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RECTYRE

USED TYRES VALORISATION AS LIGHTWEIGHT FILLER FOR EMBANKMENTS

D5.2: Model Analysis

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TABLE OF CONTENTS

1. INTRODUCTION

The validation of the model was developed from the comparison of previous and final methodology and technical, economical and environmental results. The environmental and technical performance of RECTYRE has been monitored during the execution of the model in Czuprynowo. Environmental analysis has been done to assure that not only the Rectyre final solution, but also its constructive process are environmentally friendly and fulfil the required environmental standards. Many environmental aspects have been taken into account, however a major concern has been given to potential groundwater contamination and temperature increase. Specific test methods have analyzed this issues.

Main results:

Environmental - Groundwater monitoring: Mostostal performed a study of the groundwater features at the site prior to Rectyre model construction and the results were reported. During the monitoring of the shredded-tire embankment following construction, two more sets of water quality samples were taken. Results were analyzed and compared. The results of the test indicated that shredded automobile tires do not show any likelihood of being a hazardous waste. Compared with other wastes for which leach tests and environmental monitoring data are available, the tire leach data indicated little or no likelihood of shredded tires having adverse effects on groundwater quality. At this stage and based on the limited scope of this effort and comparison with water quality criteria, it appears that there is no evidence in this study that there will be a detrimental effect on the environment or to human health.

Figure 1: Embankment Shred Tire, Rectyre design scheme.

Environmental - Temperature monitoring: The results of the temperature monitoring indicated no evidence of any localized heat generation within the core of the shredded-tire embankment. This is significant in view of the problems experienced elsewhere. It is likely that the use of geo-textil layers mixing tire shreds with soil fill minimizes the potential for an exothermic reaction. There are no reports of problems with similar designs. At this point, only short time results have been used for the analysis. Therefore, during the next 2 years monitoring will continue and periodical test will be carried out to obtain following results. A final evaluation will determine if our estimations remain valid. The current conclusion at this stage is that, it is possible a major increase in the number of scrap tires used for civil engineering applications, because of their growing record of successful performance combined with guidelines to limit self-heating of thick fills and groundwater data showing that they have a negligible environmental impact.

Structural monitoring: Has been developed and calibrated a numerical finite element model for the prediction of future deformations of an embankment with the characteristics used during the research project. The values used correspond to the information taken during the monitoring process.

2. MODEL ANALYSIS – TECHNICAL

A numerical simulation/modelling of different construction processes is important to ascertain the safety of current and planned construction. Numerical modelling software offers a unified and generic framework for such computations such as analysis of deformations, stresses, thermal behaviour and continuous stability assessment in soils, rocks and structures, including soil structure interaction. The software has evolved and now allows us to perform the modelling in 2D and/or 3D. All the stages of construction i.e. from the initial stage to the final construction can be simulated in a single environment[1].

According to Bergado and Patawaran (2000) there are three important steps in the computational modelling of any physical process: (i) problem definition, (ii) mathematical model, and (iii) computer simulation. The first step is to define the problem in terms of a set of relevant measurable parameters. The second step is to represent the idealization of the physical reality by a mathematical model. These mathematical models use numerical time-stepping procedure to obtain the models behaviour over time. After establishing the suitable boundary and initial conditions, the third and final step is to proceed to its solution using computer simulation.

The settlement of embankments with ST (Shreds Tire) is traditionally an important geotechnical problem and has been extensively studied by a large number of researchers. Excessive settlement can render the highways unserviceable, increase the cost of maintenance, and even be detrimental to the stability of embankment. Therefore it's very important to accurately evaluate the embankment settlement during the highway construction design

For predicting the behaviour of embankment on soft ground, one of the key point is to simulate the consolidation process. The consolidation rate is mainly influenced by the foundation soil elastic modulus.

Available methods for calculating embankment settlement are the layer-wise summation method (LSM), empirical formulation method, finite element method (FEM), etc. (Qian and Yin, 1996; Wang, 2004). Of these methods, FEM is a very powerful numerical tool for solving complicated 2D or 3D consolidation settlement problems. It can handle arbitrary boundary conditions, different loading schemes and it considers the coupling effects of loading and soil consolidation.

2.1 Selection of technical analysis model

A finite difference method (FDM) discretization is based upon the differential form of the Partial Difference Equation to be solved. It utilizes a point-wise approximation to a solution. The domain is discretized into a grid of hexahedral cells or nodes. The solution will be obtained at each nodal point. Although FDM is easy to implement and the compute time for each step is fast, however the number of steps required for convergence is high. The other disadvantage is that the domain is not accurately represented if the domain is discontinuous or non-rectangular in shape.

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[1] Th. Zimmermann, A Truty and J.L Sarf (2005), "Numerical simulation of underground works and application to cut and cover construction".

A finite element method (FEM) discretization is based upon a piecewise representation of the solution in terms of specified basis functions. In FEM the discretization is not restricted to a grid of hexahedral cells or nodes, instead, a solution is approximated using interconnecting sub-regions or elements. These elements are typically simple geometrical figures as illustrated next Fig. This flexibility of construction of elements in FEM allows it to accurately model the complex geometries. The downside is that FEM is difficult to implement but the opinions vary on this. Section 2.4 defines the model ANALYSIS selected.

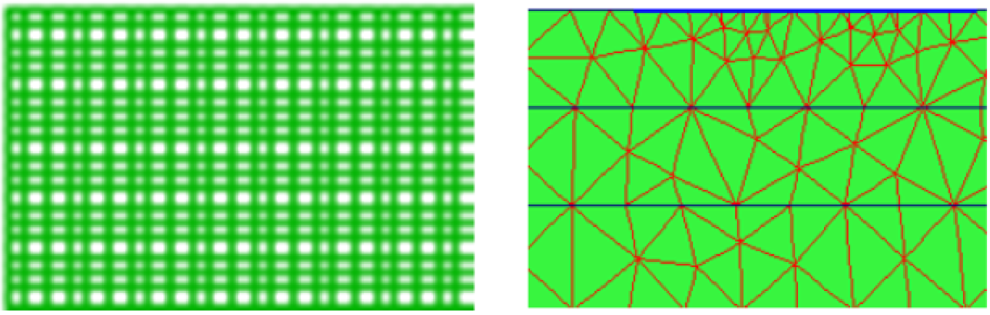


Figure 2: Discretization methods (a) FDM (b) FEM

2.2 Instrumentation

The main objective of this section is to present a brief review on instruments used in this study. Instruments provide actual field data and helps in evaluating the movement and failures under actual field conditions. The instrumentation was used in this study to compare the performance of the Embankment Shreds Tire (ETS). The choices of instruments depend on many factors like geological understanding of the area, subsurface material and the groundwater depth. The other factors include the transportation facility, the rate and magnitude of movement and type of movement i.e. horizontal or vertical movement or both. For large and fast movements relatively crude instrumentation can be used but if the movement is slow and small instrumentation accuracy and the repeatability of its measurement takes precedence.[2]

2.2.1 Characteristics and instrumentation details

Field instrumentation is very important in geotechnical engineering and therefore, geotechnical engineers should have proper knowledge of instrumentation. But instrumentation is not answer to everything so its use must be prudent. The wrong type of instruments or wrong placement of instruments can provide wrong or confusing results which can divert the attention from real problems.

The objectives of a geotechnical instrumentation plan are grouped into four categories: analytical assessment; prediction of future performance; legal evaluation; and development and verification of future designs.

2.2.1.1 *Analytical Assessment*

The following objectives are met during the analytical assessment.

[2] George Machan and Victoria G. Bennett (2008), "Use of Inclinometers for Geotechnical Instrumentation on Transportation Projects". Transportation Research Circular E-C129.

i. Verification of design parameters – Observed data from instrumentation can be used to not only verify the selected design parameters but also used to modify and refine the future designs.

ii. Verification of design assumptions and construction techniques – The data obtained from satisfactory actual performance of new or modified design can help its chances of acceptance.

iii. Analysis of adverse events – Causes of various types of failures and deformations at the project site can be uncovered from the precious instrumentation data.

iv. Verification of apparent satisfactory performance – The instrumentation data of satisfactory performance as well as adverse events can prove to be valuable records for future design purposes and development of new and innovative technology.

2.2.1.2 *Prediction of future perfomance*

Instrumentation data analysis can be used for the predictions such as continued satisfactory performance or indicating a sign of potential future distress. The instrumentation data recorded during and after events like rainfall can be very useful for future performance.

2.2.1.3 *Legal evaluation*

Instrumentation data can be used in determining causes or extent of adverse events so that the merit of various legal claims can be evaluated.

2.2.1.4 *Development and verification of future designs*

Analysis of the performance of existing normal fill and EST fill embankments and instrumentation data generated during operation, can be used to further the construction technology. Instrumentation data from existing embankment construction projects can provide safer and economical design for future construction of embankments

2.2.2 Different types of instruments used in the field monitoring

There are various field instruments like Digital Hydrostatic Profile Gauge - Settlement monitoring, Vibrating Wire Pressure Cell, Temperature sensor Testo 177-T4 (Temperature sensors o thermocouples) and digital hidrostatic profile gauge.. They also warn us about the design assumptions suitable for the given field conditions. The following sections present the details of instruments used in the current study and the installation procedures followed. The deliverable 5.1 is mentioned in detail the instrumentation used during the construction and monitoring.

Figure 3: Details of the installation test site, pressure & temperature data recorder.

2.2.3 Surface elevation surveying

The surface surveying consists of establishing benchmark control stations and survey points at various locations of interest. The survey points are periodically measured to monitor for potential deformations at test section and control sections. For this technique, the control stations are established on stable ground. Surface monitoring is accurate to a resolution of approximately 0.25 in. (6 mm). However, long term deformation trends can be difficult to establish, due to personnel turnover, susceptibility to damage of control points, etc. This method provides essentially provides the relative movement of the pavement surface relative to its' initial position (i.e. settlement or heave).

2.2.4 Visual monitoring

This approach consists of occasional on-site inspections. Field inspection is a good technique to identify signs of distress or change. However, visual observations are typically not accurate method in detecting small movements or long-term settlements. Periodic good resolution photographs may be a good idea for comparison.

2.2.5 Summary

This chapter discusses various causes of settlement, its remedial measures, different types of fill materials and finally the instrumentation used in determining vertical movement. It is observed that among all the different types of embankment fill materials, EST is the most suitable for the test site since it is easily produced and very economical. For this study Digital Hydrostatic Profile Gauge were used to and for vertical surface movement.

2.3 Experimental studies

Laboratory testing is an essential aspect of geotechnical engineering. Laboratory test are conducted using standard procedures. Material properties like cohesion unit weight, internal friction angle etc can be determined from different laboratory tests. Visual observation and field test results are the primary source of information before doing laboratory testing. Laboratory test results provide a clear understanding and knowledge of soil properties.

Quality control for Lab Testing involves proper handling of samples while transporting and storage, Its important to maintain quality otherwise it can result in misleading test results. In addition, the following guidelines given by Mayne, et al., (2002)[3] for laboratory testing of soils was followed.

To study the behavior of EST and Normal fill, Laboratory tests namely, sieve and hydrometer test, Atterberg limits tests and proctor's compaction tests. The soil used for various tests were collected from site and then wrapped in a plastic bags and transported to the laboratory.

[3] Mayne, P. W., Christopher, B.R., and DeJong, J., (2002), " Subsurface Investigations – Geotechnical Site Characterization", Publication No. FHWA NHI-01-031, National Highway Institute, Federal Highway Administration, Washington, DC, 300 pp.

2.3.1 Soils

2.3.1.1 Sieve analysis and hydrometer analysis

Sieve analysis was done as per ASTM D22. There are two different procedures for dry and wet sieving. For our study, the sample collected was in the form of hard lumps and the sample was pulverized to very fine particles before doing dry sieve analysis. For normal fill material, first dry sieving was performed, where the sample was oven dried and allowed to cool. An oven dried sample of 1000 grams passing through 4.75, 2.0, 1.8, 0.6, 0.425, 0.25, 0.125, 0.075 mm sieves was taken. The pan was attached at the bottom of the sieve stack. The sample was poured on the top sieve and stirred for about 10 minutes. Soil retained at each sieve was measured and weighed. The weights of the sample on all the sieves were added to compare it with initial sample weight. The difference shouldn't be more than 1%.

Secondly, wet sieving was performed where oven dried sample was kept soaked in a tap water for about 2 hours. The sample was transferred to 200 sieve. The sample was washed thoroughly, discarding the material passing no. 200 sieve. The retained material collected from no. 200 sieve was oven dried and weighed it after it has cooled. Difference between dry weight before and after washing was around 50% recorded.

Hydrometer analysis was performed on the same sample which was finer than no. 200 sieve size. The lower limit of the particle size determined by this procedure is about 0.001mm. Hydrometer analysis test procedure was adopted as per ASTM D-422.

For embankment soil support, the material had less than 5% fines, so wet sieve analysis was not done. An oven dry sample of 500 grams passing through 4.75, 2.0, 1.8, 0.6, 0.425, 0.25, 0.125, 0.075mm sieves was taken. Soils retained on various sieves were calculated and a particle distribution was obtained, in the next figure shows the particle distribution curve for the materials.

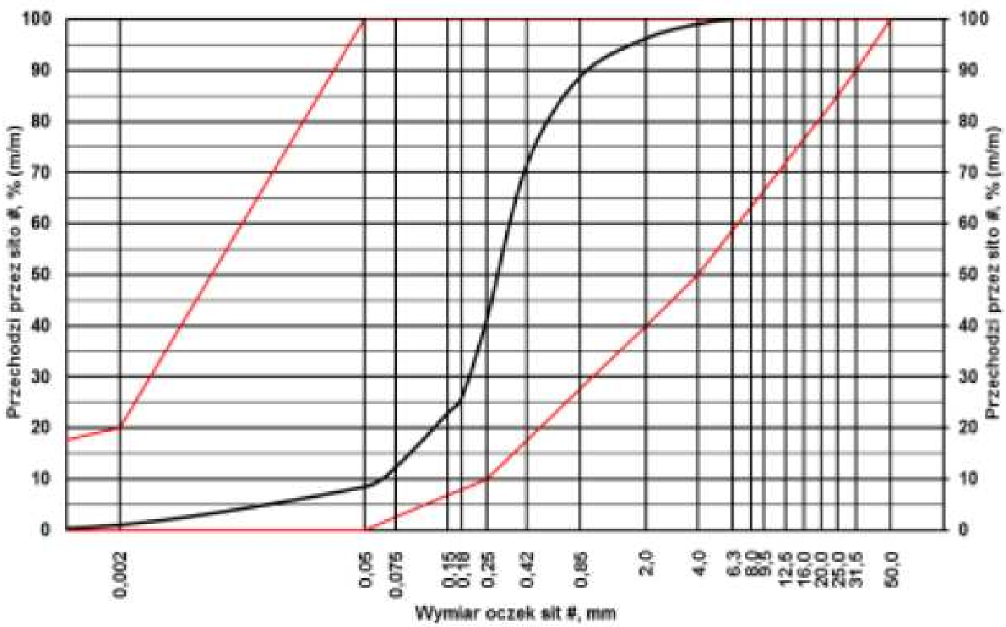


Figure 4: Particle size distributions for soil of test site.

Table 1: Particle size distributions for soil of test site.

Mesh dimension mm	Remained material g	Remained material %	Passing summary %	Mesh dimension mm	Remained material g	Remained material %	Passing summary %
Soil # 1 –Middle sized sand (bore-hole # 1)				Soil # 2 –Middle sized sand (bore-hole # 2)			
# 50,0	0,0	0,0	100	# 50,0	0,0	0,0	
# 31,5	0,0	0,0	100	# 31,5	0,0	0,0	100,0
# 25,0	0,0	0,0	100	# 25,0	0,0	0,0	100,0
# 20,0	0,0	0,0	100	# 20,0	0,0	0,0	100,0
# 15,0	0,0	0,0	100	# 15,0	0,0	0,0	100,0
# 12,5	0,0	0,0	100	# 12,5	0,0	0,0	100,0
# 9,5	0,0	0,0	100	# 9,5	0,0	0,0	100,0
# 8,0	0,0	0,0	100	# 8,0	0,0	0,0	100,0
# 6,3	1,1	0,0	100	# 6,3	5,3	0,2	100,0
# 4	28,4	0,9	99,1	# 4	48,3	1,4	99,8
# 2	95.2	2,9	96,2	# 2	148,9	4,4	98,4
# 0,85	246,3	7,5	88,8	# 0,85	311,0	9,1	85,0
# 0,42	569,6	17,3	71,5	# 0,42	447,8	13,1	71,9
# 0,25	987,1	29,9	41,6	# 0,25	890,7	26,0	45,9
# 0,18	513,0	15,5	26,1	# 0,18	746,6	21,8	24,1
# 0,15	100,8	3,1	23,0	# 0,15	131,7	3,8	20,2
# 0,075	353,6	10,7	12,3	# 0,075	414,0	12,1	8,1
< # 0,075	406,6	12,3		< # 0,075	277,7	8,1	
Σ przesiewu	3302	100%		Σ przesiewu	3422	100%	

2.3.1.2 Atterberg limits

For classification of soil, Atterberg Limits tests (Liquid Limit and Plastic Limit) were performed on the collected sample. The liquid limit test of a soil was performed using casagrande liquid limit apparatus. About 250 grams of air dried sample passing sieve no. 40 was used for both liquid and plastic limit test. Distilled water was preferred instead of tap water to avoid ion exchange between soil and water impurities, which may affect the soil plasticity. Place about 50 grams of soil paste in a cup, level off with the spatula the top surface symmetrically to give maximum depth of 1 cm. The grooving tool was used to straight groove through the soil paste along the diameter through the center of the hinge. The handle was turned at a rate of 2 revolutions per second and counted the number of blows until the two parts of the soil come in contact at the bottom of the groove. About 15 grams of soil was transferred in the container to determine the water content by oven drying. The test was repeated at least 3 to 4 times. The flow curve was plotted to represent the number of blows on logarithmic scale and corresponding moisture content. The plastic limit test was done to determine plasticity of the soil. Here 30 grams of soil passing sieve no. 40 was used. Distilled water was used to mix water thoroughly in to the soil. 10 grams of plastic soil mass was used to form a ball and then roll in to thread with the fingers on the ground glass plate. Keep on rolling until the thread starts to crumble at a diameter of 3mm. The crumbled thread was kept in a container for moisture content determination. The processes were repeated 2 more times with fresh sample and the average of three moisture contents was obtained to calculate plastic limit. After determining liquid limit and plastic limit, the plasticity index was calculated to know the type of soil.

2.3.1.3 Compactation test

Compaction characteristics were determined according to ASTM D-1557 (Modified Proctor Compaction Test). Laboratory compaction tests are used to determine the relation between water content and dry weight and to find the maximum dry unit weight and optimum water content. For each sample the required amount of sample was air dried and weighted and the mass of material required is around 1,5kg passing no. 4 sieve. A suitable amount of water was added to the dry soil to obtain the desired moisture content. The soil sample was evenly distributed so that the mold is about half full. Is placed soil sample with a selected water content in five layers in a mold 101.6 mm in diameter, and each layer is compacted with 25 or 56 blows of a hammer of 44.5 N which leaves fall from a distance of 457 mm, giving the soil compaction effort of about 2700 total kNm/m3. Repeat the resulting dry unit weight. The process is repeated for a sufficient number of water content to establish a relationship between water content for soil and dry unit weight. By plotting this data is a curvilinear relationship known as the compaction curve. The values of optimum water content and maximum dry unit weight is determined by the compaction curve. Soil layers of the embankment were performed using all-ups extracted from nearby deposit. It was brought to the building site by dump truck and formed by excavator and loaders.

Parameters: c=0 (uncohesive soil), Φu=36º, ρ= 1,70 [$t*m^{-3}$].

After compaction: ID = 0,98 -> Φu=42,2º, ρ= 1,85 [$t*m^{-3}$].

2.3.2 Tire shreds

2.3.2.1 Tire shred gradation

The tires were brought to the construction site, shredded in pieces ranging from 20 to 40 cm. The supplier of tire shreds was J&B Recycling.

This company has offered the best price of tire shreds in aid of its quality.

- Weightiness (1,0 – 1,3 g/cm^3)
- Slack condition (0,3 – 0,5 g/cm^3)
- Compacted (0,5 – 0,8 g/cm^3).

Figure 5: Tire shred in pieces ranging from 20 to 40 cm.

Table 2: Size distribution of the tire shreds (Kg)

SIEVE MESH MEASUREMENT [mm]	TIRE SHREDS			
	Sample I	Sample II	Sample III	Sample IV
	Sieve, weight [Kg]			
400	43,40	34,36	36,28	37,50
300	10,06	21,79	27,45	30,26
200	19,92	17,88	18,95	1,05
45	25,79	25,00	16,99	10,86
4	0,83	0,97	0,33	0,33

Table 3: Size distribution of the tire shreds (%)

SIEVE MESH MEASUREMENT [mm]	TIRE SHREDS			
	Sample I	Sample II	Sample III	Sample IV
	Sieve [%]			
400	20,7	24,6	11,1	11,4
300	4,8	15,6	8,4	9,2
200	9,5	12,8	5,8	6,4
45	12,3	17,9	5,2	3,3
4	0,4	0,7	0,1	0,1
Total weight	47,7	71,6	30,6	30,4

2.3.3 Geomembrane

Geomembrane has the task to prevent water and soil pieces infiltration into shredded tires filling that may provoke a self-ignition. Furthermore, it holds the layer in entirety.

Table 4: Mechanical characteristics of the geotextile used in the numerical model

No #	FEATURE	FOLGAM H
1	Thickness [mm]	1
2	Weightiness [g/m^2]	1700
3	Broadness x lenght [m]	2m x length till 30m
4	Colour	black
5	Max tensile stress [Mpa] -along -across	 >15 >15

6	Extension at bust-up [%] -along -across	> 200 > 200
7	Rent resistance [N/mm] -along -across	> 200 > 170
8	Moisture capacity [%]	< 0,5
9	Water infiltration at pressure 0,4 [Mpa]	waterproof
10	Penetration resistance (CBR) [kN]	1,7

2.4 Numerical modelling

The use of numerical modelling to predict soil deformation and stresses has been practiced for years. During the numerical analysis, detailed site-specific properties of the road and embankment systems were incorporated to simulate complex construction sequences. The main field of application of constitutive models is the execution of numerical calculations by means of appropriate methods such as Finite element or Finite difference methods.

2.4.1 Modelling methods

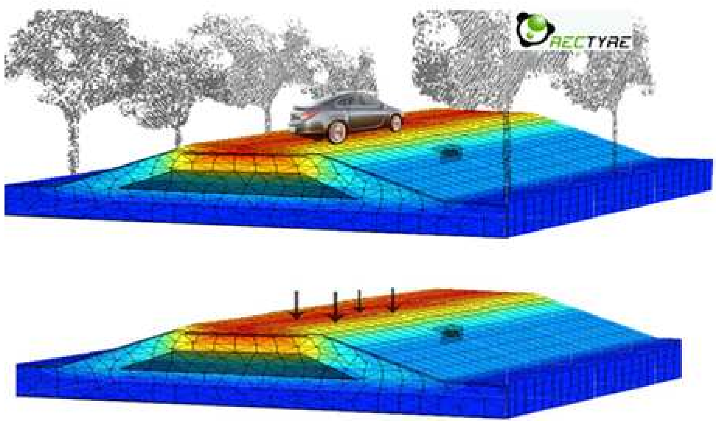


Figure 6: **Numerical modelling using Rectyre model.**

Numerical modelling using linear model has a benefit of fast estimate of the material response but the downside is its limited accuracy. Therefore the application of linear model is limited to cases where the stress or deformation states of a soil mass are of interest. For getting reliable description of the soil behaviour it is necessary to employ nonlinear models[4]. The non-linear models can be divided into two groups. The first group of models originates from the Mohr-Coulomb failure criterion. The Mohr Coulomb model belongs to this group. According to Coulomb C.A., 1776, "the Mohr–Coulomb failure criterion represents the linear envelope that is obtained from a plot of the shear strength of a material versus the applied normal stress". The second group of material models is represented by the Modified Cam-Clay model. This model is based on the concept of critical state of soil (GEO5 - Theoretical Manual, 2010). Accurately modelling the constitutive behaviour of the soil is difficult because of the complexity involved in the selection of design parameters and the soil properties. Simplified non-linear models such as Mohr-Coulomb, or more advanced such as Modified Cam-Clay and the Hardening Soil Model can be used with some degree of accuracy.

[4] GEO5, Theoretical Manual, (2010), http://www.finesoftware.eu/geotechnicalsoftware/help/ fem/materials-models/.

2.4.2 Finite element modelling procedure

Numerical modelling enables the designer to study the effects of embankment loading, surcharge and the soil behaviour in various conditions without resorting to simplified assumptions. Two dimensional finite elements modelling of the different fill embankments is performed using PLAXIS 2D software. A parametric study was performed to arrive at the critical parameters that define the behaviour of the system. The parametric study comprised of all the elements which had an influence on the behaviour of the system. The various aspects like lateral movements and the total settlements were studied. The standard units length (m), force (N) and time (days) were used. The geometry was drawn using geometric lines and standard fixities were then used to define the boundary conditions.

Table 5: Designed for "KR2" road traffic category

Road traffic category	Number of computational design acses (100 kN) on computational lane [L]	Number of computational design acses (100 kN) in assumend period (20 years)
KR2	13 ÷ 70	90000 ÷ 510000

Table 6: Properties of soils used in Finite Element Analysis

SOIL PROPERTIES	Embankment Soil	Tire shreds	Sandy aggradate mud	Middle sized sand	Clay
Compression Index, Cc	0.98	-	-	0.80	0.34
Swelling Index, Cs	-	-	-	-	0.043
Initial Void Ratio, eo	-	-	-	-	1.3
Young Modulus, E (Mpa)	240	550	200	125	-
Poisson Ratio, μ	-	-	0.25	0.32	-
POP (kPa)	-	-	-	-	35 – 48
Unit weight, γ (kN/m^3)	17	-	17.65	18.05	18.85
Cohesion, c (kPa)	0	7 - 10	-	0	45
Friction Angle, Φ (deg.)	42.2	29 - 34	33	35	-
Dilation Angle, Ψ (deg.)	-	-	-	-	-
Weightiness Compacted (g/cm^3)	-	1.15	-	-	-
Slack condition (g/cm^3)	-	0.40	-	-	-
Compacted (g/cm^3)	-	0.65	-	-	-
Model	Soft-Soil Model		Mohr-Coulomb	Mohr-Coulomb	Hardening Soil Model

The properties of different soil material sets were created and assigned to material model. After the model was created and material models were assigned, finite mesh was generated using different mesh settings. The following sections present the details of the finite element model including the choice of material models, finite element mesh, and boundary and loading conditions that were adopted to simulate field conditions and obtain settlements of the embankments.

2.4.2.1 *Choice of constitutive and material properties*

In the material set, type of material and type of model from material model box can be selected. In order to simulate the behaviour of the soil, a suitable model and appropriate material parameters must be assigned to the geometry. In PLAXIS, soil properties are collected in material data sets and the various datasets are stored in a material database. The material properties used in the model for different material types are presented in Table 6.

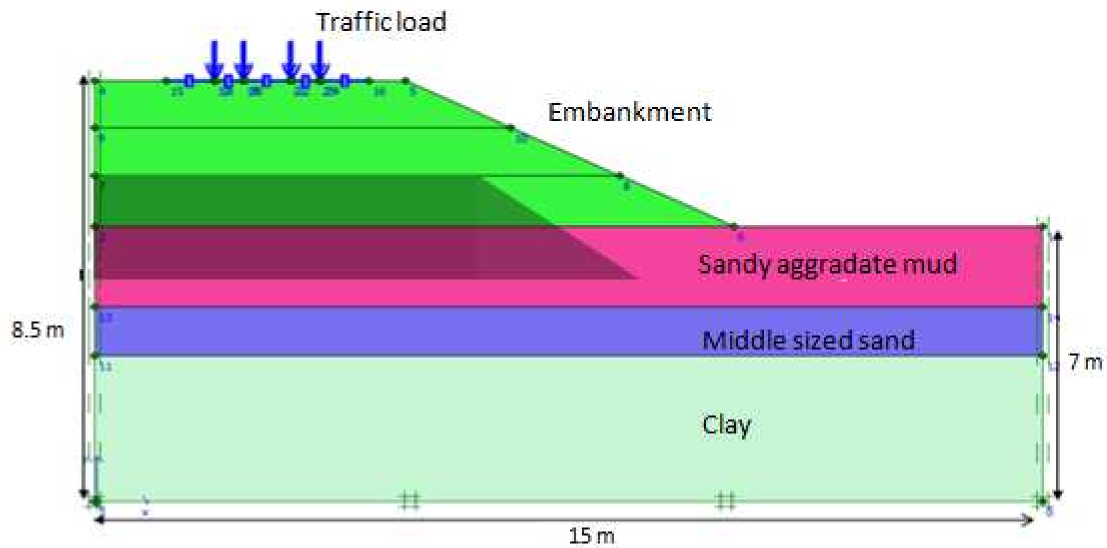


Figure 7: Geometry of embankment model in PLAXIS.

The numerical model has been analyzed with 2D plain strain model considering only half of the section due to the symmetry of the problem. A total width of 15m has been used which starts from the centre of the embankment. The geometry of an embankment has been made using geometric line option with approximate dimensions as per the field dimensions.

Two cases were investigated in the finite element analysis to evaluate the influence of the following:

1. Vertical settlement on control section and test section using Mohr Coulomb Model (MCM) for embankment fill.

2. Vertical settlement on control section and test section using Cam-Clay Model or Soft-Soil Model (SSM) for embankment fill.

Here the actual settlement behaviour of the embankment over ST is expected to be between these two cases.

The soft clay, the sand and the embankment fill were modelled as elastic-perfectly plastic materials. No deformation below the sand layer was assumed. Mohr-Coulomb failure envelope was used as the failure criterion in first case and critical state based soft soil (similar to CAMCLAY) failure criterion was used in the second case. The elastic modulus adopted for the normal fill was typically between 7 to 21MPa[5].

2.4.2.2 *Mesh Generation*

Two types of triangular elements are used in the PLAXIS, 6 noded triangular elements and 15 noded triangular elements. Advantages of higher order triangular elements is that they provide better representation of the description of continuous strain and stress variations and also provides good description of a continuous displacement field with relatively few elements. The disadvantages of higher order elements is that the failure loads may be dependent on the mesh and makes poor description of discontinuous stress and strain. In PLAXIS, the program automatically creates unstructured mesh as there is no possibility of making a so-called structured mesh. The mesh size cannot be set explicitly. The mesh is generated based on random seeds. The mesh size may be changed globally by means of global coarseness and locally by means of local coarseness. The next Figure presents a typical mesh generated for the current analysis.

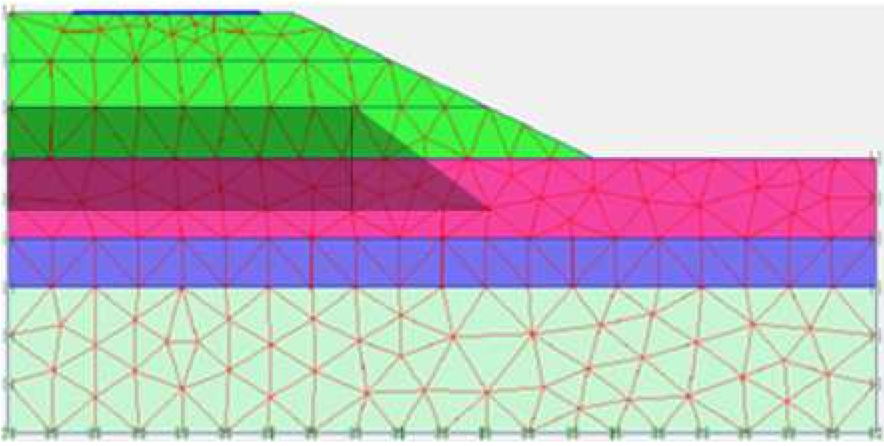


Figure 8: Typical mesh generation in PLAXIS

2.4.2.3 *Initial and boundary conditions*

In the initial conditions, water unit weight is set to 10kN/m3. The water pressure is fully hydrostatic and is based on a general phreatic level. In addition to phreatic level, boundary condition for consolidation analysis can be additional input. The lines of consolidation need to be selected in vertical direction that means vertical boundaries must be closed to restrain the horizontal flow and no free outflow is allowed at that boundary.

The water conditions can also be specified in the Geometry configuration mode using phreatic level by generating pore pressure using phreatic level. In the analysis, constant ground water level has been considered.

2.4.2.4 *Initial stresses*

[5] Bowles, J. E. (2000), “Foundation Analysis and Design”, McGraw-Hill, New York.

In initial stresses which are effective stresses, Over-Consolidation Ratio (OCR) and Pre-Overburden Pressure (POP) are used in analysis when using Soft-soil model. Initial stresses are developed by the POP procedure (PLAXIS 8, User Manual). It is also possible to specify the initial stress state using the Pre-Overburden Pressure (POP) as an alternative to the over consolidation ratio. The Pre-Overburden Pressure is defined by:

$$POP = \sigma_p - \sigma_{yy}'^{o}$$

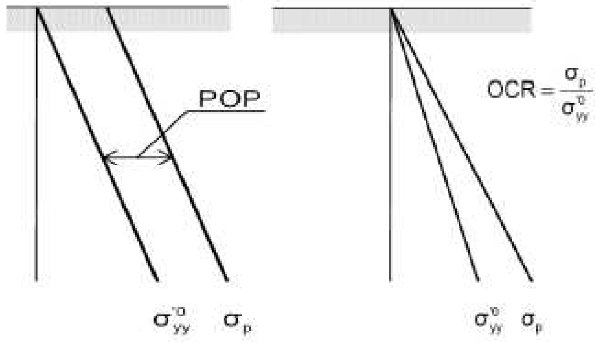


Figure 9: POP and OCR profile illustrations – PLAXIS 8. user manual.

Once the geometry of the model was developed, finite element model is complete. Initial situation and initial stress state should be stated before calculation. This was done in the initial conditions part of the input program. When using Mohr Coulomb model, the analysis require the generation of the initial stresses by means of Ko procedure. Ko procedure can be used to calculate initial stresses. The suggested Ko procedure is based on Jaky's formula (1 – Ko * Sin Φ).

2.4.2.5 *Calculation*

After the generation of Phreatic level and initial stresses, the input is complete and calculations can be generated. These calculations are generally used to define the different phases of embankment construction. The next figure presents a snapshot of different phases of the construction process as implemented in FEM program.

Four loads coming in contact with road through tires were used to simulate the traffic loading. The loading consisted of 40kN having uniform maximum vertical contact stress over the contact area with ratio of 1:0.85 (width=19.27 cm, length=16.38 cm) placed on top of the pavement.

Next | Insert | Delete...

Identification	Phase no.	Start from	Calculation	Loading input	Time
Initial phase	0	0	N/A	N/A	0.00 ...
Gravity Loading	1	0	Consolidation	Staged Construction	15.0...
1st stage Emb Loading	2	1	Consolidation	Staged Construction	30.0...
Consol Period	3	2	Consolidation	Staged Construction	60.0...
2nd Stage Emb Loading	4	3	Consolidation	Staged Construction	30.0...
Consol Period	5	4	Consolidation	Staged Construction	60.0...
3rd stage Emb Loading	6	5	Consolidation	Staged Construction	30.0...
Consol Period	7	6	Consolidation	Staged Construction	60.0...
Pavement Const	8	7	Consolidation	Staged Construction	30.0...
Traffic Loading	9	8	Consolidation	Staged Construction	1000...
Pore Pressure	10	9	Consolidation	Minimum pore pressure	17.0...

Figure 10: Calculation step using FEM program

In the modelling analysis, the consolidation option in FEM software allows fully automatic time stepping procedure that takes the critical time step into account. The future of pavement construction and traffic loading were also taken into the consolidation analysis with different time intervals. The last phase in consolidation analysis was selecting minimum pore pressure where the default value of 1 kN/m^2 was used for the pore pressure.

To calculate the global safety factor for the road embankment, the phi-c reduction option available in the PLAXIS was selected and used in the next phase.

2.4.2.6 *Results of finite element analysis*

On evaluating the total displacement, it can be seen that the failure mechanism is developing with excess pore pressure distribution. The settlement at the pavement surface and embankment were increasing considerably after the end of the construction of embankment. This is due to the dissipation of excess pore pressure in soft soil layer which causes consolidation in soils.

The vertical displacement (or settlement) contours for normal fill and EST fill from the numerical analysis (using Mohr coulomb MCM and soft-soil SSM for embankment) over 60 months of time are presented in next figures respectively. The others figures shows maximum settlement that can occur after full dissipation of pore pressure at both embankment locations.

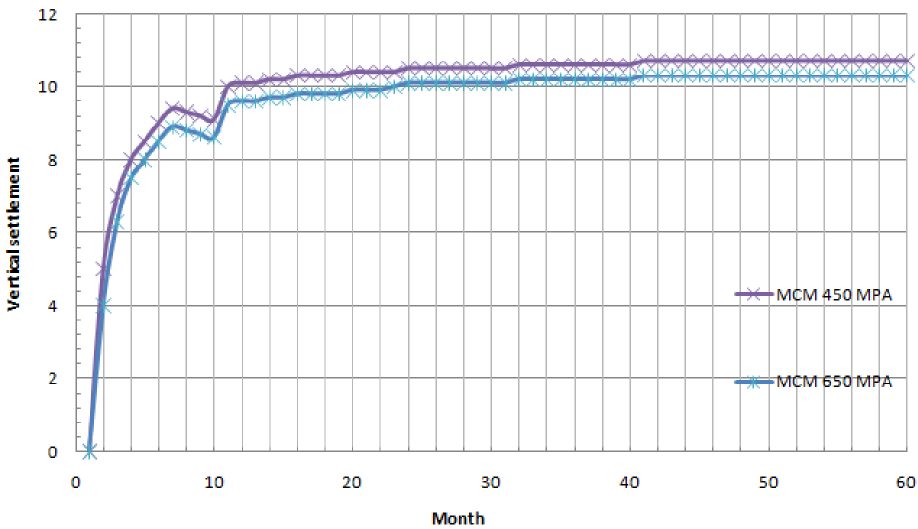


Figure 11: Settlement vs Time plot in the surface in FEM using MCM for embankment

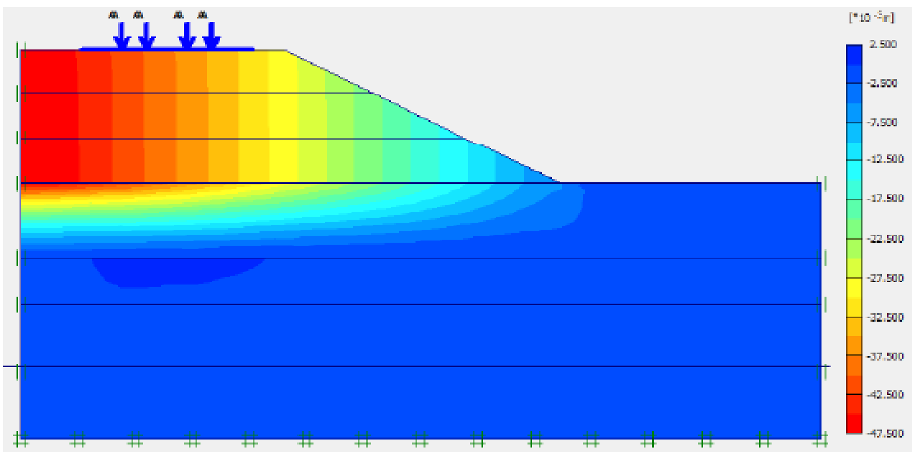


Figure 12: Settlement contours at the end of pore pressure dissipation in EST using MCM.

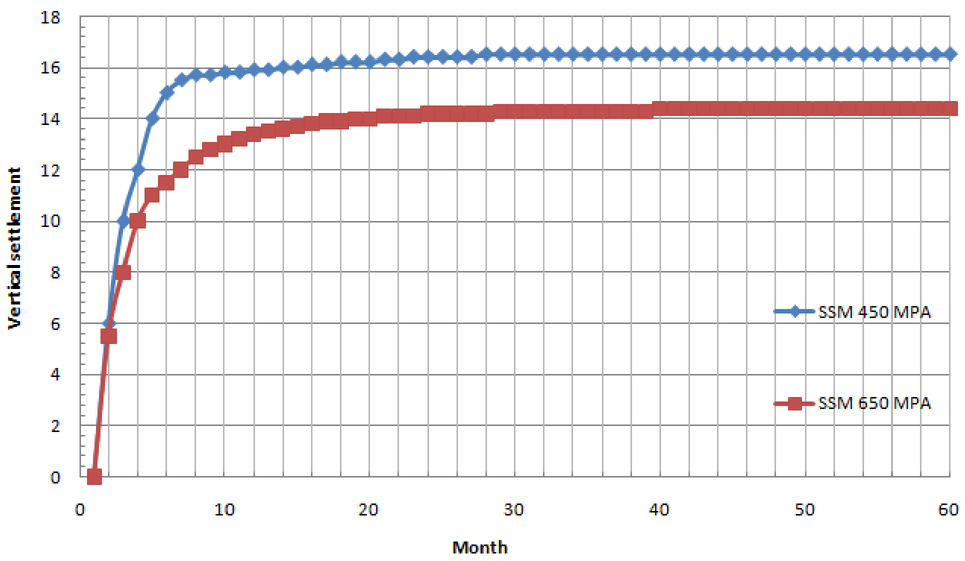


Figure 13: Settlement vs Time plot in the surface in FEM using SSM for embankment

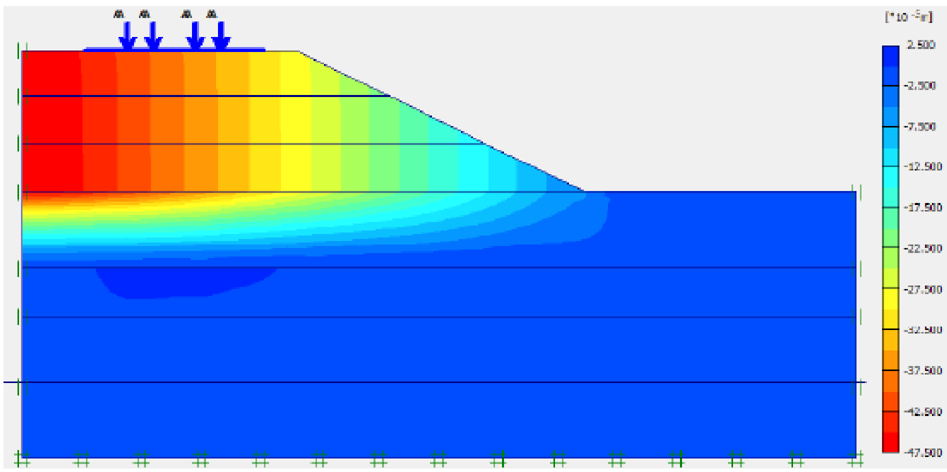


Figure 14: Settlement contours at the end of pore pressure dissipation in EST using SSM.

The vertical stress contours from the numerical analyses for the two cases are also presented in the next figures. It is shown that more stress concentration occurs at bottom of the normal fill as the loads are transmitted from the top to the bottom. The degree of stress concentration is slightly reduced when EST materials are used instead of normal fill. In addition, the EST carry fewer loads than the normal fill due to the low weight and high strength properties.

It has been observed that a maximum stress of 80kPa has been transmitted to the soft foundation soil in the case of the ETS embankment after the full dissipation of pore water pressure; whereas, a maximum vertical stress of 150kPa is recorded at the interface of the embankment base and soft foundation soil for the control embankment. This is expected since the EST is a LWA material which has approximately half the unit weight of the normal fill materials and hence imparts lower thrust on the foundation soil.

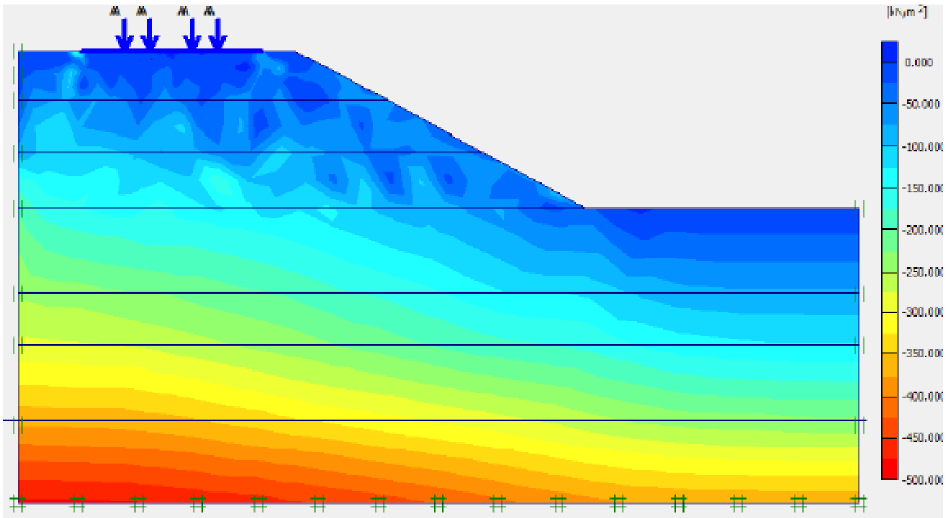


Figure 15: Stress distribution in Normal Fill after full dissipation of pore pressure using MCM for Embankment.

It has been observed that a maximum stress of 50kPa has been transmitted to the soft foundation soil in the case of the EST embankment; whereas, a maximum vertical stress from 150kPa is recorded at the interface of the embankment base and soft foundation soil interface in the case of the control embankment.

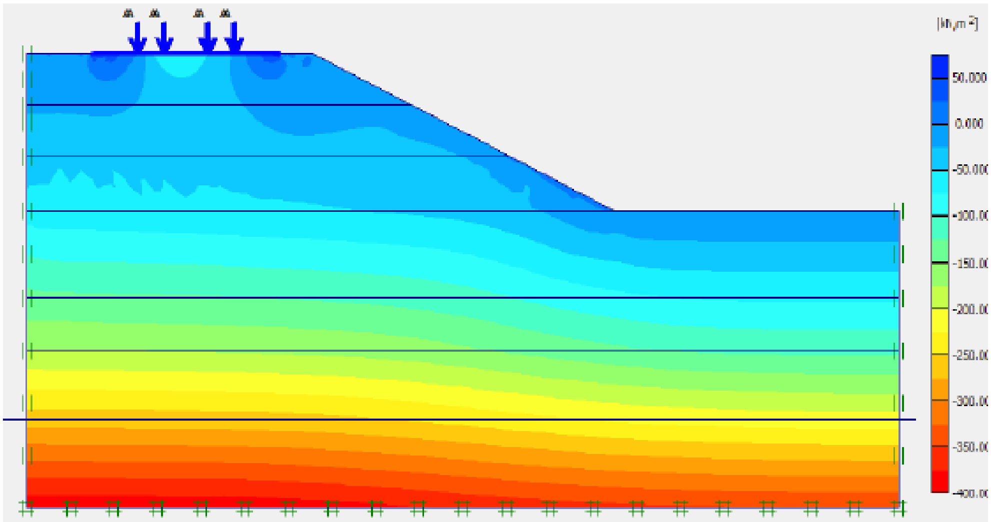


Figure 16: Stress distribution in EST Fill using SSM for embankment

2.5 Conclusions and analysis of results

Has been developed and calibrated a numerical finite element model for the prediction of future deformations of an embankment with the characteristics used during the research project. The values used correspond to the information taken during the monitoring process.

The behaviour of Embankments Shreds Tire sections has been comprehensively studied through field observation of full scale physical model, laboratory testing and numerical simulation. However, the cost of constructing and monitoring are quite high. An alternative method such as numerical experiment or simulation by means of appropriate methods such as finite element and finite difference techniques is essentially required. The numerical simulation of these embankments systems were realized by means of Finite Difference and Finite Element methods using 2D analysis program. The aim of this study is to investigate the influence of characterization of mechanical modules, using 2D numerical simulations of the test embankments. Particular attention is given to the vertical displacements or settlement. Subsequent comparisons are made to study the long term settlement behaviours between the findings of 2D numerical simulations and those from the actual measured field data used by the formulation method of the two full scale embankments (test section and control section).

Two cases were analyzed to evaluate the long term influence of the shreds tire in the Embankment (1) Vertical settlement on control section and test section using Mohr Coulomb Model for ST (PLAXIS) (2) Vertical settlement on control section and test section using Soft-Soil Model for ST (PLAXIS).

The vertical displacements (or settlement) for EST fill from the numerical analysis were compared near the embankment surface because in the field, maximum settlement at normal fill was recorded near the surface and very less settlement was seen at the surface of EST fill. The long term maximum settlement at Embankment surface was then determined using SSM and MCM formulation and these settlements are determined at 10, 20 and 60 months using the formulation results are used as a benchmark to compare the numerical analysis modeling results.

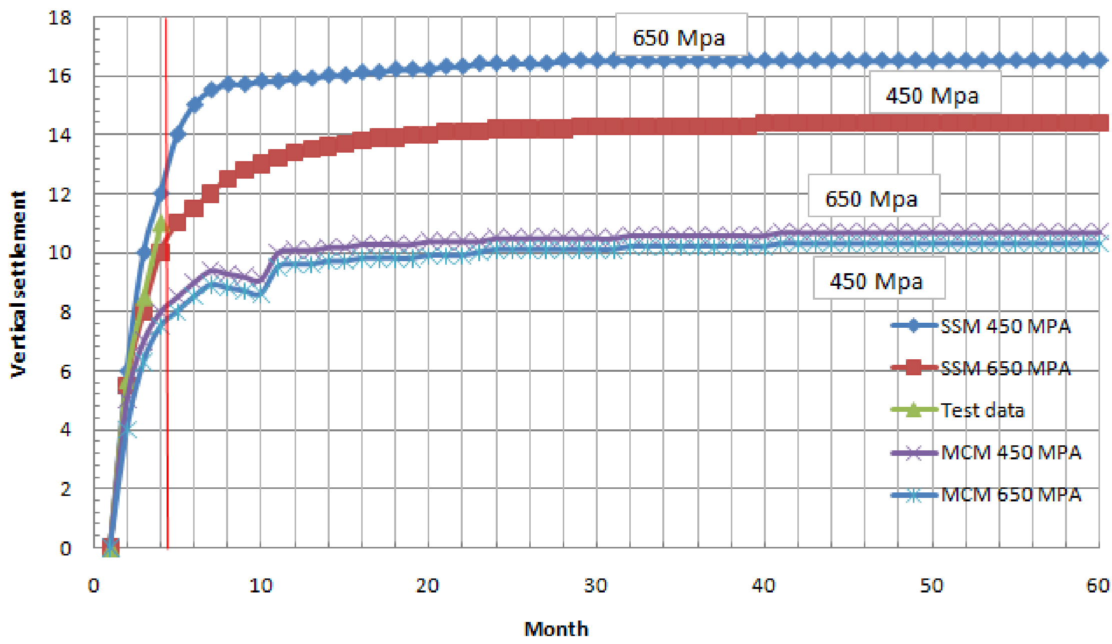


Figure 17: Comparación de resultados de monitorización con los re la modelación numérica.

One of the main results of technical analysis modeling. Is the similarity of the true strain of EST with curves obtained with the numerical model SSM. Other models such as MCM do not apply such scientific RECTYRE embankments. The SSM model provides valuable information to predict the maximum possible for embankments deformations with similar characteristics. The SSM model indicates that the maximum vertical deformation will reach 17 cm and at 24 months of construction, bringing the important values of deformation during the first 12 months of construction.

Comparing the curves of the SSM model with actual data monitoring module allows us to determine an approximate those of full of pieces of tires, this value ranges around 500 Mpa. For future type design RECTYRE embankments, it is advisable to plan buildings with this module mechanical strength.

Although the monitoring information is for 3 months has allowed us to determine the relationship between the actual vertical deformation obtained in the monitoring of construction, and numerical modeling to predict outcomes. However due to the interest of the project partners will continue to monitor the EST, and to validate the model SSM modules and resistance for future construction processes.

3. MODEL ANALYSIS – ENVIRONMENTAL & ECONOMICAL

The environmental performance of RECTYRE has been monitored during the execution of the model in Czuprynowo. Environmental analysis has been done to assure that not only the Rectyre final solution, but also its constructive process are environmentally friendly and fulfil the required environmental standards. Prior to the analysis, no detrimental environmental impact has been observed. In the next images (taken during the execution of Rectyre embankment, it is shown that major efforts have been taken into consideration to avoid environmental impacts due to the construction process.

Figure 18: Demo site of Czuprynowo in Poland prior Rectyre execution

Figure 19: Construction process of Rectyre embankment in Czuprynowo

Potential groundwater contamination has been a major concern, but existing studies indicate that shredded tires placed in highway embankments do not pose an environmental hazard. Conclusions of previous studies state that shredded-tire embankments should be used where feasible as an environmentally prudent approach to waste tire disposal. The stocks of used tires are growing and, in some cases, the only way of reducing them is using the tires as combustible, producing energy, but also contributing to Greenhouse and Acid Rain effect due to the emissions of VOCs and other hazardous gases. Therefore, the impact of this project claims to be environmentally beneficial as gives a new trend to reduce the huge stocks of tires. This case model executed by Mostostal in Poland (Czuprynowo) is at this point being monitored, and the results at the moment show that the use of scrap used tires as filler has no negative influence in the environment. These results mean that the methodology and the technology are suitable to be used in every scenario, contributing to reduce the footprint of the construction of roads and railways and also avoiding the use of natural soil. Although the use of recycled rubber has many advantages, there are potential problems that needed to be monitored for its evaluation and verification. These problems include leakage of metals and organics, fire risk and increased compressibility due to the tire chips. The main focus of this study was to identify potential contaminants associated with CRM asphalt mixtures, specifically trace metals organics. Not only leakage, but many other environmental aspects have been taken into account, as shown in the next table. However a major concern has been given to potential groundwater contamination and temperature increase. Specific test methods have analyzed these issues. For this purpose, the monitoring has been designed to detect any leakage of any organic compound or heavy metal leakage (groundwater analysis), and the other parameter (the temperature of the filler) has been controlled as any rise of the temperature could mean a degradation of the filler. At the moment all the parameters are showing normal values.

Table 7: Key Environmental Parameters on RECTYRE Solution from the method Batelle-Columbus

Environmental Parameters of the method BATELLE-COLUMBUS			
ENVIRONMENTAL IMPACT			
Ecology	**Environmental &Health**	**Aesthetic Factors**	**Human interest aspect**
SPECIES AND POPULATIONS Terrestrial Grassland Crops Natural vegetation Harmful species Continental game birds Aquatic Commercial Fisheries Natural Vegetation Harmful Species Waterfowl	WATER CONTAMITATION Losses in watersheds D.B.O. Dissolved oxygen Fecal-Colombes Inorganic Carbon Nitrogen-Inorganic Inorganic phosphate Pesticides Ph Variant of Current Flow Temperature Total dissolved solids	GROUND Geological Surface materials Terrain and topography Extension and alterations	EDUCATION & SCIENTIFIC VALUES Archaeological Ecological Geological
HABITAT AND COMMUNITY Terrestrial Food Chain Land use Rare and endangered species Species diversity Aquatic Food chains Rare and endangered species Fluvial features Species diversity	AIR POLLUTION Carbon monoxide Hydrocarbons Nitrogen -Oxide Solid particles Oxidants	AIR Odor and visibility Sounds	HISTORICAL VALUE Architecture and Styles Events Personal Religions and cultures Western borders
ECOSYSTEM Ecosystem	SOIL CONTAMINATION Land use Erosion	WATER Presence of Water Odor, color and Taste Floating materials Area of water surface Trees and geological margins	CULTURES Ethnic groups Religious Groups
	NOISE POLLUTION Noise	BIO Pets Wild animals Diversity of vegetation Variety of other types of vegetation	SENSATIONS Admirations Isolation, loneliness Mystery Integration with nature
		COMPOSITION Effects of composition Singular elements	LIFESTYLE (cultural norms) Employment opportunities Social interactions

Most of the parameters shown on table 1 has been considered as environmental aspects to take into account on Rectyre Environmental Analysis. However, the ones that appear highlighted on the table are the points that can differ from traditional embankments construction to the Rectyre solution.

Figure 20: The concept of environmental analysis for proper interaction with nature and society

The environmental analysis has been focused on the comparison between prior road construction methodologies and the Rectyre embankment construction, in order to evaluate its viability and compliance with current environmental European policies and standards. This analysis, although it takes into consideration the global environmental impact that performs on the site, is set to determine the specific impact of a road tire embankment on groundwater and temperature, bypassing other features as road design, location or impact on wildlife.

Therefore, the next two points will describe the environmental analysis on Groundwater and Temperature, as these are the main interest areas to be focused on. Although it is important to mention that the impact due to construction of highways include the noise and dust from construction, the use of non-renewable aggregates, the loss of natural habitats and green space and increase in traffic (with all its impacts). The best practice is to undertake an environmental impact assessment (EIA) before the road is designed.

Environmental Impact Assessment (EIA) is defined as the process of examining the environmental effects of the development –from consideration of the environmental aspects at design stage, through to the preparation of the Environmental Impact Statement, evaluation of the EIS by a competent authority and the subsequent decision as to whether the development should be permitted to proceed, also encompassing public response to that decision. Regardless the embankment method to perform and the results shown on this analysis, it is necessary to evaluate for each project its individual environmental impact prior to the execution.

3.1 Groundwater monitoring

Mostostal performed a study of the groundwater features at the site prior to Rectyre model construction and the results were reported. During the monitoring of the shredded-tire embankment following construction, two more sets of water quality samples were taken: the first test was done one week after the completion of the works, and the other 4 weeks later.

Table 8: Groundwater quality analysis EDEM-European Department on Environment Management

Groundwater Quality Analysis EDEM			
No#	**Contaminant**	**Unit**	**Maximum Contaminant**
1	Arsenic	mg/L	0,05
2	Barium	mg/L	2
3	Cadmium	mg/L	0,005
4	Chromium	mg/L	0,1
5	Selenium	mg/L	0,05
6	Aluminium	mg/L	0,05-0,2
7	Iron	mg/L	0,3
8	Manganese	mg/L	0,05

The results were analyzed and compared with the maximum accepted levels. The levels that the groundwater tests should comply with are shown in the next table. This is the list of elements selected for the testing, compiled in accordance with the requirements of European regulations.

Humphrey and Swett [2006][6] provided a comprehensive literature review on the effects of Tyre Lightweight Filler for Embankments (TLFE) on groundwater quality. In field studies presented by Humphrey and Katz [2000 and 2001], TLFE was placed either above or below the groundwater table, and groundwater quality was then evaluated. Results showed that the presence of TLFE had a negligible effect on the concentration of metals such as arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), and lead (Pb) relative to primary drinking water standards. However, concentrations of other metals related to secondary drinking water standards, such as iron (Fe) and manganese (Mn), were encountered at elevated levels. When TLFE is placed below groundwater level, the manganese and iron released by TLFE can be significantly above the secondary drinking water standard. Because secondary standards are based on aesthetic factors (e.g., color, odor, and taste) and not on health concerns, the release of manganese and iron is not a critical concern. However, aesthetic concerns should be evaluated if TLFE is to be placed below the groundwater table (ASTM D 6270 [ASTM, 2008])[7].

The leaching potential of organic compounds was also evaluated in these studies. The release of organics from TLFE placed above the groundwater table was found to be below method-detection limits [Humphrey and Katz, 2000][8] and was not considered a significant concern. TLFE

[6] Humphrey, D.N. and Swett, M. [2006]. *"Literature Review of the Water Quality Effects of Tire Derived Aggregate and Rubber Modified Asphalt Pavement", prepared for USEPA Resource Conversion Challenge, University of Maine, Orono, Maine.*

[7] *ASTM [2008]. "Annual Book of ASTM Standards", American Society for Testing and Materials,*

[8] Humphrey, D.N. and Katz, L.E. [2000]. "*Five-Year Field Study of the Effect of Tire Shreds Placed above the Water Table on Groundwater Quality*", Transportation Research Record No. 1714, Transportation Research Board, Washington, D.C., pp. 18-24.

placed below the groundwater table released a few organic compounds at low concentrations based on field results provided by Barris [1987][9] and Twin City Testing [1990].

Table 9: First Groundwater quality analysis at demo site, prior to Rectyre model execution

Research results of groundwater - Czuprynowo				
No#	Contaminant	Unit of measurement	Result	Date
1	Arsenic intensity	mg As/dm³	< 0,001	30.09.2010
2	Barium intensity	mg Ba/dm³	0,058	05.10.2010
3	Boron intensity	mg B/dm³	0,132	05.10.2010
4	Overall Chrome intensity	mg Cr/dm³	< 0,002	12.10.2010
5	Overall Zinc intensity	mg Zn/dm³	0,055	05.10.2010
6	Aluminium intensity	mg Al/dm³	0,330	05.10.2010
7	Cadmium intensity	mg Cd/dm³	<0,00002	04.10.2010
8	Cobalt intensity	mg Co/dm³	< 0,001	05.10.2010
9	Magnesium intensity	mg Mg/dm³	13,700	05.10.2010
10	Manganese intensity	mg Mn/dm³	1,128	05.10.2010
11	Copper intensity	mg Cu/dm³	0,0079	12.10.2010
12	Nickel intensity	mg Ni/dm³	< 0,005	08.10.2010
13	Overall intensity of organic Carbon	mg C/dm³	34,300	01.10.2010
14	Plumb intensity	mg Pb/dm³	0,009	20.10.2010
15	Mercury intensity	mg Hg/dm³	0,00020	01.10.2010
16	Selenium intensity	mg Se/dm³	< 0,001	05.10.2010
17	Sodium intensity	mg Na/dm³	3,190	05.10.2010
18	Argent intensity	mg Ag/dm³	< 0,0001	06.10.2010
19	Petroleum-derived Hydrocarbon intensity	mg /dm³	< 0,100	06.10.2010
20	Overall Ferrum intensity	mg Fe/dm³	23,000	05.10.2010

[9] Barris, D.C. [1987]. *Report of Ground & Surface Water Analyses*. Unpublished Report, Environmental Consulting Laboratory.

Results show that trace levels of a few volatile and semivolatile organics were found in water taken directly from TLFE filled trenches. In these studies, the concentrations of water containments such as benzene, chloroethane, cis-1,2-dichloroethene, and aniline were above their respective preliminary remediation goals (PRG) for tap water when water is in direct contact with TLFE.

Table 10: Second and Third Groundwater quality analysis after Rectyre execution

Research results of groundwater - Czuprynowo				
No#	Contaminant	Unit of measurement	1st Monitoring Results June 2011	2nd Monitoring Results June 2011
1	Arsenic	mg/L	< 0,001	< 0,001
2	Barium (Ba)	mg/L	0,063	0,060
3	Cadmium (Cd)	mg/L	<0,00002	<0,00002
4	Chromium (Cr)	mg/L	0,0033	0,0034
5	Selenium (Se)	mg/L	< 0,001	< 0,001
6	Aluminium (Al)	mg/L	0,038	0,036
7	Iron (Fe)	mg/L	0,47	0,45
8	Manganese (Mn)	mg/L	0,14	0,12
9	Copper (Cu)	mg/L	0,0087	0,0080
10	Lead (Pb)	mg/L	0,009	0,009
11	Zinc (Zn)	mg/L	0,102	0,089
12	Magnesium (Mg)	mg/L	5,05	5,05
13	Sodium (Na)	mg/L	3,198	3,193
14	Organic Carbon	mg/L	1,62	1,62
15	Chloride (Cl^-)	mg/L	15,30	15,05
16	Organic Halides	mg/L	Non-detect	Non-detect

However, samples taken a few feet downgradient show that the effects are reduced to negligible levels. Humphrey and Swett [2006] concluded that TLFE placed below the groundwater table have negligible effects for off-site water quality. From this study and other related literature papers, we can conclude that placement of tire shreds above the water table under simulated field conditions will have little or no environmental impact. However, the placement of tire shreds below the water table might have some impact over time according to the characteristics of each field particulars. Thus it is recommended that tire shred embankments be built above the water table. If a tire shred embankment is to be built below the water table, precaution in the design and construction of the embankment must be taken to assure that water does not pond up in the embankment and that water will be able to drain from the tire shreds[10].

[10] Iowa DNR. 2005. Waste tire recycling. Iowa Department of Natural Resources, Des Moines, IA. Viewed on July 26, 2005 at http://www.sciswa.org/Landfill/tires.html.

Our case model executed in Czuprynowo is slightly over groundwater level, as shown in the bore-hole scheme. Groundwater samples were analyzed for the presence of the relevant elements as per table 1 and the results are shown graphically in the next tables: First groundwater samples were collected between September 30th and October 8th 2010, as shown in the table, prior to the model construction. Second groundwater samples was collected on the first week of June 2011, immediately after Rectyre model execution; and the Last water testing has been done on July 2011, 5 weeks after the completion of the works, as shown in the next tables.

3.2 Temperature monitoring

For accurate monitoring of embankment temperature, it was designed and installed appropriate instrumentation to read out temperature hesitation in the embankment layers. The sensor used was the “Temperature sensor Testo 177-T4” model. This sensor immediately provide information about current indications, the last saved value max. and min. values and the number of limited border. It provides 4-channel temp recorder, a measuring range from -100ºC to +400ºC, and an internal memory of 48,000 readings. On the next images it is shown the instrumentation and methodology carried out at the demo site to obtain temperature data.

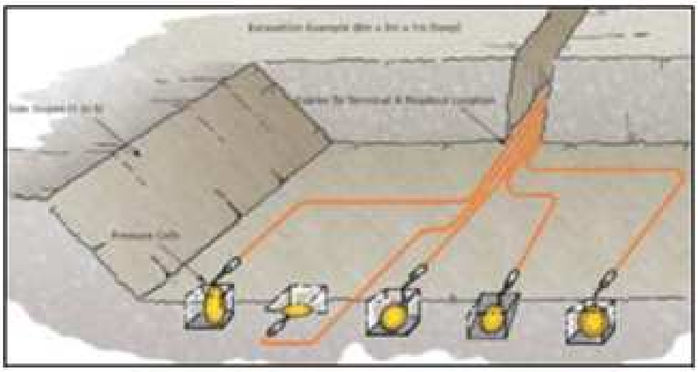


Figure 21: Temp. Sensor Testo 177-T4 and Image 6: Disposal of sensors through the embankment

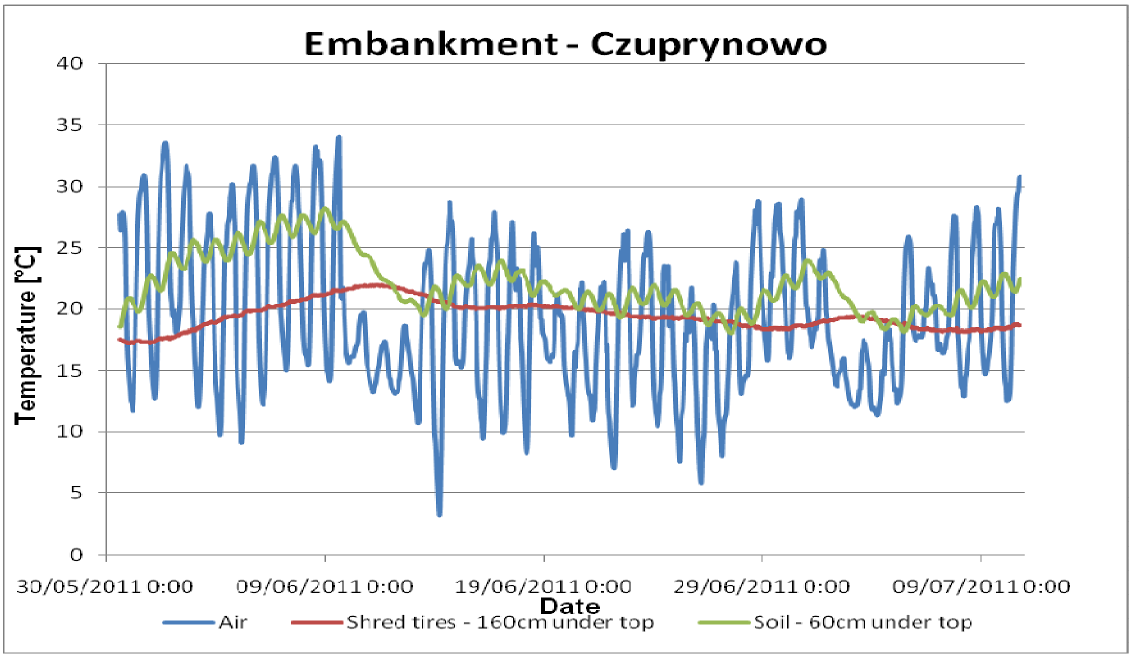
The results obtained from multiple data compilation are shown on the next tables:

Table 11: Summarized Temperature Control Data

Temperature Control Data *(Summarized Data)*			
Date	Air	Shred tires 160 cm under top	Soil 60 cm under top
30/05/2011 15:00	27.7	17.6	18.6
31/05/2011 1:00	14.2	17.3	20.9
31/05/2011 11:00	26.9	17.5	19.8
01/06/2011 7:00	15.6	17.5	22
01/06/2011 17:00	33.5	17.7	22.5
02/06/2011 13:00	29.5	18.2	23.3
02/06/2011 23:00	20	18.4	25.6
03/06/2011 9:00	18.5	18.7	24.4
03/06/2011 19:00	27.1	19	24.9

04/06/2011 5:00	9.7	19.1	25.3
04/06/2011 15:00	27.6	19.4	24.2
05/06/2011 1:00	12.7	19.4	26.3
05/06/2011 11:00	28.1	19.9	24.5
05/06/2011 21:00	26.8	19.9	26.6
06/06/2011 17:00	32.4	20.2	26.1
07/06/2011 13:00	30.7	20.6	25.9
08/06/2011 9:00	25.8	21.1	26.5
09/06/2011 5:00	14.1	21.3	27.7
10/06/2011 21:00	16.3	21.9	24.4
11/06/2011 17:00	17.4	21.9	22.4
12/06/2011 13:00	17.2	21.7	20.7
13/06/2011 9:00	17	21.2	19.7
14/06/2011 5:00	3.2	20.6	21.4
15/06/2011 1:00	15.5	20.2	22.8
16/06/2011 7:00	12	20.1	22.7
17/06/2011 13:00	27.1	20.2	22.3
18/06/2011 9:00	18.4	20.3	21.5
19/06/2011 15:00	21.2	20.3	21.2
20/06/2011 11:00	15.3	20.1	20.1
25/06/2011 16:00	19.3	19.3	19.8
01/07/2011 16:00	23.3	19	22.6
05/07/2011 16:00	25.7	18.6	19
10/07/2011 16:00	30.6	18.7	22.2

Figure 22: Temperature Analysis at Rectyre demo model in Czuprynowo



The results of the temperature monitoring indicated no evidence of any localized heat generation within the core of the shredded-tire embankment. This is significant in view of the problems experienced elsewhere. It is likely that the use of geo-textil layers mixing tire shreds with soil fill minimizes the potential for an exothermic reaction. There are no reports of problems with similar designs.

3.3 Economical analysis

For projects where special properties of tire shreds are needed, they are often the lowest cost alternative. Some of these properties are a low unit weight, high permeability, and high insulating value making them an excellent fill for embankments constructed on weak ground, landslide stabilization, retaining wall and bridge abutment backfill, insulation to limit frost penetration beneath roads, and drainage layers for landfills. Thus, civil engineers are choosing tire shreds because they offer both the properties needed to solve special problems and lower costs to satisfy the demands of their clients for the most economical project possible. A disadvantage may be, that the cost can be increased because of the gaps in gathering and recycling networks. If the key actors are not well connected, the cost will increase. On the other hand if this project generates stable networks the costs of transportation and the acquisition of raw materials (used tyres) will be lower, even lower than that of natural soil. Projects costs and material quantities estimation are shown in the next Table. The principal sources of a significant cost overrun, as compared with the original construction estimate, were the quantities of shredded tires and borrow excavation. The contractor was paid on the basis of loose volume of shredded tires delivered to the site as estimated from truck capacity.

Table 12: Rectyre material quantities and project costs

Material Quantities and Project Costs					
Item	Estimated Quantity	Final Quantity	Units	Unit Price	Cost (€)
Construction Surveying			L.S.	2,625.00	2,625
Surplus Regular Excavation	27,067	30,677	m³	1.6021	49,147
Borrow Excavation	15,789	26,083	m³	9.8640	257,280
Settlement Plates	4	4	EA.	1,000.00	4,000
Shredded Tires	13,082	24,119	m³	10.3701	250,112
Surcharge	8,555	9,570	m³	9.8640	94,396
Total Final Cost (as of 24/05/2011)					657,560 €
Total Estimated Cost (work order 5/10/2010))					460,292 €
Cost Overrun					197,268 €

Rectyre process is competitive in all the situations where standard or lightweight materials are not available in the close vicinity of the embankment location. In that cases, transportation may represent a significant cost, thus influencing the final budget of the project; it is possible instead that ELTs, which are a recycled material providing improved chemical, physical and mechanical characteristics with respect to soil, are available close to the worksite, minimising the overall cost of the work.

Furthermore, supply availability is a key aspect in the RECTYRE value proposition, as the use of ELTs is a good alternative when soil or other lightweigth fillers are difficult to retrieve. This is strictly related with costs, as the competitiveness of the RECTYRE embankment construction process in terms of costs increases when it is combined with lack of supply availability. It is difficult to provide quantitative estimations of the costs involved in the case of RECTYRE model, as they strongly depend on the price for ELTs, which varies from country to country and also within the same country in case of free market regime. It is rather possible to describe the type of cost structure involved and estimate the weight of each component on the total costs of the model.

As indicated in Table 12, the reported unit cost of shredded tires was approximately 5 percent higher than the unit cost of a borrow excavation (10.3701 versus 9.8640). The contractor was paid for the regular soil fill based on the compacted in-place volume. Since approximately 30 percent compression is expected to occur after the placement, the effective in-place (compacted) unit cost of tire shreds was at least 37 percent higher than that of the conventional fill. Further, the construction of shredded-tire embankments was administered as a change order to the previously awarded contract, thus potentially skewing the fair market price for this activity.

Table 13: Variables Description in Poland Data Set

Variables Description			
Input Variables	**Description**	**Units**	**Range**
PWA	Predominant Work Activity	Category	New Construction Asphalt or Concrete
WD	Work Duration	Month	14-30
PW	Pavement Width	m	7-14
SW	Shoulder Width	m	0-2
GRF	Ground Rise Fall	m/km	2-7
ACG	Average Site Clear/Grub	m^2/km	12605-30297
EWV	Earthwork Volume	m^3/km	13134-31941
SURFCLASS	Surface Class	Category	Asphalt or Concrete
BASEMATE	Base Material	Category	Crushed Stone or Cement Stab.
Output Variable			
USDPERKM	Unit Cost of New Construction Project	US Dollars	572,501.64–4,006,103.95

Cost estimates were made to determine the economic advantages of using shredded tires as the embankment material. The cost estimates were based on prevailing labour costs and included all other major costs such as excavation and material costs. The construction site was assumed to be located relatively close to the material suppliers. Based on the information collected from local vendors, the average cost of soil was 25€ per cubic meter (m^3). The cost of shredded tires depends on the processing costs to shred the tires to the required tire chip sizes and the transportation costs which depend on the distance of the project site from the shredding facility. Based on the information obtained from the local tire shredding companies, the cost of shredded tires ranges from 10€ to 15€ per cubic meter.

For this research, ROCKS Database has been used. This database contains road works cost data from 65 developing countries. Among these countries Poland has a relatively large number of projects. It has been developed by the World Bank Transport Unit in form of Road Costs Knowledge System (ROCKS) to develop an international knowledge system on road work costs in order to establish an institutional memory, and obtain average and range unit costs based on historical data. The table 13 show a list of input variables taken into account: work duration, pavement width, shoulder width, ground rise and fall, average site clearing and grubbing (ACG), earthwork volume (EWV), surface class, and base material. These variables have been used to evaluate the relevance of each one on the global cost of a road construction, as shown on table 3 for the influence of each input variable to output variable. This serves as feedback, indicating which input channel has a significant effect. It was found that pavement width, earthwork volume, work duration, average site cleaning and grubbing, surface class, and base material have a relatively high influence on an average new construction project's cost.

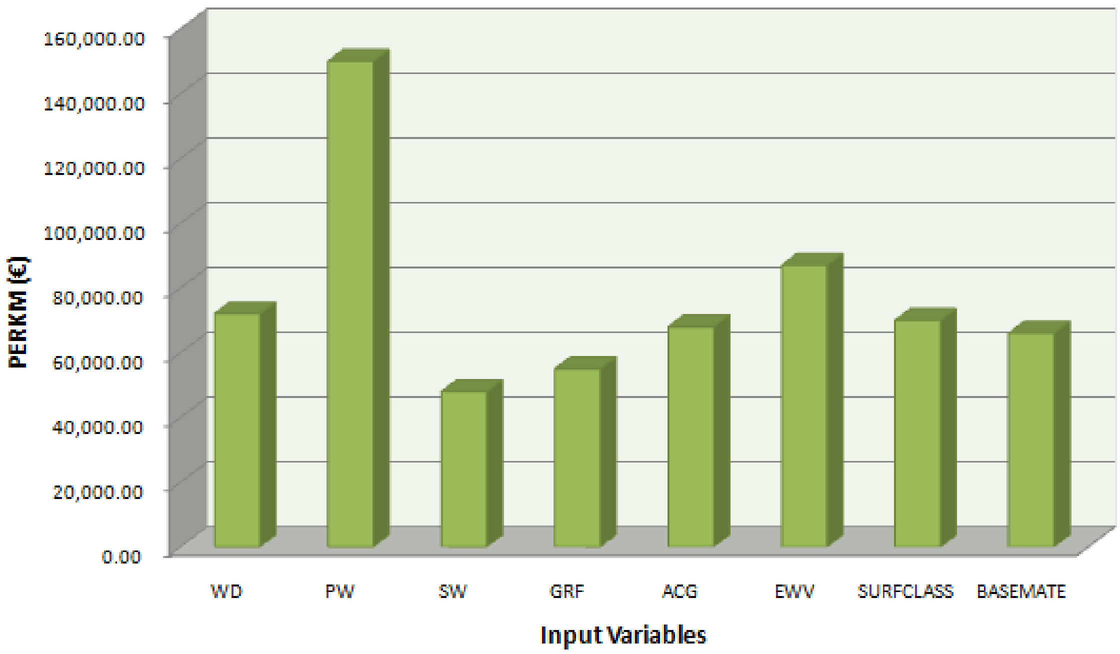


Figure 23: Evaluation of the influence of each input variable on project average cost (Poland case).

In conclusion, the economic viability of the implementation of used tyres as filler for embankments has been proved in previous studies. The benefits, apart from those environmental benefits already described, will depend on the management model applied in each scenario. The optimal situation is that in which the construction has the support of the Management Agency or Association to use the used tyres. In that case cost will be reduced to a minimum.

3.4 Conclusions and analysis of results

On previous points 1 and 2, the conclusions obtained for the Groundwater and Temperature environmental analysis carried out, were evaluated and shown. At this point, only short time results have been used for the analysis. Therefore, during the next 2 years monitoring will continue and periodical test will be carried out to obtain following results. A final evaluation will determine if our estimations remain valid. The current conclusion at this stage is that, it is possible a major increase in the number of scrap tires used for civil engineering applications, because of their growing record of successful performance combined with guidelines to limit self-heating of thick fills and groundwater data showing that they have a negligible environmental impact.

Conclusions drawn from the tests were as follows: No evidence was found that tire shreds increased the concentration of metals with a primary drinking water standard, including barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and selenium (Se) or the following substances with secondary drinking water standards: aluminum (Al), chloride (Cl^{-}), and Zinc (Zn). There was some evidence that tire shreds could increase the levels of iron (Fe) and exceed the secondary drinking water standard under some conditions. Tire shreds increase the levels of manganese (Mn), which has a secondary drinking water standard. It is likely that the levels will exceed this standard. However, manganese is of aesthetic concern only. Negligible levels of organics were measured. Overall, tire shreds placed above the water table had a negligible impact on water quality for the near neutral pH conditions.

The most abundant metals found in the leakage were zinc and iron. However, the study concluded that the results indicate that concentrations of metals in the leakage are below regulatory levels. On the next table there is a comparison between the results.

Table 12: Comparison of Groundwater quality Analysis on Rectyre case study site.

COMPARISON ON GROUNDWATER QUALITY TESTING RESULTS				
Contaminant (Units mg/L)	Maximum allowed (MCL /SMCL)	Monitoring Results before Rectyre	1st Monitoring Results after Rectyre	2st Monitoring Results after Rectyre
Arsenic	0,05	< 0,001	< 0,001	< 0,001
Barium (Ba)	2	0,058	0,063	0,060
Cadmium (Cd)	0,005	<0,00002	<0,00002	<0,00002
Chromium (Cr)	0,1	< 0,002	0,0033	0,0034
Selenium (Se)	0,05	< 0,001	< 0,001	< 0,001
Aluminium (Al)	0,05-0,2	0,033	0,038	0,036
Iron (Fe)	0,3	0,023	0,27	0,25
Manganese (Mn)	0,05	0,011	0,14	0,12
Copper (Cu)	-	0,0079	0,0087	0,0080
Lead (Pb)	0,015	0,009	0,009	0,009
Zinc (Zn)	5	0,055	0,102	0,089
Magnesium (Mg)	No established	4,90	5,05	5,05
Sodium (Na)	No established	3,190	3,198	3,193
Organic Carbon	2	1	1,62	1,62
Chloride (Cl^{-})	250	12,07	15,30	15,05
Organic Halides	No established	Non-detect	Non-detect	Non-detect

The results of the test indicated that shredded automobile tires do not show any likelihood of being a hazardous waste. Compared with other wastes for which leach tests and environmental monitoring data are available, the tire leach data indicated little or no likelihood of shredded tires having adverse effects on groundwater quality. At this stage and based on the limited scope of this effort and comparison with water quality criteria, it appears that there is no evidence in this study that there will be a detrimental effect on the environment or to human health.

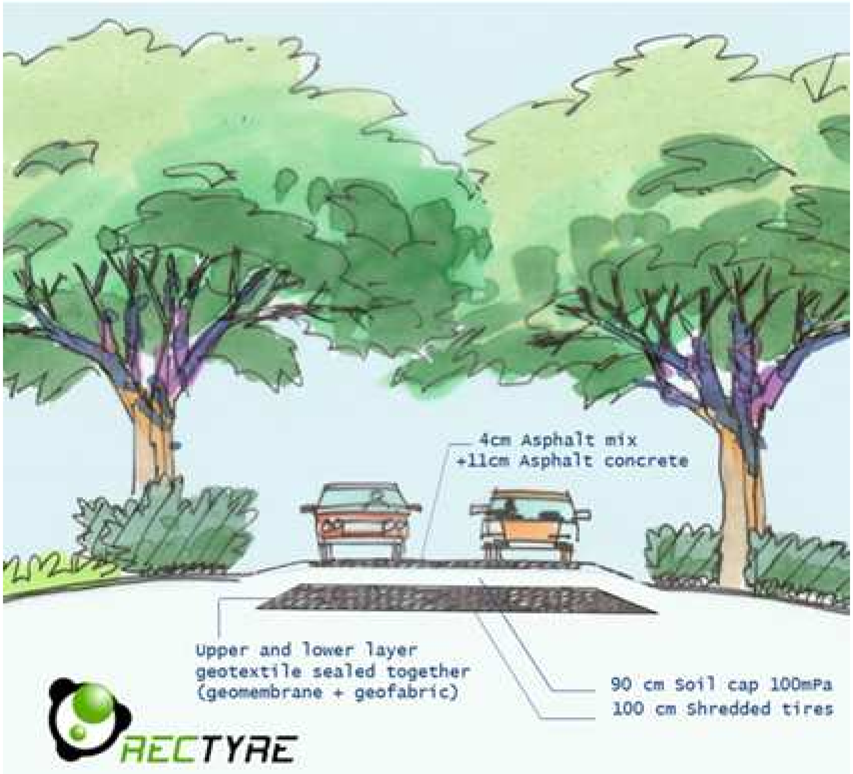


Figure 24: RECTYRE design scheme

The temperature monitoring indicated no evidence of any localized heat generation within the core of the shredded-tire embankment. This is significant in view of the problems experienced elsewhere. It is likely that the use of geo-textil layers mixing tire shreds with soil fill minimizes the potential for an exothermic reaction. There are no reports of problems with similar designs

The economic viability of the implementation of used tyres as filler for embankments has been proved in previous studies. The benefits, apart from those environmental benefits already described, will depend on the management model applied in each scenario. The optimal situation is that in which the construction has the support of the Management Agency or Association to use the used tyres. In that case cost will be reduced to a minimum.

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RECTYRE

USED TYRES VALORISATION AS LIGHTWEIGHT FILLER FOR EMBANKMENTS

D5.2: Model Analysis

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TABLE OF CONTENTS

1. INTRODUCTION

The validation of the model was developed from the comparison of previous and final methodology and technical, economical and environmental results. The environmental and technical performance of RECTYRE has been monitored during the execution of the model in Czuprynowo. Environmental analysis has been done to assure that not only the Rectyre final solution, but also its constructive process are environmentally friendly and fulfil the required environmental standards. Many environmental aspects have been taken into account, however a major concern has been given to potential groundwater contamination and temperature increase. Specific test methods have analyzed this issues.

Main results:

Environmental - Groundwater monitoring: Mostostal performed a study of the groundwater features at the site prior to Rectyre model construction and the results were reported. During the monitoring of the shredded-tire embankment following construction, two more sets of water quality samples were taken. Results were analyzed and compared. The results of the test indicated that shredded automobile tires do not show any likelihood of being a hazardous waste. Compared with other wastes for which leach tests and environmental monitoring data are available, the tire leach data indicated little or no likelihood of shredded tires having adverse effects on groundwater quality. At this stage and based on the limited scope of this effort and comparison with water quality criteria, it appears that there is no evidence in this study that there will be a detrimental effect on the environment or to human health.

Figure 1: Embankment Shred Tire, Rectyre design scheme.

Environmental - Temperature monitoring: The results of the temperature monitoring indicated no evidence of any localized heat generation within the core of the shredded-tire embankment. This is significant in view of the problems experienced elsewhere. It is likely that the use of geo-textil layers mixing tire shreds with soil fill minimizes the potential for an exothermic reaction. There are no reports of problems with similar designs. At this point, only short time results have been used for the analysis. Therefore, during the next 2 years monitoring will continue and periodical test will be carried out to obtain following results. A final evaluation will determine if our estimations remain valid. The current conclusion at this stage is that, it is possible a major increase in the number of scrap tires used for civil engineering applications, because of their growing record of successful performance combined with guidelines to limit self-heating of thick fills and groundwater data showing that they have a negligible environmental impact.

Structural monitoring: Has been developed and calibrated a numerical finite element model for the prediction of future deformations of an embankment with the characteristics used during the research project. The values used correspond to the information taken during the monitoring process.

2. MODEL ANALYSIS – TECHNICAL

A numerical simulation/modelling of different construction processes is important to ascertain the safety of current and planned construction. Numerical modelling software offers a unified and generic framework for such computations such as analysis of deformations, stresses, thermal behaviour and continuous stability assessment in soils, rocks and structures, including soil structure interaction. The software has evolved and now allows us to perform the modelling in 2D and/or 3D. All the stages of construction i.e. from the initial stage to the final construction can be simulated in a single environment[1].

According to Bergado and Patawaran (2000) there are three important steps in the computational modelling of any physical process: (i) problem definition, (ii) mathematical model, and (iii) computer simulation. The first step is to define the problem in terms of a set of relevant measurable parameters. The second step is to represent the idealization of the physical reality by a mathematical model. These mathematical models use numerical time-stepping procedure to obtain the models behaviour over time. After establishing the suitable boundary and initial conditions, the third and final step is to proceed to its solution using computer simulation.

The settlement of embankments with ST (Shreds Tire) is traditionally an important geotechnical problem and has been extensively studied by a large number of researchers. Excessive settlement can render the highways unserviceable, increase the cost of maintenance, and even be detrimental to the stability of embankment. Therefore it's very important to accurately evaluate the embankment settlement during the highway construction design

For predicting the behaviour of embankment on soft ground, one of the key point is to simulate the consolidation process. The consolidation rate is mainly influenced by the foundation soil elastic modulus.

Available methods for calculating embankment settlement are the layer-wise summation method (LSM), empirical formulation method, finite element method (FEM), etc. (Qian and Yin, 1996; Wang, 2004). Of these methods, FEM is a very powerful numerical tool for solving complicated 2D or 3D consolidation settlement problems. It can handle arbitrary boundary conditions, different loading schemes and it considers the coupling effects of loading and soil consolidation.

2.1 Selection of technical analysis model

A finite difference method (FDM) discretization is based upon the differential form of the Partial Difference Equation to be solved. It utilizes a point-wise approximation to a solution. The domain is discretized into a grid of hexahedral cells or nodes. The solution will be obtained at each nodal point. Although FDM is easy to implement and the compute time for each step is fast, however the number of steps required for convergence is high. The other disadvantage is that the domain is not accurately represented if the domain is discontinuous or non-rectangular in shape.

[1] Th. Zimmermann, A Truty and J.L Sarf (2005), "Numerical simulation of underground works and application to cut and cover construction".

A finite element method (FEM) discretization is based upon a piecewise representation of the solution in terms of specified basis functions. In FEM the discretization is not restricted to a grid of hexahedral cells or nodes, instead, a solution is approximated using interconnecting sub-regions or elements. These elements are typically simple geometrical figures as illustrated next Fig. This flexibility of construction of elements in FEM allows it to accurately model the complex geometries. The downside is that FEM is difficult to implement but the opinions vary on this. Section 2.4 defines the model ANALYSIS selected.

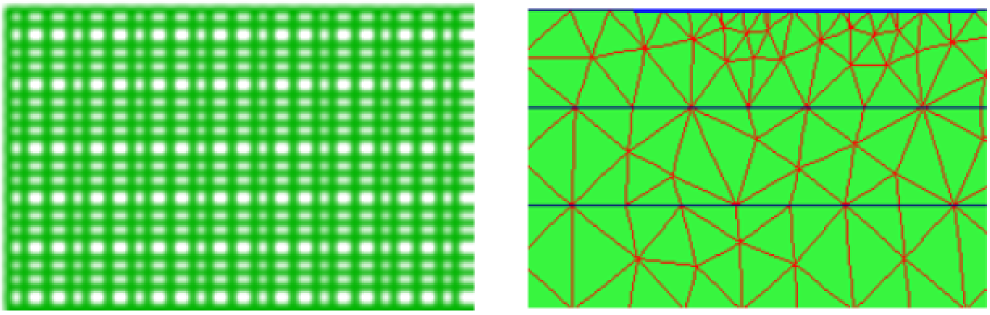

Figure 2: Discretization methods (a) FDM (b) FEM

2.2 Instrumentation

The main objective of this section is to present a brief review on instruments used in this study. Instruments provide actual field data and helps in evaluating the movement and failures under actual field conditions. The instrumentation was used in this study to compare the performance of the Embankment Shreds Tire (ETS). The choices of instruments depend on many factors like geological understanding of the area, subsurface material and the groundwater depth. The other factors include the transportation facility, the rate and magnitude of movement and type of movement i.e. horizontal or vertical movement or both. For large and fast movements relatively crude instrumentation can be used but if the movement is slow and small instrumentation accuracy and the repeatability of its measurement takes precedence.[2]

2.2.1 Characteristics and instrumentation details

Field instrumentation is very important in geotechnical engineering and therefore, geotechnical engineers should have proper knowledge of instrumentation. But instrumentation is not answer to everything so its use must be prudent. The wrong type of instruments or wrong placement of instruments can provide wrong or confusing results which can divert the attention from real problems.

The objectives of a geotechnical instrumentation plan are grouped into four categories: analytical assessment; prediction of future performance; legal evaluation; and development and verification of future designs.

2.2.1.1 *Analytical Assessment*

The following objectives are met during the analytical assessment.

[2] George Machan and Victoria G. Bennett (2008), "Use of Inclinometers for Geotechnical Instrumentation on Transportation Projects". Transportation Research Circular E-C129.

i. Verification of design parameters – Observed data from instrumentation can be used to not only verify the selected design parameters but also used to modify and refine the future designs.

ii. Verification of design assumptions and construction techniques – The data obtained from satisfactory actual performance of new or modified design can help its chances of acceptance.

iii. Analysis of adverse events – Causes of various types of failures and deformations at the project site can be uncovered from the precious instrumentation data.

iv. Verification of apparent satisfactory performance – The instrumentation data of satisfactory performance as well as adverse events can prove to be valuable records for future design purposes and development of new and innovative technology.

2.2.1.2 *Prediction of future perfomance*

Instrumentation data analysis can be used for the predictions such as continued satisfactory performance or indicating a sign of potential future distress. The instrumentation data recorded during and after events like rainfall can be very useful for future performance.

2.2.1.3 *Legal evaluation*

Instrumentation data can be used in determining causes or extent of adverse events so that the merit of various legal claims can be evaluated.

2.2.1.4 *Development and verification of future designs*

Analysis of the performance of existing normal fill and EST fill embankments and instrumentation data generated during operation, can be used to further the construction technology. Instrumentation data from existing embankment construction projects can provide safer and economical design for future construction of embankments

2.2.2 Different types of instruments used in the field monitoring

There are various field instruments like Digital Hydrostatic Profile Gauge - Settlement monitoring, Vibrating Wire Pressure Cell, Temperature sensor Testo 177-T4 (Temperature sensors o thermocouples) and digital hidrostatic profile gauge.. They also warn us about the design assumptions suitable for the given field conditions. The following sections present the details of instruments used in the current study and the installation procedures followed. The deliverable 5.1 is mentioned in detail the instrumentation used during the construction and monitoring.

Figure 3: Details of the installation test site, pressure & temperature data recorder.

2.2.3 Surface elevation surveying

The surface surveying consists of establishing benchmark control stations and survey points at various locations of interest. The survey points are periodically measured to monitor for potential deformations at test section and control sections. For this technique, the control stations are established on stable ground. Surface monitoring is accurate to a resolution of approximately 0.25 in. (6 mm). However, long term deformation trends can be difficult to establish, due to personnel turnover, susceptibility to damage of control points, etc. This method provides essentially provides the relative movement of the pavement surface relative to its' initial position (i.e. settlement or heave).

2.2.4 Visual monitoring

This approach consists of occasional on-site inspections. Field inspection is a good technique to identify signs of distress or change. However, visual observations are typically not accurate method in detecting small movements or long-term settlements. Periodic good resolution photographs may be a good idea for comparison.

2.2.5 Summary

This chapter discusses various causes of settlement, its remedial measures, different types of fill materials and finally the instrumentation used in determining vertical movement. It is observed that among all the different types of embankment fill materials, EST is the most suitable for the test site since it is easily produced and very economical. For this study Digital Hydrostatic Profile Gauge were used to and for vertical surface movement.

2.3 Experimental studies

Laboratory testing is an essential aspect of geotechnical engineering. Laboratory test are conducted using standard procedures. Material properties like cohesion unit weight, internal friction angle etc can be determined from different laboratory tests. Visual observation and field test results are the primary source of information before doing laboratory testing. Laboratory test results provide a clear understanding and knowledge of soil properties.

Quality control for Lab Testing involves proper handling of samples while transporting and storage, Its important to maintain quality otherwise it can result in misleading test results. In addition, the following guidelines given by Mayne, et al., (2002)[3] for laboratory testing of soils was followed.

To study the behavior of EST and Normal fill, Laboratory tests namely, sieve and hydrometer test, Atterberg limits tests and proctor's compaction tests. The soil used for various tests were collected from site and then wrapped in a plastic bags and transported to the laboratory.

[3] Mayne, P. W., Christopher, B.R., and DeJong, J., (2002), " Subsurface Investigations – Geotechnical Site Characterization", Publication No. FHWA NHI-01-031, National Highway Institute, Federal Highway Administration, Washington, DC, 300 pp.

2.3.1 Soils

2.3.1.1 Sieve analysis and hydrometer analysis

Sieve analysis was done as per ASTM D22. There are two different procedures for dry and wet sieving. For our study, the sample collected was in the form of hard lumps and the sample was pulverized to very fine particles before doing dry sieve analysis. For normal fill material, first dry sieving was performed, where the sample was oven dried and allowed to cool. An oven dried sample of 1000 grams passing through 4.75, 2.0, 1.8, 0.6, 0.425, 0.25, 0.125, 0.075 mm sieves was taken. The pan was attached at the bottom of the sieve stack. The sample was poured on the top sieve and stirred for about 10 minutes. Soil retained at each sieve was measured and weighed. The weights of the sample on all the sieves were added to compare it with initial sample weight. The difference shouldn't be more than 1%.

Secondly, wet sieving was performed where oven dried sample was kept soaked in a tap water for about 2 hours. The sample was transferred to 200 sieve. The sample was washed thoroughly, discarding the material passing no. 200 sieve. The retained material collected from no. 200 sieve was oven dried and weighed it after it has cooled. Difference between dry weight before and after washing was around 50% recorded.

Hydrometer analysis was performed on the same sample which was finer than no. 200 sieve size. The lower limit of the particle size determined by this procedure is about 0.001mm. Hydrometer analysis test procedure was adopted as per ASTM D-422.

For embankment soil support, the material had less than 5% fines, so wet sieve analysis was not done. An oven dry sample of 500 grams passing through 4.75, 2.0, 1.8, 0.6, 0.425, 0.25, 0.125, 0.075mm sieves was taken. Soils retained on various sieves were calculated and a particle distribution was obtained, in the next figure shows the particle distribution curve for the materials.

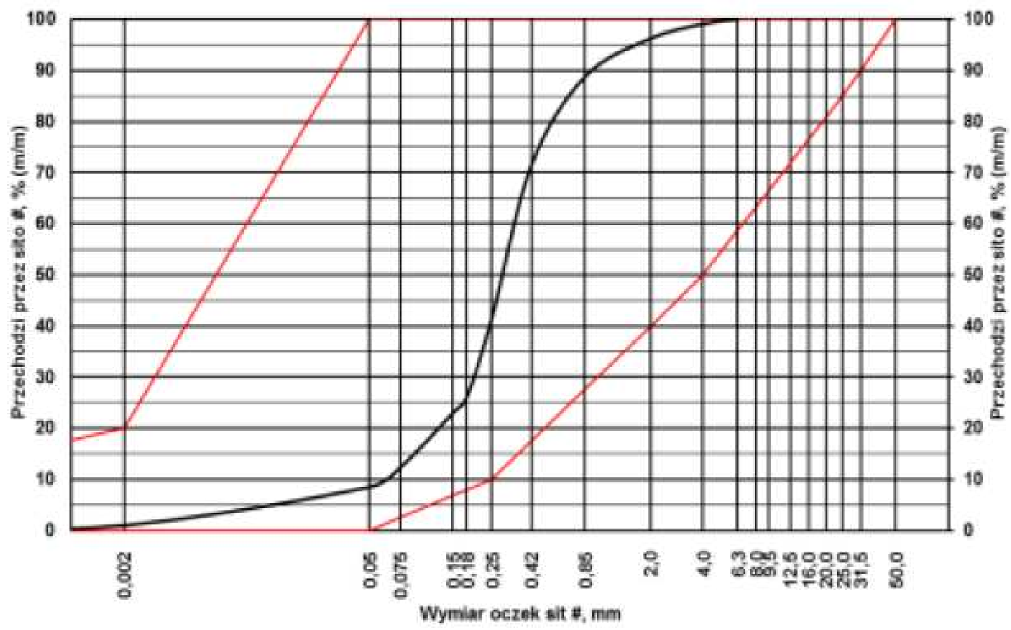

Figure 4: Particle size distributions for soil of test site.

Table 1: Particle size distributions for soil of test site.

Mesh dimension mm	Remained material g	Remained material %	Passing summary %	Mesh dimension mm	Remained material g	Remained material %	Passing summary %
Soil # 1 –Middle sized sand (bore-hole # 1)				Soil # 2 –Middle sized sand (bore-hole # 2)			
# 50,0	0,0	0,0	100	# 50,0	0,0	0,0	
# 31,5	0,0	0,0	100	# 31,5	0,0	0,0	100,0
# 25,0	0,0	0,0	100	# 25,0	0,0	0,0	100,0
# 20,0	0,0	0,0	100	# 20,0	0,0	0,0	100,0
# 15,0	0,0	0,0	100	# 15,0	0,0	0,0	100,0
# 12,5	0,0	0,0	100	# 12,5	0,0	0,0	100,0
# 9,5	0,0	0,0	100	# 9,5	0,0	0,0	100,0
# 8,0	0,0	0,0	100	# 8,0	0,0	0,0	100,0
# 6,3	1,1	0,0	100	# 6,3	5,3	0,2	100,0
# 4	28,4	0,9	99,1	# 4	48,3	1,4	99,8
# 2	95.2	2,9	96,2	# 2	148,9	4,4	98,4
# 0,85	246,3	7,5	88,8	# 0,85	311,0	9,1	85,0
# 0,42	569,6	17,3	71,5	# 0,42	447,8	13,1	71,9
# 0,25	987,1	29,9	41,6	# 0,25	890,7	26,0	45,9
# 0,18	513,0	15,5	26,1	# 0,18	746,6	21,8	24,1
# 0,15	100,8	3,1	23,0	# 0,15	131,7	3,8	20,2
# 0,075	353,6	10,7	12,3	# 0,075	414,0	12,1	8,1
< # 0,075	406,6	12,3		< # 0,075	277,7	8,1	
Σ przesiewu	3302	100%		Σ przesiewu	3422	100%	

2.3.1.2 Atterberg limits

For classification of soil, Atterberg Limits tests (Liquid Limit and Plastic Limit) were performed on the collected sample. The liquid limit test of a soil was performed using casagrande liquid limit apparatus. About 250 grams of air dried sample passing sieve no. 40 was used for both liquid and plastic limit test. Distilled water was preferred instead of tap water to avoid ion exchange between soil and water impurities, which may affect the soil plasticity. Place about 50 grams of soil paste in a cup, level off with the spatula the top surface symmetrically to give maximum depth of 1 cm. The grooving tool was used to straight groove through the soil paste along the diameter through the center of the hinge. The handle was turned at a rate of 2 revolutions per second and counted the number of blows until the two parts of the soil come in contact at the bottom of the groove. About 15 grams of soil was transferred in the container to determine the water content by oven drying. The test was repeated at least 3 to 4 times. The flow curve was plotted to represent the number of blows on logarithmic scale and corresponding moisture content. The plastic limit test was done to determine plasticity of the soil. Here 30 grams of soil passing sieve no. 40 was used. Distilled water was used to mix water thoroughly in to the soil. 10 grams of plastic soil mass was used to form a ball and then roll in to thread with the fingers on the ground glass plate. Keep on rolling until the thread starts to crumble at a diameter of 3mm. The crumbled thread was kept in a container for moisture content determination. The processes were repeated 2 more times with fresh sample and the average of three moisture contents was obtained to calculate plastic limit. After determining liquid limit and plastic limit, the plasticity index was calculated to know the type of soil.

2.3.1.3 Compactation test

Compaction characteristics were determined according to ASTM D-1557 (Modified Proctor Compaction Test). Laboratory compaction tests are used to determine the relation between water content and dry weight and to find the maximum dry unit weight and optimum water content. For each sample the required amount of sample was air dried and weighted and the mass of material required is around 1,5kg passing no. 4 sieve. A suitable amount of water was added to the dry soil to obtain the desired moisture content. The soil sample was evenly distributed so that the mold is about half full. Is placed soil sample with a selected water content in five layers in a mold 101.6 mm in diameter, and each layer is compacted with 25 or 56 blows of a hammer of 44.5 N which leaves fall from a distance of 457 mm, giving the soil compaction effort of about 2700 total kNm/m3. Repeat the resulting dry unit weight. The process is repeated for a sufficient number of water content to establish a relationship between water content for soil and dry unit weight. By plotting this data is a curvilinear relationship known as the compaction curve. The values of optimum water content and maximum dry unit weight is determined by the compaction curve. Soil layers of the embankment were performed using all-ups extracted from nearby deposit. It was brought to the building site by dump truck and formed by excavator and loaders.

Parameters: c=0 (uncohesive soil), Φu=36º, ρ= 1,70 [$t*m^{-3}$].

After compaction: ID = 0,98 -> Φu=42,2º, ρ= 1,85 [$t*m^{-3}$].

2.3.2 Tire shreds

2.3.2.1 Tire shred gradation

The tires were brought to the construction site, shredded in pieces ranging from 20 to 40 cm. The supplier of tire shreds was J&B Recycling.

This company has offered the best price of tire shreds in aid of its quality.

- Weightiness (1,0 – 1,3 g/cm^3)
- Slack condition (0,3 – 0,5 g/cm^3)
- Compacted (0,5 – 0,8 g/cm^3).

Figure 5: Tire shred in pieces ranging from 20 to 40 cm.

Table 2: Size distribution of the tire shreds (Kg)

SIEVE MESH MEASUREMENT [mm]	TIRE SHREDS			
	Sample I	Sample II	Sample III	Sample IV
	Sieve, weight [Kg]			
400	43,40	34,36	36,28	37,50
300	10,06	21,79	27,45	30,26
200	19,92	17,88	18,95	1,05
45	25,79	25,00	16,99	10,86
4	0,83	0,97	0,33	0,33

Table 3: Size distribution of the tire shreds (%)

SIEVE MESH MEASUREMENT [mm]	TIRE SHREDS			
	Sample I	Sample II	Sample III	Sample IV
	Sieve [%]			
400	20,7	24,6	11,1	11,4
300	4,8	15,6	8,4	9,2
200	9,5	12,8	5,8	6,4
45	12,3	17,9	5,2	3,3
4	0,4	0,7	0,1	0,1
Total weight	47,7	71,6	30,6	30,4

2.3.3 Geomembrane

Geomembrane has the task to prevent water and soil pieces infiltration into shredded tires filling that may provoke a self-ignition. Furthermore, it holds the layer in entirety.

Table 4: Mechanical characteristics of the geotextile used in the numerical model

No #	FEATURE	FOLGAM H
1	Thickness [mm]	1
2	Weightiness [g/m^2]	1700
3	Broadness x lenght [m]	2m x length till 30m
4	Colour	black
5	Max tensile stress [Mpa] -along -across	 >15 >15

6	Extension at bust-up [%] -along -across	> 200 > 200
7	Rent resistance [N/mm] -along -across	> 200 > 170
8	Moisture capacity [%]	< 0,5
9	Water infiltration at pressure 0,4 [Mpa]	waterproof
10	Penetration resistance (CBR) [kN]	1,7

2.4 Numerical modelling

The use of numerical modelling to predict soil deformation and stresses has been practiced for years. During the numerical analysis, detailed site-specific properties of the road and embankment systems were incorporated to simulate complex construction sequences. The main field of application of constitutive models is the execution of numerical calculations by means of appropriate methods such as Finite element or Finite difference methods.

2.4.1 Modelling methods

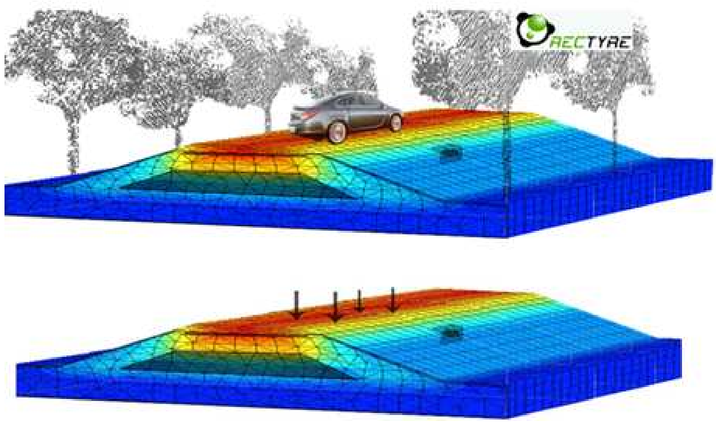

Figure 6: **Numerical modelling using Rectyre model.**

Numerical modelling using linear model has a benefit of fast estimate of the material response but the downside is its limited accuracy. Therefore the application of linear model is limited to cases where the stress or deformation states of a soil mass are of interest. For getting reliable description of the soil behaviour it is necessary to employ nonlinear models[4]. The non-linear models can be divided into two groups. The first group of models originates from the Mohr-Coulomb failure criterion. The Mohr Coulomb model belongs to this group. According to Coulomb C.A., 1776, "the Mohr–Coulomb failure criterion represents the linear envelope that is obtained from a plot of the shear strength of a material versus the applied normal stress". The second group of material models is represented by the Modified Cam-Clay model. This model is based on the concept of critical state of soil (GEO5 - Theoretical Manual, 2010). Accurately modelling the constitutive behaviour of the soil is difficult because of the complexity involved in the selection of design parameters and the soil properties. Simplified non-linear models such as Mohr-Coulomb, or more advanced such as Modified Cam-Clay and the Hardening Soil Model can be used with some degree of accuracy.

[4] GEO5, Theoretical Manual, (2010), http://www.finesoftware.eu/geotechnicalsoftware/help/ fem/materials-models/.

2.4.2 Finite element modelling procedure

Numerical modelling enables the designer to study the effects of embankment loading, surcharge and the soil behaviour in various conditions without resorting to simplified assumptions. Two dimensional finite elements modelling of the different fill embankments is performed using PLAXIS 2D software. A parametric study was performed to arrive at the critical parameters that define the behaviour of the system. The parametric study comprised of all the elements which had an influence on the behaviour of the system. The various aspects like lateral movements and the total settlements were studied. The standard units length (m), force (N) and time (days) were used. The geometry was drawn using geometric lines and standard fixities were then used to define the boundary conditions.

Table 5: Designed for "KR2" road traffic category

Road traffic category	Number of computational design acses (100 kN) on computational lane [L]	Number of computational design acses (100 kN) in assumend period (20 years)
KR2	13 ÷ 70	90000 ÷ 510000

Table 6: Properties of soils used in Finite Element Analysis

SOIL PROPERTIES	Embankment Soil	Tire shreds	Sandy aggradate mud	Middle sized sand	Clay
Compression Index, Cc	0.98	-	-	0.80	0.34
Swelling Index, Cs	-	-	-	-	0.043
Initial Void Ratio, eo	-	-	-	-	1.3
Young Modulus, E (Mpa)	240	550	200	125	-
Poisson Ratio, μ	-	-	0.25	0.32	-
POP (kPa)	-	-	-	-	35 – 48
Unit weight, γ (kN/m^3)	17	-	17.65	18.05	18.85
Cohesion, c (kPa)	0	7 - 10	-	0	45
Friction Angle, Φ (deg.)	42.2	29 - 34	33	35	-
Dilation Angle, Ψ (deg.)	-	-	-	-	-
Weightiness Compacted (g/cm^3)	-	1.15	-	-	-
Slack condition (g/cm^3)	-	0.40	-	-	-
Compacted (g/cm^3)	-	0.65	-	-	-
Model	Soft-Soil Model		Mohr-Coulomb	Mohr-Coulomb	Hardening Soil Model

The properties of different soil material sets were created and assigned to material model. After the model was created and material models were assigned, finite mesh was generated using different mesh settings. The following sections present the details of the finite element model including the choice of material models, finite element mesh, and boundary and loading conditions that were adopted to simulate field conditions and obtain settlements of the embankments.

2.4.2.1 *Choice of constitutive and material properties*
In the material set, type of material and type of model from material model box can be selected. In order to simulate the behaviour of the soil, a suitable model and appropriate material parameters must be assigned to the geometry. In PLAXIS, soil properties are collected in material data sets and the various datasets are stored in a material database. The material properties used in the model for different material types are presented in Table 6.

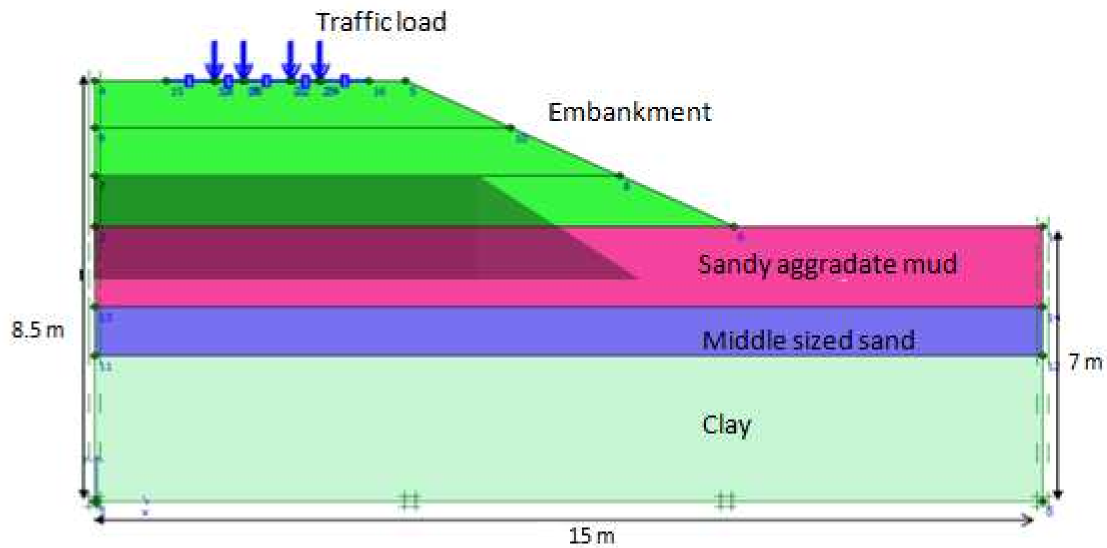

Figure 7: Geometry of embankment model in PLAXIS.

The numerical model has been analyzed with 2D plain strain model considering only half of the section due to the symmetry of the problem. A total width of 15m has been used which starts from the centre of the embankment. The geometry of an embankment has been made using geometric line option with approximate dimensions as per the field dimensions.

Two cases were investigated in the finite element analysis to evaluate the influence of the following:

1. Vertical settlement on control section and test section using Mohr Coulomb Model (MCM) for embankment fill.

2. Vertical settlement on control section and test section using Cam-Clay Model or Soft-Soil Model (SSM) for embankment fill.

Here the actual settlement behaviour of the embankment over ST is expected to be between these two cases.

The soft clay, the sand and the embankment fill were modelled as elastic-perfectly plastic materials. No deformation below the sand layer was assumed. Mohr-Coulomb failure envelope was used as the failure criterion in first case and critical state based soft soil (similar to CAMCLAY) failure criterion was used in the second case. The elastic modulus adopted for the normal fill was typically between 7 to 21MPa[5].

2.4.2.2 *Mesh Generation*

Two types of triangular elements are used in the PLAXIS, 6 noded triangular elements and 15 noded triangular elements. Advantages of higher order triangular elements is that they provide better representation of the description of continuous strain and stress variations and also provides good description of a continuous displacement field with relatively few elements. The disadvantages of higher order elements is that the failure loads may be dependent on the mesh and makes poor description of discontinuous stress and strain. In PLAXIS, the program automatically creates unstructured mesh as there is no possibility of making a so-called structured mesh. The mesh size cannot be set explicitly. The mesh is generated based on random seeds. The mesh size may be changed globally by means of global coarseness and locally by means of local coarseness. The next Figure presents a typical mesh generated for the current analysis.

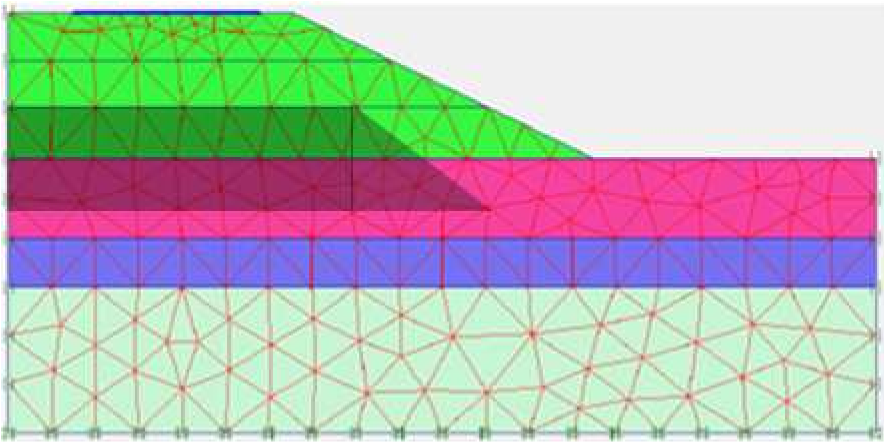

Figure 8: Typical mesh generation in PLAXIS

2.4.2.3 *Initial and boundary conditions*

In the initial conditions, water unit weight is set to 10kN/m3. The water pressure is fully hydrostatic and is based on a general phreatic level. In addition to phreatic level, boundary condition for consolidation analysis can be additional input. The lines of consolidation need to be selected in vertical direction that means vertical boundaries must be closed to restrain the horizontal flow and no free outflow is allowed at that boundary.

The water conditions can also be specified in the Geometry configuration mode using phreatic level by generating pore pressure using phreatic level. In the analysis, constant ground water level has been considered.

2.4.2.4 *Initial stresses*

[5] Bowles, J. E. (2000), "Foundation Analysis and Design", McGraw-Hill, New York.

In initial stresses which are effective stresses, Over-Consolidation Ratio (OCR) and Pre-Overburden Pressure (POP) are used in analysis when using Soft-soil model. Initial stresses are developed by the POP procedure (PLAXIS 8, User Manual). It is also possible to specify the initial stress state using the Pre-Overburden Pressure (POP) as an alternative to the over consolidation ratio. The Pre-Overburden Pressure is defined by:

$$POP = \sigma_p - \sigma_{yy}'^{o}$$

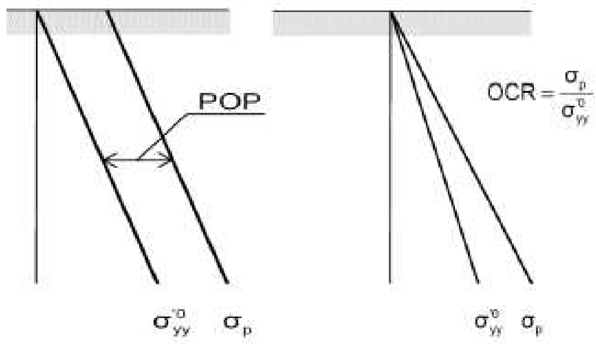

Figure 9: POP and OCR profile illustrations – PLAXIS 8. user manual.

Once the geometry of the model was developed, finite element model is complete. Initial situation and initial stress state should be stated before calculation. This was done in the initial conditions part of the input program. When using Mohr Coulomb model, the analysis require the generation of the initial stresses by means of Ko procedure. Ko procedure can be used to calculate initial stresses. The suggested Ko procedure is based on Jaky's formula (1 – Ko * Sin Φ).

2.4.2.5 *Calculation*

After the generation of Phreatic level and initial stresses, the input is complete and calculations can be generated. These calculations are generally used to define the different phases of embankment construction. The next figure presents a snapshot of different phases of the construction process as implemented in FEM program.

Four loads coming in contact with road through tires were used to simulate the traffic loading. The loading consisted of 40kN having uniform maximum vertical contact stress over the contact area with ratio of 1:0.85 (width=19.27 cm, length=16.38 cm) placed on top of the pavement.

Identification	Phase no.	Start from	Calculation	Loading input	Time
Initial phase	0	0	N/A	N/A	0.00 ...
Gravity Loading	1	0	Consolidation	Staged Construction	15.0...
1st stage Emb Loading	2	1	Consolidation	Staged Construction	30.0...
Consol Period	3	2	Consolidation	Staged Construction	60.0...
2nd Stage Emb Loading	4	3	Consolidation	Staged Construction	30.0...
Consol Period	5	4	Consolidation	Staged Construction	60.0...
3rd stage Emb Loading	6	5	Consolidation	Staged Construction	30.0...
Consol Period	7	6	Consolidation	Staged Construction	60.0...
Pavement Const	8	7	Consolidation	Staged Construction	30.0...
Traffic Loading	9	8	Consolidation	Staged Construction	1000...
Pore Pressure	10	9	Consolidation	Minimum pore pressure	17.0...

Figure 10: Calculation step using FEM program

In the modelling analysis, the consolidation option in FEM software allows fully automatic time stepping procedure that takes the critical time step into account. The future of pavement construction and traffic loading were also taken into the consolidation analysis with different time intervals. The last phase in consolidation analysis was selecting minimum pore pressure where the default value of 1 kN/m^2 was used for the pore pressure.

To calculate the global safety factor for the road embankment, the phi-c reduction option available in the PLAXIS was selected and used in the next phase.

2.4.2.6 *Results of finite element analysis*

On evaluating the total displacement, it can be seen that the failure mechanism is developing with excess pore pressure distribution. The settlement at the pavement surface and embankment were increasing considerably after the end of the construction of embankment. This is due to the dissipation of excess pore pressure in soft soil layer which causes consolidation in soils.

The vertical displacement (or settlement) contours for normal fill and EST fill from the numerical analysis (using Mohr coulomb MCM and soft-soil SSM for embankment) over 60 months of time are presented in next figures respectively. The others figures shows maximum settlement that can occur after full dissipation of pore pressure at both embankment locations.

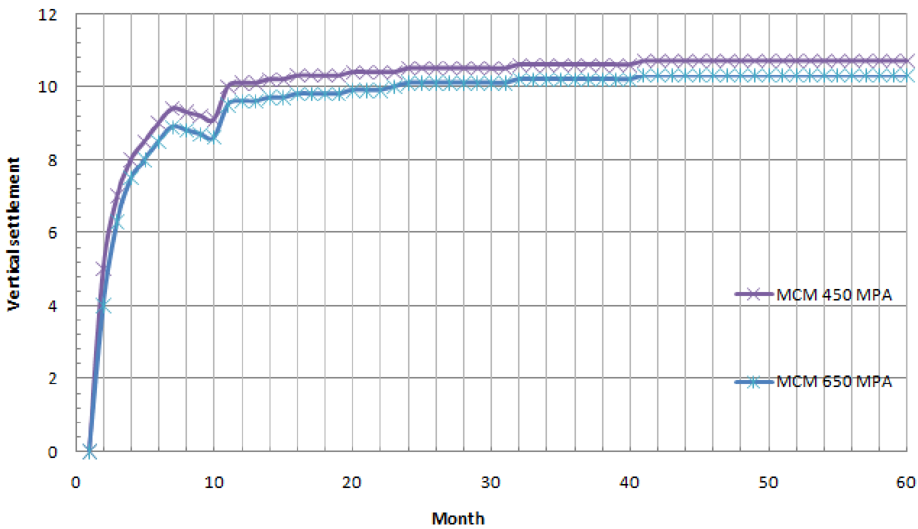

Figure 11: Settlement vs Time plot in the surface in FEM using MCM for embankment

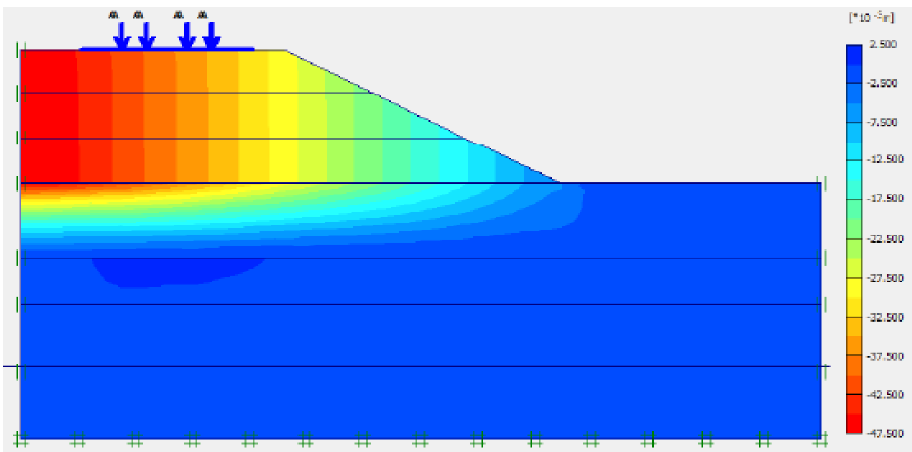

Figure 12: Settlement contours at the end of pore pressure dissipation in EST using MCM.

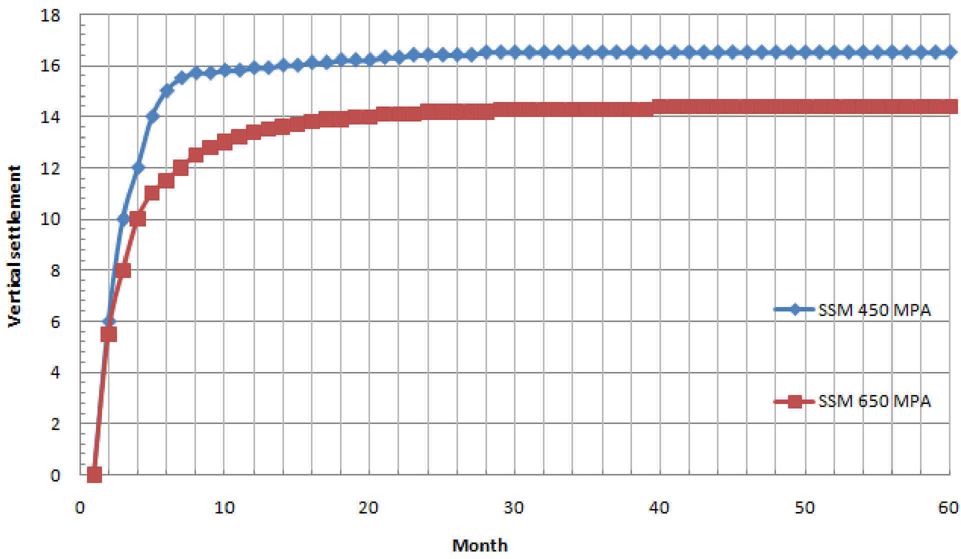

Figure 13: Settlement vs Time plot in the surface in FEM using SSM for embankment

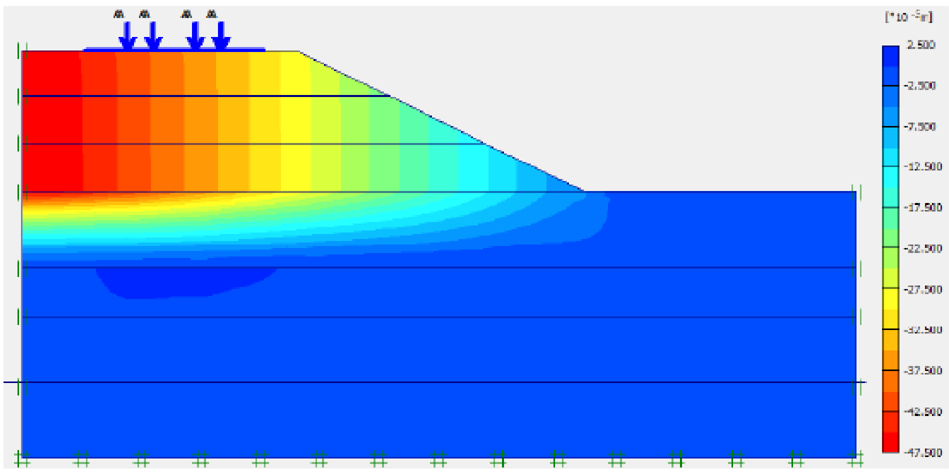

Figure 14: Settlement contours at the end of pore pressure dissipation in EST using SSM.

The vertical stress contours from the numerical analyses for the two cases are also presented in the next figures. It is shown that more stress concentration occurs at bottom of the normal fill as the loads are transmitted from the top to the bottom. The degree of stress concentration is slightly reduced when EST materials are used instead of normal fill. In addition, the EST carry fewer loads than the normal fill due to the low weight and high strength properties.

It has been observed that a maximum stress of 80kPa has been transmitted to the soft foundation soil in the case of the ETS embankment after the full dissipation of pore water pressure; whereas, a maximum vertical stress of 150kPa is recorded at the interface of the embankment base and soft foundation soil for the control embankment. This is expected since the EST is a LWA material which has approximately half the unit weight of the normal fill materials and hence imparts lower thrust on the foundation soil.

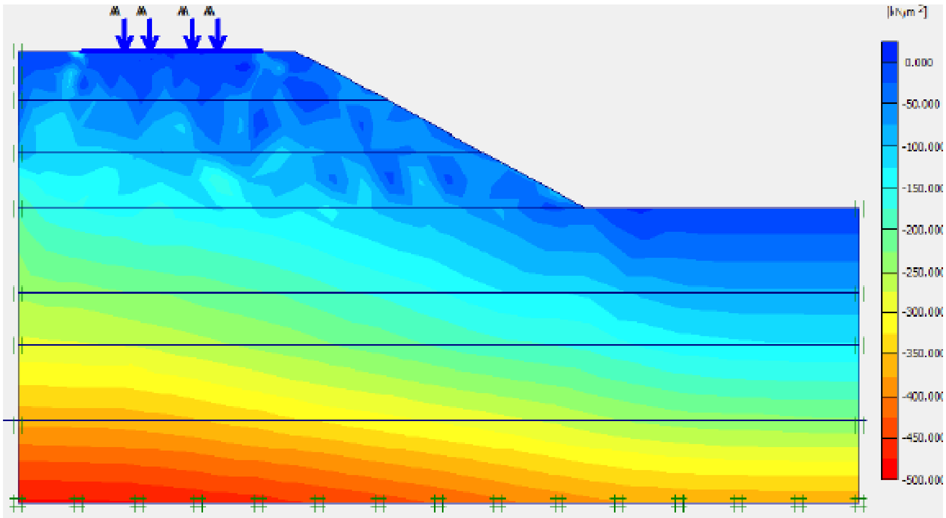

Figure 15: Stress distribution in Normal Fill after full dissipation of pore pressure using MCM for Embankment.

It has been observed that a maximum stress of 50kPa has been transmitted to the soft foundation soil in the case of the EST embankment; whereas, a maximum vertical stress from 150kPa is recorded at the interface of the embankment base and soft foundation soil interface in the case of the control embankment.

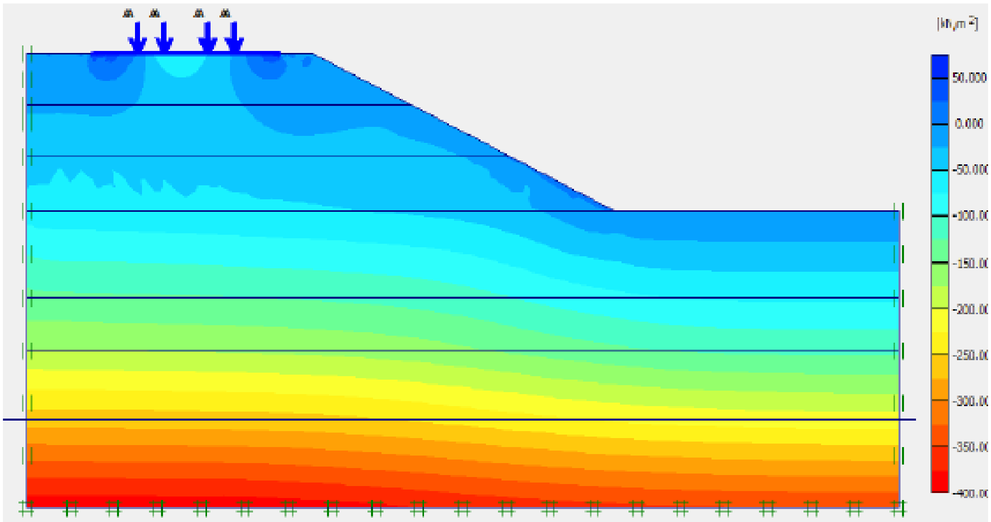

Figure 16: Stress distribution in EST Fill using SSM for embankment

2.5 Conclusions and analysis of results

Has been developed and calibrated a numerical finite element model for the prediction of future deformations of an embankment with the characteristics used during the research project. The values used correspond to the information taken during the monitoring process.

The behaviour of Embankments Shreds Tire sections has been comprehensively studied through field observation of full scale physical model, laboratory testing and numerical simulation. However, the cost of constructing and monitoring are quite high. An alternative method such as numerical experiment or simulation by means of appropriate methods such as finite element and finite difference techniques is essentially required. The numerical simulation of these embankments systems were realized by means of Finite Difference and Finite Element methods using 2D analysis program. The aim of this study is to investigate the influence of characterization of mechanical modules, using 2D numerical simulations of the test embankments. Particular attention is given to the vertical displacements or settlement. Subsequent comparisons are made to study the long term settlement behaviours between the findings of 2D numerical simulations and those from the actual measured field data used by the formulation method of the two full scale embankments (test section and control section).

Two cases were analyzed to evaluate the long term influence of the shreds tire in the Embankment (1) Vertical settlement on control section and test section using Mohr Coulomb Model for ST (PLAXIS) (2) Vertical settlement on control section and test section using Soft-Soil Model for ST (PLAXIS).

The vertical displacements (or settlement) for EST fill from the numerical analysis were compared near the embankment surface because in the field, maximum settlement at normal fill was recorded near the surface and very less settlement was seen at the surface of EST fill. The long term maximum settlement at Embankment surface was then determined using SSM and MCM formulation and these settlements are determined at 10, 20 and 60 months using the formulation results are used as a benchmark to compare the numerical analysis modeling results.

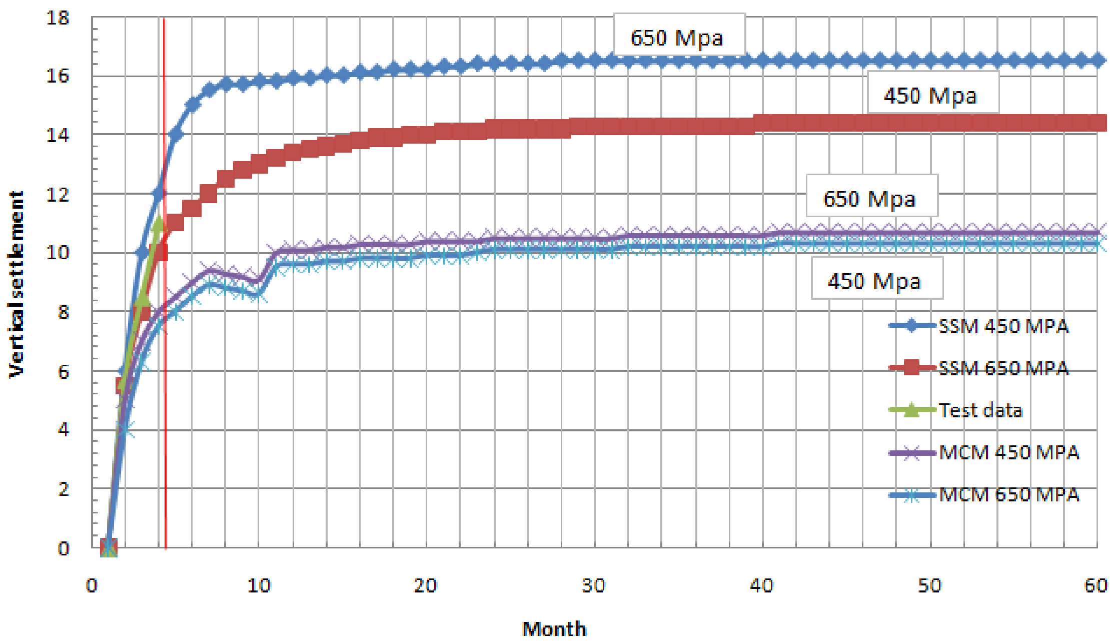

Figure 17: Comparación de resultados de monitorización con los re la modelación numérica.

One of the main results of technical analysis modeling. Is the similarity of the true strain of EST with curves obtained with the numerical model SSM. Other models such as MCM do not apply such scientific RECTYRE embankments. The SSM model provides valuable information to predict the maximum possible for embankments deformations with similar characteristics. The SSM model indicates that the maximum vertical deformation will reach 17 cm and at 24 months of construction, bringing the important values of deformation during the first 12 months of construction.

Comparing the curves of the SSM model with actual data monitoring module allows us to determine an approximate those of full of pieces of tires, this value ranges around 500 Mpa. For future type design RECTYRE embankments, it is advisable to plan buildings with this module mechanical strength.

Although the monitoring information is for 3 months has allowed us to determine the relationship between the actual vertical deformation obtained in the monitoring of construction, and numerical modeling to predict outcomes. However due to the interest of the project partners will continue to monitor the EST, and to validate the model SSM modules and resistance for future construction processes.

3. MODEL ANALYSIS – ENVIRONMENTAL & ECONOMICAL

The environmental performance of RECTYRE has been monitored during the execution of the model in Czuprynowo. Environmental analysis has been done to assure that not only the Rectyre final solution, but also its constructive process are environmentally friendly and fulfil the required environmental standards. Prior to the analysis, no detrimental environmental impact has been observed. In the next images (taken during the execution of Rectyre embankment, it is shown that major efforts have been taken into consideration to avoid environmental impacts due to the construction process.

Figure 18: Demo site of Czuprynowo in Poland prior Rectyre execution

Figure 19: Construction process of Rectyre embankment in Czuprynowo

Potential groundwater contamination has been a major concern, but existing studies indicate that shredded tires placed in highway embankments do not pose an environmental hazard. Conclusions of previous studies state that shredded-tire embankments should be used where feasible as an environmentally prudent approach to waste tire disposal. The stocks of used tires are growing and, in some cases, the only way of reducing them is using the tires as combustible, producing energy, but also contributing to Greenhouse and Acid Rain effect due to the emissions of VOCs and other hazardous gases. Therefore, the impact of this project claims to be environmentally beneficial as gives a new trend to reduce the huge stocks of tires. This case model executed by Mostostal in Poland (Czuprynowo) is at this point being monitored, and the results at the moment show that the use of scrap used tires as filler has no negative influence in the environment. These results mean that the methodology and the technology are suitable to be used in every scenario, contributing to reduce the footprint of the construction of roads and railways and also avoiding the use of natural soil. Although the use of recycled rubber has many advantages, there are potential problems that needed to be monitored for its evaluation and verification. These problems include leakage of metals and organics, fire risk and increased compressibility due to the tire chips. The main focus of this study was to identify potential contaminants associated with CRM asphalt mixtures, specifically trace metals organics. Not only leakage, but many other environmental aspects have been taken into account, as shown in the next table. However a major concern has been given to potential groundwater contamination and temperature increase. Specific test methods have analyzed these issues. For this purpose, the monitoring has been designed to detect any leakage of any organic compound or heavy metal leakage (groundwater analysis), and the other parameter (the temperature of the filler) has been controlled as any rise of the temperature could mean a degradation of the filler. At the moment all the parameters are showing normal values.

Table 7: Key Environmental Parameters on RECTYRE Solution from the method Batelle-Columbus

Environmental Parameters of the method BATELLE-COLUMBUS			
ENVIRONMENTAL IMPACT			
Ecology	**Environmental &Health**	**Aesthetic Factors**	**Human interest aspect**
SPECIES AND POPULATIONS Terrestrial Grassland Crops Natural vegetation Harmful species Continental game birds Aquatic Commercial Fisheries Natural Vegetation Harmful Species Waterfowl	WATER CONTAMITATION Losses in watersheds D.B.O. Dissolved oxygen Fecal-Colombes Inorganic Carbon Nitrogen-Inorganic Inorganic phosphate Pesticides Ph Variant of Current Flow Temperature Total dissolved solids	GROUND Geological Surface materials Terrain and topography Extension and alterations AIR Odor and visibility Sounds	EDUCATION & SCIENTIFIC VALUES Archaeological Ecological Geological
HABITAT AND COMMUNITY Terrestrial Food Chain Land use Rare and endangered species Species diversity Aquatic Food chains Rare and endangered species Fluvial features Species diversity	AIR POLLUTION Carbon monoxide Hydrocarbons Nitrogen -Oxide Solid particles Oxidants SOIL CONTAMINATION Land use Erosion	WATER Presence of Water Odor, color and Taste Floating materials Area of water surface Trees and geological margins BIO Pets Wild animals Diversity of vegetation Variety of other types of vegetation	HISTORICAL VALUE Architecture and Styles Events Personal Religions and cultures Western borders CULTURES Ethnic groups Religious Groups SENSATIONS Admirations Isolation, loneliness Mystery Integration with nature
ECOSYSTEM Ecosystem	NOISE POLLUTION Noise	COMPOSITION Effects of composition Singular elements	LIFESTYLE (cultural norms) Employment opportunities Social interactions

Most of the parameters shown on table 1 has been considered as environmental aspects to take into account on Rectyre Environmental Analysis. However, the ones that appear highlighted on the table are the points that can differ from traditional embankments construction to the Rectyre solution.

Figure 20: The concept of environmental analysis for proper interaction with nature and society

The environmental analysis has been focused on the comparison between prior road construction methodologies and the Rectyre embankment construction, in order to evaluate its viability and compliance with current environmental European policies and standards. This analysis, although it takes into consideration the global environmental impact that performs on the site, is set to determine the specific impact of a road tire embankment on groundwater and temperature, bypassing other features as road design, location or impact on wildlife.

Therefore, the next two points will describe the environmental analysis on Groundwater and Temperature, as these are the main interest areas to be focused on. Although it is important to mention that the impact due to construction of highways include the noise and dust from construction, the use of non-renewable aggregates, the loss of natural habitats and green space and increase in traffic (with all its impacts). The best practice is to undertake an environmental impact assessment (EIA) before the road is designed.

Environmental Impact Assessment (EIA) is defined as the process of examining the environmental effects of the development –from consideration of the environmental aspects at design stage, through to the preparation of the Environmental Impact Statement, evaluation of the EIS by a competent authority and the subsequent decision as to whether the development should be permitted to proceed, also encompassing public response to that decision. Regardless the embankment method to perform and the results shown on this analysis, it is necessary to evaluate for each project its individual environmental impact prior to the execution.

3.1 Groundwater monitoring

Mostostal performed a study of the groundwater features at the site prior to Rectyre model construction and the results were reported. During the monitoring of the shredded-tire embankment following construction, two more sets of water quality samples were taken: the first test was done one week after the completion of the works, and the other 4 weeks later.

Table 8: Groundwater quality analysis EDEM-European Department on Environment Management

Groundwater Quality Analysis EDEM			
No#	**Contaminant**	**Unit**	**Maximum Contaminant**
1	Arsenic	mg/L	0,05
2	Barium	mg/L	2
3	Cadmium	mg/L	0,005
4	Chromium	mg/L	0,1
5	Selenium	mg/L	0,05
6	Aluminium	mg/L	0,05-0,2
7	Iron	mg/L	0,3
8	Manganese	mg/L	0,05

The results were analyzed and compared with the maximum accepted levels. The levels that the groundwater tests should comply with are shown in the next table. This is the list of elements selected for the testing, compiled in accordance with the requirements of European regulations.

Humphrey and Swett [2006][6] provided a comprehensive literature review on the effects of Tyre Lightweight Filler for Embankments (TLFE) on groundwater quality. In field studies presented by Humphrey and Katz [2000 and 2001], TLFE was placed either above or below the groundwater table, and groundwater quality was then evaluated. Results showed that the presence of TLFE had a negligible effect on the concentration of metals such as arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), and lead (Pb) relative to primary drinking water standards. However, concentrations of other metals related to secondary drinking water standards, such as iron (Fe) and manganese (Mn), were encountered at elevated levels. When TLFE is placed below groundwater level, the manganese and iron released by TLFE can be significantly above the secondary drinking water standard. Because secondary standards are based on aesthetic factors (e.g., color, odor, and taste) and not on health concerns, the release of manganese and iron is not a critical concern. However, aesthetic concerns should be evaluated if TLFE is to be placed below the groundwater table (ASTM D 6270 [ASTM, 2008])[7].

The leaching potential of organic compounds was also evaluated in these studies. The release of organics from TLFE placed above the groundwater table was found to be below method-detection limits [Humphrey and Katz, 2000][8] and was not considered a significant concern. TLFE

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[6] Humphrey, D.N. and Swett, M. [2006]. *"Literature Review of the Water Quality Effects of Tire Derived Aggregate and Rubber Modified Asphalt Pavement", prepared for USEPA Resource Conversion Challenge, University of Maine, Orono, Maine.*

[7] *ASTM [2008]. "Annual Book of ASTM Standards", American Society for Testing and Materials,*

[8] Humphrey, D.N. and Katz, L.E. [2000]. "*Five-Year Field Study of the Effect of Tire Shreds Placed above the Water Table on Groundwater Quality*", Transportation Research Record No. 1714, Transportation Research Board, Washington, D.C., pp. 18-24.

placed below the groundwater table released a few organic compounds at low concentrations based on field results provided by Barris [1987][9] and Twin City Testing [1990].

Table 9: First Groundwater quality analysis at demo site, prior to Rectyre model execution

Research results of groundwater - Czuprynowo				
No#	Contaminant	Unit of measurement	Result	Date
1	Arsenic intensity	mg As/dm^3	< 0,001	30.09.2010
2	Barium intensity	mg Ba/dm^3	0,058	05.10.2010
3	Boron intensity	mg B/dm^3	0,132	05.10.2010
4	Overall Chrome intensity	mg Cr/dm^3	< 0,002	12.10.2010
5	Overall Zinc intensity	mg Zn/dm^3	0,055	05.10.2010
6	Aluminium intensity	mg Al/dm^3	0,330	05.10.2010
7	Cadmium intensity	mg Cd/dm^3	<0,00002	04.10.2010
8	Cobalt intensity	mg Co/dm^3	< 0,001	05.10.2010
9	Magnesium intensity	mg Mg/dm^3	13,700	05.10.2010
10	Manganese intensity	mg Mn/dm^3	1,128	05.10.2010
11	Copper intensity	mg Cu/dm^3	0,0079	12.10.2010
12	Nickel intensity	mg Ni/dm^3	< 0,005	08.10.2010
13	Overall intensity of organic Carbon	mg C/dm^3	34,300	01.10.2010
14	Plumb intensity	mg Pb/dm^3	0,009	20.10.2010
15	Mercury intensity	mg Hg/dm^3	0,00020	01.10.2010
16	Selenium intensity	mg Se/dm^3	< 0,001	05.10.2010
17	Sodium intensity	mg Na/dm^3	3,190	05.10.2010
18	Argent intensity	mg Ag/dm^3	< 0,0001	06.10.2010
19	Petroleum-derived Hydrocarbon intensity	mg $/dm^3$	< 0,100	06.10.2010
20	Overall Ferrum intensity	mg Fe/dm^3	23,000	05.10.2010

[9] Barris, D.C. [1987]. *Report of Ground & Surface Water Analyses*. Unpublished Report, Environmental Consulting Laboratory.

Results show that trace levels of a few volatile and semivolatile organics were found in water taken directly from TLFE filled trenches. In these studies, the concentrations of water containments such as benzene, chloroethane, cis-1,2-dichloroethene, and aniline were above their respective preliminary remediation goals (PRG) for tap water when water is in direct contact with TLFE.

Table 10: Second and Third Groundwater quality analysis after Rectyre execution

Research results of groundwater - Czuprynowo				
No#	Contaminant	Unit of measurement	1st Monitoring Results June 2011	2nd Monitoring Results June 2011
1	Arsenic	mg/L	< 0,001	< 0,001
2	Barium (Ba)	mg/L	0,063	0,060
3	Cadmium (Cd)	mg/L	<0,00002	<0,00002
4	Chromium (Cr)	mg/L	0,0033	0,0034
5	Selenium (Se)	mg/L	< 0,001	< 0,001
6	Aluminium (Al)	mg/L	0,038	0,036
7	Iron (Fe)	mg/L	0,47	0,45
8	Manganese (Mn)	mg/L	0,14	0,12
9	Copper (Cu)	mg/L	0,0087	0,0080
10	Lead (Pb)	mg/L	0,009	0,009
11	Zinc (Zn)	mg/L	0,102	0,089
12	Magnesium (Mg)	mg/L	5,05	5,05
13	Sodium (Na)	mg/L	3,198	3,193
14	Organic Carbon	mg/L	1,62	1,62
15	Chloride (Cl^-)	mg/L	15,30	15,05
16	Organic Halides	mg/L	Non-detect	Non-detect

However, samples taken a few feet downgradient show that the effects are reduced to negligible levels. Humphrey and Swett [2006] concluded that TLFE placed below the groundwater table have negligible effects for off-site water quality. From this study and other related literature papers, we can conclude that placement of tire shreds above the water table under simulated field conditions will have little or no environmental impact. However, the placement of tire shreds below the water table might have some impact over time according to the characteristics of each field particulars. Thus it is recommended that tire shred embankments be built above the water table. If a tire shred embankment is to be built below the water table, precaution in the design and construction of the embankment must be taken to assure that water does not pond up in the embankment and that water will be able to drain from the tire shreds[10].

[10] Iowa DNR. 2005. Waste tire recycling. Iowa Department of Natural Resources, Des Moines, IA. Viewed on July 26, 2005 at http://www.sciswa.org/Landfill/tires.html.

Our case model executed in Czuprynowo is slightly over groundwater level, as shown in the bore-hole scheme. Groundwater samples were analyzed for the presence of the relevant elements as per table 1 and the results are shown graphically in the next tables: First groundwater samples were collected between September 30th and October 8th 2010, as shown in the table, prior to the model construction. Second groundwater samples was collected on the first week of June 2011, immediately after Rectyre model execution; and the Last water testing has been done on July 2011, 5 weeks after the completion of the works, as shown in the next tables.

3.2 Temperature monitoring

For accurate monitoring of embankment temperature, it was designed and installed appropriate instrumentation to read out temperature hesitation in the embankment layers. The sensor used was the "Temperature sensor Testo 177-T4" model. This sensor immediately provide information about current indications, the last saved value max. and min. values and the number of limited border. It provides 4-channel temp recorder, a measuring range from -100ºC to +400ºC, and an internal memory of 48,000 readings. On the next images it is shown the instrumentation and methodology carried out at the demo site to obtain temperature data.

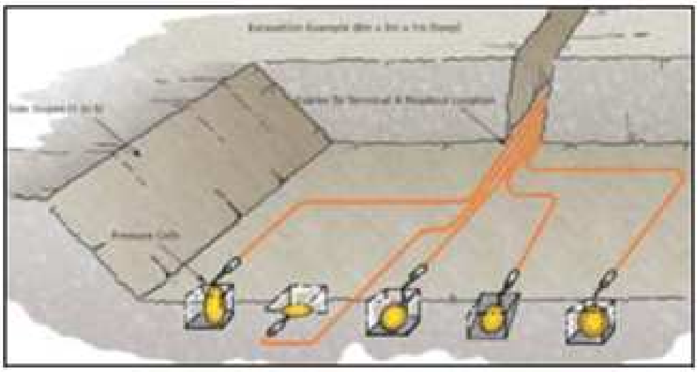


Figure 21: Temp. Sensor Testo 177-T4 and Image 6: Disposal of sensors through the embankment

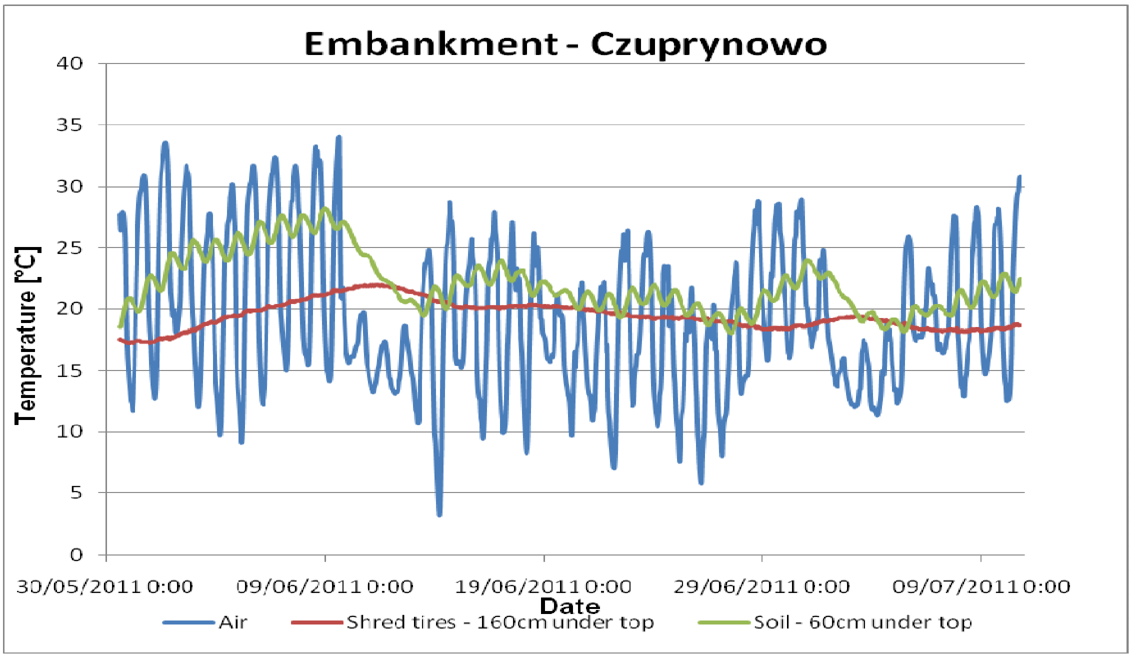
The results obtained from multiple data compilation are shown on the next tables:

Table 11: Summarized Temperature Control Data

Temperature Control Data *(Summarized Data)*			
Date	Air	Shred tires 160 cm under top	Soil 60 cm under top
30/05/2011 15:00	27.7	17.6	18.6
31/05/2011 1:00	14.2	17.3	20.9
31/05/2011 11:00	26.9	17.5	19.8
01/06/2011 7:00	15.6	17.5	22
01/06/2011 17:00	33.5	17.7	22.5
02/06/2011 13:00	29.5	18.2	23.3
02/06/2011 23:00	20	18.4	25.6
03/06/2011 9:00	18.5	18.7	24.4
03/06/2011 19:00	27.1	19	24.9

04/06/2011 5:00	9.7	19.1	25.3
04/06/2011 15:00	27.6	19.4	24.2
05/06/2011 1:00	12.7	19.4	26.3
05/06/2011 11:00	28.1	19.9	24.5
05/06/2011 21:00	26.8	19.9	26.6
06/06/2011 17:00	32.4	20.2	26.1
07/06/2011 13:00	30.7	20.6	25.9
08/06/2011 9:00	25.8	21.1	26.5
09/06/2011 5:00	14.1	21.3	27.7
10/06/2011 21:00	16.3	21.9	24.4
11/06/2011 17:00	17.4	21.9	22.4
12/06/2011 13:00	17.2	21.7	20.7
13/06/2011 9:00	17	21.2	19.7
14/06/2011 5:00	3.2	20.6	21.4
15/06/2011 1:00	15.5	20.2	22.8
16/06/2011 7:00	12	20.1	22.7
17/06/2011 13:00	27.1	20.2	22.3
18/06/2011 9:00	18.4	20.3	21.5
19/06/2011 15:00	21.2	20.3	21.2
20/06/2011 11:00	15.3	20.1	20.1
25/06/2011 16:00	19.3	19.3	19.8
01/07/2011 16:00	23.3	19	22.6
05/07/2011 16:00	25.7	18.6	19
10/07/2011 16:00	30.6	18.7	22.2

Figure 22: Temperature Analysis at Rectyre demo model in Czuprynowo



The results of the temperature monitoring indicated no evidence of any localized heat generation within the core of the shredded-tire embankment. This is significant in view of the problems experienced elsewhere. It is likely that the use of geo-textil layers mixing tire shreds with soil fill minimizes the potential for an exothermic reaction. There are no reports of problems with similar designs.

3.3 Economical analysis

For projects where special properties of tire shreds are needed, they are often the lowest cost alternative. Some of these properties are a low unit weight, high permeability, and high insulating value making them an excellent fill for embankments constructed on weak ground, landslide stabilization, retaining wall and bridge abutment backfill, insulation to limit frost penetration beneath roads, and drainage layers for landfills. Thus, civil engineers are choosing tire shreds because they offer both the properties needed to solve special problems and lower costs to satisfy the demands of their clients for the most economical project possible. A disadvantage may be, that the cost can be increased because of the gaps in gathering and recycling networks. If the key actors are not well connected, the cost will increase. On the other hand if this project generates stable networks the costs of transportation and the acquisition of raw materials (used tyres) will be lower, even lower than that of natural soil. Projects costs and material quantities estimation are shown in the next Table. The principal sources of a significant cost overrun, as compared with the original construction estimate, were the quantities of shredded tires and borrow excavation. The contractor was paid on the basis of loose volume of shredded tires delivered to the site as estimated from truck capacity.

Table 12: Rectyre material quantities and project costs

Material Quantities and Project Costs					
Item	Estimated Quantity	Final Quantity	Units	Unit Price	Cost (€)
Construction Surveying			L.S.	2,625.00	2,625
Surplus Regular Excavation	27,067	30,677	m³	1.6021	49,147
Borrow Excavation	15,789	26,083	m³	9.8640	257,280
Settlement Plates	4	4	EA.	1,000.00	4,000
Shredded Tires	13,082	24,119	m³	10.3701	250,112
Surcharge	8,555	9,570	m³	9.8640	94,396
Total Final Cost (as of 24/05/2011)					657,560 €
Total Estimated Cost (work order 5/10/2010))					460,292 €
Cost Overrun					197,268 €

Rectyre process is competitive in all the situations where standard or lightweight materials are not available in the close vicinity of the embankment location. In that cases, transportation may represent a significant cost, thus influencing the final budget of the project; it is possible instead that ELTs, which are a recycled material providing improved chemical, physical and mechanical characteristics with respect to soil, are available close to the worksite, minimising the overall cost of the work.

Furthermore, supply availability is a key aspect in the RECTYRE value proposition, as the use of ELTs is a good alternative when soil or other lightweigth fillers are difficult to retrieve. This is strictly related with costs, as the competitiveness of the RECTYRE embankment construction process in terms of costs increases when it is combined with lack of supply availability. It is difficult to provide quantitative estimations of the costs involved in the case of RECTYRE model, as they strongly depend on the price for ELTs, which varies from country to country and also within the same country in case of free market regime. It is rather possible to describe the type of cost structure involved and estimate the weight of each component on the total costs of the model.

As indicated in Table 12, the reported unit cost of shredded tires was approximately 5 percent higher than the unit cost of a borrow excavation (10.3701 versus 9.8640). The contractor was paid for the regular soil fill based on the compacted in-place volume. Since approximately 30 percent compression is expected to occur after the placement, the effective in-place (compacted) unit cost of tire shreds was at least 37 percent higher than that of the conventional fill. Further, the construction of shredded-tire embankments was administered as a change order to the previously awarded contract, thus potentially skewing the fair market price for this activity.

Table 13: Variables Description in Poland Data Set

Variables Description			
Input Variables	**Description**	**Units**	**Range**
PWA	Predominant Work Activity	Category	New Construction Asphalt or Concrete
WD	Work Duration	Month	14-30
PW	Pavement Width	m	7-14
SW	Shoulder Width	m	0-2
GRF	Ground Rise Fall	m/km	2-7
ACG	Average Site Clear/Grub	m^2/km	12605-30297
EWV	Earthwork Volume	m^3/km	13134-31941
SURFCLASS	Surface Class	Category	Asphalt or Concrete
BASEMATE	Base Material	Category	Crushed Stone or Cement Stab.
Output Variable			
USDPERKM	Unit Cost of New Construction Project	US Dollars	572,501.64–4,006,103.95

Cost estimates were made to determine the economic advantages of using shredded tires as the embankment material. The cost estimates were based on prevailing labour costs and included all other major costs such as excavation and material costs. The construction site was assumed to be located relatively close to the material suppliers. Based on the information collected from local vendors, the average cost of soil was 25€ per cubic meter (m^3). The cost of shredded tires depends on the processing costs to shred the tires to the required tire chip sizes and the transportation costs which depend on the distance of the project site from the shredding facility. Based on the information obtained from the local tire shredding companies, the cost of shredded tires ranges from 10€ to 15€ per cubic meter.

For this research, ROCKS Database has been used. This database contains road works cost data from 65 developing countries. Among these countries Poland has a relatively large number of projects. It has been developed by the World Bank Transport Unit in form of Road Costs Knowledge System (ROCKS) to develop an international knowledge system on road work costs in order to establish an institutional memory, and obtain average and range unit costs based on historical data. The table 13 show a list of input variables taken into account: work duration, pavement width, shoulder width, ground rise and fall, average site clearing and grubbing (ACG), earthwork volume (EWV), surface class, and base material. These variables have been used to evaluate the relevance of each one on the global cost of a road construction, as shown on table 3 for the influence of each input variable to output variable. This serves as feedback, indicating which input channel has a significant effect. It was found that pavement width, earthwork volume, work duration, average site cleaning and grubbing, surface class, and base material have a relatively high influence on an average new construction project's cost.

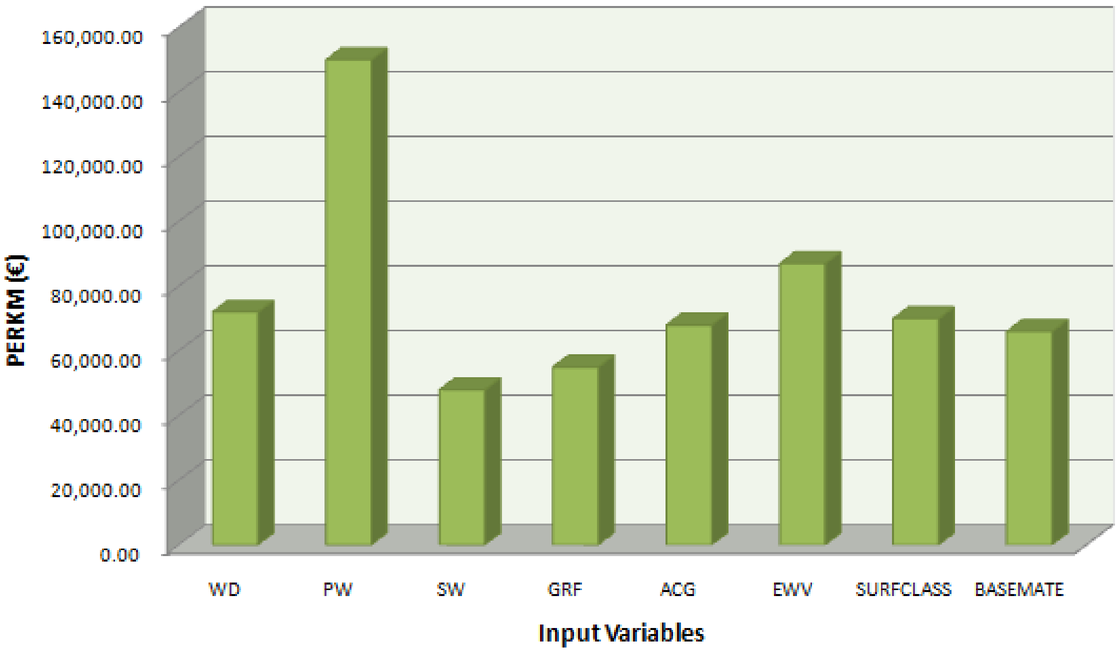


Figure 23: Evaluation of the influence of each input variable on project average cost (Poland case).

In conclusion, the economic viability of the implementation of used tyres as filler for embankments has been proved in previous studies. The benefits, apart from those environmental benefits already described, will depend on the management model applied in each scenario. The optimal situation is that in which the construction has the support of the Management Agency or Association to use the used tyres. In that case cost will be reduced to a minimum.

3.4 Conclusions and analysis of results

On previous points 1 and 2, the conclusions obtained for the Groundwater and Temperature environmental analysis carried out, were evaluated and shown. At this point, only short time results have been used for the analysis. Therefore, during the next 2 years monitoring will continue and periodical test will be carried out to obtain following results. A final evaluation will determine if our estimations remain valid. The current conclusion at this stage is that, it is possible a major increase in the number of scrap tires used for civil engineering applications, because of their growing record of successful performance combined with guidelines to limit self-heating of thick fills and groundwater data showing that they have a negligible environmental impact.

Conclusions drawn from the tests were as follows: No evidence was found that tire shreds increased the concentration of metals with a primary drinking water standard, including barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and selenium (Se) or the following substances with secondary drinking water standards: aluminum (Al), chloride (Cl^{-}), and Zinc (Zn). There was some evidence that tire shreds could increase the levels of iron (Fe) and exceed the secondary drinking water standard under some conditions. Tire shreds increase the levels of manganese (Mn), which has a secondary drinking water standard. It is likely that the levels will exceed this standard. However, manganese is of aesthetic concern only. Negligible levels of organics were measured. Overall, tire shreds placed above the water table had a negligible impact on water quality for the near neutral pH conditions.

The most abundant metals found in the leakage were zinc and iron. However, the study concluded that the results indicate that concentrations of metals in the leakage are below regulatory levels. On the next table there is a comparison between the results.

Table 12: Comparison of Groundwater quality Analysis on Rectyre case study site.

COMPARISON ON GROUNDWATER QUALITY TESTING RESULTS				
Contaminant (Units mg/L)	Maximum allowed (MCL /SMCL)	Monitoring Results before Rectyre	1st Monitoring Results after Rectyre	2st Monitoring Results after Rectyre
Arsenic	0,05	< 0,001	< 0,001	< 0,001
Barium (Ba)	2	0,058	0,063	0,060
Cadmium (Cd)	0,005	<0,00002	<0,00002	<0,00002
Chromium (Cr)	0,1	< 0,002	0,0033	0,0034
Selenium (Se)	0,05	< 0,001	< 0,001	< 0,001
Aluminium (Al)	0,05-0,2	0,033	0,038	0,036
Iron (Fe)	0,3	0,023	0,27	0,25
Manganese (Mn)	0,05	0,011	0,14	0,12
Copper (Cu)	-	0,0079	0,0087	0,0080
Lead (Pb)	0,015	0,009	0,009	0,009
Zinc (Zn)	5	0,055	0,102	0,089
Magnesium (Mg)	No established	4,90	5,05	5,05
Sodium (Na)	No established	3,190	3,198	3,193
Organic Carbon	2	1	1,62	1,62
Chloride (Cl^{-})	250	12,07	15,30	15,05
Organic Halides	No established	Non-detect	Non-detect	Non-detect

The results of the test indicated that shredded automobile tires do not show any likelihood of being a hazardous waste. Compared with other wastes for which leach tests and environmental monitoring data are available, the tire leach data indicated little or no likelihood of shredded tires having adverse effects on groundwater quality. At this stage and based on the limited scope of this effort and comparison with water quality criteria, it appears that there is no evidence in this study that there will be a detrimental effect on the environment or to human health.

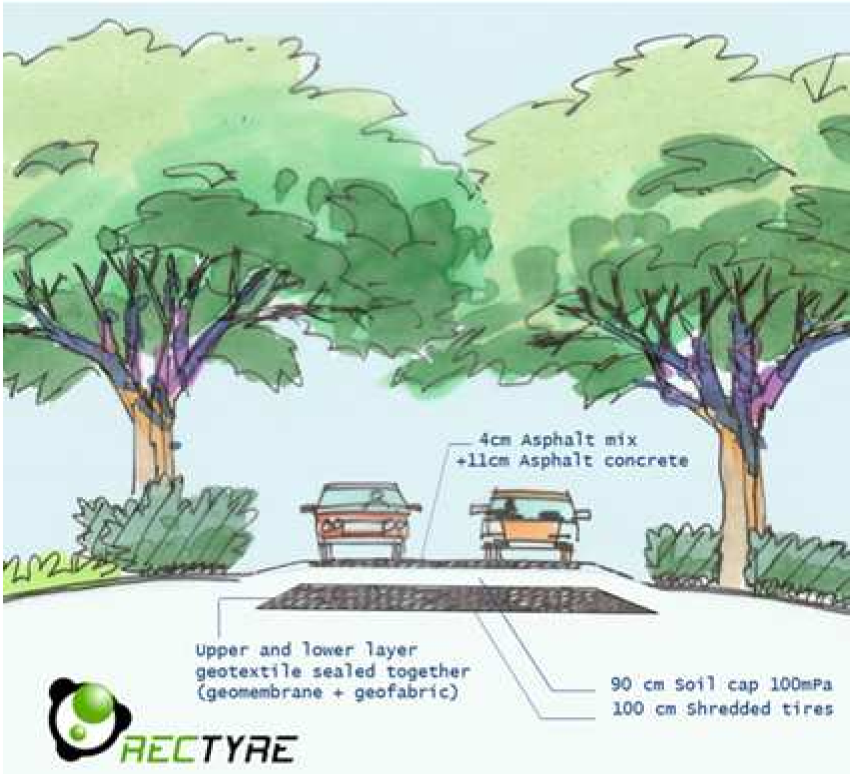


Figure 24: RECTYRE design scheme

The temperature monitoring indicated no evidence of any localized heat generation within the core of the shredded-tire embankment. This is significant in view of the problems experienced elsewhere. It is likely that the use of geo-textil layers mixing tire shreds with soil fill minimizes the potential for an exothermic reaction. There are no reports of problems with similar designs

The economic viability of the implementation of used tyres as filler for embankments has been proved in previous studies. The benefits, apart from those environmental benefits already described, will depend on the management model applied in each scenario. The optimal situation is that in which the construction has the support of the Management Agency or Association to use the used tyres. In that case cost will be reduced to a minimum.

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