Ground Improvement Using Steel Reinforcing Strips

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ABSTRACT: Consideration is given to improvement of the ground using steel reinforcing strips. Soil nails and ground anchors are not included in this short review.

1 INTRODUCTION

A distinction needs to be made between the use of reinforcing strips to create a composite ground structure and the improvement or strengthening of ground using steel reinforcing strips.

Ground Structures
for example

- Retaining walls
- Bridge abutments
- Storage facilities
- Bund walls
- Dam spillways
- Protective structures

Ground Improvement
for example

- Steepening of slopes
- Basal reinforcement beneath embankments
- Increase overall stability of slopes
- Raft foundations *****

* Raft foundation is really a ground structure placed on top of the ground to improve the foundation characteristics of the ground beneath.

Since the bond between the reinforcing strips and the ground is by way of friction only, granular ground can be improved using reinforcing strips. Frictional ground has shear and compressive strength, but insignificant tensile strength. The introduction of reinforcing strips in the ground provides an apparent anisotrophic cohesion in the direction of the reinforcing strips.

Horizontal strain in the ground is captured by the reinforcing strips in friction. The reinforcing strips take up this frictional force in tension. The reinforcing strips are much stiffer than the ground and may be considered as inelastic. The modulus of steel is typically 34 times greater than that of polyester.

2 GROUND IMPROVEMENT USING STEEL STRIPS

2.1 Basal reinforcement

2.1.1 The analysis of steel reinforced embankments on soft clay foundations

Rowe and Mylleville used numerical models to study the behaviour of steel reinforced embankments. Some results are presented which illustrate the mode of failure according to the amount of reinforcement and properties of the foundation soil.

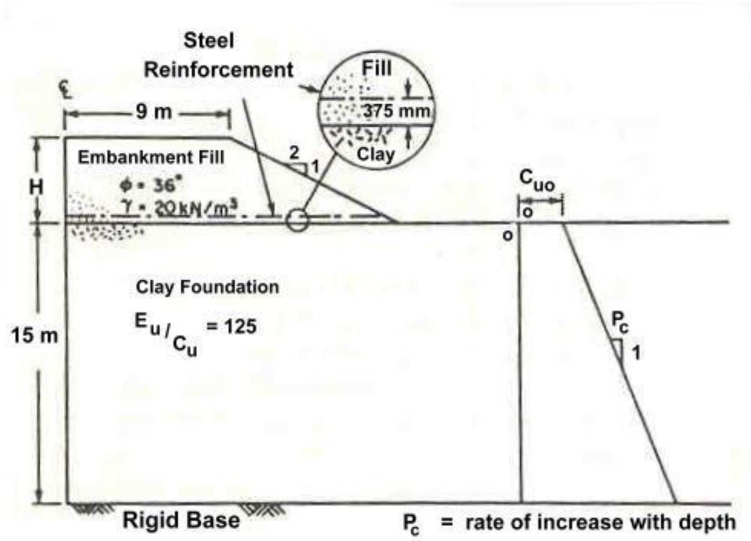


Figure 1. General arrangement of the physical problem being analyzed (Rowe & Mylleville, 1987)

Failure Mechanisms

1 Pullout of reinforcement
2 Sliding of the soil along upper face of reinforcements
3 Soft foundation soil squeezed out from below the reinforcements

Failure is defined to occur when δ H = Δ Fill thickness

Geotextile reinforced failure could occur at heights considerably less than the plasticity collapse height at which uncontained plastic flow occurs. This is not the case for heavily reinforced embankments as shown here.

Figure 2 shows significant plasticity and lateral strains in the embankment when a spacing of 375 mm is used. The reduction in plasticity with a decreased spacing is given in Figure 3. The velocity vectors are mainly vertical.

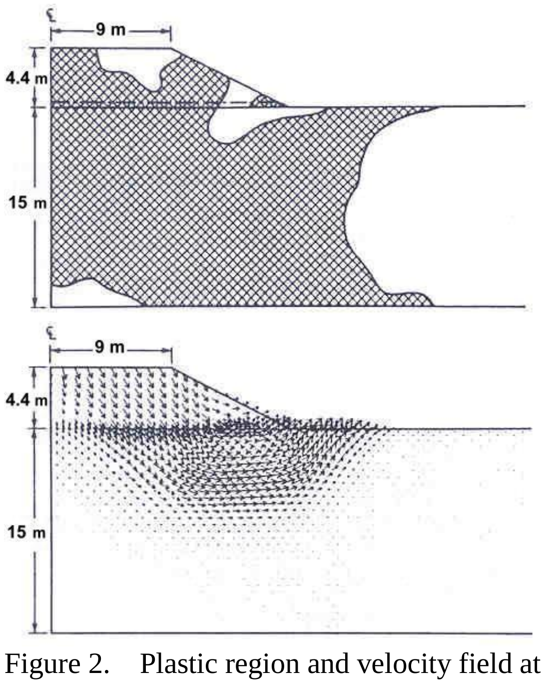


Figure 2. Plastic region and velocity field at failure for nominal parameters
C_{uo} = 15 MPa, P_c = 2.5 kPa/m, S = 375 mm

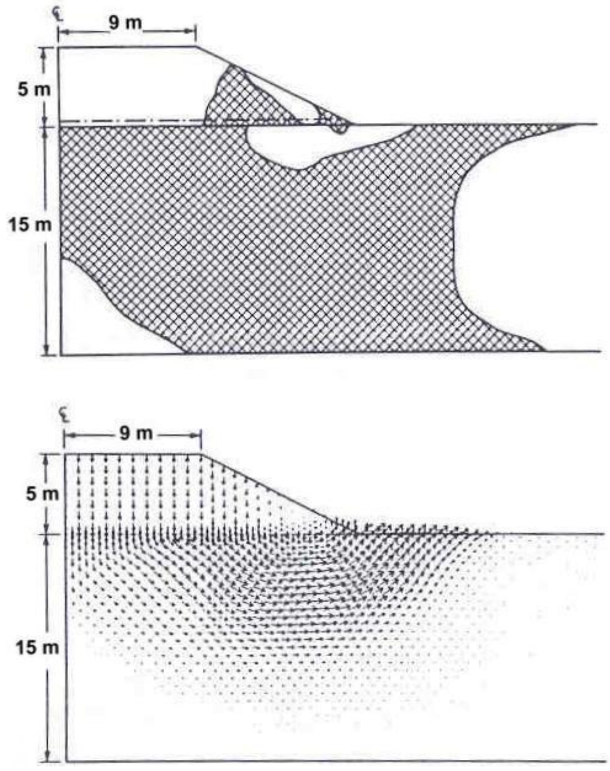
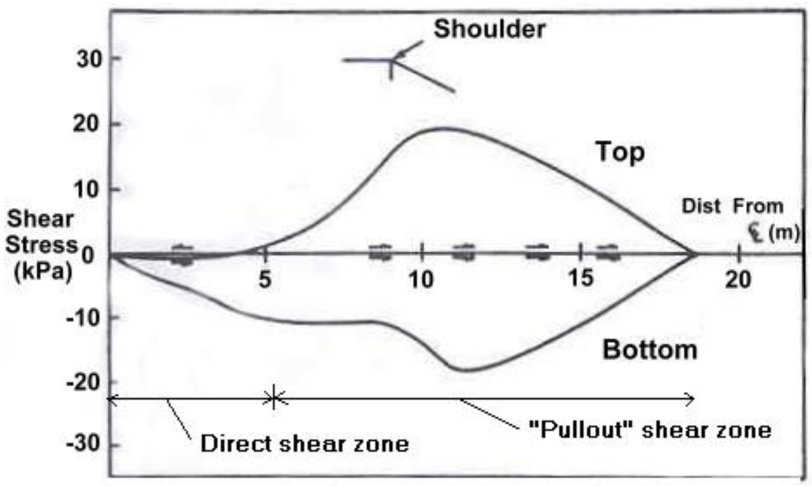
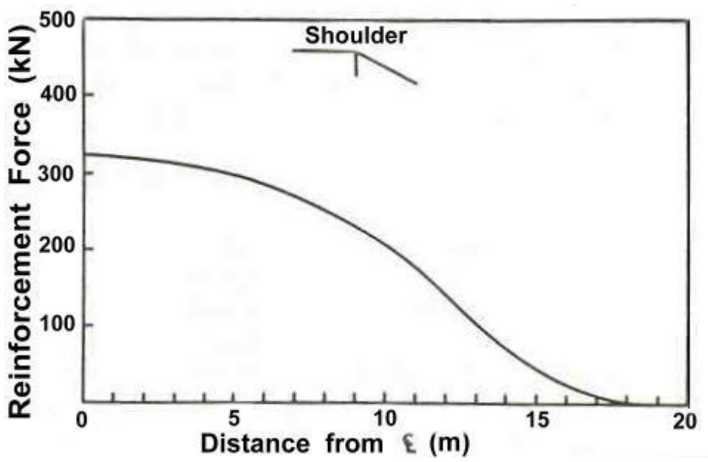


Figure 3. Plastic region and velocity field at failure for nominal parameters
C_{uo} = 15 kPa, P_c = 2.5 kPa/m, S = 125 mm



At failure, pullout is only occurring along the outer 10 m.

Figure 4. Shear stress distribution along reinforcement at failure for nominal parameters
C_{uo} = 15 kPa, P_c = 2.5 kPa/m, S = 125 mm



After yield has occurred in the reinforcements, additional fill can be added prior to collapse of the entire embankment.

The magnitude of the forces indicates that the position of splices is important (in the reinforcement).

Figure 5. Force distribution in the reinforcement at failure for nominal parameters
C_{uo} = 15 kPa, P_c = 2.5 kPa/m, S = 125 mm

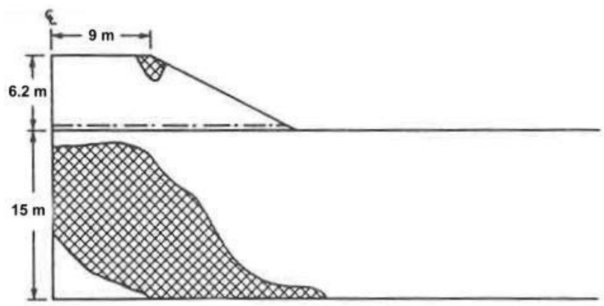


Figure 6. Plastic region at first yield of reinforcement for nominal parameters
C_{uo} = 30 kPa, P_c = 2.5 kPa/m, S = 125 mm

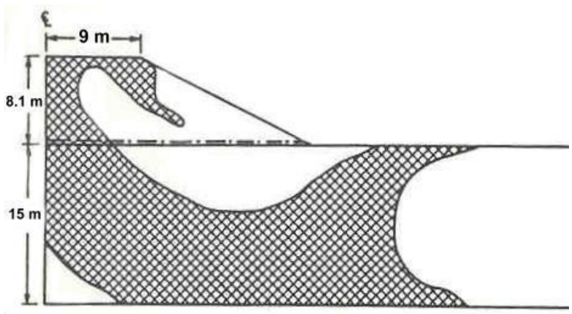


Figure 7. Plastic region at failure for nominal parameters
C_{uo} = 30 kPa, P_c = 2.5 kPa/m, S = 125 mm

Notes: In some cases yield of the reinforcement occurs well before the collapse of the entire embankment.

Fig 6. Yield in the fill and foundation has been limited by the stiff reinforcement and what failure there is in the foundation is contained by a large region of elastic soil.

Fig 7. Following first yield 1,9 m fill was added before failure occurred.

2.2 Rafts

2.2.1 Case Study : Route 202 Pennsylvania

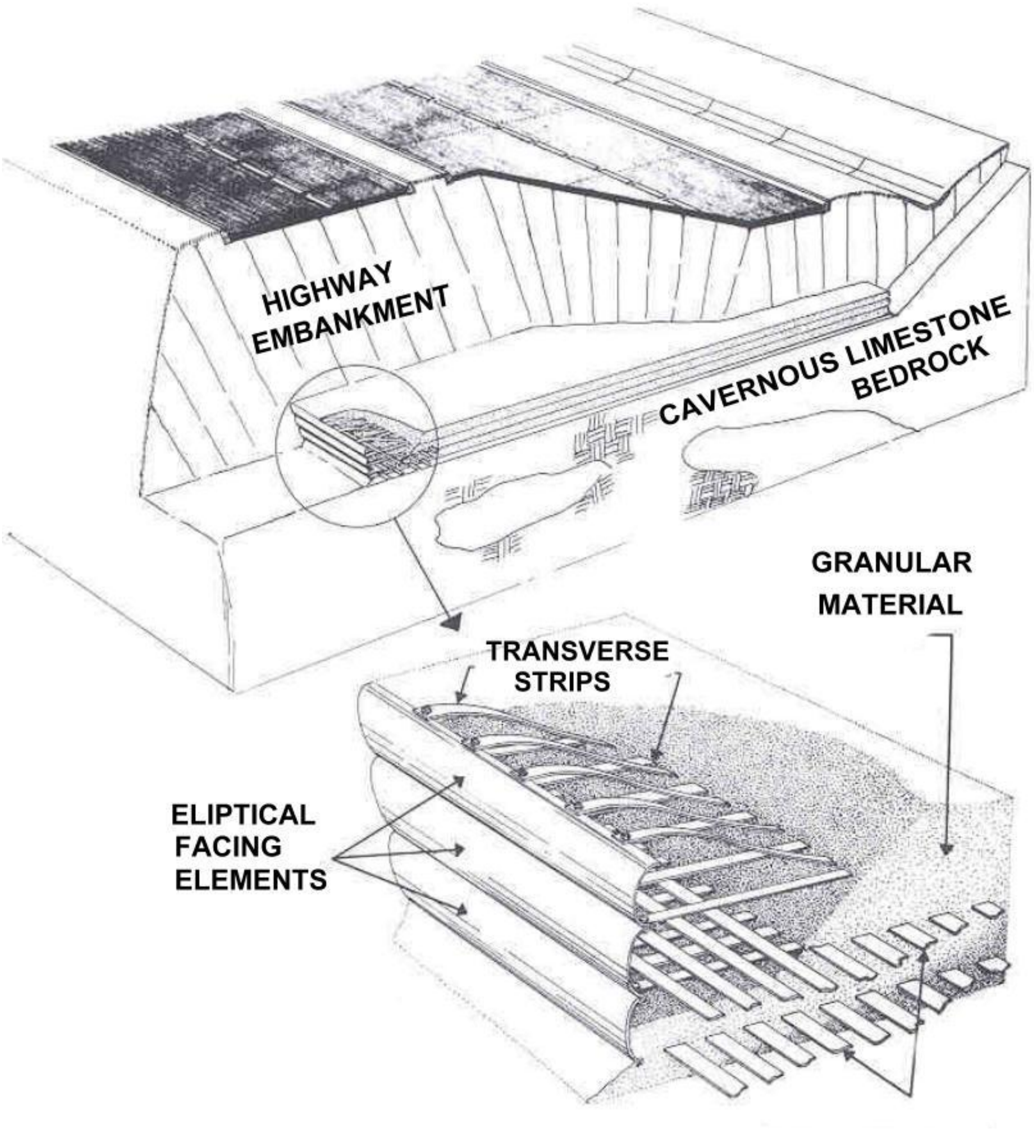
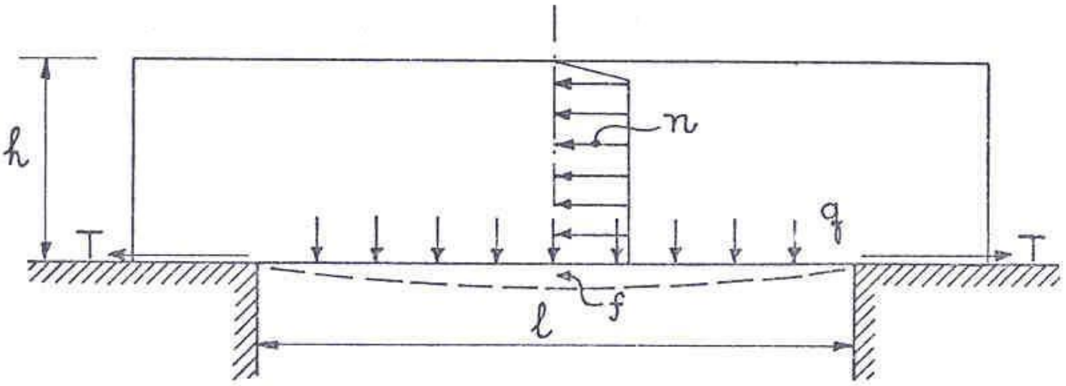


Figure 8. The Reinforced Earth® serves as a foundation slab, using longitudinal and transverse reinforcing strips within the granular backfill.

2.2.2 Reinforced Earth beam theory



n = compressive stress in unreinforced section

q = unit load on membrane $= K_a \cdot n$.

ℓ = span or diameter of slab

f = deflection at midpoint of slab

T = Tensile force at edge of membrane

h = depth of beam or slab

A_s = area of reinforcement

E = modulus of elasticity of steel

$$T = A_s \cdot E \cdot \frac{\Delta \ell}{\ell} \quad \text{...... Equation 1}$$

$$f = \frac{q \cdot \ell^2}{16T} \quad \text{............ Equation 2}$$

2.2.3 Scottish sliding raft

Coal mining causes abrupt settlements of the order of 360 mm (1977) on one side of the Sheriffhall Fault. The Dalkeith Bypass crosses the fault.

Design Concepts

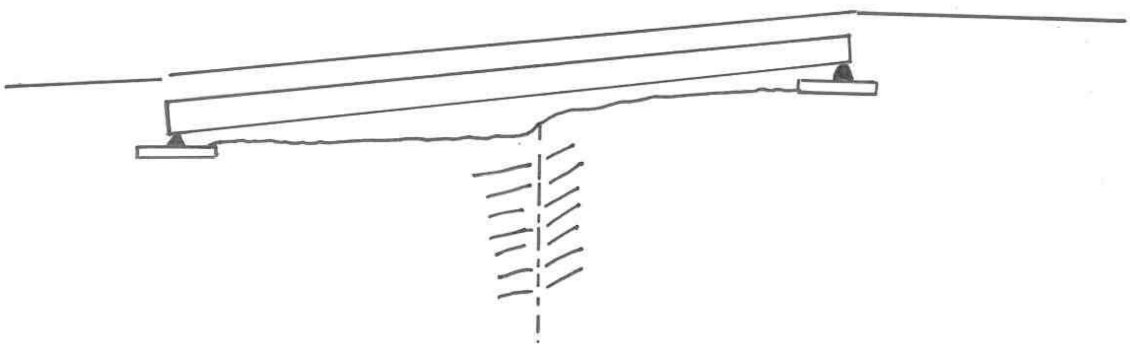


Figure 9. Structural bridge deck

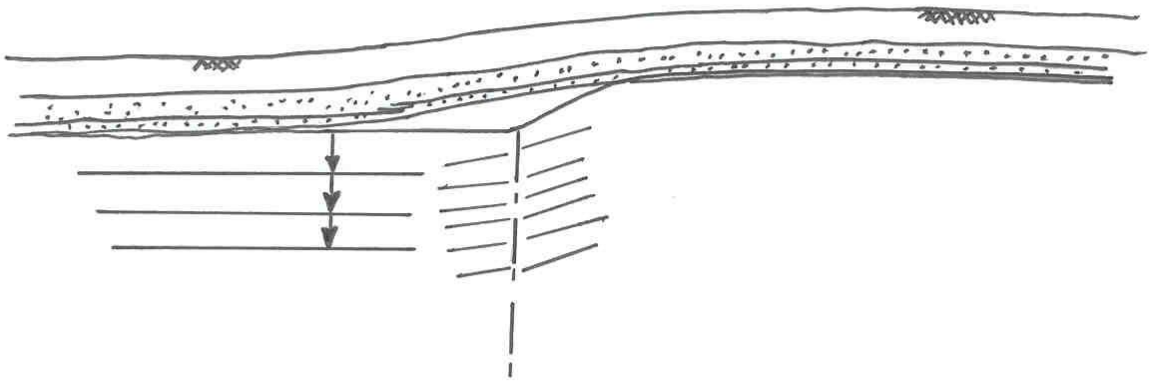


Figure 10. Soft bridge

As Events Occur

- Catenary length is increased and force in reinforcing strips is increased
- Pull out of reinforcing strips reduces catenary length and equilibrium is restored
- The road is made up on surface after each event to correct the alignment.

2.3 Stability of slopes - Iswepe Embankment

The Iswepe embankment carries the Richards Bay coal line. It failed 10 years after construction. "Deformation of the embankment occurred due to decrease in stiffness modulus and increased volumetric compressibility."

"Excessive differential movement of this embankment caused large tension zones and deep cracks to develop." (Johan Lourens, Engineering News Oct 2-8, 1998)

Part of the embankment was reinforced with galvanized steel strips as shown in the sketch.

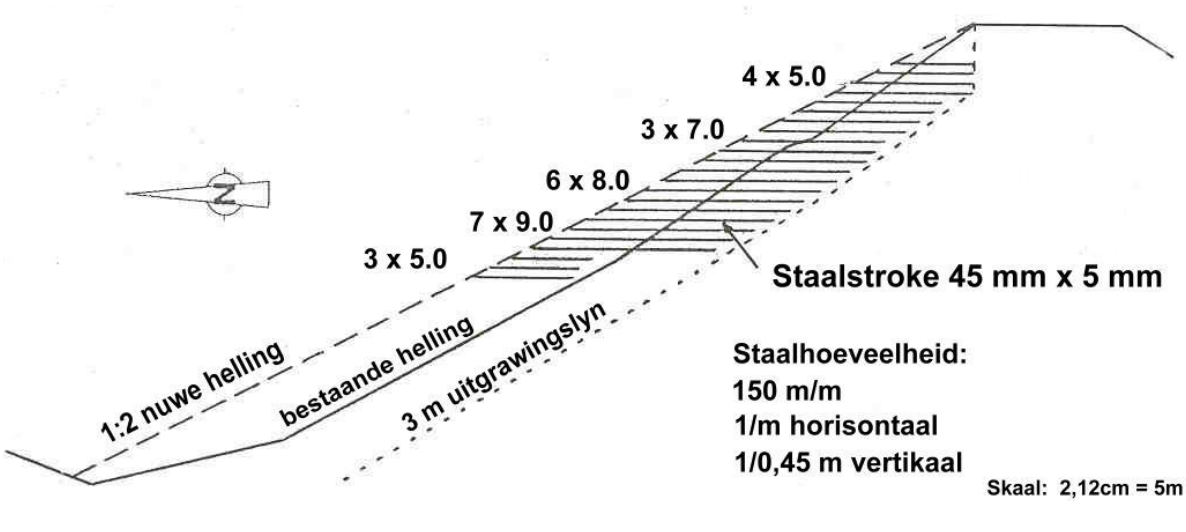


Figure 11. Iswepe Embankment

In 1995/1996 a 1 : 2000 year rainfall occurred. No indication of distress in the embankment confirmed the success of the solution.

3 CONCLUDING STATEMENT

Prime difference between ground improvement using geosynthetic reinforcing and ground improvement using steel reinforcing strips:

Steel determines the stiffness of the structure whereas with geosynthetic reinforcement this is determined by the composite ground / geosynthetic reinforcement modulus.
The order of difference is approximately 7 times.

References

- Rowe & Mylleville, University of Western Ontario, Canada, Geotechnical Research Centre Report, August 1987

- Engineering News, October 2-8 1998, Johan Lourens

- Groupe Terre Armee Internationale - Internal Reports