Geosynthetics - 7th ICG - Delmas, Gourc & Girard (eds) © 2002 Swets & Zeitlinger, Lisse ISBN 90 5809 523 1

13 m Stress Relief Modular Wall

J TURGEON-SCHRAMM & J PAULSON, Anchor Wall Systems, Minnetonka, Minnesota, USA

ABSTRACT: A 13.4 m high modular block wall was built facing a 13.4 m below grade structural building wall. An air gap is present between the walls. The below grade wall was part of a 5 story underground building expansion project at the Minneapolis, Minnesota, USA, Convention Center. The purpose of the modular wall was to prevent the soil lateral earth pressure and surcharge loads from being imposed on the below grade building wall. The modular wall was designed using the National Concrete Masonry Association, USA, design method. Slope inclinometers were installed and measured during and after construction as an aid to evaluate the modular wall facing deflection and performance. This paper describes the alternative wall choices evaluated by the general contractor, the unique project constraints, the wall design, construction and instrumentation.

1 INTRODUCTION

Modular retaining walls using geosynthetic reinforcement have been successfully used in numerous structures over the last fifteen years. These structures are generally in areas where a grade separation problem exists on a site with sloping ground. The acceptance of these structures in North America has led to a wider use of geosynthetic reinforced modular retaining walls in applications previously reserved for more traditional soil retaining technologies. The subject of this paper is one such application.

2 SITE DESCRIPTION

The Minneapolis, Minnesota Convention Center recently added 62,200 square meters of exhibit hall and a 5 story below grade building expansion. The below grade building has an access tunnel and is used for cleaning and processing equipment and machinery prior to display. The below grade expansion is located outside the perimeter walls of the above grade portion of the Convention Center. The roof of the below grade building is located from 1 to 1.8 m below the proposed finished grade. Above the below grade building is a paved loading dock and parking area.

The geomorphology of this area generally consists of 8 to 20 m of fine and course alluvial deposits over limestone and sandstone bedrock. The subsurface investigation performed for the structures generally encountered about 1 to 2.5 m of fill overlying alluvial deposits. Most of the alluvium was course grained clean sand. Limestone bedrock was encountered below the alluvium at a depth of 18 to 19.5 m. An exception was encountered in the center portion of the excavation for the modular wall where alluvial deposited lean clay was encountered from about 10 to 14 m below grade. Perched groundwater conditions were present in the area of the clayey soils.

The below grade building addition was in-place at the time of modular wall construction. The below grade building consisted of a 13.4 m high reinforced concrete wall, exposed for a length of 86 m. Perpendicular to one end of the concrete building wall was a driven H-pile wall with grouted tie backs and wood lagging. Perpendicular to the other end of the below grade wall was a reinforced concrete tunnel access wall that extended to about 11 m in height.

3 RETAINING WALL OPTIONS

On-grade paved loading dock and parking areas were proposed above the building addition. Thus, it was necessary to completely bury the below grade building addition. Originally, a reinforced concrete counterfort below grade wall was proposed to accommodate the loads imposed by the lateral earth pressure, overburden fill and traffic surcharge. Preliminary analysis indicated that the wall would have been excessively thick and would have required reinforced concrete buttresses on about 2.5 m centers, extending about 10 m in height. The material and labor cost to construct this option were considered excessive. A second option considered was to construct a geosynthetic reinforced wall with a modified wrap fascia. This wall would be constructed facing the below grade wall with a small air gap between the walls. The facing of this system consisted of the primary reinforcement wrapped up the wall face and then back into the reinforced structure about 2 m. An L shape welded wire cage was proposed to be used to assist in the location and forming of the reinforced wrapped face during construction.

A value engineering proposal was submitted to the project general contractor for a third alternative. This alternative consisted of constructing a geosynthetic reinforced modular block retaining wall. The modular wall would face the below grade wall, with an air gap between the structures. The purpose of the modular wall is to retain the soil and prevent the lateral earth pressure and traffic loads from being imposed on the below grade building wall. To cover the gap between the walls, pre-cast concrete planks were designed to span between the modular wall and the below grade building wall. For many reasons the modular wall option was selected. Factors influencing the selection were relationships, the mechanical connection of the reinforcement products to the modular facing units, the rigidity of the face during and after construction compared to alternative solutions, the wall deflection instrumentation package offered and of course price.

4 MODULAR WALL DESIGN

The modular wall design was performed in accordance with the National Concrete Masonry Association, Design Manual for Segmental Retaining Walls, 1997. The design is based on the site soil and bedrock conditions revealed by the subsurface investigation. The granular retained soils left in-place were assigned a peak effective stress friction angle of 30 degrees and a moist unit weight of 20.4 kN/m^3. The fine grained alluvial soils were assigned a friction angle of 24 degrees and a moist unit weight of 19.6 kN/m^3. Direct shear tests were performed on the imported fill to be used in the geosynthetic reinforced zone and in the retained soil zone at higher elevations. The friction angle obtained from this testing and used in design for the granular soil, with not more than 12% fines was 35 degrees, with a moist unit weight of 19. 6 kN/m^3.

The geometry of the wall face was obtained from the Convention Center addition foundation plans. The modular wall is founded on a gravel leveling pad place on top of the exterior foundation wall spread footing. Six foundation elevation changes are present along the 54 m length of wall. The modular wall height ranges from 12.4 to 13.4 m. The top of the modular wall and the building wall are at the same elevation. Pre-cast concrete plank were designed to span the 1 m gap between the walls at the top. From 1 to1.8 m of fill was required above the walls and concrete plank to achieve proposed pavement grade. The dead load of the planks, overburden fill and the live load from traffic were taken into account in the wall design. The overall height of the modular wall and overburden fill ranged from 14 to 15.3 m.

The concrete modular wall units are the Anchor Landmark System. The units are 380 mm in height by 200 mm in length by 300 mm in depth. The geosynthetic reinforcement products consisted of various strength TC Mirafi Miragrid, coated polyester geogrids. The index strength of the geogrids ranged from 52 to 121 kN/m. The reinforcement products are mechanically attached to the modular units by an extruded polymer lock bar that is placed into a recessed into the top of the units.

The referenced modular wall design methodology is a working stress method, based on limit equilibrium methods of analysis, with factors of safety applied to the component materials. The design method focuses on stability analysis for external, internal, facing and global modes of failure. Coulomb active earth pressure theory is used to calculate the internal and external forces acting on the system. The minimum reinforcement length required to satisfy bearing capacity and external sliding was the default design minimum of 60% of the wall height or 8.1 m. Global stability analysis was performed. The global stability analysis also uses limit equilibrium methods of analysis to solve for the factor of safety for circular or specified irregular failure surfaces, given the wall geometry, soil conditions, reinforcement layout and strength. The minimum reinforcement length of 8.1 m provided a factor of safety against global stability failure of 1.4. Nineteen layers of geogrid were required to satisfy internal strength, sliding, pullout and facing connection and bulging modes of failure. The maximum vertical spacing of the reinforcement ranged from 380 to 760 mm. A total cumulative reinforcement index strength of 1,806 kN/m was required to satisfy all aspects of design.

One end of the modular wall abuts to the H-pile and wood lagging wall at a 90 degree angle. To prevent migration of soil into the air gap between the modular and building walls, assuming the wood lagging fails, a pre-cast concrete plank was designed to be placed, parallel to, and in front of, the lagging. The plank was restrained from moving laterally at the building wall and the modular wall was abutted to the plank. The opposite end of the modular wall abutted the concrete tunnel wall to about the 11 m elevation and then extended onto the tunnel roof, turned a 90 degree inside corner and abutted the building foundation wall.

Geotextile filter fabric was designed for placement behind the modular units and the drainage aggregate and drain tile system constructed at the toe of the wall. Filter fabric was also placed completely over and down the sides of the pre-cast concrete planks spanning the two walls prior to placing the 1 to 1.8 m of overburden fill.

Project specific construction plans, details and specifications were prepared and certified by a registered professional engineer.

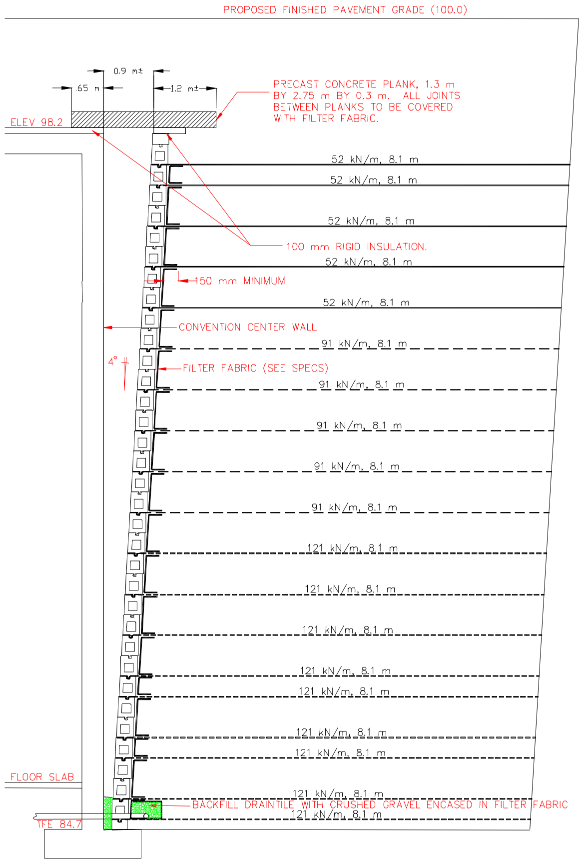

Figure 1. Profile View of Building and Modular Wall

5 MODULAR WALL INSTRUMENTATION

The consequence of failure of this modular wall is significant. Since the building and modular wall are completely buried during construction, access to the walls for visual inspection post construction is not possible. The modular wall, being designed with active earth pressure theory, must move or rotate during construction. To aid in determining the magnitude of this or any future movement, it was proposed to install two slope inclinometers directly behind the modular facing units during construction. The slope inclinometers were measured during construction after about 3 m of wall was constructed and about every 1 to 1.5 m vertically thereafter. The inclinometers were also measured about 4 months after completion of modular wall construction, pavement placement and inclinometer surface casing and access construction.

6 WALL CONSTRUCTION

The modular wall was constructed in May of 2001. About 3 to 4 weeks was required to construct the wall.

The site access conditions at the beginning of construction were restricted. An excavation about 15 m in depth across a horizontal span of approximately 50 m was present. An earthen embankment was constructed down into the bottom of the excavation. The construction materials, including the modular concrete facing units, geogrid reinforcement, geotextile filter fabric and backfill soils, were transported down into the excavation on the fairly steep embankment. A portion of the embankment can be seen on the left side of the photograph of Figure 2.

Figure 2. Start of Modular Wall Construction

The sequence of wall construction began with placement, compaction and leveling of the aggregate pad placed below the lowest course of modular foundation units. The foundation units were then placed, aligned horizontally and leveled in both directions. A drain tile encased in drainage aggregate and a geotextile filter fabric was installed behind the lower course of units. The drain tile was connected to the drainage system located below the floor slab of the adjacent building addition at two locations.

During construction perched water conditions were observed in the exposed cut bank, behind the reinforced soil zone. A second drain tile system, enclosed in drainage aggregate and filter fabric, was placed at the interface of the clay soil cut bank and the granular fill placed within and behind the reinforcement. This drainage system was also connected to the building below slab drainage system.

Subsequent courses of modular units were then placed, with the proper strength reinforcement products installed and connected with the lock bar, at the elevations shown on the construction plans. A needle punched non-woven geotextile filter fabric was placed adjacent to the back of the modular units and extended 150mm back along the reinforcement. The backfill placement, compaction and testing was an ongoing operation during wall facing and reinforcement placement.

Upon completion of the modular wall construction, pre-cast concrete planks were placed to span the gap between the two walls. The planks were placed on high density polystyrene insulation to protect the building waterproofing membrane.

Figure 3. Modular Unit Placement

Figure 4. Reinforcement Placement

Figure 5. During Wall Construction

Figure 6. End of Wall Construction

Figure 7. Wall Closure Detail

7 INSTRUMENTATION MEASUREMENTS

Measurements were taken on each of the two slope inclinometers after 3 m of wall and inclinometer casing were installed and at about 1.5m vertical intervals thereafter. Nine measurements were taken during wall construction. These measurements indicate the maximum horizontal wall movement ranged from about 50 to 65mm. The maximum displacement occurred about one-third the way up the wall from the toe. The lateral displacement measured represents approximately 0.5% of the height of wall. Measurements were also taken about 4 months after completion of construction. These measurements indicate the maximum post construction wall displacement to be 7 mm. The US Federal Highway Administration's "Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines" 1996, indicates that for extensible reinforcements the anticipated lateral displacement for this wall would have been on the order of 200 to 250 mm. Figure 8 depicts the cumulative horizontal displacement measured during and after construction.

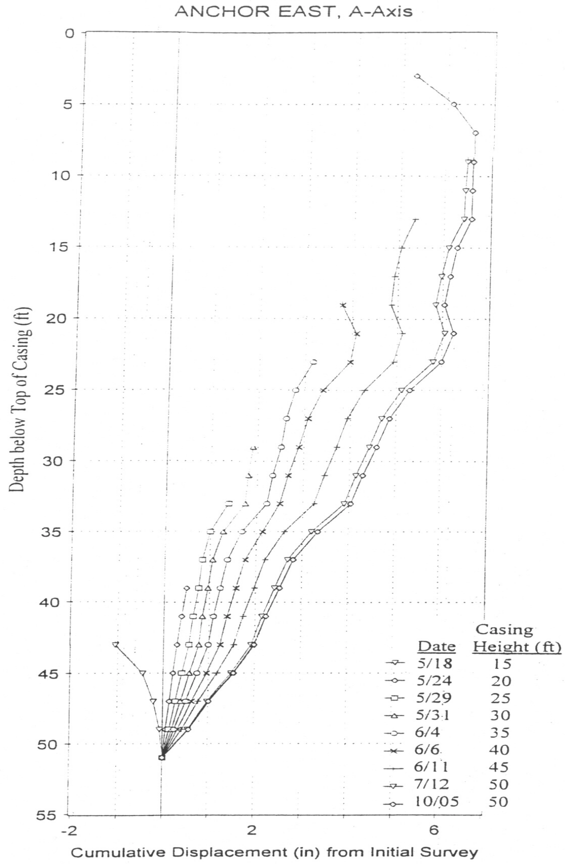

Figure 8. Slope Inclinometer Measurements

8 CONCLUSION

The acceptance in North America of modular retaining wall technology has led to a wider range of applications for this technology in projects with more difficult technical issues and more stringent space constraints. The modular wall constructed at the Convention Center is one such example. The geosynthetic reinforced modular wall saved the owner in excess of $300,000 (US), compared to the concrete counterfort wall option. The counterfort wall would have been in excess of two orders of magnitude more expensive to construct than the modular wall.

The modular wall components were ideally suited to the restricted site access. The wall instrumentation, while of little scientific value, provided the project management team and owner with a comfort level regarding the performance of the modular wall during construction and in the long term. This project proves geosynthetic reinforced modular retaining walls can be used to design and build cost effective, safe, structurally sound retaining walls for a wide variety of challenging applications.

9 REFERENCES

Elias, V. and Christopher, B.R. 1996. Mechanically Stabilized Earth Walls and Reinforced Soil Slopes, Design and Construction Guidelines, Report No. FHWA-SA-96-071, Participants Manual FHWA Demonstration Project 82, Federal Highway Administration Office of Engineering and Technology Applications

National Concrete Masonry Association , 1997. Design Manual for Segmental Retaining Walls, Second Edition.