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Anchored earth technique using Semi-Z shaped mild steel anchors

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ABSTRACT: Anchored earth technique of soil reinforcement has been developed over the last eight years as an appropriate technology and economy-intensive one with the use of Semi-Z shaped mild steel anchors, and the first Indian prototype, constructed in July 1989, has withstood two monsoons and field traffic loading successfully. The theory of resistance of the special anchors and two new prototype designs are presented in the paper.

1 INTRODUCTION

In an effort to make the anchored earth technique a simple appropriate technology and economy-intensive one, a Semi-Z shaped mild steel anchor has been developed over the last eight years. Exhaustive laboratory studies using largely small scale models, compatible with several micro-structural techniques, made this possible (Singh et. al. 1985, Singh and Finlay 1986, Singh 1987, Singh and Siavoshnia 1988).

The holding capacity of the anchors is a result of the passive resistances mobilised by them over three-dimensional soil wedges that form on the inclined and the straight arms of the anchor during its outward movement through the compacted fill soil under superimposed loading.

The first Indian field application of the technique, using Semi-Z shaped mild steel anchors, was made in July 1989, to construct a vertical-faced 3.5 m long x 2.5 m high x 7.5 m wide approach embankment to a small road bridge using the locally available silty clay soil (Singh 1989, Singh et. al. 1990). Continuous monitoring of deformation of the facing elements, holding the anchors in their positions, has shown satisfactory results, under the imposed field traffic loading and the intervening two monsoon periods. It was established that stable conditions, exhibited by negligible further movements of the facing elements, were achieved in a period of 18 months from the time of construction (Singh and Agrawal 1991). It must be recognised that anchor movement under superimposed loading is a normal and necessary event for the development of the full three-dimensional soil wedges, and hence consequently of the maximum passive pressures, or resistance, to develop in the system.

2 THEORY OF ANCHOR RESISTANCE

To estimate the maximum pull-out resistance, simplified mathematical formulae and expressions have been developed to calculate the areas of failure surfaces which develop around the effective end of the anchor (Singh et. al. 1985). The three-dimensional soil wedges, though pear-shaped in reality, were assumed to be bounded by simple surfaces of revolution. Exact delineation of these soil wedges was difficult.

Fig. 1 shows the shape of the Semi-Z shaped with rounded corner anchor used in the construction of the first Indian prototype, and the horizontal trace of the wedge boundaries that develop on the straight and the inclined arm of the anchor. The trace for the inclined arm is a segment of a cycloid or a circle, as appropriate to the type of soil under consideration, the former being for cohesive soils and the latter for cohesive-frictional soils.

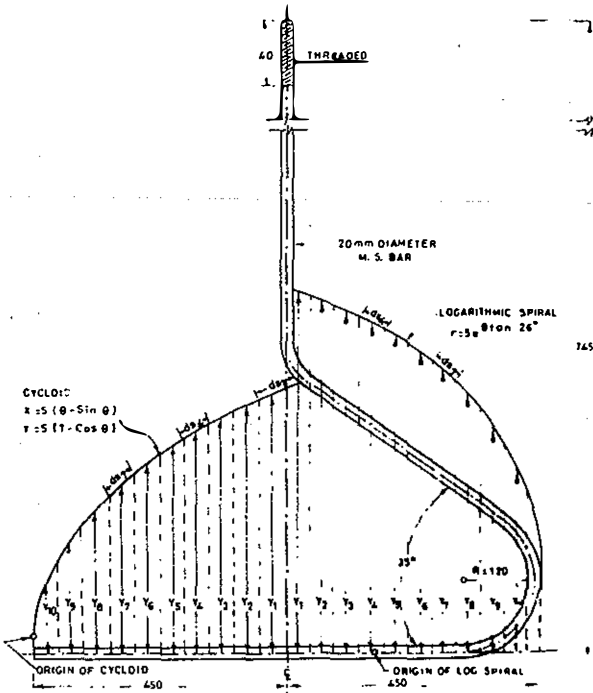

Fig.1 Semi-Z prototype anchor and horizontal traces of the three-dimensional soil wedge boundaries for full monilisation of passive resistance in the local silty clay fill

The drained or effective soil parameters, determined from triaxial tests on representative compacted fill soil samples, are used to get the numerical values of the coefficients in the equations of the log spiral and the cycloid, and they are fitted as shown in the figure. Number of slices of equal width are established, and the product of Y and ds identified in the figure, is summated for both the surfaces. The surface areas were assumed to be terminated on a vertical plane passing through the longitudinal axis of the straight arm of the anchor, i.e., a π revolution was the limit used to calculate the soil wedge surface area, A, effective in mobilising the anchor resistance. A passive wedge resistance coefficient, Kp, was determined, and was used to calculate anchor resistance as below:

$$P_p = \sigma_n \tan^2(45^\circ + \phi'/2) + 2c'\tan(45^\circ + \phi'/2)$$

where; P_p = passive resistance

σ_n = vertical stress at anchor level in KN/m^2

c' = effective cohesion in KN/m^2

ϕ' = effective angle of internal friction,

then, $K_p = P_p/\sigma_n$

and, anchor resistance = $K_p \times \sigma_n \times A$

A factor of safety of 3 was used, and the design of the anchored earth system could be proceeded in the usual way following from the anchor resistance calculated for the anchors at different levels in the compacted fill.

A method has further been worked out to determine anchor resistances for intermediate pull-out stages considering partial development of soil wedges (Gupta 1990).

Strength is also mobilised, additionally, by the "dowel" reinforcement effect of the straight shaft of the anchor, when frictional forces develop along the shaft in the incipient pull-out condition. Although these forces were considered in the analysis of laboratory pull-out results, they were neglected in design as offering a higher factor of safety than the value of 3 actually adopted.

3 ANCHORED EARTH PROTOTYPES

Details of the design and construction of the first Indian anchored earth prototype have already been presented (Singh 1989, Singh et. al. 1990).

Two alternative designs for a 6m high approach embankment for the new Varuna Bridge at Varanasi are presented hereunder:

1. Fig.2 shows the Design I, wherein there is no curtailment of the stem length of the anchors. The design is similar to that of the first Indian anchored earth prototype mentioned above.
2. Fig.3 shows the Design II, which incorporates curtailment of substantial lengths of "dowel" action component of the straight shaft of the anchor reinforcement. In this design, further savings in steel used have been attempted by providing anchors with curtailed shafts alternating on left and right sides of the centre line of the embankment in adjacent vertical sections, as depicted in the figure. In this way savings of about 70 per cent of steel could be effected, if only a 30 per cent reduction in ultimate maximum strength could be accounted for.

No propping of facing elements during the construction of the design given in Fig.2 would be required, since any small movement of the anchor or the facing element starts to mobilise the passive

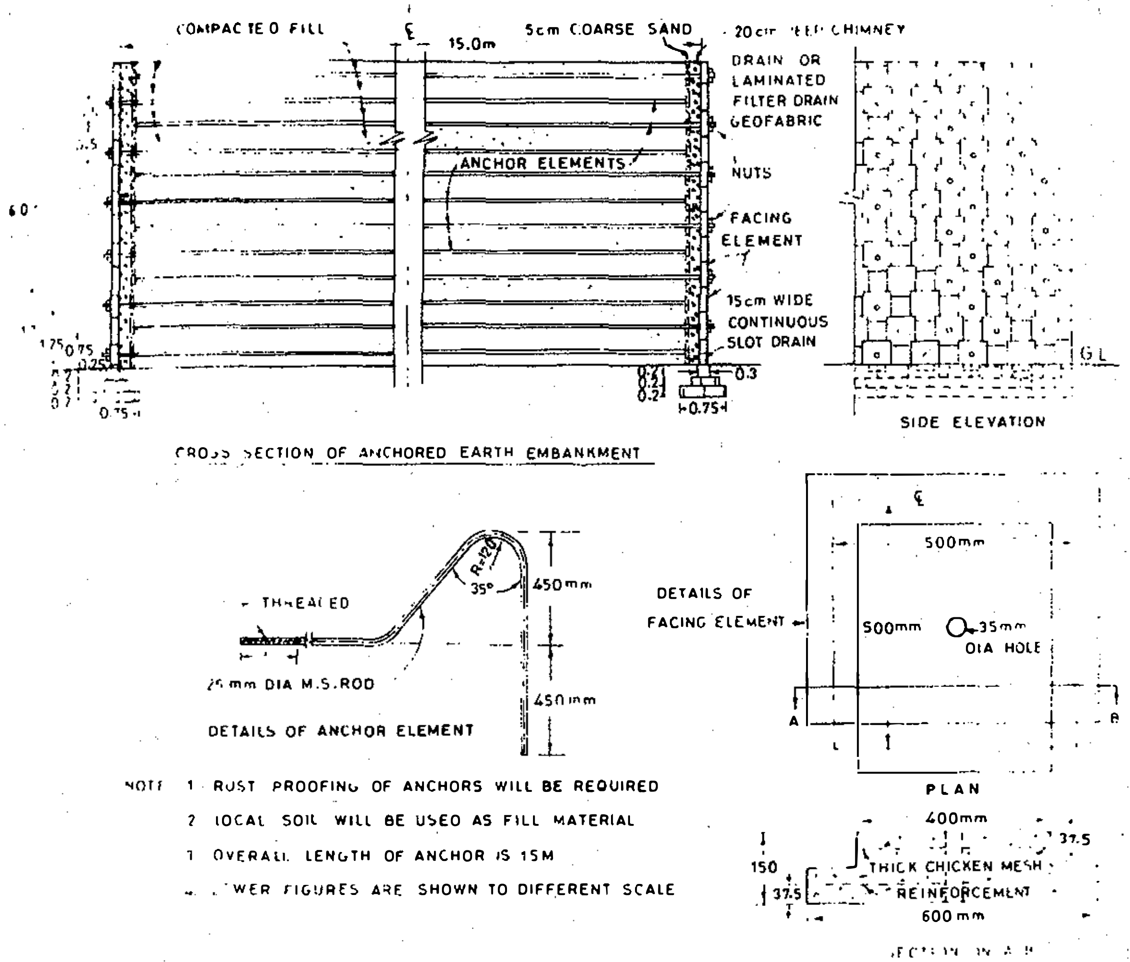

Fig.2 Design I for approach embankment for new Varuna Bridge at Varanasi

pressure. However, propping would be required in case of the construction of design given in Fig.3.

Although the fill soil for the new Varuna Bridge anchored earth prototype construction is a silty clay, it may be noted that all cohesive and cohesive-frictional soils are suitable for anchored earth construction.

Corrosion mitigation of the anchors was attempted by using a three-coat epoxy-based paint formulation. Coal tar pitch improved by epoxy resin is likely to be similarly effective but considerably cheaper.

The construction technique involved can be quickly mastered by the work force at site, and the job of site supervision is not too involved. Savings in costs of the order of 1/3rd to 1/4th are reported possible for anchored earth structures as compared to conventional alternatives.

Thus considering all relevant factors, the anchored earth technique using Semi-Z shaped anchors could be categorised as an appropriate technology and an economy-intensive technique for soil reinforcement.

4 REINSTATEMENT OF A HILL SLOPE

Figs. 4 and 5 show the design proposals for stabilisation and reinstatement of a 15m high hill slope using the anchored earth technique. The particular site location is the Gethia slip on the Bareilly-Almorah road at Km. 12.8 in Nainital district (India). The construction process for reinstatement of the slope has been proposed in five lift stages of 3m height each, as shown in Fig.4, such that each lift stage is constructed and left to stabilise for a period of one year before the next one is constructed. Fig. 5 depicting the proposal details in plan view, shows that the stems of anchors are threaded through bond stones having axial holes of appropriate diameter. The bond stones,

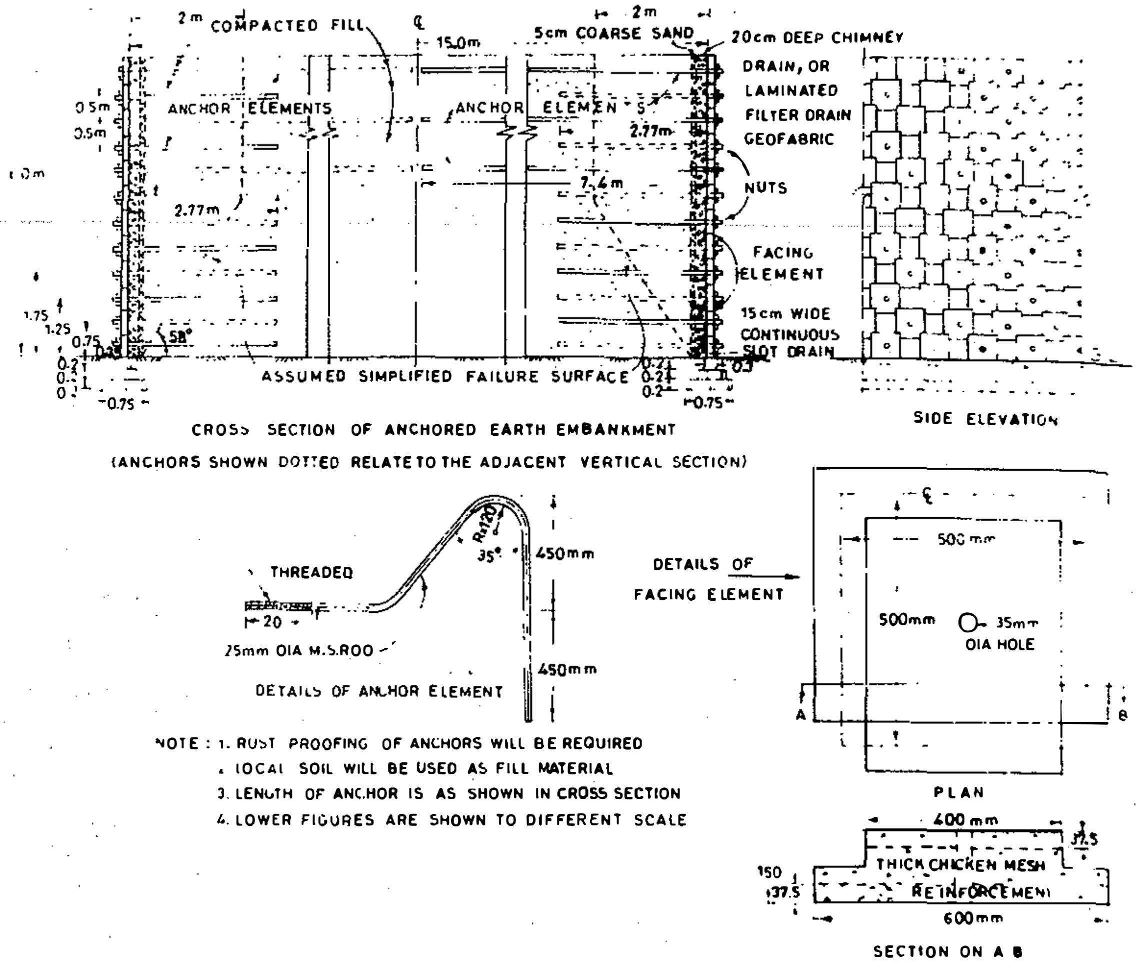

Fig.3 Design II for approach embankment for new Varuna Bridge at Varanasi

which may be of natural stone or of cement concrete, provide additional stability to the corresponding lift stage of the slope, as well as they give added protection to the shafts of the anchors.

5 MERITS AND DEMERITS OF THE TECHNIQUE

Two of the unmatched merits of the anchored earth technique are that no catastrophic failure can ever occur in a properly designed and constructed system, and that almost all types of soils, including waste soils like colliery overburden soils or fly ashes, can be used as fill in the system. Other merits of the technique are that costly and time-consuming land acquisition problem is much minimised or altogether avoided, and that it is a very cost effective soil reinforcement technique.

The inherent demerit arises from the fact that the mild steel of the anchors is prone to corrosion, and waterproof painting to inhibit it is required.

A more effective system, called the 'Combined System', using Semi-Z shaped mild steel anchors alternating with a heavy grade non-woven synthetic permeable geotextile in depth of the fill structure has also been developed by the author and reported earlier (Singh 1990a, Singh 1990b).

6 CONCLUSIONS

Anchored earth technique, using Semi-Z shaped mild steel anchors, has good potential for application as an appropriate and economy-intensive soil reinforcement technology. The first Indian prototype application, made in 1989, has performed very well. Two alternative designs for a 6m high approach embankment, and one for the reinstatement of a 15m high hill slope, are presented in the paper. In the alternative design for the approach embankment, savings of about 70 per cent of steel could be effected, if only a 30

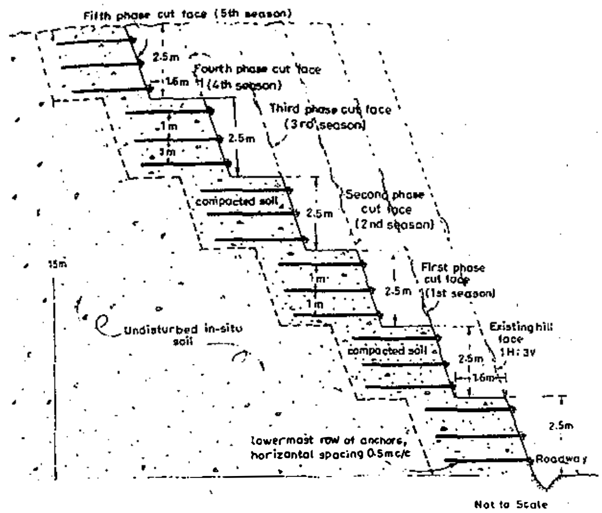

Fig.4 Reinstatement proposal for Gethia slip, Nainital (India), showing the five lift stages in sectional elevation

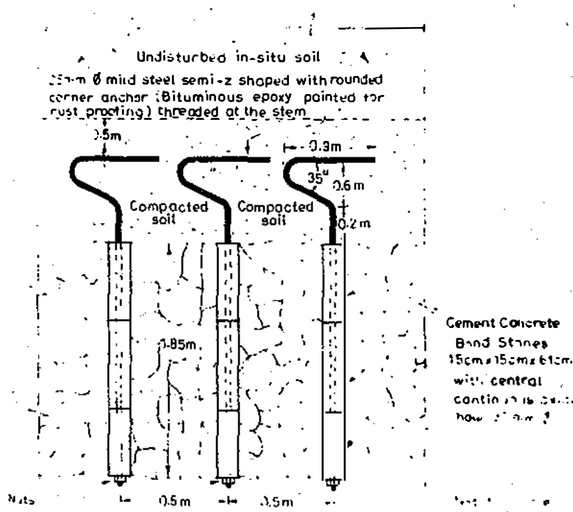

Fig.5 Reinstatement proposal for Gethia slip, Nainital (India), showing details in plan view

per cent reduction in ultimate maximum resistance mobilised could be accounted for.

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