Geomembranes as a Remedial Measure for Swelling in Irrigation Channel Foundations

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ABSTRACT : The aim of the present study was to determine the use of geomembranes as a remedial alternative for overcoming the swelling foundation problems encountered in irrigation channels. A finite element analysis was performed and the results indicated that rigid concrete linings could not be used effectively in soils with swelling potential. The use of geomembranes with roughened surfaces was seen to be a viable technical and financial alternative to soil removal and replacement. The geomembrane lining did not require a geotextile buffer to provide additional friction between the concrete slab and the geomembrane.

1. INTRODUCTION

An effective solution has been developed by today's technology for one of the oldest and most severe problems plaguing the use of irrigation channels: water losses during conveyance. The effective usage of concrete lined irrigation channels is often hampered by leakage of water from cracking of the concrete and the subsequent wetting of the soil underneath the channel linings. The type and magnitude of the problems created by the wetting of the soils will largely depend on the soil properties. It is well known that the shear strength of cohesive soils decrease with increasing water content which weakens the foundation underneath the concrete lined irrigation channel; this, in turn, leads to greater deformation in the concrete lining from the water pressures in the channel and further increases the cracking of the concrete. This problem is much more severe in swelling soils since large swell pressures are applied from the foundation to the concrete lining which may lead to complete failure of the concrete.

The aim of the present study was to investigate remedial alternatives for the swelling foundation problems encountered in the irrigation channels constructed as part of the State Water Works Turkish Southern Anatolian Project. The scope of work of the study consisted of:

- investigating the effects of the swelling soils on the concrete linings using finite element analysis;
- investigating the use of geomembranes as a remedial measure for swelling soil problems; and
- comparing costs between the use of a geomembrane liner and the soil removal and replacement remedial alternative that was being implemented at the time of the study; the geomembrane remedial alternative was taken to be financially viable only if it was less expensive than the soil removal and replacement alternative.

2. ANALYTICAL INVESTIGATION

The deformations in channel linings constructed in swelling soils may be investigated by modelling the behaviour of the system with the finite element method. The soil behaviour was previously modeled by the investigators (Güler and Edinçliler, 1994) using available soil information for the main distribution channels (20m bottom width) to be constructed within the framework of the Southern Anatolian Project. The magnitude of the deformations created by the swelling of the soils and the resulting effects on the concrete lining cross-sections were examined using the "CRISP" finite element model (Britto and Gunn, 1990); this model which uses critical state soil mechanics theory was developed by the Geotechnical Group at Cambridge University and is known to be particularly well suited for examining the modelling of soils. The simulation of the soil excavation and installation of the concrete lining was modeled using 264 elements (Figure 1). The concrete lining was taken to be reinforced concrete with a 35 cm thickness and the swell pressure of

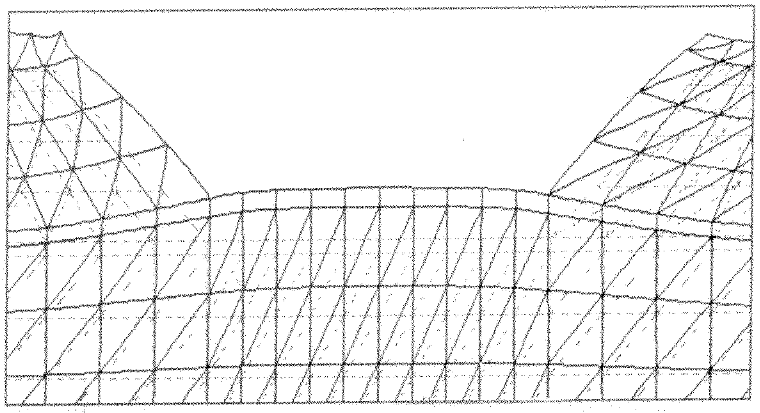

Figure 1 - Deformed shape of Finite Elements due to swelling

the foundation soil was set to 50 kPa; the hydrostatic pressures of the water column was subsequently added into the analysis. It was seen that the continuity of such a rigid structure could be preserved with great difficulty under the deformations modelled in the soil foundation; the swelling of the soil due to water seepage into the soil rendered the concrete lining useless.

3. EXPERIMENTAL WORK

The use of geomembranes for water proofing irrigation channels and thus increase their longevity is quite widespread in developed countries (Martin and Sanger, 1986 ; Williams and Houlihan, 1986; Montez and Maroni, 1990; Marrison, 1990). The use of geomembranes are often coupled with the use of geotextiles since concrete linings cannot adhere to the inclined surface of geomembranes due to the generally smooth and very slippery surface of geomembranes. Geotextiles are placed on top of the geomembranes to increase the friction for the concrete liner; the use of geotextiles, however, leads to increased costs.

The use of geomembranes with surfaces roughened to increase the frictional surface characteristics was considered in this study in order to decrease the costs that would be associated with lining the channel surfaces with a combination of geomembranes and geotextiles. The study was conducted by performing experiments aimed at determining the frictional characteristics of the geomembrane and the adequacy of using concrete linings that are thinner than the linings used in the design projects.

The geomembrane with a roughened surface was installed on a wooden surface and a frame was constructed around it to create a containment region which would hold a 5cm thick concrete. Figure 2 shows the geomembrane and the 1.5m long and 0.5m wide frame. The frame was set at a 1(vertical):1.5(horizontal) slope to simulate the inclination of the side slopes of the irrigation channels. Concrete was

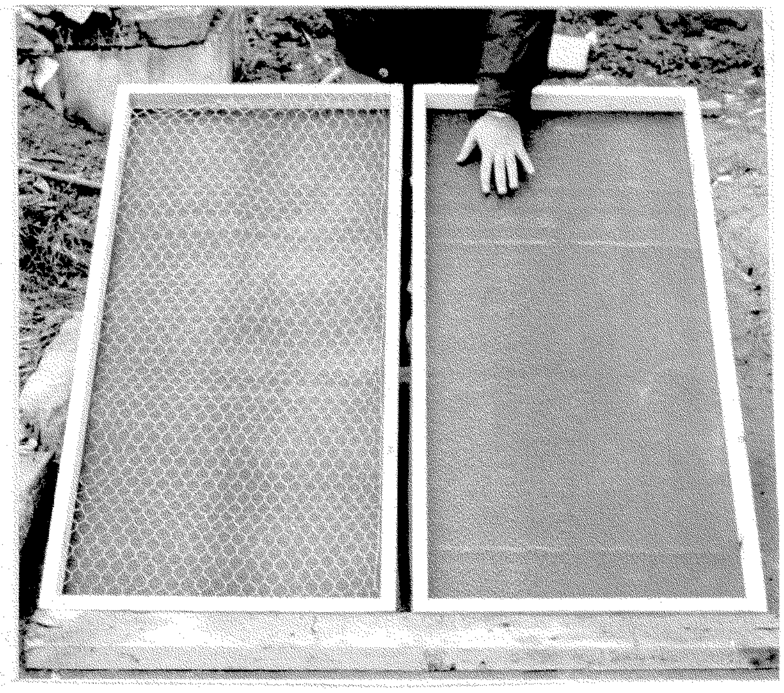

Figure 2 - Frame for concrete slab with geomembrane lining

applied on the surface of the geomembrane within the enclosed frame; it was noted that slippage of the concrete did not occur during the application of the fresh concrete on the surface of the geomembrane. The concrete was allowed to cure for a period of 10 days after which the frame surrounding the concrete was removed.

The angle of inclination angle of the frame was increased to determine the maximum allowable inclination prior to slippage of the concrete slab from the surface of the geomembrane; it was noted that the concrete block remained attached to the surface of the geomembrane even at a 90^0 angle of inclination and as Figure 3 shows the concrete slab could only be pried from geomembrane using mechanical means. The results of the experiment indicated, therefore, that a sliding problem would not be present in the installation of concrete liners on top of the frictional geomembrane during the construction of irrigation channels.

The thickness of the concrete block had been reduced to 5cm from an original design thickness of 10cm in order to decrease the costs involved in concrete lining; the second part of the experiment was aimed to see whether a concrete slab with 50% decrease in thickness would still fulfil the mechanical requirements required of the 10cm concrete lining. It should be noted that the use of geomembranes effectively remove the water proofing role that the concrete lining, otherwise, has to perform; the purpose of the concrete lining is, therefore, reduced only to the protection of the geomembrane from mechanical damages during the lifetime of the channel. Cracks which may develop along the concrete lining will not pose problems as long as breakage and removal of concrete pieces do not occur.

Figure 3 - Prying of the concrete slab

A second frame was prepared similar to the first one where a thin wire mesh was installed on top of the geomembrane prior to the application of the concrete on the geomembrane surface. The presence of the mesh was not to increase the strength of the concrete lining, but was to minimize the effects of any cracking that the concrete lining might suffer. The results that were obtained for the second frame setup were similar to the results observed for the first concrete frame setup in terms of the installation, removal of the concrete slab and friction characteristics.

The concrete slabs were separated from the geomembrane linings for both frames and subsequently tested in the laboratory to review the behaviour of the concrete linings after stress cracks had developed. The concrete slabs were loaded with the help of a U beam installed in the middle of the concrete that was cantilevered 7.5 cm at both ends. The concrete blocks failed under loading at 210 kg for the plain concrete and 235 kg for the concrete containing the wire mesh, respectively.

The presence of the wire mesh was not found to significantly increase the strength of the concrete. It was noted, however, that complete separation had occurred in certain sections of the failure planes in the block without the wiremesh whereas the concrete block containing the wire mesh remained as a single piece and separation was not seen along the failure planes.

4. COST COMPARISON

The cost of using geomembranes was investigated as an alternative to the soil removal and replacement remedial measure at locations along the irrigation channel path where swelling soils existed. The approximate costs for the two remedial measures were calculated for two cases. The first case referred to the condition when the channel had to be constructed in a cut cross section; the second case occurred when the channel was to be constructed in a fill cross-section. A typical cross section was taken as having a 2.8m base width and a 1.2m water depth.

The cost associated with the two cases with the soil remediation alternative and the geomembrane usage are shown in Tables 1 and 2. Plans for excavating earth underneath the typical cross sections in areas with swelling soil foundations was to be removed were obtained from the company presently performing the soil remediation alternative. The results indicated that the controlling factor in the cost comparison analysis was the distance between the channel and the source of earth to be used for replacing the problematic soils. It was noted that the geomembrane use became more economical than the soil removal and replacement scheme when the distance to the source of replacement soil was greater than 2 km for cut sections of the channel and 5 km, respectively for fill sections of the channel.

5. CONCLUSIONS

The results of a finite element analysis indicated that rigid concrete linings could not be used effectively for waterproofing the irrigation channels in soils with swelling potential in the State Water Works Turkish Southern Anatolian Project; testimony to this fact was observed in existing channels that have been laid out in the region and have not yet even been used.

The remedial measure for new irrigation channel layouts that is presently being implemented consists of the soil removal at locations where swelling soils are encountered and subsequent replacement with a nonswelling soil. The use of a geomembrane lining that is indicated in the literature as an effective means of water proofing channels was examined as an alternative to the soil removal remedial measure both in terms of technical feasibility and cost competitiveness.

A geomembrane with a roughened surface onto which a 5cm thick concrete lining could be applied proved to be technically feasible alternative to the soil improvement scheme. The results of the cost comparison study indicated that using the geomembrane liner became more economical than the soil removal and replacement scheme when the distance from the channel to the source of the replacement soil was greater than 2 km for cut sections of the channel and 5 km, respectively for fill sections of the channel.

Table 1 - Comparison Data : Cut Cross - Section

A. Soil replacement

Construction Item	Unit Cost	Quantity	Total Cost
Excess excavation due to replacement	0.70 $ /m3	20 m3	14.00 $ /m
Excavation at the borrow	0.50 $ /m^3	20 m^3	10.00 $/m
Transportation	Variable	30 tons	Variable
Concrete Lining (10 cm)	27.00 $ /m^3	0.92 m^3	24.84 $ /m
		Total	: 48.84 $ /m + Transportation

B. Use of Geomembrane

Construction Item	Unit Cost	Quantity	Total Cost
Concrete Lining (5 cm)	27.00 $ /m^3	0.46 m^3	12.42 $/m
Geomembrane	5.40 $/ m^2	9.2 m^2	49.68 $/m
		Total	: 62.10 $/m

Table 2 - Comparison Data : Fill Cross -Section

A. Soil replacement

Construction Item	Unit Cost	Quantity	Total Cost
Excess excavation due to replacement	0.70 $ /m^3	6.7 m^3	4.69 $ / m
Excavation at the borrow	0.50 $ /m^3	28.8 m^3	14.40 $/m
Transportation	Variable	43.2 tons	Variable
Concrete Lining (10 cm)	27.00 $/m^3	0.92 m^3	24.84 $/m
		Total:	43.93 $/m+ Transportation

B. Use of Geomembrane

Construction Item	Unit Cost	Quantity	Total Cost
Concrete Lining (5 cm)	27.00 $/m^3	0.46 m^3	12.42 $/m
Geomembrane	5.40 $/ m^2	9.2 m^2	49.68 $/m
Excavation for Highway	0.55 $/m^3	22.1 m^3	12.16 $/m
		Total	: 74.26 $/m

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