Conceptual design and construction methodology of reinforced earth wall structures: Case study

Arun Kumar
M.E,MIET,GMICE, Qatar

ABSTRACT: Reinforced earth wall construction is very economical and less time consuming in comparison with the conventional retaining wall, with the significant material advancement of synthetic fabrics-geotextile or geogrid and with the soil-geogrid interaction, solely based on the fundamental mechanism of friction and with soil interlocking, results as reinforcement in inducing tensile loads, with shear stresses at interfaces and confining stresses being developed simultaneously, redistributes these stresses back into soil, this enables more conveniently, for reinforced earth wall to take up the surcharge and other anticipated loadings more firmly. In this paper, design and actual construction of varying heights of reinforced earth wall from 2.4m to 12.60m with Pedestrian underpass, Vehicular underpass, Flyover and Rail over bridge types of reinforced earth wall will be highlighted. Further, the pull-out test, connection strength between the fascia panels and the Geogrid used, with the practical difficulties of Geogrid identification, PCC laying, tissue corner types, water logged site, panel distortion, selection of backfill material, edge compaction, reinforcing skew portion and settlements will be discussed practically.

Keywords: Fasica panel, Backfill, Geogrid, compaction, friction, interaction, stability

1 INTRODUCTION

The two major districts Krishnagiri and Dhamapuri are connected by total length of National Highway 62.5kms comprising of 4 flyovers (Ch: 105+ 440 Ch: 116+ 880, Ch: 137+765 and Ch: 142+ 135) 1 ROB (Ch: 136+ 532), 2 vehicular underpasses (Ch: 96+ 300 and Ch: 124+125) and 3 pedestrian underpasses (Ch: 100+100, Ch: 108+ 440 and Ch: 111+ 860 respectively, approximately 54,000Sq.m of precast fascia area for construction of these reinforced earth walls serving to the better infrastructural development as part of National Highway Development Program, to cater to public, thereby attaining to a sustained economic growth.

The reinforcement Geosynthetics material used here at constant level of incremental depth of 0.60m, with geogrids of different tensile strength ranges with GX 40/40, GX 60/30, GX 80/30 and GX 100/30, supplied in rolls, based on design, during construction, the geogrids are placed normal to the flexible panel fascia wall. The design methodology adopted as per BS 8006:1995, with peak ground acceleration considered to be 0.04 and with seismic Zone II. Inorder to check the stability of MSE walls, external stability checks, includes sliding failure, Tilting/Bearing failure, overturning failure and slip failure are analyzed individually. Further the geogrid reinforcing embedded in soils needs to be ascertained for rupture or pullout and adherence for internal stability are assessed on design basis. The construction of all 10nos of are explained subsequently, along with the practical difficulties encountered during execution and construction stages.

2 REINFORCED SOILS CONCEPTS

The fundamental mechanisms start with an application of vertical load applied to reinforced soil, the vertical load gets distributed within the soil mass, leading to tensile stresses within the soil and resulting in lateral tensile strain. But the lateral movement of the soil particles are restrained by the reinforcement. If the tensile stiffness of the reinforcement is greater than that of the soil, the soil tends to get retained.

2.1 *Soil reinforcement interface*

However, due to the movement of soil, relative to the reinforcement will generate shear stresses at the soil/reinforcement interface and these shear stresses induce tensile loads in the reinforcement which are re-distributed back in the confined soils mass in the form of an internal confining stress. (see Figure 1).

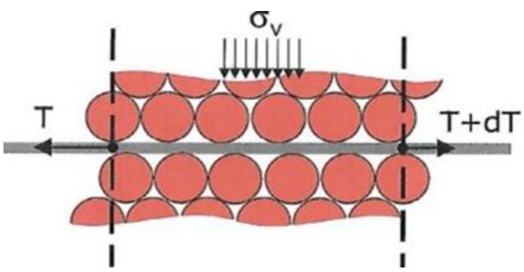


Figure 1. Shear stresses generated at soil/structure interaction

3 COMPONENT PARTS OF REINFORCED EARTH WALL

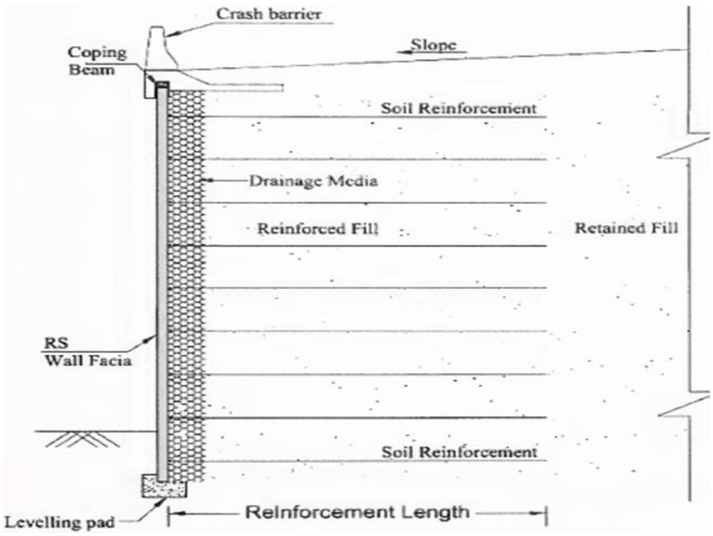


Figure 2. Typical cross section of reinforced earth wall

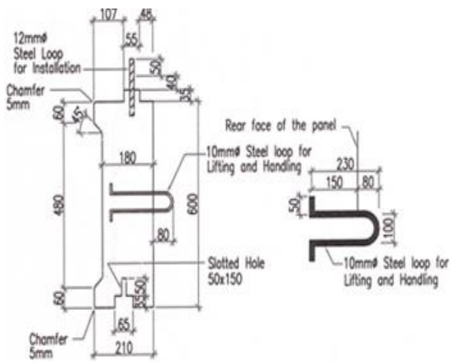


Figure 3. Typical section of Panel

3.1 *Reinforcing element*

The reinforcing element used in this project is Miragrids, as uniaxial geogrids of polyester strips available in a range of strengths, tensile strength imparts both in principal and transverse directions, conventionally, the geogrids are placed, in such a way that the principal tensile strength direction, is placed normal to pre-cast concrete panel fascia. The material offers excellent in-soil creep resistance, develops high panel-to-grid connection strength, provides a high long-term design strength thus reducing the total amount of geogrid required, and offer high modulus and low long-term tensile strain compatible with the soil structure. (see Figure 2)

3.2 *Retained fill*

The middle portion of the reinforced earth wall, do exist as the natural fill or borrowed fill, in either case the retained fill need to be ascertained for index and engineering properties of the fill, like grain size analysis, angle of internal friction, Atterberg limits, density and permeability should be determined even before design, the frictional angle of the retained fill should be lesser than the reinforced soil considering the active earth pressure acting as a function of friction angle of retained fill. During construction, in this project. The black top of the road was removed and remaining firm strata retained as fill of the reinforced wall.

3.3 *Reinforced soil/fill*

The reinforced earth backfill shall be selected as granular fill having high frictional resistance, low compressibility and free draining fill. The granular fill with more than 15% passing 75-micron sieve but should be less than 10% of particles smaller than 15 microns are acceptable provided plasticity index is less than 6 and friction angle is not less 30^0 and co-efficient of uniformity, Cu > 2. Backfill placing is followed immediately after fascia panel/block erected at each reinforcing level, the backfill has to be levelled and compacted to the required Maximum dry density and optimum moisture content before actual placing of reinforcement layer. Vibratory plate compactor of 1 ton or non-vibratory type roller 8-10 tons can be used in 200 mm layer thickness and at 95% maximum dry density.

3.4 *Facing element*

Facings can be soft or hard depending on the backfill material to support and provide cover aesthetically and the conditions that is feasible, based on design and construction aspects. precast concrete fascia panels or blocks are more extensively used for reinforced earth wall structures. A precast concrete panel of length 1380mmm height 600mm and average width of 210mm were used during the construction of RE wall structures in this project. (see Figure 3)

3.5 *Drainage*

The drainage aggregate bay behind the block / panel wall facing (minimum 600mm thick) shall be clean well graded stone or granular fill material of size between 9.5mm to 19.1mm. The drainage collection pipe shall be top half perforated or slotted PVC/HDPE pipe of 150mm diameter and shall be wrapped with non-woven geotextile that will function as filter. The outlets shall be provided at suitable intervals.
The drainage geotextile shall be of Mirafi 140P type non-woven needle punched geotextile composed of polyester fibres formed into stable network, such that the fibres retain their relative position. The geotextile fabric shall be inert to biological degradation and resistant to naturally encountered chemical alkalis and acids.

4 BASIS FOR DESIGN

In reinforced earth wall structure, two types of check are done in order to ascertain the stability, as a whole structure both externally and internally.

4.1 *External stability*

The following checks are carried out inorder to assess for the external stability considering all the dead loads, live loads and the forces acting on the structure.

4.1.1 *Sliding failure*

The stability against forward sliding of the structure at the interface between the reinforced fill and the subsoil should be considered. The resistance to movement should be based upon the properties of either the subsoil or the reinforced fill whichever is the lesser in magnitude. Consideration should be given to sliding on or between any reinforcement layer used at the base of the structure. Ref. pg – 58, BS 8006
$f_s R_h < (R_v \times a' \tan \phi_p / f_{ms}) + (C' / f_{ms}) L$, Eq.(1) Where,

Rh	=	Horizontal factored distributing force
fs	=	Partial factor against base sliding
fms	=	Partial material factor applied to tan fp, C' & Cu
C'	=	Cohesion of the soil
a'	=	Interaction coefficient relating soil/reinforcement bond angle with tan ϕ_p
ϕ_p	=	Peak friction angle

Long term stability
For soil-to-soil contact
R_v (tan ϕ_p / f_{ms}) + (C' L / f_{ms}) >f_s x R_h Eq.(2)
For Soil-to-Reinforcement contact
Rv (a' tan fp / f_{ms}) + (a' bc C' L/ f_{ms})> fs x Rh Eq.(3)
Short term stability
For soil-to-soil contact
C'_U L / f_{ms})> fs x Rh Eq.(4)
For Soil-to-Reinforcement contact
a' bc C' L/ f_{ms} > fs x Rh Eq.(5)

4.1.2 *Overturning failure*

The resultant vertical force is considered as summation of vertical forces exerted due to fascia, backfill and surcharge. With these resultant vertical and horizontal forces, the resisting moment and overturning moment are assessed. In reinforced earth structure restoring moment about the toe should be always greater than the overturning moment about the toe. The factor of safety towards overturning due to lateral pressure imposed should be adequate and at least 1.2 should be achieved. (see Figure 4).

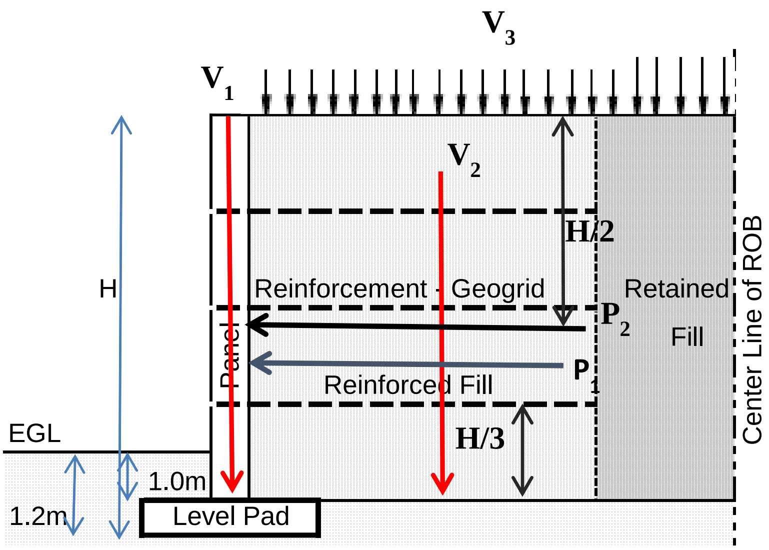


Figure 4. Vertical and Horizontal forces acting in RE Wall

Check for Overturning
Vertical Forces
Vertical load due to fascia
$V_1 = w\ H\ \gamma_c\ f_{fs}$ Eq.(6)

Vertical load due to fill
$V_2 = LH\ \gamma_f\ f_{fs}$ Eq.(7)

Vertical load due to surcharge
$V_3 = L\ (DL + LL).\ f_q$ Eq.(8)

Resultant Vertical load
$R_v = V_1 + V_2 + V_3$ Eq.(9)

Horizontal forces
Earth pressure due to backfill
$P_1 = 1/2\ K_a\ \gamma\ H_2\ f_{fs}$ Eq.(10)

Earth pressure due to Surcharge

$P_2 = K_a$ (D.L + L.L).H.f_q Eq.(11)
Resisting moment, M_r = V_1 x w/2 + V_2 x L/2 + V_3 x L/2
Overturning Moment, Mo = P_1 x H/3 + P_2 x H/2
FS overturning = ∑ Resisting moments / ∑Overturning moments > 1.35

4.1.3 *Tilting/Bearing failure*

The imposed bearing pressure acting below the base of the wall should be compared with the ultimate bearing capacity of the foundation as follows. This bearing pressure is evaluated based upon Meyerhoff distribution as shown in figures below. A typical bearing pressure imposed by reinforced earth wall structure on the bearing foundation soil is also shown in Figure 5, c) Tilting/bearing failure and see Figure. 6

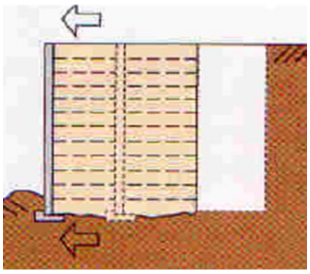
$q_r \leq q_{ult} / f_{ms} + \gamma\ D_m$ Eq.(12)
q_r = Factored bearing pressure acting on the base of the wall
R_v = Resultant of all factored vertical load components
L = Reinforcement length at the base of the wall
e = Eccentricity of resultant load, R_v about the centre line of the base of width L

4.1.4 *Slip failure*

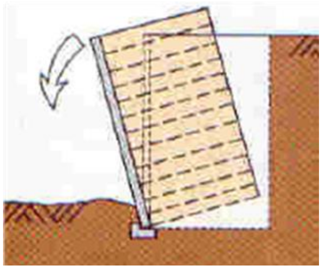
Global stability analysis shall be carried out using Geotechnical software ReSSA, to check slip circle failure, that was used in this project and factor of safety atleast 1.30 under static condition and 1.1 under dynamic/earthquake conditions are considered to ensure, there is no slip failure.

4.2 *Internal stability*

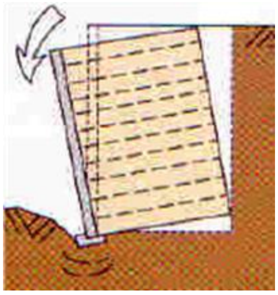
The integrity of the reinforced earth wall as a whole primarily, depends on the reinforcement and backfill, the vertical loads get transferred within the soils mass, the movement of the soil particles are restrained by the presence of reinforcement in the form of geogrids, due to sliding friction and interlocking of the soils particles within the confinement of the reinforcements generates shear stresses with inducing tensile loads. The reinforcement based upon different grades depending upon design is placed at different levels on to each compacted fill of 600mm and needs to be essentially checked against rupture and adherence property of the reinforcement at each layer as part of internal stability analysis.



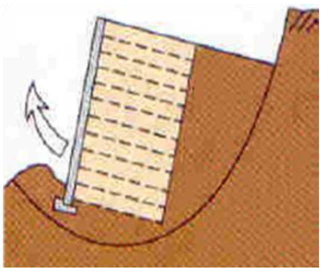
a) Sliding failure



b) Overturning failure

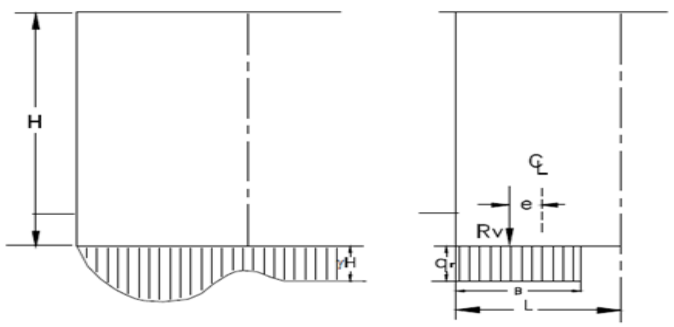


c) Tilting/bearing failure



d) Slip failure

Figure 5. External failure mechanism



a) Pressure imposed at base   b) idealized bearing pressure

Figure 6. Pressure distribution along the base of wall

4.2.1 *Rupture*

The tensile strength of the j_{th} layer of reinforcing element is given as

$T_D / f_n \geq T_j$ Where, Eq.(13)

T_j = Maximum Tensile Force,

T_D = Design tensile strength of the reinforcement- geogrid

f_n = is the partial factor for the economic ramification of failure

$T_D = T_{ult} / R_{Fd} . R_{Fid} . R_{Fcr}$ Eq.(14)

Where, T_{ult} – Ultimate tensile strength of geogrid (kPa)

R_{Fd} – Durability, R_{Fid} -Installation Damage (based on type of soil), R_{Fcr} –Creep, varies based on temperature of soil,

4.2.2 *Pull out*

The geogrid reinforcing embedded in soils, need to be checked for pullout or rupture when tensile force exceeds the tensile capacity of the grid. The peak pullout load is obtained in laboratory testing.

P = Peak pullout load (kN) = $2\ \alpha\ \sigma_v\ L_e\ B \tan\phi$ Eq.(15)

Where,
α = Interaction parameter, σ_v = is the vertical pressure, L_e = is the embedded length of geogrid in the tank, B = is the width of the geogrid, ϕ = is the friction angle of the soil.

5 CONSTRUCTION METHODOLOGY OF REINFORCED EARTH WALL

5.1 *Excavation*

The Plan area of the of Reinforced Soil/ Earth Structures shall be excavated in accordance with the requirements of site conditions and reasonably close conformity to the excavation limits based on the marked survey lines and considering all construction stages as per the approved drawings. Should take precautions to minimize over- excavation. Excavation support, if required shall be designed accordingly.

5.2 *Foundation preparation*

The foundation for Reinforced Soil/ Earth Structures shall be graded level for width equal to or exceeding the length of reinforcing geosynthetics. Prior to wall construction, if required by the Engineer, the foundation shall be compacted with a smooth wheeled roller. The depth of foundation below the finished ground level shall not be less than as specified in BS 8006-1995 or 600mm, whichever is greater.

5.3 *Ground improvement*

Where foundation soil is found to be unsuitable, either removal and replacement technique or ground improvement is required to be carried out, as required by the Engineer. The need for ground improvement, design and ground improvement methodology shall be verified and approved by the Engineer prior to construction. Suitable ground improvement technique shall be identified based on the results of subsoil exploration. Foundation preparatory works and foundation treatment/ improvement shall be treated as integral part of the reinforced soil structure.

5.4 *Levelling pad*

An unreinforced smooth finish concrete levelling pad is formed, shall have a minimum concrete grade of M-15 ($15N/mm^2$) and cast at each foundation elevation, maximum size of aggregates shall be 20mm and the pad shall be cured for at least 48 hours before placement of first precast fascia panels/blocks.

5.5 *Geogrid placement*

After compaction of original ground level soil, the primary function of geogrid is reinforcement, the geogrid shall be laid in one continuous length both in principal strength and transverse directions, the principal strength directional tensile strength is placed normal to the reinforced earth wall

5.6 *Erecting the initial panel course*

The first panel is placed on the leveling pad. The face of the panel is aligned considering the batter of the wall, based on the design the batter angle upto 4 degree can be provided.

5.7 *Reinforced soil/ Backfill*

The reinforcing elements shall be laid free from all kinds of kinks, damage and displacement during laying, spreading, leveling and compaction of the fill. The filling shall be planned in such that no construction plant equipment runs directly on to the reinforcement. It shall be ensured that the exposure of soil reinforcement to ultraviolet rays is minimal and should be covered with earth within one day of placement.

5.8 *Drainage*

The removal of excess water from a saturated soil mass is known as drainage. Drainage collection pipes shall be installed to maintain gravity flow of water outside of the reinforced soil zone. The drainage collection pipe should be directed to discharge into a storm sewer, manhole or along a slope at an elevation lower than the lowest point of the pipe within the aggregate drain. The drainage collection pipe shall be a perforated or slotted, PVC or corrugated HDPE pipe. The pipe and drainage aggregate shall be wrapped with a geotextile that will function as a filter,

5.9 *Erection of subsequent layers*

The erection of precast panels further continued till the height upto finish road level,(FRL), panel batter should be checked at each course layer to ensure its aligns to exact plumb line.

5.10 *Completion of Reinforcement Earth wall structure*

The placement of course panel is continued with the same construction sequences as explained in previous upto step 9.A sloping edge finish is required for top course panels, so coping concrete beam is done. Finally, friction concrete slab along with crash barrier is erected considering gradient, vertical and horizontal alignment of the approach road access for Reinforced earth wall structure to complete it

6 PRACTICAL DIFFICULTIES DURING CONSTRUCTION STAGE

6.1 *Geogrid identification*

For easy identification of geogrid roll of particular tensile strength, color coding either in blue, yellow, red green etc is done. However sometimes due to urgency of delivery, the color coding is missed, and this causes difficulty once all rolls are transported and shifted to construction site and during installation, higher and lower tensile strength geogrid get misplaced.

6.2 *PCC laying*

Plain Cement concrete placed on to compacted level virgin ground, is very important for the stability of the reinforced earth wall, it shouldn't have undulated, inclined/sloping surface but concrete casted with uniformly levelled plinth along the length with width 300mm- 500mm thickness 150-200-mm depending on the existing ground surface, with minimum concrete grade of M15 can be used.

6.3 *Water logged sites*

With the water logged site for one of the pedestrian underpass a circular concrete pipe of 1-m diameter was passing through the proposed foundation of reinforced earth wall, transversely across the road, at 2.5-m depth, apart from the presence of existing water table at shallow depth of 1.5-m depth, though the embedment depth of RE wall foundation was 1.2-m to 1-5-m, during construction, with an effective dewatering was carried out and upon lowering of ground water table, with sufficient granular materials mixed with crushed stone dust was adequately backfilled and compacted in 150-200-mm layers and to confirm a series of dynamic cone penetration test was done, inorder to check the allowable bearing capacity of the foundation.

6.4 *Panel distortion*

The placing of very first precast concrete fascia panel course is very important, during construction stage one of the fascia panel was placed slightly out of alignment, and later the subsequent layer continued with the same misaligned, and finally causing a visible panel distortion at the fourth fascia panel course, the entire, fascia layers from 4th to the bottom 2nd layer of the course layers removed and replaced.

6.5 *Backfill material*

The backfill material or the engineering fill, to be used carefully, need to be checked before use, even before being transported to site from the nearest borrow area pit, usually clayey lumps along with boulders was noticed during regular site inspections. At one of the site locations, the granular soils with boulders or pebbles greater than 75-mm to 150-mm was noticed with non-desirable gradation for reinforced soil fill, the particular borrow pit was rejected and an alternative borrow area was selected during construction.

6.6 *Settlement*

During construction of reinforced earth walls at one of the flyover, due to the excavation made for the construction of abutment pier, was just backfilled, the portion after completion of pier construction, when the plain cement concrete was laid for 500-mm wide, after sufficient curing after min 24hrs of time, the erection of the very first layer of facing element was done, though nothing noticed, but later subsequent erection of fascia panels till 3rd course layer resulted subsidence of 25-30mm due to the weight of the precast concrete fascia, and later at the tissue corner, cracks longitudinally was observed to have propagated.

6.7 *Edge compaction*

During compaction of backfill or engineering fill and the retained fill, its usually compacted with a vibratory roller with 8 to 10tones capacity, however the edge compaction of the backfill towards the installed precast fascia wall is neglected and just filled up with insufficient compactness, that caused, unexpected subsidence and lack of interaction and friction of the soils particles also caused when in contact with the reinforcing layers. Hence an exclusive 2tonne vibratory roller or hand held compactor to be necessarily used during edge compaction.

6.8 *Reinforcing skew portion*

More often during the construction of reinforced earth wall, the skew portion of the wall at corners no reinforcing layers are being placed, apart from being laid only normal to the facing element, however, for stability of wall its very important the reinforcing layers in the form of geogrids be placed normal to the abutment wall as well.

7 COMPLETION OF PROJECT

CH: 108+440- Pedestrian Underpass

CH: 116+880- Flyover

CH: 137+765- Flyover

CH: 111+860- Pedestrian Underpass

CH: 105+915- Flyover

CH: 142+135- Flyover

8 CONCLUSIONS

The construction of Reinforced Earth Structures with 3nos. of Vehicular Underpasses, 4nos of Flyovers 2nos of Pedestrian Underpass Passages, and 1no.of Road Over Bridge were constructed with a total pre-cast panel fascia area of 53,832.43Sq.m^2. Even though with all the practical difficulties that were encountered during the construction of these reinforcement earth wall structures, this project was titled as one of the best project to be completed in a year's time successfully.

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