To:	Bob Simon, Project Manager, Excel Project Management
From:	Pirahas Balasingam M.S., MBA, P.Eng., P.E.
CC:	Jason Jagodich, MBA, P.Eng., PMP
Date:	November 27, 2019
RE:	Design of 8 m High Retaining Wall Using Standard Size RASBlox System

1. INTRODUCTION

RASBlox Retaining wall system is stackable “Lego Block” concrete blocks being arranged to form a solid monolithic structural system to act as one of the earths retaining means and methods. This system consists of prefabricated hollow blocks designed to be filled the hollows with rebar and concrete to ensure a monolithic structural behaviour and action. The system consists of several advantageous over conventional gravity type concrete retaining wall systems. Some of the direct advantageous are; faster assembly, save in construction time, scalable to suit field requirements and needs, easy to adapt terrain incorporating various types of custom-made blocks, etc. The standard blocks are available in half block, full block, extended block and various end block configurations. The tapered rectangular shape of voids ensures maximum strength by incorporating rebar away from the neutral axis. Blocks having vertical slots on the outer edges would allow quick forming to close gaps when blocks are placed with gaps to produce nonstandard configurations (Archway Bridge and Tunnel Systems n.d.). The blocks forming a retaining wall can be anchored or tie back to increase overturning capacity of wall system.

2. PROBLEM STATEMENT

In this analysis, each RASBlox block was assumed to have the following dimensions (in mm): 750 (W), 1500 (L) & 1000 (H). A typical block is as shown below (Excel Project Management n.d.).

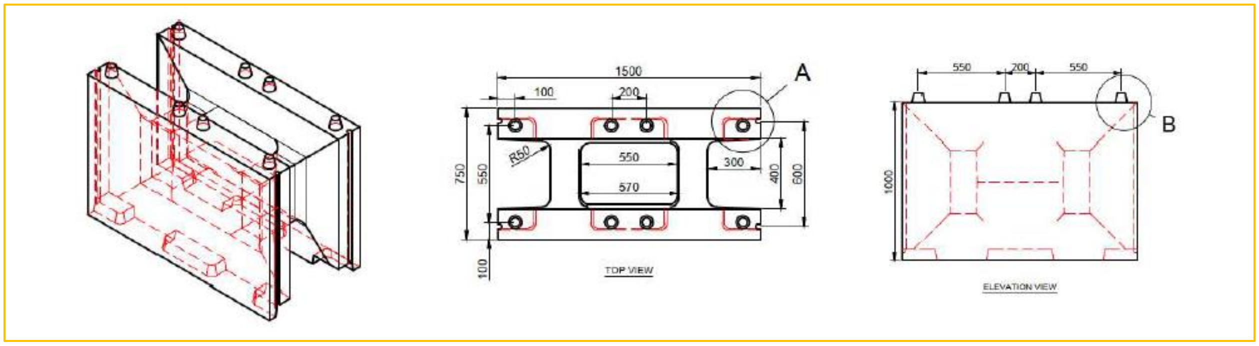

Figure 1: Typical RASBlox Dimensions

The overall retaining wall dimensions defined for the analyses discussed in this report are; a total length of 33 m with a maximum height of 8 m and the height being tapered off to 6 m and 3 m towards ends. Due to the size of a block, each block element was discretized into 0.5 m X 0.2 m elements. This is to ensure that a smooth transition of stress distribution within the wall system under consideration. In Finite Element (FE) modeling, the finer the elements are the results would be more accurate. However, there is a trade off balance between the run time of a model, size of an element to be employed and type of problem being analysed (i.e., stress concentration, sudden changes in cross-sections, etc.). Based on those criteria, the element size was determined to define the problem being analyzed.

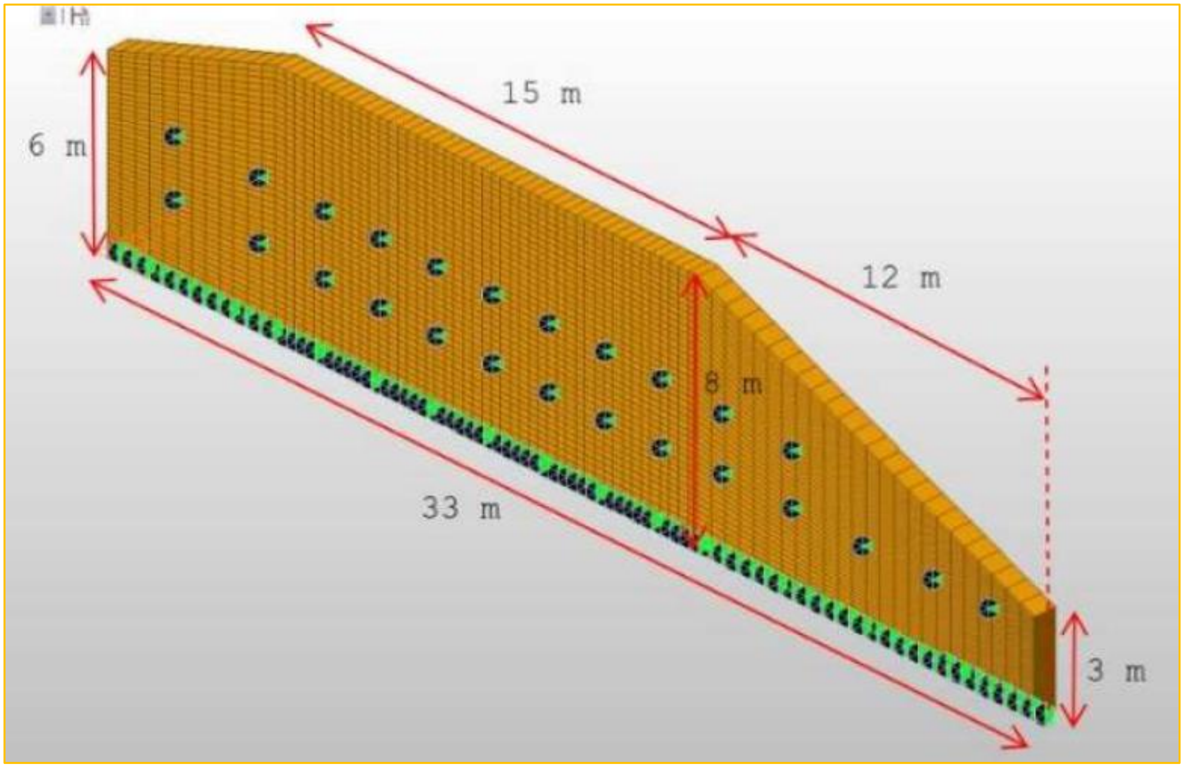

Figure 2: Global View of the Proposed Retaining Wall

3. DESIGN ASSUMPTIONS

- The RASBlox blocks to be supported on a firm rock base with mud sill underneath;
- The loads considered; self-weight of blocks, lateral soil pressure, compaction surcharge and Live Load surcharge (if it's in proximity of transportation structure such as bridges, tunnels and culverts);
- At rest pressure coefficient of K_o = 0.5 considered for lateral soil pressure calculation;
- Assumed to have adequate drainage to ignore any water pressure behind walls being exerted;
- Assumed to have granular backfill behind the wall;
- No transverse PT forces being applied/considered;
- Assumed a min concrete strength of RASBlox block $f''c$ = 30 MPa (28 days);
- Design of blocks by others (custom built);

- No anchor slippage occurs at the tie-in locations and thus, included pinned support and the anchors being provided to resist movements in a horizontal direction;
- Internal hollow sections being filled with concrete and rebars to have full strength to transfer loads;

4. 3D FINITE ELEMENT MODEL ANALYSIS

A 3D FE analysis has been conducted to analyses and study the structural behavior of the RASBlox retaining wall assembly. The FE analyses included four node shell elements being utilized to model the entire wall structure. The base of the wall was fixed for displacements in all three orthogonal directions, allowing rotations in all three directions (a conservative approach). At tie-in locations, the wall was supported by pinned supports restraining only out of plane displacement in Y-direction (in this analysis) and allowing all other movements (in X and Z directions) as well as rotations (in X, Y and Z directions).

The loads being applied on the structure are:

- Self-weight (vertically)
- Lateral soil pressure with the assumption of at-rest pressure (K_0 = 0.5) and soil density of 20 kN/m^3.
- A compaction surcharge pressure (during backfilling – transient load) of triangular variation of 12 KPa to 0 kPa over 1.7 m applied – Laterally.
- A Live Load surcharge load of 16 KPa being applied over the entire height of the wall – Laterally.

The wall in these analyses considered at final stage of the construction sequence and as thus, it will be a monolithic structure with hollows filled with concrete reinforcement.

The wall system was analyzed based on Load & Resistance Factor Design (LRFD) considering the Ultimate Limit State (ULS) and Serviceability Limit State (SLS). The load factors associated with dead load (DL), soil pressure load (PL) and live load (LL) are in accordance with the CAN/CSA S6-14 (CHBDC) code (CHBDC n.d.).

5. RESULTS

5.1. Without the use of Tieback Soil/Rock Anchors

Based on the FE analyses, it was determined that the wall system of 8 m tall subject to loading scenarios under consideration appeared to have approximately 750 mm displacement at wall tip elevation as shown in **Figure 3**, representing approximately 10% of maximum wall height (Δ/H = 750/8000 ≈ 10%) at SLS limit state, which is well beyond an allowable limit.

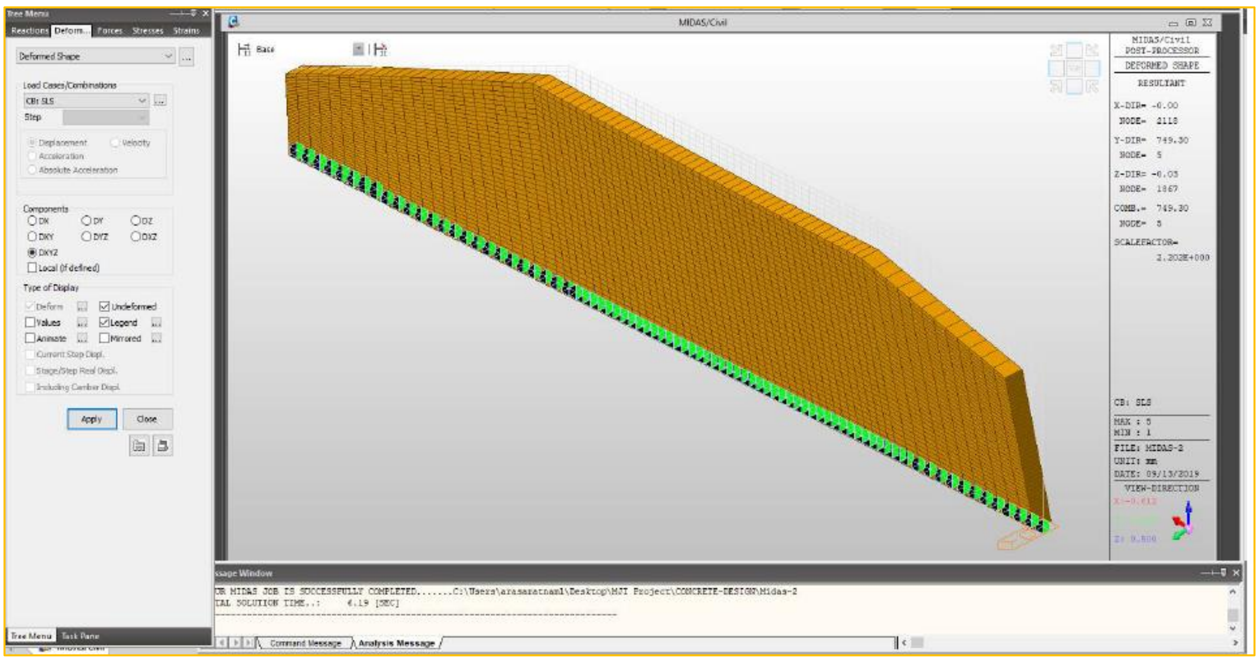

Figure 3: Lateral Displacement at the tip of the Retaining Wall

The wall seemed to have a maximum (ULS) effective stress of 192 MPa at the base level. Note that the stresses are well above the concrete compressive strength of 30 MPa, clearly indicating a wall failure. The stress contour variation within the wall system is as shown in **Figure 4**.

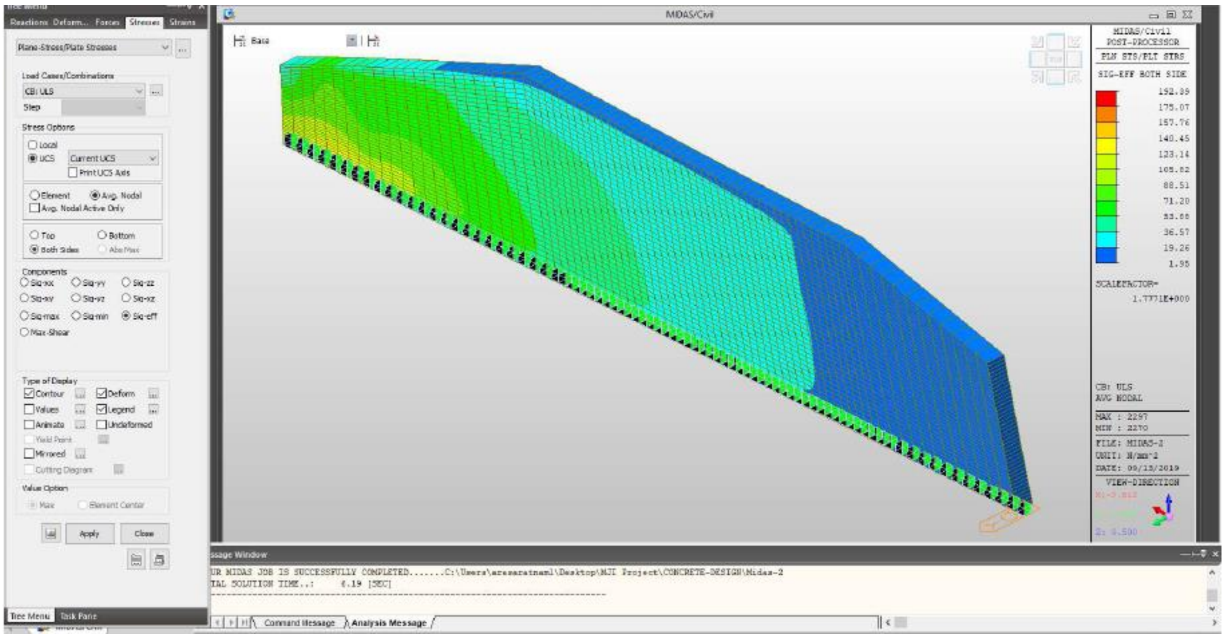

Figure 4: Effective Stress Contours within Wall under ULS Condition

Figure 5 shows the effective stress contour within the wall at SLS, illustrating a maximum stress of 155 MPa

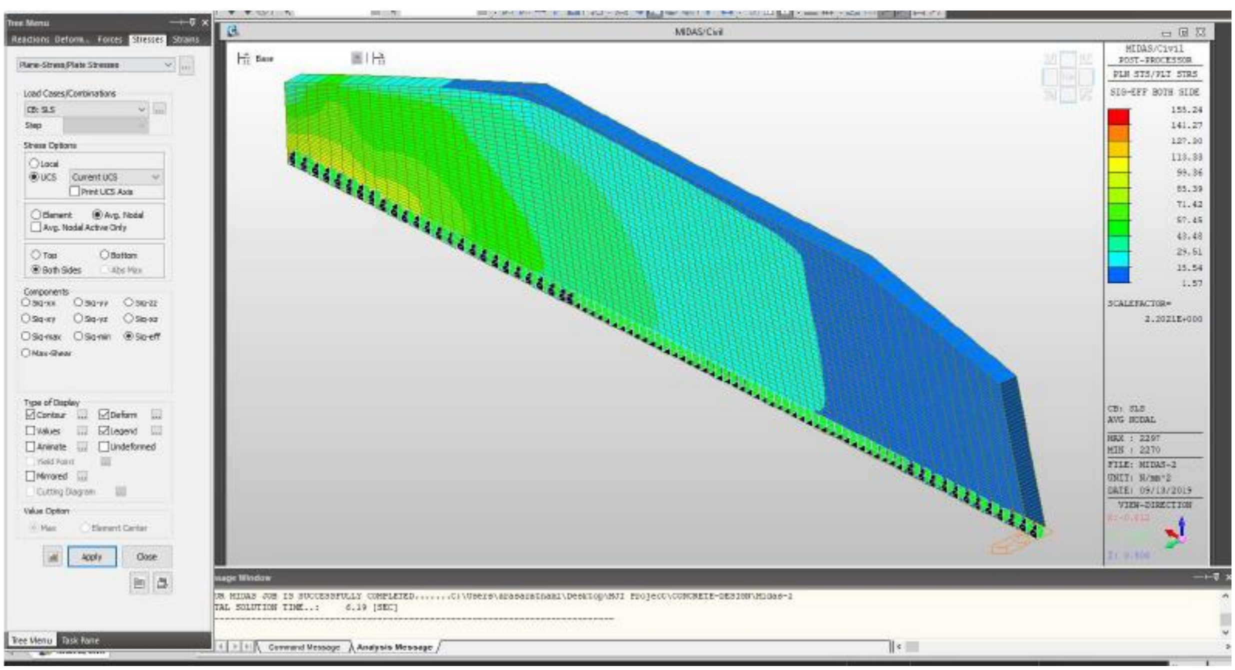

Figure 5: Effective Stress Contours within Wall under SLS Condition

Note that this is not uncommon in this type of free-standing cantilever wall type system of 8 m tall subjected to heavy lateral loads as described, resulting in a high turnover lateral force/moment. Thus, this type of free-standing tall wall system can be stabilized by providing lateral supports in terms of soil anchors.

5.2. With the use of Tieback Soil/Rock Anchors

The FE analysis also included the 2nd model with soil anchors/tie-ins placed at spacing of 2.25 m (H) X 2.0 m (V). Two rows of tie-in locations were chosen to stabilize the block retaining wall. As such, the lateral displacements of the wall and resulting stresses within the wall were reduced significantly to an acceptable level or even well below that. **Figure 6** illustrates the lateral movement of the wall tip at SLS limit state. As seen in the **Figure 6**, a maximum lateral movement of the wall is approximately 2 mm, resulting in displacement-to-wall height ratio of (Δ/H) 0.025%, which is well below the allowable limit.

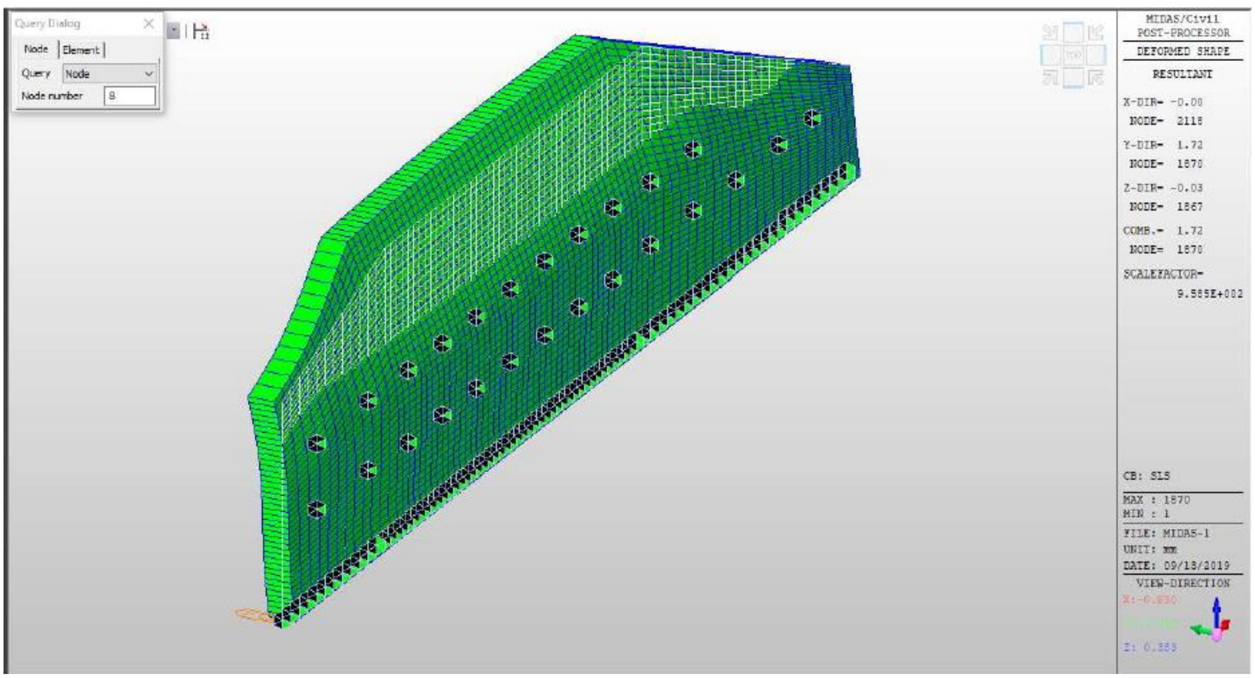

Figure 6: Lateral Displacement of Retaining Wall with Tie Back Anchors under SLS Condition

Figure 7 shows the effective stress contour over the entire wall system at ULS limit state. A maximum effective stress of 5 MPa was noted at this state, which is well below the design concrete compressive strength of 30 MPa and as thus, it is acceptable. Moreover, the variation of stresses across the wall system at SLS limit state is as shown in **Figure 8** indicating a maximum effective wall stresses of 4.2 MPa, which is well below the concrete design compressive strength of 30 MPa and as thus, its acceptable.

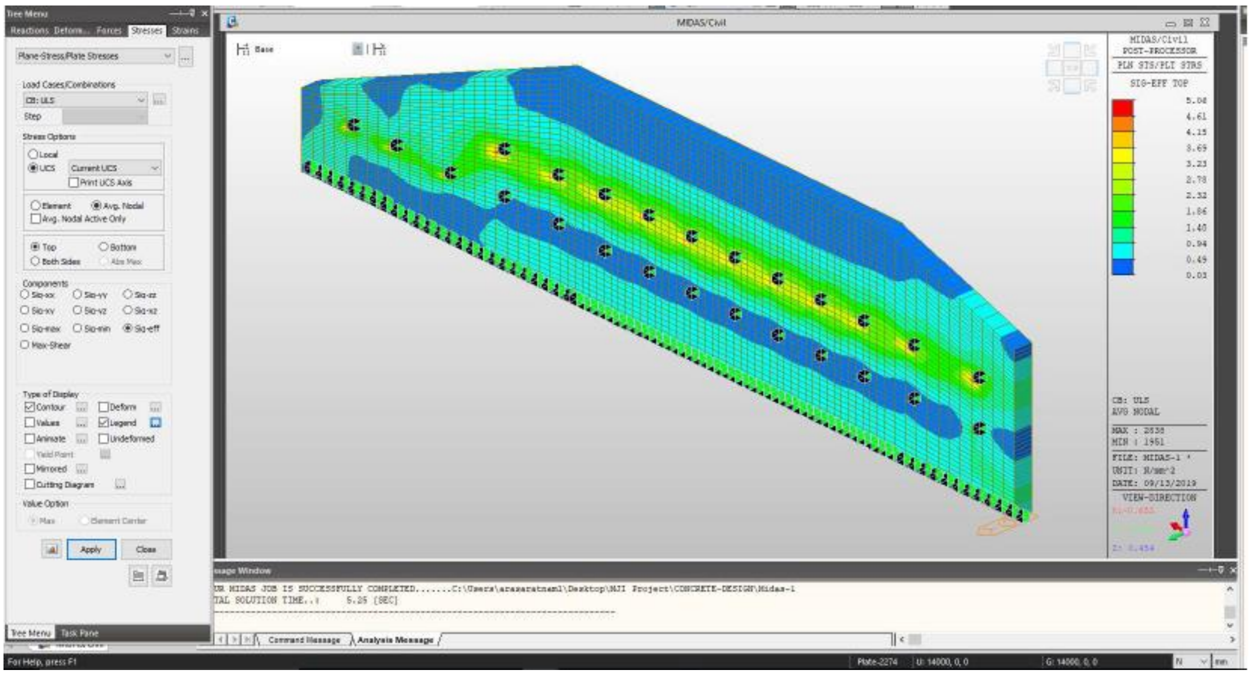

Figure 7: Effective Stress Contours within Retaining Wall with Tie Back Anchors under ULS Condition

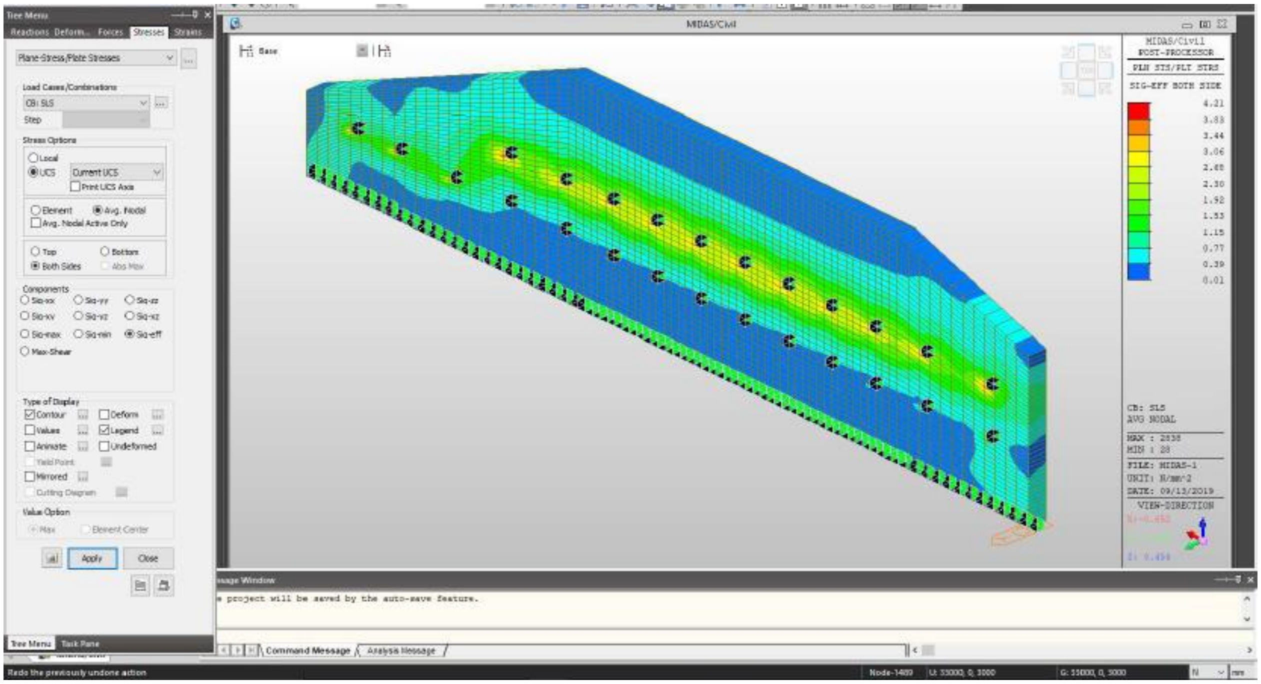

Figure 8: Effective Stress Contours within Retaining Wall with Tie Back Anchors under SLS Condition

The forces at tie-ins/soil anchor locations were determined from the FE Model. As thus, a maximum tensile load of 958 kN noted as seen in **Figure 9** below. The magnitude of force varies with the location. However, from the design perspective of such soil anchors, engineers would be interested in the maximum value. As seen in **Figure 9**, the force demand reduces as the tie-in location move away from the center of rigidity of the overall retaining wall system.

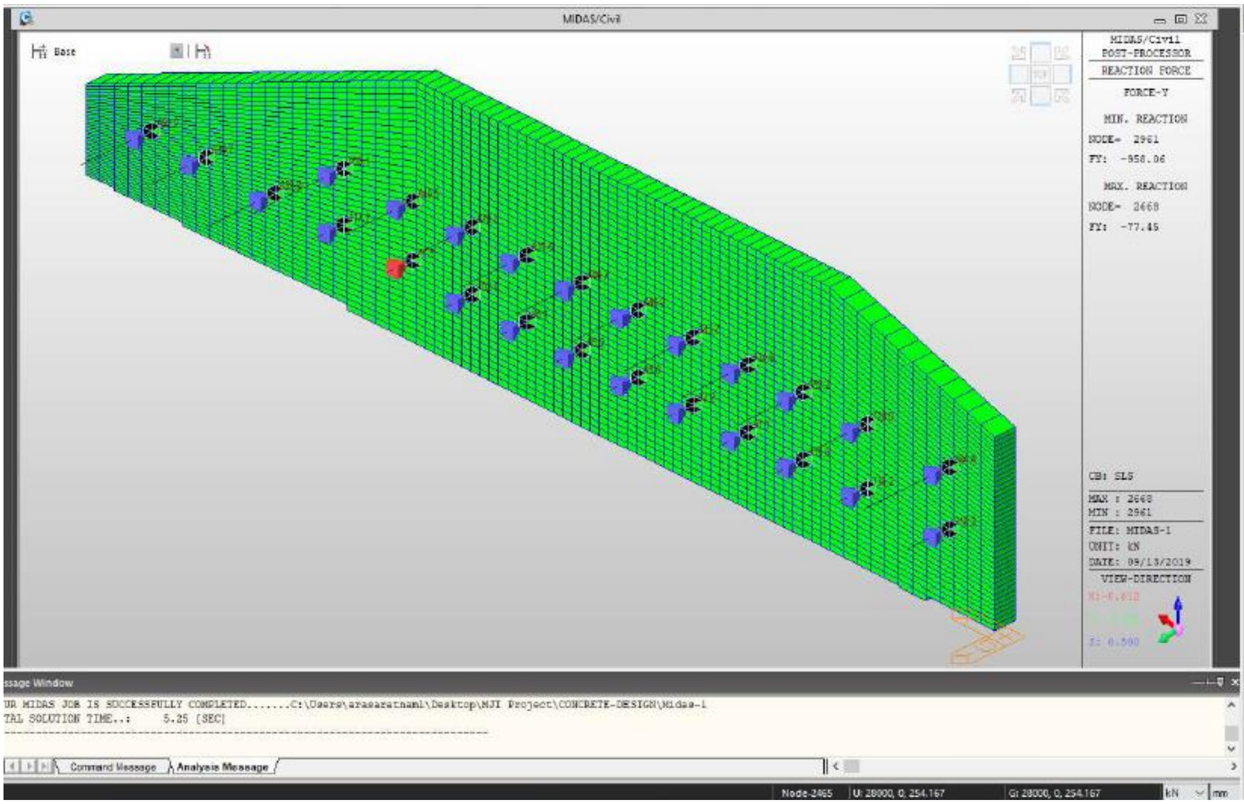

Figure 9: Forces on Tie Backs under ULS Condition

6. RESULTS

The RASBlox stackable blocks can be effectively used with the provision of adequate lateral soil anchors as required depending upon the wall height-to-thickness ratio, load versus capacity demand, allowable lateral movement requirements, bearing pressure, etc. The hollow forming within the stacked blocks are required to be structurally integrated with the provision of adequate reinforced concrete. Additionally, the blocks can be post tensioned after assembly to enhance strength at high load sections of the wall system to ensure structural stability and integrity, in which case the hollow section may or may not be filled with reinforced concrete. Nevertheless, such condition and requirement will need to be analyzed and decided based a competent engineering decision/judgement.

Based on the 3D FE analyses, the following conclusion/recommendations can be derived:

- The RASBlox system can be effectively used with appropriate consideration of wall overturning, shear and overall soil slippage failure modes;
- Due to flexibility in system design, the wall can be built to suit any terrain;
- Provision of anchorage/tie-ins to be determined based on project specific design criteria;
- The number of anchoring system, i.e., how many blocks require anchoring instead of having to anchor each block component to be determined by a design engineer based on the site-specific geotechnical information.

7. RECOMMENDATIONS

7.1. Base Preparation for softer soil conditions

Stripping and clearing should be carried out to remove surficial soil containing organics. All vegetation, organics (topsoil/organic clay) or any other materials containing organics, if encountered during site grading, should be completely removed to expose the underlying, inorganic subgrade. Contaminated soils (if any) should also be excavated and disposed off-site; as recommended by an environmental professional and or guidelines.

After clearing and stripping, the exposed subgrade should be scarified to a minimum depth of 500 mm, moisture conditioned to within 2% of the OMC, and compacted to at least 98% of the SPMDD. Following compaction, the subgrade should be proof rolled to identify any soft spots. To conduct the proof roll test, it is recommended to use a fully loaded dump truck or water truck with a weight of at least 20 tons and a tire pressure of at least 480 kPa. It is not recommend using off road earth moving equipment (*i.e.* loaders and scrapers), compactors, or track-mounted vehicles (*i.e.* bull dozers and front-end loaders) for proof-rolling. Proof-rolling specifications should require rut depths less than 25 mm and no visual evidence of pumping. If soft spots are encountered, those areas should be removed and replaced with properly placed and compacted structural granular Fill. After the completion of the site preparation activities, the areas should be brought to design grade using properly placed and compacted structural clay Fill. All soft or weak areas should be over-excavated to expose the underlying competent soil to a maximum depth of 600 mm and backfilled using compacted general engineered Fill. The recommended gradations of Engineered Granular Fill materials are presented on **Table 1** below.

Table 1: Recommended Properties of Engineered Granular Fill

Grain Size (mm)	Percent Passing Engineered Structural Fill
80.0	100
38.0	--
20.0	40 – 90
10.0	--
5.0	20 – 60
1.25	--
0.160	0 – 15
0.080	2 – 10

The Engineered Common Fill may be used to backfill the excavated areas to raise elevation to their design elevations. Common Fill may consist of medium to low plasticity clays. Common Fill should have a liquid limit of less than 40, a plasticity index between 8 and 20, at least 60 percent of the material finer than the No. 200 Sieve and be non-dispersive. Common Fill should be free of deleterious materials such as topsoil's, soft soils, frozen lumps, debris and high plasticity clay. It is considered that the site excavated soils meeting above described specifications can be used as Engineered Common Fill to raise excavated areas to required design elevations. A qualified geotechnical engineer should inspect and approve the excavated materials prior being used as Engineered Common Fill. General engineered fill should be moisture conditioned to within 2% of OMC and compacted to 98% of SPMDD. The fill should be placed in lifts not greater than 150 mm in thickness. The prepared subgrade should be graded to drain towards side ditches and/or natural drainage.

Over saturated areas will require dewatering by pumping out. Subgrade stabilization of such areas may be achieved by placing a layer of non-woven filter fabric (Nilex 4554 or equivalent) directly overlain geogrid (Nilex BX 1200 or equivalent) on the exposed subgrade prior to placing any fill.

If fill is being placed in the fall season, caution should be taken due to the possibility of frost in the underlying subgrade. Settlement of the subgrade could occur as the frost thaws if fill is placed on seasonally frozen soils. Probing should be carried out prior to construction to check that there are no frozen layers in the subgrade prior to grading operations.

Cut sections should be avoided in areas of high groundwater table to reduce difficulties associated with construction. The prepared subgrade should not be left exposed for extended periods of time to avoid wetting, drying, or freezing of the subgrade.

Full-time monitoring and compaction testing should be provided during any fill placement to confirm that it is placed in accordance with the recommendations in this report. Monitoring should be carried out by experienced geotechnical personnel.

7.2. Tieback Anchor Spacing

For the analysis of retaining wall in this report, we have chosen a tieback spacing of 2.25 m in horizontal direction and 2.0 m in vertical direction. This is solely based on the assumption that alternative block is supported by a tie back to resist the lateral pressure from the retained soil behind the wall and the rock slope. Based on site specific geotechnical study, If the rock behind the wall was found to be competent for the installation of high capacity rock anchors, the flexural strength of the wall would support a maximum tie back spacing of approximately 6.0 m. The following **Table 2** provides the maximum anchor spacing allowed at each configuration using the standard blocks. This spacing is solely based on flexural strength of the wall. Therefore, a spacing that suits the location of the tieback holes on the block should be used during construction.

Table 2: Maximum Anchor Spacing

Tieback Configuration	Horizontal Spacing (m)	Vertical Spacing (m)
Standard 1	6.00	2.0
Standard 2	4.64	3.0
Standard 3	5.60	3.0

This spacing recommendation is solely for the purpose of the wall described in this memorandum. For any other wall, the anchor spacing, and anchor designs must be completed on a case by case basis depending on the encountered geotechnical conditions.

7.3. Expansion Joints

Vertical expansion joints are incorporated into the wall to account for expansion due to temperature changes. These joints may be filled with flexible joint fillers. Typically, greased steel dowels are often cast horizontally into the wall to tie adjacent sections together. In the case of RASBlox retaining wall, the break end blocks can be customized and used in the wall construction to accommodate the design engineer's recommendation.

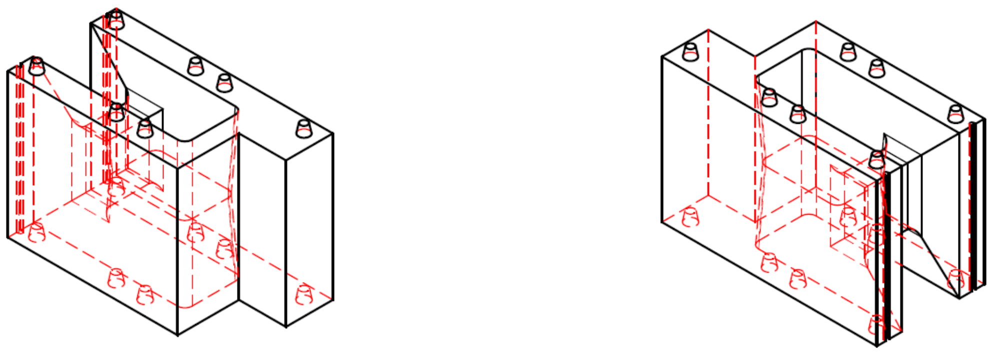

Figure 10: Standard Break End Blocks - Left & Right

For 8 m retaining wall discussed in this report, expansion joints should be located at an interval up to 30 m. Again, this is a general recommendation and must be reviewed and selected by a competent engineer.

7.4. Vertical Reinforcement Design

Based on proposed wall design dimensions, the vertical reinforced columns design was completed to provide the proprietary owner with the guidelines for selecting the appropriate rebar cage for a typical wall. **Appendix A** provides design recommendation for the rebar cage. 20M bars have used in the design. Based on this assumption, the vertical cage could be built using eight 20M bars and 10M stirrups at 150 mm intervals. Alternatively, six 25M bars and 10M can also be used to build the cage. Depending on the encountered site conditions, and wall dimensions, the design engineer shall determine the reinforcement requirement for the construction of the retaining wall.

7.5. Horizontal Reinforcement Design

Based on proposed wall design dimensions, the horizontal reinforcement design was completed to provide the proprietary owner with the guidelines for selecting the appropriate rebar cage for a typical wall. **Appendix A** provides design recommendation for the rebar cage. 20M bars have used in the design. Based on this assumption, the horizontal cage could be built using eight 25M bars and 10M stirrups at 150 mm intervals. Depending on the encountered site conditions, and wall dimensions, the design engineer shall determine the reinforcement requirement for the construction of the retaining wall.

7.6. Use of Oversized Blocks

The oversized blocks may be considered in walls with heights of 8 m or greater. Taller retaining walls generally requires tieback support system. The analysis indicates that the number of tiebacks required to build an 8 m wall with larger blocks would be half of what would take to build the same wall with the smaller blocks.

Respectfully submitted by,

Morton & Jagodich Incorporated
Permit to Practice: P11879

8. REFERENCES

Archway Bridge and Tunnel Systems. n.d. "RASBlox Retaining Wall System."

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