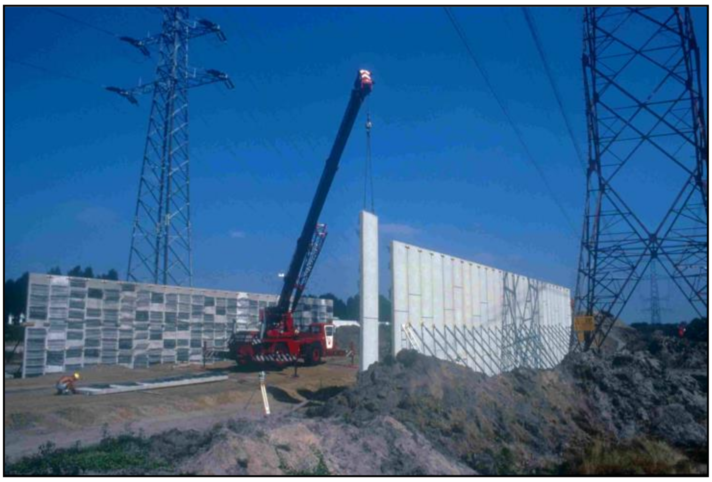
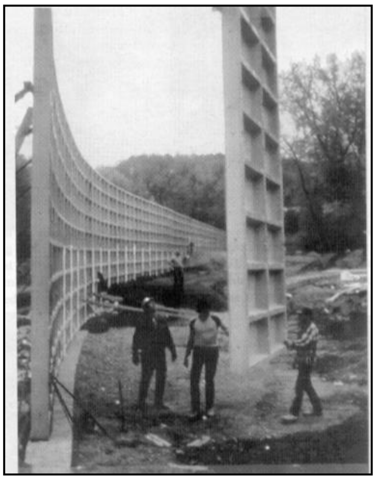
Mechanically Stabilized Earth (MSE) Walls

& Reinforced Soil Slopes (RSS):

Indian Scenario: A Comprehensive Review

Presented at 67th Annual Session of the Indian Roads Congress held at Panchkula on 19th November 2006





By

Goel Rajiv, CEO Earthcon Systems

EARTHCON SYSTEMS

B-28, SHIVALIK, NEW DELHI 110 017

Phone: 011-46626262 Fax: 011-26692044

E-mail: earthcon_systems@rediffmail.com

Mechanically Stabilized Earth (MSE) Walls & Reinforced Soil Slopes (RSS): Indian Scenario: A Comprehensive Review

By

Goel Rajiv, CEO Earthcon Systems

CONTENTS

SYNOPSIS

India has undertaken large infrastructure up-gradation projects and 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.

MSE or Reinforced soil is an internally stabilized composite engineered mass; consisting of selected backfill, soil reinforcing elements and a non-structural facia. 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.

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.

1. INTRODUCTION

1.1 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 1).

1.2 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 1).

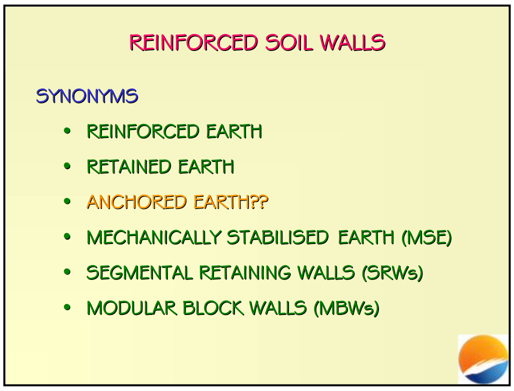


PLATE 1 : MSE WALL SYNONYMS

1.3 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.

1.4 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 2.

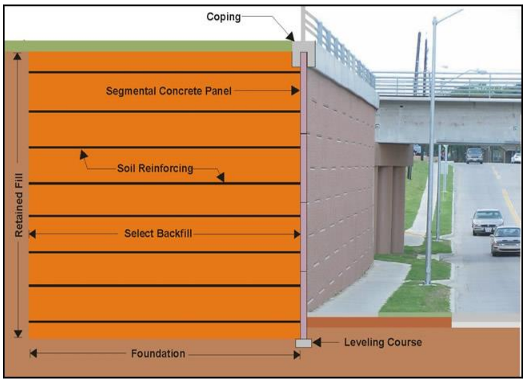


PLATE 2: MSE WALLS: TYPICAL COMPONENTS

1.5 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 subgrades. 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.

1.6 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.

1.7 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.

1.8 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.

2. ADVANTAGES AND DISADVANTAGES

2.1. 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.

2.2. 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.

2.3. 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.

2.4. 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.

3. TYPICAL APPLICATIONS

Typical applications of MSE walls and RSS include:

- Approach to Flyovers, Underpasses and ROBs
- Landslide reparation
- Bridge abutment
- Increase working area
- Reduce filled area
- Reduce filling material
- High Embankments for poor founding soil conditions
- Reinforced soil dikes, which have been used for containment structures for water and wastewater impoundments around oil and LNG storage tanks
- Bulk material storage using sloped walls
- Cost effective temporary structures
- Dams and seawalls

Some applications are depicted in plates 3 to 6.

PLATE 3 to 6: TYPICAL APPLICATIONS (CLOCKWISE FROM TOP LEFT) 3. A HYBRID ABUTMENT CONSTRUCTION, 4. AN APPLICATION FOR INCREASING WORKING AREA, 5. RSS FOR A HIGH EMBANKMENT CONSTRUCTION AND 6. APPROACHES TO A BRIDGE

4. REINFORCING ELEMENTS' TYPES

4.1 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

4.1.1. <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 7 and 8 depict the use of the same.

PLATE 7: MSE WALL WITH GI STEEL STRIPS

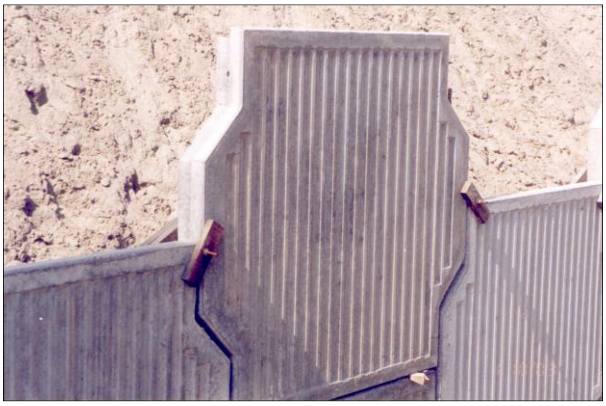


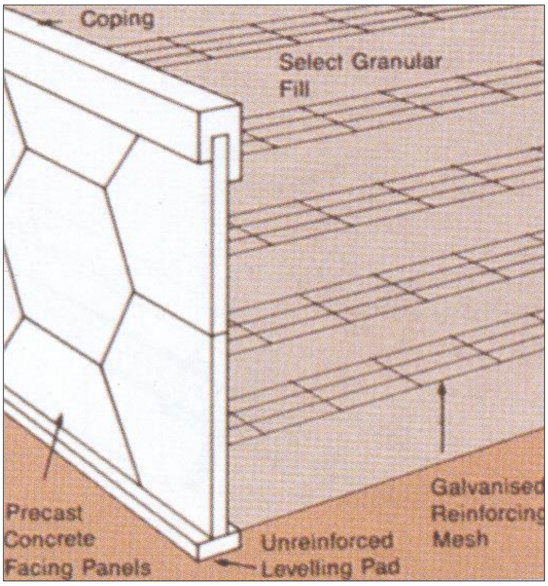
PLATE 8: LARGE SIZE PANELS USED FOR MSE WALL ON NH2

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.

4.1.2. <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 9, 10 & 12 depict the use of the same. Plate 11 gives a comparison of the stress transfer mechanisms in the ribbed steel strips and mats of metal.

4.1.3. <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 13 and 14 depict the same.



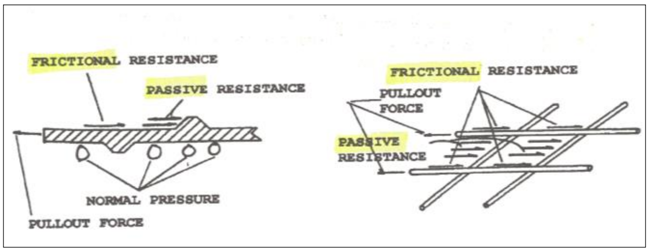


PLATE 9 to 12: MATALLIC BAR MATS: TYPICAL COMPONENTS (CLOCKWISE)
9. CONCEPTUAL DEPICTION OF THE RETAINED EARTH SYSTEM
10. MATS OF METAL BEING LAID ON SITE
11. COMPARISON OF STRESS TRANSFER MECHANISM BETWEEN RIBBED STEEL STRIPS AND MATS OF METAL
12. TYPICAL CONNECTION DETAIL WITH THE PANEL USING CLEVIS LOOP JOINT (THE WOODEN WEDGES ARE FOR REMOVING ANY SLACKNESS)

4.1.4. 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 15 to 18 depict use of these grids for making reinforced soil walls & slopes.

PLATE 13 & 14: WWM GABION FACING USED FOR DERA BASSI ROB IN PUNJAB

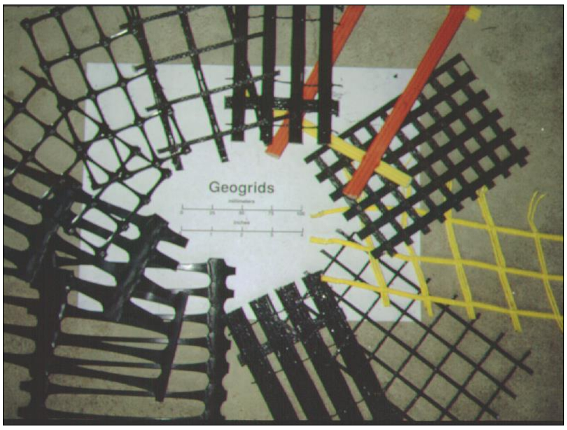


PLATE 15: PET AND HDPE GEOGRIDS

PLATE 16: MODULAR BLOCK WALL CONSTRUCTION USING GEOGRIDS

PLATE 17: RSS CONSTRUCTION USING PET GEOGRID FOR LANDSLIDE CONTROL, AT 38m HEIGHT THIS IS THE CURRENT WORLD RECORD HOLDER IN TAIWAN

PLATE 18: MSE WALL CONSTRN. USING PET GEOGRIDS

4.1.5. <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 19 depicts the construction of a RSS schematically.

PLATE 19: RSS CONSTRUCTION

4.1.6. 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 20 for a view of Paraweb[R] (of Linear Composites Ltd.).

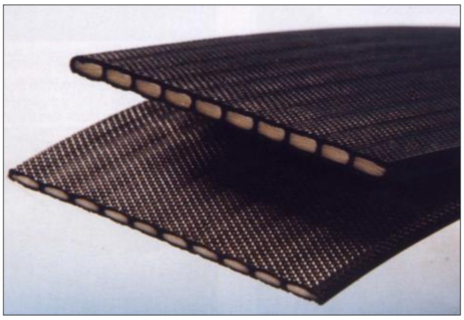


PLATE 20: PARAWEB OF LINEAR COMPOSITES LTD.

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 21.

PLATE 21: USE OF GEO-STRAP AS SLINGS

PLATES 22 TO 24
(CLOCKWISE FROM TOP LEFT)
PLATE 22: USE OF GEO-STRAPS FOR REINFORCED SOIL WALLS
PLATE 23: A MSE WALL CONSTRCUTED WITH GEO-STRAP NEEDS OUTSIDE PROPS DURING CONSTRUCTION ITSELF
PLATE 24: 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 22 to 24 for details.

4.2. 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:

4.3. 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.

4.4. 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.

5. PATENTS: SOME CLARIFICATIONS

5.1. 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.

5.2. 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.

5.3. 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.

5.4. 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.

5.5. 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.

6. FACIA: DISCRETE AND WRAP AROUND

6.1. As already mentioned, reinforced soil is an internally stabilized composite engineering mass, consisting of selected backfill, soil reinforcing elements and a non-structural facia. Facing is a component of the reinforced soil system used to prevent the soil from raveling out between the rows of reinforcement. The facing plays only a minor structural role in the stability of the structure.

6.2. The facing can be of many shapes, sizes and finishes. Plate 25 shows the variety that has been used for MSE walls. Discrete panels (or blocks, discussed separately) is the most popular facing that has been used for MSE wall construction due to the

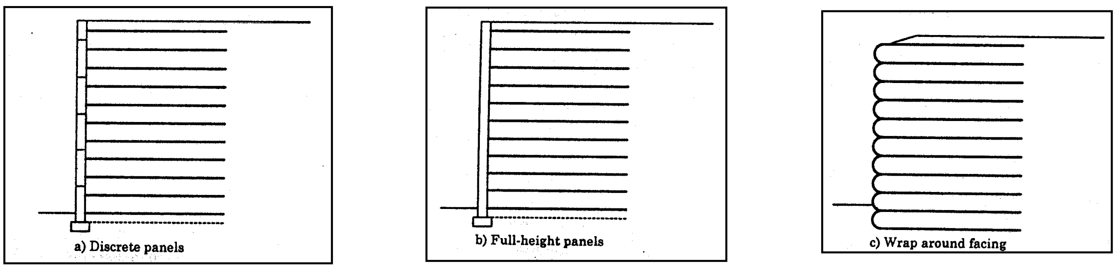


PLATE 25: MSE WALL FACIA TYPES: DISCRETE, FULL HEIGHT & WRAP AROUND

unlimited options it offers in terms of size, shape and finishes. The ease of handling is another plus point. Full height panels are rarely used as they have low facia flexibility and are unwieldy to handle. Wrap around facing is used for specific conditions where either the soil is likely to settle excessively precluding the use of hard facing or a green facia is required. Hard facings can be added later, if required. Any wrap around construction done using geogrids (in combination with non-woven Geotextile at the exposed surface) or woven Geotextiles has to be covered with a protective layer within about one month of it being exposed to sun light to minimize UV degradation. Japanese often put a hard facing after completing the wrap around construction. Plates 26 to 31 depict various examples of what has been highlighted above.

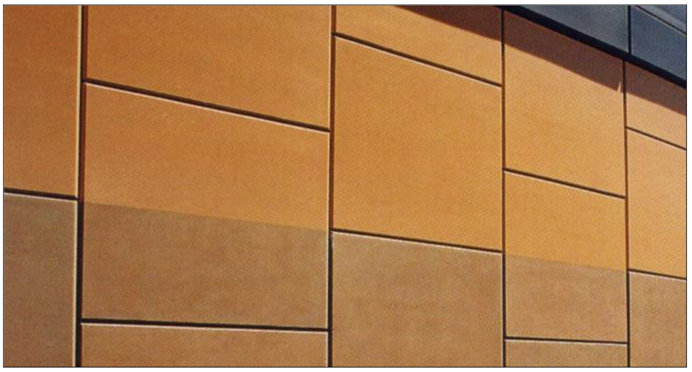


PLATE 26: USE OF DISCRETE FACIA, RECTANGULAR SHAPE WITH PLAIN FINISH

PLATE 27: DISCRETE FACIA: SHAPES AND FINISHES

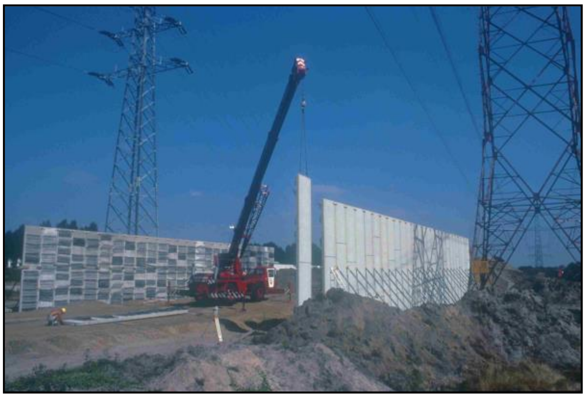


PLATE 28: USE OF FULL HEIGHT FACIA: NOTE THE PROPS IN PLACE

PLATE 29: ANOTHER EXAMPLE OF FULL HEIGHT PANEL DURING ERECTION

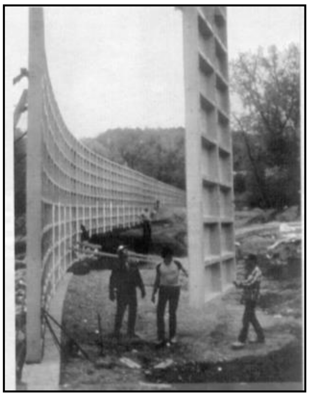


PLATE 30: USE OF WRAP AROUND FACIA

PLATE 31: ANOTHER DISCRETE FACIA EXAMPLE

7. USE OF MODULAR BLOCK FACIA

7.1. 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 32 for details.

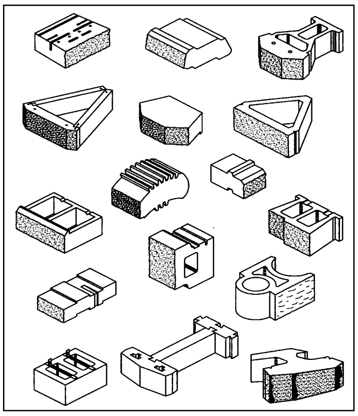


PLATE 32: A VARIETY OF MODULAR UNITS

7.2. Geogrid is generally used as the reinforcing element (Refer Plate 33 for details), although metal bar mat (with two longitudinal only) has also been used successfully.

7.3. 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 34 for details.

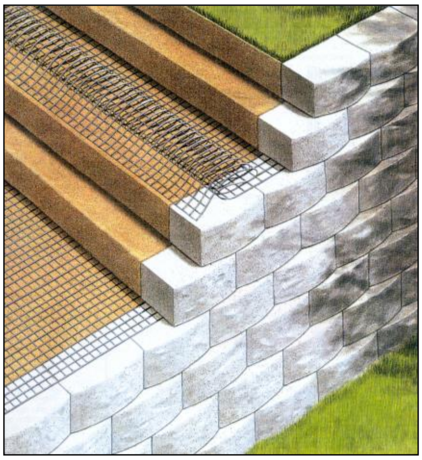
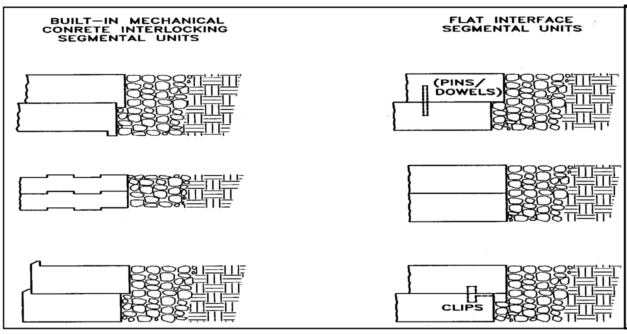


PLATE 33: USE OF GEOGRIDS AS THE REINFORCING MATERIAL WITH BLOCK UNITS

7.4. Use of coloured concrete units has been successful to break monotony on large wall faces. Refer plate 35 & 36 for some examples. Unfortunately use of plane faced units on some of the projects (plate 37) 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 38).



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 34: SHEAR TRANSFER MECHANISMS BETWEEN BLOCKS

PLATE 35 & 36: USE OF COLOURED FACIA TO BREAK MONOTONY OF LARGE WALLS, CAN BE UTILISED FOR URBAN CONSTRUCTION

PLATE 37 & 38: USE OF PLANE FACED UNITS?

BEVELLED FACED UNITS FOR BETTER LOOKING MSE WALLS

8. TOLERANCE FOR SETTLEMENT

8.1. One of the greatest advantages of MSE walls is their flexibility and capability to absorb deformation due to poor subsoil conditions in the foundations. In fact how much settlement the reinforced soil mass can absorb is solely limited by the flexibility of the facia.

8.2. Wrap around constructions can absorb settlements with practically no limits defined. Welded wire mesh can also allow large total and differential settlement of the founding soil. Plate 39 shows the allowable angular distortion for various types of panels and joint widths used in discrete panel facia. Angular distortion is defined as the slope of the line joining the settlement value points along the facia in the longitudinal direction. In other words if a graph is drawn with distance along the facia as abscissa and settlement as ordinate, the slope of the line joining these points is defined as angular distortion. Theoretically, if the height of the MSE wall is constant, the angular distortion is zero and there is no limit for the total settlements from the structural stability point of view. However, some limits can be imposed from functional point of view.

Panel Type	Angular Distortion
• FULL HEIGHT PANELS	1/500
• BLOCK WALLS	1/200
• WELDED WIRE FACING	1/50
• LARGE PANELS: JOINT WIDTH	
➢ 06mm	1/300
➢ 13mm	1/200
➢ 20mm	1/100

PLATE 39: PERMISSIBLE ANGULAR DISTORTION FOR VARIOUS PANEL TYPES AND JOINT WIDHTS

8.3. From plate 39 it can be observed that full height panels are the least flexible facia type while WWM is highly flexible. Increasing the joint width between the facia panel units can increase the flexibility of discrete facia. The joint width is the vertical height of the horizontal panels joints and from practical considerations the other joint widths should be at least 75% of it.

8.4. Axial rigidity of the facia is another important issue that needs to be looked into for desirable performance of high MSE walls. The reinforced soil mass shall get compacted with time and would drag the reinforcing element with it. Please note that we are talking about the reinforced soil mass alone and not the foundation soil. In case of MSE wall constructions with hard facing, the reinforcing element is connected with the facing and such downward dragging of the reinforcing element would overstress the connection. The facia should have some axial flexibility to accommodate the same. Introducing rubber pads between the panels' horizontal joints can cater for it, but it is important that the pads are not solid rubber pads as the same would possess low compressibility, and the purpose would be lost.

8.5. Some engineers have provided heavily reinforced U beams below the facia thinking that it would preclude differential settlement of the facia (Plate 40). Theoretically it certainly does, but in the wrong plane. With the reinforced soil mass settling differentially than the facia, would increase the probability of overstressing and hence failure of the connection of the reinforcing element with the facia. In such an eventuality the facia can fall off leading to local failures of the wall. Needless to say that an unreinforced levelling pad is what is required, and should only be provided below the facia. It is customary to build block walls on a levelled gravel pad alone.

PLATE 40: USE OF U BEAM BELOW THE PRECAST FACIA TO MINIMISE FACIA SETTLEMENT

8.6. The flexibility of the MSE walls is often not utilised to its fullest extent primarily because of psychological reasons. On many projects ground has been dug for many meters to overcome the fear of excessive settlement. Refer plate 41 for one such example on NH2 on GQ Package IV-D. We can be sure that no such suggestion would have come from the Supervision Consultant, in case an embankment alone had to be constructed at the same place. In the said case stringent settlements limits, suitable even for rigid RCC walls, were applied, resulting in extra cost to the client and variations. The example only highlights that the MSE walls are still designed like the RCC walls by the structural designers, without understanding that it is only a soil fill, which is reinforced to stand by itself.

PLATE 41: GROUND IMPROVEMENT BY WAY OF EXISTING SOIL REPLACEMENT, NH2 GQ, PACKAGE IV-D

8.7. The permissible angular distortion (plate 39) can mean that lot of settlement can be absorbed by MSE walls with hard facia, as the vertical profile of the highway is varying moderately say in a slope of 1 in 50 to 1 in 25. However, notwithstanding the fact that MSE walls can absorb all practically observed settlements, post construction settlements limits as given in IRC:75 can be adopted as the limiting criteria for MSE walls as well. Any ground improvement required to limit the settlement within the above said permissible limits should be incorporated in the DPR, and not left for the execution stage. This is one of the most contentious issues author has faced on several occasions, wherein it has been insisted upon that ground improvement required to meet an undefined settlement criteria is in the scope of MSE wall item.

8.8. MSE wall and abutment pier interface is another issue, which needs to be looked into. It is certainly not acceptable to have a MSE wall settling differentially w.r.t. to the non-yielding abutment by a large amount as this would impair the riding quality. Again guidance can be taken from IRC: 75, which specify a limit of 30mm differential settlement between the approach embankment and the abutment.

8.9. The maximum height of the approach occurs near the abutment and results in maximum settlement at the interface, further aggravating the problem. Ground improvement would invariably be required to limit excessive settlement near the interface. The length of zone where ground improvement can be carried out can reasonably be limited to 20-30m near the abutment.

8.10. Many solutions are possible to obviate the need of even this ground improvement viz.:

i) Adopt pure load bearing abutment i.e. let the super structure rest on the bank seat supported by the MSE walls,
ii) Redesign the abutment foundations to increase its settlement, thus reducing the differential settlements, and lastly
iii) Shift the cross MSE wall away from the rigid abutment shaft and let the approach slab span the gap. This way additional advantage can be obtained as per the permissible differential deflection limits specified in clause 706.3.2.1. of IRC:78-2000 for simply supported spans.

8.11. All the above solutions are definitely feasible for simply supported spans. For continuous spans additional analysis needs to be carried out to see the impact of this additional differential settlement on the structural system. The cost of ground improvement vis-à-vis the cost of additional structural strengthening required needs to be compared. Changing the structural system to simply supported spans can also be a feasible solution.

8.12. Needless to say that under the present scenario of mass production of DPRs by the consultants, wherein two different wings handle Bridges and Approaches, this exercise may not be implement-able. The DPR consultants would be more than willing to shift the problem from design stage to construction stage, as has been done on many recent NHAI projects, wherein the RE wall item has been modified to include ground improvement required, if any. To add salt to the burn the criteria to be followed for ground improvement is not specified. This has made the item even more vague, leading to arbitrary pricing by the contractors, and would directly reflect on the economy of the technology when compared with other retaining wall systems, wherein there is no such uncertainty. It is obvious that the said approach would result in larger complications and delays, just because proper engineering is not done at the DPR stage. Certainly, it is not advisable to postpone the problem to the execution stage if the desired economy is to be achieved.

9. MORT&H SPECIFICATIONS ANALYSED

9.1. 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.

9.2. 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 42 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 42: A WISH LIST OF WHAT THE SPECIFICATIONS NEED TO COVER

9.3. A sample specifications covering the above issued are prepared by the author and are Available in Appendix A for perusal of the users.

9.4. 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 included in Appendix A, and are as listed below:

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

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.

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

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.

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.

9.5. As indicated in plate 42, 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:

9.5.1. <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 the it as well.

9.5.2. 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.

i) 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]***

ii) 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

9.5.3. Reinforcing Element's Specifications

9.5.3.1. 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.

9.5.3.2. 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).

9.5.4. 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

9.5.5. 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

Plate 43 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

		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

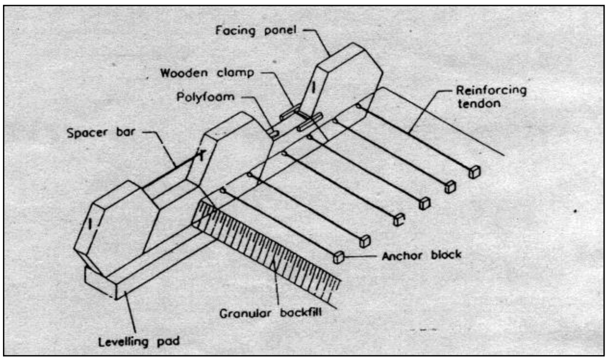
PLATE 43: THE MATERIAL PARTIAL SAFETY FACTORS USED ON TWO LARGE PROJECTS IN INDIA

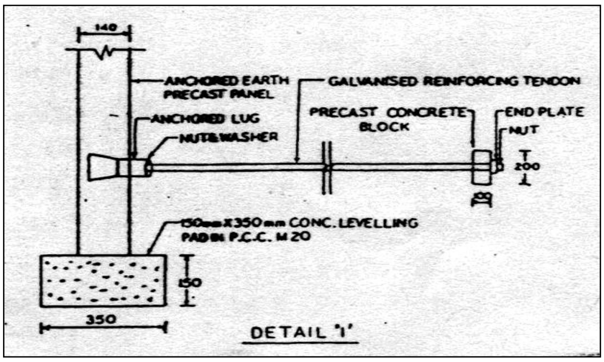
project the specifications called for a higher FoS and also provided for a separate measurable item for the reinforcing element, resulting in an over safe and expensive structure. The FoS used of the second project is 4.24, only 2.5 times of that used for the first project!

The above case study clearly highlights the need for unambiguous and comprehensive specifications. The detailed specifications are available in Appendix A for perusal.

10. ANCHORED DEADMAN FILL RETAINING SYSTEMS

10.1 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 44). 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.

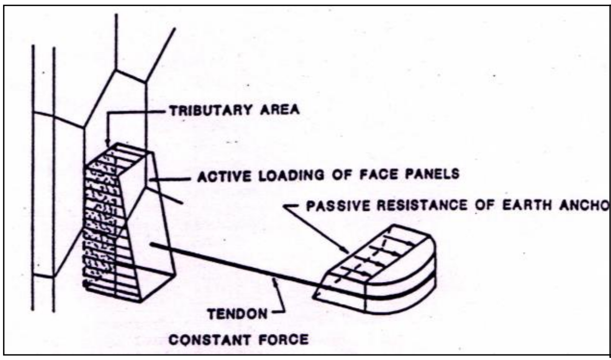


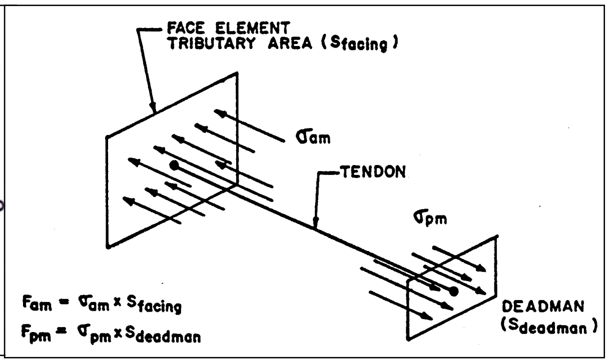


PLATES 44 AND 45: MULTI-ANCHORED DEADMAN FILL RETAINING SYSTEMS, ANCHORED DEADMAN SYSTEM: TYPICAL COMPONENTS

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

10.2. Plate 46 and 47 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 46 AND 47: VARIATION OF TENSILE FORCE IN AN ANCHORED DEADMAN SYSTEM, PL. NOTE THAT TENDON FORCE IS CONSTANT

10.3. 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.

10.4. 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.

10.5. The facing, the tendons and the deadman along with their connections are all important components of the system (Plate 45) 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

10.6. 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.

10.7. 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

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

11. DESIGN PRINCIPLES I/C ASEISMIC DESIGN

11.1. The design of reinforced soil walls is quite straightforward and a no. of codes/manuals are available for the same viz.

- AASHTO Standard Specifications for Highway Bridges 17th Edition – 2002[2]
- BS: 8006-95: Code of practice for Strengthened/Reinforced Soil and other fills[3]
- NCMA*: Design manual for Segmental Retaining Walls, 2nd Edition[4]
- NCMA*: Segmental Retaining Walls: Seismic Design Manual, 1st Edition[10]

** NCMA: National Concrete Masonry Association, USA*

Out of the above, in author’s opinion, AASHTO is the most comprehensive and simplified code and BS the least, which is more of a philosophical code. NCMA manuals are equally simplified and comprehensive documents and are used for the design of block walls.

11.2. Apart from above many publications from Federal Highway Administration (FHWA) are available highlighting the design and construction aspects. The publication nos. are FHWA-RD-89-043[9], FHWA SA96-071[11] and FHWA-NHI-00-043[1]. Out of the above the last one is the latest in the series and is most comprehensive of all the documents. This document can be downloaded from FHWA website.

11.3. The design primarily consists of two major components viz.

- Internal Stability and
- External Stability

11.3.1. Internal Stability

Internal stability consists of three checks on the reinforced soil mass (Plate 48):

- Pull out overstress: to ensure that the tensile force developed in the reinforcement is transferred to the embedment zone safely with a factor of safety (FoS) of 1.5.

- Tensile overstress: to ensure that the tensile force developed in the reinforcement is carried by the reinforcing element safely with its long-term design strength with a FoS of 1.5.

- Internal sliding: to ensure that the reinforcing element are long enough to mobilize frictional resistance sufficient to prevent sliding of a part of the reinforced fill over the sheet of reinforcing element under the lateral trust from the retained fill. This check is required only for planar reinforcing element such as Geogrids/Geotextiles. Internal sliding does become critical for geogrid spacing more than 600mm.

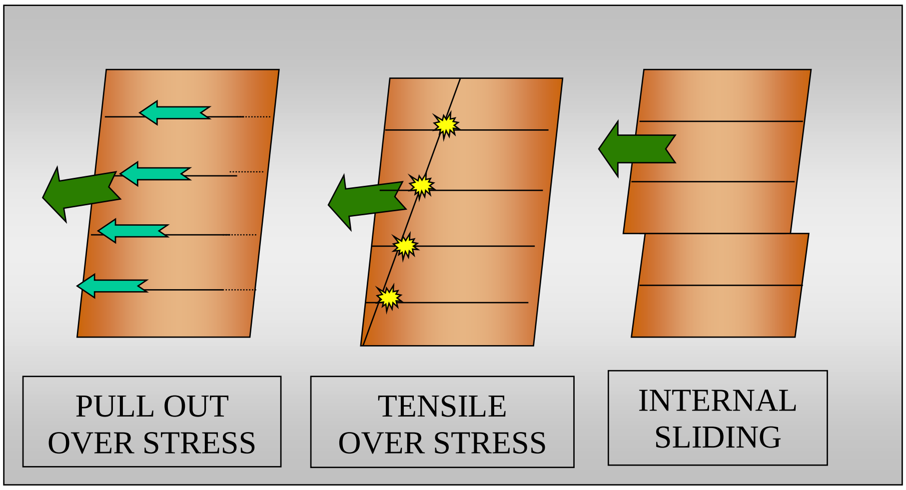


PLATE 48: INTERNAL STABILITY CHECKS CONSISTS OF

- *PULL OUT*
- *TENSILE STRENGTH &*
- *INTERNAL SLIDING*

11.3.2. External Stability

External stability checks consist of checks for the foundation soil and reinforced soil mass similar to a retaining wall assuming the reinforced soil mass as one coherent entity (Plate 49).

The first two checks are seldom critical. The bearing capacity should be evaluated using general shear failure with a factor of safety of 2.0. Settlement analysis is performed separately and analysed in relation to facia flexibility. Ground improvement to increase bearing capacity is seldom necessary except for exceptionally poor founding soils conditions.

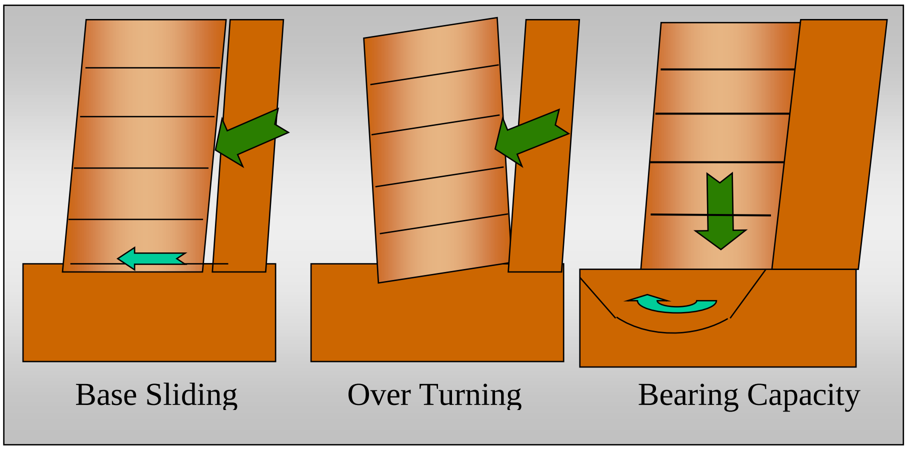


PLATE 49: EXTERNAL STABILITY CHECKS CONSIST OF

- *BASE SLIDING*
- *OVER TURNING*
- *BEARING CAPACITY*

11.3.3. Global Stability

Global stability analysis is not necessary for routine structures, unless the reinforced soil wall is founded on a slope, which itself may become unstable in the process.

11.3.4. Facia Stability

Facia stability is critical for Segmental Retaining Walls (SRW) and consists of three checks (Plate 50).

The NCMA design manuals deal with these aspects explicitly and should be followed [4,10]. The checks are critical for large spacing e.g. $\geq$600mm of reinforcing elements and should invariably be performed. However, for lower spacing viz. $\leq$400mm these checks can be taken as deemed to be satisfied [16].

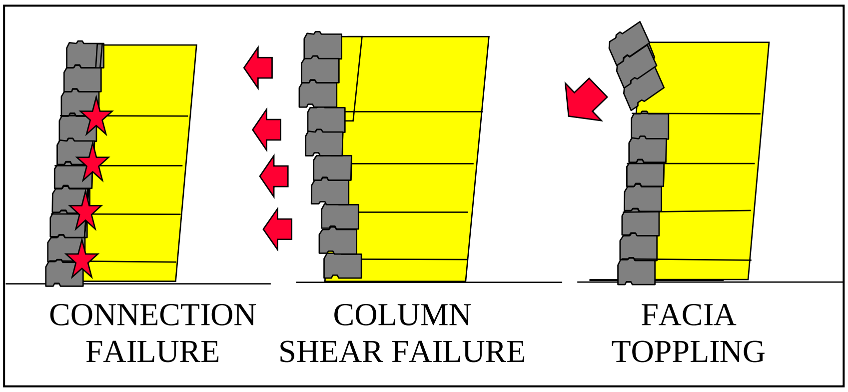


PLATE 50: FACIA STABILITY OF BLOCK WALLS CONSISTS OF
- *CONNECTION FAILURE*
- *COLUMN SHEAR FAILURE &*
- *FACIA TOPPLING*

11.3.5. Aseismic Design

Aseismic design is performed based on the Mononobe-Okabe analysis (M-O) method depending on the peak ground acceleration expected at site. The maximum ground acceleration expected at any site is as given in IS: 1893:2002 and summarized below:

Seismic Zone	*Peak ground acceleration, A*
II	0.10g
III	0.16g
IV	0.24g
V	0.36g

The M-O method is a pseudo-static method (Plate 51). Peak ground acceleration is converted to the structure acceleration Am using the equation [2]:

$$Am = (1.45 - A)\, A$$

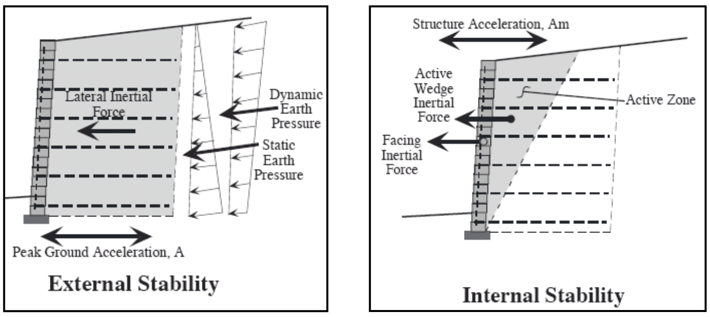


PLATE 51: SEISMIC FORCE EVALUATION USING MONONOBE-OKBAE ANALYSIS BASED ON PEAK GROUND ACCELERATION 'A'

<u>External Stability</u> computations (i.e. sliding, overturning and bearing capacity) shall be made by including, in addition to static forces, the Lateral Inertial Force (P_{IR}) acting simultaneously with 50% of the Dynamic Earth Pressure (P_{AE}) to determine the total force applied to the wall. The Dynamic Earth Pressure (P_{AE}) is applied at a

height of 0.6H from the base for level backfill conditions. Multiplying the weight of the reinforced wall mass by the acceleration Am, with dimensions H (wall height) and 0.5H, assuming horizontal backfill conditions, determine the Lateral Inertial Force (P_{IR}). P_{IR} is located at the centroid of the structure mass. These forces are determined using the following equations:

P_{AE}	=	$0.375\ Am\ \gamma_f\ H^2$	Dynamic Earth Pressure
P_{IR}	=	$0.500\ Am\ \gamma_f\ H^2$	Lateral Inertial Force

Factors of safety against sliding, overturning and bearing capacity failure under seismic loading may be reduced to 75% of the factors used for static conditions.

Internal Stability computations include design of reinforcement to withstand horizontal forces generated by the active wedge inertial force (P_I) in addition to the static forces. The facing inertial force can be neglected for thin facing but should be included for block walls. The total inertial force P_I shall be considered equal to the weight of the active zone times the maximum wall acceleration coefficient Am. This inertial force is distributed to the reinforcement proportionally to their resistant areas on a load per unit of wall width basis as follows:

P_I	=	Active wedge mass * Am
T_{md}	=	P_I * Lei / Σ Lei

The dynamic component of the reinforcement load (T_{md}) is added to the static component to find out the total load. For seismic loading conditions, the value of F* (the pullout resistance factor) shall be reduced to 80% of the values used in the static design. Factors of safety under combined static and dynamic loads for pullout and tensile capacity of reinforcement may be reduced to 75% of the factors of safety used for static loading.

Allowable stresses used for the design of the wall facing are permitted to be increased by 50% for steel and 33% for concrete. A detailed treatment of above is available in references [1], [2] and [10].

12. CONSTRUCTION DETAILS

12.1. 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.*

12.2. 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.

12.3. 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 ±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.

12.4. 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.

12.5. 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.

12.6. 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 52). 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 (Plates 11, 24 & 52). In case of block walls many connection details have been adopted and depicted in plates 16, 53 to 57.

12.7. 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 52: CONNECTION OF PET GEOGRIDS USING GI HOOKS AND FIBRE GLASS/ STEEL DOWEL

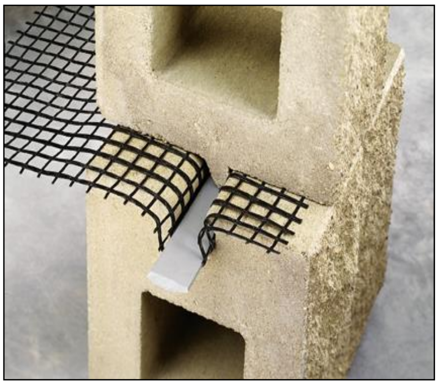


PLATE 53 TO 55: (CLOCKWISE FROM ABOVE) CONNECTION OF HDPE GEOGRIDS USING CLIPS, BY PVC FLAT AND FRICTION FOR PET GEOGRIDS

PLATE 56 & 57: HOLLOWS IN THE BLOCKS ARE FILLED WITH AGGREGATES TO PROVIDE AGGREGATE INTERLOCK, (ON RIGHT) BLOCK UNITS BEING PLACED USING PINS FOR ALIGNMENT

12.8. The RSS construction is even simpler and require lesser no. of tools and tackles. A typical construction sequence is depicted in Plate 58.

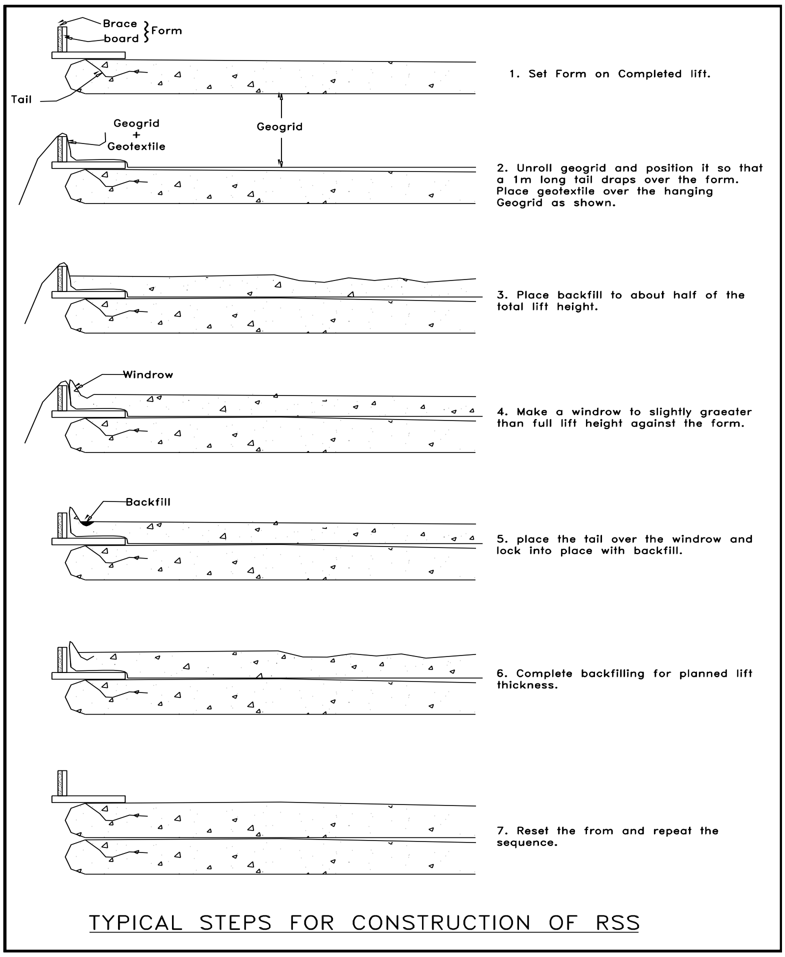


PLATE 58: TYPICAL STEPS FOR CONSTRUCTION OF REINFORCED SOIL SLOPE

13. COST ANALYSIS

13.1. 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%*

13.2. 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)	

13.3. 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.

14. APPURTENANCES

A list of appurtenances discussed in the following sections include Surface Drainage, Sub-Surface Drainage, Drainage During Construction, Crash Barrier & Friction Slab, Corner Unit, Panel Joints and Abutment – Wall Interface.

14.1 Surface Drainage

On approaches to flyovers/ bridges etc. the surface runoff has to be drained out

PLATE 59 & 60: TYPICAL DRAINAGE PIPE ARRANGEMENT ON TWO FLYOVERS IN DELHI, IN THE FIRST THE PIPE IS LEFT EXPOSED AWAY FROM THE FACIA WHILE IN THE SECOND IT IS COVERED WITH PRECAST UNITS WITH MATHCING FINISH without having it to travel for long distances on the sloped approaches. The crash barrier and the friction slab arrangement have to accommodate a collection chamber and pipe to collect and drain out the water. It is important that the drainage pipe after coming out of the crash barrier should be hugging the wall else there are chances of it getting damaged apart from looking ugly. It is also possible to cover the pipes with precast units having the same finish as the precast panels. Plates 59 and 60 show the typical arrangements followed on two flyovers in Delhi and clearly highlight the points mentioned above.

A typical detail of the collection chamber, as adopted on NH2 package IIA is depicted in Plate 61.

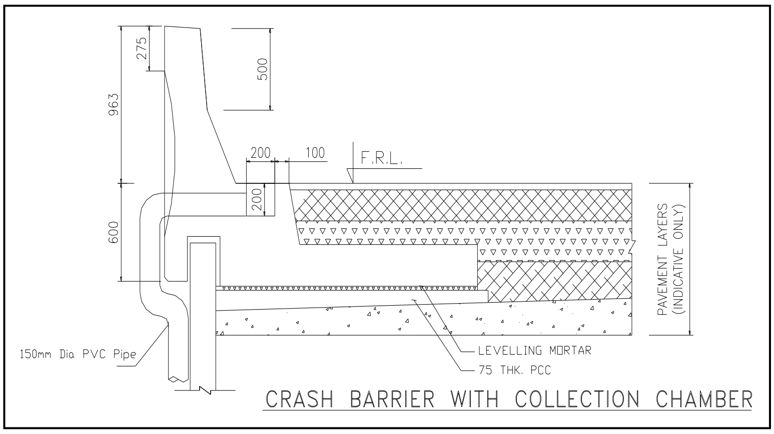
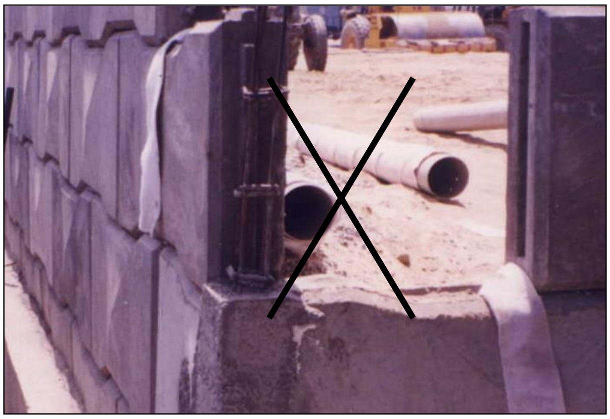


PLATE 61: TYPICAL DETAIL OF CRASH BARRIER WITH COLLECTION CHAMBER, AS ADOPTED ON NH2, PACKAGE IIA, GQ

14.2 Sub-Surface Drainage

Sub-surface drainage has to be provided for draining out water getting into the reinforced embankment. As already mentioned, the flyover approaches are black topped minimizing the water ingress level to insignificant levels. However, whatever little may be the amount it should be drained off to avoid development of pore water pressure within the reinforced soil mass, a condition it is not designed for. A drainage gallery / separation layer is generally provided behind the facia and the water is allowed to go through the facing joints. Alternately, the facing joints can be covered with filter fabric so that only the water is allowed to go out and does not carry



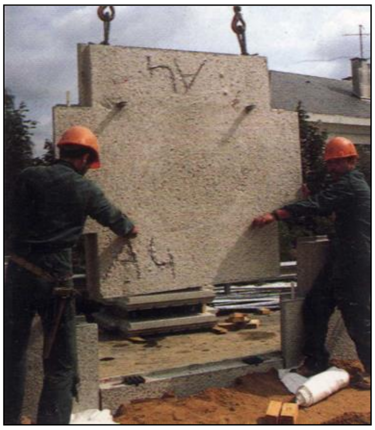


PLATE 62 TO 64:
(ANTI-CLOCKWISE FROM TOP LEFT)
62:FILTER BABRIC SANDWICHED WRONGLY BETWEEN THE JOINTS, 63:CORRECT APPLICATION TO COVER THE JOINTS, 64:IN LANDSCAPED STRUTURES ONLY PERFORATED PIPE MAY BE CALLED FOR DUE TO LARGE WATER INGRESS, FLYOEVRS' APPROACHES WITH BLACK TOPPING PRECLUDES ITS USAGE

the backfill along. Both chimney drain and filter fabric are not required at the same time. At times the fabric has been applied wrongly and resulted in problems (plate 62). The correct way to use filter fabric is to cover the joints and not to sandwich it between the panels (plate 63).

It has also been observed that many a time half perforated pipe wrapped in filter fabric is provided near the outside ground level to collect and drain out the water (plate 64). The author is yet to see any water coming out of these pipes. The fact remains that since the water ingress is low, reinforced fill is self-draining and the facia is not water tight, the water will never reach the pipe. The provision of pipe is specially suited for landscaped applications where the top is permeable and allows substantial water ingress.

At times, the retained backfill can be a poor draining material. Wherever, there is a probability of such occurrence, a 300mm wide drainage bay should be provided between retained and reinforced fills to allow free drainage of the retained fill along with the reinforced fill.

14.3 Drainage During Construction

In case water ponding is used as an aid to compaction e.g. in pure sands, suitable drainage for this water percolating down below should be designed and provided for, to avoid saturation/softening of the founding soils.

14.4 Crash Barrier & Friction Slab

Crash barrier over the reinforced soil walls is provided along with a friction slab to provide stability during a vehicular impact (plate 65). Not explicitly shown in the plate is the fact that the crash barrier is not touching the facia panels and derives its support from the reinforced fill through the friction slab. The practice to build crash barrier is to pack the space around the crash barrier with foam and cast it in-situ (plate 66). The other option is to precast the facia unit erect it in place and pour the in-situ friction slab (plate 67 to 69). The third option, which has also been used, is to cast the entire unit along with the friction slabs in suitable modules and erect it in place (plate 70).

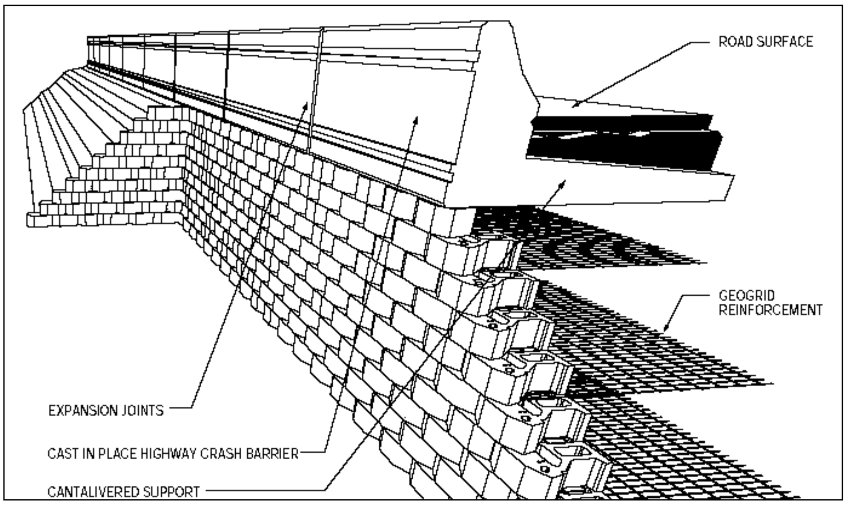


PLATE 65: TYPICAL COMPONENTS OF A CRASH BARRIER OVER MSE WALL, CRASH BARRIER WITH EXPANSION JOINTS, CAST-IN-PLACE OR PRECAST FRICTION SLAB AND ROAD CRUST OVER THE FRICTION SLAB PROVIDING STABILITY

PLATE 66 & 67: IN-SITU CRASH BARRIER CONSTRUCTION, FINISHED CRASH BARRIER USING PRECAST MODULES

There are many types of shapes and finishes that have been used for crash barrier and some are highlighted in plate 67, 68, 71 and 72. The design aspects of crash barrier have been covered in Appendix B.

PLATE 68 to 70: PRECAST CRASH BARRIER FACINGS, FIRST IS ONLY A THIN FACIA WHILE SECOND IS A 5m LONG PRECAST UNIT WITHOUT FRICTION SLAB, THRID IS THE PRECAST CRASH BARRIER ALONG WITH FRICTION SLAB

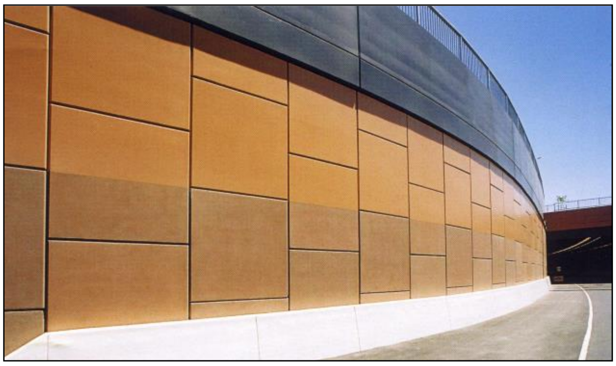


PLATE 71 & 72: CRASH BARRIER SHAPES AND FINISHES

It is necessary to standardize the design, dimensions (to the extent possible) and the main rebar so that it is not necessary to evolve design and dwg. for every MSE wall project. Apart from repetitions of the effort, at times imaginary designs are evolved similar to the one depicted in plate 73.

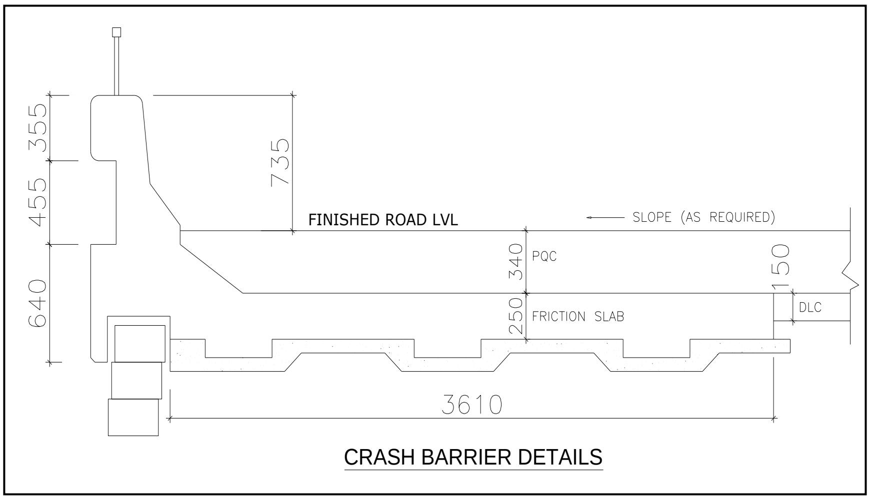


PLATE 73: A CRASH BARRIER DESIGN ADOPTED ON NH2 (GQ), WHEREIN THE FRICTION SLAB LENGTH PROPOSED IS ONLY 200% OF WHAT IS GENERALLY ADOPTED!

14.5 *Corner Unit*

At the junction of long wall and the cross wall, a corner unit has to be introduced for transition. With modular blocks it is quite easy to make the transition by cutting the blocks suitably. With panels a special unit has to be designed and provided at the corner. This unit can be easily precast and erected like all other panels (Plates 74 & 75). It is sad to see some ugly looking in-situ construction being done in the corner. These in-situ reinforced constructions eventually crack and become an eye soar (Plates 76 & 77).

PLATE 74 & 75: AN EXAMPLE OF AN ELEGANT LOOKKING PRECAST CORNER UNIT, PRECAST CORNER UNITS FOR A FLYOVER IN DELHI AT LAJPAT NAGAR

PLATE 76 & 77: A REINFORCED IN-SITU CORNER UNIT BEING CONSTRUCTED ON ONE OF THE FLYOVERS IN DELHI, A CLOSER VIEW OF THE SAME

14.6 Panel Joints

In addition to controlling the facia flexibility and permitting drainage of water, the panel joints play a major role in the overall performance of the MSE wall construction.

The joints are always made with a tongue and groove arrangement, which is often wrongly considered as a mechanism for interlocking the panels. In fact the panels are never touching each other unless there is severe differential settlement of the founding soil, causing panel movement and possible interlocking and cracking of the panels. The tongue and groove arrangement serves as a barrier to avoid UV exposure of the filter fabric put on the joints from inside. A straight-faced panel sides (plate 78 & 79) will result in UV exposure of the filter fabric and can become a possible source of backfill erosion through the joints.

PLATE 78 & 79: STRAIGHT FACED PANELS USED IN A MAJOR MSE WALL WORK IN INDIA, THE JOINTS ARE PACKED RANDOMLY WITH THERMOCOL, PERHAPS TO PREVENT UV EXPOSURE OF THE FILTER FABRIC!

14.7 Abutment – Wall Interface

Generally for flyovers, the abutment support is identical to the intermediate supports viz. a non-yielding type, and an interface with the MSE wall has to be conceived and designed. The MSE wall is sitting on a yielding strata and the design philosophy has to marry the two differently behaving systems without causing distress in any of them.

At times it is insisted to bring the cross wall closer to the abutment and hence the MSE wall has to sit on the unyielding support e.g. a pile cap. The junction of this transition should be provided with a vertical slip joint to avoid panel cracking (plate 80). Although it is much better to stop the cross wall before the pile cap and let the approach slab or any other structural system span the gap thus created (plate 81). The former solution, though correct, is inferior to the second one.

15. USE OF HARD FACING OVER SOFT FACINGS

15.1. As already mentioned that one of the greatest advantages of MSE walls is their flexibility and capability to absorb deformation due to poor subsoil conditions in the foundations. In fact how much settlement the reinforced soil mass can absorb is solely limited by the flexibility of the hard concrete facia.

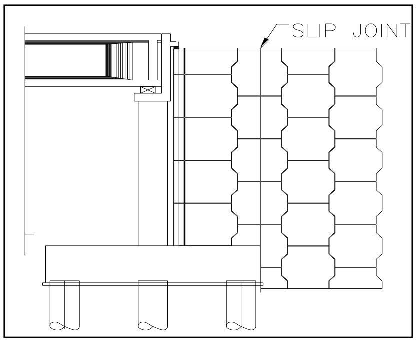
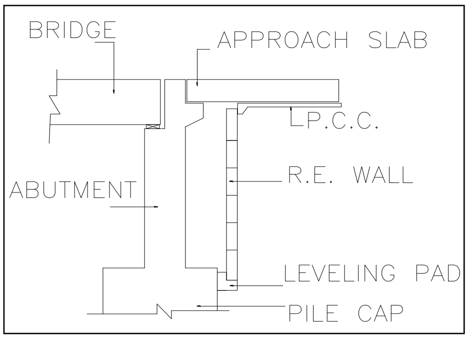


PLATE 80 & 81: VERTICAL SLIP JOINT NEAR THE PILE CAP Jn., MSE WALL IS RESTING BELOW AND THE GAP IS BRIDGED USING APPROACH SLAB



15.2. Wrap around constructions can absorb settlements with practically no limits defined. This fact has been utilized for constructions on poor soil conditions e.g. highly plastic water borne clays viz. marine clays. While constructing high embankments (MSE or RSS) over such soils a suitable technique to accelerate consolidation such as PVD or stone columns is utilized. Even with these measures the time required for major consolidation can be as much as 3 to 4 years and settlements of the order of few feet.

15.3. Under the given conditions it is not possible to build the MSE wall with a hard facing. Following construction sequence can be followed for a successful construction:

- Large Settlement Expected
- Facia Cracking is Possible
- Wrap-Around Construction in The First Phase
- Allow Settlement Period
- Post Install The Hard Facia, if Required

15.4. Japanese use hard facing on majority of their MSE constructions built using wrap around facia in first stage. This way a hard faced MSE construction can be accomplished successfully on very marginal soils.

16. CONCLUSIONS / RECOMMENDATIONS

16.1. 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.

16.2. 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.

16.3. 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.

16.4. 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.

16.5. 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.

16.6. 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.

16.7. 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.

16.8. 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.

16.9. 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.

17. ACKNOWLWDGEMENTS

Author acknowledges with thanks for the pictures and photographs that have been taken from various catalogues and Internet websites of various suppliers. Special thanks are due to Mr. Alok Bhowmick of Bridge & Structural Engineering Consultants and Mr. Somnath Biswas of AIMIL Ltd. for their valuable comments.

18. REFERENCES

1. Publication no. FHWA-NHI-00-043, "Mechanically Stabilized Earth Walls and Reinforced Soil Slopes: Design and Construction Guidelines", US DoT, Federal

Highway Administration, March 2001, Victor Elias, P.E.; Barry R. Christopher Ph.D., P.E. and Ryan R. Berg, P.E.

2. AASHTO Standard Specifications for Highway Bridges 17th Edition – 2002

3. BS: 8006-95: Code of practice for Strengthened/Reinforced Soil and other fills

4. NCMA*: Design manual for Segmental Retaining Walls, 2nd Edition

5. "Seismic Design and Performance of MSE Retaining Structures", Nov'19-21, 2001, Taipei, Taiwan ROC, International Geo-synthetics Engineering Forum

6. AFNOR NF-P 94-220, July 1992, "Soil Reinforcement: Backfilled Structures with inextensible and flexible reinforcing strips and sheets"

7. "Designing with Geo-synthetics", 4th Edition, Prof. Robert M Koerner

8. BS:EN:10025-1999, "Hot Rolled Products of Non-Alloy Structural Steels - Technical Delivery Condition"

9. Publication no. FHWA-RD-89-043 "Reinforced Soil Structures, Volume 1: Design and Construction Guidelines", US DoT, Federal Highway Administration, 1989, Barry R. Christopher Ph.D., P.E.; S. A. Gill, J. P. Giroud, J.K. Mitchell, F. Schlosser and J. Dunnicliff

10. NCMA*: Segmental Retaining Walls: Seismic Design Manual, 1st Edition

11. Publication no. FHWA-SA-96-071, "Mechanically Stabilized Earth Walls and Reinforced Soil Slopes: Design and Construction Guidelines", US DoT, Federal Highway Administration, 1996, Victor Elias, P.E.; Barry R. Christopher Ph.D., P.E. and Ryan R. Berg, P.E.

12. "Precast Segmental Flyovers of Delhi – A sea change in flyover construction Technology Brought About", Paper no. 483, IRC Journal Vol 63-1, Banwait S P, Tandon Mahesh, Jain NMD and Goel Rajiv

13. "MSE Walls' Construction Systems in Indian Context: A Critic's Review", S I Patel, Vice President IRC, Indian Highways, Vol.32, No.6, June 2004

14. Personal correspondence with Prof. Robert M. Koerner

15. Personal correspondence with Prof. Barry R. Christopher

16. Publication no. FHWA-RD-03-048 "Effect of Geosynthetic Reinforcement Spacing on the Performance of MSE Walls", Office of Infrastructure Research & Development, Federal Highway Administration, 2003, Christina Vulova and Dov Leshchinsky

17. Personal correspondence with Prof. R J Bathurst of RMC, Ontario, Canada

* NCMA: National Concrete Masonry Association, USA

APPENDIX B: CRASH BARRIER AND FRICTION SLAB DESIGN

The crash barrier and friction slab design presented here is based on the design philosophy contained in AASHTO'02 and IRC: 6.

Parapets and traffic barriers, constructed over or in line with the front face of the wall shall be designed to resist overturning moments by their own mass. Base slab shall be either cast continuously with sufficient longitudinal reinforcement or precast along with crash barrier in small lengths say 1.6m and joined with shear keys or by shear dowels. AASHTO [2] suggests a base slab length of 6m without any joint, but smaller lengths can be/have been used with concrete keys.

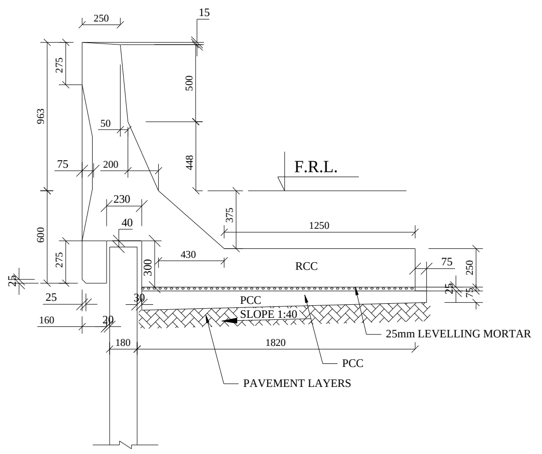
The crash barrier has to be designed for the following loading:

As per AASHTO'02 [2]	Load of 10kips (44.5kN) acting on a length of 1.5m at the top of crash barrier e.g. at a height of 0.95m above FRL
As per IRC: 6	to provide a minimum moment of resistance of 22.5kN/m at the base

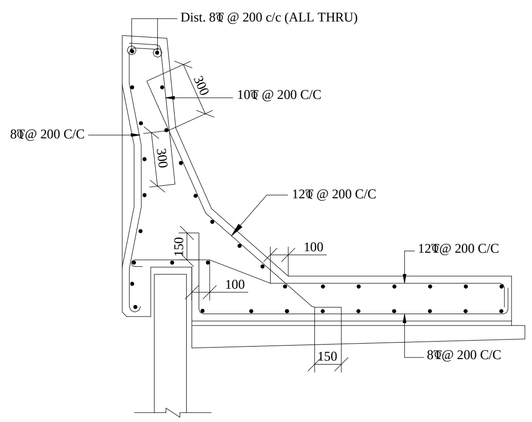
The moment of resistance required by the above two formulations is not very different. In any case a conservative reinforcement design is always adopted for psychological reasons.

Typical crash barrier plus friction slab dimension and reinforcement details are shown in plates 82 and 83, and can be adopted for future applications. Suitable drainage arrangement can also be in-built in these precast units (Plate 61), placed at regular intervals say 30-50m c/c. Overturning and sliding is not a problem with the configuration thus detailed.

Engineers often put excessive reinforcement in the crash barrier ignoring the fact that capacity of such barriers is limited by the sliding and overturning capacity of the system. Shear key(s) below the crash barrier friction slab to mobilize passive resistance and/or anchoring strips/ geogrids to the base slab result in over designed systems, and are generally put for psychological reasons. Similar details can be found in FHWA publications [1].



CRASH BARRIER DIMENSION DETAIL



CRASH BARRIER REINFORCEMENT DETAIL

PLATE 82 & 83: TYPICAL CRASH BARRIER AND FRICTION SLAB DIMENSIONS AND REINFORCEMENT DETAILS

APPENDIX C: INTERNAL STABILITY DESIGN FOR TRAFFIC IMPACT LOAD

Internal Stability check under the traffic impact load involves checking strength and pullout resistance of the upper few layers of reinforcement. External stability check is not relevant.

The upper row(s) of soil reinforcement shall have sufficient capacity to resist a concentrated load of 45kN (10 kips) distributed over a barrier length of 1.5m. This force distribution accommodates the local peaking of force in the soil reinforcements in the vicinity of the concentrated load. The distribution of this force to the upper layers is as given in plate 84. Adequate room shall be provided laterally between the back of the facing panels and the traffic barrier/slab to allow the traffic barrier and slab to resist the impact load in sliding & overturning without directly transmitting load to the top facing units.

For checking pullout safety of the reinforcements, the lateral traffic impact load shall be distributed to the upper soil reinforcement layers, as detailed in plate 84. The full length of reinforcements shall be considered effective in resisting pullout due to impact load. The upper rows of reinforcements shall have sufficient pullout capacity to resist a horizontal load of 45kN distributed over 6m length of base slab. The force distribution for pullout computation is different than what is used for tensile capacity computations (longer base slab length considered in the later) because the base slab must move laterally to initiate a pullout failure due to relatively large deformation required.

Due to the transient nature of traffic barrier impact loads, when designing for reinforcement rupture, the geosynthetic reinforcement must be designed to resist the static and transient (impact) components of the load without accounting for creep effects.

Seismic and traffic impact load should not be combined.

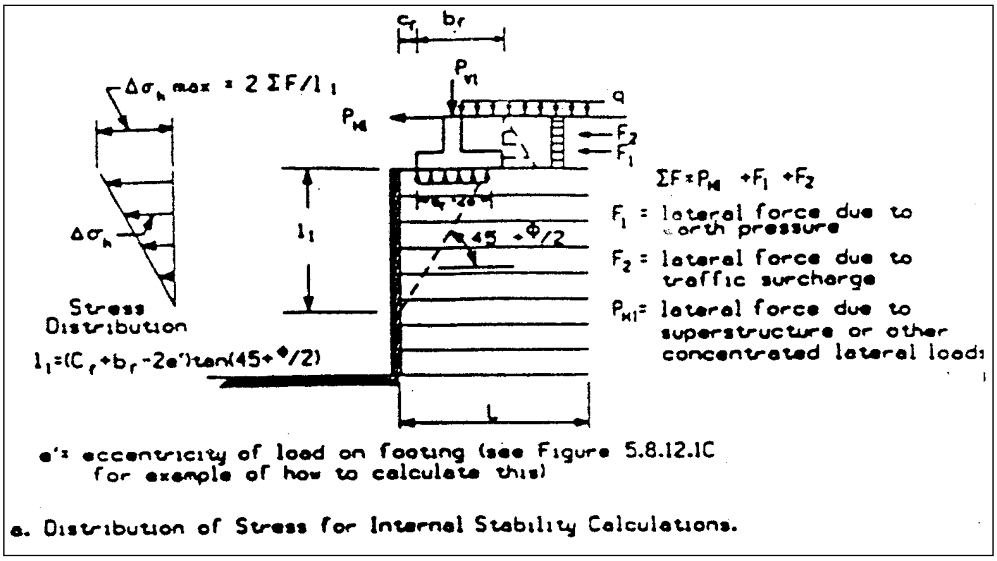


PLATE 84: DISTRIBUTION OF TRAFFIC IMPACT LOAD TO THE UPPER LAYERS OF THE REINFORCEMENTS [2]