Redmud containment using composite reinforced soil structure; a green perspective

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ABSTRACT: Environmentally sound and sustainable development is the demand of the day. Recognizing its importance, the concept of green technology is advocated through various approaches such as low and no waste technology, environmentally sound technology, waste recycling and utilization, technology with less carbon footprint etc. In this context, utilization of Geosynthetics is gaining ground as it results in less carbon footprint than many of the conventional materials. With this in view, the paper presents a case study which describes the capacity augmentation of a redmud pond using composite reinforced soil structure with high strength geogrids as ‘primary reinforcement’ with due consideration to the hazardous corrosive nature of redmud and the locally available red mud as structural fill. For compensating the poor drainage characteristics of red mud, a high performing drainage geo-composite was provided to ensure proper drainage and to dissipate the pore water pressure, which is reported to be performing very well. The utilization of drainage geocomposite instead of conventional gravel filter, where gravel is a nonrenewable natural resource, further helps in the reduction of carbon footprint and to bring the concept of sustainable development.

Keywords: Redmud, reinforced soil structure, drainage composite, carbon footprint

1 INTRODUCTION

Effective utilization and appropriate handling/storage of industrial by products are of greater significance in the day-to-day life. This is mainly due to the fact that the spread of the waste, due to lack of proper containment, may resultin spread of pollution which would cause environmental degradation and irreparable loss to ecology. Industrial by-products contains high toxic, organic, and inorganic substances that have deleterious effects on soils as well as on the water-bodies. Red mud is one of the major by-products produced during extraction of alumina from bauxite by resorting to Bayer process (Samal et al., 2013; Deelwali et al., 2014; Garg and Yadav, 2015). Depending upon the raw material processed, 1–2.5 tons of the red mud is generated per ton of the alumina produced (Deelwali et al., 2014). In India, about more than 4 million tons of the red mud is produced per annum (Samal et al., 2013; Deelwali et al., 2014).

The red mud in slurry form is usually disposed of in sealed or unsealed artificial or natural areas (read ponds). Even though, most of the storage areas are lined with impervious earth or PVC liners, the possibility of seepage or leakage still exists. The environmental impact of the red mud disposal could become critical due to the seepage of the alkaline leachate (of very high pH, ≈12-14) into the ground water and nearby water bodies. This mechanism might get accelerated during monsoons while during dry spells the red mud might get airborne (Garg and Yadav, 2015). These situations result in severe environmental pollution (read contamination). Every ton of alumina produced leaves behind about 1 ton of solid (bauxite) residues in suspension and 4 tons of slurry which requires a vast area of land for its disposal and hence the cost of the entire process becomes a very critical parameter. In short, the treatment and utilization of red mud is becoming a major challenge for the alumina industry in todays’ scenario.

2 CASE STUDY

M/S Hindalco Industries Limited is a major Aluminium manufacturing company in India. The manuscript is intended to walk through a case study at Hindalco's alumina extraction plant, Muri, wherein proper containment of red mud became essential by augmenting the storage capacity of the red mud disposal pond (refer Figure 1). The red mud is dumped in the storage pond, from the dumping point, and it flows like a viscous fluid by gravity and subsequently gets deposited in the pond. It should be noted that the existing embankment of the storage pond is a 'non-engineered structure', which was constructed over a period of time by increasing the height stage wise. When the storage capacity of the pond got exhausted, M/S Hindalco Industries decided to explore the possibility of augmenting its storage capacity. Maximum utilization of the red mud generated by the plant was a major criterion, while selecting the appropriate solution.

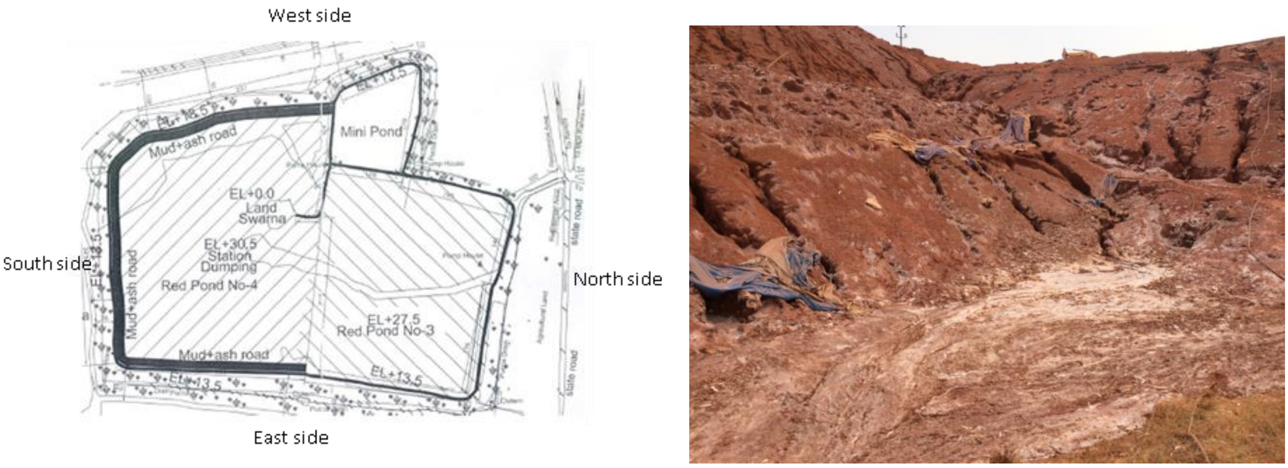

Figure 1 (a) Plan of the project site (b) Initial site conditions

2.1 *Solutions*

The shear strength characteristics of redmud, viz., angle of internal friction and cohesion are not too poor but not to the extent of giving steep slopes for the dump. Hence it was required to provide heap with wide base or to limit the height of the dump. Studies were carried out on properties of redmud and analysis of the steep slopes was done. To stabilize and augment the capacity of the existing redmud pond, it was suggested to construct a retaining wall above the existing embankment. Hence an innovative initiative was adopted for this project- a retention system with reinforced soil structure which is one of the most evolving concepts in the field of Geotechnical Engineering. Maccaferri innovated the reinforced soil concept by adopting methods to use 'redmud –a waste product' as its structural fill component. The poor drainage characteristics of the redmud and resulting building up of pore water pressure was another concern. Hence drainage measures are provided by a new Geosynthetic system viz., drainage geo-composite which is reported to be performing very well.

In order to avoid cutting and excavation at some locations (where space is available), reinforced soil wall with Gabion facia with extended bottom steel wire mesh panel of gabion as reinforcement was constructed. In addition, at few locations where the natural profile is steep, a gabion toe wall was constructed. Composed reinforced soil structure is a reinforced soil structure with high strength geogrids as "primary reinforcement", which is termed as 'paralink' and gabion facia units with integrated tail of double twisted wire mesh as a secondary reinforcement which is termed as 'terramesh' (refer Figure 2). Here primary reinforcement is used to provide the tensile forces required to ensure global stability with the desired Factor of Safety, while the facing units, which are produced with a "tail" of double twisted wire mesh act as secondary reinforcement and provide the local stability at the face, ensuring that no local mechanism of direct sliding, pullout or rotational failure would occur.

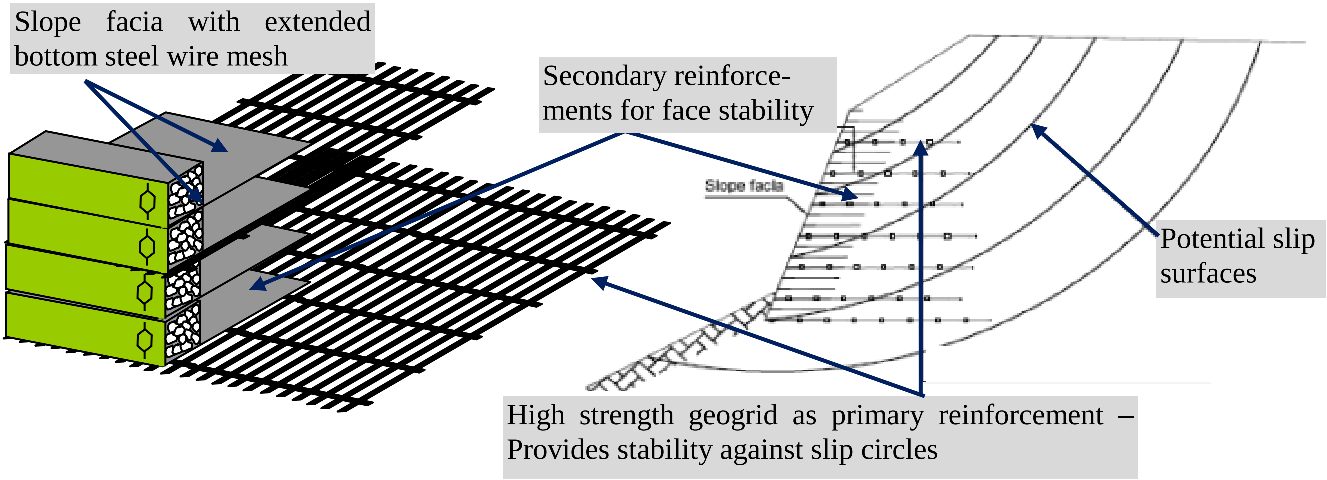

Figure 2 Typical sketch and mechanism of 'Composite reinforced soil system'

Along with it, the utilization of drainage geocomposite instead of conventional gravel filter, where stone being the main component (nonrenewable natural resource), further helps in the reduction of carbon footprint and to bring the concept of sustainable development. The leachate coming out through the RMP is a potential pollutant. It can pollute the nearby water resource and ground water. Hence, here it is collected by means drainage geocomposite and semi-perforated pipes wrapped with non-woven geotextiles. Further it is diverted to a longitudinal drain in front of the wall which leads to a lined pond (Figure 3). Subsequently this water can be treated and reused for the activities in the plant which reinforces the concept of sustainability.

Figure 3 longitudinal drain in front of the wall to collect leachate

2.2 *Benefits of the system provided over the conventional solutions*

The demand of the situation was to provide a cost effective solution which shall take into account the several constraints like limitation of space, providing good drainage measures and to withstand the degrading effect of the Redmud to be retained and dumped. Also the proposed dumping height for the pond was as high as 40 m. It was required to use the locally available materials as construction ingredient. Among the many solutions considered Reinforced Soil System (RSS) was selected due to its flexibility, seismic performance, suitability for use with the local materials, cost and speed of construction. Conventional solutions like RCC wall would result into heavy damage over the period of time when comes in contact with degrading Redmud. The reinforcement used for the construction of RCC wall was deemed to get rusted and thereby loosing the overall strength of the structure was likely. RSS with gabion facia, itself act as a good drainage unit. While specific drainage arrangement has to be made behind the concrete wall with additional weep holes which tend to clog over a period of time hampering the drainage.

The strength of the foundation soil i.e., the existing red mud fill of the embankment was very poor, (SPT value < 10). Hence it was recommended to provide ground improvement measures. However minimum ground improvement measures was required since resultant bearing pressure from RSS was lesser than the conventional structures. Use of locally available redmud as a structural fill, eliminated the need for import or export of construction fill materials and polluting truck movements in this region and increased cost effectiveness of the project. As a result of this, there was a reduction in carbon footprint as well.

Other than the major advantages mentioned RSS has the following general and technical advantages in comparison to the conventional solutions considered like Reinforced Cement Concrete (RCC). Flexibility of the system within acceptable limits helps to accommodate ground settlement without any compromise in structural integrity and help to stand stable during seismic effect. Whereas, for rigid structures like RCC failure is spontaneous and it is highly sensitive to even slightest settlement in foundations hence extensive ground improvement techniques may be required or wall needs to be founded on hard strata. Also there is no limitation in terms of height of retention to which the reinforced soil systems can be constructed. As on date case study exists for more than 70 m height retention. In case of RSS facia systems options like Gabions, Composite system of coir and woven wire mesh allows growth of vegetation and helps to synchronize with the environment. Moreover social and economic advantages are other vital aspects to be considered. As the technology suggested is being simple and the construction does not require skilled labour force or special equipment, it allows recruitment of an unqualified work force usually hired on site which is sometimes a much more important social benefit than that represented by the final work.

Based on the life cycle assessment study the environmental performance of a filter with geosynthetics is considerably better than that of gravel based filters. Overall, the major benefits of the solution provided are the maximum utilization of 'redmud- a waste material' as an engineering system component, saving the land usage, reduction in carbon footprint by the use of drainage composite and locally available material, eliminated the export of external structural fill, replaced the use of aggregates which is a non-renewable natural resource etc. In addition, based on the life cycle assessment study carried out by Laidie et al., 2012 and Ehrenberg et al., 2012, the environmental performance of a filter with geosynthetics is considerably better than that of gravel based filters. The study carried out by EAGM (Europian Association of Geosynthetic Manufacturers) presents that the carbon foot print reduction, while using geosynthetic systems, can go upto 80%.

2.3 *Carbon credit calculation with respect to conventional solutions*

Going beyond the integration aspects and other benefits of the solution provided, the following study demonstrates how the use of gabions is a solution that reduces the impact on climate change, showing a lower carbon footprint than equivalent traditional engineering solutions. The calculation of the carbon footprint was carried out using "GHG Protocol Product Life Cycle Accounting and Reporting Standard", released by World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). The gases that are considered in the Protocol are the ones indicated in the United Nations Framework Convention on Climate Change (UNFCCC) and in the Kyoto Protocol.

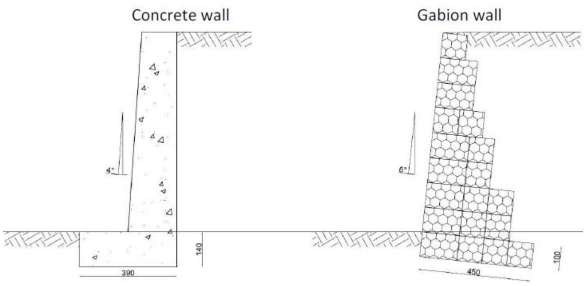

Figure 4 Gravity walls comparison: concrete and gabion walls

In the analysis all the activities that were detected are related to the release of CO2, therefore the GHG of reference for the calculation was CO_2. GHG removal was not considered even if DT products allow a fast regeneration of vegetation in the areas interested by the works. The gabions are steel double-twisted wire mesh containers that can be coated with: Zinc, Zn-Al (GALMAC™) and PVC when required for durability issues. The single units are filled with rocks that can be sourced (a) from quarries (b)locally (i.e. at the jobsite proximity). The gravity wall that was chosen to represent the functional unit 1 is 10 m long and 8 m high. The wall foundation is 4.5 m wide with a transversal area of 22.5 m^2 so that the total gabion wall volume to be filled in is 225 m^3. The single industrial unit is a 2x1x1 gabion: mesh size 8x10, wire diameters 2.7/3.7 mm, GalmacTM and PVC coating. The gabion has a specific weight of 9.5 kg/m^3 and is filled in with stones that have an equivalent weight of 1,750 kg/m^3, therefore the total weight of stones needed to fill in all the gabions of the wall is about 415 tons of stones (5% loss is considered).The analysis was carried out considering the transportation of the stones from (a) a quarry less than 100 km away from the job site (b) a distant quarry. The traditional solution that was considered is a concrete wall, R_{ck} 45 class, with an equivalent section of 18.9 m^2 and no reinforcement steel (the shape allows the concrete wall to work only in compression). This means a volume of 189 m^3 and a total weight of 465 tons of R_{ck} 45 concrete. The ready-mix concrete plant was considered at a distance of about 50 km from the job site.

Production of steel has been considered as coming from three Italian steel furnaces, but in all cases the method of production of steel has been considered is from scrap-iron furnaces, being this the type of steel used for the manufacturing of double twisted products considered in Italy since 2009. Transport emissions are calculated based on Sina-net typical transport emission factors for heavy duty vehicles, while normal road itineraries with a mix of 70% highway and 30% urban roads has been considered. All steel is transported to a single production factory where the drawing and coating process take place. Resulting emission factors are calculated in kgCO2eq/kg of semi-finished product of the three categories: Zinc, Galmac and PVC. A simplified approach is therefore introduced, because no specific EF is calculated for each wire diameter per type of wire. The final results are emission factors in kgCO2eq related to each solution (gravity wall and river bank revetment). In the case of the wall, two alternatives are gabion walls (one with stones from a close quarry, one with stones from a distant quarry) and one alternative is a concrete wall (traditional solution) (Figure 4).

2.4 *Carbon footprint calculation: results*

In the case of walls, the gabion solution is characterized by an emission of 95 tCO_2/m^2 instead of the 665 tCO_2/m^2 released with the concrete wall solution. When using locally available stones, the carbon footprint for gabion walls drops to 58 tCO_2/m^2 only (Figure 5).

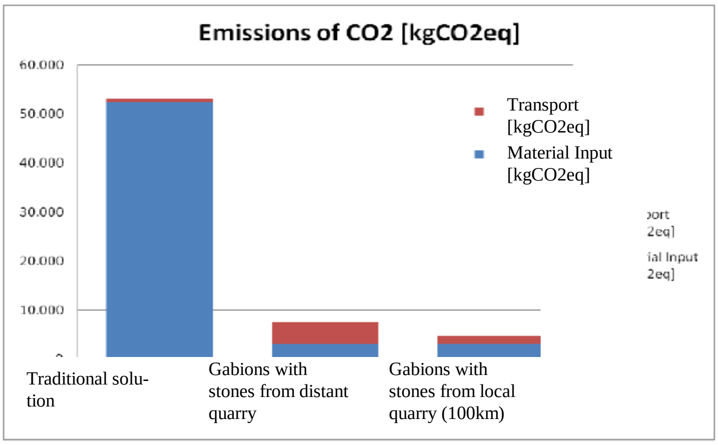

Figure 5 Comparison between CO_2 emissions related to the construction of a GRAVITY WALL: traditional solution (concrete wall) vs. gabion walls (with stones for the filling from a distant and a local quarry)

2.5 *Characterization of the red mud*

Laboratory tests for characterization ofthe red mud included: grain size analysis (IS: 2720 -Part4), Atterberg limits (IS: 2720-Part5), free swell index (IS: 2720-Part40), modified Proctor test (IS: 2720-Part8) and direct shear/triaxial tests.

2.6 *Stability analysis and codal references adopted for the design*

The design and stability analysis of the reinforced soil structure, for static and dynamic conditions, was carried out as per FHWA-NHI-00-43 and BS 8006 Part 1, 2010, which include check for the external stability, i.e., stability of the reinforced soil structure as a unit and internal stability, i.e., effectiveness of the geosynthetic reinforcement to hold the reinforced soil mass together against pullout and rupture without losing monolithicity. Typical Analysis results (in the form of computer generated outputs) are presented in Figure 6.

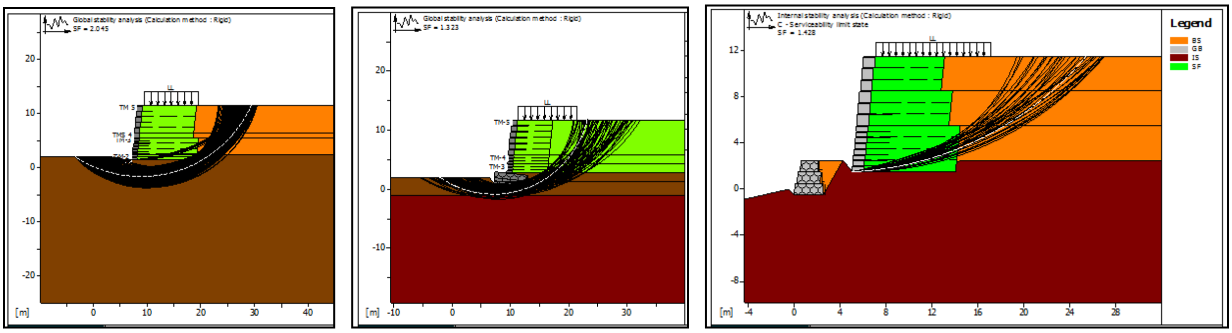

Figure 6 Global stability analysis (seismic condition): (a) 10 m high composite reinforced soil system and (b) 11 m high wall with composite reinforced soil system and gabion wall (c) Internal stability analysis - 10 m high composite reinforced soil system and 3 m high gabion toe wall (seismic condition)

2.7 *Construction sequence*

The prevailing site conditions before starting the construction are illustrated in Figure 7. For construction of both the gabion wall and Composite soil reinforced wall, the in-situ stratum was excavated to the required formation level as per the drawings (). Loose pockets observed during the excavation were excavated and filled with suitable granular or backfill material. Later, the backfill was compacted using a vibro-roller to achieve a density greater than or equal to 95% of the modified Proctor value (refer **Figure 8** b & c). In addition, the formation prepared was leveled without ruts and undulations (refer Plate 2a). In case of composite reinforced soil system, high strength geogrids were placed before the placement of the Gabion facia units (Figure 8).

Figure 7 (a) Initial site condition and (b) Excavation (c) marking the layout

Subsequently, the outer alignment of the facia, as per the requirements in the section and plan drawings (for both gabion and composite reinforced soil system) and rear end of the reinforced zone, as per the design length requirement (for Composite soil reinforced system) at every section, were marked (**Figure** 7c). Later, in case of Composite reinforcement soil system, the high strength geogrid, as mentioned in the section drawing (refer Figure 9), was laid starting from the outer line of the facia by unrolling it perpendicular to the wall alignment. The starting end of the high strength geogrid was secured by pinning it to the formation. Further, the slackness or undulations developed during laying were corrected immediately by stretching it (Figure 8 a). It was ensured that under no circumstances, tracked vehicles were allowed to move over the laid high strength geogrid. A layer of structural fill was carefully spread and compacted (minimum 200 mm compacted thickness) on the installed reinforcement to facilitate the vehicular movement before installation of the gabion facia units.

Figure 8. (a) Laying of high strength geogrid and (b) Compaction by vibro-roller (c) Rolling near the wall by baby roller

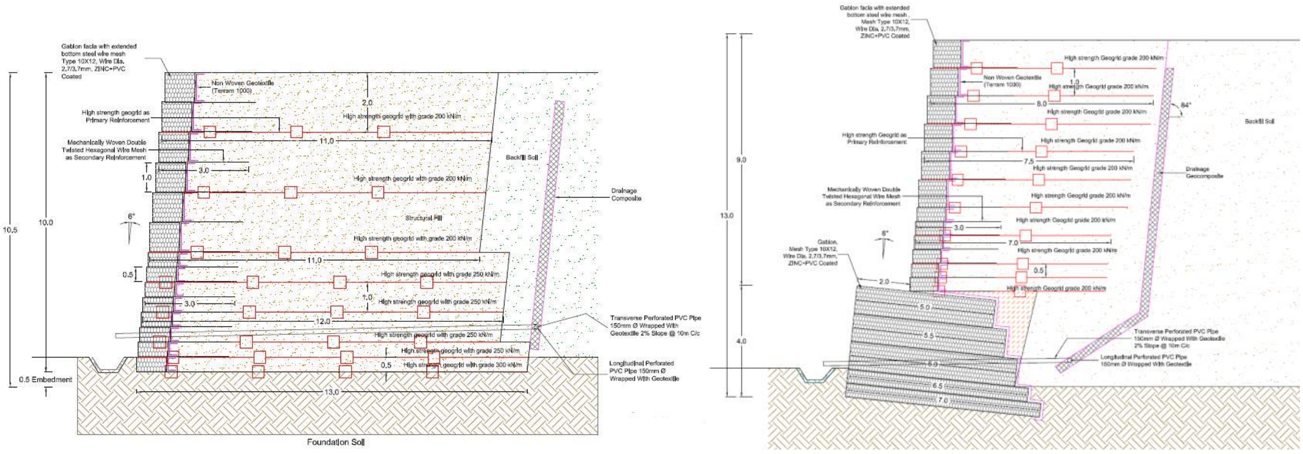

Figure 9. Typical cross section of 10 m high composite reinforced soil system (b) typical cross section of 13 m high gabion and composite reinforced soil system

Further, folded facia units including secondary reinforcement of composite soil reinforcement system/gabion units were opened and straightened out by placing it on a flat surface. Required number of facia units were placed manually at the proposed structure location with the front face along the outer facia alignment marked by the survey team. All the gabions placed were connected to each other by the lacing procedure. Mild steel pipe/frame formwork was provided at the facia for achieving good appearance and keeping the bulges within the specified tolerances. Formwork enables to achieve uniformity in the gabion box dimensions during the filling and placement of stones (refer Figure 10) . The stones were placed in lifts of 300 mm. The filled layer should never be more than 300 mm higher than any adjoining cell. Internal cross ties, lacing wire, were installed after every 300 mm of fill connecting the front and back faces of any supported or exposed face. Facia units in the upper layer were connected to the top of the facia unit in the lower layer, along front and back edges of the contact surface. Facia of adjoining units were securely joined together, along the vertical facing and top edges of their contact surfaces.

Further, at the back of the facia a non-woven geotextile was fixed extending up to 250 mm into the backfill at top and bottom in the form of C shaped wrapping, which prevents the structural fill form being washed into the stone voids in the event of a rainfall and to drain off excess water from the structural fill. Subsequently, structural fill was placed and compacted to 95% of modified Proctor density in the area behind the facia units extending up to the end of design reinforcement length. The movement of vibro-roller was not permitted in the area upto1.5 m from the facia unit as per the general codal provisions of the reinforced soil systems. The compaction within this 1.5m zone was carried out using a vibratory plate compactor or walk behind rollers. The procedure mentioned above was repeated as per the design to achieve the required height of the gabion wall/composite reinforced soil structure. In **Figure 3** finished composite reinforced soil wall is depicted.

Figure 10. (a) Gabion box laying and Shuttering (b) Laying of Gabion facia with extended bottom with steel wire Drainage measures

At the rear end of the structural fill, a filter bay made of drainage geocomposite (Figure 11a) was provided for drainage purpose considering quality assurance, easy installation, less availability of stones etc. The main purpose of the filter bay is to facilitate drainage of water in the backfill. From the filter bay, PVC perforated pipes (refer Figure 11 b) of 200 mm diameter wrapped with non-woven geotextile, with 2 to 3 % slope across the structure for quick removal of water collected in the filter bay out of the structure.

The perforations of 10 mm diameter were provided at 75 mm c/c spacing. These PVC pipes are to be provided at every 20 m spacing, along the wall length. Suitable arrangements were provided to drain this water away from the structure. As depicted in Figure 12b, the drainage geocomposite is successfully performing till date.

Figure 11 (a) Drainage geo composite and (b) Laying of drainage composite and perforated pipes

Figure 12 (a) Laying of drainage composite and (b) Proper functioning of drainage composite

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