Innovative and cost-effective method of road embankment foundation design using basal reinforcement technique for Duqm roads project in Oman

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Engineering a Better Solution

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- The Duqm area in the Central Eastern Oman is located 600km south west of Muscat, the capital city of Sultanate of Oman.

- This area is marked by the significant presence of ‘soft sabkha’ soil which drastically influences the construction of foundations for civil engineering structures in that area.

Physiography map of Arabian Peninsula with location of Duqm area.

View of the Duqm roads project location showing the extend of muddy sabkha soil

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- Construction of embankments on soft soil can be critical because they have low strength and high compressibility.
- ‘Sabkha’ is an Arabic expression to describe a type of soft soil with high salt content and are characterized by low bearing capacity and low SPT values.
- Sabkha soils are widely distributed in the Arabian Peninsula.

Properties	Muddy Sabkha	Sandy Sabkha
Percentage Fines (%)	25 to 95	5 to 25
Salt content (%)	2 to 18	2 to 15
Water content (%)	25 to 90	4 to 40
In-situ density (KN/m3)	10 to 13.5	13 to 18.5
Angle of internal friction angle	0 to 22	20 to 35
Percentage of CaCO3 (%)	20 to 90	> 30
Plasticity index	0 to 40	Non-plastic
Cohesion (kN/m2)	0 to 55	Zero
Compression index	0.4 to 0.95	Zero
S.P.T. values (blows)	0 to 4	2 to 10
Static cone resistance (MN/m2)	0.2 to 2	1 to 6
Bearing capacity (kN/m2)	15 to 30	30 to 60

Consistency	Undrained strength (kPa)
Very stiff or hard	>150
Stiff	100-150
Firm to stiff	75-100
Firm	50-75
Soft to firm	40-50
Soft	20-40
Very soft	<20

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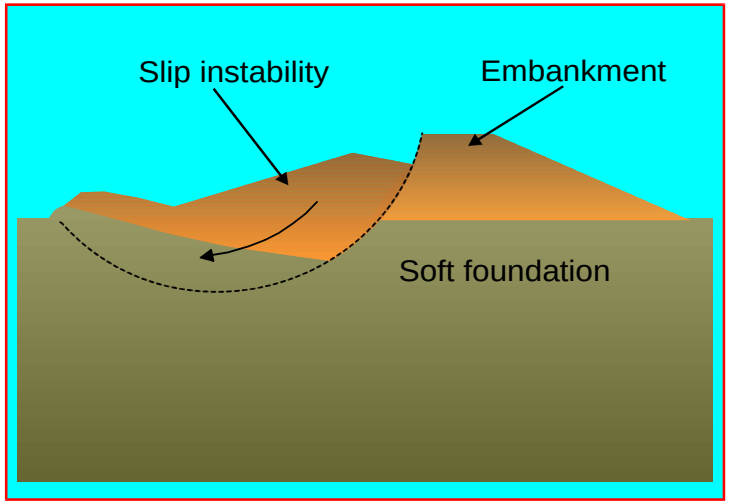
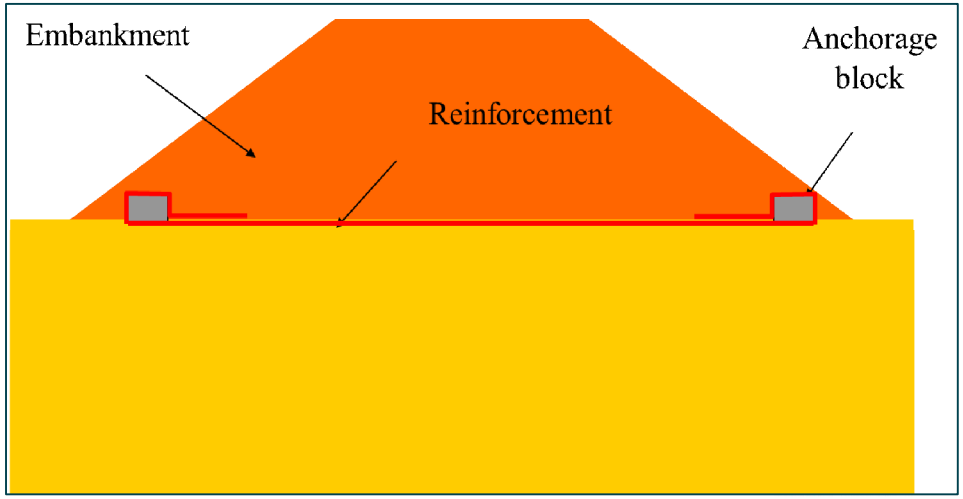
- Basal Reinforcement - a cost effective and technically feasible solution of ground improvement instead of the conventional methods

- High strength geosynthetic layers can be used as basal reinforcement for the construction of embankments over soft soils, satisfying the stability criteria laid by the international standards like BS 8006: 2016.





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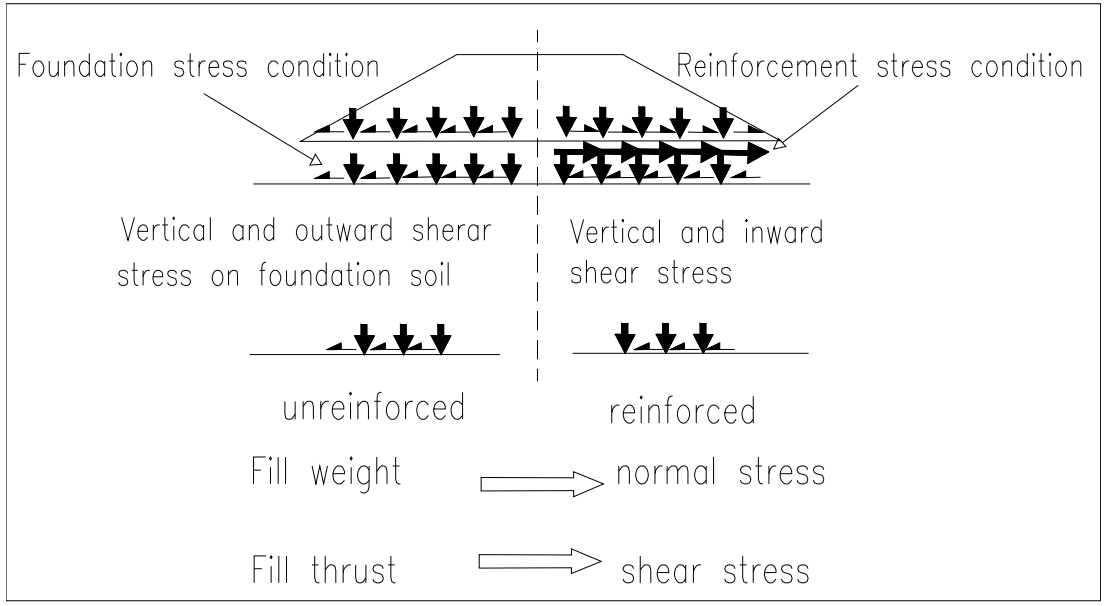
- Contribution of reinforcement in stability of basal embankments



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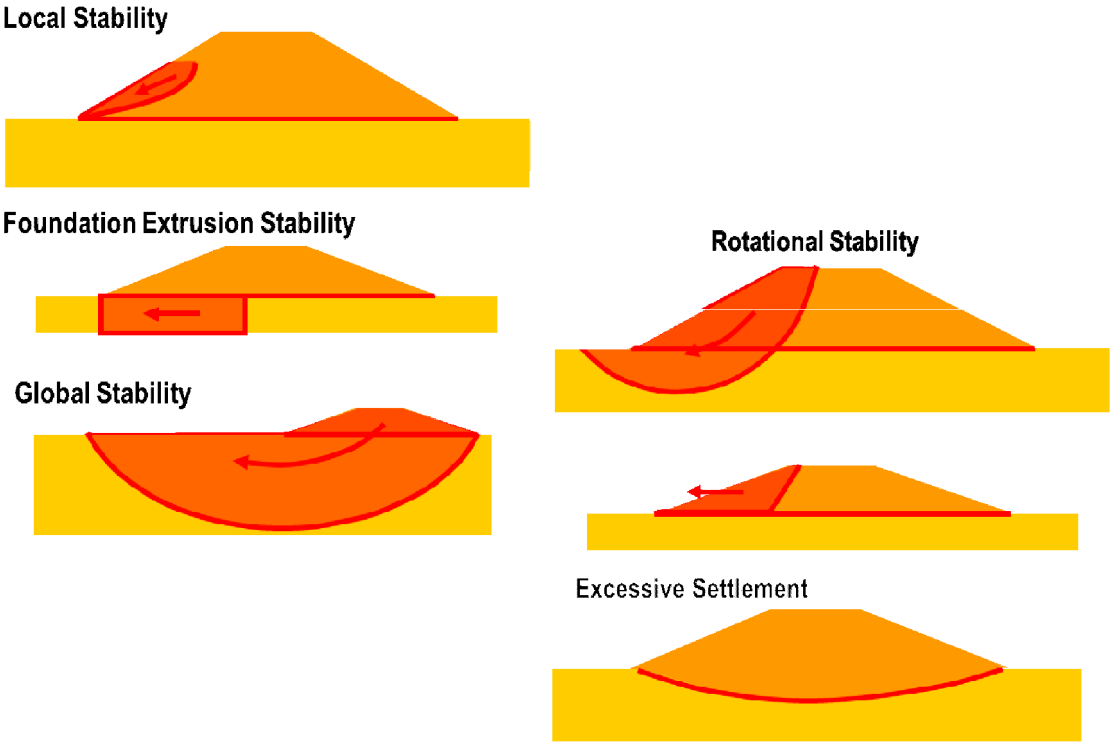
Ultimate Limit States Considered in BS 8006 are:

- Local Stability of the embankment fill.
- Rotational Stability of Embankment.
- Lateral Sliding Stability of the embankment fill.
- Foundation Extrusion Stability.
- Overall Stability .

Serviceability Limit States Considered in BS 8006 are:

- Excessive Strain in the Reinforcement
- Settlement of the foundation.



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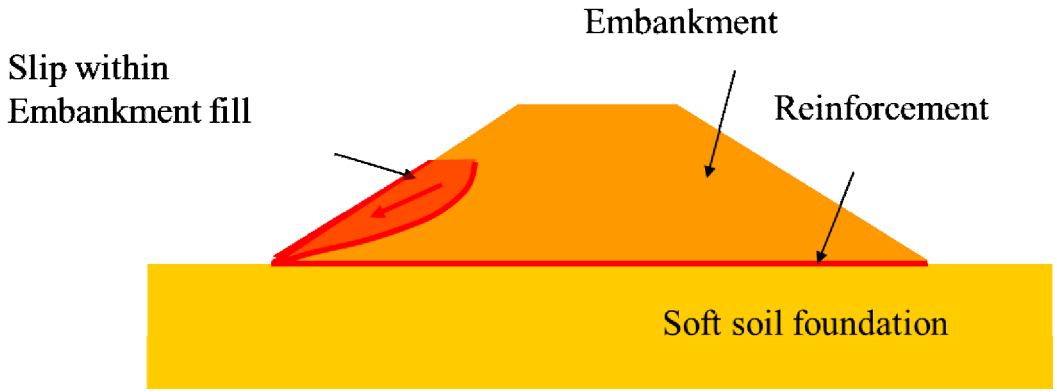

For local stability, the geometry of the embankment side slopes should meet the following

$$\frac{H}{L_s} \leq \frac{\tan\phi'_{CV}}{f_{ms}}$$

Where,

H	is the height of the embankment
L_S	is the horizontal length of the side slopes of the embankment
ϕ'_{CV}	is the large strain angle of friction of the embankment fill under effective stress conditions,
f_{ms}	is the partial material factor applied to $\tan\phi'_{CV}$.

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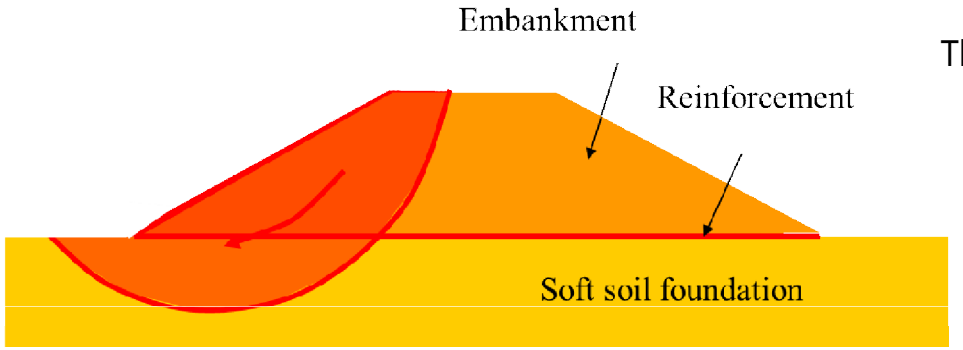
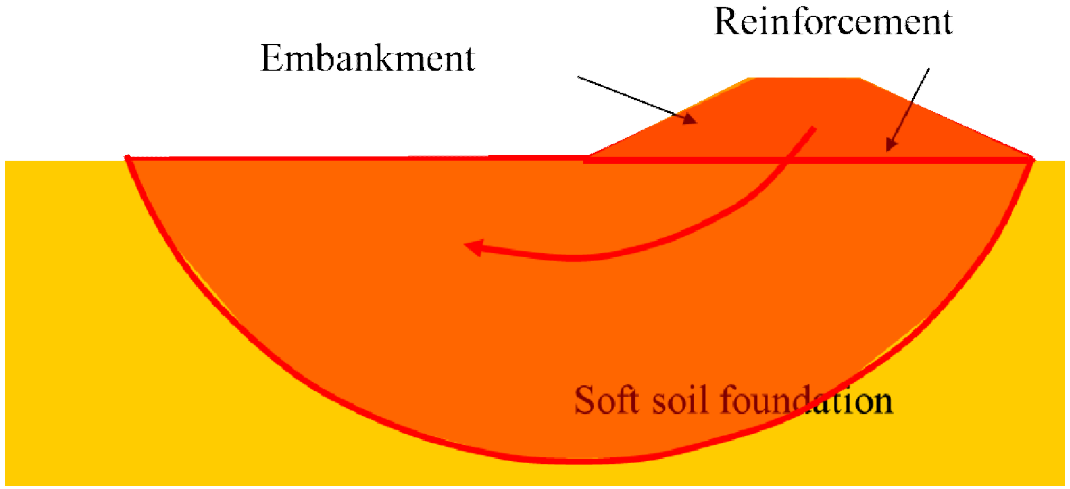


The Rotational stability of the embankment may be analysed by

1. Slip Surface Analysis
2. Plasticity Solutions
3. Finite Element Analysis

Overall stability of the embankment and Foundation may be analysed by Conventional Slip Surface Analysis.



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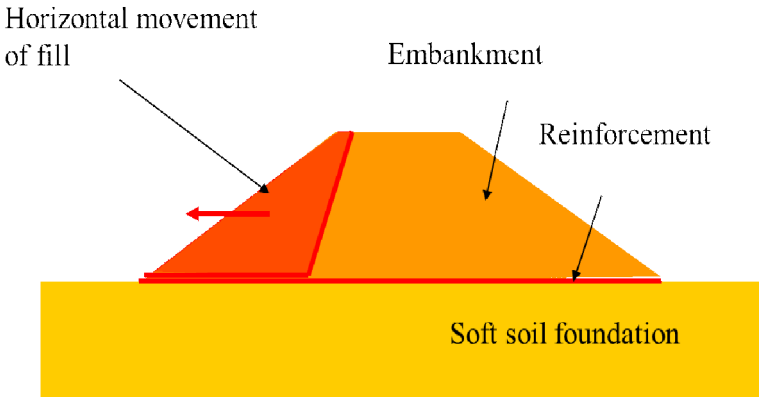

The basal reinforcement functions to resist the horizontal outward thrust of the embankment fill. The load in the reinforcement is a maximum at the edge of the crest of the embankment. The reinforcement load is:

$$T_{ds} = 0.5K_aH(f_{fs}\gamma H + 2f_q w_s)$$

Where, K_a is the active earth pressure coefficient $= \tan^2\left(45^0 - \phi'_{CV}/2\right)$

f_{fs} is the partial factor for soil unit weight,

γ is the unit weight of the embankment fill,

f_q is the partial load factor for external applied loads,

w_s is the external surcharge loading.

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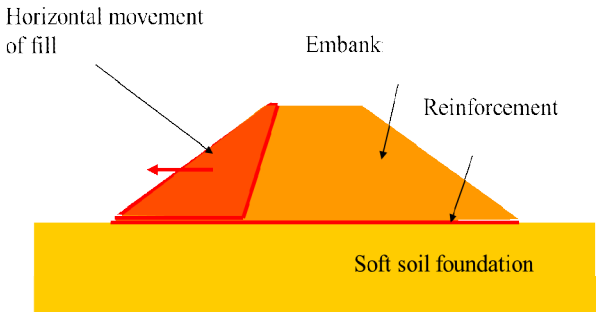
To generate the tensile load, T_{ds} , in the reinforcement, the embankment fill should not slide outward over the reinforcement. To prevent this horizontal sliding the maximum reinforcement bond length, L_e ,

$$L_e \geq \frac{0.5K_aH\left(f_{fs}\gamma H + 2f_q w_s\right)f_s f_n}{\gamma h \dfrac{\alpha' \tan \phi'_{CV}}{f_{ms}}}$$

Where, f_s is the partial factor for reinforcement sliding resistance

h is the average height of the embankment fill above the reinforcement length L_e ,

α' is the interaction coefficient relating the embankment fill/reinforcement bond angle to $\tan \phi'_{CV}$



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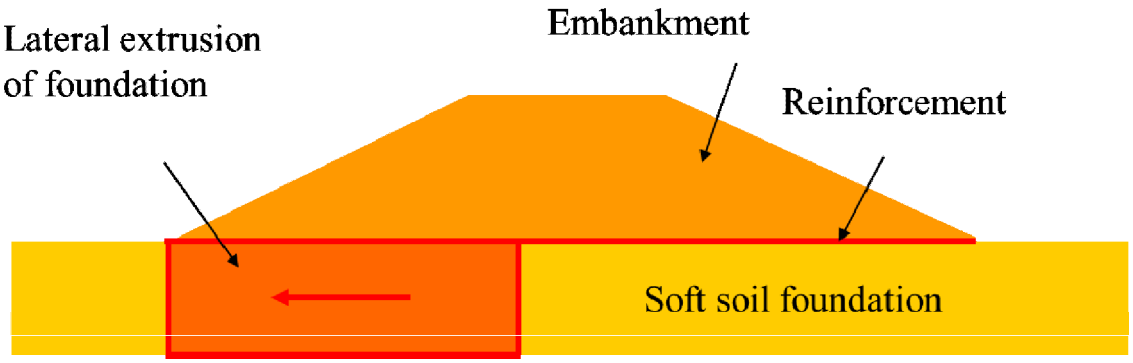


To prevent foundation extrusion the following relationship should apply

$$R_{ha} \leq R_{hp} + R_s + R_R$$

where

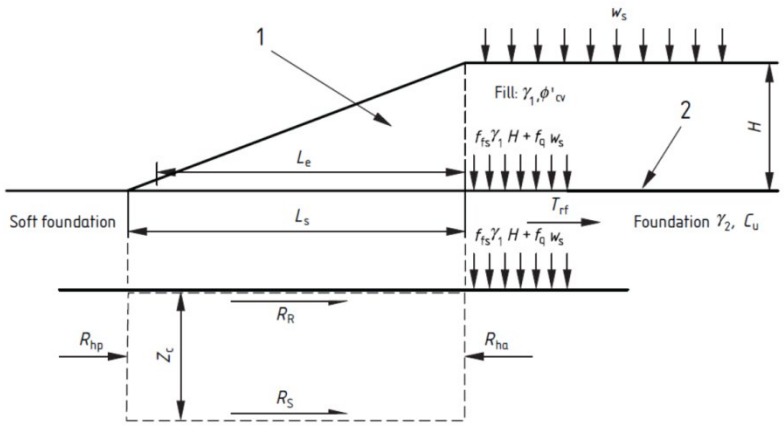
R_{ha} is the factored horizontal force causing foundation extrusion;

R_{hp} is the factored horizontal force due to passive resistance of the foundation;

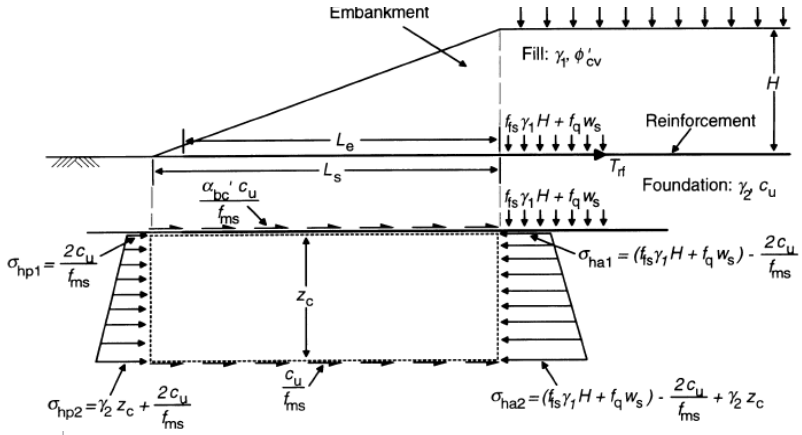
R_s is the factored horizontal force due to the shear resistance of the foundation soil at depth z_c;

R_R is the factored horizontal force due to the shear resistance of the foundation soil at the underside of the reinforcement.

Foundation extrusion stability (contd…)



a) Force components in foundation extrusion stability analysis



The minimum required sideslope length L_s may be determined as follows:

$$L_s = \frac{\left[f_{fs}\gamma_1 H + f_q w - \frac{(2c_u + z_c \rho)2}{f_{ms}}\right] z_c}{\frac{c_u(a_{bc} + 1) + \rho z_c}{f_{ms}}}$$

where

- f_{fs} is the partial factor for soil unit weight, see Table 22;
- f_q is the partial load factor for external applied loads, see Table 22;
- γ_1 is the unit weight of the embankment fill;
- H is the maximum height of the embankment;
- w_s is the surcharge intensity on top of the embankment;
- c_u is the undrained shear strength of the soft foundation layer;
- f_{ms} is the partial material factor applied to c_u, see Table 22;
- z_c is the critical depth;
- a'_{bc} is the interaction coefficient relating the soil/reinforcement adherence to c_u.

Foundation extrusion stability (contd…)

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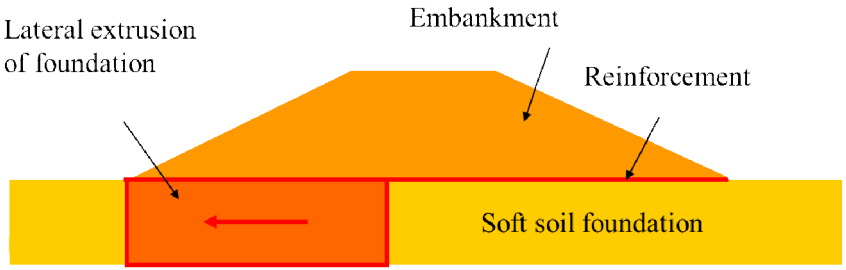

The tensile load generated in the basal reinforcement T_{rf} per metre run due to outward foundation shear stress may be taken from:

$$T_{rf} = \frac{a'_{bc} c_{uo} L_e}{f_{ms}}$$

where

L_e is the length of the reinforcement required, see Figure 73;

c_{uo} is the undrained shear strength of the foundation soil at the underside of the reinforcement;

f_{ms} is the partial material factor applied to c_u, see Table 22.

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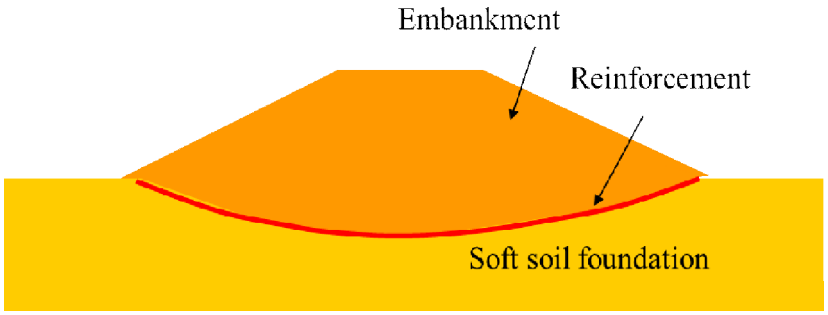
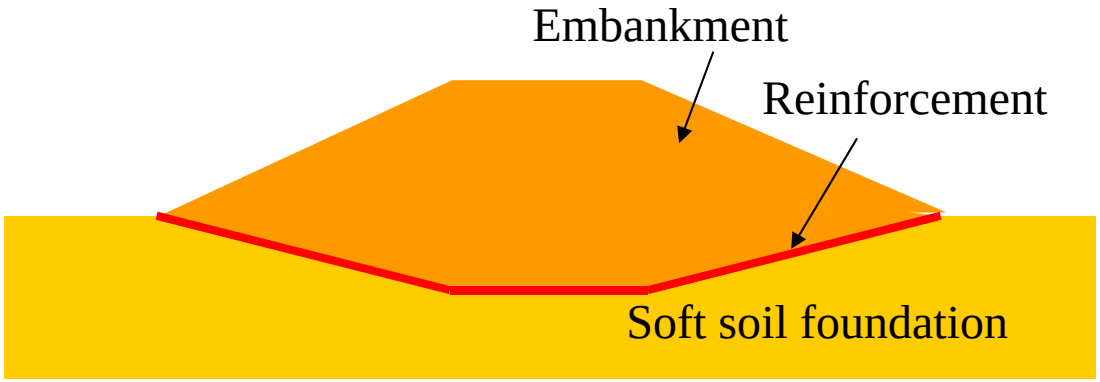


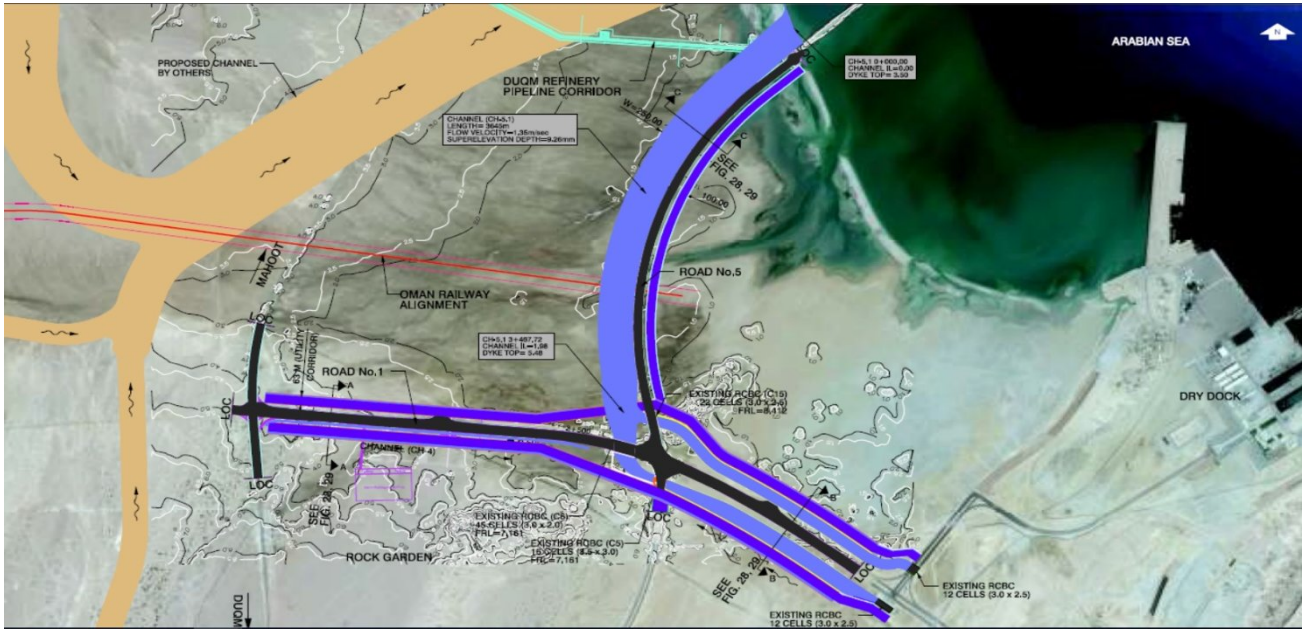
The maximum allowable strain in the reinforcement ε_{max} should be limited to

1. Initial short term conditions; strain < 5 %
2. Long term conditions; strain < 5-10 %

Presence of Basal Reinforcement does avoid foundation settlement but only reduce the differential settlements due to less deformation considered in design



Plan view of road network and drainage channels in Duqm roads project.



Road network (indicated in black colour thick lines) and drainage channels (indicated in light blue colour thick lines).

The roads are designed to be constructed on a 3m high embankment with 2H:1V side slopes.

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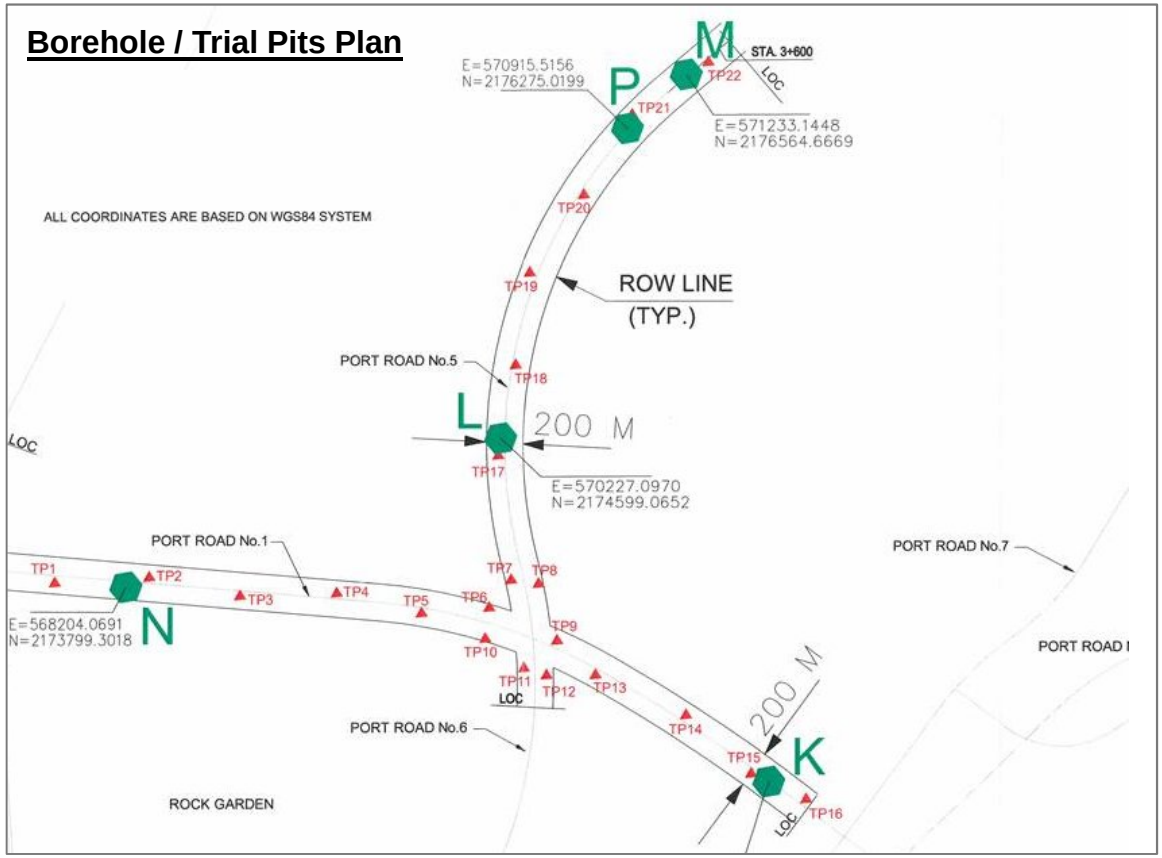
Borehole / Trial Pits Plan



Summary of SPT N-Value

NSPT Values vs depth

z [m]	BH-K	BH-L	BH-M	BH-N	BH-P
1	50	1	5	5	26
2	50	1	8	9	50
3	50	1	6	2	50
4	50	1	25	36	
5	50	1	6		
6	50	4	6		
7	50	2	50		
8		16			
9		50			
10					

Gravel / Gravel with Cobbles
Sand/Sanstone
Silt/Sitstone
Conglomerate

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- Soil investigation reports confirmed the presence of Compressible, Very Soft to Soft cohesive soil (Silt / Clay), which demanded the ground improvement works prior to the construction of the proposed road embankments.

- The report summary also concluded that the soft soil layer (Soft Sabhka deposits) extended down to a depth of 3.5m – 8m below the existing ground levels.

- Based on the SPT N Values the undrained shear strength of the subsoil was recommended as **Cu=10 Kpa.** As given in the Geotechnical Report, the below Geotechnical Parameters were considered in our design and analyses:

Moisture Content [%]	27.0 to 45.0
Liquid Limit [%]	25 to 106
Plastic Limit [%]	19 to 55
Plasticity Index	6 to 51
Bulk Density [kg/m3]	1710 to 1850
e_0	0.81 to 1.24
Cc	0.300 to 0.733

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Consolidation Settlement Calculation

As a summary:

- Settlement calculations at different locations indicates that except at BH-L location, settlements at all other location are comparatively low.

- At BH-L, the calculated consolidation settlement is 552mm which is expected to be completed in 534 days. 50% settlement (276mm) is expected to be completed in 124 days which is within the construction period and the remaining 276mm in another 410 days (~one year).

Rotational Stability Analysis results for Duqm Roads 1 & 5 project

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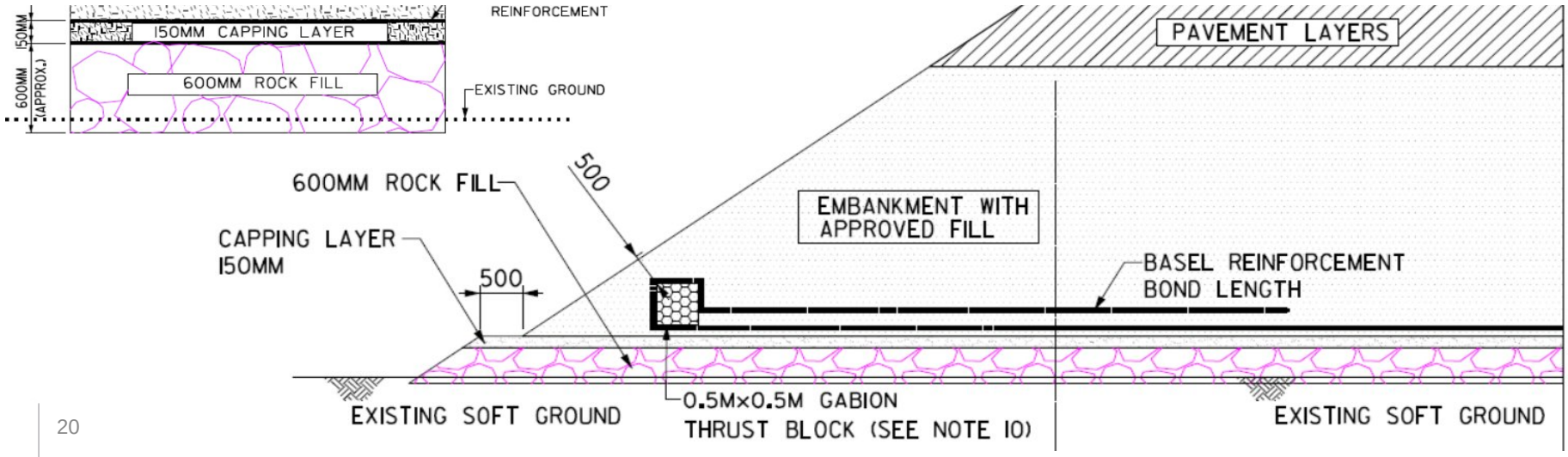

Cost comparison between basal reinforcement option and other available ground improvement solutions in Oman market for Duqm Roads 1 & 5 project

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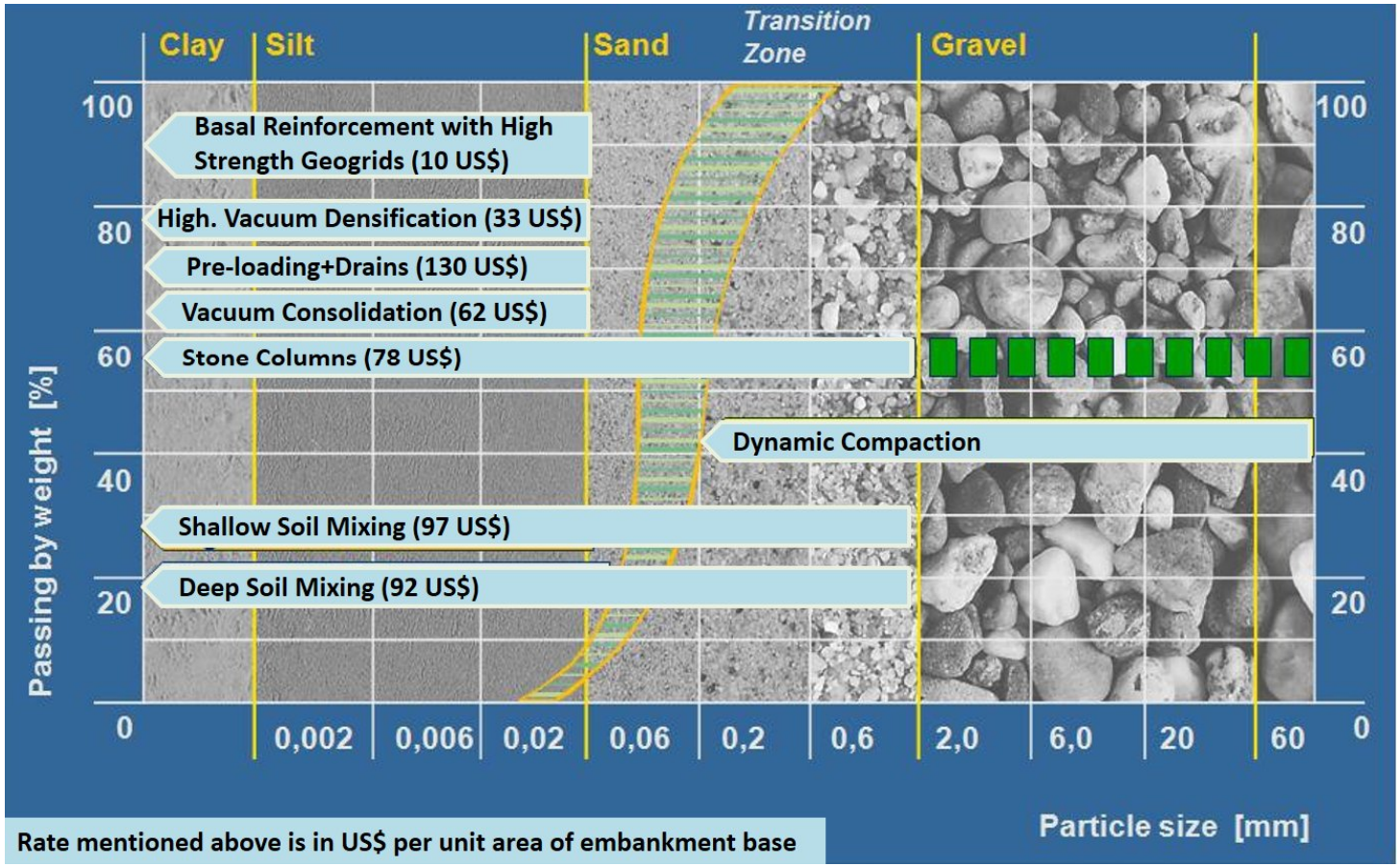

Rate mentioned above is in US$ per unit area of embankment base

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Duqm Roads 1 & 5 project: Current stage of construction…

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Duqm Roads 1 & 5 project: Current stage of construction…

Concluding remarks

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- Very low bearing capacity muddy sabkha soils are often found around the coasts of the Middle Eastern Peninsula.
- A very cost-effective way of stabilization of these sabkha soils is the use of geosynthetics.
- High strength geosynthetic layers can be used as basal reinforcement for the construction of embankments over soft soils, satisfying the stability criteria laid by the international standards like BS 8006: 2016.
- Depending on the type and magnitude of expected settlement of foundation sabkha soil, this technique can be adopted replacing the conventional deep ground improvement solutions for majority of the cases.
- Present case study clearly throws light to understand the problems associated with the design and construction of embankments over soft sabkha soil which is commonly found in the Arabian Peninsula.

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THANK YOU

For further assistance, please contact;

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