The effect of adverse weather on construction sites

Working Group

Richard Radevsky, Charles Taylor adjusting, London, UK - Chairman
Brad Dalton, Suncorp, Sydney, Australia
Simon Chen, Engineering Insurance Association, Taipei, Taiwan
Alessandro Stolfa, Assicurazioni Generali S.p.A., London UK
Matia Cazzaniga, Zurich Insurance, Zurich, Switzerland
Raik Wittowski, Swiss Re, Zurich, Switzerland

Executive Committee Sponsor

Emanuel Baltis, Zurich Insurance Group
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Executive Summary

A wide variety of construction projects may be damaged by snow, ice, extreme cold, heavy seas, strong winds, hurricanes, typhoons, tornadoes, torrential rain, flooding or wildfires / bushfires. Some weather risks are obvious and precautions taken against damage as a matter of course, whilst others may surprise those managing construction sites.

Since a site may be particularly vulnerable to a certain type of weather damage for only a limited period it may be tempting to take no special precautions and hope that an adverse weather event does not happen until the period of vulnerability has passed. Construction best practice however is based upon risk awareness and the implementation of suitable precautions to minimise the risk of damage as a result of damaging events during the life of a project.

Insurance policies include special clauses that are tailored to specific classes and addressed to the insured to incentivise contractors to assess risks and undertake construction tasks progressively rather than finishing one construction task (such as trench excavation) before moving to the next (pipe or cable laying and backfilling).

Making preparations for adverse weather is a sensible risk management activity and this paper identifies tasks for each type of weather considered. It also cites references where further information can be obtained.

Climate change is likely to make adverse weather more intense and unpredictable and heighten the need to prepare for the worst if losses are to be minimised.
1 Introduction

Damage at construction sites caused by adverse weather is a common occurrence.

The form of construction sites changes during the construction process as does their vulnerability to damage. It is not cost-effective to spend as much money, design or construction effort on temporary works, as is needed for the permanent works since temporary works will only be vulnerable for a short period.

To increase resilience to adverse weather, contractors often have to spend time, effort and money on temporary works and may be tempted to economise on preparations by gambling that adverse weather will not hit the site at the time when it is vulnerable.

There is a cost/benefit judgement to be made between spending money on weather resilience versus the perceived risk of damage. Risk management techniques are used by contractors to determine the level of precautions they should implement. In addition part of the reason for buying Contractors’ All Risks insurance is to mitigate the financial risk of weather damage.

Insurers have to judge what is reasonable to expect contractors to do. To make such a judgement it requires knowledge of the types of adverse weather to which a construction project can be exposed and the type of damage that can result. This depends on the location, form and nature of the construction site at the time adverse weather strikes. It is important for insurers to know what types of precaution can be taken so that when projects are underwritten or surveyed before or during construction the underwriter can judge if weather damage risk is being adequately managed.

The subject of weather damage to construction sites is covered in many existing publications. A document providing general guidance on this subject has not been found during the research for this paper. These generally concentrate on particular weather perils or particular types of construction. The aim of this paper is to bring together, in one place, references relevant to most sites and summarise the subject. Given the nature of this paper, the authors have had to apply some limits to the subject-matter.

The following forms of adverse weather have been addressed:

- Snow, ice and extreme cold
- Heavy seas
- Strong winds – hurricanes, tomados and typhoons
- Torrential rain and flooding
- Lightning
- Hail
- Wildfire/Bushfire

Authoritative information about the prevalence of different types of adverse weather at any location in the world can be obtained using the Globe of Natural Hazards produced by Munich Re and available at


Each of the forms of adverse weather listed above has then been considered from the following points of view:
• Projects most exposed to this type of weather
• Potential damage
• Examples of damage (case histories)
• Precautions to be taken to minimise damage

The paper then considers the insurance aspects of the subject matter under the following headings:

• Underwriting considerations (including PML)
• Standard Policy Clauses

An extensive list of references for further reading is included in the paper.
2 Definitions of adverse weather considered in this paper

2.1 Snow, ice and extreme cold

Precipitation that reaches the ground in a frozen state includes snow, snow pellets, snow grains, ice crystals, ice pellets and hail.

SNOW

*Frozen precipitation in the form of white or translucent ice crystals in complex branched hexagonal form.*

Snow most often falls from stratiform clouds, but can fall as snow showers from cumuliform ones. It usually appears clustered into snowflakes.

BLIZZARD

*A severe weather condition characterized by low temperatures, winds 56 km/h or greater, and sufficient falling and/or blowing snow in the air to frequently reduce visibility to 0.4 kilometre or less for a duration of at least 3 hours.*

A severe blizzard is characterized by temperatures near or below -12°C, winds exceeding 72 km/h, and visibility reduced by snow to near zero.

WINTER STORM

*Any one of several storm systems that develops during the late autumn to early spring and deposits wintry precipitation, such as snow, freezing rain, or ice.*

ICE STORM

*A severe weather condition characterized by falling freezing precipitation:* Such a storm forms a glaze on objects, creating hazardous travel conditions and utility problems.

ICE

*Water that has frozen*

If water is present and the temperature drops below the freezing point of that water, the water will turn into ice. Ice has a greater volume than the water from which it is formed and if the water which freezes is constrained from expanding as it freezes it can generate a
significant and in some cases damaging bursting force. Some materials that have water as a constituent can deteriorate or be damaged if the temperature sinks below the freezing point of the water.

EXTREME COLD

No specific definition exists for Extreme Cold but the characteristics of an Extreme Cold event are that temperatures are at or below freezing for an extended period of time. The lowest recorded temperatures depend upon location. In some parts of the world temperatures below freezing have never been recorded. In Antarctica the lowest recorded temperature was -89°C.

2.2 Heavy seas

STORM SURGE

The increase in sea water height from the level that would normally occur were there no storm.

A list of notable surge events is shown in Appendix 3.

2.3 Strong winds – hurricanes, tornados and typhoons

WIND

Air that flows in relation to the earth’s surface, generally horizontally (Damaging Microbursts can occur generated by air sinking vertically in a very localised area).

There are four areas of wind that are measured: direction, speed, character (gusts and squalls), and shifts.

CYCLONE

An area of closed pressure circulation with rotating and converging winds, the centre of which is a relative pressure minimum.

The circulation is counter clockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere, also called a low pressure system.

TROPICAL CYCLONE

A warm core low pressure system which develops over tropical, and sometimes subtropical, waters, and has an organized circulation.

Depending on sustained surface winds, the system is classified as a tropical disturbance, a tropical depression, a tropical storm, or a hurricane or typhoon.

TROPICAL STORM

A tropical cyclone in which the maximum sustained surface winds are from 63 kilometres per hour (34 knots) to 117 kilometres per hour (63 knots).

The system is given a name to identify and track it.

TYPHOON

A tropical cyclone with sustained winds of 119 kilometres per hour (65 knots) or greater in the western North Pacific Ocean.

This is known as a hurricane in the eastern North Pacific and North Atlantic Ocean, and as a cyclone in the Indian Ocean.
HURRICANE

The name for a tropical cyclone with sustained winds of 119 kilometres per hour (65 knots) or
greater in the North Atlantic Ocean, Caribbean Sea, Gulf of Mexico, and in the eastern North
Pacific Ocean
This is known as a typhoon in the western Pacific and a cyclone in the Indian Ocean.

EXTRATROPICAL CYCLONE

Any cyclone that is no longer tropical in origin. Generally considered to be a migratory frontal
cyclone found in the middle and high latitudes
This cyclone no longer derives its energy source from the processes involved in sustaining a
tropical cyclone, but thrives on the temperature contrast between warm and cold air masses.

2.4 Torrential rain and inland flooding

RAIN

Precipitation in the form of liquid water droplets greater than 0.5 mm
If widely scattered, the drop size may be smaller. The intensity of rain is based on rate of fall.

- "Very light" (R--) means that the scattered drops do not completely wet a surface.
- "Light" (R-) means it is greater than a trace and up to 2.5 mm an hour.
- "Moderate" (R) means the rate of fall is between 2.5 to 7.6 mm per hour.
- "Heavy" (R+) means over 7.6 mm per hour.

MONSOON

Monsoons are the result of the seasonal shift of winds created by the great annual
temperature variation that occurs over large land areas in contrast with associated ocean
surfaces. The monsoon is associated primarily with the moisture and copious rains that
arrive with the southwest flow across southern India. This pattern is most evident on the
southern and eastern sides of Asia, although it does occur elsewhere, such as in the south-western United States.

FLOODING

‘High water flow or an overflow of rivers or streams from their natural or artificial banks,
inundating adjacent low lying areas’

Flash floods occur as a result of the rapid accumulation and release of runoff waters as a
result of torrential rainfall, cloud bursts, landslides or the failure of flood control works. They
are characterised by a sharp rise followed by relatively rapid recession causing high flow
velocities. Discharges quickly reach a maximum and diminish almost as rapidly. Local floods
are generally confined to rather small geographical areas and are normally not of long
duration. However in regions of extended rainy seasons (monsoon climates), local floods
may last for weeks, resulting in widespread destruction.

River floods are triggered by heavy rainfall or snow melt in upstream areas, or tidal influence
from the downstream. Ground conditions such as soil, vegetation cover, and land use have a
direct impact on local flow capacities. The river levels rise slowly and the period of rise and
fall is particularly long, lasting a few weeks or even months, particularly in areas with flat
slopes and deltaic areas. Failure or bad operation of drainage or flood control works
upstream can also sometimes lead to riverine flooding.
2.5 Hail

HAIL

Precipitation in the form of spherical or irregular pellets of ice larger than 5 millimetres (0.2 inches) in diameter

Hail is formed in huge cumulonimbus clouds, commonly known as thunderheads.

Hail falls along paths known as hail swathes. These vary from a few square acres to large belts 16 kilometres (10 miles) wide and 160 kilometres (100 miles) long.

2.6 Lightning

LIGHTNING

The occurrence of a natural electrical discharge of very short duration and high voltage between a cloud and the ground or within a cloud accompanied by a bright flash and typically also thunder

Lightning is one of the most common weather phenomena. Recent satellite data suggests that there are more than 3 million lightning flashes worldwide per day, or about 40 flashes per second on average. This includes flashes within or between clouds as well as flashes extending from cloud to ground.

2.7 Bushfires/Wildfires

BUSHFIRES / WILDFIRES

An uncontrolled fire in the bush or wild area; a scrub or forest fire

The Mediterranean climate found not only in that region but also along the coasts of California and Chile, the east coast of Australia, and elsewhere, provides a setup for wildfire vulnerability. The typical pattern is a wet season that spurs plant growth, followed by a dry season in which the new vegetation withers, becoming tinder in abundance.

2.8 Types of adverse weather not covered by this paper

In addition to those types of adverse weather that this paper considers, there are other types which the paper does not consider (such as dust storms, sandstorms, extreme heat and salt air). That is not to say that these other types of adverse weather cannot cause damage to construction sites however research has suggested that damage from them is relatively uncommon.

The view of the working group for this paper was that the above-mentioned types of adverse weather did not warrant dedicated sections in this paper.

In addition the paper does not consider tsunami as this is not considered to be a weather event but rather the consequences of an earthquake.
3 Snow, ice and extreme cold

3.1 Projects most exposed to this type of weather

Some project types most sensitive to cold weather are listed below:

- Heavy civil projects which include large foundations and contain large volumes of concrete require special care in cold conditions.
- Hydropower plants, dams and reservoirs also frequently contain large volumes of concrete as well as roller compacted concrete, waterproofing membranes and clay layers which can be affected by cold conditions. Such projects which are generally located on rivers can also be exposed to events triggered by glacial lakes.
- Pipelines and in-line infrastructure projects including railways and motorways usually spread across wide areas which can include areas affected by winter weather. They may also include materials with a plastic element, such as high density polyethylene (HDPE) pipes and/or multi-layer structures and embankments produced from cement treated base materials both of which can be vulnerable to damage in cold weather.
- Mining ore/mineral processing plants with primary crushing and ore processing operations usually involve the use of heavy equipment and they have to be carried out as close as possible to mines to minimise transportation costs. Therefore the routes for the construction of ore-ducts and conveyor belts in mountain regions can cross avalanche-exposed areas.
- Wind farms often include large concrete foundations which require special care in winter weather and they can be located in areas exposed to cold weather, strong winds, snow and ice.
- Transmission and distribution lines extend over long distances and are often made up of light tower structures and cables vulnerable to ice storms, freezing rain and ice build-up.
- Sewage treatment facilities and drainage systems are often constructed in low lying areas where thawing snow and ice can produce large flows of water. They also contain pipes and inlets that can be blocked by snow and ice.
- Buildings, Factories and Warehouses often contain large quantities of brickwork and masonry as well as porous materials. Aluminium and glass curtain walls are commonly used in low and high-rise buildings but it may be difficult to provide adequate heat circulation especially during construction to ensure they dry out without damage. Sprinkler systems and other services may need to be filled with water for testing which can freeze if not properly managed.
- Solar power plants and photovoltaic plants include modules with collectors or mirrors (flat or parabolic). Each unit is normally provided with an electro-mechanical system to track the sun and during peak winds or snow/ice storms collectors or mirrors are placed face down or vertical. During construction, units installed on site may not have the tracking system activated. Furthermore thermo solar plants usually use a heat transfer fluid to generate steam and this fluid can be extremely sensitive to low temperature (even above zero) when it is not constantly circulated in the system and heated.
- Tunnelling and underground works in a permafrost region or a cold weather environment require particular care. Frozen soil presents similar conditions to ground freezing but seasonal temperature variations have to be carefully analysed as a minor temperature increase can considerably affect soil stability and groundwater ingress.
3.2 Potential damage

Exposure to cold weather effects is strongly dependent on the construction site location e.g. on the persistence/magnitude of cold weather conditions and on the surrounding ground morphology. Vulnerability is also associated with the stage of construction. For example, temporary roofing or temporary supports to large roofs which may not be completed before the cold season causes problems with heavy snow fall.

Construction works depend heavily on favourable weather conditions and thus the impact of minor material damage can create a significant delay if repairs have to be carried out in unsuitable cold weather conditions. Repairs during the cold season may require more time or have to be postponed until the cold season has ended with consequent impact on the project schedule. In certain areas access by heavy vehicles is only possible when the cold winter weather causes the ground to freeze. If damage occurs at the end of the cold season it may be necessary to wait until the next winter when the ground re-freezes before access is again possible.

Projects in cold weather areas require careful programming if the project has to be completed before the start of the bad weather season. If work is interrupted then the critical path may have to be extended over the cold season.

Damage to construction operations as a result of snow, ice and extreme cold include the following:

- Construction sites on or at the base of steep slopes/narrow valleys can be particularly exposed to avalanches and both temporary and permanent structures have to be designed accordingly. Pipelines and infrastructure projects (e.g. railways and motorways) usually spread across wide areas and the mitigation of avalanche hazard is of utmost importance depending on local conditions. Damage to property can occur due to direct impact or blast effects from an avalanche.

- Large construction sites with extensive outdoor operations (including motorways and pipelines) can suffer from snow accumulation due to heavy snowfalls so that snow and ice removal become critical to restore safe conditions before proceeding and to keep access routes open. Additional weight (overload) on horizontal surfaces. Snow or ice storms (combined with strong wind exposure) can affect mobile crane booms as a result of the build-up of ice or snow. Blades or nacelles of wind turbines are similarly vulnerable. Ice storms and freezing rain can produce some of the most destructive effects on the core elements of T&D lines: light tower structures and cables are among the items most exposed to these conditions since overloading due to ice can result in collapses and extensive damage.

- When building on frozen ground, permafrost and specific geo-cryological (frozen ground) conditions have to be duly considered in the design of foundations. Settlements or jacking of the soil depending on subsoil characteristics, cyclical temperature variations and continuous permafrost layer thickness can cause distorted buildings, sagging roofs or even structural collapse. During the construction building elements not designed for exposure to frost may be accidentally exposed which can lead to heave or tilting due to the expansion of freezing ground.

- Rapid thawing of snow and ice can produce downstream flooding. Drainage and sewage systems are affected by cold weather because of overflow due to snow thaw. These effects are common when systems are in operation and under construction. Runoff is caused by snow, rain-on-snow, natural and man-made snow redistribution/removal. Frozen ground surfaces and frost penetration into the ground can result in freezing of pipes and clogging of gutters and inlets. Runoff events can be triggered during warmer weather as a result of rapid thawing. Problems during
construction are mainly due to flooding as a result of combined sewer overflows and overloading of wastewater treatment plants.

- Ice up and thaw of areas with challenging and changeable soil conditions

- Excessive snow load can be imposed on structures which are incomplete and unable to withstand them. Damage to or collapse can occur because of snow or frost accumulation (overload of horizontal surfaces and light structures). Both solar thermal and photovoltaic plants include modules with collectors or mirrors (flat or parabolic). Each unit is normally provided with an electro-mechanical system to track the sun and during peak winds or snow/ice storms collectors or mirrors are placed face down or vertical. During construction, units installed on site may not have the tracking system activated resulting in snow accumulation and overloading.

- Slowing or stopping the development of concrete/mortar strengths. Brickwork is affected by low temperature in much the same way as concrete (until the mortar has hardened) and is especially susceptible to frost damage. Porous materials are exposed to freezing/thawing cycles. Concreting and masonry suffer from delayed or poor chemical reactions in the cold and concrete strength development is reduced when temperatures fall below normal. Casting concrete (such as for large foundations) at temperatures below normal but still above freezing requires special precautions since temperature affects the rate at which hydration of cement occurs. Low temperatures retard concrete hardening and strength gain or even make it impossible to reach design strength at all or result in other damage – cracks easily form which are not compliant with project specifications. Massive concreting to form dams, water intakes and barrages amplify the issues for large foundations works and can become critical to RCC (roller-compacted concrete) dams. Specific controls need to be included in the design to minimize adverse effects and preserve quality and design intent of materials critical to dam stability. Weather conditions (snow, ice, high winds, etc.) may require special measures (such as the use of hot water) to maintain the concrete at the desired temperature and thus may make this operation less cost-effective than in mild weather.

- Damage to rubber, membranes and plastic elements (alteration of material properties or increased brittleness causing cracks as a consequence of shocks/lifting operations). Metals also can become brittle under shocks at low temperature. Minimum service temperature should be considered for metals to be used for equipment, tools and construction materials since brittleness varies significantly depending on metal alloy specifications. The performance of waterproofing membranes and clay layers depends on material properties which can be impaired by low temperatures. Plastic elements like high-density polyethylene (HDPE) pipes commonly used for pipelines or water distribution systems become brittle under shocks at low temperature requiring careful planning of the installation process. Multi-layer structures and embankments can suffer from poor performance of cement-treated base materials. Cracks, non-cohesive layers
and alteration in chemical composition in building materials can be created by cold temperatures resulting in application problems, poor quality, low durability or lack of waterproof properties.

- Should a dam or hydro-electric power project be built on a river that is fed by a glacier attention needs to be paid to the exposure from a glacial lake outburst flood (GLOF). Glacial lakes can form where a naturally formed dam blocks the water from a melting glacier. If it breaks this can result in a flash flood raising the river level within minutes by several metres with very little time to respond (Sutlej River flood August 2000 in India was assumed to be caused by a GLOF).
- Damages to pipework, services or equipment due to internal fluids freezing and bursting. Water used for testing sprinklers systems always has to be removed/blown out from pipes once testing operations are completed. Water left in pipes in unoccupied buildings can freeze and damage systems including sprinkler systems.
- Damage to works under construction caused by impact from floating ice or ice pressure build up
- Aluminium and glass curtain walls are commonly used in low and high-rise buildings but it may be difficult to provide adequate air and heat circulation especially during construction. Condensation and frost can build up on the back of panels which thaw in warmer conditions resulting in water infiltration and damage to interior finishes.
- Thermo solar plants usually use a heat transfer fluid to generate steam and this fluid can be extremely sensitive to low temperature (even above zero) when it is not constantly circulated in the system and heated. Solidification of the heat transfer fluid can result in damage to the entire plant.
- Underground works in a permafrost region or a cold weather environment may rely on heat insulation between the soil/initial support and the final lining of the tunnel to mitigate frost damage during concreting operations. Frozen soil presents similar conditions to ground freezing but seasonal temperature variations have to be carefully analysed since a minor temperature increase can considerably affect soil stability and groundwater ingress leading to a collapse or ingress of material.
- Building damage or collapse due to permafrost settlement
- Flood damage, landslides or subsidence due to thaw
- Rock falls and material alteration due to freeze/thaw cycles
- Water damage and infiltration due to condensation
- Fire damage due to lack of water as a consequence of frozen or ice-blocked pipes/reservoirs making fire-fighting facilities temporarily unusable.
- Loss or damage resulting from the operation of fighting a fire (e.g. ice build-up leading to collapse)
- Consequential loss due to ice building up during fire fighting temporarily blocking streets that led to the fire

Efficiency

Most works outdoors require more time and effort when performed in a cold environment whose principal characteristics are not only limited to low temperature but also include:

- Wind
- Precipitation (snowfalls/freezing rain)
- Avalanches
- Frost and ice
- Thaw/ice up and permafrost alteration
Specific factors to estimate increasing effort for performing tasks in cold conditions have been developed by the construction industry and the military services.

Since almost any kind of construction work may be performed on outdoor construction sites and mitigation measures can just be limited to small areas/sections (e.g. temporary shelters or hot air blowers), it is critical to consider lower efficiency levels for equipment and manual tasks when planning works in cold environments.

The following charts showing lower and upper efficiency levels in relation to temperature and snowfalls were developed in the 1980’s on the basis of military field tests and – regardless of noticeable improvements resulting from the deployment of the most recent technologies – they show exponential effects against minor temperature decrease or new snow drift.

Challenges associated with cold weather working include:

- Short building season/tight work schedule, delayed or slowed construction operations including excavation and disrupted material supply/procurement and external services.
- Material challenges (masonry, cement, polymers/HDPE, glass and aluminium elements, etc.) plus frozen stockpiles
- Deposition of frost on construction materials (e.g. reinforcement or scaffolding), completed structures and tools
- Increased costs
- Labour force safety, efficiency, and health issues to deal with increasing discomfort and hazards for personnel including slippery conditions and difficulties in movement, construction site ingress and egress
- Location of suitably knowledgeable design expertise
- Location of suitably knowledgeable construction workers
- Timely communication between design and operational teams
- Timely procurement and shipping of materials. Transport disruption, procurement and shipping difficulties (barges or air freight delivery can be impossible during cold weather)
- Third party or own facilities management (power/water supply e.g. for fire extinguishing)
- Mechanical construction equipment which may fail resulting in the need for maintenance/winterisation
• Additional hazards in relation to transportation and mobile machinery operations
• Provision of adequate site lighting (reduced daylight hours)
• The need for storage areas/shelters and protective measures
• Freezing soil and preventing subsequent works in contact with it (e.g. concreting)
• Interruption to the supply of power, water and other external services

3.3 Examples of cold damage

a) Frost/ice damage to pre-cast walls

Between Milan – Turin in the north/west of Italy pre-cast walls were extensively used to support embankments. This was considered the best way to speed up the project and reduce the size of embankment bases since most of the line runs next to an existing motorway and some urbanized areas.

Pre-cast walls placed on site

Noise barrier supports were designed to be fixed on the top of the pre-cast walls by means of
threaded holes which were fixed into the walls during pre-casting. Temporary plastic caps prevented debris from getting into the holes but these caps were not designed to be watertight. When the pre-cast walls were placed and the embankment built up, it rained for several days and after that the temperature suddenly fell below zero.

Walls and threaded holes facing north did not get the benefit of the heat of the sun since the embankment fill insulated them. Water in the holes started freezing on the surface and did not melt during the day so that it created a plug held in place by the threaded surface of the holes. After a couple of nights when the temperature was far below zero all the water in the holes froze. The frozen plug in the top of the holes prevented upwards expansion of the water below as it froze increasing pressure cracks and partial collapse of the outlying pre-cast wall finish. As it was not economic to remove the embankment and replace all the damaged panels (some kilometres were affected by the same loss) repairs took place in situ with extensive use of skilled labour.

This case shows how minor details can lead to a large loss particularly when the same cause applies to a large area and a single deductible applies.

b) Fire in a refinery

- Fire occurred in a refinery
- Efficient fire fighting contained the fire and allowed purging of the installation of hydrocarbons but the outside temperature was below -40°C
- Ice built up on the installation
- Repair was only possible when milder weather set in and the ice melted away
- There was a high impact on the DSU period due to delayed repair as a consequence of cold weather

Unintentional ice falls not for climbing….

c) Wooden frame structure in Canada

- A fire affected wooden frame buildings
- A fire fighting system was in place at the site including a ring main
- The ring main was well maintained and regularly checked
- When the fire occurred however the temperature was below -25°C and the ring main and hydrants were frozen……
3.4 Precautions to be taken to minimise damage

These can be classified into three main groups:

- Labour force health and safety on construction sites
- Construction plant and equipment winterisation
- General provisions for cold weather construction practice

Labour force health and safety on construction sites

Efficiency in cold conditions (not only in an extreme cold but just with temperatures slightly above zero) is reduced as compared with performance under normal conditions. Tactile sensitivity and manual dexterity deteriorate when the temperature falls below 10°C or when wind-chill is particularly strong. The body has to be maintained at a normal temperature and proper insulating materials have to be used in combination with work planning and shift duration to take into account climatic conditions.

Useful information on workplace safety and health topics related to cold weather can be found at the website of CDC – US Government Centres for Disease Control:

http://www.cdc.gov/niosh/topics/coldstress/

Construction plant and equipment winterisation

Construction works in cold weather expose equipment to extreme conditions which warrant special care. A proper winterisation process has to be planned for all outdoor equipment. This can include the use of winter fuels mixed with antifreeze and auxiliary heat or power for both starting and operation.

Equipment requires:

- Reasonable protection with comfort and visibility for the operator
- Capability to start and re-start reliably and warm-up
- Proper operation in cold weather (hydraulic components such as pumps and power steering can be impaired by frozen fluids or increased fluid viscosity)

General provisions for cold weather construction practice

Protection of construction operations mainly depends on local conditions at the site and the materials which are going to be used. Measure can include:

- Shelters for workers including:
  - Scaffolding enclosures formed by sheet materials fixed to a framework (translucent plastic materials are best but use of PET or other flammable plastic materials can increase fire exposure)
  - Air-supported structures (tents formed of low pressure cushions with air provided by blowers)
  - Windbreaks

- Safe surfaces for the movement of workers and equipment
- Avalanche shelters and protections are needed for both temporary and permanent structures where there is a specific exposure. Steep slopes may have to be monitored in case of snow accumulation and detailed contingency measures prepared – e.g. controlled avalanches to prevent snow overloading critical areas.
• Measures to avoid pressure or impact damage from ice floes in river side works including barriers and bubble curtains.

• Materials and construction processes behave differently in cold weather and have to be treated accordingly.

• Conditions have to be kept as stable as possible during concreting and rapid changes in temperature should be prevented.

• Additives may have to be added to the concrete mix to facilitate chemical reactions and may be used in combination with forced air heaters and protective shelters.

• Sand and aggregate may have to be protected from frost and stockpiles stored in a protected area and kept warm by means of electric blankets or heaters.

• More radical options include the use of pre-cast panels or walls rather than cast in situ concrete and planning to avoid concreting during the cold season.

• Steel elements such as reinforced steel and pipes need to be protected from being covered by snow or ice and thus unavailable.

• Untreated timber elements used in the construction process should never be left fully exposed to very cold weather. A combination of icing and thaw cycles can damage timber and impair its structural properties. When timber elements cannot be stored in a protected area they should be preventatively treated.

• Earthworks, and in particular large embankments in difficult conditions (e.g. on permafrost), require special measures. Permafrost with an ice content combined with global warming effects and local disturbances as a consequence of new works can result in stability issues. Special techniques such as ventilation ducts (to allow air to pass through embankments) have to be used in such cases to assure work durability. These measures can be effective in raising the permafrost table and reducing the soil temperature e.g. in preventing ground ice from thawing and to ensure road base stability in permafrost regions. Soil structures and construction elements that are subject to expansion when freezing (especially clay and silt) need to be protected from freezing. This could mean that work has to stop during the cold season and a sufficient temporary cover layer has to be laid and then removed before the works can continue in spring time.

• Cement-stabilized embankments, largely used where locally available soil quality does not meet minimum technical requirements, need specific care during laying operations in cold weather.
- Polyurethane foam filling, installation of heating cables or forced air heating are some of the most common solutions to prevent condensation in curtain wall erection. Proper design such as continuous air and thermal barriers with parapet cladding vented and drainage to the exterior are often more effective and less expensive.

- Works time schedules and planning must be carefully set up (identifying activities to be completed before the cold season) and potential exposure due to works delays must be addressed by means of an appropriate risk assessment process. Delays before the cold season can result in noticeable works deferments and additional exposure if all design specifications and safety measures are not complied with.

**Opportunities**

Precautions and preventative measures for cold weather are critical to successful construction in cold weather and, although such measures may create challenges for contractors, they may also provide opportunities as follows:

- A faster construction process may be possible (e.g. using pre-cast rather than cast in situ panels)
- Improved cost control and process efficiency
- The development of a more skilled labour force
- More effective time planning and general safety awareness
4 Heavy seas

4.1 Projects most exposed to this type of weather

A wide variety of marine structures can be damaged by heavy seas. Most common are breakwaters and sea walls, typical structures used for the protection of harbours.

Some projects are located in areas exposed to major waves creating challenging conditions for works both in terms of exposure to extreme loads and to a very short period available over the year for the execution of the works. It is therefore very important to assess the program of works to determine if it will be necessary to suspend works during the stormy season. In this case works already performed up to suspension must be adequately protected.

It is also very important to check the reliability of the historic data for waves on which the statistics used for the calculation of the significant wave height (Hs) were based. The number of data available must be high enough to assure adequate reliability.

The design should also be checked through modelling.

4.2 Potential damage

Although the most dramatic surges are associated with hurricanes, even small low pressure systems can cause a slight increase in the sea level if the wind and fetch (the area over which the wind has blown) is just right. Size is estimated by subtracting the normal astronomic tide from the observed storm tide. Along the coast, storm surge is often the greatest threat to life and property from a hurricane. In the past, large death tolls have resulted from the rise of the ocean associated with many of the major hurricanes that have made landfall. (See Appendix 3) Hurricane Katrina (2005) is a prime example of the damage and devastation that can be caused by surge. At least 1500 persons lost their lives during Katrina and many of those deaths occurred directly, or indirectly, as a result of storm surge.

As with many other phenomena associated with water, waves can be very powerful. We can see their continuous effect on the reshaping of the coastline.

Engineering insurance applies to marine structures designed to cope with the effect of waves (including breakwaters and sea walls) during the period of their construction, i.e. when they are not yet able entirely to withstand the dynamic or static loads foreseen by the design.

Since this can lead to major damage, or even to the complete destruction of these structures, it is easy to understand why underwriters are particularly concerned with this type of project. The recent IMIA paper “Engineering Insurance Exposure related to Wet Risk” (IMIA-WGP 50(07)) described in details the different type of wet works normally insured and their exposure during the period of construction.

Before commenting about their exposure it is helpful to understand the concepts relevant to the design of these structures.

The most important factor in the design of marine structures is the height of the wave whose impact the structure must resist for a determined period of time (the lifetime expressed in years). The structure is required to withstand this without failing and thus endangering human life or causing major damage to property. This is the “Significant wave height (Hs)”, associated with a certain Return Period.

During bad sea conditions, structures will be hit by packages of waves of variable height. "Hs" is defined as the average of the highest third of waves recorded during one event.
The Return Period (RP) associated with “Hs” is the average length of time in years for an event of given magnitude to be equalled or exceeded.

“RP” and “Hs” are calculated for each structure once its lifetime and the degree of protection that it must offer have been determined. After that, the choice of the geometry of the breakwater allows the design of the final protection of the rubble mound breakwater ( armouring) or the caissons to be undertaken.

Whatever the type of structure chosen, it should be noted that the energy per unit length developed by waves when impacting such structures is proportional to the square of the wave height (the relationship being a quadratic function) and to its period. If the wave height doubles the energy will increase fourfold.

In the formulae used to determine the dimension of protection elements the weight of the element is directly proportional to the cube of “Hs”. This shows how important the accuracy of data available is for the calculation of “Hs”.

Such structures are highly exposed during construction, until the final armouring is in place. When a structure’s resistance relies only on aggregate or rocks of small dimensions and therefore low weight, large waves can readily provide more energy than the aggregate or rocks can withstand.

Inadequate design can cause major losses to the whole of a breakwater, including already completed sections, leading to the potential failure of the breakwater even with wave heights (Hs) less than the one chosen for the design. The fault in the design can be a consequence of a wrong estimation of Hs for the location and the lifetime of the structure or can be due to the lack of laboratory tests.

Underwriters should also take into account that this kind of “live projects” may require changes in design during the period of their construction. It is beneficial therefore to have surveys carried out by an expert who can identify elements to be monitored.

### 4.3 Examples of damage

Famous cases of major failures due to design are:

a) Sines West breakwater (Portugal)

A 2 km long rubble mound breakwater was protected by two armour layers made up of 21,000 unreinforced 42 ton dolos constructed between 1973 and 1978.
The breakwater was designed on the basis of a 100 year return period with $H_s=11\text{m}$ and at that time it was one of the largest in the world of its kind. On 26th February 1978, when construction was nearly complete, a storm hit the site with waves below $H_s$. This storm caused the loss of about two thirds of the armour layer and severe damage to the structure. Further storms in December 1978 and February 1979 caused the failure of almost the entire structure.

One of the major causes for this loss was found to be inadequate design, wave statistics and modelling.

The reconstruction of the breakwater was designed using Antifer Cubes of 92 ton on the trunk and 107 ton on the hammerhead for the armour layer.

b) Tripoli breakwater (Libya)

This was constructed in two phases between 1973 -1977 and 1976 – 1980. Problems occurred in 1974, 1975, 1977 and 1981 in the form of damage to the front and rear faces and heavy spray, venting and overtopping, resulting in delays in the construction of a carriageway behind the breakwater during severe storms. Design values of $H_s$ were 4m and 4.5m for sections 1B and 2A respectively; however, in 1981 values of $H_s=8-9\text{m}$ were recorded. Failure was attributed to an underestimation of design parameters and especially an underestimation of wave heights, with no consideration being given to maximum wave heights.¹

4.4 Precautions to be taken to minimise damage

When carrying out the risk assessment, underwriters should carefully assess the items listed below that can cause a particular exposure to heavy seas.

The loss exposure can be reduced by an adequate emergency plan that contractors should prepare at site and put into action in the event of an incoming storm covering the following:

- Sections of the rubble mound breakwater without final protection
- Caissons, making part of a seawall, already put in position but not secured
- Storage of caissons exposed to wave action
- Items of machinery (cranes particularly) positioned on the breakwater and used for the placing of the elements making part of the armouring or for the casting of the sea wall
- Works to the tip of the breakwater which must be suspended during the stormy season

In this section there is also brief consideration of:

- Loss or damage to the armouring due to faults in workmanship or materials.
- Loss or damage due to faulty design which is identified after bad sea conditions

Sections of the rubble mound breakwater without final protection

Rubble mound breakwaters are built in layers. Over the period of construction, it is very important to assess what will be the maximum length left without the final protection

(armouring) and for the underwriter to decide the appropriate limit for this to be stated in the policy.

Unprotected layers remain exposed to the action of waves until completion with the possibility of them being damaged or even washed away. During the normal process of construction the core is the most advanced part, followed by the various filters and the armoured section. On this basis it is not unusual to reach an overall unprotected section of 100 metres or more.

An adequate minimization of the risk exposure should be based on the possibility of stopping the advancement of the core as soon as the site becomes aware of a warning about an incoming storm. Thereafter all the subsequent layers, including the armouring, should be advanced up to the last core section that can be affected by the wave action. This should result in the formation of a section of complete breakwater with exposure only at its tip. Taking into account that nowadays meteorological stations can forecast an incoming storm 5 or 7 days ahead, it should be easy to keep the maximum extent of the unprotected breakwater within the length that can be reasonably completed with the final protection in this period of time.

Underwriters should take into account that this type of procedure will minimize the exposure but not avoid loss or damage to the breakwater in case of wave overtopping the breakwater during a storm. This will happen nevertheless only for major waves, therefore there will be a lower probability of damage associated with such an event.

Many breakwaters are designed with a crest wall on top to prevent overtopping waves causing damage to the side of the breakwater facing onshore (leeward). The crest wall can nevertheless only be placed when the whole breakwater is completed. Therefore until then the leeward side remains exposed in case of large waves.

Caissons, making part of a seawall, already put in position but not secured

The construction of a breakwater with caissons allows the final degree of resistance foreseen by the design to be reached in a very short time, provided that their placement has been completed in accordance with the design specification. Caissons on their own, even if filled with water when sunk in position, do not have the final resistance on which the design of the seawall will have been based as water has a density lower than aggregate. In order to reach the required resistance, it is important that, after their positioning, they are filled with aggregate. It is also important that concrete lids are placed after the filling otherwise aggregate remains exposed to extraction by the action of waves. Last but not least the stability on the foundations must be assured with the placement of the foreseen stoppers in front of the caissons.
Storage of caissons exposed to wave action

In some cases at a certain moment the number of caissons produced may exceed the number that is possible to position. This happens, for example, when the sea conditions delay or do not allow placement to be done.

In this case caissons must be stored usually semi-submerged in an area of shallow water on the site. In this situation they are not very stable and can easily be moved if hit by waves thereby causing damage to them. It is therefore important that the storage location is not exposed to the action of waves, whether directly or due to refraction or overtopping of existing structures. This is particularly important since the value of one caisson can range from EUR 200,000 up to more than EUR 1,200,000.

Items of machinery (particularly cranes) positioned on the breakwater and used for the placing of the elements of the armouring or for the casting of the sea wall

The movement and positioning of the armouring items requires huge cranes of high value.

Owing to their long jibs, it is important to check that the site has an emergency plan available in case of a storm to ensure that these valuable pieces of machinery are safely stored/protected. Plans should include consideration of loss prevention measures in the event that work has to be suspended.

Works to the tip of the breakwater which must be suspended during the stormy season

This type of exposure can happen when breakwaters are built in locations exposed to major waves during certain months of the year when it is foreseeable that it will not be possible to carry out the works without taking unreasonable risks.

If a suspension of works is foreseen, it is very important for underwriters to check that the tip of the breakwater and the section built up to the moment of suspension have been adequately protected, in accordance with the design specification. Underwriters should also decide whether loss or damage that is likely happen to the protection during the suspension period can be considered insurable or not.

Example of a breakwater with the tip protected for the interruption of works

Example of a tip protection after a storm

Loss or damage to the armouring due to faults in workmanship or materials

The placement of the elements making up the armouring is particularly critical and requires care and skill to ensure the degree of interlocking required by design specifications.
If this is not achieved, the action of waves can lead to cracking, breaking, and/or sliding of the protection elements or a combination of all of these. The replacement of these elements can be an expensive operation due, in the extreme case, to the need to remove all of them before repositioning. The cost of repairs can also be severely affected by the expenses incurred in the re-mobilization of the site.

This situation can be prevented by a robust quality assurance/quality control (QA/QC) program at site. Checks should be carried out both on the quality of the armouring items fabricated at site and on their positioning on the structure.

**Loss or damage due to faulty design**

Underwriters should always request evidence of the wave statistics on which a design has been based, making sure that values have been recorded and not estimated. Moreover, these should refer in a reliable way to the situation at site. The experience of the designer must also be checked.
5 Strong winds, hurricanes, tornadoes and typhoons

5.1 Projects most exposed to strong winds, hurricanes, typhoon and tornadoes

The causes of damage associated with strong wind include:

- wind penetrating a building’s envelope
- uplift of the roof
- flying debris
- storm surge
- irregularities in elevation and plan
- siting problems

Based on past loss events, we illustrate some typical projects which are most exposed to wind forces during construction:

- Buildings, factories and warehouses
  Wind can tear off roofs from buildings, rip sidings from exterior walls, and throw debris through windows. Falling trees can crush roofs and walls. Wind can act on building components: horizontal racking forces (forces that occur in walls parallel to the wind direction), vertical uplift forces (as a result of internal pressurization and external suction), and overturning forces.

- Special construction such as radar or antenna structures
  Installing antennas on windy days can be dangerous. Even slight winds create strong forces. Antennas improperly installed on an inadequate or incomplete structure are very susceptible to wind damage.

- Towers (including electric towers, transmission towers, electricity pylons, ironman or hydro towers, cell towers, and mobile phone base station towers).

- Silos and bins
  Some structural damage has been seen in grain bins resulting from negative pressure that develops on the sheltered side during a high wind event. An open man way on the sheltered side of an empty structure can create a path for air to move from the interior to the negative pressure zone on the exterior of the bin. This creates an external overpressure on the side exposed to the wind that can cause the wall to buckle or the structure to collapse.

- Tanks
  Tanks under construction can be damaged by direct pressure and/or suction forces caused by wind. In some cases, a vacuum is created inside a tank that is designed for positive pressure. Once the negative pressure exceeds the design pressure the tank can be crushed.

- Hydraulic structures, hydro projects, marine works, seawall and harbour works
  Seawater levels are usually raised significantly by strong onshore winds and by suction due to low atmospheric pressure. The wind causes the water surface to assume a slope due to wind shear, thus forming a storm surge which is further affected by the topography of the coastline. Thus waves imposed by wind are one of the major causes of coastal flooding and damage to coastal structures.
• Bridges
Wind gusts at a similar frequency to the bridge’s harmonic frequency can cause poorly designed suspension bridges to sway. In dozens of loss events in the 18th and the first half of the 19th Century, oscillation by wind was one of the major causes of damage to bridges.

• Pumping stations
If the location of a pumping station during construction is close to the coast it will be vulnerable to storm surges and damaging winds.

• Overhead transmission lines
Damaging/destructive winds can have a significant impact on transmission and distribution systems. Experience from Hurricanes Katrina and Rita showed that most damage was attributed to trees falling on equipment, windborne debris, and the effects of wind whipping the lines against insulators and equipment.

• Wind turbines, wind farm
There are more and more cases showing wind turbines damaged by gales and high winds because of the slenderness of their towers or their blades rotating too fast when out of control or damaged by excessive wind pressure.

• Solar heating systems, solar power plants or photovoltaic parks
Some of these systems can be severely damaged by gusts of wind lifting them due to their lightness and shape or by being hit by flying debris.

5.2 Potential damage

The Saffir-Simpson Hurricane Wind Scale (see Appendix 2) - is a 1 to 5 categorization based on the hurricane’s intensity at the indicated time. The scale – originally developed by wind engineer Herb Saffir and meteorologist Bob Simpson – has been an excellent tool for alerting the public about the possible impacts of various intensity hurricanes. The scale provides examples of the type of damage and impacts in the United States associated with winds of the indicated intensity. In general, damage rises by about a factor of four for every category increase. The maximum sustained surface wind speed (mean wind speed measured during a 1-minute period at the standard meteorological observation height of 10m [33 ft] over unobstructed exposure) associated with the cyclone is the determining factor in the scale. The historical examples provided in each of the categories correspond with the observed or estimated maximum wind speeds from the hurricane experienced at the location indicated.

The scale does not address the potential for other hurricane-related impacts, such as storm surge, rainfall-induced floods, and tornadoes. It should also be noted that these general descriptions of wind-caused damage are to some degree dependent upon the local building codes in effect and how well and how long they have been enforced. Hurricane wind damage is also very dependent upon other factors, such as duration of high winds, change of wind direction, and age of structures.

In the last three decades there has been a dramatic increase in the number and severity of major windstorm events. A Munich Re report on natural catastrophe loss events since 1980 identified 773 events as “great natural catastrophes” (catastrophe category 6) and “devastating natural catastrophes” (catastrophe category 5). Roughly 88% were weather-
related. Insured losses attributable to all “great” and “devastating” natural catastrophes amounted to roughly USD 600bn. Storms account for 78% of these.

![Pie chart showing percentage distribution worldwide of insured losses attributable to great and devastating natural catastrophes since 1980.](image)

**Sources:** Data from Munich Re, 2011 TOPICS GEO - Natural catastrophes 2010

- On August 25, 2005 Hurricane Katrina hit the USA, the Gulf of Mexico, Bahamas and North Atlantic, etc. with insured losses of US$ 72 bn (indexed to 2010) and overall losses of USD 145 bn.
- On August 23, 1992 Hurricane Andrew struck the USA and Bahamas with insured losses of USD25 bn (indexed to 2010).

Wind speeds as low as 23 knots (43 km/h) can lead to power outages due to tree branches damaging power lines. Once winds exceed 135 knots (250 km/h), homes may completely collapse, and significant damage may occur to larger buildings. Total destruction of many man-made structures occurs when winds reach 175 knots (324 km/h).

Uncompleted structures are more vulnerable than completed ones. The strength and lateral stability of an uncompleted structure are, in most cases, much lower than for a completed one. Severe damage can result on building sites exposed to wind forces, in particular to roofs, uncompleted walls, formwork and temporary buildings. Perhaps the most vulnerable to wind forces during construction is the large steel storage tank. Hurricanes have a wind speed greater than 120 km/h and tomatoes, among the three types of whirlwinds, are the most destructive, with wind speeds of 400km/h or more. At that velocity, lightweight structures and industrial buildings are often completely demolished, while reinforced concrete and steel framed structures may suffer serious damage. In steel-encased reinforced concrete buildings, the cross sectional area of steel frames is relatively small making them vulnerable to wind during erection. It is therefore necessary to carefully plan construction in areas that are susceptible to wind storms. Wind turbulence may cause certain buildings to develop oscillations. Vortices can detach from building causing resonance of the structure, especially bridges and tanks, whether they have been completed or not.
5.3 Examples of damage

a) Crane collapse

The beams of a crane collapsed in a viaduct project after it was brought down by strong winds from Typhoon Conson in Paranaque city, south of Manila, Philippines on 11 July, 2010.

b) Damage to radar

Strong winds gusting to around 225 km/h caused damage to the Reno/Virginia Peak radar in western Nevada in December 2008. This is an example of damage to completed property; however, it could happen during the last stage of the erection project.

c) Wind turbine collapse

On September 28, 2008, a wind turbine in Taichung, Taiwan was blown down by Typhoon Jangmi shortly after the transfer of the completed work to the owner. The EAR policy had lapsed, since the turbine had already passed the commissioning period and the claim was withdrawn.

[Image of a damaged wind turbine]

The cause of loss was suspected to be defective material of the bolts which failed under the stress of strong wind force.

Source: Courtesy of Wins Adjusters & Surveyors Taiwan

[Image of corroded bolts]

d) Formwork, scaffolding and rebar damage

On 1st September 2005, unsecured formwork, scaffolding and a vast area of reinforcing bars were damaged by strong wing during Typhoon Talim in central Taiwan.

[Image of damaged formwork and scaffolding]

Source: Courtesy of Wins Adjusters & Surveyors Taiwan
e) Collapse of coal handling equipment

On 1\textsuperscript{st} October 2004, a coal storage dome and surrounding equipment of Hoping coal power plant was destroyed by storm during Typhoon Nock-ten in Hualien in eastern Taiwan. Although this was an example of damage to completed property, it could happen during the final stage of erection.

Source: Courtesy of Cunningham Lindsey Taiwan

f) Tower crane collapse

On 25\textsuperscript{th} October 2004, a tower crane on a construction site in Taipei County, Taiwan collapsed under strong wind force during Typhoon Nock-Ten. The cause was bad workmanship in erection of the tower crane.

Source: Courtesy of Wins Adjusters & Surveyors Taiwan
g) High voltage pylon collapse

In a storm high-voltage masts are affected, not only by direct wind forces, but also by resonance of wires generated by the storm. This can produce a domino effect pulling over several masts.

![High voltage pylon collapse](image_url)

Source: Munich Re publication – Windstorm - New Loss Dimensions of Natural Hazard ©1990

h) Empty tank blown off foundation

Empty tanks are particularly exposed to storm damage and may be carried through the air hundreds of metres, as was the case here in Edmonton, Canada hit by a tornado in 1987.

![Empty tank blown off foundation](image_url)

Source: Munich Re publication – Windstorm - New Loss Dimensions of Natural Hazard ©1990

i) Salt contamination through wind-blown seawater

A coastal power station site suffered a loss due to salt contamination when sea water was blown by strong winds onto the site during construction.
5.4 Precautions to minimize damage in construction sites

A project-specific windstorm hazard action plan will help to minimise the chances and scale of damage. Checklists are often useful for different phases of exposure. For example, the plan may cover 5 phases: pre-construction planning; imminent storm when storm is actually named; storm watch; storm warning & storm recovery.

Checklists should be regularly up-dated as the works proceed by referring to different construction activities. Organizational measures are outlined below:

**General**

- Detailed planning of construction schedules should avoid hazardous activities in the storm season to minimise exposure time. If the storm season cannot be avoided a strategy has to be carefully established.
- Awareness of site conditions that require advance attention or special materials is important so as to reduce emergency preparation time.
- Unstable works or assembly conditions should be avoided by providing suitable reinforcement, support ropes or girders. If necessary these should be installed at short notice when a storm is approaching.
- Identify vulnerable materials and work in progress and determine how best to protect these from the effects of strong wind.
- Large pieces of light insulation and surface sheeting materials must be protected from wind forces prior to and during installation, for example by keeping such materials rolled up or packed away until they are used.
- Construction site offices, workers' sheds, building material warehouses, construction equipment, etc. must be securely anchored and fastened in position.
- All hoardings, temporary structures, plant and other loose objects must be properly secured.
- Workers other than emergency team members should be evacuated from remote sites when a storm is approaching.
- Organize on site a full emergency team, including plant operators and fitters, who remain on duty throughout the severe weather period.

**Preparedness**

- Keep continuous check on weather forecasts.
- When warned by weather forecasters, designate an observer to monitor real time weather radar and warn the site.
- Keep the project site free from an accumulation of debris and scrap material that can become windblown hazards. This will reduce the amount of time necessary to complete preparations on the job site in the event of a storm emergency.
- Loose scrap material should be gathered up and disposed of.
- Waste bins should be emptied or if this is not possible they should be securely covered with nets.
- All loose forming materials should be neatly stacked and banded.
- Any non-essential barricades should be removed and essential barricades should be anchored.
• Top off the fuel tanks of all equipment and ensure fill caps are properly secured.
• Ensure diesel powered equipment is ready to operate.
• Ensure there is backup electrical generator power as required.
• All emergency equipment should be primed, tested and ready for use.
• Avoid long-term material storage in areas prone to wind.
• Prepare a list, procure and store supplies necessary for preparing the site.
• Be prepared to anchor or restrain anything that could blow away with banding and banding tools for lumber, form work, scaffold planks, portable lavatories, etc. Look and see what will fly and restrain it.
• Locate and turn off electricity, water and gas.
• Consider cancelling delivery of construction materials to all job sites except any materials needed to secure the construction site from storm damage.

**Scaffolding and/or Cranes:**

• Secure scaffolding to buildings or solid structures.
• Replace worn, corroded, or other unsafe components and make regular checks.
• Operation of mobile cranes should be suspended. Booms should be laid down if time permits or the load line hooked to the structure at some low point.
• Raise tower crane hooks, trolley in and unlock the jib on a tower crane to permit flexible alignment to the wind.
• For cranes that run on rails, anchor the chassis to the rail foundation with bolts and latches.
• Check the bearing capacity of the ground under cranes in view of the one-sided load during windstorms. If necessary, cranes should be secured with a cable-tensioning system.

**Motor vehicles parked at the construction site:**

• Put vehicles in a garage, if available, when there are storms or severe weather warnings.
• Close particularly exposed road sections and bridges to large lorries and caravans.
• At camp sites, secure caravans with cables.

**Special precautions for tornadoes:**

• Tornadoes are less predictable than other types of windstorm hazard. Approach time can be very short. There is normally less than 48hrs or even 24hrs reaction time. Safety of personnel has to be the first priority.
• Take refuge in a designated shelter structure on the site preferably underground. Avoid window and door openings. Do not seek shelter in vehicle or trailers.
• Operations of mobile cranes should be suspended. Booms should be laid down if time permits or the load line hooked to the structure at some low point. In some circumstances, equipment and/or other construction locations should be
vacated and refuge taken in a shelter.

After the storm:

- Organise a damage survey and repair team. This team should be the first on the site to assess damage and make the site safe enough for the return of the workforce.
- Assign persons in charge to inspect the site so that damage to scaffolds, temporary works, electrical installations, cranes etc. are identified and made good.
- Ensure that fuel supplies and generators are adequate for repairs.
6 Torrential Rains and Flooding

6.1 Projects most exposed to this type of weather

Any project site is potentially vulnerable to flash flooding if the terrain is steep, surface runoff rates are high, streams flow in narrow canyons or valleys if severe thunderstorms prevail.

In built-up environments a project site located in an area where surface run-off is in excess of local drainage capacity is potentially exposed to localised flooding.

Any project site situated on low-lying areas in the middle or lower reaches of rivers is particularly exposed to riverine floods. In most major river basins, without extensive flood mitigation infrastructure, flood plains are subjected to annual flooding.

A floodplain is an area of mostly flat land surrounding a river, stream or creek that experiences flooding when one of these waterways overflows its banks. Floodplains are divided into two main parts:

- The Floodway: the main area affected by an overflow, where the majority of water gathers to create a new, stronger water path
- The Flood Fringe: the outer area that lies beyond the floodway, where less water gathers and it moves much slower.

6.2 Potential Damage

The probability of experiencing a riverine flood at a construction project site is generally expressed as an average recurrence interval (ARI) in years. The ARI is the average interval between events likely to affect the site. Two flood risk measures are provided:

- the ARI (in years) of inundation of the project site at ground level, and
- the water depth during a flood with an ARI of 100 years.

The first metric represents the probability of flooding at the project site and it is this that dictates the overall risk. The second provides a surrogate indication of the potential loss from flooding as water depth is a key determinant of damage.

ARI is categorised into 5 levels and indicates the likelihood of the recurrence of a riverine flood across 5 categories:

<table>
<thead>
<tr>
<th>Category</th>
<th>ARI Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High (5)</td>
<td>ARI less than 20 years</td>
</tr>
<tr>
<td>High (4)</td>
<td>ARI between 20-50 years</td>
</tr>
<tr>
<td>Medium (3)</td>
<td>ARI between 50-100 years</td>
</tr>
<tr>
<td>Low (2)</td>
<td>ARI above 100 years</td>
</tr>
<tr>
<td>Negligible (1)</td>
<td>ARI above the Probable Maximum Flood</td>
</tr>
</tbody>
</table>

Hazards associated with heavy rains include flash floods, stream flooding, and landslides. Heavy rain events can also be accompanied by high winds and lightning. If it rains over an area for a long period of time, secondary damage can also result as the ground becomes saturated with precipitation. This can cause problems in watersheds and building stability. In addition, if temperatures are low enough, freeze-thaw cycles can cause problems for other structures including roadways.

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2 Risk Frontiers – Natural Hazards Research Centre
Flood Categories

Common flood categories are minor, moderate, and major flooding. The magnitude of the damage depends on the flood type (especially in terms of depth, flow velocity, water quality, duration and sediment load).

Minor Flooding is defined to have minimal or no property damage. In remote areas with few specific impacts, floods with 5-10 year recurrence interval would be assumed to be causing minor flooding on streams in the area.

Typical damage:
- water over banks and onto the project site but water flow is not deep or fast flowing
- minor damage to trenches, foundations, earth and civil works
- inconvenience or nuisance flooding

Moderate Flooding is defined to have some inundation of a project site near a stream or river. In remote areas with few specific impacts, floods with 15-40 year recurrence interval would be assumed to be causing moderate flooding on streams in the area.

Typical damage:
- minor or moderate damage across the project site specifically to civil and earthworks.
- various types of infrastructure rendered temporarily useless e.g. generator station flooded
- unpaved roads probably eroded due to current water moving over them

Major Flooding is defined to have extensive inundation of the project site. In remote areas with few specific impacts, floods with 50-100 year recurrence interval would be assumed to be causing major flooding on streams in the area.

Typical damage:
- substantial damage or destruction across the project site
- infrastructure destroyed or rendered useless for an extended period of time
- damage to earth and civil works likely to be severe.
- loss of transportation access, communication and power
- high estimates of damage

In urban areas flash floods are more destructive than other types of flooding because of their unpredictable nature and unusually strong currents carrying large concentrations of sediment and debris, giving little or no time for project or site managers to prepare for it and causing major destruction across the project site.

6.3 Examples of flood damage

a) Damage to hydraulic power plant project

A weir construction for a hydraulic power plant project in central Taiwan suffered a loss during Typhoon Gary passage in July 31, 1995. The flood overflowed the cofferdam and damaged the concreting work of the sluiceway and intakes.
b) Scaffolding washed away

The scaffolding for the erection of steel superstructure of a bridge construction work was washed away during a typhoon passage in eastern Taiwan.

Source: Provided by Simon S. T. Chen


c) Bridge fabrication yard washed away

The foundation of a fabrication yard for bridge pre-stressed beams was washed away causing the stored beams to break away during a typhoon.

Source: Provided by Simon S. T. Chen
d) Damage to dam site

Dead trees and flood debris damaged the construction site of the Cotter Dam, west of Canberra, Australia in Feb. 2012

Source: ACTEW (Australian Capital Territory Electricity and Water)

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e) Damage to Tower construction site

Flood damaged the construction site for the Vision Tower Brisbane CBD during the Brisbane Floods in January 2011

Source: Brisbane Times

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6.4 Precautions to be taken to minimise damage

Hazard Assessment

Evaluate the rain or flood hazard potentially confronting the construction site. Assessment should include:

- Ground elevation
- Seasonal climatic variations and the probability of torrential rain
- The local hydrology including groundwater and surface water
- Evaluate the ARI – the threat of flood from external water sources - rivers, canals, water courses.
The effect of adverse weather on construction sites

- Depth of previous or design floods over the site.
- Velocity of flood water
- Local topography including temporary and surface flow paths - where a water course would form and its likely course onto the construction site

**General Precautions:**
- Appropriately locate the storage of construction materials or earthwork stockpiles above design flood levels
- Provision to move and store all office equipment, plans and materials along with construction plant / machinery within safe areas above the design flood level.
- Locate fuel storage/ refuelling areas out of the floodplain
- Adopt a phased excavation program to minimise open works exposed
- Perimeter control around stockpiles
- Consult frequently with local weather agencies/ bureaus of meteorology.
- Exterior operations shut down before event (e.g. no concrete pours or paving)
- Soil treatments (e.g. fertilizer) ceased 24 hours ahead of event
- Materials and equipment properly stored and covered
- Waste and debris disposed in covered dumpsters or removed from site
- Trenches and excavations protected
- Perimeter controls around site areas
- Fuelling and repair areas covered and bermed.

**Site work precautions**
- Raise level of land where materials and plant can be temporarily located in a rain / flood event.
- Construct earthen embankments or dikes cutting out new water canals to by-pass the construction site.
- Keep dewatering trenches clean.
- Excavate a site drainage basin where water accumulates in a safe area where it will not interrupt construction.
- Hold additional sump pumps on site to drain out excavations and draw water down a safe path.

**Erosion & Sediment precautions**
- Ensure adequate capacity in sediment basins and traps to cater for excessive rainfall. A sediment basin is a temporary basin with a controlled release structure, formed by excavating or constructing an earthen embankment across a waterway or low drainage area. Sediment basins may be placed where sediment laden storm water may enter a storm drain or watercourse, and around and/or upslope from storm drain inlet protection measures.
- Temporary erosion controls deployed
  - Sediment fences are in place and appropriate to runoff conditions
- Sand bag barriers installed to block and divert flow
- Gravel bag berms utilised where appropriate to intercept and filter sediment-laden storm water run-off from disturbed areas, retaining the sediment and releasing the water.
- Use straw bale dikes, where permitted, at the base of slopes to capture incidental run off and sediment.

- Identify existing and/or planned storm drain inlets that have the potential to receive sediment-laden surface runoff. Determine if storm drain inlet protection is needed, and which method to use.
- Install filtration booms at site run-off culverts to control flow into river ways or city storm water system to prevent pollution
- Temporary perimeter controls deployed around disturbed areas and stockpiles
- Roads swept; site ingress and egress points stabilized

**Rain or Flood Event Action Plan (REAP)**

Develop and continually review and update a Rain Event Action Plan (REAP) based around developing site and climatic conditions.

Ensure that plans allow for the safe and timely evacuation of the project site for both plant and personnel in the event of a flood or severe weather warning or a subsequent flood.

A good example of effective measures taken is MidAmerican Energy (June 2011)

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3 California Environmental Protection Agency – State Water Resources Control Board

Source: IMIA News Sheet No. 20 March 2012
7 Lightning

7.1 Projects most exposed to this type of weather

Lightning is totally random and therefore any construction project is potentially vulnerable to a lightning strike with 70% of all lightning occurring between 35° north and south of the Equator.

Importantly 16 out of 20 accidents involving petroleum products storage tanks are due to lightning strikes.

7.2 Potential Damage

Within prone areas, lightning is one of the most common weather phenomena. The Munich Re Globe of Natural Hazards indicates which areas of the world are most prone to lightning strikes.

A recent Carnegie-Mellon study showed that 33% of U.S. businesses are affected by lightning — and that more businesses are affected by lightning storms than by floods, fires, explosions, hurricanes and earthquakes.

In the US lightning is responsible for more than USD5 billion in total insurance industry losses annually, according to Hartford Insurance Co.

Damage from Lightning falls into two broad categories:

- Physical damage to buildings under construction
- Electrical and electronic systems within structures

Due to their high energy electromagnetic effects lightning flashes may affect electrical and electronic systems (lightning electromagnetic impulses – LEMP). While the greatest risk is after construction and installation has been completed damage can occur within a building during the course of construction and prior to handover. Damage can occur either by:

- possible conducted and induced surges transmitted to apparatus via connecting wiring or
- the effects of radiated electromagnetic (EM) fields directly into apparatus itself.

Surges can be generated either:

- externally – lightning flashes striking incoming lines or the ground nearby the lines and transmitted to electrical and electronic systems via the lines themselves or
- internally – coupling due to lightning lashes striking either the building under construction or the surrounding ground.


7.3 Examples of Damage

The Lightning Safety Institute compiled a listing of losses related to Lightning in 2008. While not directly related to construction activities it provides a comprehensive view of potential loss scenarios on a construction site.

- During 2002-2004 U.S. fire departments responded annually to about 31,000 fires caused by lightning with USD 213,000,000 in direct property damages.
- Some 30% of all power outages annually are lightning-related, on average, with total costs approaching USD1 billion dollars.
- Lightning struck the automatic gauging device of a 38,800 m³ fixed-roof tank being filled with kerosene at 43.5°C (temperature higher than the flash point). The poor equipotentiality of the device resulted in sparks that triggered a fire. The gaseous cloud over the tank exploded destroying the roof. The burning liquid spread the fire to six other tanks in the dike. The fire was extinguished after three days.
- South African South Deep JV mine lost 1 month production due to lightning and flooding (2005).
- Porgera JV mine in Papua New Guinea had a severe lightning strike shutting down 50% of electrical power for more than three months at a production loss of USD 750,000/day (2006).
- A Tennessee smelter pot line was “frozen” by a lightning-induced electrical outage. 164 pots had to be dug out by hand. Production was shut down for seven weeks (2007).

7.4 Precautions to be taken to minimise damage

The Technical Committee on Lightning Protection of the International Electrotechnical Commission (IEC C81) has produced a complete standard that provides the general principles to be followed in the protection of structures against lightning.

Physical Damage to Structures

Part 3 of the Standard (IEC 62305-3) deals with the protection in a structure against physical damage, fire and explosion, by use of both external and internal Lightning Protection Systems (LPS)

The external Lightning Protection System (LPS) is intended to intercept direct strikes to the structure (air termination system, including the sides of the structure), to conduct the lightning current to the earth (down-conductor system) and to disperse it into the earth (effective earth termination system).

An internal LPS prevents dangerous sparking within the structure using either equipotential bonding or a separation distance (electrical insulation) between the external LPS components and other electrically conducting elements inside the structure.

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7 http://www.lightningsafety.com/nlsi_lls/nlsi_annual_usa_losses.htm
Electrical and electronic systems within structures

Basic protection measures against lightning electromagnetic impulses (LEMP) are:

- earthing (conduction and dispersion of the lightning current into the earth)
- magnetic shielding (spatial shielding by grid-like or continuous metallic shields attenuating the magnetic field inside LPZ arising from lightning strikes direct to or nearby the structure and reducing internal surges,
- shielding of internal lines using shielded cables or cable ducts minimising internal surges induced into the installation,
- shielding of external lines incoming to the structure reducing external surges transmitted to the connected electrical and electronic system)
- line routing of internal lines (by minimising induction loops and reducing internal surges);
- surge protective device system (SPD system), limiting both external and internal surges; this system generally consists of a co-ordinated set of SPDs.
8 Hail

8.1 Projects most exposed to this type of weather

Any construction project with:

- light metal cladding
- glass-roofed structures or skylights
- Photovoltaic / solar panels
- plant or materials in the open air

To assess the potential for hail damage at a construction site it is necessary to calculate the product of the maximum-recorded hail stone size at the project location along with the normalized annual frequency of hail at the site. In some locations this information may be readily available and in others will require investigation.

The likelihood of hail damage at a project site can then be classified as follows:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Very High</td>
<td>For a project site that experiences very frequent hailstorms and damage.</td>
</tr>
<tr>
<td>High</td>
<td>For a project site that experiences relatively frequent hailstorms and has a history of damaging hail.</td>
</tr>
<tr>
<td>Medium</td>
<td>For a project site where damaging hail is possible.</td>
</tr>
<tr>
<td>Low</td>
<td>For a project site that rarely experiences damaging hail.</td>
</tr>
<tr>
<td>Negligible</td>
<td>For a project site that has never experienced damaging hail.</td>
</tr>
</tbody>
</table>

8.2 Potential Damage

Hailstorms can potentially cause damage to any exposed components, materials or structures on a construction site, more so when the hailstone diameter exceeds two centimetres. The level of hail damage depends on the size, density, falling velocity and distribution of the hailstones, as well as the climate, the building structure and the stage of construction. Roofs typically are most susceptible to damage but hail can cause damage to skylights, glass roof structures and any exposed materials and equipment on site.

In general, hailstone damage can be categorized in two main types:

- Aesthetic / cosmetic - damage that has an adverse effect on appearance of the structure e.g. dents and damaged coatings, but does not affect the performance of the roof or building surfaces.
- Functional or structural – damage that results in leaks and cracks and may reduce the expected service life of the impacted surface.

In either of the above hail damage to impacted property will require repair or replacement to ensure either aesthetic appearance or functional performance.

In addition deep hail can easily worsen a flash flood situation. Since ice (hail) floats on water it has the potential to clog drains, culverts and grates and may cause water damage to partly completed civil works or incomplete structures.
8.3 Examples of Damage

Damage to Solar panels:

Damage to Roofing surfaces and structures:

Damage to exposed machinery e.g. non protected air conditioning units

8.4 Precautions to be taken to minimise damage

Scientists have tried many techniques to lessen the damage from hail storms. The most well-known technique involved "seeding" large thunderstorms with silver iodide. The theory was that the resulting small hail would probably melt and therefore not cause any damage. Unfortunately other experiments using this technique were not successful, and hail suppression remains elusive.
There are several techniques that can be used to reduce hail damage.

Pre-construction
- Install protective shields for rooftop equipment such as HVAC (high voltage alternation current) units that shield the fragile condenser coils.
- Install protective screens over skylights.
- Specify an impact resistant roof covering. Roof coverings are tested for impact resistance using Underwriters Laboratories test standard 2218, “Impact Resistance of Prepared Roof Covering Material” and assigned a class from 1 to 4, with Class 4 having the most impact resistance. Class 3 or 4 products are recommended in hail-prone areas.

During the course of construction
- Have a hail risk management plan and be aware of prevailing atmospheric conditions likely to give rise to hail.
  - Move any exposed plant and machinery
  - Shut off all unnecessary electric use on the project site.
9 Wildfire/Bushfire

9.1 Projects most exposed to this type of weather

Several countries have now developed maps to show zones most exposed to bushfires. In the absence of local hazard identification maps the following distances should act as a guide to judging whether there is an exposure:

- Within 0.5 miles (0.80 km) of any forest
- Within 100 ft. (30 m) of grasslands

The 0.5 miles (0.80 km) separation recognises that there are three significant ways a wildfire / bushfire can impact a project site, a building under construction or materials in the open air.

- Flying embers blown by the wind
- Direct flame encroachment
- Heat radiation leading to auto-ignition

9.2 Potential damage

Fire is a chemical reaction, combustion, requiring three components:

- fuels—anything that can burn
- heat sufficient to ignite available fuels
- oxygen to feed the chemical reaction, known as oxidation

Removing any "side" of this fire triangle stops a fire. The availability of fuels, heat, and oxygen to a wild land fire (i.e. in an area not significantly modified by human activity) is strongly influenced by the interplay of fuels, the topography of the landscape and climate patterns.

Fuels

The amount and type of fuel play a key role in determining the strength and extent of a fire. Fuel loading is the term used to describe the amount of burnable material in a given area, by weight.

A 1cm depth of fuel on the ground represents 5 tonnes per hectare. This is considered light fuel loading and could carry a mild fire. Thirty (30) tonnes per hectare or a depth of 6cm is considered a heavy fuel loading.

Fuels within 15 metres of a project site should be kept to no more than 8 tonnes per hectare. Grassland areas depend on the amount of cured, brown grass present. On a high fire danger day, a fire in sparse, fully cured grass land may have a 2 metre flame height. If the project is surrounded by grasslands with heavy levels of cured grass, this may produce 7 metre flame heights.

Climate plays a key role in fuel availability. The typical pattern is a wet season that spurs plant growth, followed by a dry season in which the new vegetation withers, becoming tinder in abundance.

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11 FM Global - Property Loss Prevention Data Sheets 9-19 – Wildland / Bushfire Exposures
Seasonal climate and recent weather also shape fuel moisture content. Live plants and trees can hold as much as three times their weight in moisture during a healthy growing season. Dead fuels hold far less moisture.

**Topography**

Hills and mountains also influence the direction and speed of wildfires. Valleys on the lee side of a mountain ridge, the side away from the prevailing wind, are vulnerable to hot, dry downslope winds. The prevailing winds rise along the windward side and shed their moisture as snow or rain as they reach cool temperatures at ridge tops. Once over the top, they are heated by increasing pressure as they descend to lower altitudes on the lee side of the ridge. Called Foehn in the Alps and Chinook in the Rocky Mountains, these downslope winds increase fire danger first by drying out the fuels in their path and then by steering the fire into new fuels once started. California's Santa Ana winds are another, particularly notorious example.

Along mountain valleys, solar heating and night-time cooling bring changes in wind direction. Fires driven upslope by daytime heating will typically settle down after sunset. This nocturnal laydown happens as decreased temperatures and raised relative humidity cause the moisture content in dead fuels to rise. However, night-time does not always ensure cooling and increased humidity. For example, temperature inversions can leave mid-slope areas much warmer and drier, and thus more vulnerable to fire, than other parts of the mountainside or valley.

Flames at the base of a slope heat the vegetation higher up, releasing combustible gases that burst into new flames, spreading fire uphill. Typically, this heating can move a blaze up a hillside at speeds up to 24 km/h. But observers have seen acceleration as fast as 161 km/h during a crown fire in treetops on a steep slope, when hot gasses suddenly leaped out from the treetops, igniting ground fuels farther up the slope. This threat makes fire fighting on steep slopes especially dangerous.

Generally the forward rate of spread of fire on level ground doubles for each 10-degree increase in up-slope (up to 30 degrees). As the slope increases, more of the ground fuel is brought closer to the radiant and convective heat from the flame front, thereby decreasing the time to ignition and increasing the rate of spread and intensity of the fire. A fire on a 30 degree upward slope can produce flames twice as high and travel several times faster than a fire on level ground.

**Climate Patterns**

Cold fronts and other regional features bring moist air that slows fires down with cooler temperatures and raised humidity. But the strong winds of a passing front can feed fresh oxygen to stir up a fire that has died down, steer a fire in new directions, or accelerate its progress, making cold fronts a mixed blessing.

Dry thunderstorms with lightning and winds are major culprits in starting and spreading wildfires. A wet thunderstorm however can offer relief if it brings sufficient rain. Lightning is the ignition source for most wildfires in remote areas. But wherever they live close to forests, people now cause the majority of wild land fires.

Besides the weather brought in by regional cold fronts or local thunderstorms, wild land fires create their own weather. The heated air in a raging wildfire rises, sending water vapour released during combustion into the atmosphere. This buoyancy also produces intense updrafts and horizontal winds that shape and drive the fire line itself, possibly triggering sudden changes in direction and intensity that can threaten a project site.
9.3 Examples of damage (case histories)

In recent years, with the on-going climate changes, wild land fire/bushfire incidents have become more frequent and more destructive. In 2003, approximately 62,000 fires burned roughly 3.87 million acres (1.57 million hectares) in the United States alone. In February 2009, the Black Saturday bushfires burned across the state of Victoria in Australia resulting in the highest loss of life ever from a bushfire. There were 400 recorded individual fires which burned 1.1 million acres (450,000 hectares) with various confirmed ignition sources including power lines, arson, lightning, and machinery. From July 2009 through November 2009, significant wild land fires occurred in Southern California, USA. There were several individual fires that collectively burned more than 336,020 acres (135,982 hectares), resulting in firefighter fatalities. Most of these fires were believed to be caused by arson, although some of the fires did not have a known cause.  

9.4 Precautions to be taken to minimise damage

Construction sites in wildfire-prone areas face unique risks from what are potentially destructive events. The building and combustible materials used during the course of construction make it important to identify, understand and take steps to prevent or reduce these risks before a wildfire threatens.

Flying embers driven by the wind are the biggest threat to a construction site during a wildfire. Once these embers land on a combustible material, the potential for the wildfire to spread across the site is significantly greater.

A project site well prepared is more likely to survive a bush fire or ember attack and easier for on-site fire teams or external fire-fighters to defend.

Precautions should therefore be taken as follows:

Fire Fighting & Water Supplies

- A bushfire protection plan and site bushfire plan is implemented and updated regularly.
- Ensure adequate fire fighting equipment and sufficient extinguishing agents are available and operative at all times and are regularly inspected
- Site personnel are trained in bushfire response and fire fighting.
- A reliable fire alarm system is installed and a direct communication link to the nearest fire brigade
- Ensure an adequate and reliable water supply to meet bushfire fighting demands.
- Install external hydrants and hose reels prior to construction beginning.
- Alternatively construct reservoirs or utilise on-site ponds as a source of water with a reserve of water and hose connection for public fire services to refill their appliances.

Vegetation

Create a clearance zone around the project site dependent on topography. For projects on steep slopes or hilltops remove vegetation 200 ft. / 60 m) downslope from the site and for projects on level ground remove vegetation a minimum of 100 ft. / 30 metres. This can be done by:

12 FM Global - Property Loss Prevention Data Sheets 9-19 – Wildland / Bushfire Exposures
Removal or pruning of trees and shrubs: the management of existing vegetation involves selective fuel reduction (removal, thinning and pruning) and retention of vegetation, which may have beneficial effects by acting as windbreaks and radiant heat barriers.

Raking or manual removal of fine fuels: remove fuels such as dry grass, fallen leaves, twigs and bark on a regular basis.

Performing low intensity hazard reduction burns in the non-hazardous periods of the year

Mowing grass: keep grass short, green and well watered.

Ploughing and grading: these methods can produce effective firebreaks, however, the areas need constant maintenance. Loose soil may erode in steep areas, particularly where there is high rainfall and strong winds.

Materials in the open air:

- Combustible waste material is removed regularly
- Maintain a minimum of 150 ft (45 m) space separation between materials in the open air and any building undergoing construction
- Locate materials on the opposite side of the building under construction to the prevailing wind.
- Separate materials into small blocks with a minimum of 30 ft. (9 m) space separation.
- Locate propane, fuel and lubricant tanks at least 30 feet from structures undergoing construction. Alternatively create a 10-foot zone around the tank using low combustible materials such as rock, gravel or mulch.
- Create an emergency response plan to relocate materials during wild land fires.
- Do not allow uncontrolled heating or cooking fires anywhere within or near the construction site or stores.

Equipment & Machinery use:

When carrying out welding, grinding, soldering or gas cutting in the open air:

- Place a shield or guard of fire resistant material in such a way as to prevent emission of sparks and hot pieces of metal.
- Keep an area of 3 metres around the work completely cleared of flammable material or wet down sufficiently to prevent the spread of fire. This is particularly important where waste wood, sawdust, bark, or dry grass is in the vicinity.
- Have a fire extinguisher (liquid type) of 9 litre minimum capacity.
- Avoid work when fire weather is hazardous, especially on days of high wind.
- If possible, bring the project into a safe, clean working area - on bare ground, concrete or within the confinement of an enclosed working area, rather than working in the field.
10 Insurance considerations

10.1 Underwriting considerations (including PML)

Major items to be taken into account by underwriters during their risk assessment are:

- The location of the project

Each of the weather perils should be assessed independently with a thorough and detailed risk assessment focussed on the sites natural-hazard exposure utilising specific geographical coordinates, hazard maps and/or their electronic equivalent geographical information system (GIS).

- The method of construction

As construction progresses the form of what is being constructed will change and its vulnerability to adverse weather will also change. Setting this against a background of differing weather severity creates a complex matrix of changing risks and vulnerabilities with time.

- The program of works

Different construction activities are however vulnerable to different types of weather. In addition since many areas of the world have marked seasonal difference in weather it is important for the underwriter to understand how the vulnerability of the site will change over time and which activities are programmed to take advantage of benign weather conditions.

Since projects can always be delayed it is also important that the consequence of a delay in terms of increased exposure to adverse weather are fully understood. In extreme cases some construction activities may have to be suspended during the season for adverse weather and only recommenced once it is over. If delays do occur it is important for the underwriter to appreciate that contractors may be tempted to continue after the benign weather season is finished in an effort to catch up.

- Assessment of the site specific weather perils

To be able to properly underwrite a construction risk the underwriter must be aware of the risks of different types of adverse weather that the construction site will be exposed to during the construction period.

In each of the detailed sections above potential damage scenarios were addressed for specific perils at a project site. The underwriters role is to assess the likelihood of damage, including but not limited to weather event probability, return periods and severity.

- Clients risk management & precautionary measures

Taking into account the range of perils a project site might be exposed to the importance of risk management becomes clearly evident. As risk assessment is core to the underwriter to enable the provision of capacity an individual assessment of a clients/projects risk management capability is a critical element of the underwriting process.

In each of the detailed sections above, risk mitigation / precaution strategies appropriate to the respective weather perils are discussed. The underwriter’s role is then to assess how
these strategies will limit or control exposure to the particular peril and allow for it in the pricing, terms and conditions for the individual project.

All these parameters are linked together and influence one another and in turn determine:

- Pricing
- Conditions & Endorsements
- Excess / Deductible levels

Additionally, Insurers may inspect the site at various times during the construction period, evaluate the situation and may make adequate recommendations.

**PML assessment and considerations**

Adverse weather conditions can be some of the most significant events to define possible loss scenarios for PML assessment.

Different loss scenarios resulting from a single event (e.g. simultaneously affecting several parts of a project) or triggered by different natural hazards have to be considered and analysed separately.

A base estimate of PML does mainly depend on the magnitude and the extent of natural hazards affecting a construction site but it can also be affected by the current status of works or the construction method and preventative measures in place at the time of the event.

Extremely severe conditions recurring in certain periods/seasons can be better managed than unexpected events with occasional recurrence and both these scenarios have to be carefully considered with a specific focus on local unfavorable geo-morphological conditions (e.g. potential floods in hollow areas or heavy rainfalls on steep and slide-prone slopes) and projects' critical paths.

The wide range of adverse weather conditions included in this paper make it difficult to present a specific PML assessment process but the following flow chart may be of assistance to identify the most probable hazards which could affect a project.

### PROJECT INFORMATION – ADVERSE WEATHER EXPOSURE

- Project features (technology, design and construction method) and their relevant Natural Hazards proneness including exposure to correlated perils following main events (e.g. fire following wind storm or earthquake if relevant)
- Project time schedule - Critical path and specific exposure related to different construction phases
- Natural Hazards/adverse weather exposure:
  a) Geographical area - Historical data (e.g. hydrologic statistics from local stations)
  b) Local morphology (e.g. critical local conditions: folds, river basins, flood areas)
It is also appropriate to focus attention on some peculiarities of large projects including different sections as partial hand over and wording restrictions can have a sizeable impact on PML assessment.

When projects are handed over and operated – other than for specific wording extensions – the construction coverage expires but it is possible that completed sections not put into operation remain covered and exposed to adverse weather conditions until the full completion of the project.

This has to be duly considered in the PML assessment as completed works are theoretically less exposed to Natural Hazards but they are still exposed and standard Section clauses normally used have no effect as they refer to actual state of completion of the insured works and they are not valid for completed works.

### 10.2 Standard clauses relevant to adverse weather on construction sites:

**Swiss Re**

- Clause 3.3.10 – 72 Hours Clause
- EPI 40 – Storage of materials
- EPI 44 – Pipelines, Conduits and cables
- EPI 45 Road Construction
- EPI 46 Ground Water Pumping Operations
Munich Re:

- Endorsement 1231 Special Exclusion: flood or inundation
- Endorsement 1232 Special Exclusion: windstorm
- Endorsement 1243 Special Exclusion: normal action of the sea
- Endorsement 1243 Special Exclusion: marine and off-shore work
- Endorsement 1248 Special Exclusion: section lengths
- Endorsement 1264 Special conditions: open trenches, pipes, cables and ducts
- Endorsement 1265 Special conditions: loss prevention in respect of flood and inundation
- Endorsement 010 Exclusion of loss, damage or liability due to flood and inundation
- Endorsement 012 Exclusion of loss, damage or liability due to windstorm or wind-related water damage
- Endorsement 013 Property in off-site storage
- Endorsement 106 Warranty concerning sections
- Endorsement 107 Warranty concerning camps and stores
- Endorsement 108 Warranty concerning construction plant, equipment and machinery
- Endorsement 109 Warranty concerning construction material
- Endorsement 110 Special conditions concerning safety measures with respect to precipitation, flood and inundation
- Endorsement 111 Special conditions concerning removal of debris from landslides
- Endorsement 117 Special conditions for laying water supply and sewer pipes
- Special conditions concerning fire-fighting facilities and bushfire safety on construction sites
- Endorsement 1260 Special conditions: contract time schedule
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## Appendix 1 – Beaufort Scale

<table>
<thead>
<tr>
<th>Beaufort scale number</th>
<th>Descriptive term</th>
<th>Units in km/h</th>
<th>Units in knots</th>
<th>Description on Land</th>
<th>Description at Sea</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Calm</td>
<td>0</td>
<td>0</td>
<td>Smoke rises vertically</td>
<td>Sea like a mirror.</td>
</tr>
<tr>
<td>1-3</td>
<td>Light winds</td>
<td>19 km/h or less</td>
<td>10 knots or less</td>
<td>Wind felt on face; leaves rustle; ordinary vanes moved by wind.</td>
<td>Small waves, ripples formed but do not break. A glassy appearance maintained.</td>
</tr>
<tr>
<td>4</td>
<td>Moderate winds</td>
<td>20 - 29 km/h</td>
<td>11-16 knots</td>
<td>Raises dust and loose paper; small branches are moved.</td>
<td>Small waves - becoming longer; fairly frequent white horses.</td>
</tr>
<tr>
<td>5</td>
<td>Fresh winds</td>
<td>30 - 39 km/h</td>
<td>17-21 knots</td>
<td>Small trees in leaf begin to sway; crested wavelets form on inland waters</td>
<td>Moderate waves, taking a more pronounced long form; many white horses are formed - a chance of some spray</td>
</tr>
<tr>
<td>6</td>
<td>Strong winds</td>
<td>40 - 50 km/h</td>
<td>22-27 knots</td>
<td>Large branches in motion; whistling heard in telephone wires; umbrellas used with difficulty.</td>
<td>Large waves begin to form; the white foam crests are more extensive with probably some spray</td>
</tr>
<tr>
<td>7</td>
<td>Near gale</td>
<td>51 - 62 km/h</td>
<td>28-33 knots</td>
<td>Whole trees in motion; inconvenience felt when walking against wind.</td>
<td>Sea heaps up and white foam from breaking waves begins to be blown in streaks along direction of wind.</td>
</tr>
<tr>
<td>8</td>
<td>Gale</td>
<td>63 - 75 km/h</td>
<td>34-40 knots</td>
<td>Twigs break off trees; progress generally impeded.</td>
<td>Moderately high waves of greater length; edges of crests begin to break into spindrift; foam is blown in well-marked streaks along the direction of the wind.</td>
</tr>
<tr>
<td>9</td>
<td>Strong gale</td>
<td>76 - 87 km/h</td>
<td>41-47 knots</td>
<td>Slight structural damage occurs - roofing dislodged; larger branches break off.</td>
<td>High waves; dense streaks of foam; crests of waves begin to topple, tumble and roll over; spray may affect visibility.</td>
</tr>
<tr>
<td>10</td>
<td>Storm</td>
<td>88 - 102 km/h</td>
<td>48-55 knots</td>
<td>Seldom experienced inland; trees uprooted; considerable structural damage.</td>
<td>Very high waves with long overhanging crests; the resulting foam in great patches is blown in dense white streaks; the surface of the sea takes on a white appearance; the tumbling of the sea becomes heavy with visibility affected.</td>
</tr>
<tr>
<td>11</td>
<td>Violent storm</td>
<td>103 - 117 km/h</td>
<td>56-63 knots</td>
<td>Very rarely experienced - widespread damage</td>
<td>Exceptionally high waves; small and medium sized ships occasionally lost from view behind waves; the sea is completely covered with long white patches of foam; the edges of wave crests are blown into froth.</td>
</tr>
<tr>
<td>12+</td>
<td>Hurricane</td>
<td>118 km/h or more</td>
<td>64 knots or more</td>
<td>Very rarely experienced - widespread damage</td>
<td>The air is filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected</td>
</tr>
</tbody>
</table>
Appendix 2 - The Saffir-Simpson Hurricane Wind Scale

**Category One Hurricane** (Sustained winds 74-95 mph, 64-82 kt, or 119-153 km/h)

*Very dangerous winds will produce some damage*

People, livestock, and pets struck by flying or falling debris could be injured or killed. Older (mainly pre-1994 construction) mobile homes could be destroyed, especially if they are not anchored properly as they tend to shift or roll off their foundations. Newer mobile homes that are anchored properly can sustain damage involving the removal of shingle or metal roof coverings, and loss of vinyl siding, as well as damage to carports, sunrooms, or lanais. Some poorly constructed frame homes can experience major damage, involving loss of the roof covering and damage to gable ends as well as the removal of porch coverings and awnings. Unprotected windows may break if struck by flying debris. Masonry chimneys can be toppled. Well-constructed frame homes could have damage to roof shingles, vinyl siding, soffit panels, and gutters. Failure of aluminium, screened-in, swimming pool enclosures can occur. Some apartment building and shopping centre roof coverings could be partially removed. Industrial buildings can lose roofing and siding especially from windward corners, rakes, and eaves. Failures to overhead doors and unprotected windows will be common. Windows in high-rise buildings can be broken by flying debris. Falling and broken glass will pose a significant danger even after the storm. There will be occasional damage to commercial signage, fences, and canopies. Large branches of trees will snap and shallow rooted trees can be toppled. Extensive damage to power lines and poles will likely result in power outages that could last a few to several days. Hurricane Dolly (2008) is an example of a hurricane that brought Category 1 winds and impacts to South Padre Island, Texas.

**Category Two Hurricane** (Sustained winds 96-110 mph, 83-95 kt, or 154-177 km/h)

*Extremely dangerous winds will cause extensive damage*

There is a substantial risk of injury or death to people, livestock, and pets due to flying and falling debris. Older (mainly pre-1994 construction) mobile homes have a very high chance of being destroyed and the flying debris generated can shred nearby mobile homes. Newer mobile homes can also be destroyed. Poorly constructed frame homes have a high chance of having their roof structures removed especially if they are not anchored properly. Unprotected windows will have a high probability of being broken by flying debris. Well-constructed frame homes could sustain major roof and siding damage. Failure of aluminium, screened-in, swimming pool enclosures will be common. There will be a substantial percentage of roof and siding damage to apartment buildings and industrial buildings. Unreinforced masonry walls can collapse. Windows in high-rise buildings can be broken by flying debris. Falling and broken glass will pose a significant danger even after the storm. Commercial signage, fences, and canopies will be damaged and often destroyed. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks. Potable water could become scarce as filtration systems begin to fail. Hurricane Frances (2004) is an example of a hurricane that brought Category 2 winds and impacts to coastal portions of Port St. Lucie, Florida with Category 1 conditions experienced elsewhere in the city.

**Category Three Hurricane** (Sustained winds 111-130 mph, 96-113 kt, or 178-209 km/h)

*Devastating damage will occur*

There is a high risk of injury or death to people, livestock, and pets due to flying and falling debris. Nearly all older (pre-1994) mobile homes will be destroyed. Most newer mobile homes will sustain severe damage with potential for complete roof failure and wall collapse. Poorly constructed frame homes can be destroyed by the removal of the roof and exterior walls. Unprotected windows will be broken by flying debris. Well-built frame homes can experience major damage involving the removal of roof decking and gable ends. There will be a high percentage of roof covering and siding damage to apartment buildings and
industrial buildings. Isolated structural damage to wood or steel framing can occur. Complete failure of older metal buildings is possible, and older unreinforced masonry buildings can collapse. Numerous windows will be blown out of high-rise buildings resulting in falling glass, which will pose a threat for days to weeks after the storm. Most commercial signage, fences, and canopies will be destroyed. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to a few weeks after the storm passes. Hurricane Ivan (2004) is an example of a hurricane that brought Category 3 winds and impacts to coastal portions of Gulf Shores, Alabama with Category 2 conditions experienced elsewhere in this city.

**Category Four Hurricane** (Sustained winds 131-155 mph, 114-135 kt, or 210-249 km/h)

*Catastrophic damage will occur*

There is a very high risk of injury or death to people, livestock, and pets due to flying and falling debris. Nearly all older (pre-1994) mobile homes will be destroyed. A high percentage of newer mobile homes also will be destroyed. Poorly constructed homes can sustain complete collapse of all walls as well as the loss of the roof structure. Well-built homes also can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Extensive damage to roof coverings, windows, and doors will occur. Large amounts of windborne debris will be lofted into the air. Windborne debris damage will break most unprotected windows and penetrate some protected windows. There will be a high percentage of structural damage to the top floors of apartment buildings. Steel frames in older industrial buildings can collapse. There will be a high percentage of collapse to older unreinforced masonry buildings. Most windows will be blown out of high-rise buildings resulting in falling glass, which will pose a threat for days to weeks after the storm. Nearly all commercial signage, fences, and canopies will be destroyed. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Long-term water shortages will increase human suffering. Most of the area will be uninhabitable for weeks or months. Hurricane Charley (2004) is an example of a hurricane that brought Category 4 winds and impacts to coastal portions of Punta Gorda, Florida with Category 3 conditions experienced elsewhere in the city.

**Category Five Hurricane** (Sustained winds greater than 155 mph, greater than 135 kt, or greater than 249 km/h)

*Catastrophic damage will occur*

People, livestock, and pets are at very high risk of injury or death from flying or falling debris, even if indoors in mobile homes or framed homes. Almost complete destruction of all mobile homes will occur, regardless of age or construction. A high percentage of frame homes will be destroyed, with total roof failure and wall collapse. Extensive damage to roof covers, windows, and doors will occur. Large amounts of windborne debris will be lofted into the air. Windborne debris damage will occur to nearly all unprotected windows and many protected windows. Significant damage to wood roof commercial buildings will occur due to loss of roof sheathing. Complete collapse of many older metal buildings can occur. Most unreinforced masonry walls will fail which can lead to the collapse of the buildings. A high percentage of industrial buildings and low-rise apartment buildings will be destroyed. Nearly all windows will be blown out of high-rise buildings resulting in falling glass, which will pose a threat for days to weeks after the storm. Nearly all commercial signage, fences, and canopies will be destroyed. Nearly all trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Long-term water shortages will increase human suffering. Most of the area will be uninhabitable for weeks or months. Hurricane Andrew (1992) is an example of a hurricane that brought Category 5 winds and impacts to coastal portions of Cutler Ridge, Florida with Category 4 conditions experienced elsewhere in south Miami-Dade County.
Appendix 3 - Notable Surge Events

- **Ike 2008** (SLOSH Historical Run)
  
  Hurricane Ike made landfall near the north end of Galveston Island as a Category 2 hurricane. Storm surges of 15-20 feet above normal tide levels occurred along the Bolivar Peninsula of Texas and in much of the Galveston Bay area. Property damage from Ike is estimated at USD24.9 billion. More...

- **Katrina 2005** (SLOSH Historical Run)
  
  Katrina was one of the most devastating hurricanes in the history of the United States. It produced catastrophic damage - estimated at USD75 billion in the New Orleans area and along the Mississippi coast - and is the costliest U. S. hurricane on record. Storm surge flooding of 25 to 28 feet above normal tide levels was associated with Katrina. More...

- **Dennis 2005** (SLOSH Historical Run)
  
  Dennis affected much of Florida, and its effects extended well inland over portions of the south-eastern United States with the maximum rainfall of 12.80 inches occurring near Camden, Alabama. Storm surge flooding of 7-9 ft. produced considerable storm surge-related damage near St. Marks, Florida, well to the east of the landfall location. The damage associated with Dennis in the United States is estimated at USD2.23 billion. More...

- **Isabel 2003** (SLOSH Historical Run)
  
  Isabel was the worst hurricane to affect the Chesapeake Bay region since 1933. Storm surge values of more than 8 feet flooded rivers that flowed into the bay across Virginia, Maryland, Delaware, and Washington, D.C. Isabel was the most intense hurricane of the 2003 season and directly resulted in 17 deaths and more than USD3 billion in damages. More...

- **Opal 1995** (SLOSH Historical Run)
  
  Hurricane Opal made landfall near Pensacola Beach, Florida as a Category 3 hurricane. The storm caused extensive storm surge damage from Pensacola Beach to Mexico Beach (a span of 120 miles) with a maximum storm tide of 24 feet, recorded near Fort Walton Beach. Damage estimates for Opal were near USD3 billion. More...

- **Hugo 1989** (SLOSH Historical Run)
  
  Hugo impacted the south-eastern United States, including South Carolina cities Charleston and Myrtle Beach. Hugo was responsible for 60 deaths and USD7 billion in damages, with the highest storm surge estimated at 19.8 feet at Romain Retreat, South Carolina. More...
- **Camille 1969** (SLOSH Historical Run)

  Camille was a Category 5 hurricane, the most powerful on the Saffir-Simpson Hurricane Wind Scale with maximum winds of more than 155 mph and storm surge flooding of 24 feet that devastated the Mississippi coast. The final death count for the U.S. is listed at 256. This includes 143 on the Gulf coast and another 113 from the Virginia floods. More...

- **Audrey 1957** (SLOSH Historical Run)

  There were 390 deaths associated with Audrey as the result of a storm surge in excess of 12 feet, which inundated the flat coast of south-western Louisiana as far as 25 miles inland in some places. More...

- **New England 1938** (SLOSH Historical Run)

  The Long Island Express was a fast-moving Category 3 hurricane that struck Long Island and New England with little warning on September 21. A storm surge of 10 to 12 ft. inundated the coasts of Rhode Island, Connecticut, south-eastern Massachusetts, and Long Island, NY, especially in Narragansett Bay and Buzzards Bay. Six hundred people died due to the storm. More...

- **Galveston 1900** (SLOSH Historical Run)

  At least 8,000 people died when hurricane storm tides (the surge plus the astronomical tide) of 8-15 feet inundated most of the island city of Galveston, TX and adjacent areas on the mainland. More...