Alternate Technologies in Highway Construction

By

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CONTENTS

1. INTRODUCTION

India has undertaken large highway infrastructure up-gradation projects that also entail maintenance of the same in long run. Alternate cost effective technologies are seeing light of day in many areas of highway construction. Some of these are i) use of biodegradable non-woven coco mattresses for erosion control as an alternate to stone pitching, ii) use of fiberglass grids for flexible overlays as an alternate to PET/PP grids and/or higher thickness of overlay in order to prevent/retard reflective cracking and iii) Mechanically Stabilized Earth (MSE) Walls and Reinforced Soil Slopes (RSS) for building high embankments as an alternate to RCC retaining walls.

The paper deals with first two of the three technologies mentioned above in brief, focusing primarily on the introduction to the technology, case studies to support the cause and benefits of the same like more environment friendly nature and economy etc.

More focus has been laid on the last of the above, as Mechanically Stabilized Earth (MSE) Walls and Reinforced Soil Slopes (RSS) are being widely used for building high embankments due to various reasons such as limited ROW, to minimize land acquisition, poor founding soil conditions, economy considerations and ease of construction etc. However, the Indian market of the MSE walls' systems is predominantly supplier driven and lot of (mis) information is fed into it. Generic comprehensive specifications are not available and in its absence many problem arise during design and execution stages apart from many instances of Contractual complications. Some case studies out the experience of the author and colleagues have been presented to highlight the seriousness of the issue.

Incorrect implementation of the design and construction practices has given the technology a bad name and adverse opinions are already doing circles in the implementing authorities' corridors, which need to be corrected.

2. SURFACE EROSION CONTROL FOR HIGH EMBANKMENTS

2.1 The exposed surface of the high embankments is prone to rain cuts. Stone pitching has been used as the only solution for the problem, which also, in the opinion of the author, is not a permanent solution. Breaches have been observed in many cases and the repair is an expensive affair. Refer Plate 1.

PLATE 1 : STONE PITCHING FOR EROSION CONTROL OF HIGH EMBANKMENTS

2.2 A more permanent solution that is close to nature lies is stabilising the surface of the soil by using native vegetation like grass and shrubs etc.

2.3 Jute based geotextiles have been used in many instances and given satisfactory results. However, problems have been noticed in these treatments, as well. A more detailed description of the same can be found in the literature.

2.4 A more permanent solution was desired and has been found in use of biodegradable non-woven coco mattresses for erosion control. The mattress has a blend of polymeric fibers, which gives it some strength. The application process is very simple and consists of dressing of the embankment surface, laying of the mattress, spreading of seeds and watering for about 2 weeks. The roots of the vegetation shall develop and grow with time, which shall eventually stabilize the embankments. The life of the coco fibers is about 4-5 years and during this period, it helps stabilize the surface in addition to the vegetation. The final product is a more greener, environment friendly construction, which is not only more economical but also a more permanent solution. Refer plate 2 for a case study of a railway embankment.

PLATE 2: LAYING OF COCO EROSION CONTROL BLANKET (CLOCKWISE FROM TOP LEFT) DRESSING OF EMBANKMENT, LAYING OF COCO ECB, PERFORMANCE AFTER 10 DAYS AND AFTER SEVEN WEEKS

3. FIBERGLASS GIRDS TO PREVENT REFLECTIVE CRACKING

3.1 WHAT IS REFLECTIVE CRACKING?

Many pavements, which are considered to be structurally sound after the construction of an overlay, prematurely exhibit a cracking pattern similar to that which existed in the underlying pavement. This propagation of an existing crack pattern, from discontinuities in the old pavement, into and through a new overlay is known as **reflective cracking.**

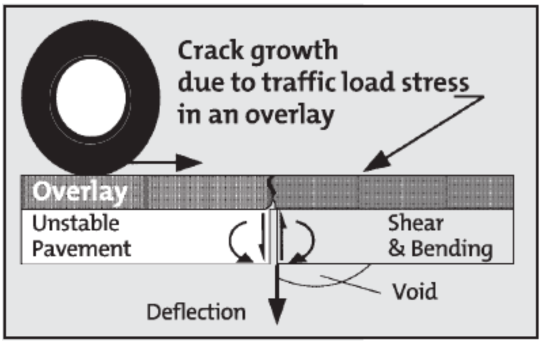
Reflective cracks destroy surface continuity, decrease structural strength, and allow water to enter sublayers. Thus, the problems that weakened the old pavement are extended up into the new overlay. The cracking in the new overlay surface is due to the inability of the overlay to withstand shear and tensile stresses created by movements of the underlying pavement. This movement may be caused by either traffic loading (tyre pressure) or by thermal loading (expansion and contraction). Refer Plate 3 and 4.

Fatigue associated cracking occurs when shear and bending forces due to heavy traffic loading create stresses that exceed the fracture strength of the asphalt overlay. This is a structural stability problem.

Pavement instability is generally due to heavy loading, improper drainage, and time. Unstable Portland cement concrete (PCC) slabs are often identified by excessive movement or deflection during loading accompanied by the presence of water and fines pumping upward at the joint.

Instability in asphalt cement concrete (ACC) pavement is typically characterized by a series of closely spaced multidirectional fatigue cracks. The distinctive pattern is often referred to as alligator cracking because it much resembles the appearance of the reptile's back.

Pavement rehabilitation strategies with flexible overlays require drainage improvements such as edge drains, surface sealing, structural improvements with full depth asphalt, patching, or subgrade reinforcement and sufficient structural overlay thickness to adequately support the design load. Load induced reflective cracks will inevitably appear in thin overlays that are under designed or in overlays placed on unsuitable base structures.



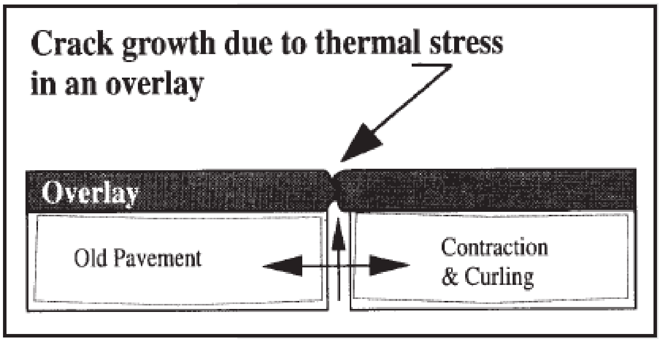


PLATE 3 & 4: MOVEMENT CAUSED BY TYRE PRESSURE &/OR THERMAL CHANGES IN THE UNDERLYING PAVEMENT, CAUSING REFLECTIVE CRACKING

Structurally sound composite pavements are relatively resistant to load induced stresses. These traffic load stresses occur very rapidly and the stiffness, or fracture resistance, of both the asphalt overlay and base structure are very high.

Temperature associated cracking occurs when horizontal movement due to thermal expansion, contraction, and curling of base pavement layers create tensile stresses in the overlay that exceed the strength of the asphalt.

Overlays placed on both ACC and PCC pavements are subject to thermal cracking. Thermal cracks usually appear in transverse and longitudinal directions. Temperature cycling occurs over an extended period of time. The resultant horizontal stress loading occurs at a very slow rate, as compared to traffic loading stress rates. Under these very slow loading rates, the stiffness or fracture resiliency of the asphalt material is quite low, perhaps 1,000 to 10,000 times lower than the modulus exhibited by these same materials under traffic induced loading rates.

Flexible overlays placed on PCC pavements are particularly susceptible to thermal cracking at the slab joints. Thermal rates of expansion and contraction vary between materials such that any slab joint spacing almost always assures premature joint Reflective.

3.2 TESTING REFLECTIVE CRACK PROPERTIES OF OVERLAYS

For many years, engineers have investigated the use of interlayers within the overlay to reduce the effects of reflective cracking. Interlayers can dampen stress, relieve strain, and provide tensile reinforcement to the asphalt.

The conventional laboratory method of measuring an asphalt mixture's resistance to fracture is by flexural beam fatigue testing. Flexural loading simulates the action of traffic on the overlay. Unfortunately, it is difficult to predict performance of these same materials under age, hardening and thermal load conditions.

The only device, which appears capable of simulating the effects of temperature cycling, is the Overlay Tester in the Texas Transportation Institute (TTI) at Texas A&M University. The effects of many interlayer materials of varied strengths, configurations, tack coats, and embedment quantities have been evaluated at TTI.

Beam fatigue testing is also conducted, distinguishing TTI as the first research institution able to predict the effects of both thermal and flexural loading. Separately testing each mode of fracture permits a more careful investigation of optimum interlayer reinforcement properties and positions within the overlay. TTI has adopted this approach because these tests more clearly isolate the contribution of the interlayer to reduce or eliminate the rate of crack growth through an overlay. This leads directly to more effective rules, guidelines, and specification limits on the use of interlayers. Since 1986 extensive “overlay” and “beam fatigue” testing has been completed at TTI on asphalt beams reinforced with Fiberglass Grids. A more detailed treatment on the subject matter is available in the literature.

Finally, in 1988 fiberglass grids were used that were found to provide sufficient reinforcing to the overlay above and strain-relief beneath the grid to actually turn the crack horizontally, and not permit it to propagate vertically upward through to the top of the sample. This new grid has self-adhesive glue with increased tensile strengths. Refer plates 5 & 6.

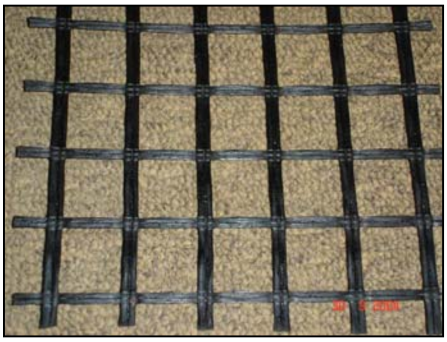


PLATE 5 & 6: FIBERGLASS GEOGRID WITHOUT AND WITH SELF-ADHESIVE, LATER IS PREFERRED FOR FASTER CONSTRUCTION

Mode II (Crack propagates to bottom of reinforcement and then is redirected horizontally) crack propagation occurs when the material in the overlay “reinforces” the overlay. This can only occur if the material has a higher modulus and sufficient cross sectional area to substantially strengthen the overlay. “There are no methods to predict the reflective cracking life of an overlay when this happens, but there is suspicion that it could be indefinite. Any deterioration will be due to another cause”, as stated by Dr. Lytton from Texas A&M University. Overlay subjected to large temperature changes exhibit reflective cracking. Based on the research conducted at the Texas Transportation Institute, it can be concluded that fiberglass grids can prevent this phenomena from occurring and offer a substantial increase to crack resistance caused by traffic load induced stresses.

3.3 CHECKLIST FOR SPECIFYING OVERLAY REINFORCEMENT

History has shown that three major influences dictate the performance of asphalt reinforcement: Material Composition, Product Geometry, and Jobsite Constructability.

Material Composition
As with any product of quality, it is essential to begin with the proper raw materials. Asphalt reinforcement must provide increased tensile strength at a very low deformation. It must be compatible with the asphalt to provide a strong internal bond within the composite. It must be thermally stable and physically durable to withstand the rigors of the paving operation. And finally, for long-term performance, it must exhibit no creep deformation or chemical breakdown over time.

Product Geometry
The geometric configuration of an interlayer will greatly affect its reinforcement capability. The cross-sectional area must be sufficient so that it will redirect tensile stresses. The width of the product must exceed the limits of the redirected stress energy. Finally, the opening (windows) in the mesh must be such that optimum shear adhesion is achieved while promoting aggregate interlock and confinement.

Jobsite Constructability
Practical application of any reinforcement requires the ability to adapt to any paving operation. Placement must be quick and easy, and the product must remain secure during paving. Fiberglass Grid is composed of high modulus fiberglass strands coated with bitumen and adhesive backing.

Why Does Fiberglass Grid Retard Reflective Cracking?	
High Tensile Strength	Low Elongation
No Long-Term Creep	Cross-Sectional Area
Asphalt Compatibility	Thermal Stability
Chemical Stability	Physical Durability
Width	Shear Adhesion
Interlock & Confinement	Quick Installation

PLATE 7: WHY DOES FIBERGLASS GRID RETARD REFLECTIVE CRACKING?

3.4 OVERLAY REINFORCEMENT PROPERTIES

High Tensile Strength
High modulus, E, fiber glass exhibits a tremendous strength to weight ratio and is pound for pound stronger than steel. With a modulus ratio up to 20:1 over asphalt concrete, fiberglass clearly provides the stiffness required to redirect crack energy.

Low Elongation
The stress-strain diagram for glass is virtually a straight line of nearly vertical slope. This indicates that the material is very stiff and resists deformation. Fiberglass exhibits less than 5% elongation at break.

No Long-Term Creep
Many reinforcement materials that appear to be initially stable, exhibit creep deformation due to constant loading over long periods of time. Fiberglass exhibits no creep. This assures long-term performance.

Cross Sectional Area
Sufficient cross sectional "Area, A" multiplied by the "Modulus, E" of the material (= AE) is required to redirect crack energy. The research conducted at Texas A&M shows Fiberglass meets this requirement.

Asphalt Compatibility
The specially formulated polymer coating was designed to deliver high asphalt compatibility. Each fiber is completely coated to insure no slippage within the composite asphalt.

Thermal Stability
The melting point of fiberglass is 1000°C (1800°F). This insures stability when subjected to the excessive heat of a paving operation.

Width
Field trials indicate that the reflective crack energy of a redirected horizontal crack can travel up to 0.6m (2 feet) beyond its point of origin. 1.5m wide patch reinforcement helps insure complete dissipation on either side of the crack. Lesser widths have shown horizontal propagation to turn vertically upward at the reinforcement limits resulting in a lesser crack on each side of the interlayer.

Shear Adhesion
The specially formulated polymer coating provides Fiberglass reinforced overlays with sufficient adhesion to maintain a good bond between asphalt concrete overlays.

Interlock & Confinement
Asphalt concrete gains its compressive strength through compaction. The mix aggregate is specifically selected to provide interlock and confinement within the load bearing stone structure, and asphalt cement (AC) is the glue that holds the particles together.

The quality of both the aggregate and the AC will determine the quality of the final pavement structure. As particles strike through the Fiberglass structure, they become mechanically interlocked within the composite system. This confinement zone impedes particle movement. Asphalt mixtures can achieve better compaction, greater bearing capacity, and increased load transfer with less deformation.

Easy Installation
Fiberglass with its unique adhesive allows quick and easy installation. The product can be rolled out mechanically with special placement tractor or manually from the back of a pick up truck.

3.5 FIBERGLASS GRID REINFORCED OVERLAY CONSTRUCTION

Pavement Preparation
Surface must be prepared as a clean, dry, even surface with pavement cracks sealed.

a. Cracks between 3mm (1/8") and 6mm (1/4") should be filled with suitable crack filler. Wider cracked surfaces need to be addressed with a method that provides a level surface. Any holes need to be filled with hot mix. Uneven surfaces and extensive cracking shall use a levelling course preferably with a dense graded mix of a minimum average thickness of 19mm (3/4").
b. On milled surfaces the following surface treatment shall be carried out:
   1. A minimum 19mm (3/4") asphalt concrete levelling course shall be applied to the milled surface prior to placing the glass mesh.
   2. The surface temperature before laying the grid shall be between 5°C and 60°C.
c. Prior to placing grid, the existing pavement shall be cleaned and provide significant adhesion to the grid to the satisfaction of the Engineer. Pavement shall be cleaned by a mechanical device by sweeping or vacuuming and be free of oil, vegetation, sand, dirt, water, gravel, and other debris.

Construction

a. Tack coats are optional. If local conditions require a tack coat to be used, the grid manufacturer shall recommend a tack coat rate that will provide proper adhesion.
b. The grid shall be laid out by mechanical means (Plate 8 to 11) or by hand under sufficient tension to eliminate ripples. Should ripples occur, these must be removed by pulling the grid tight or in extreme cases (on tight radii), by cutting and laying flat.
c. Transverse joints must be lapped in the direction of the paver 75 - 150mm (3" - 6"). Longitudinal joints must be 25 - 50mm (1" - 2") overlapped.
d. The surface of the grid shall be rolled with a rubber coated roller, or pneumatic tire roller, to activate the adhesive. Tires must be clean to avoid pick up of the grid.
e. Construction and emergency traffic may run on grid after being rolled. However, it must be ensured that damage is not caused to the grid by vehicles turning or braking etc., and that the mesh must be kept clean of mud, dust and other debris. Damaged sections shall be removed and patched, taking care to completely cover the damaged area.

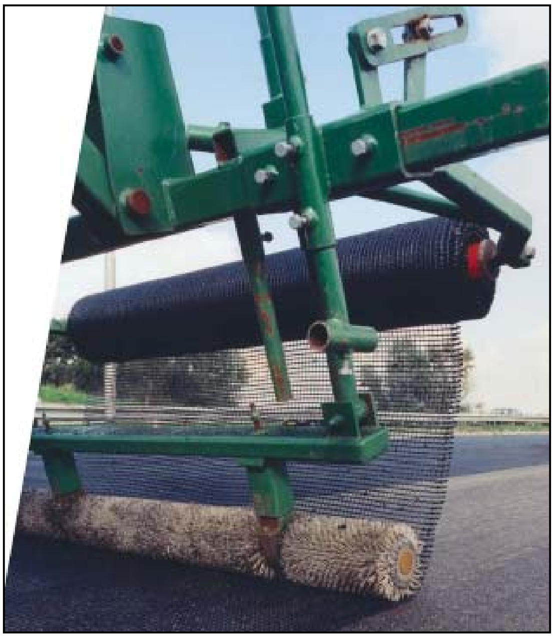


PLATE 8: PLACEMENT OF FG GRIDS BY TRACTOR

PLATES 9, 10 & 11: LAYING OF GRIDS

f. The contract price per square meter for the reinforcing grid shall include full compensation for furnishing all labor, materials, tools, equipment and incidentals involved in furnishing and placing the grid completely in place, as shown on the plans required by these special provisions and as directed by the Engineer.

Tests For Proper Adhesion

a. Cut approx. 1m2 of grid. Place on area to be paved.
b. Activate self-adhesive glue by rolling with a rubber-tired roller or by walking on the sample.
c. Insert hook of spring balance under center of grid piece.
d. Pull upwards until grid starts to pull from the surface and record results (Plate 12).
e. If approx. 5 kg or more, OK to pave. Stop immediately if grid moves or ripples. If less than 5 kg - do not pave.

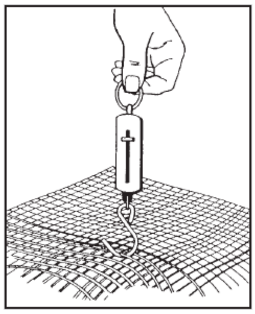


PLATE 12: ADHESION TEST

4. MECHANICALLY STABILIZED EARTH (MSE) WALLS AND SLOPES

4.1. INTRODUCTION

a. Mechanically Stabilized Earth (MSE) Walls is a generic term that includes reinforced soil. Multiple layers of reinforcing element are included in the soil for it to get stabilized. Reinforced Earth^{R} is a trademark for a specific reinforced soil system, but has gained popularity as a generic name. There are many names this technology is known by (Plate 13).

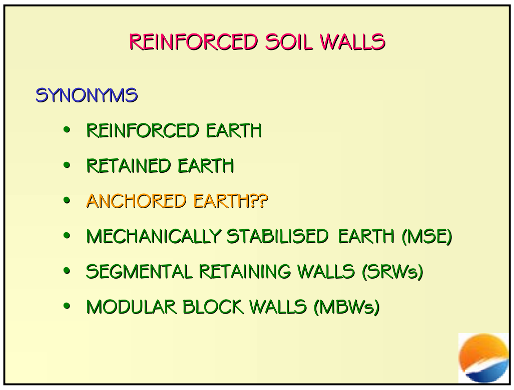


PLATE 13: MSE WALL SYNONYMS

b. Reinforced soil is an internally stabilized composite engineering mass; consisting of selected backfill, soil reinforcing elements and a non-structural facia. There are few systems wherein the facia is an essential part of the soil stabilization process and hence cannot be termed as soil reinforcing system. The author would rather like to call the same as a soil retaining system e.g. Anchored Earth (Plate 13).

c. Reinforced Soil Slopes (RSS) are a form of reinforced soil that incorporate planar reinforcing elements in constructed earth-sloped structures with face inclinations of less than 70^{o} with horizontal.

d. Facing is a component of the reinforced soil system used to prevent the soil from raveling out between the rows of reinforcement. Common facings include precast concrete panels, dry stacked modular blocks, metal sheets and plates, gabions, welded wire mesh, shotcrete and wrapped sheets of geo-synthetics. The facing plays only a minor structural role in the stability of the structure. For RSS structures it usually consists of some type of erosion control material. A typical cross section of the MSE is shown in Plate 14.

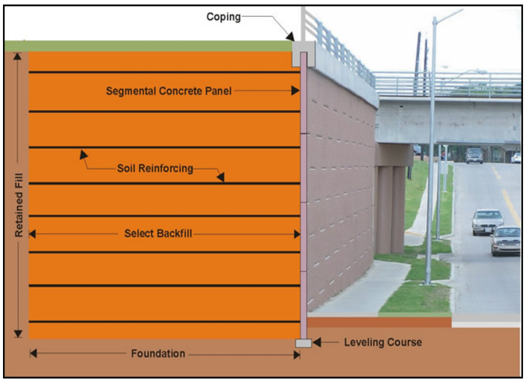


PLATE 14: MSE WALLS: TYPICAL COMPONENTS

e. The French Architect and Engineer Henri Vidal pioneered the modern methods of reinforced soil construction in the early 1960s. His research led to the development of Reinforced Earth^{R}, a system in which steel strips reinforcement is used. Use of Geotextiles in MSE walls and RSS started after beneficial effects of reinforcement with Geotextiles were noticed in highway embankments over weak subgrade. The first Geotextile reinforced soil wall was constructed in France in 1971, and the first structure of this type in the United States was constructed in 1974. Since about 1980, the use of Geotextiles in reinforced soil constructions has increased significantly.

f. The reinforced soil mass is a flexible mass and can tolerate lot of total and differential settlements making it a good option for poor founding soil conditions. However, since it is in most of the cases used as an approach to a bridge / flyover structure resting on non-yielding type of foundations, marrying the two differently behaving systems is still a gray area. Some light has been thrown on the issue and remedial measures suggested. The settlement tolerance of a MSE wall with rigid facing, depends solely on the flexibility of the facia. Flexibility of the various types of facia used in terms of permissible angular distortion has also been presented.

g. There are many myths associated with this technology and often phrases like proven technology, proprietary, patented and certified systems are used by the engineers to shield their ignorance. This paper apart from clarifying the above misunderstanding provides a comprehensive discussion on typical applications, reinforcing elements types, use of discrete facia, use of modular block facia, generic specifications, cost analysis, construction details, design principles, appurtenances, use of soft facing and other relevant issues like surface drainage, sub-surface drainage, drainage during construction, crash barrier construction, choice of facia type & finish etc.

h. As part of the section on specifications, MORT&H specifications have been analysed critically and many issues like their generic nature, BOQ, drainage requirements, reinforcing element, backfill specifications, design loads, factors of safety, ground improvement, quality control for the reinforcing material, and crash barrier & friction slab design etc. have been discussed in detail. In the absence of elaborate specifications many problem arise during design and execution stages apart from many instances of contractual complications. Some case studies out the experience of the author and colleagues have been presented to highlight the seriousness of the issue. Generic specifications have been proposed for the benefit of the fraternity.

4.2. ADVANTAGES AND DISADVANTAGES

a. *Advantages of Mechanically Stabilized Earth (MSE) Walls*

MSE walls have many advantages compared with conventional reinforced concrete and concrete gravity retaining walls. Some of these are:

- They use simple and rapid construction procedures and do not require large construction equipment.
- They do not require experienced craftsmen with special skills for construction.
- They require less site preparation than other alternatives.
- They need less space in front of the structure for construction operations.
- They reduce right-of-way acquisition.
- They do not need rigid, unyielding foundation support because MSE structures are tolerant to deformations.
- They are cost effective.
- They are technically feasible to heights in excess of 25m (80 ft).

The relatively small quantities of manufactured materials required, rapid construction, and, competition among the developers of different systems has resulted in a cost reduction relative to traditional types of retaining walls. MSE walls are likely to be more economical than other wall systems for walls higher than about 3m or where special foundations would be required for a conventional wall.

One of the greatest advantages of MSE walls is their flexibility and capability to absorb deformation due to poor subsoil conditions in the foundations. Also, based on observations in seismically active zones, these structures have demonstrated a higher resistance to seismic loading than have rigid concrete structures [5].

Precast concrete facing elements for MSE walls can be made with various shapes and textures (with little extra cost) for aesthetic considerations. Masonry units, timber, and gabions also can be used with advantage to blend in the environment or for temporary applications to reduce cost.

b. *Advantages of Reinforced Soil Slopes (RSS)*

The economic advantages of constructing a safe, steeper RSS than would normally be possible are the resulting material and rights-of-way savings. It also may be possible to decrease the quality requirement of materials required for construction. For example, in repair of landslides it is possible to reuse the slide debris rather than to import higher quality backfill. Right-of-way savings can be a substantial benefit, especially for road widening projects in urban area where acquiring new right-of-way is always expensive and, in some cases, unobtainable. RSS also provide an economical alternative to retaining walls. In some areas, reinforced slopes can be constructed at about one-half the cost of MSE structures.

The use of vegetated-faced reinforced soil slopes that can be landscaped to blend with natural environment may also provide an aesthetic advantage over retaining wall type structures. However, there are some potential maintenance issues that must be addressed.

In terms of performance, due to inherent conservatism in the design of RSS, they are actually safer than flatter slopes designed at the same theoretical factor or safety. As a result, there is a lower risk of long-term stability problems developing in the slopes. Such problems often occur in compacted fill slopes that have been constructed to low factors of safety and/or with marginal materials (e.g. deleterious soils such as shale, fine grained low cohesive silts, plastic soils, etc.). The reinforcement may also facilitate strength gains in the soil over time form soil aging and through improved drainage, further improving long-term performance.

c. *Disadvantages*

The following general disadvantages may be associated with all soil-reinforced structures:

- Require a relatively large space behind the wall or outward face to obtain enough wall width for internal and external stability.
- MSEW require select granular fill (At sites where there is a lack of granular soils, the cost of importing suitable fill material may render the system uneconomical). Requirements for RSS are typically less restrictive. Soils having up to 50% passing 75µ sieve can be used for RSS construction as compared to a limit of only 15% for MSE walls.

d. *Some Limitations*

- Suitable design criteria are required to address corrosion of steel reinforcing elements, deterioration of certain types of exposed facing elements such as geosynthetic by ultra violet rays, and potential degradation of polymer reinforcement in the ground.
- Since design and construction practice of all reinforced systems are still evolving, specifications and contracting practices have not been fully standardized, especially for RSS.
- The design of soil-reinforced systems often requires a shared design responsibility between material suppliers and owners and greater input from geo-technical specialists in a domain often dominated by structural engineers.

4.3. REINFORCING ELEMENTS' TYPES

a. A variety of reinforcing element types are used for constructing MSEW and RSS as listed below:

i) GI Steel Strips: Plain and Ribbed
ii) Metallic Bar Mats
iii) Welded Wire Mesh
iv) Polymeric Grids: Geogrids
v) Woven Geotextiles
vi) Geo-Strap / Geo-Tie

a.i. <u>GI Steel Strips</u>

The Reinforced Earth Co. through their licensee in India uses GI strips. Delhi based Earthcon Systems have also successfully completed a project on NH2 using ribbed GI steel strips. Plate 15and 16 depict the use of the same.

PLATE 15: MSE WALL WITH GI STEEL STRIPS

PLATE 16: LARGE SIZE PANELS USED FOR MSE WALL ON NH2

Plain strips can also be used as reinforcing elements but result in under utilisation of steel strength as lower friction development compared to ribbed strips results in more no. of strips to be used. The ratio of friction developed on plain vis-à-vis ribbed strips is at least 0.4 is to 1.5[1,6]. The higher requirement of steel quantities precludes the use of plain strips as reinforcing material.

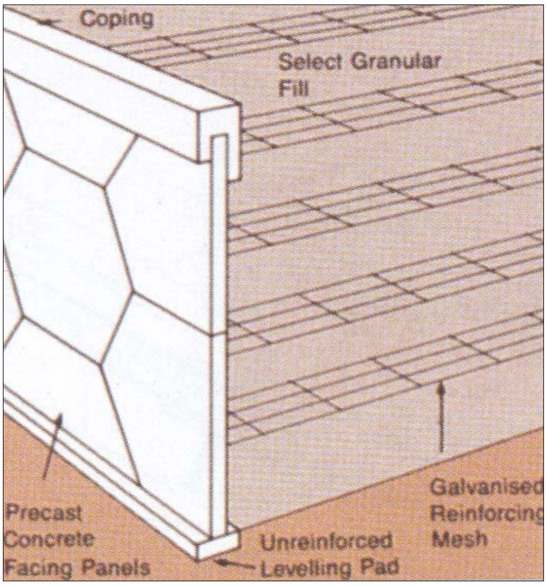
a.ii. <u>Metallic Bar Mats</u>

M/s VSL initially used metallic bar mats (or mats of metal) under the name Retained Earth[R]. Metal mats are made using plain cold drawn wires, fusion welded with cross wires and the assembly is then hot dip galvanised. The spacing of the cross elements is constant throughout the length of the metal mat. The design can be carried as per AASHTO [2] and other available codes of practices. Plates 17, 18 & 20 depict the use of the same. Plate 19 gives a comparison of the stress transfer mechanisms in the ribbed steel strips and mats of metal.

a.iii. <u>Welded Wire Mesh</u>

Galvanised welded wire mesh (WWM) is also used as a reinforcing material. Same wire mesh can also be used to form the gabion facia filled with stones. By far this is the most flexible facia and can absorb lot of differential settlement. In India, Dera

Bassi ROB has been constructed in Punjab using Maccaferri Terramesh system. Plates 21 and 22 depict the same.



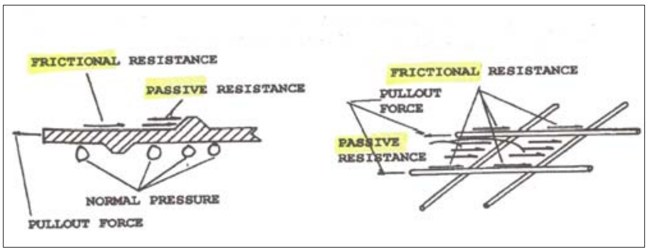


PLATE 17 to 20: MATALLIC BAR MATS: TYPICAL COMPONENTS (CLOCKWISE)
17. CONCEPTUAL DEPICTION OF THE RETAINED EARTH SYSTEM
18. MATS OF METAL BEING LAID ON SITE
19. COMPARISON OF STRESS TRANSFER MECHANISM BETWEEN RIBBED STEEL STRIPS AND MATS OF METAL
20. TYPICAL CONNECTION DETAIL WITH THE PANEL USING CLEVIS LOOP JOINT (THE WOODEN WEDGES ARE FOR REMOVING ANY SLACKNESS)

a.iv. Polymeric Grids: Geogrids

With the use of polymeric geogrids a whole new chapter has been written in the field of reinforced soil wall and slope construction. There are primarily two types of geogrids that are being used at present:

- HDPE (High Density Poly Ethylene) Geogrids and
- PET (Polyester) geogrids

PP (Poly Propylene) geogrids are seldom used for reinforced soil wall construction in India. The HDPE geogrids have monolithic joints, possess higher creep and are termed as rigid geogrids. The PET geogrids have joints, which are either welded, woven or knitted (the later possessing high junction strengths resulting in a stable network of longitudinal and cross elements), possess low creep and are termed as flexible geogrids. Plates 23 to 26 depict use of these grids for making reinforced soil walls & slopes.

PLATE 21 & 22: WWM GABION FACING USED FOR DERA BASSI ROB IN PUNJAB

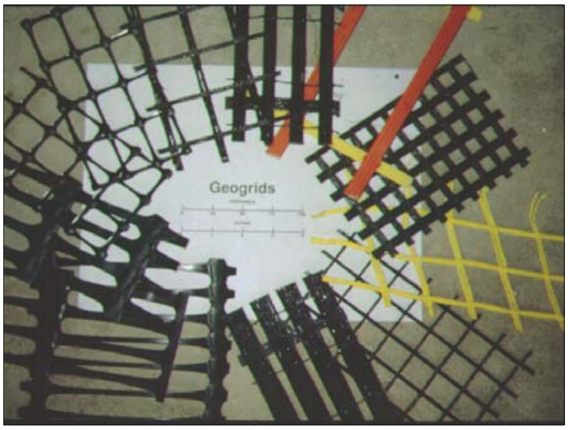


PLATE 23: PET AND HDPE GEOGRIDS

PLATE 24: MODULAR BLOCK WALL CONSTRUCTION USING GEOGRIDS

PLATE 25: RSS CONSTRUCTION USING PET GEOGRID FOR LANDSLIDE CONTROL, AT 38m HEIGHT THIS IS THE CURRENT WORLD RECORD HOLDER IN TAIWAN

PLATE 26: MSE WALL CONSTRN. USING PET GEOGRIDS

a.v. <u>Woven Geo-Textile</u>

Woven Geotextiles have been used successfully for building reinforced soil walls. These walls are susceptible to large post construction deformations due to high strains developing in the fabric. Their major usage still remains for the construction of Reinforced Soil Slopes. Plate 27 depicts the construction of a RSS schematically.

PLATE 27: RSS CONSTRUCTION

a.vi. Geo-Strap/Geo-Tie

Geo-straps are wide bands of polymeric polyester yarn bundles coated with HDPE/PVC while it is manufactured. The product has good resistance to installation damage. Only two companies in the world are making it at present viz. Kolon International of Korea and Linear Composites Ltd. of UK. Refer plate 28 for a view of Paraweb[R] (of Linear Composites Ltd.).

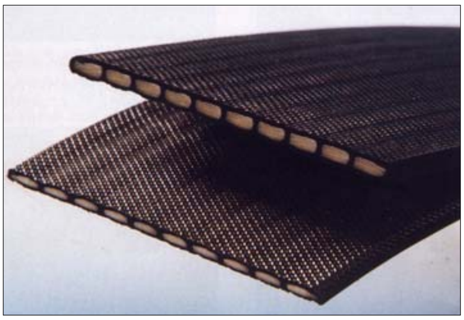


PLATE 28: PARAWEB OF LINEAR COMPOSITES LTD.

It is quite interesting to note that the use of this material started as slings used at ports and harbours for handling shipments. PET straps are still very popular in the packaging industry for their durability and non-staining properties. Refer plate 29.

PLATE 29: USE OF GEO-STRAP AS SLINGS

PLATES 30 TO 32
(CLOCKWISE FROM TOP LEFT)
PLATE 30: USE OF GEO-STRAPS FOR REINFORCED SOIL WALLS
PLATE 31 : A MSE WALL CONSTRCUTED WITH GEO-STRAP NEEDS OUTSIDE PROPS DURING CONSTRUCTION ITSELF
PLATE 32: CONNECTION OF GEO-STRAP WITH THE PANELS USING POLYMER DOWELS

The Phagwara flyover in Punjab was the first flyover to be built using this material and the technology was called Websol. Widespread use in India started with M/s Kolon International promoting the technology for building reinforced soil wall. However, it is still not recognised as a reinforcing element by MORT&H specifications. Whether to consider this as an extensible or inextensible reinforcement is still not clearly spelt out in the current codes of practices. It is sad that the current usage of this technology has been with highly under-designed forms and sign of distress are already showing up. Refer plates 30 to 32 for details.

b. A brief description on the issue of comparison of metallic and polymeric reinforcements can be found in reference 13, which is reproduced below for sake of completeness:

"*3. METALLIC & POLYMERIC REINFORCEMENTS: A QUALITATIVE ANALYSIS*

3.1 The metallic reinforcements have to be heavily galvanised in order to retard the process of corrosion, which is inevitable. MORT&H specifications call for a galvanization thickness of 1000gm/m2 (140μ), which will last for about 30 years under mildly corrosive backfill conditions. After the loss of galvanization the residual carbon steel decays at a rate of 12μ/year. Such loss of base metal is duly accounted for in the design. The above analysis is valid for a uniform galvanization coating only. In case holidays are created during the galvanization process, pitting corrosion can start which is much faster than the rates mentioned above. High quality control is required during the galvanization process to obviate such occurrences, but is difficult to achieve during mass production process.

The metallic steel strip system utilizes large shaped panels (area=2.25m^2 and weight about 1.0t). The panels are elegant looking and are widely accepted. A crane is invariably required to handle the panels both at the casting facility and the erection site. The facia is an integral part of the system and has to be designed as a flexural member due to larger spacing of strips both in vertical and horizontal directions (steel consumption is of the order of 4-6 kg/m2). A higher grade of concrete viz. M35 is generally suggested although lower grades would serve the purpose equally well.

The strips have to be anchored to the facia using galvanised nuts and bolts. The system is relatively costlier because of high accessories cost, reinforcing steel in the panels, crane requirement, and, recent sharp increase in the steel prices has made the system even more costlier as more than 50% of the cost of the system is the cost of reinforcing elements itself.

The codes of practices and the design procedure adopted are well established except for the seismic design aspects. This is primarily because BS code is followed for static design and reference has to be made to other codes of practices such as AASHTO for doing the aseismic design. A third code has to be referred to get the friction coefficient between the steel strips and backfill! Synthesis of these codes of practices is quite subjective as they follow different design philosophies.

Apart from some of the drawbacks/limitations mentioned above, the system is quite popular in India and has performed satisfactorily.

3.2 Polymeric geogrids (both HDPE and PET) are also widely used for making MSE walls. The HDPE geogrids are generally used with large panels, whereas PET geogrids are preferably used with modular blocks. Some applications of HDPE geogrids with modular blocks and PET geogrids with large size panels have also been tried. The HDPE geogrids can be embedded in the panels while casting, whereas PET geogrids have to be anchored to the panels by means of an external connection.

The alignment of panels during and after construction has been a ticklish issue with *panel+geogrids constructions. Unlike the steel strip system there is no well-established methodology available by which the panels' alignment can be controlled during execution. The construction of joints using bearing pads has also been implemented rather crudely (incompressible solid rubber pads are used) and is devoid of correct understanding of the subject matter.*

The above issue has been resolved with modular block construction viz. Reinforced Segmental Retaining Wall (SRW) (with both types of geogrids). The interlocking mechanism between the blocks results in good alignment as a predetermined position of the successive layers is defined by the shear keys/pins/dowels. Good aesthetics can also be obtained using beveled surface units. The most attractive advantage of the modular blocks is that it does not require a crane for handling and erection purposes. Recent mechanization in terms of availability of locally made block casting machines has been a boon for this method of MSE construction. M25 concrete is generally used for blocks.

There are no accessories required to be embedded in the blocks and only minor accessories like pins/dowels are required while erecting. The rigid geogrids are required to be anchored to the blocks with clips, whereas flexible geogrids are held in position by friction /aggregates' interlock or a combination of the two.

The low cost of facia, no mechanization in terms of cranes and large availability of SRW system suppliers has made this methodology very popular. Another advantage of the system is that block casting can begin without waiting for the backfill source identification/ characterization and design approval etc.

The codes of practices and the design procedure adopted are well established including the seismic design aspects. NCMA manuals are specifically written for the design of SRW.

However there is a gray area which needs to be addressed viz. the partial safety factors to be used in evaluating the long-term design strength of geogrids. It should not be left for the execution stage/to the supplier, as this has become a source of arguments/claims/delays in many instances."

The author would like to add as follows:

c. The main applications of the metallic reinforcing systems is limited to steel strips and bar mats with a market share of about 85% and 15%, respectively. Welded wire mesh has not got wide acceptance because of obvious reasons that the facia exposes more than it hides. The disproportionate market share as indicated above is attributed only to late entry of the later in the Indian market. There are other attempts of using steel tendons/ plain strips with passive deadman anchorages of steel/ concrete. The issue is discussed later in detail and it is concluded that such systems cannot be categorized as soil reinforcing systems. The galvanization recommended for steel strips is 1000 gm/m^2, whereas for bar mats it is usually 610 gm/m^2, increasing the sacrificial thickness to be accounted for in the design.

d. Out of three polymeric reinforcing systems, the one with geogrids is the most popular and better performing. Geogrids because of their planar configuration with openings at regular intervals provide better confinement to the reinforced backfill compared to geo-straps.

4.4. PATENTS: SOME CLARIFICATIONS

a. A system for MSEW structures is defined as a complete supplied package that includes design, specifications and prefabricated materials of construction necessary for the complete construction of a soil reinforced structure. Often technical assistance during the planning and execution phase is also included. Components marketed by commercial entities for integration by the owner in a coherent system are not classified as systems.

b. There are many myths associated with this technology and often phrases like proven technology, proprietary, patented and certified systems are used by the engineers to shield their ignorance. On many projects Consultants have even demanded BBA certification though the same is required for using the system in UK alone.

c. In fact, since the expiration of the fundamental process and concrete facing panel patents obtained by the Reinforced Earth Co. for MSEW systems and structures, the engineering community has adopted a generic term Mechanically Stabilized Earth to describe this type of retaining wall construction.

d. Trademarks such as Reinforced Earth^{R}, Retained Earth^{R}, Genesis^{R} etc., describe systems with some present or past proprietary features or unique components marketed by commercial suppliers. Currently, most process patents covering soil-reinforced system construction or components have expired, leading to a wider availability of systems or components that can be separately purchased and assembled by the erecting contractor. The remaining patents in force generally cover only the method of connection between the reinforcement and the facing.

e. It needs to be emphasized that for desirable performance of any reinforced soil wall construction, only three components require proper control viz. i) reinforcing material and select backfill properties, ii) design as per existing codes of practices and iii) proper execution in the field. Many suppliers coin phrases like proprietary and patented systems to bypass the above requirements, which give rise to increased probability of distress.

4.5. USE OF MODULAR BLOCK FACIA

a. Use of small blocks as facia for the reinforced soil walls has been rising in the recent past due to many reasons viz. ease of handling, ready availability from pre-casters, low cost and adaptability to the required layout etc. The technology of making reinforced soil walls using small blocks has been termed as Reinforced Segmental Retaining Wall (SRW) or Modular Block Wall (MBW). A variety of shapes and finishes have been developed for modular blocks. Refer plate 33 for details.

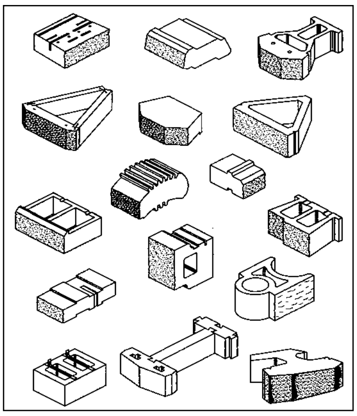


PLATE 33: A VARIETY OF MODULAR UNITS

b. Geogrid is generally used as the reinforcing element (Refer Plate 34 for details), although metal bar mat (with two longitudinal only) has also been used successfully.

c. The block units have two different mechanisms to maintain alignment and transfer shear among the units to maintain facia stability viz. i) built-in mechanical concrete interlocking and ii) flat surface units relying on friction alone. Please note that the usage of pins/dowels is only for maintaining alignment and are not relied upon to transfer shear among units. Refer plate 35 for details.

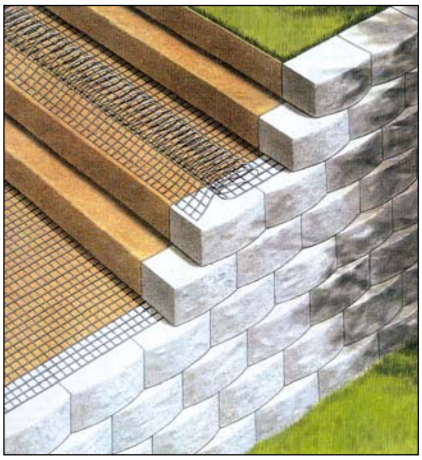
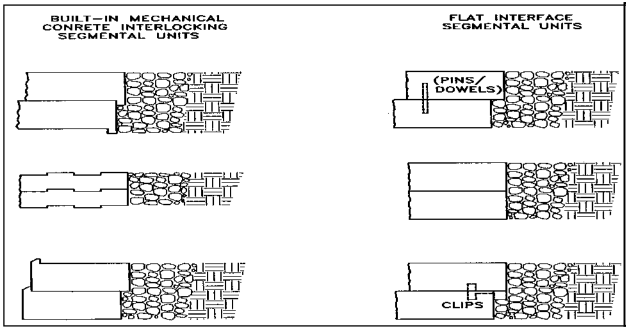


PLATE 34: USE OF GEOGRIDS AS THE REINFORCING MATERIAL WITH BLOCK UNITS

d. Use of coloured concrete units has been successful to break monotony on large wall faces. Refer plate 36 & 37 for some examples. Unfortunately use of plane faced units on some of the projects (plate 38) prompted a shift to large discrete panels, e.g. Delhi PWD and other agencies responsible for building flyovers in Delhi have started demanding large panels for the reinforced soil walls for flyover approaches. This is not desirable for two reasons viz. i) higher cost has to be paid for large panels and ii) block systems are technically superior to large panels when used with geogrids [14]. This trend needs to be reversed immediately. Better-looking structures are possible with bevelled faced units (plate 39).



THE BUILT IN CONCRETE KEYS AND PINS/DOWELS ETC. HELP MAINTAIN THE ALIGNMENT OF THE BLOCKS DUIRNG ERECTION. THE PINS/DOWELS DO NOT HELP IN SHEAR TRANSFER AND THE PRINCIPLE MECHANISM OF SHEAR TRANSFER IS FRICTION ALONE

PLATE 35: SHEAR TRANSFER MECHANISMS BETWEEN BLOCKS

PLATE 36 & 37:
USE OF COLOURED FACIA TO BREAK MONOTONY OF LARGE WALLS, CAN BE UTILISED FOR URBAN CONSTRUCTION

PLATE 38 & 39:
USE OF PLANE FACED UNITS?

BEVELLED FACED UNITS FOR BETTER LOOKING MSE WALLS

4.6. MORT&H SPECIFICATIONS ANALYSED

a. On most of the major highway projects in India the specifications contained in the orange book are followed with some minor modifications depending on the DPR consultant's liking or disliking for a specific system.

b. The orange book specifications are quite generic in nature and allow all types of reinforcing materials such as Geotextiles, geogrids, steel strips and mats of metal etc. WWM and geo-strap are not explicitly mentioned but are being allowed and used successfully. Still the specifications spell out much less than desired and often leads to delays in approval of designs apart from leading to many cases of severe Contractual complications. Plate 40 gives a wish list of what the specifications should cover comprehensively.

- GENERIC IN NATURE
- DRAINAGE REQUIREMENTS
- REINFORCING ELEMENT / BACKFILL SPECIFICATIONS
- DESIGN LOADS & FACTORS OF SAFETY
- GROUND IMPROVEMENT
- CHOICE OF FACIA
- QUALITY CONTROL FOR THE REINFORCING MATERIAL
- CRASH BARRIER & FRICTION SLAB DESIGN PARAMETERS
- BOQ

PLATE 40: A WISH LIST OF WHAT THE SPECIFICATIONS NEED TO COVER

c. A sample specifications covering the above issued is prepared by the author and are Available web site for perusal of the users.

d. There are many clauses in the orange book, which need to be specifically omitted till the time one decides to adopt the comprehensive generic specifications available on website, and are as listed below:

d.i) It allows Aluminium and stainless steels, which are not recommended [2].

d.ii) Clause pertaining to the minimum geogrid strength of 40kN/m at 100 years etc. needs to be omitted. The clause promotes use of high strength geogrids at larger spacing, which is not desirable. The clause also refers to a document viz. GRI:GG3, which has been withdrawn long back.

d.iii) The limit of particles passing 75μ needs to be increased to 15% from 10% in line with internationally accepted practice.

d.iv) The depth of the foundation below the finished ground level has been specified as minimum 1m, which should be revised to 0.45m. BS:8006 can be referred for further details.

d.v) BOQ suggests measuring and paying for the reinforcing material separately, which should be included in the cost of the facia measured in sqm in elevation.

e. As indicated in plate 40, many issues like drainage material requirement, reinforcing element and backfill specifications, design loads & factors of safety, ground improvement if necessary, choice of facia, quality control for the reinforcing material and crash barrier & friction slab design etc. are not explicitly covered in the specifications. Design for crash barrier and friction slab is detailed in Appendix B. Some of these points are discussed in brief below:

e.i. <u>Drainage Material Requirement</u>

A 300 wide separation layer consisting of mixture of 10mm down coarse aggregates (65%) and 0.425mm up medium coarse sand (35%) shall be placed behind the facia.

The phrase drainage/ filter media is a misnomer as the reinforced backfill is considered a self-draining media, having sufficient permeability of the order of 0.01cm/sec or higher to relieve hydrostatic pressures. The chimney drain suggested is only to keep the sand from migrating through the open spaces in the facia. A properly designed and placed non-woven Geotextile would serve the purpose better.

Perforated PVC pipe wrapped in filter fabric placed near the ground level is not required in situations where top surface of the embankment is black topped, reducing water ingress to insignificant levels.

At times, the retained backfill can be a poor draining material. Wherever, there is a probability of such occurrence, a 300mm wide chimney drain should be provided between retained and reinforced fills to allow free drainage of the retained fill along with the reinforced fill. In case water ponding is used as an aid to compaction e.g. in pure fine sands, suitable drainage for this water percolating down below should be designed and provided for, to avoid saturation/softening of the founding soils. In addition excess water can also damage the side service roads, as water does find a way below it as well.

e.ii. Reinforced Backfill Specifications

Backfill materials used in the Reinforced Soil volume shall be reasonably free from organic or otherwise deleterious materials and shall conform to the following mechanical and electrochemical requirements. Fly ash can only be used as reinforced/retained fill with geogrids.

e.ii.1.) Mechanical requirements

The backfill material used for Reinforced Soil Retaining Walls shall meet the following mechanical requirements.

Sieve size	*percent passing*
100mm	100%
0.425mm	0-60%
75 micron	0-15%

Coefficient of uniformity Cu=(D60/D10)$\geq$ 2*

The peak internal friction of backfill material shall not be lesser than 30^0.

**** With regard to Cu, there is no minimal value specified explicitly in any code of practice. However, both FHWA [1] and AASHTO [2] do not allow default pullout values to be used for backfill soils having Cu<4 i.e. pullout tests must be performed under such conditions. Needless to say that geogrids being planar structures have less dependence on the Cu and the default friction parameters defined in these codes can be safely adopted even for backfill soils with Cu<4. [15][17]***

e.ii.2.) Electrochemical Requirements

Recommended limits of electrochemical properties for backfills when using polymeric geogrid reinforcements are as given below:

Base Polymer	*Property*	*Criteria*
Polyester (PET)	pH	>3<9
Polyolefin (HDPE)	pH	>3

Recommended limits of electrochemical properties for backfills when using steel reinforcements are as given below:

Property	*Criteria*
Resistivity	>3000 ohm-cm
pH	>5<10
Chlorides	<100ppm
Sulphates	<200ppm
Organic content	1%max

e.iii. Reinforcing Element's Specifications

e.iii.1. Geogrid Reinforcement

The Geogrid shall be made from high molecular weight and high tenacity polyester (PET) yarn or high-density polyethylene (HDPE).

The PET geogrids should satisfy the following electrochemical conditions:

- *Minimum molecular weight no.* *> 25,000*
- *Maximum carboxyl end group no. (CEG)* *< 30*
- *Minimum mass per unit area* *> 270 gm/sqm*

Polyester geogrids shall be coated with a protective coating (e.g. PVC /HDPE/ PP) to minimize damage during construction. Geogrid shall be produced by weaving/knitting process to ensure junction strength.

High-density polyethylene geogrids shall be manufactured by extruded, drawn sheets and by punched and orientation process in one direction so that the resulting ribs shall have a high degree of molecular orientation, which is continued through the integral transverse bar. It shall contain adequate stabilizers to enhance stability to environmental stress cracking (ESC), photo oxidation (UV exposure) and thermal oxidation.

In all cases, the Long Term Design Strength (LTDS) shall be calculated by using the following **minimum** values of material partial safety factors based on 100 years service design life.[1]

Minimum partial FOS for calculation of 100 years Long Term Design Strength (LTDS)		**HDPE based Geogrids**	**PET based Geogrids**
1	Partial FOS for creep deformations	2.6 (range 2.6 to 5.0)	1.6 (range 1.6 to 2.5)
2	Partial FOS for variations in manufacture w.r.t. control specimens with 95% confidence limit	1.00	1.00
3	Partial FOS for extrapolation of creep test data (10000 hours creep test results should be available)	1.10	1.10
4	Partial FOS for construction/installation damage	1.20	1.30
5	Partial FOS for potential chemical and biological degradation (environment)	1.10	1.15

The FoS for construction/installation damage can be refined for the type of backfill used, but a conservative and uniform value is advisable.

e.iii.2. Hot Dip Galvanised Soil Reinforcing Strips

Shapes and dimensions of these elements shall as per French Standard AFNOR NFP 94-220[6]. Reinforcing steel strips shall be hot rolled. Their physical and mechanical properties shall conform to European norm EN 10025[8]. Reinforcing and tie strips shall be hot-dip galvanised (> 140 μ).

e.iv. Design Loads

The following loads shall also be considered while designing the structures:

For Walls

- Traffic Live load surcharge 2.2t/m^2
- Dead load surcharge 1.2t/m^2
- Traffic impact load on the crash barrier: 30kN/m for tensile strength and 7.5 kN/m for pullout resistance
  (Refer appendix C for treatment on how to account for these forces in the internal stability design)
- Seismic loads as per maximum acceleration expected at the site as per IS: 1893:2002 and analysed as per Mononobe-Okabe (M-O) method

e.v. A case study

A case study has been presented to illustrate the point made in the section on specifications. In the absence of specific load factors given in the specifications or in the codes of practices, the MSE wall designers/suppliers have been following abnormally low factors of safety to cut cost and thus endangering the safety of structures. On the other hand some projects are being executed with abnormally high factors of safety clubbed with a faulty BOQ leading to severe contractual complications.

The two projects under discussion are:

- Lucknow Bypass, and
- Kanpur Bypass

The two projects have many similarities:

- Largest MSE Wall Projects, under execution at present in India
- Same Client viz. NHAI
- Same Supervision Consultant
- PET Based Reinforcing Material
- Large Size Discrete Facia Panels as facia
- Both Follow Contract Specifications

		LUCKNOW BYPASS	KANPUR BYPASS
	100 years Long Term Design Strength (LTDS)	PET based Tie	PET based Geogrids
1	Creep	1.35	2.75
2	Variations in manufacture	1.0	1.0
3	Extrapolation of creep	1.0	1.1
4	Construction / installation damage	1.2	1.22
5	Biological degradation	1.05	1.15
		1.70	4.24

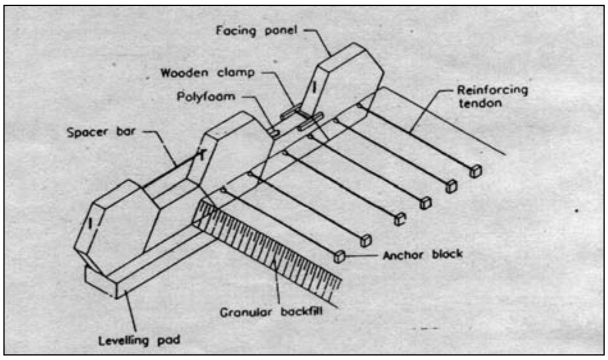
PLATE 41: THE MATERIAL PARTIAL SAFETY FACTORS USED ON TWO LARGE PROJECTS IN INDIA

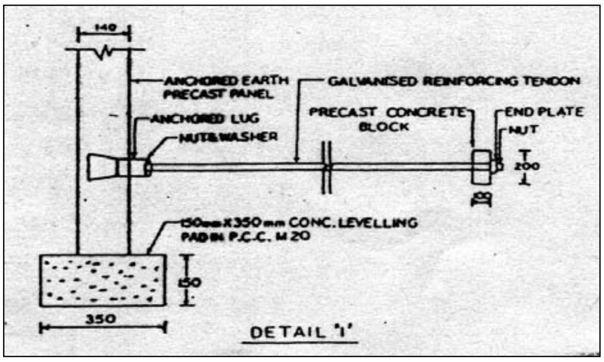
Plate 41 shows the material partial safety factors used on the two projects to arrive at the allowable long-term design strength given the instantaneous strength of the PET based reinforcing material. As can be noticed that in the first project a FoS of only 1.7 is used since the cost of reinforcing element is in-built in the price. In the second project the specifications called for a higher FoS and also provided for a separate measurable item for the reinforcing element, resulting in an over safe and expensive structure. The FoS used of the second project is 4.24, only 2.5 times of that used for the first project!

The above case study clearly highlights the need for unambiguous and comprehensive specifications. The detailed specifications are available web site for perusal.

4.8. ANCHORED DEADMAN FILL RETAINING SYSTEMS

a. This section presents a discussion on multi-anchored retaining systems, which derive their pullout resistance from the passive soil pressure on the anchored deadman (plate 42). The structures consist of three basic components viz. i) precast concrete facing, ii) steel tendons and iii) precast concrete deadman. Unlike the soil reinforcing systems which transfer the working load to the surrounding soil through frictional stress and/or passive resistance developed along the entire embedment length, anchored deadman systems are designed to ensure the load transfer to the soil through the passive earth resistance developed on the deadman which is located at the free end of the tendon.

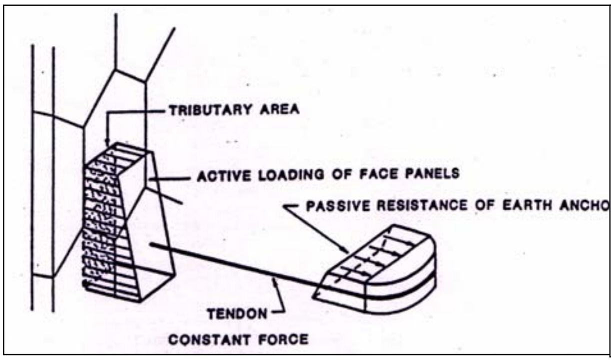


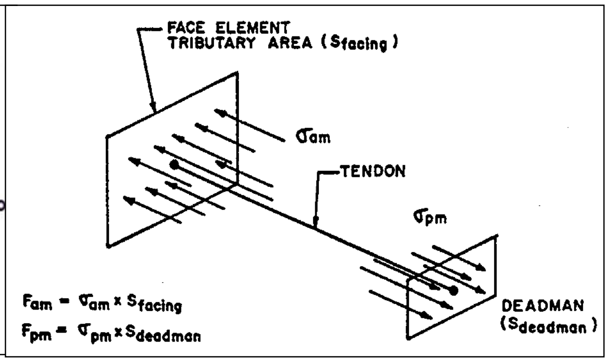


PLATES 42 AND 43: MULTI-ANCHORED DEADMAN FILL RETAINING SYSTEMS, ANCHORED DEADMAN SYSTEM: TYPICAL COMPONENTS

Therefore, these systems do not create a composite reinforced soil mass and their behavior is substantially different from that of reinforced soil systems [9].

b. Plate 44 and 45 show schematically the variations of tensile force along an anchored deadman system. The stress transfer is assumed to be primarily through passive resistance and the frictional stress developing along the steel tendon is neglected. As such the retaining system operates similarly to a tied-back wall and the tensile forces are assumed to be constant along the tendons.





PLATES 44 AND 45: VARIATION OF TENSILE FORCE IN AN ANCHORED DEADMAN SYSTEM, PL. NOTE THAT TENDON FORCE IS CONSTANT

c. The main difference between these systems and tieback walls, which rely upon ground anchors resides in the load transfer mechanism form the anchors to the soil. In ground anchor retaining systems, the load transfer is being realized by the friction mobilized at the grout-ground interfaces whereas in anchored deadman systems, the load transfer is being realized through the passive soil pressure mobilized on the deadman. These two load transfer mechanisms require a significantly different magnitude of soil displacements to be mobilized and can therefore result in a substantially different behavior (e.g. earth pressure distribution on face elements, location of potential failure surface and structure displacements etc.). However, as the field experience with the multi-anchored deadman systems is rather limited, several basic design assumptions for tied back walls have been followed for evolving design schemes.

d. Unlike reinforced soil wall systems, in a multi-anchored deadman system, similar to a tied back wall, the facing is primarily a structural element which has to withstand both bending moments and shear forces due to the lateral earth pressure of the retained soil and to transfer tension forces to the tendons.

e. The facing, the tendons and the deadman along with their connections are all important components of the system (Plate 43) and should conform to the following requirements:
   - Bending and shear resistance of the facing elements should be sufficiently high to withstand the working stresses due to the lateral earth pressures applied by the retained backfill and surcharge
   - Tensile resistance of the tendon should be adequate with respect to the forces transferred to the deadman
   - Pullout resistance of the deadman should be high enough to prevent slippage of the anchor in the retained mass
   - Connections of the tendons to the facing and to the deadman elements should be properly designed with an adequate shearing resistance to prevent the tendons from pulling out of the elements

f. In India, present design for anchored deadman systems are carried out using the provisions contained in BS: 8006, a widely accepted code of practice. The code suggests considering both friction along the tendon and passive resistance of the anchored deadman for resisting the pullout forces developing in the tendons. How both friction along the tendon and the passive resistance on the anchored deadman can be mobilized simultaneously is any body's guess. Also since the code allows friction to be accounted for, system suppliers have changed over from round plane tendon to wide strips to enhance frictional component. It is also to be noticed that BS: 8006 is the only code, which contains provisions for designing an anchored deadman system. The said code does not have any aseismic design provisions and other codes/literature have to be referred to for the purpose. The code actually deals with the strengthened soil conditions as well, in addition to the reinforced soil constructions. No other widely accepted code such as AASHTO'02 has any mention of such systems under the generalized section on Mechanically Stabilized Earth (MSE) walls.

g. From the above discussion following comparison can be drawn between the reinforced soil walls and anchored deadman fill retaining systems:

   - In anchored deadman soil retaining systems the facia is a structural component and systems stability is dependent on the same.

- Any failure of the facia can be catastrophic for the stability of the entire fill
- The connection of the tendon with the facia and the deadman is equally important and is the single line of defense available against failure
- The system has negligible built-in redundancy unlike other soil reinforcing techniques such as those using geogrids
- The behavior of anchored deadman in a seismic activity is not very well documented and is not codified at all

h. One should be cautious before adopting such systems for building soil retaining systems and should verify the above facts independently.

4.8. CONSTRUCTION DETAILS

a. Construction of reinforced soil walls is fairly simple & consists of following steps:
   - *Casting Facia Panels/Blocks*
   - *Laying Levelling Pad*
   - *Erection Of Facia Panels/Blocks*
   - *Laying Of Reinforcing Elements*
   - *Backfilling & Compacting*
   - *Crash Barrier & Railing Etc.*

b. The above list details what consists of construction of reinforced soil walls. The facia panels or blocks are cast in a centralized facility or on the site depending on the size of the project. The facia is then transported to the site and stacked for further erection.

c. The construction site is excavated to the desired level and rolled. An unreinforced levelling pad is laid as given in the dwgs. The levelling pad should be level to a tolerance of $\pm$5mm as the alignment of the erected facia is highly dependent on this. The stiffness and strength of the levelling pad is of no consequence, as already discussed earlier. The facia can be erected on the levelling pad after 24 hours of its casting. It should be noticed that an economical and faster alternative is adopted for block walls in terms of providing a levelled gravel pad in place of PCC pad. Any groove, trough guide etc. should no be put in the pad as they only hinder the process of making the levelling pad level, and do not contributing to the facia stability.

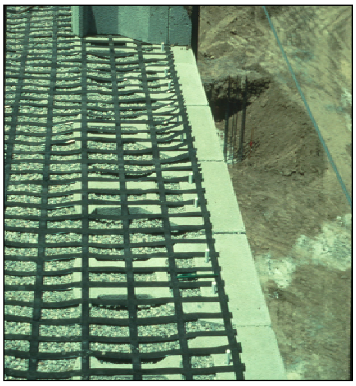
d. The panels are placed on the levelling pad with a slight inward batter (about 20mm/m height) and are propped from outside to begin with. The inward batter is corrected with the placement of the backfill as the panels move out. The outward movement and hence the inward batter required is dependent on the reinforcing material stiffness, backfill properties and has to be determined in the field, as its theoretical prediction is quite involved and approximate.

e. The blocks are aligned using the inbuilt concrete keys or the pins/dowels if provided. As mentioned earlier the concrete keys also help in shear transfer across the facia, whereas pins/dowels are only a mean of alignment.

f. The reinforced backfill is filled, rolled and compacted in desired layer thickness and to required density. The filter media/ separation layer is also placed simultaneously. Once the level of first reinforcing layer is reached, it is to be laid and connected to the facia as required (Plate 46). The steel strips are connected to the facia using nuts and bolts, bar mats through the rod inserted in the loops, Geogrids through the dowels or wrapped around. In case of block walls many connection details have been adopted and depicted in plates 47 to 50.

g. The above sequence is continued till the wall is completed. After which the crash barrier or the railing etc., as required is laid along with the pavement crust.

PLATE 46: CONNECTION OF PET GEOGRIDS USING GI HOOKS AND FIBRE GLASS/ STEEL DOWEL



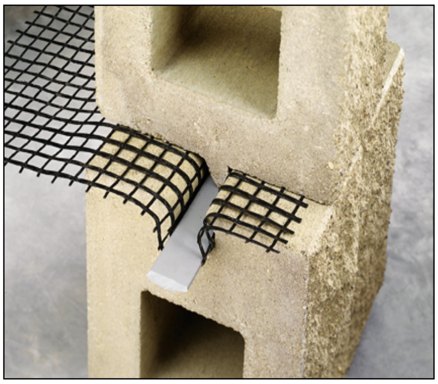


PLATE 47 TO 48: (CLOCKWISE FROM ABOVE) CONNECTION OF HDPE GEOGRIDS USING CLIPS, BY PVC FLAT AND FRICTION FOR PET GEOGRIDS

PLATE 49 & 50: HOLLOWS IN THE BLOCKS ARE FILLED WITH AGGREGATES TO PROVIDE AGGREGATE INTERLOCK, (ON RIGHT) BLOCK UNITS BEING PLACED USING PINS FOR ALIGNMENT

h. The RSS construction is even simpler and require lesser no. of tools and tackles.

4.9. COST ANALYSIS

a. As already mentioned above that MSE walls are likely to be more economical than other wall systems for walls higher than about 3m or where special foundations would be required for a conventional wall. Having established this fact, its time to look at the most economical ways of building a reinforced soil wall out of the so many alternatives already discussed. The reinforced soil wall has four typical components, which are variable as per the system adopted. These are listed below and also specified against each is the typical range of cost of each of these components:

Work Component	% of Cost
• *Design, Dwgs. & Technology Cost*	*02-03%*
• *Facia Casting And Erection*	*35%*
• *Permanent Accessories*	*01-02%*
• *Reinforcing Element*	*61-62%*

b. For the purpose of comparative cost analysis a typical MSE wall has been designed with two alternate systems and priced. The two systems adopted are i) GI steel strips with large size panels and ii) Modular block wall with PET geogrids. The MSE wall analysed has an elevation area of 10,000 sqm and average height of 5m.

Cost of MSE wall with GI steel strips and Large Panels

COMPONENT	COST	(%)
Design, Dwgs. & Technology Cost	05 Lakhs	(2)
Facia Casting And Erection	90 Lakhs	(35)
Permanent Accessories	05 Lakhs	(2)
Reinforcing Strips	157 Lakhs	(61)
Total 257 Lakhs	(Rs. 2,570 / Sqm)	

Cost of MSE wall with PET geogrids and Modular Blocks

COMPONENT	COST	(%)
Design, Dwgs. & Technology Cost	05 Lakhs	(2)
Facia Casting And Erection	69 Lakhs	(25)
Permanent Accessories	1.5 Lakhs	(1)
Reinforcing PET Geogrids	121.5 Lakhs	(62)
Total 197 Lakhs	(Rs. 1,970 / Sqm)	

c. The above are bare cost only and do not include specialist sub-contractor’s and main contractor’s overheads and profit components. From the above analysis it is clear that the construction of modular block walls is not only less equipment intensive but is also economical.

4.10. CONCLUSIONS / RECOMMENDATIONS

a. The paper highlights the current construction practices being followed in the field of Mechanically Stabilized Earth (MSE) walls and reinforced slopes in Indian context. Their advantages and disadvantages have been highlighted, clearly indicating that the advantages outweigh the disadvantages by a large degree. The various reinforcing element types have been discussed along with their merits and demerits. In the opinion of the author Geogrids, steel strips and bar mats types of reinforcing materials should be used with proper quality control for the reinforcing materials and correct design, including aseismic design should be performed, as per the available codes of practices.

b. The issue of patented/ proprietary systems has been discussed and it has been stated that all major patents have expired and the know-how is now available in public domain. It needs to be emphasized that only correct application of the know-how can result in the desired performance. The design and construction guidelines available in the codes and literature, such as those published by FHWA need to be implemented.

c. The flexibility characteristic of these structures needs to be utilized to realize the economics ever claimed for such structures. Guidelines have been presented for the total and differential settlements that can be permitted for such structures depending on the facia type. Many contentious issues like ground improvement and factors of safety to be followed etc. have been discussed and suggestions made. It has been suggested that the external stability checks should be carried out at the DPR stage and ground improvement, which is rarely required, should be included in the DPR as a separately payable item.

d. MORT&H specifications have been analysed in detail, deficiencies pointed out and remedies suggested. Generic Technical Specifications, covering all available systems, devoid of above-mentioned deficiencies have been proposed for adoption for future works by the fraternity.

e. A discussion on anchored deadman fill retaining systems had been presented from which it can be concluded that these systems cannot be classified as soil reinforcing systems. These, at best, are a mean of only retaining soil and do not create a coherent soil mass.

f. Design principles, which are available in a no. of codes of practices, have been included for sake completeness. However, seismic analysis and design procedure as per Mononoe-Okabe pseudo-static analysis has been presented in detail. In view of the author seismic design should be carried out in zones III and above, which is generally not practiced.

g. Some of the construction practices, specifically w.r.t. block walls' construction have been included. A typical construction sequence for construction of RSS has also been presented along with a typical strategy of building MSE structures with hard facing on very marginal soils in a phased manner.

h. Cost analysis of two MSE wall systems viz. steel strips with large panels and modular block walls with geogrids, has been presented to demonstrate the economy of the block walls.

i. The appurtenances to the MSE walls e.g. Surface Drainage, Sub-Surface Drainage, Drainage During Construction, Crash Barrier & Friction Slab, Corner Unit details, Panel Joints and Abutment – Wall Interface etc. have been discussed in detail. These appurtenances are equally important to the entire construction and should be standardised, especially the crash barrier and friction slab design, which should be included in the construction dwgs. to avoid repeat design efforts.

4.11. ACKNOWLWDGEMENTS

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* NCMA: National Concrete Masonry Association, USA