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Rockfall Risk Evaluation

High Angle Technologies Shares Their Experience

Cover Photos: Mark Gray

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If a rock falls in a forest and no one is there to get hurt, did it fall? If a rock falls and there is no one there to be injured or killed, or property to be damaged, then there is no hazard. On the other hand, if there is a large boulder sitting above a building filled with thousands of people, and the boulder is locked into place so it cannot fall, there is still no hazard.

When it comes to calculating rockfall risks, some risk exposure systems deal primarily with risk potential, over-looking lots of risk factors in the process. There are many formulae available to help us determine how close a rock is to falling over, which work well in a controlled environment, but there are many variables in the natural world.

At High Angle Technologies, we think the best rockfall analysis is done by skilled engineers, with the help of tools such as computer programs. A machine can't be accurate without the aid of an expert to run it and input the right information, but with the aid of these programs, a skilled geotechnical engineer can make "magic" happen. We want to share some of our experiences with rockfall analysis - so read on to learn some of our approaches to risk evaluation and to hear how we applied these techniques to a project in Utah.

Determining Risk Exposure: Basic Conditions & Calculations

At High Angle Technologies, we use a simple, but effective rockfall evaluation equation that goes like this:

risk potential x risk factor = risk exposure	
where	***risk potential*** = possibility of a rock falling ***risk factor*** = amount of damage that will be done to life or property
therefore	***risk exposure*** = number that shows you how close you, or your property are to being hit by a falling rock

Let's look at each part of the equation individually.

1. Determine *risk potential*.

The ***risk potential*** component is the foundation of our equation. If we're looking at a boulder, at quick glance it may *look* like it's close to falling, but how close to falling is it? To assess it we would look at: center of mass, fracture patterns, exposure to frost wedging, climate, type of rock, free running water (erosion), angle of the slope, shape of the rock, wind, nearby blasting, possible earthquake activity - we want to evaluate anything that will affect the possibility of the rock falling.

Ultimately, we come up with the ***risk potential*** and convert it to a ***risk potential*** number between 0 and 10. 0 means it will not fall and 10 means it will absolutely fall in the time period we are looking at.

2. Determine *risk factor*.

The next number we need is our ***risk factor*** number. The ***risk factor*** represents how serious it will be if the boulder does fall. Some of the factors that affect ***risk factor*** are: the size of the rock, its velocity, its shape, if it will knock other rocks off the cliff, if there are rockfall fences installed, how many cars or people are below the rockfall area and the amount of time they spend there, how much property is in use/stored there, how expensive the property is, how easily it could be damaged, and so on. Keeping this in mind, we create a picture of how much it would cost if the boulder falls and what injuries are likely to happen, and come up with a ***risk factor*** number between of 0 to 10, with 0 meaning nothing will be damaged and no one will be hurt, and 10 meaning it could kill someone and/or possibly do serious damage to property as well.

Photo: Doug Hansen

Rock bolt failure.

Photo: Doug Hansen

Signs of a rockfall behind the Jersey barrier. This is to be the area where the contractor will store equipment and perform work.

3. Determine *risk exposure*.

On their own, ***risk potential*** or ***risk factor*** mean little. ***Risk exposure*** is the product of ***risk potential*** multiplied by the ***risk factor***. By reducing the ***risk potential*** and the ***risk factor***, we can reduce the ***risk exposure***, or possibility of being hit. The value of this system is it takes into account both sides of the equation, which is necessary to get a true picture - ***risk exposure.*** Once mitigation techniques have been installed, the numbers can be run again to calculate the new ***risk exposure***. Generally speaking, a ***risk exposure*** number of 20 or less is reasonable. Anything over 50 is a serious risk that needs to be changed. We can use the ***risk exposure*** number to prioritize multiple hazards, or multiple areas with multiple hazards and determine the best way to use our budget dollars.

Determining Risk Exposure: Basic Conditions & Calculations

For projects with multiple hazards and multiple evaluators, we need a more complex system to evaluate and rate ***risk exposures*** for individual hazards that everyone can agree on. We can then prioritize the hazards according to the ***risk exposure*** formula shown above. Using this more complex system, multiple evaluators can assess and agree on both ***risk potentials*** and ***risk factors***.

1. Establish a group of evaluators.

This group can consist of two or more evaluators: geotechnical engineers, geologists, hazard control professionals or back country rangers - anyone who has experience and skills necessary to evaluate the natural process and the likelihood of rocks falling. Using this system we can have groups of evaluators evaluate ***risk potential*** and ***risk factors***. If all the participants are experienced in this area, the outcome of the consensus can be quite accurate. It is probably better to exclude a person with limited knowledge or experience, although these individuals can be very useful in giving input and ideas and collecting information.

2. Determine the probability of event or *risk potential.*

Brief the evaluators on the process and ensure you agree on a common set of criteria for determining risk potential. Enter this information on a Hazard Consensus Form using either the standard (range of 0 to 10) or the relative method (choose a letter - A to I, each represents a

Tension cracks, Upper Stillwater Dam, Area 1, north end. Photo: Doug Hansen

Hazards	Evaluator 1	Evaluator 2	Evaluator 3	Hazards (average)
Hazard #1:	30 *	A (27.27) *	1	22.4 % (2nd most likely)
Hazard #2:	10	I (3.09)	2.5	12.6 % (3rd most likely)
Hazard #3:	50	G (9.09)	3	29.7 % (1st most likely)
Hazard #4:	6	E (15.15)	1.5	12.0 % (4th most likely)
Hazard #5:	3	C (21.21)	1	11.4 % (6th most likely)
No event:	1	B (24.24)	1	11.75 % (5th most likely)
Total:	100	(100.00)	10	100.00 %

* Risk Potential must be normalized to range from 1 - 10. These are example numbers - actual outcome totals would likely be different.

range of likelihoods, for example: A = the event will happen in the given time period, or F = there is not a very high chance of the event occurring during the given time period, or E = there is a 50-50 chance the event could happen). If a relative method is used, each range must be assigned a numerical value before averaging or multiplying to get the ***risk exposure***.

3. Enter the evaluator's information into a spreadsheet and process the information.

This will give a consensus of the group as the likelihood of the event or ***risk potential***. Here's an example of this part of the process assuming there are five hazards to be rated, with three evaluators.

4. Determine the *risk exposure.* In this step, multiply your ***risk potential*** by your ***risk factor*** to determine the product - your ***risk exposure*** number.

Risk exposure is what we are concerned with - the risks and how they stack up. Once you have a number to work with, you can use it to study the application of resources to hazard areas, or individual hazards, to see which combination actually reduces your over-all risk exposure the most, for the least amount of money. Then, once the resources have been used on the hazards, you can re-evaluate the risk exposure priority to get a new ranking to work with.

The Bottom Line:
The Impact of Risk Exposure on Your Budget

After the hazard number crunching, we move to the next step, budget number crunching - getting the most bang for your buck. If our budget is $100,000, and we have three counties with a number of hazards in each county, we would apply various techniques and methods to effectively spend our budget on minimizing the total ***risk exposure***.

For example: let's say County A, has three hazards in it: Hazard #1, a total R.E. (***risk exposure***) rating of 79, Hazard #2, a total R.E. rating of 83 and lastly, Hazard #3 has a total R.E. rating of 65, which would mean County A has a total Rockfall Risk Exposure of 227.

A simple spreadsheet program can make calculations easy, although they can also be done with a calculator.

Budget Scenario #1.

For our first try we'll spend our entire budget, $100,000, on Hazard #2 because it has the highest rating of all. The budget will pay for: scaling, and a 1,500kJ rockfall fence. This would reduce Hazard #2 from an 83 (the highest in the county) to 19, a quite reasonable number. It also gives us an area reduction of 64 points, reducing County A's risk exposure number from 227 to 163.

Budget Scenario #2.

This time we will try to bring all three hazards R.E. numbers below 50. We'll spend $30,000 to build a catch ditch below Hazard #1, which will lower its R.E. from 79 points to 33 points. Then we'll spend $60,000 on Hazard #2, to install a 1,000kJ rock fence and do some scaling, which will reduce its R.E. from 83 to 25. Last, we'll spend $10,000 on Hazard #3 for scaling and warning signs, which will reduce the R.E. from 65 to 39. This gives us a county reduction of 130 points, reducing County A's ***risk exposure*** number from 227 to only 97.

Photo: Doug Hansen

Roll of cable fence, HAT Team, Upper Stillwater Dam.

For the same amount of money we were able to get almost twice the reduction in risk exposure. This is a simplification, but it gives a general idea of the impact of rock fall analysis on your budget. By working the numbers, you can find the best way to get the most safety for the dollar.

Applying Risk Exposure Techniques

Upper Stillwater Left Abutment Staging Area Stabilization Project

The Conditions

The Upper Stillwater Dam (USD) is located in the High Uinta Mountains, in North Eastern Utah. They are one of the largest east-west mountain ranges in the United States, and are home to Kings Peak, Utah's highest mountain, at 4,124 meters high. There are over 500 lakes, and in late July and August there are plenty of mosquitoes to prove it. These mountains are a great source of water, and like gold ore, man will go to great lengths to harness and control it. This is the case with the Upper Stillwater Dam. It's located about 66 kilometers north of a small city called Duchesne, at an elevation of 2,492 meters.

The dam is built on Pre-Cambrian sandstone and argillites with nearly horizontal bedding planes. Most of the length of the dam bears on hard sandstone. Near each abutment, the dam sits on argillite, which overlies the sandstone. It's one of the largest roller compacted concrete gravity dams in the world, relying on its weight and internal strength for stability. When full, it actually bows several inches due to the water pressure.

Photo: Doug Hansen

The east side of the dam (the end at the bottom of this picture) is the area in which rockfall evaluation and mitigation are to be evaluated. The wet spots at the base of the dam are scheduled for repair.

It is about 90 meters high structurally and the hydraulic height is 56 meters. The crest is 808 meters in length and the crest width is 9 meters, with a base width of 54 meters.

Cracks are a problem when dealing with concrete - the desired objective is to control the cracking by building in such a way that the cracks don't affect strength or operational intent. This is supposed to be the case with the cracks that have developed in the Upper Stillwater Dam. Structurally, the cracks are considered to be stable, although they are disconcerting to the homeowner or camper who is down stream. A good repair job would also help prevent the loss of water flowing through the cracks in the dam. With this in mind, the Bureau of Reclamation (BOR) and the caretakers, the Central Utah Water Conservancy District (CUWCD) decided to repair the cracks. They planned to do this using a technique that hadn't been tried before – by drilling a hole about a meter or so wide, following the crack to the bottom of the dam, then fitting a special membrane across the crack and grouting it in place. The job was put to tender by the BOR. A variety of contractors bid on the job, then a contractor team was selected.

Photo: Mark Gray

Small Inconsequential leak in the lower part of the Stillwater Dam.

The Challenge

One of the biggest problems with the project is that the only work and staging area is on the east end of the dam and along the east abutment. That area is at the base of a large cliff and a high angle slope of quartzite and/or sandstone that has a serious reputation for rockfalls – it's one of the most highly fractured (short of turning into shale) areas we've ever have seen. High Angle Technologies was hired to:

i. Evaluate the risk exposure for the staging area.

ii. Determine if the aging mitigation methods need to be replaced or revamped (the face already has the lower net plated with chain link, and there is a deflector system made of chain link above that, there are also over 100 rock bolts placed in the face, some of which are no longer effective and some of which have already failed - these were installed or placed about 15-20 years ago).

iii. Set a ***risk exposure*** number that will be considered safe for the workers.

iv. Determine what method/techniques will lower the ***risk exposure*** to this safe number.

The contractor will spend close to a year working under the East Abutment Cliffs. They'll have their hands full making the repairs, and won't have the time to be distracted by falling rocks and boulders, or by worries about being injured.

Photo: Mark Gray

Placing bolts and determining the angle and bearing at which they will be installed.

Originally, this area was designed to be a public display area for visitors, with a boat ramp for small craft and an interpretive center. Unfortunately, during the building of the dam the frequency of rockfall was serious enough that the current deflector, net plating and rock bolting were installed. Because of this, the dam management decided it was too dangerous to open to the public, so it has remained closed ever since. Just below the dam on the west side there is, however, a very nice campground, maintained by the Forest Service.

Our Approach

To begin, High Angle Technolgies divided the USD Hazard Area into three sections to make them more manageable. Our rockfall evaluation team did three reports/studies before we moved forward on the project - the first was a preliminary fact finding report, the second was a report looking at each specific area in more detail and the third was an engineer's report, suggesting control designs, tactics and the costs involved. Our initial interviews and research gave us enough information to form a good game plan, and gave us an idea of how we wanted to tackle the problem. Our objectives were:

i. To confirm it was necessary for the government to invest money in rockfall control.

ii. Determine the various risk exposure areas and their risk exposure ratings.

iii. Determine what risk exposure rating was acceptable.

iv. Find out what percentage of rockfalls would cross the Jersey barriers that were acting as a limited barrier.

v. Determine if another type of barrier was used, would it provide the protection needed (the new barrier they were considering stood 1.2 meters high, was sturdier and was to be moved further from the face).

vi. Determine if there were more cost effective method(s) to control the rockfalls.

Photo: Doug Hansen

Upper Stillwater Rockfall Area (left to right): Area 1: A prominent chute with a small stream eroding it. Area 2: Near vertical, with a deflector and chain plating on lower bench. Area 3: With cliff along the top, with scree and talus on the south end (right of picture) to more near vertical rock on the north.

After looking at our interview and research results, we examined the site. Even though this provided enough information to suggest something should be done, we needed to do live, simulated rockfalls to see the extent we needed to go to. For this you need a reliable rockfall simulation program.

In our research we used both *RocFall 4.0* and CRSP (Colorado Rockfall Simulation Program). This area has been closed to the public for quite some time, so we were able to do many live rock falls to help calibrate the rock fall simulation program *RocFall 4.0*, from Rocscience. *RocFall* allowed us to use the data we had, and multiply it many times over to get the various envelopes we needed. We also used the sample data from *RocFall's* indexes and from CRSP's sample data section, then we fine-tuned that data using data we acquired during our scaling operation. We had the results from over 500 "on the face" hours spent scaling and removing small buttresses up to around 500 metric tons, so this helped to verify our initial conclusions.

Surface roughness was an important variable on this project - we had extremes on both ends of the spectrum. On the south end, or Area 3, we had talus and scree slopes, as well as near vertical cliffs. Area 2 consisted of 100 meters of near vertical cliff that was highly fractured sandstone. It was also the area where the contractor would spend the majority of their time, so the possibility of having someone or something hit was high. Our last area, Area 1, had a prominent chute with a small spring-fed stream on the south end, which was slowly eroding it away. On the north side, there was a rough, borderline, planar type failure, slowly allowing the surface boulders to move down the mountainside, similar to the snout of a glacier, with large chunks dropping regularly. Area 1 was good example of how surface roughness affects rockfall.

For these conditions, the advanced user interface in *RocFall* allowed us to work more efficiently and try many different scenarios to make sure we didn't miss anything. CRSP also proved to be a good program, allowing us to add the concept of shape to the falling rocks. In the end, using both of these programs, we were able to get an excellent assessment of risk – you need both if you're serious about what you're doing.

Our Results

In the end, we turned in our report to the BOR and they made the final determinations. We ended up scaling all three sections. We eliminated several hazards in Area 3. We had planned to stabilize a large boulder (approx. 200 ton) we named Keystone, because it appeared to be holding others in place, but due to a poor base structure we ultimately decided to bring it down under controlled circumstances, using our sequencing pneumatic and hydraulic systems. By preventing a roll we were able to break it up and have it land at the base of the cliff rather than shoot out across the dam, possibly striking buildings below. We installed one double twist section on the apron of Area 2 and we installed a stringer cable that was capable of holding several hundred tons. On this cable we hung a layer of double twist and covered it with 8mm cable netting, with 20 cm squares. We hung a deflector in Area 1 since there was no room for absorbing the force of falling boulders with a tradition ring fence, and we designed a special shock absorbing static barrier to handle up to 1,000 kJ.

Watch a Movie: Click Here

Removal of Keystone at Upper Stillwater Dam Project

Photo: Doug Hansen

Heart of Area 1, center gulley, surface roughness, planar failure.

Photo: Doug Hansen

Area 2, deflector installed.

Photo: Doug Hansen

Area 2: Cable and double twist drape.

After all was said and done, we figure under the current operating situation, Area 1 has a ***risk exposure*** rating of approximately 35. Area 2 has one of about 19, and Area 3 has one of 34. These results are good for the next five years. Every year the situation will be re-examined in the Spring and Fall, with a thorough re-examination at the end of five years, and a projected life expectancy of 15 to 25 years. When all's said and done, this is the natural environment, so despite our hard work and results we stand by, the only absolute rule is, "there are no absolutes". With the new knowledge we gained on this project, High Angle Technologies looks forward to future challenges, while continuing to keep our eyes open for new and improved methods for dealing with these complicated natural principles.

Article by High Angle Technologies prepared for
RocNews Spring 2004