Geological Risk
Optimal design for risk management

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Introduction

The importance of risk in major international hydropower projects should not be underestimated. Convention suggests that around half the project cost may be attributed to risk. However when the risk element of financing is included, the contribution of risk to the cost of electricity may be much greater.

Project risks are often assessed but are seldom quantified. Methodologies exist for quantifying the probability and cost impacts of individual risks, and for combining risks to evaluate the probability-consequence profile of the project. Quantification of individual risks enables mitigants to be targeted at the most important ones, and by combining the risks an estimate of the outturn limits of cost and delay can be derived.

Owners have varying abilities to absorb risk depending on corporate structure and ownership, financing models and commercial terms. Projects need to be configured according to the proponents' appetite and ability to accept risk. Project layouts can vary significantly, so risk needs to be understood in the early studies.

Geological risk appears synonymous with hydro projects. With much work below ground there is an increased likelihood of unexpected conditions. Geological risks affect a wide range of scheme elements including rock support, foundations, construction materials and rates of progress.

While some risks can be eliminated and others mitigated externally through insurance, most risks need to be managed by allocation between the owner and contractors. Under re-measurable contracts the majority of risks sit with the owner, whereas under EPC contracts they tend to be with the contractor. A Geological Baseline Report (GBR) provides a mechanism for sharing the geological risk in EPC contracts. The mechanism identifies when conditions vary from the basis on which the contract price was fixed, and provides cost and programme adjustments appropriate to the changed conditions.

For many scheme components a high or low risk option can be defined. For example TBM use is typically, although not always, the higher risk option. For issues such as dam type the situation is more complex; the specific conditions of the project will dictate which option presents the lower risk. The bespoke nature of hydro requires highly experienced engineers to assess, mitigate and manage these risks.

1. How important is risk in Hydro?

An often quoted figure is that half of the cost of an international hydropower project covers civil works and equipment, and the balance is for risk. Although this is a simplification, the unique nature of hydropower does give rise to a wide range of risks that are not encountered in other infrastructure development. Among the risks faced by developers and contractors involved in construction of hydropower are the following:

- Bespoke nature of work
- Physical environment
- Programme, interfaces & seasonality
- Performance and predictability
- Quality
- Environment and social
- Location and access
- Geology
- Equipment specifications
- Commercial
- Health & Safety
- Country and political

Although many other infrastructure developments include some of these risks, the combination and severity of the risks are not matched by many other sectors. When the influences of the long gestation time and hydrological variability on the revenue stream are included, it is not surprising that risk management is so important in hydropower development.

Although it is unrealistic to assess the impact of removal of this risk, since risk can never be completely stripped out of a project, it is interesting to observe the impact of doing so. This can be achieved by modifying the inputs to a simple financial model to remove risk from some of the key parameters as follows:

> **Construction Cost:** with all these risks to be taken into account in pricing, it is reasonable to assume that a contingency of around one-third on top of the basic cost is included in the contract price to allow for downtime, lack of productively, re-working, low efficiency and other things that can go wrong. Hence without including risk the typical specific cost might reduce from USD 2 million /MW to USD1.5m /MW.
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> **EPC Premium:** many hydro projects are constructed on an Engineer, Procure and Construct (EPC) basis as a result of the owner's inability to carry risk or the financier's desire to offset risk. The premium attached to the construction cost by EPC contractors to cover design, interface, performance and fixed price/fixed term risks is widely accepted to be around 30%, compounding the standard construction risk contingency above. Hence the risk-free specific cost of USD 1.5m /MW can be compared with a compounded EPC cost of USD 2.6m /MW with all risks included.
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> **Equity Return:** as a consequence of long lead times, development uncertainty, political risk and the disproportionate vulnerability of the equity investor to commercial performance (the equity investor is uniquely exposed to profit and loss), target return on equity (ROE) is typically in the region of 20%. Without such risks an ROE akin to that of long-term US Treasury Bonds might be appropriate, say 4% to 6% (the rate before the last financial crisis).
>
> **Debt interest:** as with equity, risk-free interest rates close to the lower end of US Treasury Bond rates would be appropriate; say 4%.
>
> **Debt Service Cover Ratio (DSCR):** the critical indicator governing debt financeability is usually the minimum DSCR, which is typically required to be around 1.3. Without risk this would be 1.0.

Using these parameters including risk in a simple project financial model (100 MW scheme, 50% load factor, 30:70 equity:debt ratio, 4 year construction period) will result in a tariff of around **12 US¢/kWh** for commercial viability.

Using the "risk-free" parameters above, commercial viability could be achieved at perhaps **4 US¢/kWh.**

Although this analysis is not realistic since many risks can never be removed from a project, it does illustrate the importance of risk in hydro and the value of managing risk well.

2. Assessing project risk

During the study and engineering of projects it is surprisingly common for risks not to be fully assessed and relatively rare for them to be fully quantified.

2.1 Optimisation

Optimisation is typically undertaken using economic cost-benefit analysis on the basis of best-case estimates of parameters, and the robustness of the selection tested with sensitivity cases for variation of cost, interest rates and value of energy.

2.2 Risk matrix

In more sophisticated studies matrices are prepared of project risks, but typically the assessment is limited to the relative probability of occurrence and a relative assessment of the consequence (i.e. graded from low to high).

2.3 Risk quantification

The next step up in modelling risk is to attempt quantification of probability and consequence in terms of cost and delay. For some risks this is relatively easy: a cofferdam may be designed for a 1 in 50 year return period and be in place for three years, so there is an inherent probability of it being overtopped. If overtopped, and it is a concrete dam, the cost and period for flood subsidence, pumping out, clean-up and reinstatement can be estimated, and a reasonably accurate estimate made of the cost and delay of this risk.

Other risks are less easy to quantify. The cost and delay resulting from the rock horizon in a canal being 1 metre higher than expected can be quantified, but what is the probability of occurrence? What is the probability of a valve being left open and flooding the powerhouse, of exchange rates varying by 20% or a rare and protected species being discovered in the borrow pit? If the dam in the first example is an embankment rather than concrete, how much damage will be caused by the flood? Although not easy to quantify accurately, an experienced engineer can make an estimate sufficient to enable the risks to be ranked.

Using this ranking and quantification mitigants for the worst risks can be sought such as:

- Design changes (e.g. design for higher return period, change from embankment to concrete dam etc.)
- Insurance
- Alteration to the construction schedule to remove susceptible components from the critical path (e.g. by increasing the construction resources)
- Allocate risk to another party (e.g. EPC contractor).

Although the accuracy of the quantification is unlikely to be great, this process tends to be much better at identifying the critical risks and enabling them to be mitigated and managed.

2.4 Combination of risks

Once all the possible risks are identified and quantified, the next stage is to consider the overall risk to the project. Clearly the likelihood of all risk events occurring together is infinitesimally small. The most common means of deriving a probability-consequence profile for cost overrun and delay is to use Monte Carlo simulation, with thousands or tens of thousands of runs. By this means the cost overrun with, say, a 10% probability of being exceeded can be estimated. Probabilities of delay can be estimated the same way.

Delay can be converted to cost by taking into account lost revenue together with penalties for non-delivery of power, partly mitigated by liquidated damages and insurance proceeds.

Although not a perfect science this analysis provides a transparent methodology which can be interrogated and allows options to be compared, giving comfort to investors and lenders. However the high cost of a rigorous analysis usually restricts it to the largest schemes or ones with complex financing.

3. Risk appetite of proponents

As project risks vary greatly from project to project, also the appetite for risk of different project proponents can vary considerably. It is important to understand the appetite and ability of the various parties likely to be involved in the project at the early stages of project formulation. A risk that under one developer may be terminal for the project could be only an inconvenience for another.

3.1 Corporate structures

The ability of a project owner to absorb risk varies with corporate structure and ownership. At one end of the scale a Special Purpose Vehicle (SPV) with a single project using non-recourse finance has very limited ability to absorb cost overruns and delays, and may require more certain design and commercial solutions.

Conversely a large utility with an extensive portfolio of generation that is funding a project off its balance sheet has greater ability to take risks (subject to its corporate governance). It can gamble on achieving the lowest cost on all its projects. If one project suffers cost overruns and delays, there is reasonable likelihood that others will come in on target, achieving lower costs on average.

The optimal design and commercial solutions for the large utility may be significantly different from those developed for the non-recourse SPV.

3.2 Concessions and PPAs

Under some legislation, hydropower concessions and Power Purchase Agreements (PPAs) include tariff re-opener mechanisms to give a degree of protection to project developers in the event of adverse risks materialising.

For example, in Pakistan approved tariffs for private hydro schemes can be adjusted at various stages of implementation. If the tariff is fixed on the basis of the feasibility study cost estimate it can be adjusted at the time when the EPC price is confirmed at contract award and again when the actual price outcome is known at the Commercial Operation Date. This adjustment is made for specified events, and is particularly designed to take account of cost overruns that result from unexpected geological conditions in tunnels. While this re-opener gives some protection on cost increases it does not afford protection for delayed start to generation.

In addition to cost-reflective tariffs another mechanism affording some protection against cost overruns, often specifically linked to unexpected physical conditions, is extension of the concession term. This provides little comfort to debt funders who are unlikely to be involved in the project when the extension takes effect, but can give the equity investors time to achieve their target ROE and also increase the value of the project based on discounted future revenue.

Such mechanisms provide risk sharing between the developer and off-taker / government, but the residual risk still needs to be considered in optimising the design.

3.3 Lenders and equity investors

Equity investors by nature tend to have greater appetite for risk than commercial debt financiers. In part this is due to the more entrepreneurial nature of equity investors, and is reflected in the returns required on the different types of funding. Typically, equity investors are seeking returns of around 20% for international projects whereas secured debt commands less than 10%.

Different lenders and different types of finance have their own profiles for risk acceptance: more conservative banks seek to lay-off risks to other parties, and are particularly keen on single point responsibility EPC contracts as a means of attempting price and schedule certainty. This in turn affects the ability of developers to accept risk, and therefore needs to be taken into account in the design and contract structure.

4. Trade-off between cost and certainty

There is often a trade-off between achieving the lowest cost of the project and the most certain outcome. This can manifest itself at all stages of implementation:

- In general, more in-depth studies and investigations should lower the risk of encountering unexpected conditions. The investigation will not change the conditions, but being prepared for them can ensure designs are appropriate, and adequate resources and construction methodology are deployed.

- In tunnelling, where both options exist, the selection of use of a tunnel boring machine (TBM) may offer potentially quicker and cheaper construction. However “drill-and-blast” methodology can enable additional resources to be deployed if needed (opening up additional faces) and reduce the risk of getting completely stuck.
- In geology with variable weathering or where relic river channels may exist, the depth of excavation required to achieve satisfactory dam founding conditions may not be known in advance. Adoption of a centre-core embankment dam, which can typically be founded on weaker strata than a concrete dam, can reduce the likelihood of deep excavations or a late design change.
- Relocation of a power cavern from a position where the depth of overburden precludes site investigation and stress measurement to a shallower location could increase the cost and possibly be sub-optimal. However it can enable rock conditions to be determined in advance and verify the feasibility of the cavern before starting construction.
- Designing structures for a longer return period of event is likely to increase the cost, but will reduce the probability of occurrence. For example adopting a higher return period for the diversion flood will require a higher cofferdam or larger waterways, but will reduce the likelihood of an overtopping event with its consequential delay and cost increase.
- As discussed, paying another party to carry the risk, for instance by awarding a time-certain, fixed price EPC contract rather than traditional multiple contracts, can reduce the chances of cost-overrun and delays. However a premium of some 30% of construction cost is typically paid for this certainty.

There are many other areas where the trade-off between cost and certainty needs to be balanced, taking into account the risk appetite of the various project parties.

5. What are these geological risks?

As a result of the considerable amount of underground work on some projects, geological risk is often considered the predominant construction risk on hydro schemes. Some of the geological risks encountered are obvious, directly involving the project elements. These include rock conditions in tunnels and caverns, foundations for structures and stability of slopes. Others have more indirect influence, such as on the quality and availability of construction materials, or on landslide induced waves and glacial lake outburst floods (GLOFs). Some of these risks are described below:

5.1 Tunnels, shafts and caverns

Method of excavation
There are two main options for hard rock tunnelling, which accounts for the great majority of hydropower tunnels: use of a tunnel boring machine (TBM) or drill-and-blast (D&B). The former tends to be more economical and faster for long tunnels, and the ability to drive very long distances means that tunnels can be straight and hence shorter. The bore tends to be smooth, which together with the shorter length can reduce hydraulic losses. However when things go wrong it can take months or years to get the TBM working again, and there are instances where TBMs have been abandoned. With D&B progress is typically much slower and long drives are broken up into short sections accessed from intermediate adits. Tunnel alignments generally need to follow the river valley to minimise adit lengths, and hence the tunnels tend to be longer. However because there are multiple faces, resources can be deployed to suit conditions, and additional resources applied if needed. D&B tends to cope better with variable geological conditions, and the ability to map each face after excavation means that support requirements are more easily and accurately assessed.

Rock support
The controlling factor for cost and the works schedule in tunnel and cavern construction is rock quality, which affects the support requirement and rate of progress. In weak rock it can also affect the method of construction, with special temporary support measures being required to prevent collapses. In modern tunnelling practice, a variety of rock classes are defined based on geological conditions, and support measures are pre-defined for each class (possibly with the exception of very weak rock and fault zones, where bespoke solutions may be

required). Estimates are made of the percentage of each class of rock that will be encountered, and this commonly forms the basis of the geological baseline model (GBR).

The main risk to cost and programme is that a greater percentage of weaker classes of rock is encountered than was expected.

Excavation cost
The hardness, abrasiveness and geomorphology of the rock mass will have an impact on the cost and rate of progress for both D&B and TBM excavation.

Extent of lining
Linings are typically provided to minimise hydraulic headloss, or for rock support. Full concrete lining may be the defined support measure where rock conditions are weakest. Lining (typically steel) is also required where internal water pressure approaches the confining pressure of the rock mass. Failure to use a steel liner where required can lead to joints jacking open destabilising the rockmass and allowing water to escape.

Steel liners are very expensive and hence are only used to the extent they are needed. The final extent of the liner is generally confirmed by in-situ testing when the tunnel is excavated. The main risk, apart from low stress not being assessed properly, is for the length of lining required being longer than expected, resulting in cost increases and delay.

Expansive rock
Certain types of rock weather rapidly on exposure to air and can expand. This can require sophisticated measures to seal the rock surface quickly after excavation. If it is not anticipated, this process can result in substantial cost increase and delay.

In caverns, encountering expansive rock can require redesign of the powerhouse structure. Often it is not possible to accommodate the movement, and the entire structure, including crane beams, needs to be isolated from the surrounding rock. If not expected this change can be costly and lead to delays.

Portals
The most difficult part of any tunnelling operation is often construction of the portal and excavation through weak ground until hard rock conditions are encountered. Again this will result in cost increases and delay if the conditions are worse than expected. In order to minimise the risk to the overall programme it is prudent, where possible, to arrange the timing of portal construction so that it is not on the critical path.

Groundwater
Ingress of groundwater into tunnels can be unpredictable, and can lead to collapses and difficult tunnelling conditions. Additionally, in tunnels being driven downhill, pumping is required to clear the water.

Squeezing and rockbursts
In tunnels being driven under deep overburden, stresses can exceed the strength of the rock. Weak rock such as mudstone and shales can be subject to plastic squeezing. Harder rock can be subject to rockbursts where the stress exceeds the strength of the rock. In both cases special construction and support measures are required, resulting in cost overruns and delays if not anticipated.

5.2 Dams and barrages

Dam type
Selection of the type of dam is governed by a number of factors including topography, material availability, logistics of construction and safety. Geology plays a key role. Foundation and abutment strength requirements vary with dam type: arch dams requiring strongest foundations and embankment dams accommodating weaker conditions. Variable weathering can affect the depth of excavation required for the foundation or to achieve suitable seating for a CFRD toe plinth. Availability of suitable materials and haul distances are often the deciding factor in selection of the dam type, and this presents a significant risk if inadequate ground

investigation (GI) has been undertaken. Re-use of excavated material from other parts of the works is often proposed for economy and for environmental benefits; however both are compromised if the material proves unsuitable. Karstic conditions, although predictable on the basis of regional geology, can be difficult to forecast at a specific site. A wide range of geological variables affect the cost, constructability and programme and adoption of a design that is not robust to these variables can cause substantial cost overrun and delay if conditions are not as expected.

Grouting and cut-off

Grouting requirements depend on a range of geological factors and can be difficult to predict. Similarly cut-off formation requirements are primarily dependent on geology. These are generally finalised during construction when the full excavated footprint of the dam can be examined. Cost and delay risks result if the conditions encountered are worse than expected.

Impervious zone

The choice of impervious zone is often dependent on geology. In the absence of plastic impervious soil, a clay core dam is not possible, although fine non-plastic cores have been used. Concrete and asphalt facings and asphaltic cores depend on suitable aggregate availability. In the absence of suitable natural filter material, crushing or blending will be required. Again inadequate investigation of material sources increases the risk of late changes and overruns.

5.3 Structures

The design of structures is heavily influenced by the foundation conditions: the requirement for piling or a raft foundation will depend on the characteristics of the geology including strength and consolidation parameters and depth of weathering. As with other sub-surface conditions this presents a risk to cost and delay.

5.4 Canals

Rock horizon

A key factors affecting the cost of canals is where the rock horizon sits in relation to the cross-section. Rock excavation costs are typically more than double those of soft or weathered material, and hence the proportion of excavation in rock has a major impact on cost. As with most linear projects it is difficult to achieve comprehensive assessment of the geological conditions before construction, presenting cost and delay risks.

Weathering and rock strength

Related to the rock horizon is the strength of the rock. There is a step-change in excavation cost between rock that can be ripped with a dozer and that which requires blasting or pneumatic breakers. On the margins between the two it can be difficult to predict how the characteristics of the rock mass will affect the excavation effort.

Leakage and lining requirements

The geological characteristics of the canal alignment affect the potential for leakage, either through permeable soils or through faults and fissures, and also the stability of canal slopes. Hence the need for lining or for slope support measures will depend on the geology encountered.

5.5 Penstocks

Thrust and anchor blocks

Many penstocks problems result from movement caused by inadequate thrust and anchor blocks. The design of these blocks is dependent on bearing capacity and other geological parameters of the formation. Conditions must be assessed at each block location during construction, and unexpected conditions give rise to cost and delay risk.

Avalanche and mudslides

Avalanches and mudslides are typically caused by a combination of topography, geology and hydrology. Penstocks are often located in cuts, generally on steep slopes and frequently in regions of high precipitation.

Hence they are often susceptible to avalanches or mudslides, depending on climatic conditions. The severity of the event is partly dictated by the geology, with soft ground and boulders presenting particular hazards.

5.6 Roads and transmission lines

Formation type

Economic road design in remote regions depends on balancing cut and fill, and on the availability of suitable construction material within short haul distances. Hence geological parameters can govern the design and layout, with unexpected conditions resulting in cost overruns and delays.

Cut slopes

Many hydroelectric projects are located in hilly or mountainous regions, and stability of cut slopes is often one of the most challenging features of project construction. Steep terrain, often with marginally stable slopes, can make it difficult to achieve stable cuts. In addition the linear nature of roads, often extending over tens of kilometres, means that full coverage by the GI is impractical. Hence individual slopes are often designed as construction progresses.

Careful route selection considering the geomorphology can avoid problematic areas. Also design of scheme components to be smaller, such as the use of single-phase rather than three-phase transformers, can allow steeper grades and tighter bends, enabling the road to conform more closely to the terrain, with consequential cost and environmental benefits.

Transmission footings

An area which typically receives little attention at the planning stage is stability of transmission tower foundations. In steep terrain it can be difficult to find stable locations for towers that comply with allowable spans and clearances. Detailed assessment is often only carried out during construction. Again careful route selection, sometimes choosing a more circuitous route, can avoid problematic areas.

5.7 Reservoir slopes and upstream conditions

Rockfalls

The most extreme example of a rockfall into a reservoir occurred at Vajont Dam in Italy in 1963, when a wall of water triggered by a sudden landslide overtopped the dam, causing some 2000 fatalities. Reservoir slope evaluation is usually carried out at feasibility stage, but sometimes the detailed assessment may be deferred until the construction stage. If susceptibility is detected, design measures may include increasing freeboard, installing fuse gates and designing the dam to be overtopped. These are significant changes and present a major risk if not detected early.

Glacial Lake Outburst Floods

The propensity of upstream glacial lake outburst floods (GLOFs) or landslide lake outbursts is treated in a very similar manner to reservoir waves, and again requires early detection and robust design to avoid cost overrun and delays.

Sediment

Sediment impacts and management, although usually treated as a hydrological risk, is also affected by geology. The magnitude of sediment loads is affected by the erodibility of the soil and rocks, taking into account the topography and hydrology. The particle size of the sediments and the abrasiveness are also functions of the rock composition. Hence sediment management risks, including the need to incorporate de-sanding facilities, can be considered a geological risk.

5.8 Construction materials

Availability

A distinguishing feature of remote hydroelectric construction is that the large volume of civil works is typically constructed using locally won construction material. Such materials are used for concrete and asphaltic aggregate, dam fill, clay cores, filter zones and many other components of the scheme. The availability of construction materials is therefore a key risk, together with some of the suitability criteria discussed below.

Quality and suitability
Locating adequate quantities of construction materials is fundamental to economical construction. However there is seldom adequate GI carried out before award to confirm the adequacy of the borrow areas. Discrete sampling is common, including testing of critical characteristics, but comprehensive investigation may not take place. Consequently there is a risk that the identified sources of materials may not produce sufficient quantities for the project requirements. This may result in importation from more distant sources, requiring additional plant and incurring additional cost.

Reactivity
Alkali-silica reaction (ASR) or Alkali-aggregate reaction (AAR) is a common problem in some areas due to the mineral composition of the rocks. Petrographic analysis and mortar bar tests can indicate whether reactive potential exists, and whether it can be controlled by modifications to cement (e.g. through incorporation of fly-ash). Again testing should be carried out in advance to avoid late changes to aggregate sources or cement type.

Processing effort and cost
The cost of locally won materials is affected not only by the cost of excavation and haulage, but also the cost of processing. For aggregates, embankment fill and filter material, this may include crushing, screening and blending; impervious core material may require moisture conditioning and protection from the elements. Fill placed in dam and road embankments and backfill to structures requires appropriate compaction. Often trial embankments are used to optimise the construction equipment. Appropriate plant and techniques are essential for economic construction.

5.9 Seismicity

Seismic parameters are generally established at feasibility stage, and are used for detailed design. Because of the size of major hydroelectric projects and the consequences of failure, bespoke probabilistic and deterministic analyses are normally carried out. Dynamic analyses of key components such as dams is common in regions of significant risk. Failure to carry out this analysis at an early stage can lead to late design changes, with knock-on impacts on cost and programme.

In addition to impacts on the permanent works, seismicity can affect temporary works and remote infrastructure. In areas of high seismicity, construction camps should be designed for seismic loading. Project risks include the disruption to transportation and other civil infrastructure due to earthquakes. Earthquakes may also trigger landslides affecting site infrastructure, and also potentially blocking rivers leading to a risk of outburst floods.

6. Value of geological risk

Geological risk on a hydroelectric project varies considerably depending on the type, location and configuration of the project. Without undertaking a complete risk analysis as described in section 2.4 above, it is difficult to assess the value of geological risk. However, a ball-park estimate can be derived by examination of the components of a typical project, assessment of the percentage of works that might be subject to geological risks, and consideration of the cost impact should the risks materialise.

The analysis below relates to a typical 400 MW project with specific cost of USD 2.5m/MW, and hence a total project cost (including financing but excluding escalation and IDC) of USD 1 billion.

Owner’s costs
The owner’s costs including advisors, licences, environmental studies and works, management and similar costs may amount to 15% to 20% of the project cost – say 15%.

EPC cost
The EPC cost is therefore the total cost less the owner’s cost: USD 1000 m – 15% = USD 850 million

Civil works
On a typical hydroelectric project the percentage cost of the electrical and mechanical works is 25% to 30% - say 30%. Hence the civil works value is 70% x UD 850 m = USD 595 m – say USD 600m.

Geological risk proportion
The proportion of the works subject to geological risk varies considerably from project to project. Excavations and fill are considered to be fully exposed to geological risk. Concrete works, once the cost of cement, batching, transportation, placing and formwork is taken into account, are probably about 25% exposed to geological risk. Structural and reinforcing steel, labour, fuel and many other cost components are not subject to significant geological risk. It is unlikely that more than 50% of civil works cost is be exposed to geological risk.

Value of geological risk
The upper limit of the value of works exposed to geological risk is therefore 50% x USD 600 m = USD 300 m.

Considering individual geological risks, such as more weak rock in tunnels, higher than expected rock horizons or longer than expected haul distances, it would be unusual for the cost of the component to rise by more than 100%. Also it would be implausible for all the geological risks to materialise on the same project. Hence it would be reasonable to assume an upper limit for cost increase of 50% of the value of works at risk. In our case 50% of USD 300 m = USD 150 m, or 15% of the total project cost.

This approach may be used with the values and percentages adjusted for a specific project in order to get a ball-park feel for the value of geological risk. Although not accurate, it gives a benchmark when concerns about geological risk are expressed, or when considering mitigants for dealing with this risk.

7. Optimal design

As discussed in section 3 and 4 above, the appetite and ability of the project developer to carry risk varies depending on corporate structure, method of financing, concession and PPA conditions and other factors. Also there is typically a trade-off between cost and certainty. Hence the “Optimal Design” of a site that suits one developer may be different for another developer of the same site. The design needs to be tailored to the risk appetite of the developer and his financiers.

Since the designs may be fundamentally different – for instance the choice between a surface powerhouse with penstocks and an underground scheme – consideration needs to be given to these risk issues at the earliest stages of study. GI will need to be tailored to the specific layout of the scheme and the quantum and nature of the GI will need to take account of the contract structure and risk allocation.

Optimisation on this basis does not mean reduced safety; health and safety in construction and operation can be very similar. Utilisation of the hydropower resource is not necessarily better using one approach than the other.

In Figures 1 and 2 below two options for development of the same site are presented. The schemes are identical in function and command exactly the same head and flow.

Figure 1 presents the optimal design for a developer with a substantial appetite for risk, such as a major utility with large portfolio of assets. This arrangement may be one where the costs are potentially lowest and construction period shortest, but where there is a significant risk of it going wrong.

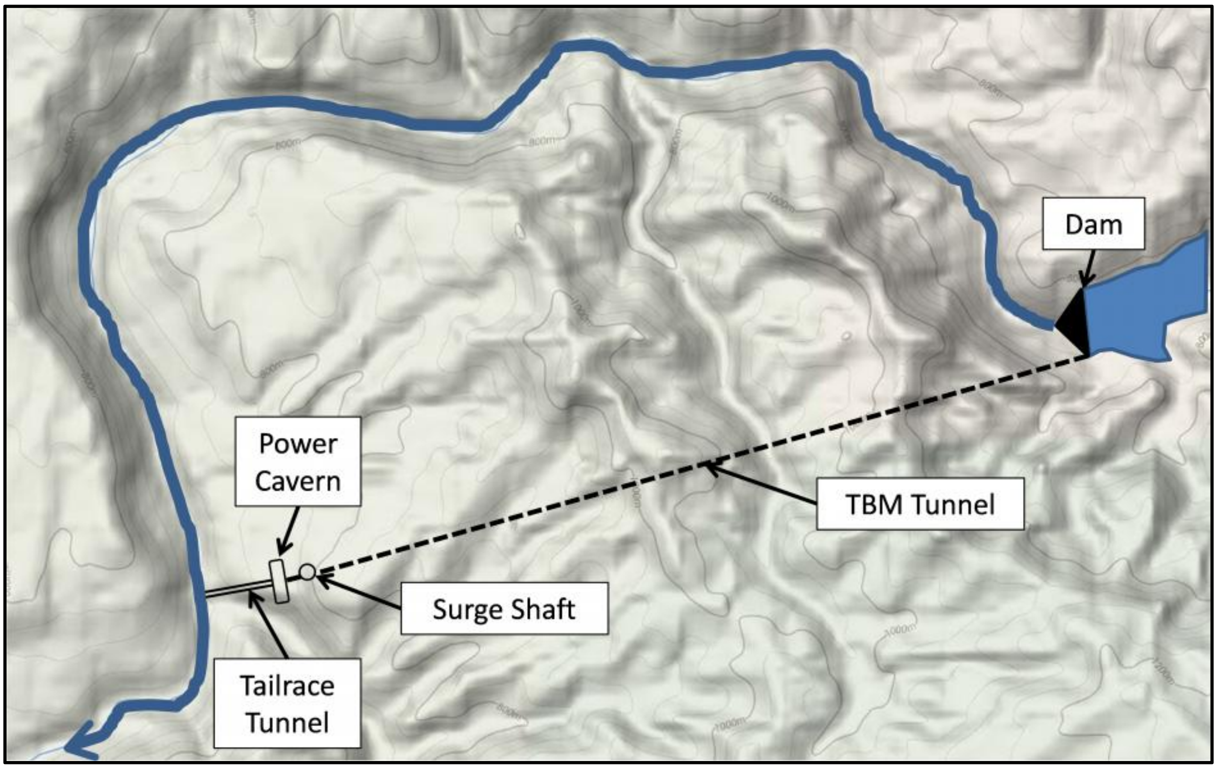

Figure 1: Layout with higher risk design options

Figure 2 presents the optimal design for a developer with less ability to accept risk, such as a single project non-recourse SPV. The scheme may not achieve the lowest cost, but the likelihood of a major event disrupting construction is reduced, and there is greater ability to increase resources to address problems.

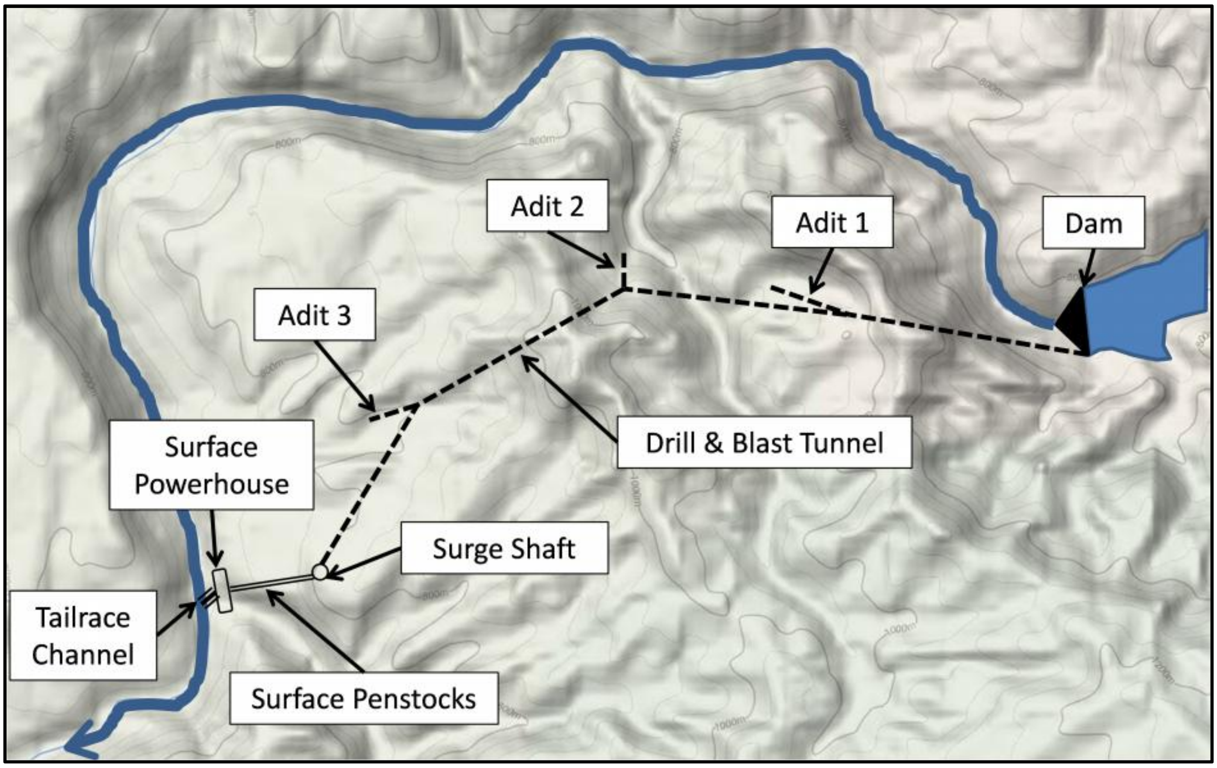

Figure 2: Layout with lower risk design options

8. Management and allocation of geological risk

Having designed out as much of the risk as is appropriate for the appetite of the developer, the next stage is to allocate and manage the residual risks. Insurance can be obtained under the Contractor's All-Risks (CAR) policy for collapses and slope failures to cover the cost of restitution. However for most geological risks that result in cost overruns and delay, insurance is not possible. Only in certain circumstances and for very select issues can geological risks be passed upwards, with a tariff re-opener on the sale price of electricity. Hence risks must generally be shared between the Owner and Contractor.

Under re-measurable contract forms such as FIDIC Red Book, geological risks are predominantly carried by the Owner. Contractors are typically paid for the quantum of work executed, and unexpected physical conditions constitute a compensation event. Measurement can be configured to pass some risk to the contractor, such as for overbreak and temporary support. Risks associated with production of aggregate and other construction materials may be shared between Owner and Contractor.

Under strict fixed-price time-certain EPD contracts, responsibility for geological risk rests with the EPC Contractor. However it is rare now for a contractor to accept all geological risks unless geological conditions are very consistent, the GI is extensive and the design minimises the likelihood of unexpected conditions being encountered.

A method becoming common for sharing of geological risk is the use of a Geological Baseline Report (GBR). The GBR defines the ground conditions which are expected to be encountered, and which form the basis of the EPC Lump Sum Price. If actual conditions encountered during construction vary from the GBR, the contract price and programme are adjusted according to a pre-agreed formula.

The adjustment formula will have the following components:

Price
The contractor will be compensated for part or all of the additional cost based on pre-agreed unit rates. There may also be a price reduction if conditions are better than shown in the GBR.

Programme
The contractor will usually be awarded an extension of time if conditions are worse than the GBR. In some cases extensions are not awarded – the additional payment is deemed to compensate the contractor for deploying increased resources in order to achieve the original programme. Even where there is provision for programme extension it is usually not automatic; typically it would be granted only if the element where delay occurs is on the critical path. It is less common for programme reductions to be due in respect of better than expected conditions, although this is conceivable where, say, a long tunnel is on the critical path.

9. Comparison of risk strategies

In Table 1 below a comparison is made between strategies for various components of a project. The "Lower cost – higher risk" strategy may suit an owner with greater appetite for risk, prepared to accept a less certain outcome for the possibility of achieving lower cost and shorter construction period. The "Higher cost – lower risk strategy would suit an owner who is more concerned about certainty of outcome than the absolute level of cost.

Element	Lower cost – higher risk	Higher cost – lower risk
Dam	RCC (embankment)	embankment (RCC)
Tunnels	TBM	drill-and-blast
Penstocks/shafts	shaft	surface penstocks
Powerhouse	underground	surface
Investigations	limited GI, testing, surveys and studies	extensive GI, testing, surveys and studies
Component sizes	maximise for efficiency	minimise for ease of transport and minimum road specification
Access roads	shortest distance, accept slope failure risks	more circuitous to avoid problem areas
Transmission line	shortest distance, accept foundation failure risks	more circuitous to avoid problem areas
Contract form	traditional split packages; re-measurable civil works with design by engineer, design-build mechanical and electrical and balance of plant.	single-point responsibility EPC contract, fixed price and fixed term, with limited contract price adjustment.
Geological Baseline Report adjustment	not needed: civil contract is re-measured	not wanted: ground risk imposed on EPC contractor
Bonds, liquidated damages, guarantees	minimal – protecting key interests and loss of revenue	substantial protecting against all eventualities
Insurance	minimal insurance – accept the risk	full insurance including advance loss of profit (ALOP) cover

Table 1: Comparison of high and low risk strategies

This table cannot be regarded as definitive, since the risks for each element on each project are different. For example if geological conditions are very consistent and suited to TBM construction, the risks associated with D&B construction of tunnels could be greater than for use of a TBM.

Similarly if the main risks for the dam relate to the foundations, the RCC dam with more onerous foundation requirements would be more risky than an embankment. However if the main risks relate to material availability or weather constrained construction windows, the embankment may be more risky than the RCC option.

This is an example of how the bespoke nature of hydro influences the complexity of the risks, and illustrates the need for highly experienced engineers to assess, mitigate and manage these risks.

The Author

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