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Tension in geosynthetic liner based on hyperbolic interface response

K.V.S. Krishna Prasad & M.R. Madhav
I.I.T., Kanpur, India

J. Kodikara
Victoria Univ. of Tech., Melbourne, Australia

A. Bouazza
Monash Univ., Clayton, Australia

ABSTRACT: The paper presents an analysis for the estimation of tension in a geomembrane liner considering lower interface response of the liner with the underlying soil to be hyperbolic. The governing equation is non-dimensionalised and solve numerically with the finite difference approach. A parametric study and few design charts have been presented for ready use.

1 INTRODUCTION

There has been significant growth in the general awareness towards the environmental aspects of the habitat in the last two decades primarily because of the enormous increase in the quantities of waste being produced. Proper management of these wastes is absolutely essential or else their harmful effects can be quite devastating. Amongst various types of wastes, disposal of municipal solid wastes (MSW) constitute a major challenge to geoenvironmental engineers. Apart from its potential to damage the environment, MSW remains highly visible. Remedial alternatives for minimizing their impact on the environment are reduction at source and/or containment with proper treatment.

Engineered landfills are considered as an answer to the above problem. One of the chief components of an engineered landfill is the liner system that prevents the migration of the leachate or harmful gases into the surrounding soil. A liner system may comprise of a combination of barrier materials such as natural clays, amended soils, flexible geomemebranes or combinations there of. Geosynthetic clay liners (GCL) composed of a geomembrane and a clay liner are frequently utilized for the containment of the leachates. These GCL placed on a slope is anchored at the crest level. Construction involves placement of soil and waste layers up to a design height because of which the GCL is subjected to down-slope shear stresses which induce tension in the geomembrane that needs to be estimated and suitably provided for in the design.

2 REVIEW OF LITERATURE

Construction of landfills involves placement of geomembrane liners on slopes and anchored at the crest. Though the primary function is containment of the leachate, Sharma & Lewis (1994) report tension failures of the liner. Rupture leads to leakage of leachate thus nullifying the purpose of providing the liner. Koerner & Hwu (1991) analyze the tension induced in the geomembrane in terms of shear stresses developed on its upper and lower faces. The stability of cover soil on liner system with geomembrane is analyzed by the FEM by Wilson-Fahmy & Koerner (1993). Kodikara (1996, 2000) presents two simple approaches for the estimation of tension in the geomembrane for the initial linear deformation and the final plastic condition of the interface stresses. This paper presents a unifying approach that incorporates a continuous hyperbolic interface response.

3 PROBLEM STATEMENT

Landfill slopes are formed in one or several benches with berms providing anchorage for individual geomembrane lining segments. Subsequent construction involves filling in stages, successively covering each bench. In this process, the weight of the overburden materials above a particular liner is transferred to the underlying clay base through the various layers, viz., waste, soil, geomembrane, etc. resulting in substantial down slope shear being applied to the upper interface of the liner that induces tension therein.

For the analysis, a single material representing all the overburden materials above the liner and an idealized model featuring a single bench is depicted in Figure 1. In the figure, L is the total length of the liner, H – the height of overburden, θ and β - the angles of inclinations of the liner and the top of the landfill respectively, γ - the unit weight of the

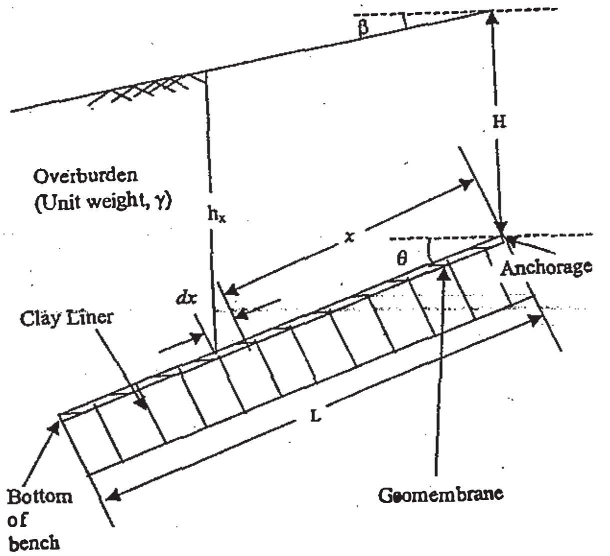

Figure 1. Statement of the problem.

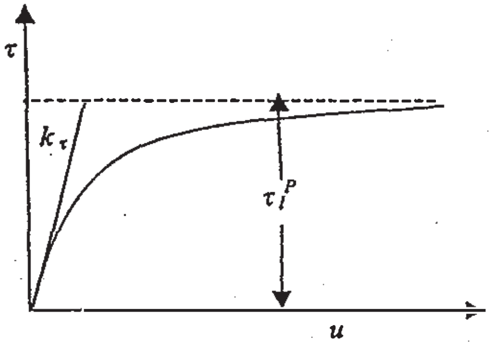

Figure 2. Hyperbolic interface response.

overburden and u – the displacement of liner at a distance, x, from the anchorage.

The shear stress, τ_l, displacement, u, response of the lower interface between the liner and the clay, is assumed to be represented by a hyperbola (Figure 2) and the relation expressed as

$$\tau_l = k_\tau u / \{1 + k_\tau u / \tau_l^p\} \tag{1}$$

where k_τ and τ_l^p are the initial slope and the maximum stress respectively. τ_l^p is given by

$$\tau_l^p = (o_n - p_l)\tan\delta_l + c_{al} \tag{2}$$

where σ_n and p_l are the normal stress and pore pressure respectively at the lower interface, δ_l and c_{al} are intrinsic friction angle and adhesion between the liner and the clay at the interface.

Following Kodikara (1996), considering the force equilibrium of an infinitesimal element (Figure 3) and simplifying, one gets

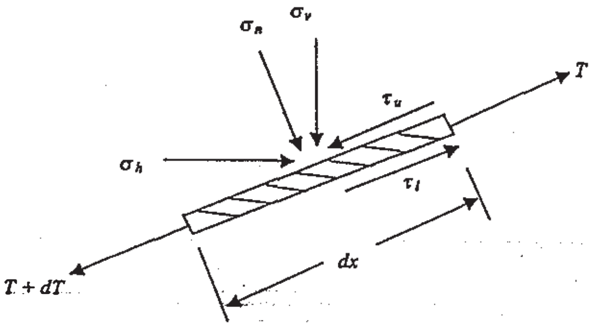

Figure 3. Forces on an infinitesimal element.

$$\frac{d^2u}{dx^2} - \frac{1}{tE}\left[\frac{k_\tau u}{1 + \frac{k_\tau u}{\tau_l^p}}\right] \tag{3}$$

$$= -\frac{1}{tE}\{(1 - K_x)(H + Fx)\gamma \sin 2\theta / 2\}$$

where t and E are the thickness and modulus of elasticity of the liner and K_x – the coefficient of lateral stress and Fx= xsinθ-xcosθtanβ. Eq. 3 is non-dimensionalised as

$$\frac{d^2U}{dX^2} - \chi^2\left[\frac{U}{1 + \frac{\chi^2 U / \lambda}{F_1}}\right] = -\lambda F_2 \tag{4}$$

where $F_1 = (F_3 - P_l)\tan\delta_l + C_l$, $F_2 = (1 - K_x)\sin 2\theta\,\{H^* + FX\}$ and $F_3 = (K_x \cos^2\theta + \sin^2\theta)\,[H^* + FX]$. γ with $\chi = \{k_\tau L^2 / t.E\}^{0.5}$, $\lambda = \gamma L^2/tE$, $H^* = H/L$, $C_l = c_{al}/\gamma L$, $P_l = p_l/\gamma L$, $X = x/L$ and $U = u/L$. The tension, T, per unit width, in the reinforcement is

$$T = tE\frac{du}{dx} \tag{5}$$

The governing equation is solved for the boundary conditions: at x = 0 (i.e. at the point of anchorage) u=0 (no displacement) and at x=L (at the bottom of the liner), T = 0 (no tension).

4 RESULTS

Eq. 4 has been solved by the finite difference method to obtain the displacements and tension at various points along the liner. The length of the liner was discretised in to a number of elements varying from 10 to 100. No increase in accuracy of results was achieved for n values greater than 100. Hence n equal to 100 was adopted for further analysis.

A parametric study was carried out for the following ranges of parameters: γ: 12-18 kN/m^3; c_{al}: 0-20 kPa; p_l: 0-20 kPa; δ_l: 10^0-25^0; θ: 5^0-30^0; β: -20^0 to +30^0; H: 0-10 m; L: 1-100 m; t: 0.5-5.0 mm; E: 100-500 MPa; K_x: 0.3-0.6 and k_τ: 10^3-10^5 kN/m^3.

The ranges of non-dimensional parameters were calculated from the above ranges of parameters. The solutions based on the proposed approach for were validated with those from Kodikara (1996) and verified to be in close agreement.

The variations of normalized tension, T* (=T/tE) and normalized displacement, U (=u/L), with distance from the anchor point, for the parameters listed therein, are presented in Figures 4a and b. The parameter, λ, represents the effects of unit weight, γ, of the overburden material and of the length, L, of the liner. As expected, the tensions are maximum (Figure 4a) at the anchor point and decay very rapidly with distance. This effect can be correlated with the full mobilization of shear stress on the lower interface as a consequence of large mobilized displacements. However, the maximum value of tension in the liner increases with λ, the value increasing from 0.003 for λ equal 80 to 0.065 for λ equal to 1500 reflecting the influences of either longer liner or that of heavier overburden. In contrast, the liner displacements appear to follow a linear increase beyond the rapid initial increases.

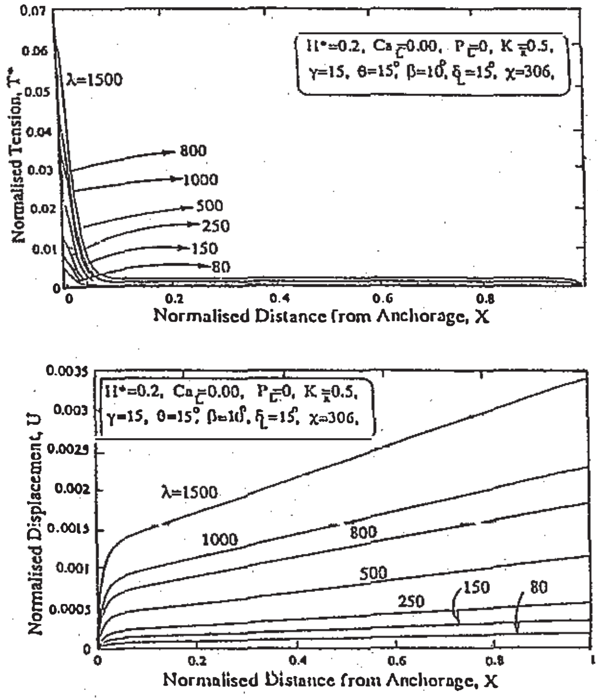

Figure 4. Variation of (a) normalized tension and (b) normalize displacement with distance.

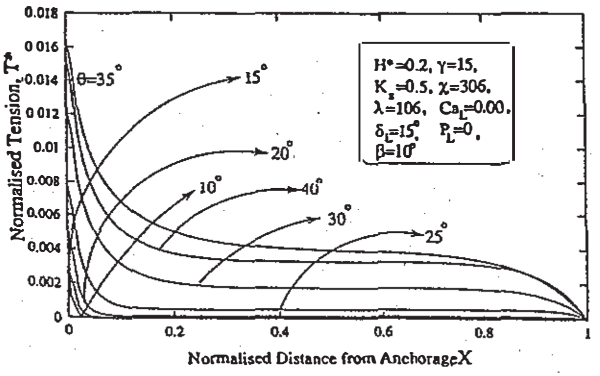

Figure 5. Normalized tension with distance: effect of θ.

Results for different angles of inclination of the liner, θ, (Figure 5), depict an interesting trend. The values of tension increase with θ for θ values up to 35^0 and decrease with θ for higher values. The variations of T* with distance extends to farther points away from the anchorage.

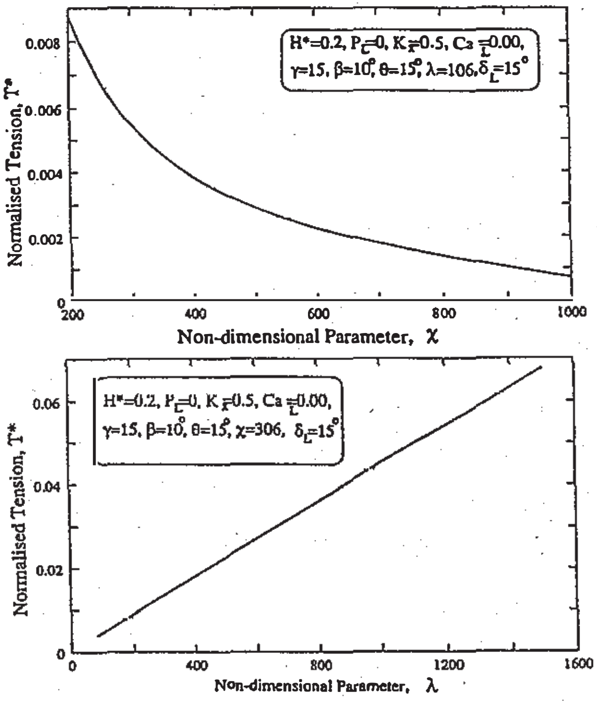

Figure 6. Design charts with respect to (a) χ and (b) λ.

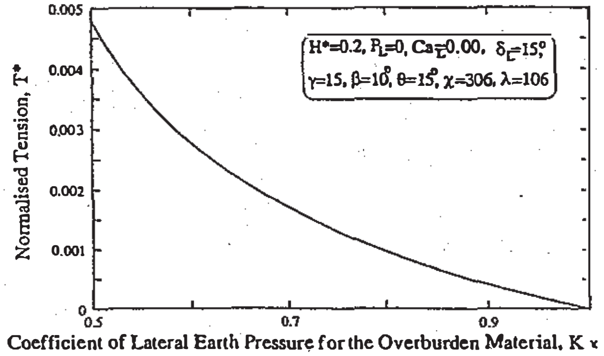

Figure 7. Design chart with respect to K.

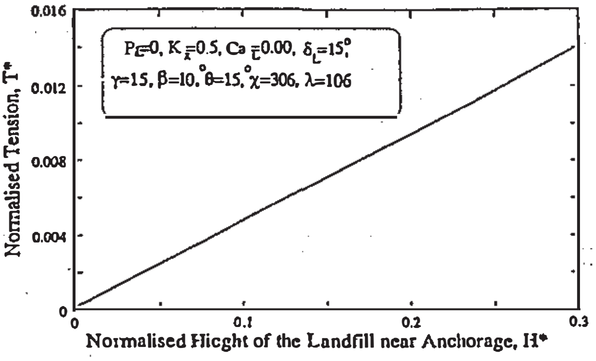

Figure 8. Design chart with respect to H*.

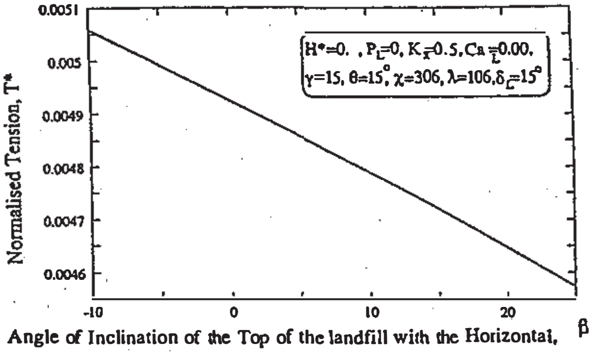

Figure 9. Design chart with respect to β.

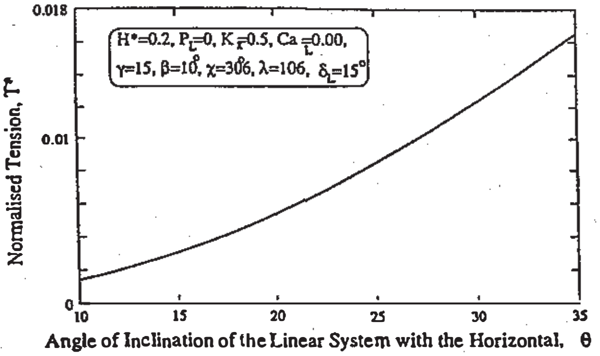

Figure 10. Design chart with respect to θ.

5 DESIGN CHARTS

A designer is often interested in the maximum value of tension so that he may choose an appropriate liner from the large variety available in the market. The variations of maximum tensions with χ, λ, K_x, H^*, β and θ are presented in Figures 6 to 10 respectively.

6 CONCLUSIONS

A simple approach is proposed for the estimation of tension in a geomembrane used as a liner in a MSW landfill project based on a hyperbolic response of the lower interface with the soil underneath. The governing equation is normalized and solved using the finite difference method. The solution obtained agrees closely with the results of Kodikara (1996) for the initial linear and the final fully plastic interface responses. A parametric study and design charts are presented quantifying the effects of stiffness of the interface, height of fill above and the length of liner, coefficient of lateral stress coefficient, height of fill above the anchorage point, inclinations of the liner and of the top of the landfill, interface strength parameters, etc.

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