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SENSOR Damage Detection System (DDS) – The unique geomembrane testing method

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ABSTRACT: SENSOR DDS™ technology which was developed by the SENSOR Company has now been available for over five years. It has been used successfully in 12 countries on more than 100 sites covering over 1,000,000 m^2 of geomembrane lining systems. SENSOR DDS was developed to control the integrity of geomembranes in situ after installation on site and usually after the installation of the drainage/protective layers. The technology is based on general similarities between water flow and electric current flow. The contaminant flow is substituted by electric current flow through the damage in the geomembrane. The electric current flow is measured by sensors installed beneath or above the geomembrane. Due to the high sensitivity of the method, damage detection is rapid and the precise location of the damage enables repairs to be effected. Depending on the type of the project, e.g. landfills, tanks, basins, storage and similar facilities, and the client's need, there are several modifications available. The main difference in the modifications is one of time durability varying from a period of 6 months to over 20 years. All modifications can be combined into manual, semi-automatic and fully automatic monitoring stations. To ensure the highest standard of quality, the SENSOR Company is in the process of obtaining the ISO 9001 certificate.

INTRODUCTION

Why is a damage detection system necessary for protection of -

a) the environment
b) the investor or user of the site
c) the installer of geomembranes?

Every year many millions of square meters of geomembranes based on HDPE, PVC, EPDM, PP, are manufactured and installed. From this amount nearly half are used for ecological use, i.e. landfills, ponds, tanks, storage, plants, waste disposal, etc. The present method in quality control involves many steps which are useful only when geomembranes are not covered by a drainage/protective layer. It is a paradox that it is mainly the installation of this 'protective' layer, i.e. gravel, sand, earth or concrete, which is the most frequent cause of damage to a geomembrane. Because of that, we developed technology by which all concerned parties are able to solve and finally eliminate damage problems.

DESCRIPTION OF THE TECHNOLOGY

DDS technology uses a feature whereby whenever there is a fault in the geomembrane, an electric connection occurs. A necessary condition is the existence of electric poles of different polarity on both sides of the geomembrane. For registering this electric connection through the geomembrane, an irregular or regular grid of sensors are used. The distance between sensors varies from 6.5 m to 12 m or more depending on the bedrock. The position of the sensors are for computing and optimalizing, and the coordinates of each sensor is determined after installation. The Sensors are connected by a cable (fig.1) specially developed for the purpose to a monitor box where electrical parameters are measured by a receiver. After that the processed parameters are transferred to the interpretation centre for analysing and interpretation (fig.2 and 3). The coordinates of the damage are transferred back to site to make the necessary repairs to the geomembrane. The site is then rechecked because of the shielding effect of the larger areas of damage.

The process is repeated until there is no damage in the geomembrane. The final step is the issue of the Clear Field Report of Integrity. The average number of surveys is between 3 and 4 per site and the time for measurement is only 2 minutes per 10,000 m^2. The time necessary for the transfer of the parameters to the interpretation centre, processing, and transfer back to site is less than 1 hour. Therefore, a site can be certified to be free of damage within one to two days depending on the extent of the damage.

The described technology comprises the following steps:

1. Mathematical 2D and 3D modelling of expecting parameters necessary for the precise detection of damage (shape of site, type of liner system, type of bedrock, type of covering layer, pipes, drainage, road access, etc.)

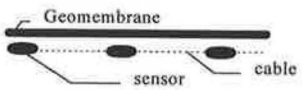


Fig.1

MUNICIPAL WASTE LANDFILL, SENSOR DDS TECHNOLOGY
12/03/96 before repair

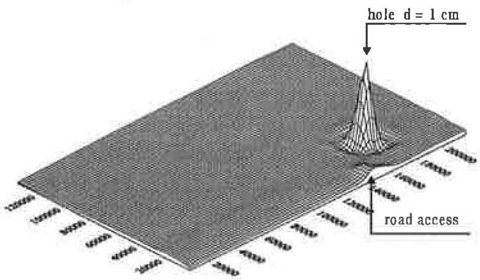


Fig.2

MUNICIPAL WASTE LANDFILL, SENSOR DDS TECHNOLOGY
12/03/96, after repair

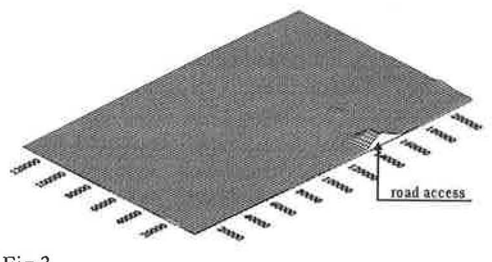


Fig.3

2. Design of grid of sensors resulting from mathematical modelling.
3. Installation of the Damage Detection System on site.
4. Quality control of installation of DDS and issue of an 'Installation Report'.
5. Measurement of electrical parameters necessary for the detection of damage.
6. Processing and interpretation in the interpretation centre and damage position determination.
7. Exposure of damaged areas and repairs.
8. Final measurement and processing in the case of no damage.
9. Issue of a Clear Field Report of Integrity.

Steps 5-7 are repeated until the geomembrane is free of any damage.

DDS technology is available in five basic versions and two special extensions.

DDS LIGHT
DDS SHORT
DDS MEDIUM
DDS LONG
DDS MOBILE

DDS-CMS
DDS-SIGNAL

Specification of basic versions:

Version type	Warranty of function	Material composition sensors	cables
DDS LIGHT	Up to 6 months	Zinc	PVC
DDS SHORT	Up to 3 years	Plated stainless steel	PVC
DDS MEDIUM	Up to 10 years	Stainless steel	HDPE
DDS LONG	Over 10 years	Stainless steel	Teflon
DDS MOBILE	Not applicable	Porcelain	PVC

DDS MOBILE is used only where there is no possibility of installing any sensors under the geomembrane or where the only purpose is for a one time measurement of the integrity of the geomembrane. In this version, mobile sensors are activated above the geomembrane on the surface of the covering layer. This version has several limitations, the most important of which is the thickness of the covering layer.

DDS-CMS is a permanently positioned monitoring station. The purpose is to monitor the integrity of the geomembrane when using on site where frequent monitoring is required. The results are displayed on the screen and informs the operator of the situation of the geomembrane on the site. The results from every measurement are stored during the time of monitoring, giving an historical record of liner performance. Alarms are included to inform the operator about any problems of integrity. In case of the need to monitor more than one site, the monitors are connected to the network by radio or modem and final results are displayed on site or in the centre.

DDS-SIGNAL is the extension developed for rapid monitoring of the change in the integrity of the geomembrane. If damage occurs suddenly, this equipment will detect a change in the environment adjacent to the liner and sound an alarm.
The SENSOR Company is in the process of having the DDS technology certified according to ISO 9001 to ensure standard quality procedures at each step of the Sensor detection process.

RESULTS

The technology described above has been successful on more than 100 sites with a geomembrane area of more than 1,000,000 m^2 in 11 countries throughout the world. On these projects, several thousand areas of damage were revealed and repaired, varying in size from holes of 0.1 mm^2 to several metres of tears in the geomembrane. By analysis of causes of the damage the following information was obtained (see Diagram No.1):
Damage can occur during three periods in the construction phase on sites involving geomembranes excluding tests of system.

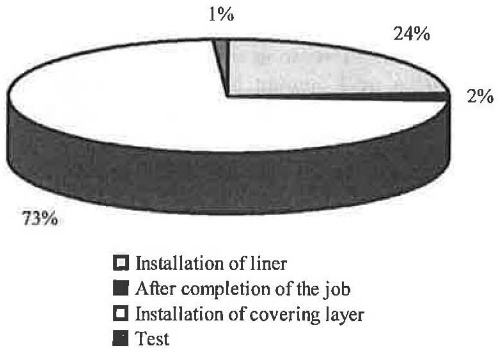


Diagram No.1:

Period A -	Installation of the geomembrane.
Period B -	Installation of the covering layer.
Period C -	Operation after the completion of the site.

PERIOD A

This period represents construction phase during which geomembrane is transported on site and installed. Normal Quality Control (QC) procedures require visual control of the geomembrane to eliminate the amount of damage done by stones, heavy plant, trucks, sharp tools etc. This is difficult mainly due to the colour of geomembrane. QC for welds is done by common test methods, (i.e. air press test, vacuum test, spark test etc.). Due to all circumstances on site as weather condition, time dependence of work, deadlines for every phase of the construction etc. resulted in faults in spite of normal QC. It can be seen from Diagram No.1 that this phase of construction of the site represent only 24% of total amount of damage. Diagram No.2 shows an analysis of the damage type.
Less of a problem are small stones by which geomembrane is punctured during different subphases, i.e. installation of geomembrane, installation of geotextile etc. (17%). Similar portion (18%) is represented by overheating/melting faults. The biggest problem is with the welds (61%), mainly from extrusion welds T-joint and Y-joint or extrusion welds around special areas of site like pipes, drainage, corners etc. The least damage (4%) is caused by cuts in geomembrane.

PERIOD B

This period represent the construction phase of installation of the protective/covering layer. This protective/covering layer usually consist of gravel,

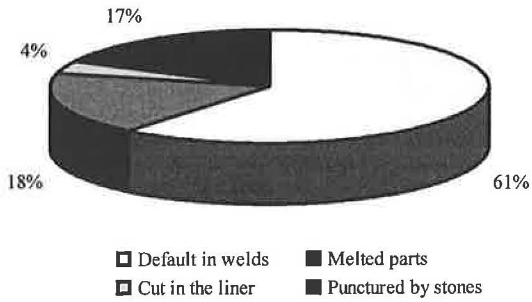


Diagram No.2:

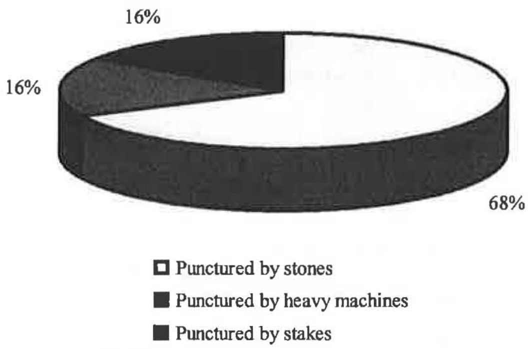


Diagram No.3:

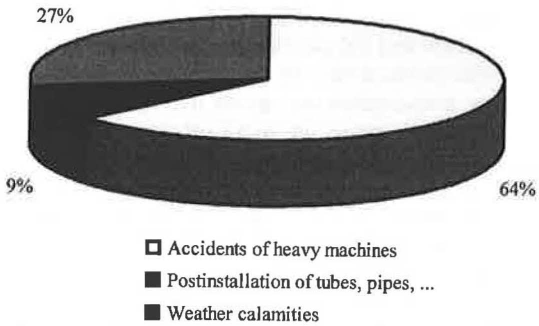


Diagram No.4:

sand, concrete slabs, reinforced concrete, etc. It is clear that this is the most dangerous time period for the geomembrane. It can be seen from Diagram No. 1 that 73% of total damage occurs during this period on site. Diagram No.3 shows the percentage of each type of damage which occurs.

Earth machines (front end loaders, bulldozers or similar heavy plant) during spreading of gravel or sand can penetrate the geomembrane even when the level (thickness) of covering material is controlled by laser equipment, because of lack of attention (human factor) or waves of geomembrane due to temperature differences (16%). The amount of leachate leaking depends on the size and amount of damage. This size varies from 10 cm^2 to several meters. Sharp stones, unacceptable stone size, incorrect techniques of spreading of gravel, no geotextile between the geomembrane and covering layer etc. causes 68% of the damage to the geomembrane in period B. Of course there are also other activities dangerous for the geomembrane. Sites were often found where the geomembrane had been punctured stakes used for checking the thickness of covering layer, or for holding some items on the surface of the cover layer. However, these activities represent only 16% of the damage - almost negligible compared with other causes described above.

PERIOD C

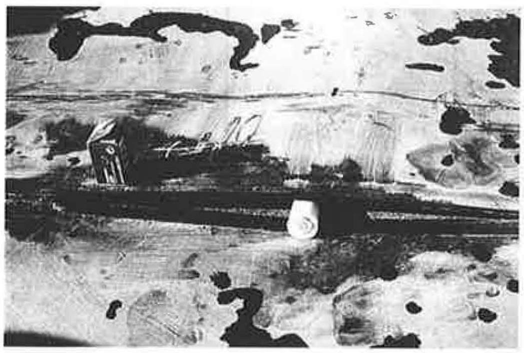
This period represents construction phase when site is completed, including the filling phase in the case of solid waste containment. It can be seen from Diagram No.1 than this period is less danger than previous ones. It represents only 2% of total damage to the geomembrane. In that period the main part, 67% is accidental damage by truck/compactors etc. The second part, 31% is post installation damage arising from the installation of pipes, drainage, sumps, road access etc. Another part is damage caused by weather calamities or other occurrences, e.g. fire. This damage represents only 2% and is negligible. This result we can see in Diagram No.4.

Special part of 'damage' is represented by test holes done by clients to be sure that Sensor System works correctly. We were tested many times and size of test hole varies from 1 mm^2 to 1 cm^2. All test holes were detected. We can see that this part represent 1% of total damage.

CONCLUSION

It can be seen from the information obtained from many sites that it really is necessary to be able to efficiently and economically detect damage to the geomembrane liner system not only on completion but also in the early stages of filling in the case of solid waste containment.

Diagram No.5 shows to us distribution of amount of sites versus total amount of damage on site. The percentage of described parts and surfaces are included. There were 23 sites (i.e. 158,055m^2 liner area) without damage, representing 17% of the total liner area tested. 48 sites of liner area 460,630m^2 had between 1 and 5 areas of damage representing 49% of the total liner area tested. This was followed by 11 sites (115,000 m^2) 6-10 areas of damage (12% of total), 5 sites (62,499 m^2), 11-20 areas of damage (7% of total), 3 sites (19,800 m^2) 21-50 areas of damage (2% of total) and 3 sites (63,780 m^2) 51-100 areas of damage (7% of total).There were 4 sites (58,640 m^2) with over 100 areas of damage (6% of total).



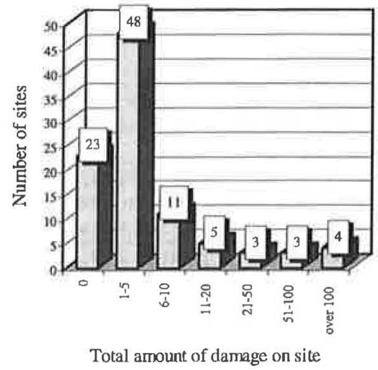


Diagram No.5:

Fewer than 17% of the sites tested were completely free of liner damage and in these cases the Sensor System was able to detect the location of all test holes made. It is very likely that sites which have not been subjected to a Sensor survey could be causing damage to the environment by seepage of polluting liquids through undetected damage of the liner system.

The client would much prefer to have confirmation of the integrity of the liner system at least on completion of the site, and could be interested in a longer term monitoring process especially in the case of liquid containment projects. It is also in the interest of the geomembrane lining contractor to know for sure that the liner he has so carefully installed is still intact after the placing of the upper drainage/protective layers and any other damaging activities.

To decrease the risk of leakage the 'Application Table Alterations' shows the various types of Sensor system available and proposed for various applications of projects involving the supply and installation of geomembrane liner systems.

ACKNOWLEDGEMENT

We would like to acknowledge to Mr. Paul W. Barker of Houston, Texas for his helpful contribution in preparation of this paper.

Application Table Alterations:

Type of application	*Type of liner system*	*Type of substrate*	*Type of protection*
Municipal waste DDS LIGHT, DDS SHORT, DDS MEDIUM, DDS MOBILE	single liner used with other geosynthetic 'sandwich' combinations	clay, special compositions	sand, gravel
Dangerous waste DDS LIGHT, DDS SHORT, DDS MEDIUM, DDS MOBILE	single liner, double liner used with other geosynthetic 'sandwich' combinations	clay, special compositions	sand, gravel, reinforced concrete
Industrial waste DDS SHORT, DDS MEDIUM, DDS LONG, DDS-CMS, DDS MOBILE	single liner, double liner used with other geosynthetic 'sandwich' combinations	clay, special compositions	sand, gravel, reinforced concrete
Nuclear waste DDS LONG, DDS-CMS	single liner, double liner used with other geosynthetic 'sandwich' combinations	reinforced concrete	reinforced concrete
Water basins (potable, industrial, dirty, etc.) DDS LIGHT, DDS SHORT, DDS MEDIUM, DDS SIGNAL, DDS MOBILE	single liner, double liner used with other geosynthetic 'sandwich' combinations	clay, special compositions, reinforced concrete	no cover layer, reinforced concrete
Evaporation basins DDS LIGHT, DDS SHORT, DDS MEDIUM, DDS SIGNAL, DDS MOBILE	single liner, double liner used with other geosynthetic 'sandwich' combinations	clay, special compositions, reinforced concrete	no cover layer
Sedimentation basins DDS LIGHT, DDS SHORT, DDS MEDIUM, DDS SIGNAL, DDS MOBILE	single liner, double liner used with other geosynthetic 'sandwich' combinations	clay, special compositions, reinforced concrete	no cover layer, reinforced concrete
Basins and tanks for chemicals (acids, etc.) DDS SHORT, DDS MEDIUM, DDS-CMS, DDS SIGNAL, DDS MOBILE	single liner, double liner	clay, reinforced concrete	no cover layer
Sewage treatment plants DDS SHORT, DDS MEDIUM	single liner, double liner used with other geosynthetic 'sandwich' combinations	reinforced concrete	no cover layer, reinforced concrete
Decontamination areas and ponds DDS SHORT, DDS MEDIUM, DDS MOBILE, DDS SIGNAL	single liner, double liner used with other geosynthetic 'sandwich' combinations	clay, special compositions, reinforced concrete	sand, reinforced concrete
Isolation of storage of dangerous materials DDS SHORT, DDS MEDIUM, DDS LONG, DDS-CMS	single liner	clay, special compositions, reinforced concrete	no cover layer, reinforced concrete
Roofs, underground garages, tunnels, etc. DDS SHORT, DDS MEDIUM, DDS SIGNAL, DDS MOBILE	single liner	reinforced concrete	no cover layer, reinforced concrete, sand, slabs, etc.
Nonspecific cases where geomembranes are used DDS SHORT, DDS MEDIUM, DDS MOBILE	single liner, double liner used with other geosynthetic 'sandwich' combinations	clay, reinforced concrete	reinforced concrete
Capping of landfills DDS LIGHT, DDS SHORT, DDS MOBILE	single liner, double liner used with other geosynthetic 'sandwich' combinations	waste, clay, sand	sand, gravel, geosynthetic materials, earth