



Evaluation of Geotechnical Alternatives for the Navajo Loop Trail, Bryce Canyon National Park, Utah

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INTRODUCTION

During the winter of 2004-2005, record setting precipitation in southern Utah initiated landsliding, debris flows and erosion related damage to the trail system at Bryce Canyon National Park. The Park requested GRD technical assistance by providing a scope, feasibility and recommendations for stabilizing and managing the Navajo Loop Trail off Sunrise Point at Bryce Canyon. Consequently, this report contains both site-specific evaluations and remediation alternatives.

SUMMARY

Based on site visits and discussions with park staff, GRD developed a range of alternatives for managing the Navajo Loop Trail at Bryce Canyon National park. Recommendations range from very detailed engineering designs such as reinforced wall systems for containment of landslides to basic trail design principles such as rolling grade dips. The Park has the choice to implement the assorted recommendations individually or as comprehensive alternatives for an entire trail. In addition to trail design and repair alternatives, this report also presents recommendations for undertaking the development of a park-wide trail management plan.

DISCUSSION

The Bryce Canyon landscape is a result of geologic processes combined with climate and topography. A lack of homogeneity in the rock types, bedrock jointing and tectonic faulting are geologic factors that helped to form the Park's unique landscape. Precipitation, frequent freeze-thaw cycles and torrential summer rains are the climatic factors driving erosion. The

amphitheaters that make up Bryce Canyon are located on the eastern rim of an escarpment that slopes to the west. Flows move to the east, away from the amphitheaters, resulting in rim retreat to the west. This results in amphitheaters enlarging and becoming more scalloped. In addition, oversteepened slopes trigger mass wasting in the form of rock falls and landslides. All of these factors come together to produce some of the most spectacular geologic features on earth.

Protection of the unique geologic features is one of the principal management issues at Bryce Canyon. Since the Park's landscape is highly dynamic, change is often noticeable within a human life span. The erosion processes that make the park so spectacular also produce difficult management challenges. Human modification to the landscape has altered geomorphic responses in the system. One of the modifications to the landscape is the trail system.

In 1924, Bryce Canyon National Park was established with most of the park trails being constructed by 1931. In the mid-1930's, the Civilian Conservation Corps (CCC) upgraded and repaired much of the trail system. It is understandable that many of the trails are currently in a degraded state since Bryce Canyon has such dynamic erosion processes and many of the trails are over 70 years old. An additional stressor to the trail system is the fact that the park receives as many as 1.5 million visitors a year, the vast majority of which limit their use to only a couple of trails. Most visitors choose to hike the Navajo Loop Trail and more specifically, the segment of the trail referred to as Wall Street.

The Navajo Loop Trail begins at Sunset Point and descends down below the rim and into a slot canyon known as Wall Street. At the end of Wall Street, the trail has descended over 500 feet in less than 1/2 mile. One of the attractions of the Navajo Loop Trail is that it allows park visitors to hike among spectacular geologic features. Unfortunately, many of these features are formed from processes which can sometimes produce hazardous conditions to the visitor.

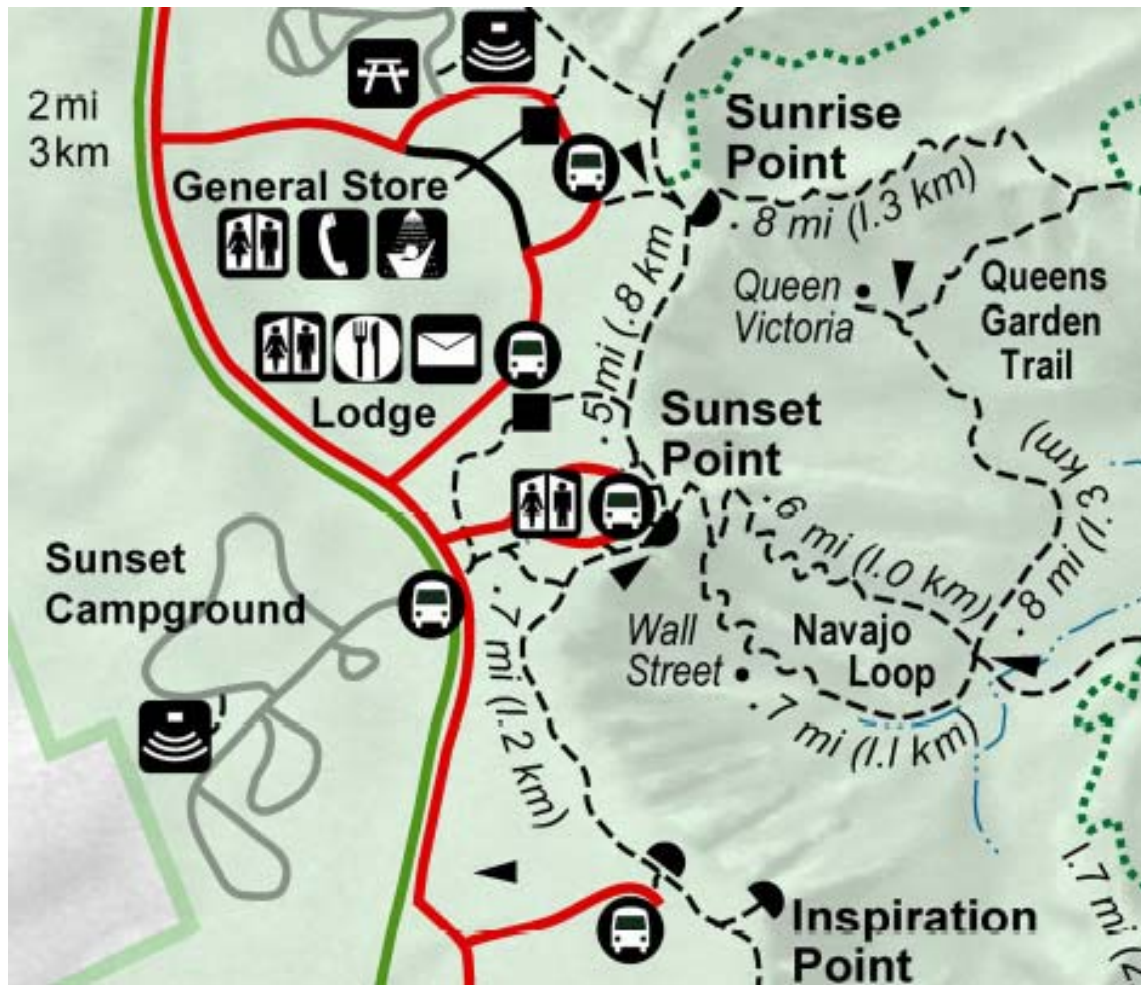


Figure 1. Trail Map.

Climate is the primary driver behind geologic hazards at Bryce Canyon. The transport of material on the amphitheater slopes is seasonally controlled. Extreme mechanical weathering from freeze-thaw action during the winter months accounts for most of the slope debris to gullies. Summer rainfall, often in the form of monsoon rains, flushes the debris from the gullies. In times of climatic extremes such as drought, heavy snow pack or extreme rainstorms, the erosion cycles at Bryce Canyon can be accelerated. In times of drought, excess debris builds up in the gullies and in the event of rainstorms or heavy snow pack runoff, the amount of material flushed has increased substantially.

Bryce Canyon National Park experienced an exceptionally wet winter in 2004-2005. The snow pack and rainfall exceeded average rainfall amounts. As a result of excessive rainfall and snow pack melt, the park experienced rock falls, landslides, accelerated erosion on the slopes and debris flows. Many park trails deteriorated under the conditions with the Navajo Loop Trail, in particular, suffering some of the most extensive damage.

At the beginning of the Navajo Loop Trail at Sunset Point, the trail is full bench construction. This has produced an exposed rock cut that is highly fractured and prone to regular rock fall. Rocks regularly fall off the face and litter the trail. During spring thaws and heavy rain events, the amount of rock debris coming from the face is increased. This produces a potential hazard to anyone hiking the Navajo Loop Trail. In addition, Park maintenance staff periodically removes fallen material from the rock cut, which is a hazardous duty.



Figure 2. The rockcut and rockfall hazards at the top of the Navajo Loop Trail.

Just below the rock cut portion of the trail, the slope has suffered a major landslide failure. The landslide has obliterated an entire segment of the return portion (past Thor’s Hammer) of the Navajo Loop Trail. An obvious indication of slope instability at this site is the loss of the trail tread. Indicators are present that determine there were signs that this site was more than just a small shallow failure and that it was destined to fail. The Aspen trees are one indicator, because they thrive in disturbed settings. Aspen have the ability to grow rapidly enough to keep up with the rate of movement of the slope. In addition, the aspens are “pistol butted” or growing in a curved upward motion. This is due to the adjustment they are making to keep up with slope movement. The slope is also hummocky, and fractures and slide scarps are apparent; all are surface expressions of deep seated instability in the slope.



Figure 3. The landslide area below the asphalt section on the Navajo Loop Trail.



Figure 4a. The landslide with tension cracks, scarps and “pistol butted” aspen trees on the slope.



Figure 4b. The landslide annotated to show the tension cracks, scarps and “pistol butted” aspen trees on the slope highlighted in red.

The series of switchbacks leading into Wall Street suffered heavy damage during the winter of 04-05. The damage from heavy snow and runoff resulted in the collapse of CCC era retaining

walls, loss of trail tread, gullies and deposition of large amounts of sediment on the trail. In addition, this portion of the trail is very steep with unstable footing. Many visitors to the park are not experienced hikers, do not wear the proper foot attire and often do not realize the hazards of navigating this segment of trail.



Figure 5. Switchbacks above Wall Street.

In addition to the trail damage, geohazards such as rockfalls and debris flow potential was exacerbated. Looking upslope and to the right at the entrance to Wall Street, there is a large gully that contains large amounts of loose rock and sediment. There is potential for the material to come down in a massive pulse such as a debris flow or a rockslide. This would occur during heavy snowmelt runoff or summer monsoons. Wall Street is a narrow slot canyon and it is the only outlet for runoff from the slope containing the switchbacks and the previously discussed gully. With this in mind, scour marks are apparent on the walls of the canyon. This is indicative of past events during which rocks and debris flowed through Wall Street.



Figure 6a. Slope above Wall Street containing large amounts of loose debris.



Figure 6b. Slope above Wall Street containing large amounts of loose debris.

After exiting Wall Street, an unnamed wash is the primary drainage for the entire amphitheater that extends from Sunset point to Inspiration Point. In the past year, the wash transported large amounts of sediment and experienced substantial geomorphic change. In freshly exposed channel banks there is evidence of heavy runoff from past flood events.

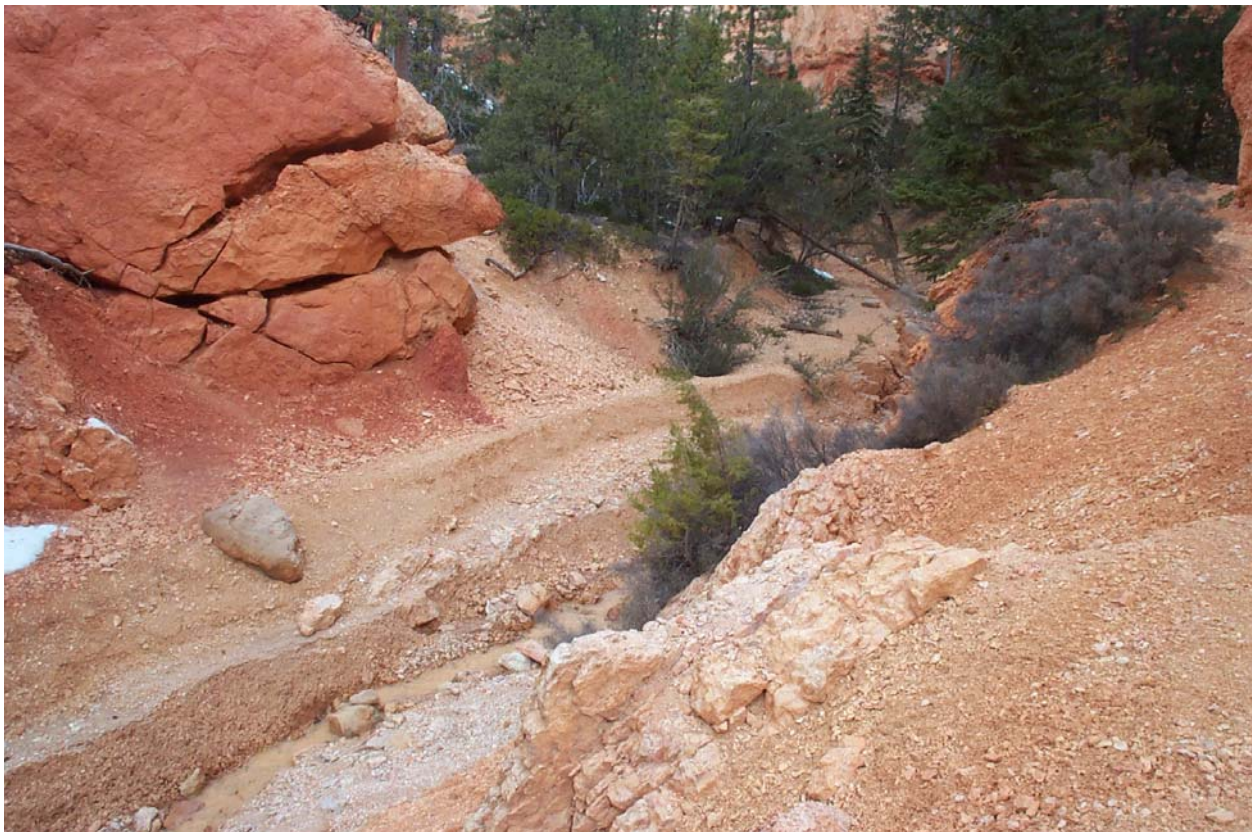


Figure 7. The wash just below Wall Street. It demonstrates sediment loading and channel morphology, after high flows during the winter.

Recommendations

The following potential recommendations are taken from the context of geomorphic processes and do not factor in all of the socio-political aspects of maintaining a trails system in the National Park Service. GRD recommends that the Park consider this report and the geologic implications when choosing one of the following recommendations.

Trail Closure

By permanently closing the trail, natural reclamation of the trail would occur. Over time, the high rates of erosion found at Bryce Canyon would quickly reclaim the hillslope and within a few years, the trail would only be vaguely visible. In the event of successive years of heavy precipitation, this process would occur at an even more rapid rate. Asphalt, rock retaining walls and fencing would be the only remaining remnants of a trail system and could easily be removed to allow natural hillslope and gully processes to reclaim the site naturally. This alternative would allow the site topography and hydrology to recover without active site intervention.

Trail Relocation

This option is not economically viable when considering that the trail has been moved on a couple of occasions in response to failures elsewhere. Park and GRD staff attempted to find an alternative location, but all others were even more hazardous and/or damaging to resources than the existing trail location.

Reroute of Navajo Loop Trail

Due to the cost and effort required to stabilize the landslide below the rockcut/asphalt section of trail, the Park may want to reroute the Navajo Loop Trail. The section of trail near Thor's Hammer at the junction with the Queen's Connecting Trail could be removed and would lengthen the trail from 1.1 to 3.0 miles. This option would: 1) remove the need to stabilize the landslide; 2) eliminate a very unstable segment of trail and thus remove significant hazards to park visitors; and 3) reduce maintenance costs.

Wall Street Stair System

The Park may want to consider constructing a stair system from the top of the switchbacks to the entrance of Wall Street. Stairs would eliminate the need for constant maintenance on the switchbacks down to Wall Street and reduce the steep trail hazards to visitors. The use of stairs is favorable because it allows natural slope processes to go mostly unimpeded and without constant maintenance. The drawback to this alternative is that the stair system would be more expensive in the short term. It would require regular inspection and would be a conspicuous structure that might not be aesthetically compatible with the natural surroundings. Commercial stair systems have been successfully implemented in other units of the National Park Service.

GRD can assist by contacting other park service maintenance personnel and experienced commercial stair suppliers.

Landslide Stabilization

This alternative addresses the need to stabilize the slope failure just below the asphalt ramp at the start of the Navajo Loop Trail. One technique is to remove the loose, unstable debris down to bedrock. This would require the use of heavy equipment, possibly a crane. It would require haul costs for transporting and disposing the material offsite. This is a very costly option and has the drawback of requiring that the trail excavated into bedrock. This could possibly lead to a full bench trail with the possibility of producing another area of rockfall hazards.

Another landslide stabilization technique is the use of a retaining structure. This would only require minimal removal of material offsite. This option would require heavy equipment and logistical hazards such as working on very steep slopes in an unstable environment. Retaining wall systems such as those produced by Hilfiker Retaining Walls have been very effective at stabilizing slide prone areas. The costs vary depending on the chosen system and logistical issues. More information on Hilfiker systems can be found at <http://www.hilfiker.com>.

Retaining structures on the rim of the amphitheater just below Sunset Point might be aesthetically incompatible with the surrounding environment. Some of the newer retaining systems allow for the use of facing material such as stone. Such a wall could be constructed to match the CCC era stone retaining walls.

Rock Fall Hazard Mitigation

The rock fall hazard found at the beginning of the Navajo Loop Trail needs attention. Maintenance staff previously have cleaned up the rock face to remove most of the hazardous material. But this activity is very dangerous and puts park staff at risk of injury or even fatality. Options such as shotcrete or wire mesh with rockbolts can be expensive and are very unsightly, but new rock fall mitigation materials can reduce visual impacts and have been used by numerous state and federal agencies. GRD staff can assist the park with making contacts with state highway agencies as well as the Federal Highway Administration for recommendations.

CCC Era Retaining Walls

The Civilian Conservation Corps (CCC) era retaining walls - utilized quite heavily on the Navajo Loop Trail - have very little structural strength. The CCC technique basically uses a stone face and backfills it with native soil. However, a more desirable and common technique used on many advanced trail systems today applies the following:

- Use large stones of at least 50 pounds.
- Inslope the foundation by removing organic material down to mineral soil. The first rocks act as an anchor. Excavate a footing that will allow for the placement of large, well anchored

rocks to form the base layer. The foundation rocks must be immobile once set into place so it is imperative to build the wall on a solid foundation.

- Use headers (a large rock used to anchor) every 4 to 6 feet and try to place it so that it extends into the bank behind the retaining wall. The wall should be insloped so that it tilts into the slope at an angle of about 2:1 but never shallower than 4:1.
- Backfill behind each layer of the wall with a layer of small rock or soil (nothing organic) to fill the spaces behind the wall. Compact the fill while it is slightly wet to prevent uneven settling. Place capstones or large flat rocks for the top layer at an outslope of approximately 5%.

Current Trail Management

As discussed earlier in this report, the park has inherited an aging trail system created at a time when trail construction techniques were rudimentary at best. Due to budget and staff limitations, the park has made every effort to maintain the trail to the highest level possible. The following suggestions are basic efforts that can often result in fewer trail problems.

Knicks:

Knicks are a semi-circular, shaved down section of trail, about 10-feet in diameter that is canted to the outside.

- The center of a knick should be outsloped at about 15%.
- To be effective, there must be lower ground next to the trail so that water will have a place to drain.
- These work best on gentle sections of trail where water tends to puddle.

Rolling Grade Dips:

Rolling grade dips are features similar to Knicks. They are outsloped depression in the tread followed by a long, gentle dirt ramp.

- The dip should be about 9 feet long.
- Create the backup ramp that fortifies the dip from the excavated soils from the dip.
- The ramp should be 10 – 20 feet from end to end and outsloped at 5%.
- The total length of the rolling grade dip varies widely depending on the steepness of the trail tread, but most are somewhere between 15 – 30 feet.
- Place rolling grade dips on a natural roll or change in trail/slope grade that can be accentuated.
- On steep trails several rolling grade dips may be necessary.
- Do not place rolling grade dips in turns.

Waterbars:

Waterbars are the installation of rock, rubber or wood barriers across a trail. They are heavily used on many trail systems. It is recommended that waterbars not be used as a means of controlling erosion at the park. They are an ineffective way to divert water. It is recommended that knicks and rolling grade dips be used instead of waterbars. Reasons for not using them are:

- Require frequent maintenance

- Easily clog with sediment
- Heavy water flows wash over the top
- Visitors tend to go around bars, widening the tread.

Wet Sites:

- Outslope trail at these locations
- Build a knick to enhance drainage
- Retrofit grade reversals or other water-diversion techniques into the trail

Trail Widening:

- If an obstacle is forcing users off the trail, remove obstacle and/or corral users on the trail.
- If wet trails are the problem, see previous section

Social Trails:

- Reroute trail to obliterate sightlines to out of bounds areas.
- Revegetate and block off disturbed areas.

Eroded Trail:

- If a trail is located on the fall-line and is steeper than a 10% grade, reroute and incorporate a rolling contour design and full bench construction. Meanders incorporated into a trail allow for outlets of runoff.
- If a trail lacks outslope and is not allowing for water to sheet off, restore the outslope. A slight tilt (5% grade) will encourage water to sheet across and off of the trail instead of funneling down the center. Since trails lose their outslope over time, make sure that grade reversals are incorporated into a trail as a defense against water. Remove water-trapping berms on the trail.
- If a trail lacks grade reversals/rolling dips, retrofit the trail if possible.

Deberming and Outsloping:

- Scrap mounded dirt off the trail tread edge to allow for drainage off the trail tread.
- Establish or reestablish a 5% outslope

Trail Management Plan

GRD recommends that the park develop a trail management plan. The plan would act as a guide for implementing and maintaining the trails in a systematic way. Besides the obvious needs for maintenance and visitor safety, the plan would act as a manual for visitor management. The plan should address and determine some of the more esoteric issues. These range from the use or need of “one-way” trails, Ranger guided only trails and the development of a warning system and recognition of the signs of hazardous conditions on trail. It could also deal with the monitoring of visitor impacts and put into place a system for monitoring erosion rates and photo documentation of trail changes.

CONCLUSION

Most of the major slope stability and erosion issues occurring on the Navajo Loop Trail during the winter of 2004-2005 were normal geomorphic responses to heavy precipitation events. Alternatives that most closely approximate naturally functioning conditions are those most likely to be effective in the long-term. The Park could implement any of the recommendations as individual actions or as a comprehensive plan. The Park should develop and analyze several alternatives with the individual actions based not only on cost but also visitor safety, level of maintenance, natural resource impacts and law enforcement concerns.

If you have questions about this report, the alternatives or recommendations, please contact me at telephone number 303.969.2351, or via email at deanna_greco@nps.gov.

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