Abstract: A major geotechnical slope failure occurred at Sta. 1663 on the US 70 Design-Build project in New Mexico a year after construction. The 1663 reinforced soil slope was 7.6 m (25 ft.) high and constructed at 0.5H:1V. A slope stability-type failure occurred, with movement associated only with severe rain storms. This case history study will describe the project site conditions, design methods, failure monitoring and analysis, and reconstruction of the RSS. The authors were involved in all aspects of design, construction, forensic evaluations, reconstruction, and claims resolution. The failure is notable because following reconstruction, the contractor was successful in a dispute claim based upon differing site conditions. This paper describes the range of project evolution from design, failure monitoring, forensic evaluations, and reconstruction, to the dispute resolution process and findings.

Introduction

The US 70 project, located in the Hondo Valley between the towns of Ruidoso Downs and Riverside, was the first design-build highway project in the State of New Mexico. The US 70 alignment winds along the foothills of mountains to the north and the rivers Rio Ruidoso and Rio Hondo to the south. A key requirement of the project was to preserve the rural character of the Hondo Valley and minimize environmental impacts to the rivers. The highway design, as a result, required extensive cut slope excavation on the north side of US 70, and retaining walls and reinforced soil slope (RSS) construction on the south side, to keep the new highway footprint from significantly affecting sensitive environmental resources.

RSS Design, Site Conditions, and Construction

The planned RSS at Sta. 1663 ranged in height from 2.4 to 6 m (8 to 20 ft.) at a 1:1 (horizontal:vertical) slope inclination above the Rio Hondo. A down slope of varying heights and inclinations was located at the toe of the proposed RSS slope and ended...
at the bank of the Rio Hondo. Photo 1 shows an aerial view of the site, with the approximate RSS location noted.

The geotechnical investigation for the site consisted of drilling two soil borings adjacent to the deepest parts of the roadway fill along this slope. The subsurface investigation in 2002 indicated the geology in the area was terrace deposits and alluvium overlying Yeso formation mudstone; groundwater was not encountered in the borings drilled at this site. No signs of slope instability were noted during the site reconnaissance.

For the critical design slope, the geotechnical engineers evaluated stability and settlement at Sta. 1663, where the tallest part of the 1:1 RSS was planned above an existing 2.7 m (9 ft.) high 1:1 slope. The design included a toe key of excavated and recompacted soil below the new RSS. Following completion of the design, environmental restrictions adjacent to the Rio Hondo reduced the distance to the toe of the RSS slope. The project designers steepened the RSS to fit within the allowable area at a ½:1 inclination; the geotechnical engineers re-evaluated the steeper slope and calculated a safety factor of 1.3, which met the project design requirements and the RSS design criteria.

The contractor, Sierra Blanca Constructors (SBC), constructed the reinforced slope at Sta. 1663 in the summer of 2003. Because the toe of the RSS was very close to the edge of the river, SBC also constructed a riprap-filled trench at the toe of the RSS to protect it from river scour. The final configuration of the RSS had a front slope that ranged from ¼:1 to ½:1, which was steeper than the planned ½:1 face.

**SLOPE DISTRESS**

In January 2004, guardrail posts were installed along the top of slope through the asphalt shoulder; shortly thereafter, cracks were observed in the guardrail pad radiating from the posts. SBC performed survey monitoring of the slope, and no movements were observed between February and early August 2004.

Heavy rains in July and August, 2004 resulted in severe pavement cracking and rotational RSS movement. The project team excavated a test trench through the roadway to evaluate the conditions at the cracked area, and noted vertical cracks
observed at the surface were about 5 cm (2 in.) deep and were located directly behind the top layer of geogrid.

FIELD INVESTIGATION

Additional field exploration activities began in August 2004. The team drilled seven additional borings to depths of 4.1 to 14.7 m (13.5 to 48.2 ft.) below the roadway. Boring, piezometer, and inclinometer locations are shown on Figure 3. The borings were used to establish a detailed stratigraphic log of the subsurface conditions at the RSS and to collect soil samples for laboratory testing. Piezometers were installed at selected drilling locations to allow groundwater measurement.

SLOPE MONITORING

In addition to the surveying points installed during January 2004, the project team constructed two inclinometers in August 2004. The inclinometer casing was set to depths below the RSS, with the principal grooves aligned in the south direction (toward the river). Figures 1 and 2 show the readings collected at Inclinometer 2 (Sta. 1663+65), which indicated the most movement.

The inclinometer readings, coupled with rain gauge readings in the area, indicated that major slope movements occurred following significant rainfall. These rainfall events correspond to points 1 through 4 on Figures 1 and 2. Between storms, the RSS essentially didn’t move. The piezometer readings were consistently below the river water elevation, even after significant storms. The RSS movement appears to be rotational, with the RSS behaving as designed – as a reinforced block. About one month after installing and reading the inclinometers, the geotechnical engineer recommended removing the top five feet of soil behind the RSS to unload the slope.

FIG. 3: Boring Location Plan
and mitigate further movement. Survey data indicated movements slowed considerably after the top 1.5 m (5 ft.) of the slope was removed (the inclinometers were destroyed during this removal). The slope moved significantly to the south towards the river between late September and early October. The maximum cumulative displacement measured at the top of the inclinometers was approximately 8.9 cm (3.5 in.) at IN-2, and a clear failure surface was apparent just beneath the bottom geogrid of the RSS.

**BACK ANALYSIS**

The additional subsurface explorations confirmed the interpretation made in 2002, although materials encountered below the RSS appeared to be either old fill or colluvium (CL and SM in Figure 4). After advancing the borings on site, establishing the geologic stratigraphy and groundwater conditions, the authors completed computer simulated slope stability (sensitivity) analysis to gain insight regarding the RSS failure mechanism(s) and remedial strategies.

The first part of the analysis involved estimating the reason for RSS movement. Readings from the inclinometers suggested movement just below the slope within a silty sand (SM) layer. These movements corresponded to periods of heavy precipitation and therefore, we hypothesized that water pressures behind the RSS...
and/or uplift water pressures beneath the slope were prompting the slope to move towards Rio Hondo. We considered circular failures with shearing behind or through the RSS reinforcement zone and through the soil beneath the RSS. We also evaluated block-type failure scenarios. In each of the analyses, we allowed the computer program to consider only those surfaces that would pass through the zone of shearing as recorded in the inclinometers. We established that when water pressures were significantly increased and translational failures were modeled, the predicted safety factors approached one. When circular-type failures were modeled, the safety factors were greater than one, which suggested translational sliding of the RSS was more likely than a deep-seated circular failure. Our analysis concluded the RSS distress was the result of peak flows and saturation during heavy and prolonged rainfall that developed excess water pressure at the rear of the RSS.

**SOURCES OF WATER INFILTRATION**

Based on the sensitivity analysis, the slope as constructed should have been stable unless excess pore water pressures developed behind the RSS backfill. We reviewed the site topographic plans and as-built information and identified the following possible sources of water:

- Rapid river water rise during storms
- Surface runoff infiltration
- Subsurface infiltration from the north side of the roadway, whether from fractures in the bedrock or infiltration from the drainage ditch
- Possible subsurface features from unknown drainage features that were hidden by past construction
- Previous culverts in the area were to have been removed during previous construction, although as-built plans indicated at least one culvert may not have been removed (a note to remove the culvert was crossed-out on the as-built plans)

**REPAIR AND RECONSTRUCTION**

Our engineering evaluation provided us with several potential remediation strategies. After discussing various scenarios with the project team and considering the constructability of the possible remediation strategies, we reached the following conclusions:

- The inclinometer readings showed the correlation of slope movement to significant rainfall events.
- Movement of the RSS was likely because of an increase of water pressure behind the RSS.
- The origin of the water pressure was not the result of water level rise in the Rio Hondo to flood level.

Based on our engineering evaluations and conclusions, and a minimum factor of safety of 1.5, we developed reconstruction recommendations as shown graphically on Figure 5.
Figure 6 shows the profile of the reconstructed RSS showing the ultimate bedrock surface and the fill section beneath the RSS. Figure 7 presents a typical as-built cross-section of the repair, with the original recommendations shaded back. During excavation, we observed about 0.6 to 0.9 m (2 to 3 ft.) of old fill overlying a layer of roots and 0.3 to 0.6 m (1 to 2 ft.) of silty fine sand immediately above bedrock. Both layers were dark gray to dark brown and contained significant quantities of organics. The old fill was recognizable as fill because of the presence of small wood fragments and other man-made debris. The underlying silty sand appeared to be alluvium because of its relatively homogenous clean sandy texture. It appears that this segment of the original road embankment involved placing fill directly over alluvium and river deposits on the north side of the Hondo River (to construct the south side of the embankment), which resulted in a slightly straightened riverbank in this area. This fill was apparently placed during the original road construction in the 1930’s.

The contractor (SBC) excavated about 6 m (20 ft.) long segments to bedrock to create a keyway and to remove unsuitable material below the embankment. SBC lined the back and sides of the keyway excavation with filter fabric to reduce the potential for piping of fines from the native, finer-grained materials into the rock fill.
Each keyway segment was backfilled with angular rockfill [typically greater than 0.6 m (2 ft.) size] to protect against undermining and erosion during peak river flows. Another 0.6 m (2 ft.) of smaller rockfill 15 cm to 0.6 m (6 in. to 2 ft.) size was placed over the large rockfill, followed by approximately a 0.3 m (1 ft.) thick layer of 1.9 cm (¾ in.) aggregate base (AB) compacted into the rock mass. The AB layer was smoothed to form a foundation for the new RSS, and SBC used filter fabric to separate the AB from the RSS fill.

On the back of the excavation, SBC placed a geocomposite drain fabric that extended vertically from just below the existing pavement down to the smaller rockfill layer. Once the drain fabric was in place, SBC reconstructed the RSS with a wire basket facing at a ½:1 stepped slope.

1664 CULVERT

During reconstruction of the RSS, an existing culvert was exposed at Sta. 1664+08 (see Photo 2). The culvert consisted of a 0.6 m (24 in.) pipe that extended from 7.9 m (26 ft.) north to 2.1 m (7 ft.) south of the US 70 centerline. The project plans from the 1930’s show the location of the culvert. A small swale is visible at the top of the cut slope along the north side of the highway adjacent to the old culvert location. Seepage had been noted in the Rio Hondo riverbank at about this location when the slope distress was
noted in August 2004. US 70 was widened in the late 1980’s and the 1988 plans showed a culvert to be removed at about Sta. 1664. However, the construction note is crossed off of the as-built plan and no other information is shown regarding the disposition of the culvert. Based on the findings during reconstruction of the RSS, the culvert had not been removed and was likely a significant source of water pressure behind the RSS. SBC abandoned the culvert with grout during reconstruction of the RSS.

DISPUTE RESOLUTION

Our team concluded the cause of the RSS failure were lateral seepage pressure and unsuitable material beneath the old fill. The presence of excess groundwater pressures and unsuitable materials deep below the previous toe of slope were not anticipated at the time the project was designed. SBC therefore submitted a differing site conditions change order to recoup the cost of the RSS reconstruction. When the claim was rejected, SBC filed a dispute with the project’s Dispute Resolution Board (DRB). A formal hearing was held to resolve the dispute that consisted of 30 minute presentations by each side (SBC and NMDOT), followed by questions from the Board. The parties were given 1 hour to prepare rebuttals, which were then presented to the Board. The Board conferred and reached their decision within about 2 hours after the final presentations.

The DRB found that the geotechnical investigation and design were appropriate and performed within the standard of care. They agreed that unsuitable materials should not have been present beneath the existing fill, and the presence of such unsuitable materials was the responsibility of the DOT. NMDOT contended during their presentation the 1664 culvert would have been crushed at the uphill side, and could not have been the cause of the water pressure behind the RSS. Because SBC did not fully expose the uphill end of the culvert, there was no proof that the culvert was indeed the culprit in causing the excess water pressures. The DRB concluded that control of groundwater was the responsibility of the contractor and denied that portion of the change order. The final result was SBC was reimbursed for about half the cost of repairing the RSS.

ACKNOWLEDGEMENTS

This work was performed while the authors were employed with Kleinfelder, Inc. Kleinfelder was a subconsultant to URS, the lead designer on the project under contract to SBC. We appreciate URS’ and Kleinfelder’s consent to present this paper. The graphics and photos presented were from the studies and reports prepared by Kleinfelder. Thanks to Sierra Blanca Constructors (a Joint Venture of Granite Construction Company, Joint Venture Sponsor; James Hamilton Construction Co., and Sundt Construction Inc.) for allowing us to share this information with the geotechnical community. We also thank Robert A. Meyers, PE, NMDOT State Materials Engineer and Gary Shubert, PE, District Engineer, NMDOT District 2.