can be prevented the damage to the two major components of a conform hole led to technical solutions advantageous for obtaining a geomembrane and pipes as well as new solutions and procedures regarding the installation and quality control.

From the research authors [Cad 93] (Temperature influence. Geomembrane with white surface) as shown in this these refer to the following conclusions:

- absorption of solar energy is higher in case of black geomembrane than white geomembrane;
- expansion / contraction need to be determined considering the quantity wave that need to be removed or when the liner is installed;
- cracking effort in HDPE geomembranes increase by 40% for every degree Celsius that the temperature rise GM;
- The lay placed under the geomembranes placed on slope was found dehydrated than on the base of the cell.

From the study "Quantification of GM wrinkles using aerial photographs and digital image processing" stands out the importance of quantifying wrinkles in idea to emphasize the importance of choosing the time and temperature suitable for installation. Also, the formation mode of the wrinkles stands out two major trends of their formation: in direction to roll and perpendicular in direction to roll.

From the research that treat this subject shows that wrinkles, with a height of more than 3mm, cover approximately 5% of installed geomembrane surface. But the most important aspect is that, in terms of hydraulic, 90% of those wrinkles were found to be hydraulically connected.

The question is to setting limits on the size of the wrinkles that appear in installation and how to modify these dimensions (width, height and length) during installation of other structural elements of the pit conform and comply pit during exploitation.

From the research presented in this thesis, which dealt with this subject are the following conclusions:

- deformations GM are greater in the presence of wrinkle;
- vertical effort distribution which acting on the wrinkle is generally on both sides of the wrinkle;
- efforts redistribution from the top of wrinkle on the sides wrinkle leading to higher contact forces near the crease;
- because deformations wrinkles are largely controlled by deflection of soil and the major of deflection wrinkle occur at low pressures, greater efforts will have the greatest influence deflection side of the geomembrane, thus making the wrinkle narrower;
- wrinkles elongation of deformations are predominantly compressed, which may cause cracks;
- the maximum elongation without wrinkle was 32%, while in the presence of wrinkles was of 42%;
- local prints usually develop because of contact between the apron and geomembrane;
- fingerprints magnitude is influenced by the existence of wrinkles and also the sort and coating.
- results show that the fingerprints were higher near the wrinkle and lower on the top of the wrinkle;

- elongations of the geomembrane were calculated from footprints measured using the procedure author of the study [Tog00] at three different locations: 1) close the wrinkle, 2) along the wrinkle, 3) on the top of wrinkle,
- results show that the prints were higher near the wrinkle and lower in the top of wrinkle; for example, the protective layer, the maximum elongation near the wrinkle was 8 times higher than the top of the wrinkle.
- local fingerprints from geomembrane do more damage in the presence of a wrinkle. For example, the maximum elongation without the wrinkle was 32% as compared to a maximum value of 42% with wrinkle;
- efforts redistribution from the top of wrinkle to the sides wrinkle leading to higher contact forces near the crease;
- the disappearance of the void beneath geomembrane depends of the pressure applied on the water content of the clay, the coating layer of drainage;
- under pressure is moved down the GM and moving up, into the void below the wrinkle, of clay;
- for a stiffer clay, containing less water, more pressure is needed to determine the disappearance of the void beneath the wrinkle;
- the clay moves from the beneath geomembrane into the gap below the wrinkle changing the dimensions wrinkles by decreasing its height and width;
- clay extrusion into the gap below the wrinkle is expected to change the size of wrinkle by decreasing in height and width; between the two sizes bigger effect is on width than on height;
- the protective layer influences the deformations of the wrinkle (from research results that a protective layer of sand gives the best protection of geomembrane deformation).

3. Studies on the influence of solar radiation on landfills

About 90% of the energy generated by the Sun in its central part is transmitted from its surface and then radiated into the cosmic space through a series of complex processes radiative and convective emission, absorption and radiation succession of different wavelengths in the spectrum continuous or discontinuous.

Solar radiation is the electromagnetic radiation emitted by the Sun with wavelengths in the spectrum of electromagnetic waves. This is an important natural factor in creating the climate of Earth and has a significant influence on the environment. Ultraviolet radiation (UV) solar spectrum plays an important role in many processes in the biosphere. Between the many beneficial effects, it can be also very dangerous if they exceed the safe limits - the capacity for self-protection of biological species falls off rapidly. In humans, this refers primarily to the skin and eyes.

Figure 3.1 - Earth picture looking in the direction of the sun at a distance of 151,884,766 km [WNA]

Here it is described The influence of solar radiation, from the sun's position relative to a flat surface and apparent movement of the sun in the sky.

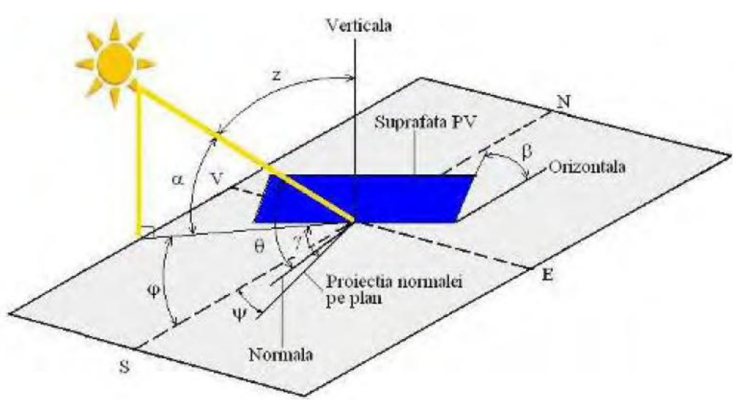

Figure 3.2 - The position of the sun relative to a flat plate inclined to the earth's surface [Dan80]

It is also written equations for constant solar and radiant flux density at ground level.

Distance variation Earth-Sun causes variation in the size *I* from one day to another. Measurements of N.A.S.A. varying the intensity indicates the boundaries of 1310 W / m2 (June) and 1,400 W / m2 (January).

It has developed a mathematical model to calculate in any day of the year, any time of day and in any location in the country to solar radiation density expressed in W / m2.

The average annual of solar radiation in the upper atmosphere is called the *solar constant* $\boldsymbol{S_{sn}}$ **=** 1367 $W/m^{2.}$

For the day N of the year, the solar constant is calculated with the correction formula:

$$S = S_{sn}\ (1 + 0{,}0034 \cos N)$$

Using AutoLISP was realized out a program for calculation of total solar radiation. So:

- in AutoCAD was charged a map of Romania that was scaled using the scale grid so that 1 unit is equal to 1 km;
- over the map straight image was drawn outline of Romania using full order. This outline was processed turning right spline segments;
- at the intersection of meridians were approximated by straight determined, the position geographic North Pole, were positioned the main cities;
- after positioning the graphics elements were obtained the main value used subsequently to write code AutoLISP: the distance on meridian between two parallel and degrees geometric value of a degree of longitude.

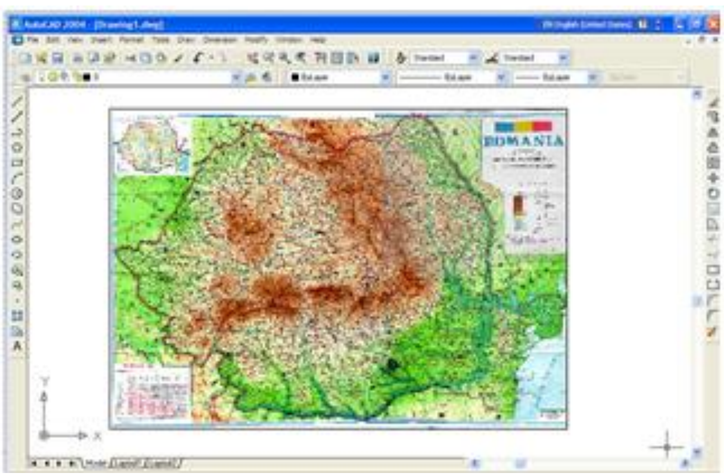

Figure 3.9 – Romania Map loaded in AutoCAD

4. Studies on virtual predictive models based on finite element analysis of the behavior of geomembranes

Chapter four is devoted to numerical simulation by finite element. In the first part of this chapter were realized numerical analyzes using solid-type items, on a geomembrane plate at a given temperature to determine movement.

General stages of a simulation approach based on the finite element method are:

- generate three-dimensional model using its own way of defining 3D or importing it from a specialized CAD software;
- the defining of the constraints, forces, pressures, sources of heat and radiation, etc. or laws defining their analysis when running dynamic;
- dividing the initial model in finit elements using different techniques which result are meshed geometric model;
- running the analysis in which obtain static maps or dynamic of tensions, displacements, deformations or temperatures, etc.
- When the analysis is dynamic, results materialized in maps can express: the state of tension, deformation energy density (deformation energy) displacement status.

In this thesis various studies are conducted using the finite element method and summarizing behavior wrinkle geomembranes are subject to different loads data from various thicknesses of waste requiring geomembrane wrinkle. It has also been envisioned and designed an experimental device which allow studying the behavior of the various layers that make up a landfill.

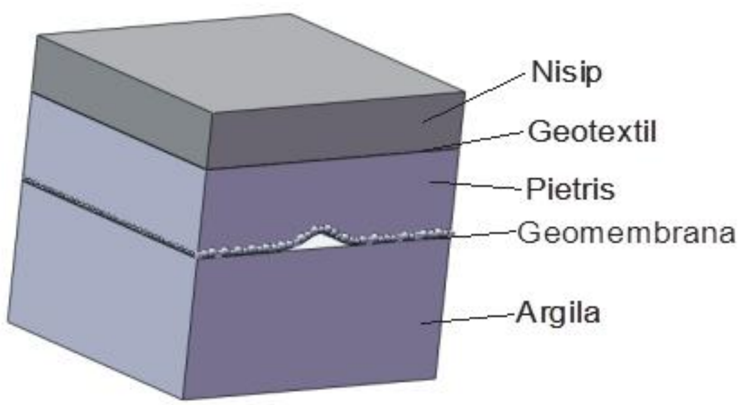

Figure 4.1 - Structure of the analyzed system layers

For 3D design and modeling of a device for testing the membrane -Preparing final model for see the analyzes, mechanical components were loaded, each one, in the SolidWorks program module assembly. This module allows defining constraints motion (axis-axis type, plan - plan, distance etc.) and allows defining the mechanical system in terms of the freedoms of movement.

It was realized a virtual experimental analysis of the behavior of a wrinkled geomembrane into the proposed test device after which we extracted the following conclusions:

- maximum tension to simulate the behavior of the geomembrane, are obtain in case of geomembrane with a single wrinkle in the virtual device testing;
- maximum deformation to simulate the behavior of the geomembrane, are obtain in case of geomembrane with a single wrinkle in the virtual device testing;
- maximum displacement, to simulate the behavior of the geomembrane, are maximized when the geomembrane has a single wrinkle.

Although the values of tension and deformation, for the case of the test device, are different from the cases studied, the values of displacements fall within the range of mean values of the four cases studied previously, the test device may thus be used for the study of geomembrane displacement.

To achieve the final model for a geomembrane with a single wrinkle, were used the following commands: *Scale, Merge, Slice, Plane, Boolean, Form New Part.*

To achieve virtual models for geomembrane with 2 wrinkles arranged at 30^0, 45^0 and 90^0 we started from this model with a single wrinkle, using the following commands: Move (30^0, 45^0, 90^0), subtractive, *Fblend, Repair*.

Following the completion of these analyzes was that positioning and dimensions of the components to be close to reality. The results quality of this analyses being close to the quality of geometrical model.

In the last part of this chapter is presented *"Statistic testing with element type" Shell " for geomembranes model with 1-2 wrinkles"*.

Virtual models of geomembrane with a wrinkle and two wrinkles were analyzed with Shell-type elements, were designed on the basis on models analyzed with solids element realized in the DesignModeler application, the preprocessor solution's AnsysWorkbench 15.0.7.

Here it is presented a nonlinear analyze of a geomembrane with a single wrinkle, two wrinkle to 30^0, 45^0 and 90^0, the waste layer having a height of 1m, 5m, 10m, 15m and 20m.

The main original contributions of studies and research in this chapter are:

1. Numerical simulation of geomembrane's behavior via 4 models based on the surface type geometric entity with 5 different cases of load;
2. It was performed a static nonlinear (contact nonlinearity) for each geometric model in part. Are presented the analyses conditions that occur simultaneously, boundary conditions and material characteristics.
3. Determination, on numerical way, of maximum equivalent tension (Von Mises), the total deformations and the total displacements of the geomembrane.
4. Performing the analysis of nonlinear defined with shell elements for all the cases developed, being subject to different loads in the vertical direction, which is represent different heights for the waste layer (1m, 5m, 10m, 15m, 20m).
5. Were extracted images for the maximum tensions equivalent, for the total deformations and the total displacements of geomembrane.

5. Experimental research methodology, experimental installations and stands used

In this chapter are presented the experimental facilities used: Machine testing tensile uniaxial Instron 5587 and Optical system for measuring deformations Aramis.

Figure 5.1. Machine to testing tensile uniaxial Instron 5587

Instron 5587 is equipped with Bluehill 2 software, used to command and control the machine and also to process the results. Bluehill 2 enables the following applications:

- System monitoring and viewing the results in real time;
- Generating predefined reports and edited by the user;
- Automatic calibration of sensors;
- The possibility of determining the conventional characteristic curves and real and also characteristics plasticity.

Optical system for measuring deformations Aramis

To determine the specific strain was used optical system for measuring deformations in real time Aramis owned by "Lucian Blaga".
This optical measuring system determines uniaxial tensile deformation tests.
For an experiment for determining the deformation is need to calibrate the measuring system.
Calibration involves the acquisition of a number of 12 to 18 images in succession in the system for measuring identify certain markers that are on the calibers. Through these markers thus fall in 3D space that the operating system can operate at a rate of error as small possible.

For research experimental measurement system Aramis is requires submission of a network on the piece surface. Regarding certain materials is needed to put on the surface piece a layer of matt white paint which aim is to eliminate unwanted reflections.

In situation of the geomembranes, was chose to determine the deformations the submission of a white grid on the surface which is intended to be measured. Was chose this way to deposition of a layer of paint on the piece because, in case of the geomembranes using another method may induce significant errors in analysis.

For the experiment were used four types of test pieces of the membrane, namely: geomembrane of 2 mm thick without concentrators, geomembrane of 2 mm thick with concentrators, 2.5 mm thick geomembrane without concentrators, geomembrane of 2.5 mm thick with concentrators.

To realize the determination of the behavior HDPE geomembranes it turned to uniaxial tensile mechanical testing. This method is one of the oldest methods of testing the behavior of materials.

By coupling Machine testing tensile uniaxial Instron 5587 with optical measuring system was not necessary to use an extensometer, Aramis optical system is actually a high precision optical extensometer.

6. Conclusions and original contributions, future directions of research

Chapter 6 is devoted to the presentation of analyzes, conclusions and main original contributions of this theses.

Original contributions

Analyzing chapters of this thesis are distinguished, at least the following elements of originality:

- Complete study and analysis of the original ecological systems based on the use of geomembranes;

- Analysis of components of landfills that have essential role in protecting the environment;

- Original approach to three-dimensional modeling of systems based geomembranes, defining models static, dynamic and thermal energy;

- Simulation of expansion material and original equivalence of contact between the various components of the systems analyzed;

- Utilization, in an original way, of the mathematical equations in different branches of science to obtain a mathematical model to determine the solar radiation every day of the year, any time of day and in any location;

- Utilization of the mathematical model for developing a program written in code AutoLISP and running inside AutoCAD program;

- Development a virtual – experimental device for testing geomembranes in the original construction.

SCOPE

The purpose of this thesis is to study the long-term behavior of geomembranes and the effect of factors influencing this behavior, given the importance of protecting the environment that has geomembrane used in waterproofing waste landfills.

Also special attention is paid to systems and leachate collection and transport.
To achieve this goal were required to solve the following objectives:

1. revealing the importance, necessity and motivation to study mechanical behavior of the membrane waste landfills;
2. Overview constructive functional of a landfill, risk factors and impacts who appear from this realize, the importance of geomembrane and its role in waterproofing landfill.
3. Conducting a bibliographic study detailed to theoretical and experimental research on the mechanical behavior of geomembranes in general and specifically to the functional role of actors such as the emergence of their wrinkle, the effects of this or perforations thereof. Synthesizing and structuring of information revealed the base of research that will be addressed in the thesis.
4. Realization of a Study of the influence of solar radiation on landfills resulted in determining a mathematical model on calculating the total density of radiant flux at a certain hour in a location once;

5.Achieving using Auto LISP programming language of a computerized application for the calculation of total solar radiation at the time and location determined by the user. It can make such predictions and strategies on geomembrane installation time to avoid it as much as wrinkling.
6. Achieving of studies on predictive virtual models based on the finite element method, of analysis of the behavior of the geomembranes;
7. The achievement of numerical analysis using solid-type items, on the geomembrane's plate at a given temperature to determine the displacement;
8. The design and modeling 3D of a virtual- experimental system for a device testing of wrinkle's geomembrane, system that allows defining constraints motion (axis-axis type, plan- plan, distance etc.) and for defining the mechanical system in terms of view of freedom of displacement.
9.Virtual modeling of geomembrane with 1 and 2 wrinkles arranged to 30º, 45º and 90º, nonlinear analysis with elements type "solid" and static testing with elements of "Shell" of geomembrane models with 1-2 wrinkles;
10.Achievement an experimental system and designing experiments for uniaxial tensile of specimens HDPE geomembrane with and without stress concentrations.

Among the concepts, methods and modern research techniques used to achieve these objectives can highlight the following:

- Mathematical modeling and environmental AUTOLIPSP use for calculating the total solar radiation on the day of the year, the time and location set by the user;
- The use of modeling software such as SolidWorks 2012 to achieve three-dimensional models of geomembranes;
- Using the finite element in static field to achieve simulations.
- Using Experimental virtual systems;
- Designing experiments.

Research directions

- The present thesis leaves open door to research. The main research directions highlighted by this thesis are:
- realization of an experimental device in which will be tested and verify various systems based on pressure applied to geomembrane;
- monitoring of the appearance of the geomembrane's wrinkle during a day at a newly established landfill;
- can develop other methods for analysis and storage, interpretation and revaluation of experimental data to improve the mathematical apparatus which determinate more accurate and rapid membrane behavior;
- can develop new algorithms, new methods and programs that will produce more accurate solutions to problems that arise in complex systems of landfills.

Methods, concepts used in making this thesis can be completed and adapted in relation to the development of sensory systems, hardware and software systems that allow studies and analyzes broader and more precise systems studied.