Design and construction of a New Type of Transportable System for Reinforced Soil Walls

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ABSTRACT: There is a growing interest in the use of reinforced soil walls in remote areas of the world, where materials, construction plant and technical support are in short supply.

The paper describes the design and construction of a new system for reinforced soil walls, using a case study. The system is designed to be pre-fabricated and transported by container to remote areas where it is simply assembled in-situ. This avoids the requirements for specialist construction equipment and skills at the site. The system can also be constructed from the soil fill side of the wall, minimizing the need for craneage or to work at heights. The system also incorporates a sliding soil compaction formwork system for convenience and an adjustable hand rail system for safety. The system can be adapted to different fill characteristics and soil reinforcement types and the facing system does not dictate the soil reinforcement type. The main benefits of the facing system include cost effectiveness, buildability, ease of maintenance and flexibility of use in a wide range of conditions.

1 INTRODUCTION

A Run of Mine (ROM) wall was required for the Goro Nickel mine in New Caledonia. ROM walls are commonly required at open cast mines as the mine haul trucks need to tip ore from height over a vertical face into the primary processing plant.

Reinforced soil is commonly used to construct ROM walls and facing types vary but are mainly concrete panels in the author’s experience. Concrete panels require heavy lifting equipment and typically cannot be practically built from the fill side of the wall. Since these latter two criteria were critical for the Goro project, a geotextile wrap around and light weight steel facing option was put forward. This was considered by the client to be an optimum solution as it allowed the hopper construction to proceed concurrently with the ROM wall.

2 THE CASE STUDY PROJECT

The ROM wall required for the Goro Nickel mine in New Caledonia is a reinforced soil (RS) wall with a geotextile, wrap around face. Wrap around faces generally need protection from damage, especially in mine environments. This protection was afforded by a steel post and panel system which is built in front of the wrap around face and ties into the reinforced soil for stability.

The wall is 120 m long and around 12 m high at its highest section. The highest section supports a thick concrete slab and edge walls which are the tipping points for the ore carrying trucks. The trucks are up to 170 tonnes in mass and tip over the edge of the wall into the primary treatment hopper.

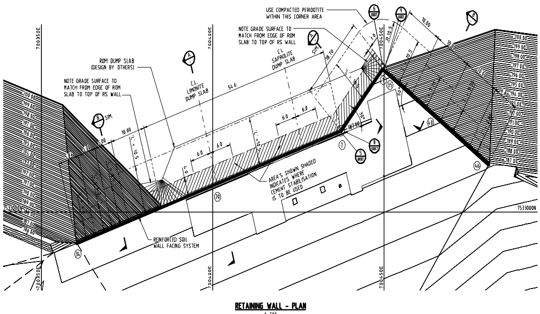

Figure 1. Retaining Wall – Plan

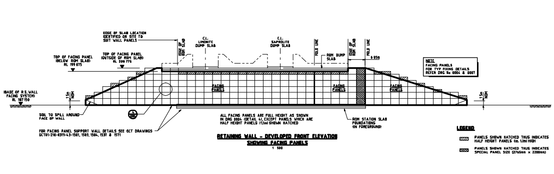

Figure 2. Retaining Wall – developed front elevation showing facing panels

Figure 3. ROM Wall – close to completion

3 DESCRIPTION OF THE RETAINING WALL COMPONENTS

The locally available soil is reinforced in layers with a geotextile which is wrapped around at the face to retain the soil locally.

The facing system comprises uprights which are bolted to concrete footings at their base. These uprights comprise back to back channels which are fixed to the wrap around face of the RS wall via threaded bars. The infill panels slide into these channels to provide weather and minor impact protection to the geotextile face. The panels consist of light, corrugated steel wall cladding, fixed to a frame. The frame is fabricated from steel channel sections.
The advantages of this facing system are:

- The system is modular and transportable in shipping containers, which minimizes site fabrication work and facilitates handling.
- The uprights are utilized to support temporary formwork for the construction of the reinforced soil. This is supplied as part of the system.
- The uprights support handrails which are used as edge protection for construction workers.
- The infill panels can slide within the upright channels allowing panel installation from the earthwork side of the wall. This means that the entire wall construction can be performed from the fill side allowing simultaneous construction of other facilities in front of the wall.
- The system components are relatively lightweight allowing construction with no craneage. Each element of the facing can be carried by two construction workers.
- The panels can be easily removed for replacement or inspection of the geotextile.
- The facing system does not dictate the type of soil reinforcement used.

Figure 4. The lower portion of the wall ready for facing panel installation – Note: geotextile ready to be wrapped around.

4 FACING SYSTEM

The following components are required to construct the facing system. All components are steel and are either hot dipped galvanized or zinc plated.

4.1 *Uprights*

The uprights are fabricated from back to back cold formed channels. The channel webs are kept apart by splice and stiffening plates. The uprights are provided in 3 m lengths with the bottom uprights including a base plate for bolted connection to a footing. The upright lengths are spliced together using plates and bolts, all supplied.

4.2 *Upright connection to the wrap around face*

The uprights gain stiffness and maintain verticality by being progressively connected to the wrap around face of the RS wall using threaded bars. The bars are buried within the soil fill by laying the bars on top of each earthworks compaction layer and filling the subsequent layers on top of the bars. Each bar is fixed to the uprights by means of the bars passing through the upright between the spaced channel webs and being bolted to the uprights via plates back and front. This allows verticality adjustment and maintains flexibility of each threaded bar vertical location.

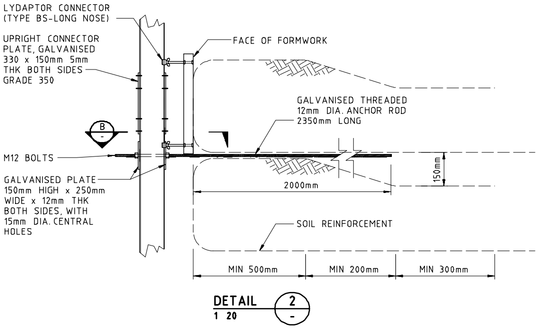

Figure 5. Upright connection to the wrap around face

4.3 *Infill panels*

The infill panels are 2.2 m high and 2.87 m wide and consist of profiled wall cladding fixed to a channel section frame via tex screws. The vertical edges of

the cladding are not fixed to allow the panels to fit snugly into the upright channels.

The frame channel sections are fabricated via tex screwing the sections together at the corners by means of corner plates. The frame is given additional stiffness by being fixed to the cladding for transport and handling.

Figure 6. Infill panels

The infill panels are designed to allow flexibility on site in terms of the sequence of installation of the panels. The panels can be installed as the earthworks progresses or be installed following earthworks completion.

4.4 *Temporary formwork and handrails*

Placing and compaction of the RS wall earthwork layers requires facing formwork against which to compact soil.

The formwork comprises a stiffened steel box section 3 m long and 0.6 m wide. The formwork connects to the inside flange of the upright channels via four vice bolts (Figure 5) for ease of connection and disconnection. The formwork can be moved upwards as the earthworks progress. Handrails are scaffold tubes which connect to the upright channels in the same way as the formwork but via 'D' bolts. The handrails can also be slid on the uprights as the earthworks progress.

5 LOADINGS

5.1 *Permanent loadings*

The main permanent loading on the facing system is its own self weight. In addition, some vertical load will be applied to the uprights via slight bending of the threaded bars as the earth fill settles relative to the facing system.

5.2 *Transient loadings*

The main post construction transient load on the facing system is wind load. A cyclonic design wind speed of 65 m/s (Ultimate) was applied in this case. A design wind pressure of 2.03 kPa was used in the design of the uprights as an overall pressure and a pressure of 2.54 kPa was used in the design of the cladding as a local pressure.

The client stated that there may be occasional impact loads on the facing due to spillage of ore during transfer from trucks to hoppers. Rocks and large clumps of soil impacting the infill panels are likely to dent the panels but this is part of mine site operation and there is no specification on aesthetics. Large rocks will cause more damage on impact and may even hole the panels. Heavily damaged or holed panels will require repair or can be replaced as part of ongoing maintenance.

5.3 *Temporary construction loadings*

The design considered that wind loading during construction will produce no effect worse than construction wind loading if infill panels are not installed more than 1 m above the level of the earthworks. Also, the maximum wind load was considered to occur after completion of the facing system when the wall is in operation.

Temporary soil compaction loading on the formwork will be transferred to the uprights. Only light compaction plant is allowed within 2 m of the RS wall wrap around face. Compaction loads on the formwork will therefore be limited and it was considered that the earth pressure loads can be represented by the earth pressure at rest factor (K_o).

6 DESIGN OF THE FACING SYSTEM

6.1 *Infill panels*

The infill panels are sized to fit into a standard shipping container. The panels consist of a box section frame with a contoured cladding. The panel thickness is sized to slide neatly between the flanges of the channel uprights (see Figure 7). The cladding profile is 23 mm deep and the frame box sections are 64 mm deep giving an overall panel thickness of 88 mm. The channel webs are 117 mm wide, therefore the panels will fit between the channel flanges, with a clearance of 14.5 mm either side. This clearance allows the panels to slide past the round headed bolts for the splice plates. The frame is tex screwed together using 3 mm thick plates across the joints and the cladding is Tex screwed to the frame (see Figure 7).

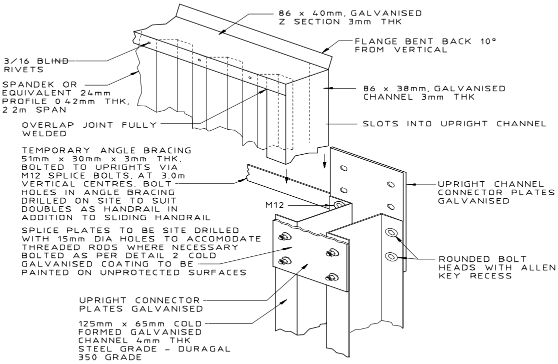

Figure 7. Detail of panel slide arrangement within the uprights

6.2 *Threaded rods*

Threaded rods are used to connect the facing system to the reinforced soils (Figure 5).

In tension, the rods will carry a maximum of around 8 kN which is well within the tensile capacity of a 12 mm diameter rod.

The highest load on the infill panels for the Goro Site is cyclonic wind.
The panels span horizontally between the uprights and the wind pressure is ultimately resisted by compression of the threaded rods. The maximum compressive load on the rods is the case where the rods are at 500 mm ctrs vertically meaning that each rod takes round 6 kN in compression. The rods are progressively buried within the reinforced soil and are considered to provide the same pull out/push in capacity in both directions.

As subsequent layers of soil are placed, the pull-out resistance of each level of threaded rods increases but the applied load stays the same. Therefore, as the soil fill height increases, the resistance available from the threaded rods quickly rises past the applied load and keeps rising. Rods were placed every 300 mm vertical spacing near the base of the wall, where the soil layers are 300 mm thick, spacing out to 500 mm vertical centres where the layers are 500 mm thick providing sufficient lateral restraint for the uprights.

6.3 *Uprights, base plate and holding down bolts*

The uprights consist of back to back channels which are cold formed, galvanized with dimensions 125 mm x 65 mm and 4 mm thick (see Figure 5).

When the uprights have been bolted onto their footings, the maximum load on the bolts, due to compaction of the fill will occur before the first level of threaded bars are placed and the upright is acting as a cantilever.

The first level of threaded bars will be placed on top of the first RS soil layer meaning that upright restraint is not available until the fill height is around 500 mm above the base of the wall. The maximum load on the cantilever will be the compaction load from the soil layers plus the handrail load.

The design of the uprights for temporary compaction loads considers the worst case horizontal restraint below the level of the compaction load. This will occur when the soil layer spacing below the compaction layer is 500 mm. It was considered that full (encastre) restraint of each upright is gained 2 layers below the compaction layer being placed and the majority of the compaction load will be applied near the base of the compaction layer. This means that the lever arm to calculate the moment in the uprights is around 1 m. the maximum moment in the uprights is then 6 kNm. Back to back channel sections were selected to accommodate this moment without excessive deflection.

Special uprights were designed for the corners of the wall (see Figure 8).

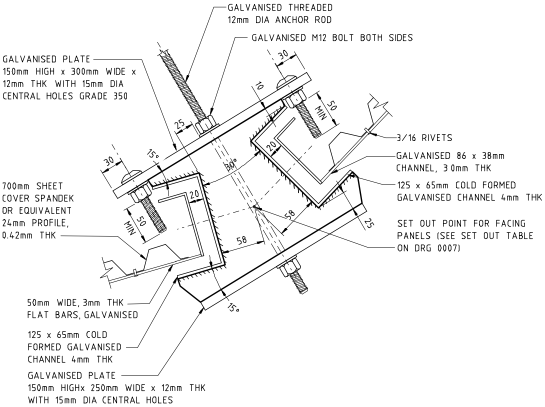

Figure 8. External corner upright

For the design of the holding down bolts, the maximum moment at the base of the uprights was calculated to be 5.0 kNm. If this is translated to a push/pull action on the bolts, the maximum tensile force per bolt is 12.5 kN. This can be accommodated by 4 x M12 holding down bolts, chem'set or mechanically anchored to the concrete footing. The shear stress that can be accommodated by the 4 bolts is 23 kN which is far in excess of the compaction soil pressure.

The design of the uprights for transient wind loads considers the design wind pressure on the panels transferred horizontally to the uprights. The worst case is where the uprights are restrained by the treaded rods at 500 mm ctrs. The uprights are considered to be simply supported between the rods. In this scenario, with a wind pressure of 2.03 kPa, imposes a line load on the uprights of 6.1 kN/m. It was found that the maximum moment in the uprights is not governed by wind load as the compaction loads induce a higher moment.

6.4 *Design of the temporary formwork*

The temporary formwork requires to span between the uprights and cater for a triangular distribution of soil pressures vertically with a value of 4 kN/m run. The simplest type of formwork is a system form. A standard square edge road beam was found to be suitable as it is designed to handle soil pressures without excessive deflection and they are available in 3 m lengths. For the application at Goro, two 300 mm high road beams required to be bolted together to provide a form 600 mm deep for a maximum 500 mm thick soil layer.

The formwork is supplied with the system and incorporates a sliding connection to the uprights so that it can be readily moved to the location of each compaction layer.

7 DESIGN OF THE REINFORCED SOIL BLOCK

The reinforced soil blocks were designed from first principles utilising a spreadsheet to conduct the iterative calculations. The critical wedge method was used, where the design considered a family of potential failure wedges at each reinforcement level and calculated the most critical wedge. The stability of the critical wedge in terms of its weight and pull-out resistance is used to calculate the reinforcement anchorage required to stabilize each wedge.

As the reinforcement anchorage increases with overburden pressure the wedges engage the anchorage at many reinforcement levels allowing the reinforcement lengths to be shortened towards the base of the wall (see Figure 9.)

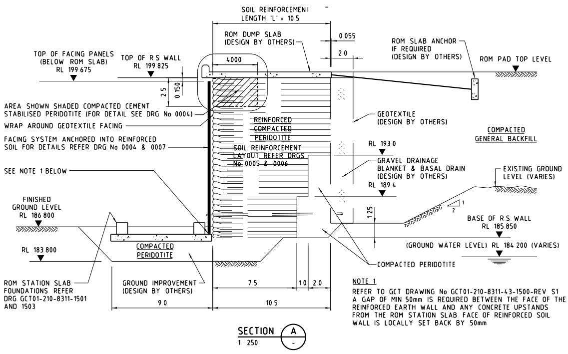

Figure 9. Reinforced soil block

8 LESSONS LEARNED DURING CONSTRUCTION

The calculations for the reinforced soil wall design showed that the vertical reinforcement spacing could be as much as 500 mm in the middle of the wall. This height of soil lift posed some practical difficulties during construction as the geotextile face sagged. This can be solved either by allowing for this sagging by initially aligning the face of the geotextile set back from its final position or providing secondary reinforcement at the centre of the thick soil layers.

During compaction of soil lifts against the formwork, some movement of the uprights was experienced as the threaded rods, which did not have high vertical loading on them, slipped slightly. This was allowed for in the design as the intention was that the rod plate connections to the uprights could be adjusted later to ensure that the uprights were vertical and the threaded rods were straight. One method of potentially improving this aspect is to provide anchor plates on the buried ends of the rods which engages passive resistance within the fill.

As mentioned earlier, the new type of facing system does not dictate the soil reinforcement type used. Of course, the soil face does need to be retained locally. Part of the case study wall was constructed using a geogrid with the soil face retention being provided using a geofabric separator at the soil face. If this is done, it is best to fix the separator to each length the geogrid in the correct location before the geogrid is installed in the wall.

It is important to provide specialist supervision for at least the construction of the first few layers of the wall system. Once the construction crew becomes familiar with the construction sequencing and techniques, supervision can be continued by the local Engineers.

As a educational aid, a model of the system could be made and this would enable the construction crew to understand the optimal construction sequence.

9 CONCLUSIONS

The new reinforced earth retaining wall system described in this paper is an innovative, convenient and cost effective solution for walls anywhere, but particularly in remote areas. The system is designed to be prefabricated and containerised so that it can be transported in sections to the work site. Local soils could be utilised in the building of the walls and retained heights could be from 1 m to 30 m or more.

The new system has the added advantages of incorporating sliding soil compaction formwork and safety handrailing. The walls can also be constructed entirely from the fill side meaning that facilities can be built simultaneously in front of the wall, saving overall construction time.

The construction does not require craneage as all the elements are designed to be handled and placed using unskilled manual labour. The only machinery required is earth moving/compaction plant and perhaps a forklift to carry the rolls of geotextile. Inspection and maintenance can be performed easily as the front panels can be readily removed and replaced. The case study described confirmed that the new system can be built successfully and the wall is performing as intended by the designers.