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Review of design of reinforced earth retaining walls for flyovers

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Among several innovative construction techniques, new materials of constructions and new technologies adopted in the construction of flyovers in Mumbai by Maharashtra State Road Development Corporation (MSRDC), the reinforced earth technique has definitely proved the advantages of this technology over conventional reinforced concrete (RC) retaining walls both in terms of saving foundation cost, working space and time.

The reinforced earth technology is in use in the west, especially in Great Britain and France, for the last 35 years or so. British Standards Institute and French Standards have also come out with codes of practice covering this technique containing guidelines and recommendations for design and construction of reinforced earth technique, vide BS 8006:1995 and NF P 94-220, in 1992. The Indian Roads Congress - Highway Research Board, published a Special Report No. 16 (SR-16) "State-of-the-art reinforced soil structures applicable to road design and construction" in 1996. The Department of Transport, UK, has also published the recommended design criteria in the *Technical Memorandum* (BR) BE-3/78.

Background

Basically, there are two commonly used reinforcing materials: one metallic, and the other polymeric. The Terre Armee International – (group TAI) is credited with the invention and development of reinforced earth technology and carried out their first major work as early as 1968 and are since then the holders of the patent filed by Henri Vidal, the inventor of the reinforced earth technique. In India Aimil Ltd are the licensees of this technology and have executed the first reinforced earth retaining wall at the Jammu arterial expressway and since then successfully carried out reinforced earth retaining walls for the ramps of a couple of flyovers recently constructed.

Soil retaining technique has several applications like simple retaining walls, abutment for bridges, high embankment, slope stabilisation, etc. It basically involves incorporating reinforcement in earth / fills to provide steeper slopes than would otherwise be possible. It involves use of a range of reinforcements; such as metallic strips, bars, grids, meshes, sheets, etc embedded in the well compacted fill behind, *Fig* 1.

The grids or meshes are either anchored

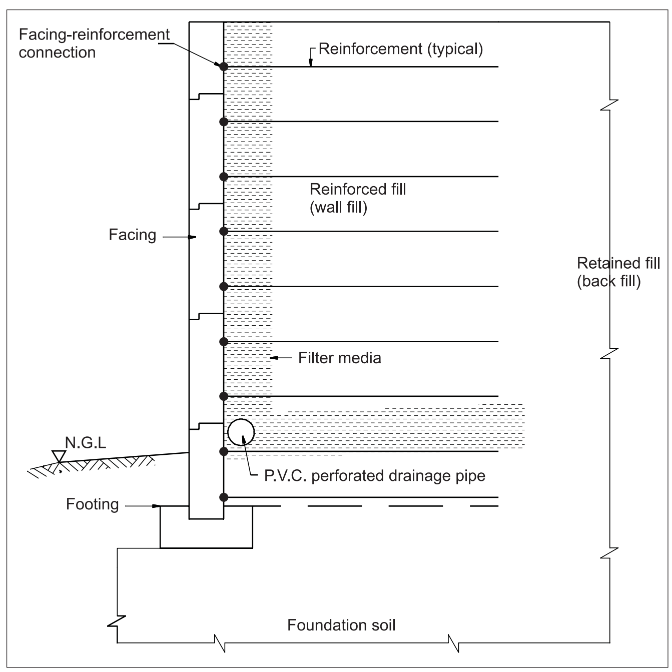

Fig 1 A typical cross section of a reinforced earth retaining wall

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Fig 2 Reinforced earth system with metallic strips, licencees: Aimil Ltd

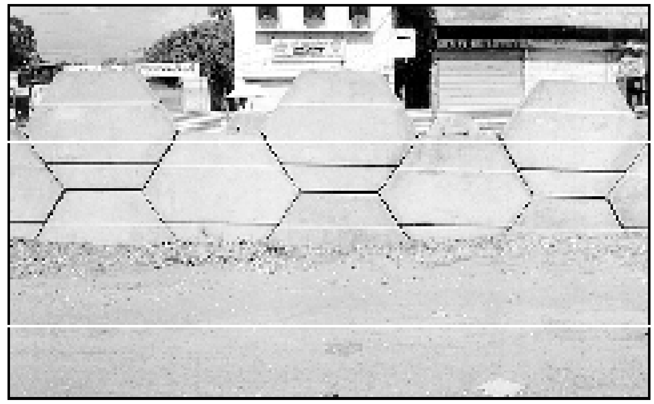

Fig 4 Nehemiah AE wall panels

in facia panels or wrap around, the latter especially in case of polymeric reinforcement. The reinforcement improves the behaviour of the fill both at service condition and the failure stage.

MSRDC has used both types of reinforcements, that is, metallic and polymeric. In India there are two agencies who use metallic reinforcement, namely, Aimil Ltd in a joint venture with group TAI for reinforced earth technology and MBN anchored earth Ltd of Hyderabad, who are representatives of Anchored Earth Sdn Bhd of Malaysia for the Anchored Earth technique. The basic difference in these two systems is the manner in which the force exerted by soil is resisted by embedded reinforcement.

In the case of anchored earth system this is provided by the passive action of anchors and friction along the perimeter of anchor shaft or reinforcement. In reinforced earth technology, only friction is taken advantage of by providing specially prepared high adherence galvanised steel strips as reinforcement, *Figs* 2 and 3. Both these processes use precast panels as facia elements, the shapes being different, *Fig* 4.

Design philosophy

As far as design is concerned both adopt the provisions of BS 8006; adopting limit state method with partial safety factors and check for 'external stability' and 'internal stability'. The IRC has not yet revised their codes to suit limit state method and continues to design roads/ bridge structures using the working stress method, with the factor of safety approach; the sample calculations of solved examples presented in Special Report No. 16 are based on the working stress method.

MSRDC in their first tenders for flyovers in 1997 stipulated that design of reinforced earthwork shall be in accordance with the ministry of surface transport (MOST) specifications and guidelines contained in IRC Special Report No. 16. Aimil Ltd, the Indian counterpart of TAI group then had no full fledged technical wing conversant with reinforced earth wall design and therefore the design calculations for their first work of flyover at Aarey junction on the western express highway in Mumbai was prepared using a computer programme available with their French counterpart. This was based on the limit state design philosophy, confirming to BS 8006. It was therefore required to revise these calculations to suit working stress method and conforming to various practices and codes published by Indian Roads Congress. This was done by project management consultants (PMC)—Technogem Consultants, Mumbai, in association with engineers of Aimil, India.

While doing this it was necessary to revise various values of engineering properties of the soil stipulated in BS:8006 as per the actual material proposed to be used on the work, after carrying out the necessary laboratory tests. This was done after confirming the suitability of source of

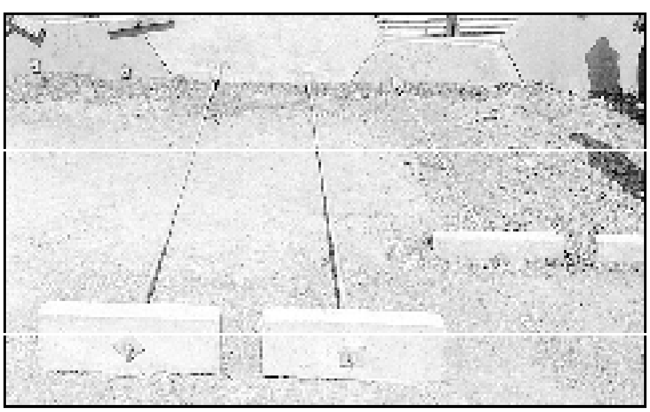

Fig 3 Anchored earth system with metallic bars and anchor blocks, licencees: MBN Anchored Earth Ltd

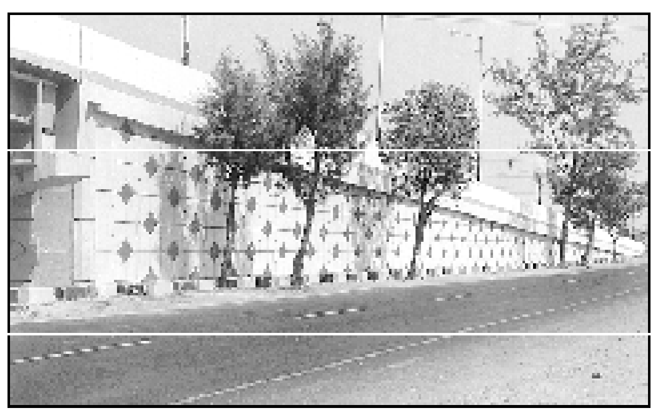

Fig 5 Reinforced earth wall

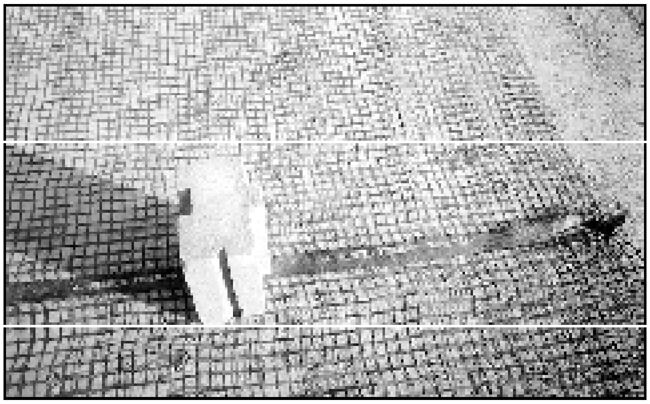

Fig 6 *Miragrid*

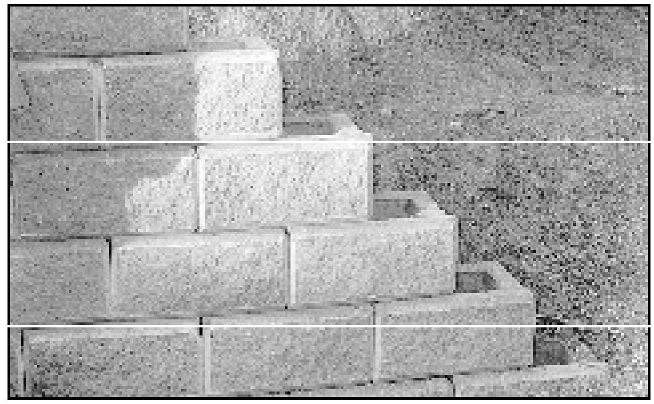

Fig 8 Jkar modular facia blocks

murum with respect to availability of quantum and its suitability for reinforced earthwork as stipulated in BS 8006 with respect to electrical resistivity, grading, etc.

Metallic reinforcement

The metallic reinforcement was supplied by Aimil which was manufactured in India (as per their parent firm as patented). Galvanised high adherence carbon steel strips of 140 micron, 40 mm x 5 mm, in class 2 steel as per IS : 1875, with minimum ultimate tensile strength (UTS) of 490 N/mm^2 were supplied. For facia panels Aimil supplied samples of forms adopted by them in their work at Jammu. Additional forms were prepared after carrying out some modifications in front appearance and panel casting was done by Aimil through Prestressing Corporation of India, factory at Kalamboli (near Panvel about 30 km away from the work site). The various fasteners required to be embedded in facia panels, joint materials like EPDM pads, foam strips, etc. were supplied by Aimil. The scope of work included erection of walls, installation of strips using labour and machinery, which was provided by the principal contractors, Simplex Concrete Piles (I) Ltd, and day-to-day supervision of the work of backfilling and compaction carried out by other agencies.

Besides a change in the design philosophy, MSRDC stipulated loading confirming to IRC Codes, that is, 1.2-m high live load surcharge effect, provision of crash barriers as per type P6; design life of 120 years; minimum depth of foundation of 1000 mm below ground level; zinc galvanised with 1000 g / m^2. The external and internal stability should yield minimum factor of safety of 1.5 under service condition.

During scrutiny it was revealed that the value of μ, the coefficient of friction between the fill and high adherence strips, adopted by Aimil, took into consideration interaction coefficient relating to soil / reinforcement bond angle (BS 8006) obtained from pull-out test, linearly varying from maximum at top to uniform value of tan ϕ at the critical depth of 6 m. The maximum value of friction between high adherence strips and backfill soil as given in French Standards NF P 94 – 220 and incorporated in SR – 16 is

$$\mu^* = 1.2 + \log C_u$$

where,

C_u = ($D60/D10$) = Coefficient of homogeneity of back fill material which is 2 (minimum) as required for soil to be suitable for reinforced earth walls.

The documentary evidence of the above assumption was considered as not sufficient. Moreover, Aimil had not carried out any pull-out test either in the field or laboratory in India as stipulated in BS-8006. Results of pull out tests carried out by Aimil outside India were not accepted by PMC who insisted on restricting the value of $\mu = \tan \delta$, where δ is angle of friction between

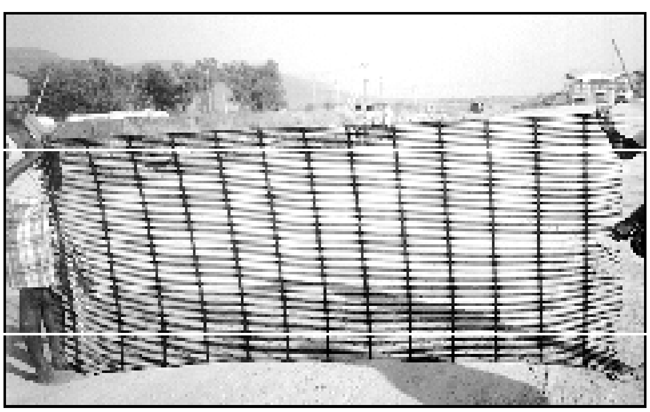

Fig 7 *Tensar* geogrid

Fig 9 Reinforced wall construction for Kalamboli flyover

the reinforcement material and the soil. As per practice, the value of δ is restricted to 2/3 ϕ, the angle of internal friction of the soil. The variation between the μ value at top and critical depth was accepted. Observations have indicated that earth pressure near the top is pressure at rest because compaction at top is more effective. The maximum and minimum value of μ was assumed as equal to tan (2/3 ϕa) and tan (2/3 ϕc), where ϕa is peak value and ϕc is critical value of angle of internal friction. The engineers from Aimil accepted this argument and allowed the PMC to revise the design accordingly.

This issue was further discussed at large in the open forum of the national workshop held in Mumbai on "Reinforced soil retaining walls" in November 1998[1]. However, no definite conclusion was arrived at.

Aimil reinforced earth walls are not provided with separate filter media behind the facia. Large gaps remain between panels because of the provision of bearing pads, for horizontal joints between panels, made of elastomer with vulcanised EPDM. These gaps are closed using flexible open cell polyurethane foam strips or non-woven fabric strips. MSRDC raised this issue in the national seminar and called for discussion. The general consensus was in favour of providing minimum 600 mm thick filter media of graded aggregate between facia panels and back fill with perforated PVC pipe of 200 mm diameter covered with non-woven geotextile at bottom, to drain out water collected from backfill, though this entailed extra cost.

The reinforced earth walls so far constructed using this patented process have behaved satisfactorily and no noticeable distress has been observed when inspected two years later, *Fig* 5.

Anchored earth system

MBN anchored earth system has also been tried for flyovers constructed in Mumbai and Hyderabad. There is no much difference in design involving checks for external and internal stability. The point of argument is whether friction capacity can be considered to co-existent with anchorage capacity, as friction more or less reduces after movement of strip and later needs large movement of anchor blocks to generate the design being based on failure condition. Recent specifications and design chapter now under consideration with MSRDC have modified these provisions of BS 8006. The other provision of BS-8006 not consistent with classical theory is ultimate value of passive pressure; the one stipulated in equation vide clause 6.6.4.2.3 of BS 8006 : 1995 which is reproduced below.

Anchored earth: There are a variety of different anchored earth systems. The tensile forces generated in the anchor should be calculated in accordance with a 6.6.4.2.1 Local stability in terms of rupture should be considered in accordance with clause 6.6.4.2.2 or a 6.6.5.2.5. The pull-out capacity of anchor reinforcing elements to satisfy local stability consideration is:

$$\frac{P_{uj}}{f_p f_n} \geq T_j$$

where,

P_{uj} = ultimate pull-out resistance of the anchor

f_p = partial factor for reinforcement pull-out resistance, see Table 16

f_n = partial factor applied to economic ramifications of failure, see Table 3;

T_j = maximum value of the $_j$th level of reinforcement from clause 6.6.4.2.1.

The ultimate pull-out resistance of an anchor element in the $_j th$ layer may be determined from :

$$P_{uj} = P_{sj} + P_{aj}$$

$$P_{sj} = 2\mu B_s s_{vj} L_{ej}$$

$$P_{aj} = 4\, K_p B_a t_a \sigma_{vj}$$

where,

P_{sj} = shaft or loop resistance developed by friction beyond the potential failure plane, at the $_j$th layer of anchors;

P_{aj} = bearing resistance at the $_j$th layer of anchors;

μ = coefficient of soil / reinforcement friction and is determined according to the relationship given in clause 6.6.4.2.2;

B_s = long term horizontal projection area of shaft or loop;

K_p = horizontal passive earth pressure coefficient;

B_a = long term width of anchor head;

t_a = long term height of anchor head;

σ_{vj} = vertical applied pressure at the $_j$th layer of anchors;

L_{ej} = length of the anchor shaft beyond the potential failure plane.

Grouted anchor elements should be treated as ground anchors and the ultimate pull-out resistance should be determined from the relations given in BS 8081.

Polymeric reinforcement

Not only the French, but the department of transport, U.K.- BE 3/78 accepted the use of geo-textile as reinforcement in soil reinforced structures. The IRC SR-16 and standard specifications for road/bridges allow use of geo-textile made from synthetic polymers using polyethylene, polyamides, polyester, polypropylene; woven, non-woven or extruded bi-axial or uni-axial grids, sheets, etc, for reinforced fill/soil walls.

MSRDC has used all the above types of geo-textile as reinforcement for retaining walls along flyover ramps and even behind abutment piers, though load bearing abutment proper have not so far been tried using this technology. As of today geogrids suitable for reinforced soil are not manufactured in India; most of geo-textiles and geogrids used so far in civil engineering works like *Kologrid*, *Miragrid*, *Fortrac* or *Tensar* are imported from abroad. All these varieties have been used in flyover ramps or reinforced walls, *Figs* 6 and 7.

Differences

The design method and approach remain the same as for metallic reinforcement with regards to check for external stability and internal stability for pull-out and tension. Most of the soil reinforcement wall so far constructed using geosynthetics have used concrete precast blocks as facia element, *Fig* 8.

Precast panels have been used exceptionally in the case of reinforced wall constructed for Kalamboli flyover between flyover proper and road over bridge. The height of this wall is more than 10 m, *Fig* 9.

Unlike metallic reinforcement, which is inextensible with very low strain value (less than one percent as per BS 8006), polymeric reinforcement has high strains greater than one percent reaching peak value as high as 15 percent including creep effect under maximum stress. Moreover, the creep value of polypropylene and polyethylene grids are higher. Both the strain and creep values are time dependent and also depend upon the temperature of the fill material. The use of geosynthetics for civil engineering purpose, particularly for soil reinforcement is of recent origin. The long term effects of stress, temperature, creep, etc, are extrapolated values from short term tests and therefore have to be cautiously used with appropriate values of partial safety factors.

The environmental effects, biological effects, fill material, damage factor, effect of construction method, joint efficiency, etc, are all based on western conditions and western practice of quality assurance schemes, which are definitely different from Indian conditions with respect to material, labour and quality control. Therefore the values suggested by manufacturers need to be vetted properly before using the same in our designs. Some of the initially constructed reinforced walls using geogrids have behaved differently from what was expected during design. Especially in Mumbai and coastal regions where total rainfall and intensity of rainfall is high and backfill material not consistent, the design using geogrid as reinforcement has to have an extra factor of safety.

The main drawback experienced in the use of geogrid is that there are no accredited laboratories in India where one can carry out even a simple tensile strength test, leave alone creep or long term strength values and isochronous curves, damage factor, u-v effect, chemical effects, biological effects etc. The designer therefore has to rely on manufacturers' literature and accept the values, tested either in their laboratories or internationally accredited laboratories under western conditions and workmanship.

Since the number of segment for facia are large, in case of precast blocks, compared to panels, it is very difficult to obtain consistent results with respect to finish, strength, colour and sharpness, and to maintain time schedule. The imported block making machines being very few, locally manufactured machines were extensively used which gives rise to large number of rejections of precast blocks hampering the time schedule of work. The skilled labour required for block work is also more when compared to cranes used for errection of facia panels, which gives rise to inconsistency in work with respect to finish, workmanship and output.

Conclusion

Mere short-term performance for a couple of years is not sufficient to infuse confidence in the minds of engineers in India and till we observe the performance of walls for at least 10 years or so (design life being 120 years), we have to be careful in design and should be extra cautious in selecting partial safety factors, load factors and factors of safety.

References

1. ______*National workshop on "Reinforced soil retaining walls"*, Mumbai, November 1998, Indian Institution of Bridge Engineers.

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