River Road Rubble

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Motorists out for a drive along the scenic Missouri River Valley on a warm Sunday afternoon last December encountered an unexpected roadblock: thousands of tons of sediment resting on a busy thoroughfare.

Thankfully no one was injured, no vehicles were damaged, and the roadway itself did not shift. But the collapse caused the closure of River Road between Wilderness Cove Road and Sandy River Drive for eight days at the end of last year (December 22-30, 2019) and again for two days this spring (March 3-4, 2020) as material continued to crumble off the scarp onto the roadway. River Road is the only route north and south along the eastern Missouri River Valley, and to drive from one side of the landslide to the other required a 20- to 25-minute detour through north Bismarck. The Burleigh County Highway Department's early estimates for the cost of remediation were in the range of one million dollars.

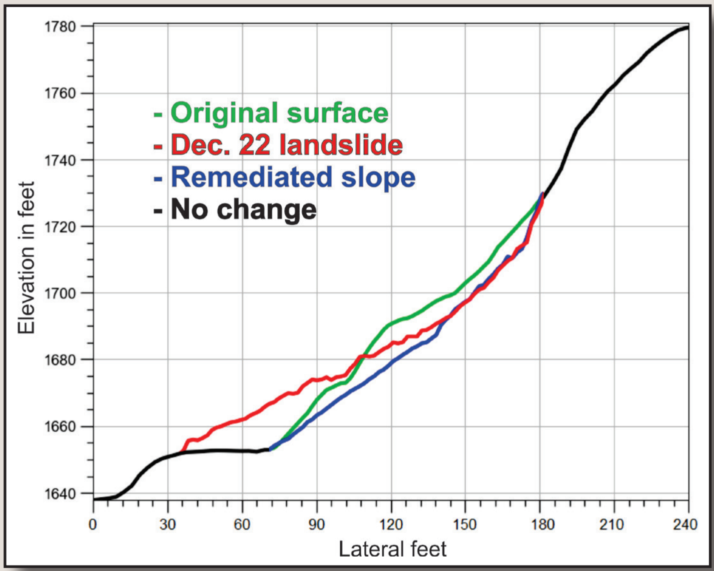

Figure 1. The changes to the slope are shown on topographic profiles through the center of the slide area. Profiles were extracted from 2009 LiDAR data (green) and NDGS drone photogrammetry immediately after the collapse (red) and after the failed material was removed (blue).

Slope failures are common in North Dakota, especially along the walls of major river valleys (Murphy, 2017, Moxness, 2019). To date, the North Dakota Geological Survey (NDGS) has identified over 27,000 landslides across the state. Most of these are relatively slow-moving slumps and areas of incremental creep that quietly undermine building foundations, roadways, and utilities when they intersect with infrastructure. Rapid mass movement events, like the River Road slide, are less common in North Dakota but are generally associated with periods of increased rainfall. Establishing direct cause-and-effect relationships surrounding the timing of these landslides in North Dakota is difficult in part because we see them in retrospect, often thousands of years after the fact. Since most new slope failures occur in rural areas and are relatively inconsequential, their triggers and development aren't directly observed. Because of its proximity to Bismarck, the collapse onto River Road offered an opportunity for NDGS geologists to collect multiple datasets quickly and easily.

In order to elevate the roadway above the Missouri River floodplain, River Road was constructed on the base of the valley wall (fig. 1). At points this required cutting into the base of the slope. Whether via natural erosion or human construction, sediment removal from the toe of a slope removes support for the overlying material and often triggers failure, especially when it involves weak sedimentary units. The slope in the Bismarck area is predominantly comprised of poorly cemented mudstone, siltstone, and sandstone of the Cannonball Formation. The mudstones contain appreciable shrink-swell clays such as montmorillonite and illite (Fenner, 1974), which destabilize slopes

Figure 2. Groundwater seeping out of the base of the remediated hillslope along River Road in June of 2020. White-colored alkali minerals show where groundwater reaches the surface and evaporates. This flow was likely a significant factor in the collapse of the slope.

as they expand and contract during cycles of wetting and drying. Groundwater moves through zones that contain higher amounts of sand and silt, which can reduce the friction and cohesion of the sediment. It can also destabilize a slope as it adds weight and exacerbates frost wedging if the surface experiences freeze-thaw cycles. Groundwater seepage is readily apparent along the base of River Road (fig. 2). 2019 was the wettest year in Bismarck since 1876 (NWS, 2020), although this area has a history of slope failure even without record precipitation. Older landslides are present to the north and south of this locality along the Missouri River valley wall, including previous movement in the same spot (note the existing scarp in 2009; fig. 3A).

The NDGS has recently started using drone-based photogrammetry to produce on-demand three-dimensional digital surface models (Maike and Moxness, 2020). The most exciting application of this modeling capability is in detecting and quantifying changes to the ground surface. Identifying movement no longer requires a visual inspection between two photographs; the digital surfaces, captured at different times, can be overlain on each other and subtracted to produce a differential elevation map. Fast-moving landslides are great modeling subjects because the movement visualizes well, and the engineering data is often pertinent. Ideally, a slope would be captured in high-resolution with the drone before it failed. This, of course, is not exactly realistic since predicting which slopes are about to fail is a low-probability exercise, but a LiDAR elevation dataset, collected over the last decade across the state, at least offers a (comparatively) coarse pre-collapse model for any new landslide activity (fig. 3A). The best opportunity to digitally capture the details of a landslide event is to catch one “in the act” with drone imagery.

NDGS geologists were able to collect 3D photogrammetric data within three hours of the initial collapse on Dec. 22 (figs. 3B & 4A). At the time, there were questions about whether the main slide body would continue to settle and if additional failure of the

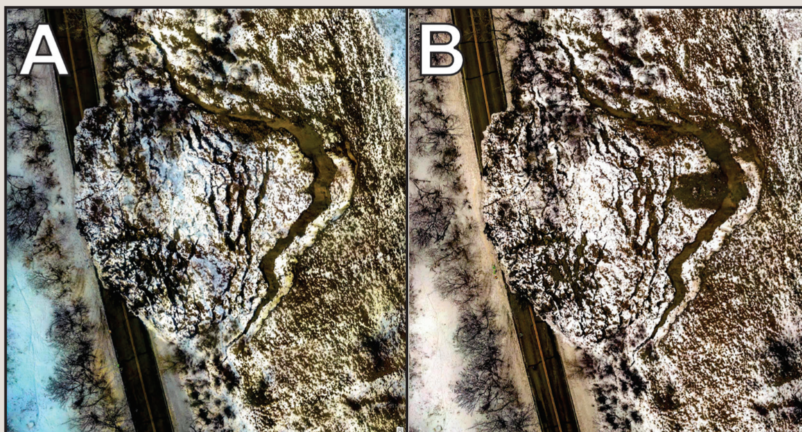

Figure 4. Orthophotos taken three hours after the initial collapse on December 22 (A) and two days later on December 24 (B). A digital comparison of these images showed the slide was stable aside from a small topple off the scarp.

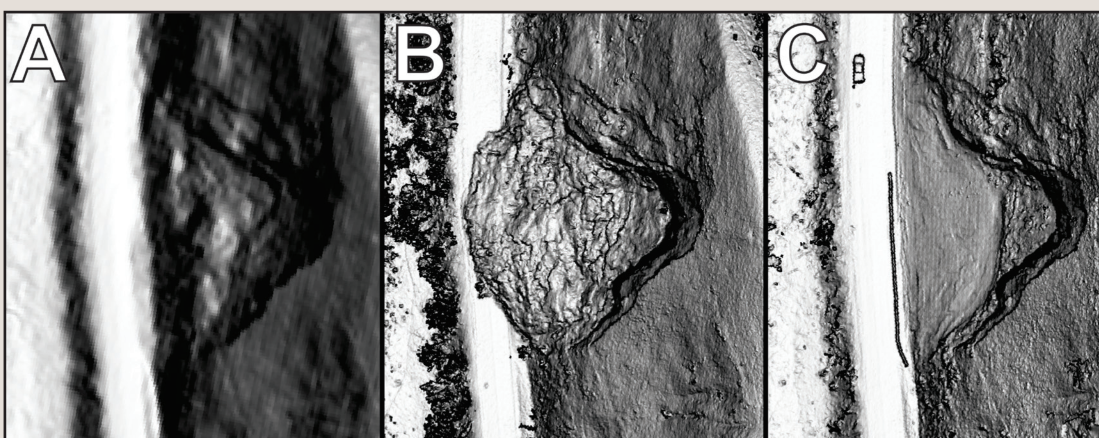

Figure 3. Hillshade models of the River Road landslide area produced with airborne LiDAR collected in May 2009 (A) and NDGS drone-based photogrammetric models taken immediately after road closures on December 22, 2019 (B) and March 4, 2020 (C).

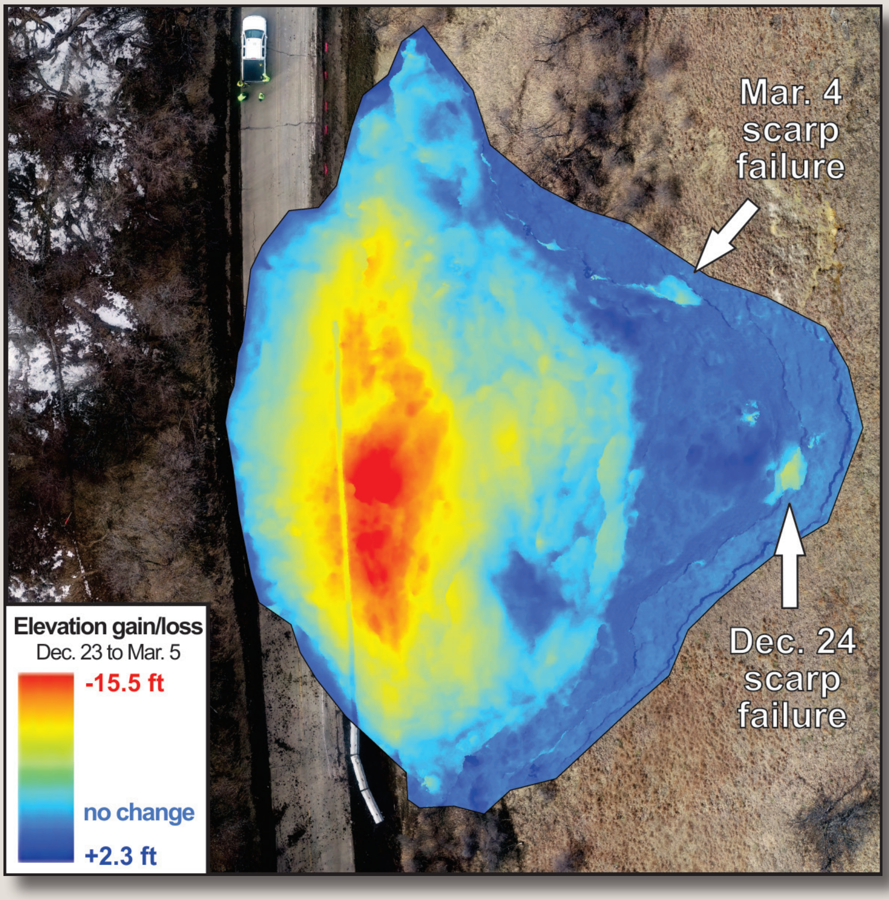

Figure 5. A map showing the elevation difference between the initial landslide (December 22, 2019) and the slope after it was remediated and closed for a second time (March 4, 2020) (models B and C in figure 3).

slope was imminent. The NDGS imaged the slide again two days later to monitor for additional movement. The only change was a small topple off the scarp visible in both the orthophotos (fig. 4B) and the differential elevation map (fig. 5). The Burleigh County Highway Department began remediation on Dec. 26, removing several thousand tons of material and resloping the hillside as far as they could safely do so. As spring arrived and material thawed, debris began to roll onto the roadway, and it was closed again on March 3. The NDGS flew the site again on March 4 (fig. 3C), and the origin of the new collapsed material was again easily visible on the differential elevation map. Little additional debris fell, and the roadway reopened that day with jersey barriers installed to prevent smaller collapses from reaching the driving lanes.

Although the drone imagery did not capture any substantial additional failures at this site, there was also an opportunity to compare its volumetric calculations to real-world figures. The photogrammetric model estimates 3,480 cubic yards (2,660 cubic meters) of material was removed from the roadway and slope, with a maximum depth of about 15.5 feet (4.7 meters). This is about 27% less than the actual amount trucked away estimated by the Burleigh County Highway Department (4,790 cubic yards / 3,360 cubic meters), suggesting a reasonable compaction ratio for the mudstone and siltstone in the slide as it became loose material upon removal.

River Road is a textbook example of how oftentimes it’s necessary to funnel highways and other infrastructure along some of the state’s steepest slopes. Most of these instances avoid major issues with slope stabilization, but sometimes unique factors of lithology, climate, and groundwater flow converge on an oversteepened slope to create an expensive and inconvenient roadblock. The NDGS continues to quantify these events, in ever-increasing detail, to add to a growing catalog of knowledge on geohazard assessment, avoidance and mitigation in North Dakota.

References

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