IMIA Working Group Paper [WGP 114 (19)]

IMIA Annual Conference, Vienna
October 2019

Underground Exposures for Hydroelectric Plants

Chief Joseph Dam, Bridgeport, Washington - https://en.wikipedia.org/wiki/Run-of-the-river_hydroelectricity

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Disclaimer

The present paper is based on the experience of the working group's members in the insurance industry. The opinions expressed hereunder are solely those of the authors for the respective chapters each member has composed and do not in any way reflect the views of any insurance company or any other legal entity involved in the insurance industry.

The paper is not meant to be exhaustive and other aspects may exist, presumably affecting the profitability of an insurance policy, which may not be described in this paper.

All the authors are serving in their personal capacities.

Should the reader have alternative views on the opinions perceived by the authors, any opportunity for further discussion / views' exchange will be welcomed.

Executive Summary

Over the last decade the Construction insurance market has been presented with a significant number of new Hydroelectric Power Projects (HPP) due to the worldwide development of this source of power. The Construction insurance market has suffered significant losses due to claims on HPP's with potentially the largest ever claim – Ituango – still under review.

This paper will identify on the significant underground exposures to HPP's by analyzing the cause and nature of the market claims. As part of this study we review the HPP facilities design, insurance cover and underwriting considerations.

A review of notable HPP losses is provided covering both the construction and operation phase. This Loss Review clearly identifies that, by far, the dominant damage to HPP's was to underground structures and more specifically to tunnel structures.

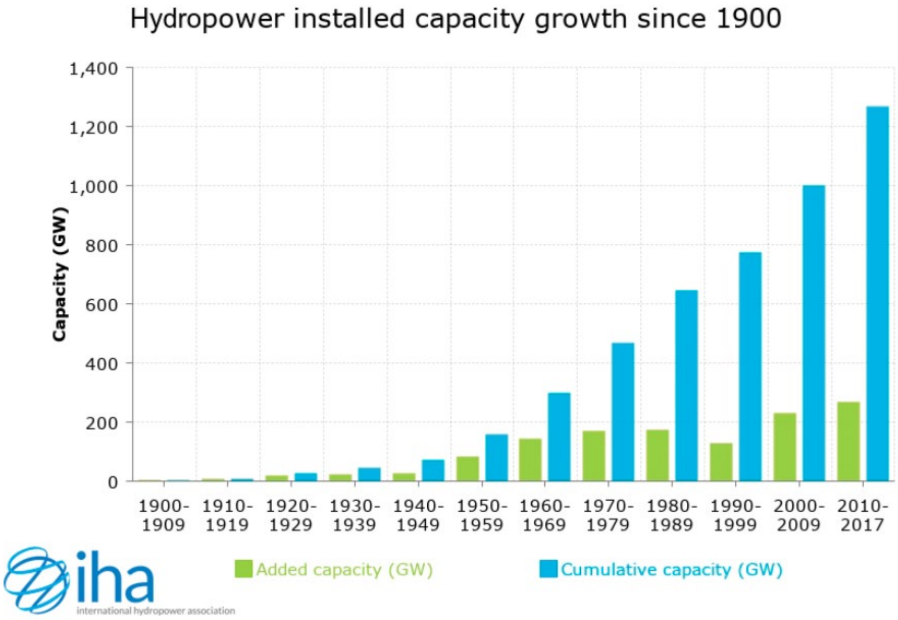
Some of the specific findings include:

- HPP are constructed in mountainous areas subject to complex and disturbed geology.
- Difficulties of carrying out a detailed SI
- Some of the geological faults are not always identified during the SI or construction works. These can contain material that deteriorates in the presence of water.
- The increasing use of partially lined, or unlined tunnels.
- HPP tunnels are subject to cyclical loading ranging from high internal pressure to an 'air' free flow tunnel.

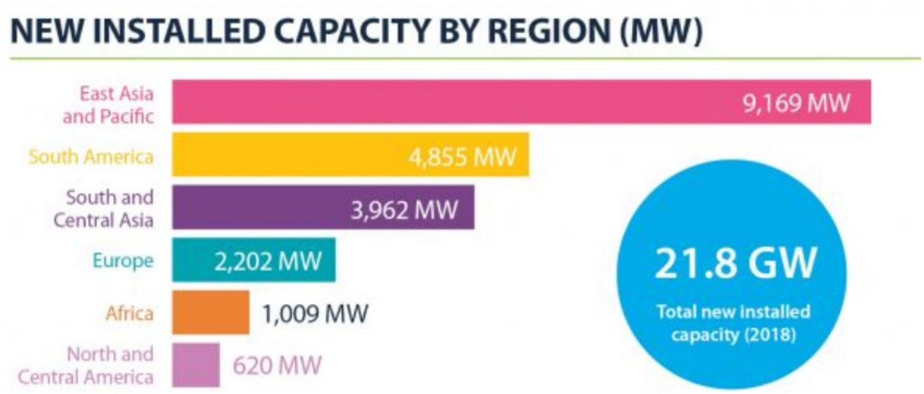
Future development includes working closely with LEG to consider the next steps for HPP tunnels. Additionally, it is proposed to consider a presentation at one of the evening meetings at the British Dam Society.

1. Introduction

Over the last decade the Construction insurance market has been presented with a significant number of new hydroelectric power projects (HPP) due to the worldwide development of this source of power. Since 2000 nearly 500 GW in hydropower installed capacity was added worldwide, representing an increase of some 65%. This rise in hydropower has been driven by the demand for affordable, reliable and sustainable energy in emerging economies particularly Brazil and China.



The particular areas of development for recent hydro developments have been in East Asia and the Pacific adding 9.2 GW followed by South America (4.9 GW) and South and Central Asia (4.0 GW), all added last year.

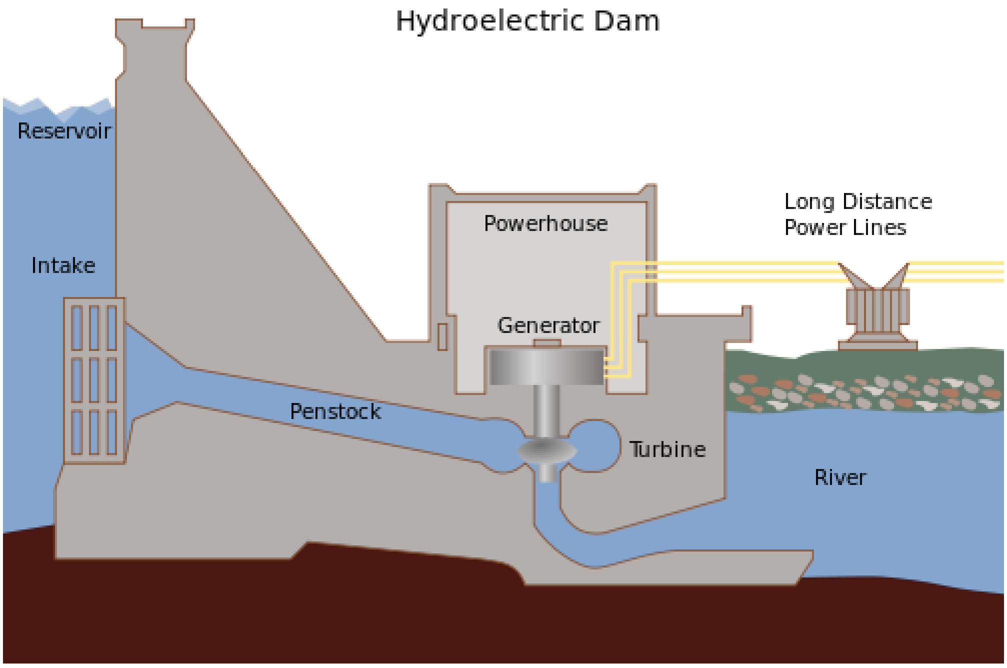


Ref International Hydropower Association

The Construction insurance market has suffered significant losses due to claims on HPP's and potentially the largest ever claim – Ituango – is still under review. This paper will identify on the significant underground exposures to HPP's by analyzing the cause and nature of the market claims occurring over the last decade.

2. Hydroelectric Power Plant Facilities

Hydro projects are very complex containing a number of individual structures including the dam, diversion tunnels, cofferdams, headrace tunnel, surge tank, penstock, power house and tail race tunnel. In additon to this are the generator and turbines.



Methods

There are many different methods for constructing underground structures in HPPS. Historically tunnel boring machines were used with segmental concrete linings, the alternative was often to fully shotcrete or employ cast in situ concrete following a drill and blast process. Penstocks and high-pressure shafts were typically fully lined with the former often being steel lined.

In recent years newer methods have been utilised. Drill and blast or road-header drilling machines and raised bore shafts bring a different type of exposure. Following the drilling and or blasting procedure the tunnels and or shafts are often left only partially or completely unlined. Depending on the nature of the rock type different types of mesh support and rock bolts will be employed, the number, type, length and distance between them should be determined in the original design and engineering process based on the original rock face mapping and geotechnical investigations. As previously mentioned, following excavation the rock types and condition may not be quite what was expected and the solutions need to be adapted accordingly. Wherever shotcrete is used it is important that the concrete mix is correct, the lining is applied uniformly and ideally installed invert to invert.

It could be stated that regardless of the method utilised the main exposure will exist during the excavation process itself. When the TBM method is utilised and the lining already in place this would be largely true, however, with the other methods the possibility of failure of the excavation still exists until handover. Depending on the geology the introduction of water may also cause a reaction/change in the rock which, in turn may result in deterioration in the rock and increased exposure/risk of collapse. The flow and pressure of the water may also exacerbate weaknesses in the rock and/or support.

Whilst the method may determine the nature of exposure to the permanent and temporary works, damage to underground plant and equipment such as tunnel boring machines, road headers and a plethora of other equipment also needs to be taken into consideration. Underwriters need to understand what equipment will be used, how it will be maintained/protected and what the fire safety plans are together with how these will be implemented in the event of a fire and what firefighting/detection equipment/training will be available. Combustible materials and fluids should be kept to an absolute minimum and avoided as much as possible.

NOTE:

- A fuller description of the principle elements of a HPP is provided in *IMIA WGP 030 (03) Construction and Operation of Hydro Power Dams and Plants*
- Developments in the technology and use of hydro electric power plants and the insurance solutions available during construction and operation are reviewed in *IMIA WGP 000(98-1) Hydro-Electric Power – 16-71*

3. Insurance Cover

Construction

Projects for the construction of Hydro Electric Power Plants are insured under conventional Construction 'All Risks' policies on a project specific basis for the full duration of the project, including in most cases (other than when the project is located in the USA or Canada) the maintenance or defects liability period. The nature and extent of cover provided can vary from standard Munich Re or Swiss Re forms to manuscript forms.

Cover is arranged in accordance with contract conditions which usually require that the policy is issued in the joint names of the contractor and the owner/principle. The insured parties are often extended to include inter alia contractors and sub-contractors of any tier, suppliers, consultants and manufacturers for their onsite physical activities only and financiers/lenders. This reflects the multi-party insurable interest in the property insured.

In most cases all aspects of the project are insured under one policy, however, in some cases separate policies will be arranged for different parts of the project, i.e. civil works and electrical and mechanical works. Coverage may range from simple material damage only, to multiple sections including cover for works, existing property, third party liability and delay in start-up. A brief description of the cover under each section is provided below.

Operational

Once construction is completed the Operational exposures are insured under Industrial 'All Risk' policies. Many Hydro Electric Power Plants are owned and insured by the owner/principal. Often the principal is a utility who owns and operates an array of different types of power generation and distribution facilities, in some cases these are insured under global programmes covering multiple locations. In cases where the facility has been constructed as part of a Build Own Operate and Maintenance contract the plant will be operated and maintained by a consortium, part of the concession who constructed the plant. In cases such as this, the policy may be stand alone or part of a programme taken out by the concessionaires for all similarly owned, operated and maintained facilities.

3.1 CAR – Property and Material Damage Cover

Damage to the permanent and temporary works (and materials intended for use in the project) in progress caused by damage (generally defined as physical loss or damage). Cover can be made available for the following if required:

- Common user plant and equipment
- Contractors' plant and equipment (usually covered by the contractors own arrangements)

- Site huts, temporary accommodation and stores
- Existing property which is the responsibility of the insured parties by contract or agreement, cover is often restricted to specified peril and damage arising out of the works being undertaken, however, dependent upon circumstances this may be extended to full ‘All Risks’ arising from any cause
- Inland transit
- Offsite fabrication

Usually indemnification can take the form of repair, replacement or reinstatement of the damage.

Once the facility is operational, cover will be incorporated under an operational ‘All Risk’ policy, typically this will exclude pre-existing defects and include machinery breakdown.

3.2 Third Party Liability (TPL) Cover

This section provides indemnity against all sums (including claimants costs and expenses) which the insured shall become legally liable to pay in respect of or consequent upon:

- death of or bodily injury to or illness or disease (including mental injury trauma anguish or shock) contracted by any person (other than employees of the insured seeking indemnity)
- loss of or damage to property (other than property insured under the Material Damage coverage) happening or consequent upon a cause occurring during the period of insurance and arising out of or in connection with the project.

Cover is often widened to include:

- Interference with traffic or property or any easement, right of air, light, water, support or way or the enjoyment of use thereof by obstruction, trespass loss of amenities, nuisance or any like cause.
- Sums Insured will generally not exceed $5m under the primary policy with separate policies in place for the excess protection.
- Once the facility is operational, this coverage will usually be placed separately to the material damage.

3.3 Delay in Start-up (DSU) / Advanced Loss of Profit (ALOP) Covers

Financial losses suffered by the Insured in consequence of delay in the commencement of or interruption or interference with the Business resulting from damage. This cover is also called Delay in Start-Up (DSU).

Cover is triggered by damage indemnifiable under the Construction ‘All Risks’ section of the policy and is provided solely for the benefit of the owner/principle and where financiers/lenders are involved, also for their benefit. Coverage, limits and basis of indemnity would be tailored to the project needs and the requirements of the insured parties. Cover is designed to protect the relevant project parties against a financial consequential loss as a result of project not being completed in time for the originally intended commencement of the business.
The sum insured may incorporate a variety of elements dependent upon the ultimate end use of the building:

- Continuing fixed costs
- Continuing debt servicing
- Reduction/Loss of profit
- Additional cost of working

Cover can be tailored to incorporate delays arising out of damage at the premises of suppliers and arising out of damage to key items of plant and equipment whether insured under the original contract insurance policy or otherwise.

The client should select a suitable indemnity period taking into account the time needed to repair, replace or reinstate the works.

This cover cannot be bought on a stand-alone basis, nor can it be bought for the benefit of the contractors. It is however possible for contractors to arrange the project insurance including the Delay In Start Up for the benefit of the appropriate insured parties only.

One thing to note is that whilst monetary deductibles apply to all other sections (with the possible exception of third party injury or death which usually has a nil deductible), a time excess, waiting period or retained liability period expressed in days (normally a minimum of 30) applies to the aspect of any delay attributable to a cause indemnifiable under the material damage section. It can either be ‘inclusive’ or ‘exclusive’ (the indemnity period is either reduced by the amount or is in excess of it). It is usually also applied not for each and every loss, rather, in the aggregate; although multiple delays may occur a claim may only be made if there is a delay of the scheduled commencement date of operation.

Application of sums insured and retained liability periods are an important factor in delay in start up, as such these should be carefully tailored to the often unique circumstances pertaining to the risk. For example, the project, once operational, may take some time to ramp up to producing full power and or not earn revenue in a consistent pattern.

Operational coverage is called Business Interruption and differs somewhat to delay in start which can only be triggered when the facility fails to achieve the schedule date of commencement. Business interruption can have multiple triggers throughout the duration of the policy and as such, both the sum insured and the deductible are on the basis of each and every loss.

4. Underwriting Considerations

4.1 Underwriting Information

Each construction project is unique, this is no less true of hydro-electric power plant projects. As this paper's focus is in relation to the underground works, we will concentrate on these elements only comprising permanent and temporary works:

- Galleries within concrete dams
- Intake and discharge structures
- Headrace and tailrace tunnels
- Shafts
- Pressure shafts
- Diversion tunnels
- Adits
- Penstocks
- Powerhouse and other subterranean caverns
- Machinery and Equipment to be installed within the underground structures
- Plant and Equipment used in the construction process

Underwriters should always maintain an awareness of changes in the constructions industry, not only regarding design, but also on the construction site in terms of new materials and working methods.

To enable a comprehensive assessment of risk, underwriters should ideally expect to receive a submission containing the following:

- Scope of cover required/policy wording
- Project organisational structure showing interface and interaction between all parties
- Details of the insured parties and their experience relevant to the work being undertaken
- Details of independent checking engineers
- Confirmation as to whether International Tunnelling Code of Practice will be utilised and adhered to
- Risk register
- Design/engineering overview
- Scope of works/description of the project incorporating detailed description of methods and materials
- Dimension of all structures
- Site Plans and drawings

- Geotechnical conditions
- Geological face mapping
- Regime for checking, inspecting and sampling rock type and conditions
- Details of on site testing/laboratory facilities
- Details of quality control and quality assurance
- Breakdown of the project value
- Construction bar chart including critical path (especially useful for DSU)
- Location of risk including overview of natural hazard exposures; storm, flood and earthquake
- Description of surrounding and third party property, particularly downstream
- Method statements
- Details of plant and equipment to be used in the construction process
- Details of machinery and equipment to be installed
- Details of any existing property to be insured
- Overview of approach to health and safety, risk management, quality management and security
- Fire safety plan
- Testing, Commissioning and Start-Up regime

If DSU insurance is required:

- Overview of project funding
- Explanation of the composition and calculation of the sum insured
- Mitigating factors
- Lead times for materials or critical items/tasks
- Details of availability of suitable resources.
- Will client and contractor sign up to delay monitoring?

During the operational phase many of the requirements in this section will become redundant, however, underwriters will require information pertaining to the inspection, maintenance and housekeeping standards and quality and experience of the permanent management and workforce.

From a business interruption perspective itinerary of spare parts and on site/local repair facilities take on a high degree of importance.

4.2 Special Considerations for Material Damage Cover (CAR)

Specific Exposures

Hydro Electric Power Plants are amongst the most complex risks that any underwriter will encounter. There are multiple challenges to the skills of the underwriter with many and varied exposures to be considered.

These facilities tend to be constructed in remote hilly or mountainous regions. The nature of the topography brings challenges due to the often volcanic nature of the geology, safe access to the site together with the inherent risk of the design, manufacture and supply of the equipment to be installed, changeable weather conditions including in some regions, extreme weather, for example the effect of the El Nino and La Nina phenomena, and last but not least seismicity.

This paper focusses on underground structures and the main exposure for underwriters in this respect tends to lie within the temporary and permanent tunnels and shafts.

In the majority of cases exposure is greatly influenced by the geology. Unfortunately, as most of the structures are located deep underground and/or within hills or mountains it is extremely difficult to carry out comprehensive ground investigation in advance. The ground investigation is also supplemented by geological rock face mapping. Consequently, once the construction process commences, the project team needs to be extremely experienced and able to adapt to what they may find during excavation. This means that there may need to be flexibility around the design and engineering solutions that were initially envisaged and a variation in the excavation and support methods may also be required. Given all of this it is difficult for the underwriter to be confident about the geological information provided. Almost more than any other risk type it is therefore highly advisable that underwriters assess this type of risk with the assistance and input of a risk engineer with civil engineering and or geological experience.

The design defect exclusion is an extremely important factor in the insurance of these types of facilities. Ideally the London Engineering Group (LEG) clauses should be used for the electrical/mechanical exposures and the Design Exclusion (DE) clauses for the civil engineering exposures. Underwriters should carefully consider which specific clauses to utilise as in the event of damage the quantum of such damage can vary considerably with the application of a less restrictive exclusion. In recent years there has been a drive to use the LEG clauses for all exposures and a move towards LEG 3 in particular. Given that a huge proportion of losses on HEPPs relates to errors or omissions in design, the provision of LEG 3 or DE5 are not to be recommended.

Erection and Installation of Electrical and Mechanical Equipment

Once the underground powerhouse cavern and associated structures have been constructed/excavated. Fit out of the installed plant and equipment will commence. This comprises an array of electrical and mechanical equipment including transformers, switchgear, cabling and of course the turbines.

These elements are all exposed to collapse of the structure and/or other structures and consequential flood as per the other underground aspects of the project. However, additionally the inherent risks of defective workmanship, materials and design, errors and omissions during the manufacturing process and electrical and mechanical breakdown are introduced. There is of course the risk of disruption of the turbines or damage to them by foreign bodies coming through from the tunnels due to failure of rock traps and filter screens, this risk could be enhanced by a tunnel collapse. Last but not least, there may be many potential sources of combustion.

Damage to installed subterranean plant and equipment and delay in start up is likely to be exacerbated by the fact that access to recover and repair may prove difficult, time consuming and ultimately much more costly than in the case of similar equipment above ground.

Once again there should be a fire safety plan, firefighting/detection equipment and appropriate training. Minimisation of combustible materials and fluids and regular removal of waste.

Although detection and fighting systems may be installed, they are often not able to be operational at this time as they could be accidentally activated by heat and dust, it is important to understand when they will be installed and operational. Fire is a major concern at this stage due to the high equipment values and damage can be disproportionately high in a modern installation due to the preponderance of electronic equipment and cabling, particularly fibre optics.

Finally, testing and commissioning is crucial, at this point equipment values are at their highest and adherence to the testing and commissioning plan is crucial. Underwriters need to know that the plan will be carried out in accordance with manufactures recommendations and by appropriately experienced personnel.

4.3 Special Considerations for Third Party Liability (TPL)

In the underwriting procedure the following factors should be considered in the process of premium calculation for the TPL exposure:

- Distance to third parties
- Fire and / or explosion risk from construction work
- Type of and method for construction machinery
- Contractor's experience and accident record
- Location of downstream communities
- Frequency of third parties visits to the site of construction
- Possibility of ground collapse exposing third party property or persons above the underground structures

4.4 Special Considerations for Delay in Start-Up (DSU / ALOP)

The main issues in this respect are access to the site/damaged areas and lead times for key items such as turbines and transformers, but not to forget road headers, tunnel boring machines and jumbo drills.

Phasing of permanent and temporary works can be extremely important, often temporary diversion tunnels are deemed to have served their purpose and are taken out of use/tapped, in some cases it has been found that they could have played a crucial role in mitigating or avoiding a delay loss had they been left operational until the last possible moment.

Working days/hours permitted and availability of appropriately experienced labour may also be a feature if there is a delay and contractors have to make up lost time.

Underwriters need to be careful about wording changes that introduce delay cover as a consequence of loss or damage to construction plant and equipment (in some cases even when not insured under the material damage section of the policy). Extensions such as denial of access should ideally make reference to specific measurable distances rather than a vague reference to "vicinity".

Special clauses: Customers Extension, Suppliers Extension, Increase Cost of Working.

4.5 Operational Cover

Once the plant has been handed over by the construction team, separate insurance arrangement will need to be made. Many of the underwriting considerations will be the same, some exposures will dissipate and new ones introduced.

Underwriters need to understand the housekeeping, maintenance and inspection regimes. The main exposure during the operational period tends to relate to the electrical and mechanical equipment so it is important to understand the extent to which the equipment will be maintained and that these standards are at least in accordance with manufacturers recommendations. The main exposures will be machinery breakdown, failure or disruption as well as fire, explosion and flood.

Fire, explosion and flood to equipment in subterranean tunnels and chambers can be difficult to contain and fight, so the level, quality, effectiveness and efficiency of detection and prevention equipment is crucial.

One exposure that is not often taken seriously with operational hydro electric power plants is that of damage or collapse within the underground structures. One particular issue is that of inspection and maintenance of the underground tunnel structures, this is exacerbated by the fact that many of the tunnels are now either unlined or at best partially lined. The tunnel surfaces can become eroded to the point where the danger of collapse is enhanced. Inspection may difficult and costly as this may often means emptying and refilling the tunnels of water, this is time consuming, but can also destabilise the structures and in turn cause damage as the internal pressure is reduced.

It is possible to inspect the structural integrity of the tunnels using submersible remotely operated vehicles (ROVs), this negates the need to empty the tunnel of water. However, with some of the longer tunnels this may be problematic if the access points are far apart and facilities for power etc may also not be readily available.

4.6 PML Assessment for Underground Structures

Insurance / reinsurance capacity is a limited resource and requires substantial capital. Therefore, optimal deployment of capacity is essential.

The realistic and reliable assessment of the loss potential of any one risk is the basis for;

- Determination of a retention in relation to capital requirements
- Determination of reinsurance needs

Engineering Insurers have historically allocated capacity in accordance with Probable Maximum Loss (PML)

Definition of PML Utilized by IMIA

“Estimate of the maximum loss which could be sustained by the insurers as a result of any occurrence, considered by the underwriter to be within the realms of probability.

This ignores such coincidences and catastrophes as may be possibilities, but which remain highly improbable."

The definition of what is "probable" is in many cases extremely difficult. It is only possible if all the risk information is available and a careful assessment of the situation is made based on the information provided and the experience of the underwriter.

Factors to be considered in the PML assessment:

Risk Related Factors

- Project layout, value concentrations, complexity, technology, materials, construction program and method, testing phases, human factors (e.g. manufacturers / contractors / designers and engineers experience), fire exposure, infrastructure (accessibility, repair facilities, spare parts availability, etc.)

Environmental Factors:

- Location; earthquake exposure, water/flood exposure, storm, geology, topography, etc.

Cover Specific Factors:

- Extent of cover; inclusion of faulty design, guarantee cover, DSU cover, unclear inclusions/exclusions, limits etc;

The process of calculating the PML considers:

- What is at risk?
- What is it worth?
- How much of it is likely to be damaged by a single event and to what extent?
- How long will repair/reinstatement take?
- How long will it take to obtain replacement equipment?
- How quickly can the construction team be remobilised?
- What could be the consequential financial loss to the project beneficiaries?
- What is the potential third party injury and/or damage?

Answering these questions in turn provides a systematic approach to the calculation of PML. The calculation needs to be done case by case. Many of the scenarios may lead to collapse with potentially huge consequences, especially shortly before completion resulting in the potential for significant loss, including removal of debris and other sub limited extensions. Normally active and passive fire protection measures would be in place shortly before finish but should not be taken in consideration when calculating the PML.

In the case of underground structures in hydroelectric power plants the PML is mainly influenced by failure of the structures but could also be due to fire/explosion and/or Nat Cat. Some considerations regarding PML Scenario might be:

- Tunnel or shaft collapse
- A typical (worst-case) scenario might be multiple failures close to completion therefore triggering significant delay.

Construction policies will more often than not contain a tunnelling clause which will contain an inner limit, however, depending on the clause the limit may be triggered by collapse only when the damage may be due to some other peril. Additionally, some clauses ae inclusive of additional heads of cover and others, exclusive. Underwriters need to thoroughly examine and consider the various clauses. Tunnelling clauses are usually a variation of the Munich Re 101 clause, however, broker amendments can often considerably alter the intent of the original clause.

On the operational policy rating is often applied to the full value, but from an indemnification perspective a sub limit often applies reflecting the client/brokers view of the maximum possible loss from a single event.

4.7 Typical Wordings/Clauses

Munich Re Tunnelling Clause 101
LEG Tunnel Works Clause
Munich Re Fire Fighting Facilities Clause 112
Tunnel Boring Machine Depreciation Clause
Munich Re Structures in Earthquake Zones 008
Munich Re loss prevention in respect of Flood and Inundation 110
Munich Re Construction or Erection Time Schedule 005

Whilst the above refers mostly to standard Munich Re clauses, there are many variations of these clauses and underwriters must ensure that any changes to the original clauses are clear and must understand the implications of these changes.

5. Loss Review

5.1 Recent Market Losses

Appendix A contains details of some of the more recent market losses. The details provided on the project description, ECV and cause of damage and quantum are all widely available on the internet.

A summary of recent market losses is provided below.

Market Losses

Location	Project Type	Damage	Date of Loss	Quantum / digit figure
Costa Rica	Hydroelectric Power Project	Spillway	01/01/2018	Low
Columbia	Hydroelectric Power Project	Diversion tunnel	28/04/2018	High
Laos	Saddle Dam linked to Hydroelectric Power Project	Dam collapse	23/07/2018	High
Brazil	Hydroelectric Power Project	Riots and building fire	15/03/2011	High
Peru	Hydroelectric Power Project	Tunnel collapse and ground failure	19/02/2016	Low
Georgia	Hydroelectric Power Project	Tunnel collapses	2017	Med
Chile	Hydroelectric Power Project	Multiple rock bursts in the tunnel	12/10/2018	Low
UK	Hydroelectric Power Project	Tunnel collapse	August 2009	Med

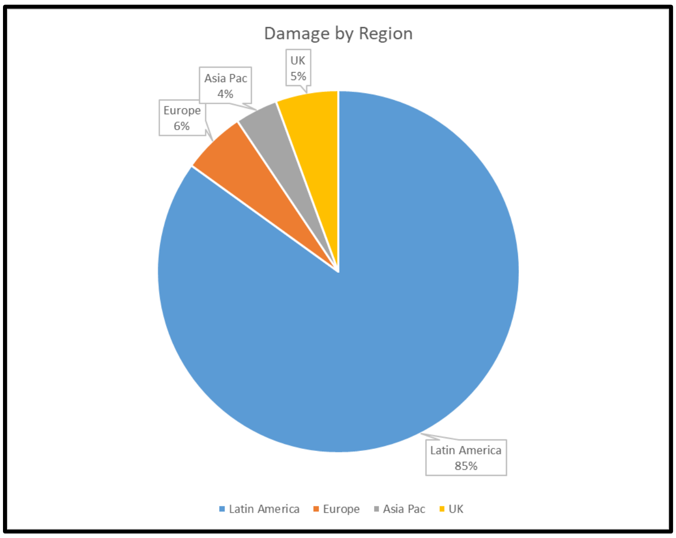
A review of the notable losses date identifies that:

- The majority of the losses occurred during construction.
- The majority of losses related to tunnel damage.

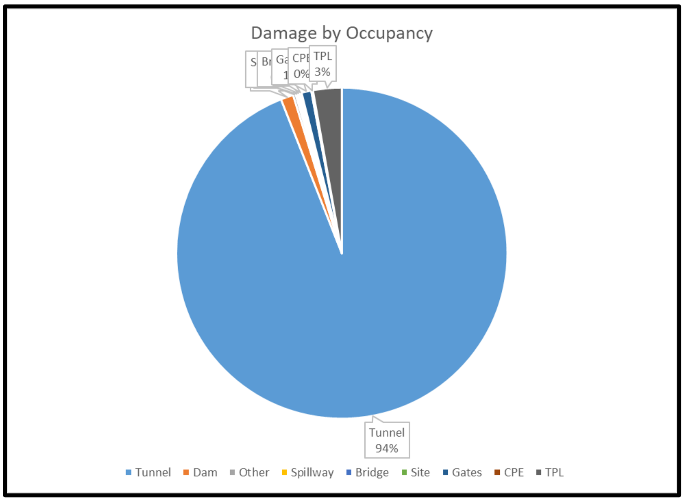
This suggests that the most prevelant form of damage is to tunnels either during construction or operational phase. Whether the damage occurs in one phase or the other is really just a matter of timing of when the damage manifests itself. The conclusion form this review is that the main cause of losses is related to tunnels.
For the purpose of this paper, considering the underground exposures for HPP, we will then focus on the main exposure indentified by the claims review – tunnelling.

We have also reviewed a wider range of hydroelectric claims by region, occupancy and whether above or below ground. Although we do not proivde a detailed list of these claims they do include damage to a variety of HPP sttructures including the dam itself, bridges, CPE, turbines and the construction sites from a variety of causes including flood, landslide, lightening.
The results of this are summarized as follows:

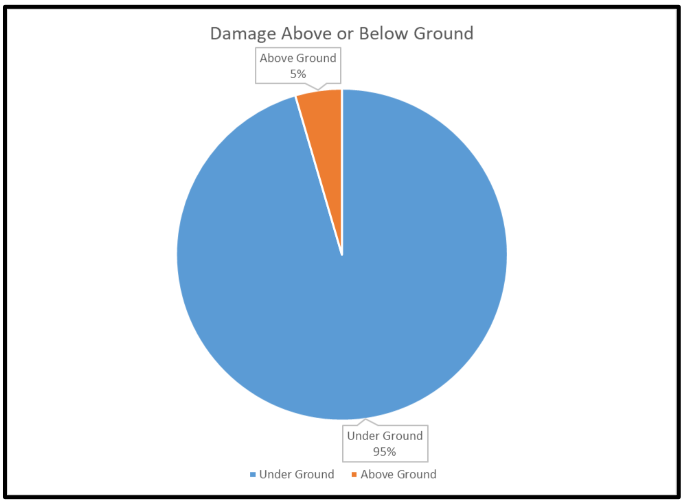
Damage by Region



Damage by Occupancy



Damage – above or below ground



The most significant damaged item (by claim quantum) is tunnel structures in Latin America.

5.2 Historical Losses

It has been more difficult to find details of historical losses but we were able to locate a paper by the International Commission of Large Dams (ICOLD) and whilst this did not relate specifically to hydroelectric power projects it does review the cause of incidents covering dams on a world wide basis. This paper Dam Failures, Statistyical Analysis – Bulletin 99 is available on the ICOLD website.

The paper analzses the data from over 180 dam incidents some of which relate to dams under construction. There are spedific references to three specific cases which suffered from instablity and sliding earthfill of the dam itself.

Some of the key findings of this paper include:

- Most failures are to newly built dams

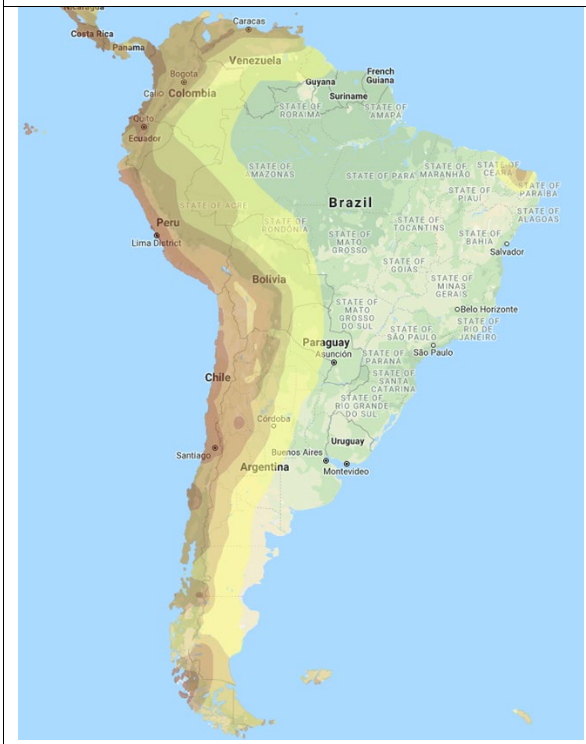
- For concrete dams the most common cause of failure is foundation problems relating to internal erosion and insufficient shear strength
- For earth and rockfill the most common cause of failure is i) overtopping ii) intenral arosion
- For masonry the most common cause is i) overtopping ii) intenral erosion
- Other noteable causation was inadequate spillway capacity.

5.3 Causation

The review of the losses indicates that a significant numer of these were in Latin America. If we review the Noteable losses we can see that:

- Reventazon, Costa Rica is in Zone 4 earthquake
- Ituango, Columbia is in Zone 4 earthquake

See Risk Zoning map below and note that these area have been subject to multiple earthquakes.

Earthquake Zone	Earthquake Locations
	

Additionally Shuakhevi in Georgia is in a Zone 3 / 4 earthquake zone. Glendoe is not in a high earthquake zone but does have geological faults in this area.

In conjunction with our review of claims and discussions with loss adjusters, geotechnical engineers and risk control engineers involved with investigating HPP losses we identified common themes:

- HPP tend to be constructed in mountainous regions that can subject to complex and disturbed geology.
- Tunnelling in volcanic rock has specific issues
    - Zeolite is found in minerals and includes laumonlite and waikarite which can damage the shotcrete.
    - Clay minerals can cause risk swelling and additionally they can degrade over time when exposed to air and water. Geologists are not always checking for the presence of these.
- Some geological faults contain gypsum which disolves over time and can lead to instability of the surrounding ground and / or lining.
- Geological faults are not always identified by the SI and additionally can be missed by the site geotechnical engineer carrying out the face mapping.
- Risk assessments should consider geology and mineralogy and this is not always being done.
- There is an increase in the use of unlined or partially lined tunnels. Older HPP schemes tended to use steel or concrete linings that would separate the water from the rock. There have been cases of the partial lining being undermined and subsequently failing.
- It is recommended to form an invert to prevent erosion by debris from undermining the sides of the tunnel.
- There are particular features that are specific to HPP tunnels
    - It is difficult to carry out a thorough SI because of significant overburden and access restraaints at grond level.
    - They can be subject to high internal pressures due to the high head of water. Equally when drained there will be no internal pressure but there could be significant build up of pressure behind the lining.

6. Future Development

- ICEIG carried out a review on HPP losses in 2018 and there is a good opportunity to work jointly with them to consider the next steps for HPP tunnels.
- As a joint initiative with LEG we attended a presentation at the BTS where we discussed the issues relating to tunnel collapse with the Chairwoman. They confirmed that they would consider providing us a slot at one of their evening meetings.

Appendices

Appendix A Market Losses

Project:	**Reventazon Hydroelectric Power Project**
Location:	Costa Rica
ECV:	US 1.4bn
Description:	The Reventazón Dam is a concrete-face rock-fill dam on the Reventazón River about 8 km (5.0 mi) southwest of Siquirres in Limón Province, Costa Rica. It was inaugurated on 16 September 2016, and its primary purpose is the production of hydroelectric power. The 1.4 billion USD project and largest power station in the country has an installed capacity of 305.5 MW and is expected to provide power for 525,000 homes. Construction on the dam began in 2009. At a height of 130 metres (430 ft) and with a structural volume of 9,000,000 m^3 (12,000,000 cu yd), it is the largest dam in Central America. To produce electricity, water from the reservoir is diverted about 3 km (1.9 mi) to the northeast where it reaches the power station along the Reventazón River. ***Reference Wikipedia***
Date of Loss	2017
Cause	A shutdown was required “to fix a ‘strong water leak’ present in the rock massif of the dam’s spillway.” As much as 180 liters of water per second is leaking from the crack. It is not clear if the cause of the leak has been determined. Reventazon was inaugurated in September 2016 and thus has been operating less than two years. ***Reference Hydro Review***
Quantum	TBA

Project:	**Ituango**
Location:	Columbia
ECV:	PD - US 2.55bn, DSU – US 630m
Description:	A 225-metre (738 ft) tall earth-fill embankment type with a clay core. The volume of the dam will be 19 million cubic m. Its reservoir will have a capacity of 2,720-million-cubic-metre of which 980-million-cubic-metre will be active capacity. The reservoir will be 127 km (79 mi) long and cover an area of 38 square km (15 sq mi). To maintain reservoir levels, the dam will have a spillway controlled by four radial gates with a design flow of 22,600 cubic m per second (800,000 cu ft/s). The dam's power plant will have a nominal hydraulic head of 197 m (646 ft) and contain eight 307 megawatts (412,000 hp) Francis turbine-generators.
	Reference: Wikipedia
Date of Loss	May 2018
Cause:	Diversion tunnel blocked by landslides causing reservoir to fill up before the dam was complete. Power house flooded to prevent dam overtopping.
Quantum:	High digit number
	Reference: Inside FAC, 9th Nov 2018

Project:	**Laos Dam**
Location	Laos
ECV	US 1.2bn
Description	Construction of the earth-filled Saddle Dam D near Paksong, part of the $1.2bn (£915m) hydroelectric project by Xe-Pian Xe-Namnoy Power Company (PNPC), was begun in 2013. The hydroelectric project was a build-operate-transfer project. PNPC is a joint investment venture formed in March 2012 by SK Engineering and Construction (SK E&C), Korea Western Power (KOWEPO), Ratchaburi Electricity Generating Holding (RATCH), and Lao Holding State Enterprise (LHSE). SK E&C holds a 26% stake in PNPC, LHSE 24%, and RATCH and KOWEPO equally own the remaining shares. Part of an overall project to build two main dams and five auxiliaries, by the time of the collapse, it was near to completion and was intended to open for business in 2019. ***Reference Wikipedia***
Date of Loss	23rd July 2018
Cause:	Ongoing review – collapse occurred following a period of recent heavy weather and torrential rain
Quantum	TBA

Project:	**Shuakhevi (Georgia Hydro)**
Location:	Georgia
ECV	TBA
Description:	**The Shuakhevi Hydro Power Plant** (**Skuakhevi HPP**), is a run-of-the-river plant currently under construction in Adjara, Georgia. Construction on the project began in 2013 and it is expected to be operational in 2016. It will have an installed capacity of 187 megawatts (251,000 hp) with expected electricity output of 452 gigawatt-hours (1,630 TJ). The plant will have the capacity for diurnal storage in two reservoirs (22-metre Skhalta dam with a 19.4-hectare reservoir and 39-metre Didachara dam with a 16.9-hectare reservoir) allowing Shuakhevi HPP to store water for up to 12 hours and sell electricity at peak demand times. Three main tunnels are to be constructed on the Shuakhevi project; the 5.8 km Chirukhistsqali to Skhalta transfer tunnel, the 9.1 kilometres (5.7 mi) Skhalta to Didachara transfer tunnel and the 17.8 km Shuakhevi headrace and pressure tunnel. It is estimated that the project will cost US$417 million. ***Reference Wikipedia.***
Date of Loss	TBA
Cause	Tunnel collapses
Quantum	Mid digit number - ***Reference Inside FAC 145th April 2019***

Project:	**Gibe 2**
Location:	Omo River, Etthiopia
ECV	US 373m
Description:	The Gilgel Gibe II Power Station is a hydroelectric power station on the Omo River in Ethiopia. It is located about 80 km (50 mi) east of Jimma in Oromia Region. The power station receives water from a tunnel entrance on the Gilgel Gibe River. It has an installed capacity of 420 MW and was inaugurated on January 14, 2010. Almost two weeks after inauguration, a portion of the head race tunnel collapsed causing the station to shut down. Construction on the power plant began on March 19, 2005, with Salini Costruttori as the main contractor.[1] The power station was originally slated to be complete in late 2007 but was delayed because engineering problems encountered during construction. In March 2005, the contract to excavate the tunnel was awarded to SELI and in October 2006, a tunnel boring machine (TBM) hit a fault, delaying the project. On June 9, 2009, both TBMs met each other and the tunnel was ready for hydraulic testing that September. The tunnel is "considered one of the most difficult tunnel projects ever undertaken, due to the critical, and in some reaches, exceptionally adverse, ground conditions."[3] The power station was inaugurated on January 14, 2010.[4]
Date of Loss	2010
Cause	Collapse of headrace tunnel
Quantum	TBA

Reference Wikipedia

Project:	**Glendoe Hydro Scheme**
Location:	Fort Augustus, Scotland
ECV	TBA
Description:	Glendoe's 600 m head (the drop from the reservoir to the turbine) is the highest of any hydroelectric scheme in the United Kingdom, and is thus ideally suited to generating large amounts of energy from the stored water in the reservoir, especially when combined with the relatively high annual rainfall in the area of around 2,000 mm. The Andritz six-jet vertical axis Pelton turbine at Glendoe is capable of generating up to 100 MW, with a peak flow of 18.6m³/s. It is the largest of Scotland's recent civil engineering projects, with Hochtief as the design and build contractor. The scheme is predicted to produce about 180 GWh[of electricity per year, enough to provide approximately 5% of the electricity consumption of the city of Glasgow. This gives an overall load factor of approximately 20%. The immediate catchment of 15 km² is supplemented by a further 60 km² connected to the scheme by an underground network of pipes and tunnels, and this is fed into the reservoir on the upper reaches of the River Tarff. The dam, a 905-metre-long concrete-faced rock-filled embankment reaching a height of 35 m above the valley floor, is hidden from view from all current houses and public roads in the area. The scheme includes a number of tunnels. An 8.6 km tunnel brings water from diversion intakes to the reservoir. An 8 km long 5m diameter tunnel carries the water to the turbine and out into Loch Ness. This was excavated by a 220m long tunnel boring machine (TBM), that was named "Eliza Jane" after a competition for local schoolchildren.[8] Finally, an access tunnel of 1.3 km in length services the turbine and power station cavern, from the B862 above Fort Augustus. The power station itself, 2 km from Loch Ness and containing the turbine and generator units, is housed in a large cavern a quarter of a kilometre below the hillside, adjacent to a smaller cavern containing the main transformer.
Date of Loss	August 2009
Cause	In August 2009 the station was shut down and the power tunnel drained because of internal rock falls near the head of the tunnel. Although the equipment in the power station was not affected, Glendoe was unable to generate power until repairs were made. SSE reported

that electricity generation was unlikely to proceed until well into 2012. The repairs involved construction of a bypass tunnel and a downstream access tunnel. The contract for the repair work was awarded to BAM Nuttall. SSE issued proceedings seeking to recover £130 million in repair and reinstatement costs and £65 million in alleged loss of profit from Hochtief, who constructed the original tunnel, but in a Judgment (Opinion) published in December 2016 Hochtief was held by the Scottish Court of Session not to have been liable for the collapse. In an appeal decided in 2018, SSE were awarded more than £100 million in compensation. The judges hearing the appeal split 2-1 in SSE's favour.

Energy generation at the scheme restarted in August 2012.

Quantum TBA

Reference Wikipedia