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Managing Risk for Geohazard Projects from Planning Through Construction

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Geohazards in the engineering community generally refer to naturally occurring or human-induced geologic conditions that put people's lives, safety, and property at risk.

The most common geohazards impacting our transportation networks, water resources infrastructure, and public and private properties are collectively known as mass wasting events and include: landslides, rockslides, rockfalls, and debris flows.

Flash flooding, persistent heavy rain, or a single heavy rain event can lead to higher volumes of precipitation runoff and be precursors to landslides, erosion, mud/debris flows, and even rockfalls. Rockfalls are often caused by erosion of the earth around larger rocks that become loose and fall.

Projects involving potentially unstable land masses are widely recognized in infrastructure engineering as challenging due to investigation, evaluation, and mitigation complexities. Best practices constantly evolve, resulting from innovations in investigative methods and technologies, analytical and visualization software advances, and progressive construction techniques.

We identify best practices for managing risk on geohazard projects from planning through construction in the following categories:

» Risk recognition

» Investigation

» Assessment and evaluation

» Design solutions

» Quality construction

Risk Recognition

What is considered a risk? A risk can be qualified by the relationship between the probability of a geohazard event occurring and the hazard's impact resulting from the failure. Localized failures involving small volumes of rock or debris can pose significant risks in densely populated areas or along transportation corridors.

Today, many private and public agencies proactively identify, prioritize, and ultimately mitigate geohazard risks through an inventory mapping program. The data provided through a geohazard inventory allows stakeholders to decide where and how to allocate design and construction funding.

Recognition of a geohazard risk may be the difference between a preventable destructive event and a regrettable tragedy. Identification of these risks may come from a review of past site history, such as a previous failure or reoccurring localized events along a particular section of road, a site-specific study in advance of improvements or new development, or public awareness. It may also be revealed, but hopefully not during construction.

Investigation

Traditionally, pre-investigation data is collected through a detailed desktop study of geological literature, maps, and reports to gain a regional understanding of the site conditions. More recently, geographic information system sources, including light detection and ranging (lidar) surveys and orthophoto datasets, have become available to the public.

These datasets include historical and current lidar and orthophoto data, hill shade relief maps, and digital elevation models. Compiling this data into a comprehensive web-based map provides greater detail of the site and a complete base map for future field reconnaissance activities.

A geohazard mitigation strategy and design project is only as good as the data on which it is based. Field investigations must include a sufficient level of effort to collect the data required to adequately characterize and evaluate the geohazard issues and develop a comprehensive mitigation strategy.

At a minimum, field activities should include:

» Topographic survey to define slope geometry and delineate physical features.

» Detailed field reconnaissance by an experienced geologist or geotechnical engineer to record pertinent observations that may influence aspects of the design and construction.

» A collection of relevant site data, which may include rock discontinuity mapping, test borings, geotechnical instrumentation installation, and geophysical surveys.

New and emerging mapping and surveying technologies such as static, mobile, and aerial lidar scanning and digital photogrammetry allow us to collect larger volumes of accurate data over more expansive areas in less time than classical geologic methods. The collection of this data reduces the need for personnel to access the geohazard features directly in some cases, significantly reducing safety risks to personnel in the field.

Assessment and Evaluation

Geohazard assessments and evaluations are typically performed using qualitative and quantitative methods to characterize conditions at a site, model potential hazard behavior, and determine where mitigation measures are needed.

Qualitative assessments systematically classify sites into relative risk categories from low- to high-risk based on a predetermined set of criteria typically related to the likelihood of a hazard occurring and the potential consequences to human life and/or infrastructure if it happens. These assessments are primarily based on engineering judgment from site observations and history. They should be performed by experienced professionals who understand the terrain's soil and rock mechanics and geometric relationships.

Quantitative assessments are often performed after the initial qualitative assessments prioritize and identify the highest risk hazard for mitigation. These detailed assessments may include kinematic analyses of rock discontinuities, limit equilibrium analyses of soil or rock slopes, and rockfall simulations.

Specialized software is utilized in these assessments that result in the development of parameters to be used in engineering design, such as the identification of problematic new cut slope orientations or gradients, loads that need to be resisted for slope or block stability, or rockfall bounce heights and energy values for the design of a rockfall barrier.

Often new or existing geotechnical instrumentation data is also included in the evaluation process to aid in understanding the geohazard, which may consist of installing and monitoring the following instrumentation:

» Piezometers to evaluate groundwater conditions.

» Tiltmeters, extensometers, or inclinometers to evaluate slope or rock block movements.

» Strain gauges to evaluate how geohazards are affecting structures.

The geotechnical instrumentation is tailored to the specific project needs, ranging from simple, manually read devices to fully automated, remotely monitored, and alarmed instrumentation stations. In addition, periodic or recurring remote-sensing techniques — drone flights — can be used as a cost-effective means of monitoring and evaluating surficial changes at a site over time.

Design Solutions

In general, geohazards are mitigated through removal and reinforcement stabilization measures or guarded against using protective measures.

Removal measures generally include:

» Scaling the rock face to remove loose debris

» Rock trimming

» Line drilling

» Re-sloping

Reinforcement measures include:

» Rock bolts

» Rock dowels

» Shotcrete reinforcement and buttresses.

» Cable lashing

» Anchored mesh

» Horizontal slope drains

» Erosion control products

Protection measures include:

» Wire mesh drapery

» Flexible debris flow barriers

» Shallow landslide fences

» Flexible and semi-rigid rockfall barriers

» Retaining walls

The design of geohazard mitigation measures is often multifaceted and performed by a team of geologists and engineers. These design projects aim to mitigate the identified geohazard risks, often only partially understood or investigated based on limited access conditions before construction.

Experienced geohazard professionals utilize lessons learned on other geohazard projects to develop a design that allows for field fitting or adjustments based on actual conditions encountered by the contractor during construction. This flexibility is often built into the design drawings, specifications, and bid documents.

The project team evaluates each potential mitigative solution alternative to determine its effectiveness at reducing the risk, constructability, possible limitations, and impacts on the project schedule and overall cost. This thorough analysis ensures that the preferred mitigation approach meets the client’s project objectives. In addition to the technical aspects of a design, mitigative schemes must account for non-geological project constraints, such as right-of-way limitations, construction access, environmental sensitivities, and protection of the public and stakeholder property.

Ultimately the designer of a geohazard mitigation project must develop drawings and specifications that provide the contractor clear guidance as to the goal of the mitigation efforts and how to deal with changes that may be required during construction due to unforeseen conditions.

Quality Construction

Geohazard mitigation construction is a complex undertaking that typically encounters difficult access environments, dynamic site conditions, and work zone limitations that require specialized safety and protection appurtenances. This specific construction should be performed by contractors with the means, methods, and experience to overcome such challenges.

Geohazard construction is similar to opening the proverbial “can of worms” in many ways. Removing vegetation, scaling loose rocks, or excavating overburdened soils can reveal conditions far worse than those anticipated prior to construction. The design specifications should include contingencies for the mitigation team — designer/contractor — to solve issues should they arise.

Best practices to reduce the impacts of unforeseen conditions and complete a successful geohazard mitigation construction project include the following:

- Understanding geologic and environmental dynamics influencing the site.
- Communicating project objectives and intents through the design.
- Providing contingency or "as-directed" measures in the contract pay items.
- Working with an experienced and flexible contractor who can adapt construction methods to site conditions.
- Working with construction management personnel familiar with the mitigation program's site conditions and objectives.
- Engaging in collaboration and communication between the project owner, design team, and contractor to overcome challenges effectively and efficiently.

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About the Article

This article was written for the online Gannett Fleming INSIGHTS Blog page. Founded in 1915, Gannett Fleming has been a driving force in shaping infrastructure and improving communities in more than 65 countries, specializing in natural resources, transportation, water, power, and facility-related projects. The company embraces sustainability and innovation in projects and internal activities and achieves results while being responsible stewards of the environment. A results-driven firm, Gannett Fleming is consistently ranked in the top one percent of engineering firms worldwide.

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