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Geosynthetic-reinforced soil bridge abutments

Measuring the performance of geosynthetic reinforcement in a Colorado bridge structure.

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The technology of geosynthetic-reinforced soil (GRS) systems has been used extensively in transportation systems to support the self-weight of backfill soil, roadway structures, and traffic loads. The increasing use and acceptance of soil reinforcement has been triggered by a number of factors, including cost savings, aesthetics, simple and fast construction techniques, good seismic performance, and the ability to tolerate large differential settlement without structural distress.

A comparatively new use of this technology is the use of GRS systems as an integral structural component of bridge abutments and piers. Use of a reinforced soil system to support directly both the bridge (e.g., using a shallow foundation) and the approaching roadway structure has the potential of significantly reducing construction costs, decreasing construction time, and smoothing the ride for vehicular traffic by eliminating the “bump at the bridge” caused by differential settlements between bridge foundations and approaching roadway structures.

The most prominent GRS abutment for bridge support in the United States is the Founders/Meadows Parkway bridge, which crosses U.S. Interstate 25 approximately 20 miles (32.2 km) south of downtown Denver, Colo., and was recently opened to traffic (**Photo 1**). Designed and constructed by the Colorado Department of Transportation (CDOT), this is the first major bridge in the United States to be built on footings supported by a geosynthetic-reinforced system, eliminating the use of traditional deep foundations (piles) altogether. Phased construction of the almost 9-m (29.5-ft.)-high, horseshoe-shaped abutments, located on each side of the highway, began in July 1998 and was completed 12 months later. Significant previous research by the Federal Highway Administration (FHWA) and CDOT on GRS bridge abutments, which has demonstrated their excellent performance and high load-carrying capacity, led to the construction of this unique structure.

Photo 1*: The Founders/Meadows bridge supported by GRS bridge abutments.*

The performance of bridge structures supported by GRS abutments has not been tested sufficiently under actual service conditions to merit unqualified acceptance in highway construction. Consequently, the Founders/Meadows structure was considered experimental, and comprehensive material testing, instrumentation and monitoring programs were incorporated into the construction operations. Design procedures, material characterization programs, and monitoring results from the preliminary (Phase I) instrumentation program are discussed by Abu-Hejleh et al. (2000). Large-size direct shear and triaxial tests were conducted to determine representative shear strength properties and constitutive relations of the gravelly backfill used for construction. Three sections of the GRS system were instrumented to provide information on the structure movements, soil stresses, geogrid strains, and moisture content during construction and after opening the structure to traffic.

Previous experiences in GRS bridge abutments

Although the Founders/Meadows structure is a pioneering project in the United States involving permanent GRS bridge abutments for highway infrastructure, significant efforts have been undertaken in Japan, Europe and Australia regarding implementation of such systems in transportation projects. Japanese experience includes preloaded and prestressed bridge piers (Tatsuoka et al. 1997, Uchimura et al. 1998) and geosynthetic-reinforced wall systems with continuous rigid facing for railway infrastructure (Kanazawa et al. 1994, Tateyama et al. 1994). European experience includes vertically loaded, full-scale tests on geosynthetic-reinforced walls constructed in France (Gotteland et al. 1997) and Germany (Brau and Floss 2000). Finally, Won et al. (1996) reported the use of three terraced geogrid-reinforced walls with segmental block facing to directly support end spans for a major bridge in Australia.

The experience in the U.S. regarding geosynthetic-reinforced bridge abutments for highway infrastructure includes full-scale demonstration tests conducted by the FHWA (e.g. Adams 1997, 2000) and by CDOT (e.g. Ketchart and Wu 1997). In the CDOT demonstration project, the GRS abutment was constructed with roadbase backfill reinforced with layers of a woven polypropylene geotextile placed at a spacing of 0.2 m (6.56 ft.). Dry-stacked hollow-cored concrete blocks were used as facing. A vertical surcharge of 232 kPa was applied to the 7.6-m (24.9-ft.)-high abutment structure. The measured immediate maximum vertical and lateral displacements were 27.1 mm (1.07 in.) and 14.3 mm (0.56 in.), respectively. The maximum vertical and lateral creep displacements after a sustained vertical surcharge pressure of 232 kPa, applied over 70 days, were 18.3 mm (0.72 in.) and 14.3 mm (0.56 in.), respectively. The excellent performance and high loading capacity demonstrated by these geosynthetic-reinforced soil abutments with segmental block facing convinced CDOT design engineers to select GRS walls to support the bridge abutment at the Founders/Meadows structure.

Description of the GRS bridge abutment

The Founders/Meadows bridge is located 20 miles south of Denver, Colo., near Castle Rock. The bridge carries Colorado State Highway 86, Founders/Meadows Parkway, over U.S. Interstate 25. This structure, completed by CDOT in July of 1999, replaced a deteriorated two-span bridge structure. In this project, both the bridge and the approaching roadway structures are supported by a system of geosynthetic-reinforced segmental retaining walls. **Photo 2** shows a picture of one of the segmental retaining wall systems, located at the east side of the bridge. This figure shows the bridge superstructure supported by the front MSE wall, which extends around a 90° curve into a lower MSE wall support-

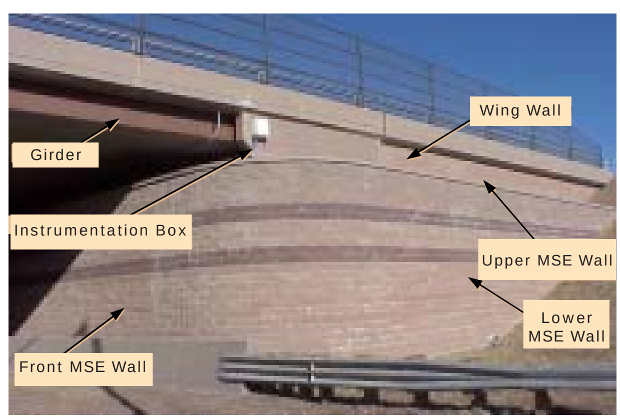

***Photo 2**: SRW components of a completed bridge abutment.*

ing the wing wall and a second tier, the upper MSE wall.

Figure 1 shows a plan view of the completed two-span bridge and approaching roadway structures. Each span of the new bridge is 34.5 m (113.2 ft.) long and 34.5 m (113.2 ft.) wide, with 20 side-by-side pre-stressed box girders. The new bridge is 13 m (42.7 ft.) longer and 25 m (82.0 ft.) wider than the previous structure, accommodating six traffic lanes and side-walks on both sides of the bridge. **Figure 2** shows a typical monitored cross-section through the front MSE wall and abutment wall. The figure illustrates how the bridge superstructure load (from girders, bridge deck) is transmitted through abutment walls to a shallow strip footing placed directly on the top of a geo-grid-reinforced segmental retaining wall. The centerline of the bridge abutment wall and edge of the foundation are located 3.1 m (10.2 ft.) and 1.35 m (4.4 ft.), respectively, from the facing of the front MSE wall. A short reinforced concrete abutment wall and two wing walls, resting on the spread foundation, confine the reinforced backfill soil behind the bridge abutment and support the bridge approach slab. The bridge is supported by central pier columns along the middle of the structure (**Figure 1**), which in turn are supported by a spread footing founded on bedrock at the median of U.S. Interstate 25.

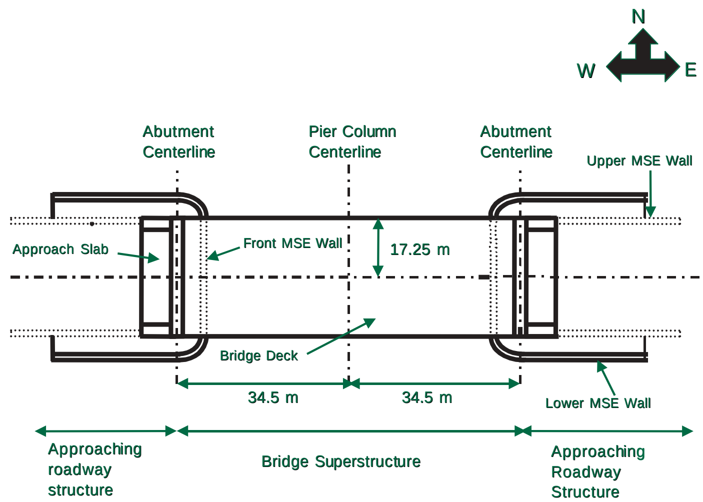

***Figure 1**: The new Founders/Meadows bridge structure, shown here in plan view, exhibits a wider span than the previous structure.*

When compared to typical systems involving the use of deep foundations to support bridge structures, the use of geosynthetic-reinforced systems to support both the bridge and the approaching roadway structures has the potential to alleviate the “bump at the bridge” problem caused by differential settlements between the bridge abutment and approaching roadway. In addition, this approach also allows for construction in stages and comparatively smaller construction working areas.

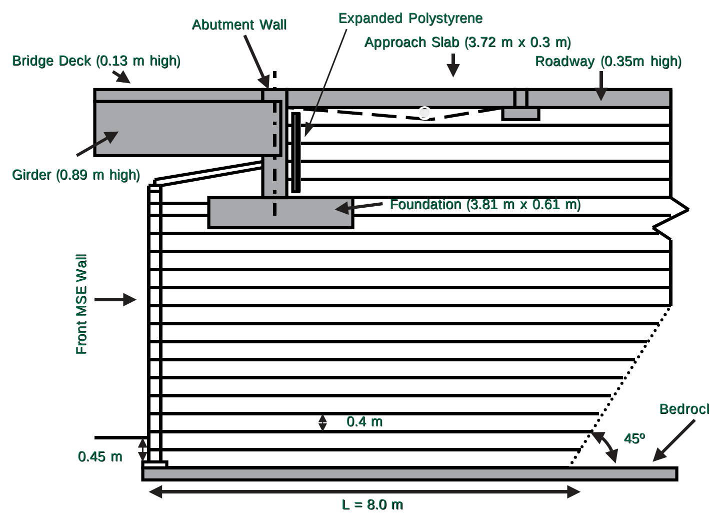

***Figure 2**: Typical monitored cross-section illustrating superstructure load transmitted through abutment walls.*

Several of the common causes for development of bridge bumps were addressed in the design of the Founders/Meadows structure. The main cause of uneven settlements in typical systems is the use of different foundation types. While the approaching roadway structure is typically constructed on compacted backfill soil (reinforced or not), the bridge abutment is typically supported on stronger soils by deep foundations. The roadway approach embankment and the bridge footing were integrated at the Founders/Meadows structure with an extended reinforced soil zone (**Figure 2**) in order to minimize uneven settlements between the bridge abutment and approaching roadway.

A second cause of differential settlements can be attributed to erosion of the fill material around the abutment wall induced by surface water runoff. Several measures were implemented in this project to prevent surface water, as well as groundwater, from reaching the reinforced soil mass and the bedrock at the base of the fill (e.g., placement of impervious membranes with collector pipes shown in **Figure 2**).

Finally, a third potential cause of differential settlements is the thermally induced movements, i.e., expansion and contraction of bridge girders rigidly attached to the abutment wall (integral abutment). A compressible 75 mm (2.95 in.) low-density expanded polystyrene sheet was placed between the reinforced backfill and the abutment walls (see **Figure 2**). It was expected that this system would accommodate the thermally induced movements of the bridge superstructure without affecting the retained backfill.

The backfill soil used in this project included fractions of gravel (35%), sand (54.4%), and fine-grained soil (10.6%). The liquid limit and plasticity index for the fine fraction of the backfill were 25% and 4%, respectively. The backfill soil classifies as SW-SM, per ASTM 2487, and as A-1-B (0), per AASHTO M 145. The backfill met the construction requirements for CDOT Class 1 backfill. A friction angle of 34° and zero cohesion were assumed in the design of the GRS walls. To evaluate the suitability of these design parameters, conventional direct shear tests and large-size direct shear and triaxial tests were conducted. In the conventional tests, the 35% gravel portion was removed from the specimens, but in the large-size triaxial and direct shear tests, the backfill soil specimens included the gravel portion. The results of conventional direct shear tests and large-size direct shear and triaxial tests indicate that assuming zero cohesion in the design procedure and removing the gravel portion from the test specimens lead to significant underestimation of the actual shear strength of the backfill.

The geogrid reinforcements used in this project were manufactured by the Tensar Corporation. Three types of geogrid reinforcements were used: UX 6 below the bridge-support footing, and UX 3 and UX 2 behind the abutment wall. CDOT considered long-term design strength (LTDS) values for these reinforcements of 27 kN/m, 11 kN/m, and 6.8 kN/m, respectively. CDOT specifications imposed a global reduction factor of 5.82 to determine the long-term design strength (LTDS) of the geogrid reinforcements from their ultimate strength. This global reduction factor accounts for reinforcement tensile strength losses over the design life period due to creep, durability and installation damage. It also includes a factor of safety to account for uncertainties.

Performance

The instrumentation program was conducted in two phases (Phases I and II), which correspond to the two construction phases of the GRS bridge abutment structure. A pilot instrumentation plan was conducted during construction of the Phase I structure in order to obtain information for tailoring the design of a more comprehensive monitoring program that would be implemented during Phase II. The Phase I instrumentation program included survey targets, pressure cells, jointmeters and an inclinometer. The more comprehensive Phase II instrumentation program included monitoring using survey targets, a digital road profiler, pressure cells, strain gauges, moisture gauges, and temperature gauges. A view of the instrumentation plan for Phase II is shown in **Figure 3**. The figure shows the four critical location lines that were instrumented in Phase II:

• Location line A, close to the facing. Data collected at this location are particularly useful for guiding the structural design of the facing and of the connection between facing and reinforcements.

• Location lines B and C, along the center and interior edge of the abutment foundation. Information collected at these locations is relevant for the design of the reinforcement elements.

• Location line D, behind the bridge foundation and the horizontal plane at the base of the fill. Data measured at these locations are useful to estimate the external forces acting behind and below the reinforced soil mass.

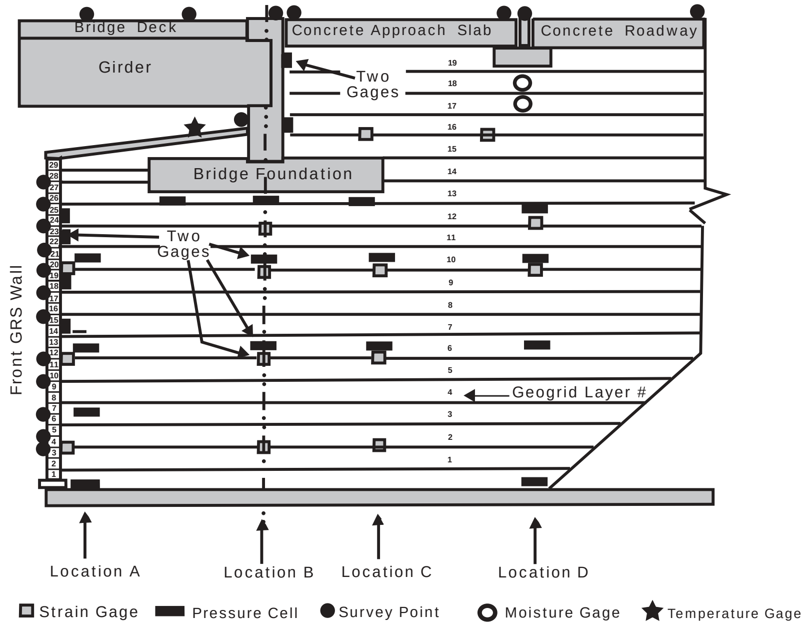

Figure 3 : *Four critical locations (A,B,C,D) were instrumented in the phase II structure.*

Monitoring results continue to be collected and analyzed by the time of preparation of this paper. Results of the preliminary Phase I instrumentation program have been reported by Abu-Hejleh et al. (2000). Although a comprehensive discusssion of the instrumentation results is beyond the scope of this manuscropt, some of the relevant findings from the information collected so far are:

•The measured response from both the pressure cells and strain gauges correlates well with the applied loads during the construction stages.

•The maximum geogrid strains experienced during construction are comparatively very small (approximately 0.45 %).

•Horizontal earth pressures collected at the facing as well as the magnitude of the reinforcement maximum tensile strains are well below design values.

•Most of the geogrid reinforcement strain occurred during construction of the wall and not during placement of the bridge surcharge load. This can be explained by the effect of compaction operations and the presence of slacks in the geogrid reinforcements. Strain-gauge monitoring results collected so far suggest that approximately 50% of the total recorded strains occurred during placement and compaction of only a few lifts of soil above the geogrid layers (e.g. approximately 2 m [6.56 ft.] of soil or 40 kPa). The maximum measured front wall outward displacement induced by wall construction (before placement of the bridge superstructure) was 12 mm (0.47 in.), which corresponds to 0.20% of the wall height.

•The maximum outward displacement induced by placement of the bridge superstructure was an additional 10 mm (0.39 in.), which corresponds to 0.17% of the wall height. The maximum settlement of the bridge footing due to placement of the bridge superstructure was 13 mm (0.51 in.).

•The maximum outward displacements induced during the 18 months from the structure's opening to traffic to June 2000 was 13 mm (0.51 in.). These movements correspond to 0.22% of the wall height. The measured settlement of the leveling pad supporting the front wall facing was approximately 5 mm (0.20 in.). However, it is important to emphasize that these movements took place only during the initial 12 months of service (until January 2000). Lateral and vertical movements have been negligible from January to June 2000.

•Srain gauge records collected so far suggest negligible post-construction movements after a service period of 1 year.

•Elevation profiling and surveying results show no signs of developing the “bump at the bridge” problem.

Overall, the performance of the Founders/Meadows bridge structure, based on the monitored behavior recorded so far, showed excellent short- and long-term performance: the monitored movements were significantly smaller than those expected in design or allowed by performance requirements; there were no signs of the “bump at the bridge” problem or any structural damage; and post-construction movements became negligible after an in-service period of one year.

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