U.S. Bank Stadium Geosynthetic Reinforced Stress Relief Wall: Design, Construction and Fire Damage Mitigation

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ABSTRACT

Demolition of the Old Metrodome Stadium in Minneapolis, MN occurred in 2013 and subsequent reconstruction of U.S. Bank Stadium, the home of the Minnesota Vikings and host of the 2018 Super Bowl, occurred between 2014 and 2015 on the same site. Stadium construction included an approximately 9.1m (30ft) tall, 213.4m (700ft) long, Geosynthetic Reinforced Soil Structure (RSS) constructed as a below-grade stress relief wall along the entire south side of the stadium. The RSS, constructed using polyester geogrid reinforcement with a high tenacity polypropylene woven geotextile wrap and welded wire basket facing, was placed at a 1m (3ft) offset from the bottom of the Stadium’s south foundation wall. The RSS was battered 2.5 cm (1 inch) per each 46 cm (18 inch) vertical wire basket resulting in a void at the top of about 1.6 m (5ft). The void was spanned by a precast concrete slab. Significant construction challenges included: altering of the site and utility plan for RSS construction, a unique RSS geometry, reinforcement diversion around utilities and structures and fire damage remediation. Cost savings from using a geosynthetic reinforced stress relief wall on a spread footing instead of a concrete cast-in-place wall on a deep drilled pier foundation on bedrock was estimated at $5.5 million. The 9.1m (30ft) tall cast-in-place concrete foundation wall would have needed to be supported on a deep drilled pier foundation because of the lower bearing capacity of the moderately weathered limestone bedrock at the base of the wall.

BACKGROUND

The stadium Architect (HKS, Inc.) provided a concept level drawing of the RSS stress relief wall in the project plans. The purpose of the RSS was to allow the 9.1m (30ft) tall south stadium foundation wall to be constructed with concrete masonry units (CMU) on a spread footing foundation rather than a thick cast-in-place concrete wall on deep foundations that would have been required to support the lateral earth pressures. Of concern was the foundation bearing soils. The cast-in-place concrete wall would have had to be supported on drilled piers to competent bedrock because of the low bearing capacity for the moderately weathered limestone bedrock at the bottom of the wall. The more cost effective CMU wall could be supported on a spread footing on the moderately weathered limestone bedrock resulting in a $5.5 million savings. The location of the RSS relative to the stadium site is shown in Figure 1.
Figure 1: RSS Location along Stadium South Foundation Wall

The concept drawing showed a 1.6 - 2.2m (5-7ft) gap to be formed at the top of the RSS that would be spanned with a precast concrete panel, thus leaving a permanent void space between the stress relief wall and the stadium foundation wall.

From the concept level drawing, the authors designed the RSS and worked with the project civil and structural engineers, the stadium general contractor and the RSS/earthwork contractor to alter the building excavation and utility plans to facilitate RSS construction. Design and construction challenges included: RSS geometric constraints, geogrid reinforcement diversion around horizontal and vertical utility structures, diversion around tower cranes and diversion around pedestrian bridge piles and pile caps.

The RSS was completed during the later phases of US Bank Stadium construction in the Spring of 2015. Shortly after RSS completion and before precast panel placement, an approximately 30ft long portion of the RSS face was damaged from the heat created by a fire that started as a result of welding sparks falling from roof construction and igniting the polystyrene installation installed along the building CMU foundation wall. The authors and RSS contractor investigated the fire damaged portion of the RSS. The wall was repaired by including percussion driven anchors, a welded wire mesh and a shotcrete facing.

Initial RSS Design

Located in downtown Minneapolis, the stadium site is in a constrained location adjacent to Chicago Avenue that required a minimal excavation width for installation of the RSS geogrid reinforcement. The Stadium Plan included a 213.4m (700ft) long RSS stress relief wall concept level design. The RSS would be subjected to relatively large surcharge loads from temporary shoring and mobile cranes during construction and from emergency service vehicles long-term. The RSS was designed to support: a 66.8 kN (15 kip) point load due to temporary shoring placed during construction, an 38.3 kPa (800 psf) distributed load from large construction/maintenance
equipment and potential emergency service vehicles and a 6.3 kN/m (4,500 lb/ft) strip load from the void spanning concrete slab.

From these limiting factors it was determined that a granular material with a friction angle of at least 35 degrees would be required for the RSS reinforced fill, which would help reduce the geogrid lengths and the subsequent excavation width required while still supporting the high surcharge loads. Internal and external stability analyses indicated that a uniaxial geogrid product, placed at 0.5m (1.5ft) vertical intervals at lengths equal to 90% of the RSS height was required. At the RSS face a relatively high tenacity polypropylene multifilament woven geotextile was used as a wrap to retain the granular material at the face. The geotextile was placed inside of a 0.5m (1.5ft) tall galvanized welded wire basket that was used to help form the facing. Each basket was placed at a 2.5 cm (1 inch) horizontal offset to keep the RSS tolerance within the 1.6 m (5ft) maximum void span length at the top of the RSS. A typical RSS section is shown in Figure 2.

Figure 2: RSS Typical Section
RSS DESIGN AND CONSTRUCTION CHALLENGES

There were some unique design and construction challenges associated with the RSS.

A portion of the RSS had to be constructed to align with a descending chevron concrete structure that was supported on grade beams on H-piles. The RSS had to turn multiple 90 degree outside corners and ascend at a specific angle to be able to support the chevron concrete structure.

Multiple horizontally oriented storm and sanitary pipes were required to be installed through the face and RSS reinforced fill. The RSS geogrid reinforcement had to be diverted around these horizontally oriented pipes. Several vertically oriented storm sewer inlets and manholes were also located within the RSS fill. A geogrid diversion system, consisting of structural bars and threaded rods were designed to divert the tensile forces in the geogrid reinforcement to opposite side of the structure where the geogrid could be extended again. Figure 5 illustrates this diversion system.

Figure 5: Geogrid Reinforcement Diversion System around Storm Sewer Inlet
A pedestrian bridge to an elevated stadium entrance was also planned along the southern portion of the stadium. The piling and pile caps which supported the pedestrian bridge were located within the reinforced backfill. The authors required that the piling be installed prior to RSS construction so that the geogrid reinforcement could be diverted around the piles during RSS construction. Where the concrete pile caps interfered with the geogrid extent, the geogrid was mechanically connected to the concrete pile caps using a pipe and rebar anchor system that was designed to transfer the tensile forces in the geogrid to the concrete cap and piles. An anchor hook was drilled and grouted into the pile cap, a 3 inch diameter pipe installed in the hooks and then the geogrid was wrapped around the pipe and placed in the anchor hook. Figures 6 and 7 show the connection details.

Figures 6: Detail Showing Geogrid Connection to Bridge Pile Cap
The RSS was completed in the Spring of 2015 with 0.9m (3ft) wide sections of the precast panel placed to span the 1.6 m (5ft) wide void between the stadium foundation wall and the RSS crest. Figure No. 8 shows the completed RSS with the footing for the precast concrete slab in place.
RSS FIRE DAMAGE AND REMEDIATION

On a Friday morning in July, 2015 welding sparks from overhead roof construction ignited the polystyrene insulation board installed on the CMU foundation wall. The CMU wall is located 0.9 m – 1.6 m (3ft - 5ft) away from the RSS face. The resulting fire sent a black cloud of smoke high into the sky. The fire was quickly extinguished with the assistance of an on-site water truck being used for dust control and then the Minneapolis Fire Department. An approximately 9.4m (30ft) wide portion of the RSS appeared to be damaged. The authors observed the damage within a few hours of the fire. The polypropylene woven geotextile face wrap and the polyester geogrid reinforcement that wrapped around the face had melted over a 9.4m (30ft) horizontal distance and over the full 9.4m (30ft) height of the RSS. The granular fill was starting to slowly slough out at the face of the damaged portion of the RSS. The Material Safety Sheets identified the geotextile polypropylene fiber melts at approximately 163°C (325°F), while the polyester geogrid melts at 204°C (400°F). These temperatures were apparently exceeded near the RSS face during the fire, since both products had melted to some degree. Figures 9 and 10 show the RSS fire damaged facing.

![Figures 9 and 10: Fire Damage: Melted Geotextile and Geogrid at RSS face](image)

Geogrid samples were cut out of the fire damaged portion of the RSS at various distances back into the fill from the face to determine the extent back into the RSS the geogrid reinforcement had been compromised. The results of the forensic ASTM D6637 testing indicated that the geogrid reinforcement was only damaged within approximately 0.3m (1ft) of the RSS face. Based on the results of this testing, it was determined that remediation would only be required at the RSS face.
and that complete excavation and reconstruction of the RSS within the fire damaged area was not necessary.

The facing remediation measure consisted of placing a new welded wire mesh on the face, shotcreting the face and then installing a series of 0.3m to 1.6m (3ft to 5ft) long Gripple® percussion driven anchors within the fire damaged area. The anchors were installed at a 1m (3ft) triangular spacing. The remediation measure was designed assuming that the outer 1m (3ft) of the geogrid and the geotextile wrap had been compromised.

The anchors and shotcrete were installed from a swing stage by a construction crew that was experienced in confined space concrete work. Two 7.5cm (3 inch) thick layers of shotcrete, reinforced with W4.0 x W4.0 welded wire mesh, was applied over the damaged RSS face. The design required that the percussion driven anchors be installed after shotcrete installation with a hammer drill at a 1m (3ft) triangular spacing. Anchor proof testing indicated that all anchors exceeded a 2.2kN (500lb) pullout capacity. The RSS fire damage remediation was completed in September, 2016. Figure Nos. 11 and 12 show the wire mesh installation and anchor installation near the top of the RSS face.

Figures 11 and 12: Fire Damage Remediation: Reinforced Shotcrete Facing with Shallow Percussion Driven Anchors
CONCLUSION

The below grade RSS stress relief wall, constructed along the southern portion of the US Bank Stadium, with a 1.6m (5ft) void at the top of the RSS, was conceived as a substitute for a 39.1m (30ft) tall cast-in-place concrete foundation wall on a drilled pier foundation. The cost savings was estimated at $5.5 million.

The RSS design required that the site excavation, grading and utility plans be altered. Implementation presented unique design challenges. Some of these challenges included unique geometric constraints, horizontal and vertical obstructions within the RSS reinforced zone and fire damage on a portion of the RSS facing. The RSS designers worked with the structural and civil engineers as well as the general and earthwork contractors to address these unique challenges and ensure that the RSS was appropriately designed and constructed complimentary to other portions of the stadium site. Figure 13 shows a large crushed rock over the precast concrete slab which spans the 1.6m (5ft) void. This photo is from the Stadium’s opening day.

![Figure 13: Location of Below-Grade RSS on Stadium Opening Day](image)

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