

A consistent method of calculation of Probable Maximum Loss for buildings under construction or undergoing refurbishment

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Introduction

For the purposes of this paper the Probable Maximum Loss (PML) for a construction project is defined as follows:-

“The Probable Maximum Loss is an estimate of the maximum loss which could be sustained by the insurers as a result of any one occurrence considered by the underwriter to be within the realms of probability. This ignores such coincidences and catastrophes which are remote possibilities, but which remain highly improbable.”

The PML is an important part of the underwriting process as it helps Underwriters to decide how much (what proportion) of a risk they can retain, and whether they need to purchase reinsurance for their share of that risk.

It is important that the PML assessment is neither excessively high, nor excessively low:

- If it is set too high, the Underwriters will be buying reinsurance cover that they do not really need, or retaining smaller shares of risks than they could otherwise hold. In either case, premium income and the potential for profit will be curtailed.
- If it is set too low, then rates could be set too low and there is an increased risk that the chosen figure will be exceeded by a loss, which also affects their profit/loss ratios and affects their credibility and relationships with their reinsurers.

For construction cases, PML assessments are normally made only for four of the six covers commonly provided – these being

- Contractors All Risks (CAR) cover
- Existing Structures cover
- Non-Negligent Damage (JCT 21.2.1) cover
- Advance Loss of Profits cover

(The other two covers – Employers Liability and Public Liability are Casualty covers, for which PML assessments are not normally made.)

This paper deals mainly with material damage calculations for the CAR class of cover. PML assessment for Existing Structures cover is discussed briefly in Appendix F

The content of the paper is presented in the following sections:-

	Page
(1) The nature of construction project PMLs	3
(2) Calculating material damage PMLs for buildings under construction or undergoing refurbishment	
(2.1) Basic considerations	4
(2.2) What is at risk?	4
(2.3) What is it worth?	6
(2.4) How much is likely to be damaged and to what extent?	8
(2.5) Development of the calculation method	
(2.5.1) Part 1 - Low-rise Buildings	8
(2.5.2) Part 2 - High-rise Buildings	11
(2.5.3) The calculation method applied to low- and high-rise buildings ...	12
(3) Why is collapse not considered to be likely?	
(3.1) General	14
(3.2) Fires in completed buildings	16
(3.3) Construction site fires	21
Appendix A – Material damage PML assessments – Summary of the method	23
Appendix B – Examples of use of the method	25
Appendix C – Application to sites with more than one building	29
Appendix D – Treatment of special cases	31
Appendix E – The effect of phased handovers	35
Appendix F – Calculating EMLs for Buildings Undergoing Alteration or Refurbishment ...	37
Appendix G – Limitations	39

(1) The Nature of Construction Project PMLs

PML assessment for construction cases can only ever be an inexact science at best, because:-

- The nature and extent of damage is often difficult to predict, particularly if there are no examples of previous, similar failures or events to use as a guide
- The cost of repairing damage is often difficult to identify. The cost of building something for the first time is often not a good indication of how much it will cost to repair or replace once it has been damaged. Construction companies only ever plan to build anything for the first time, and so do not necessarily have information available that will identify the costs that are likely to be incurred following a loss.

An extreme example of this principle is the work that was done to repair and recover the collapse of the Heathrow Express railway tunnels in the central area of Heathrow Airport in London, where the repair cost is reported to have been many multiples of the original construction cost of the parts that were damaged.

- The actions required to rectify damage can sometimes bear no similarity to the work that was done to create the thing that has been damaged. This makes estimating costs even more difficult. The Heathrow tunnel case described above is an example of this. Another example would be smoke or soot damage to, say, the finishes in a building following a fire. As the Contractor, at the outset, would not have been expecting to have a fire that would cause damage of this type, details of the costs involved in repairing it / putting it right would not be readily available prior to the event occurring.
- The conditions that will operate to create the event that will produce the PML scenario loss are not evident at the underwriting stage, or even when Risk Engineering surveys are carried out, and so are not capable of evaluation by direct inspection. This introduces a margin for error that must be approached with judgement, experience, common sense and a certain amount of innate conservatism.

PML assessments in construction insurance are normally carried out at underwriting stage, when nothing of the completed project is available to be inspected other than a few drawings and, possibly, some artists' impressions. Even the drawings and pictures give away little about the construction process as they only show the completed item, with none of the temporary works, stored materials and equipment, temporary accommodation, parked vehicles, mobile plant, gas bottle stores, fuel/oil tanks and the like that will be present on the site during the course of the project, creating potential hazards and risks. They also show nothing of the interim stages of construction, when the partly completed works may be more vulnerable to damage than the finished item will be. Method statements are sometimes provided, and they can be of considerable help in this respect.

To combat this, Underwriters and Construction Risk Engineers will need to call upon all of their knowledge and experience of the construction process, of standards and practice in the industry generally and of the standards and practice of the Contractor running the particular site being considered in order to reach a measured and sensible view of the PML for the project.

- The insurance industry generally appears to be poor at learning lessons from past losses. There may be valid reasons for this – Clients and Insurers may not want the size of

settlements reached in particular cases to become common knowledge, for a variety of reasons – and confidentiality agreements might preclude the possibility of either party releasing details of payments made. Whatever the reason, reliable databases or lists of past claims and what they were worth do not appear to be readily available; something that would be very useful to everyone involved when trying to predict the potential size of possible future losses.

Some information can be found:- in copies of Loss Adjuster's reports that might have been archived; from anecdotal evidence available from people working in the various Insurers' Underwriting and Claims departments; from trade journals and the like, reporting on problems and losses that have occurred.

(2) Calculating material damage PMLs for buildings under construction or undergoing refurbishment

(2.1) Basic Considerations

The PML being considered here is that for the CAR section of the policy, arising from material damage to the works during the course of construction.

The PML scenario for buildings is almost invariably a fire, at a late stage in the construction process, when most of the contract value has been spent/installed, but when some or many of the features and systems that will provide the finished product with its protection are either not complete, not commissioned or not working e.g. fire walls not completed; fire doors not installed or wedged open; fire detection and sprinkler systems not working.

The process of calculating the PML is best considered as comprising three parts, which present three questions to be addressed:-

- What is at risk?
- What is it worth?
- How much of it is likely to be damaged, and to what extent?

Answering these three questions in turn provides a systematic approach to the calculation of the PML.

(2.2) What is at Risk?

Answering this question allows a determination to be made of what is what is often termed the 'Target Risk'. (This is a term commonly-used in Property Insurance and so is judged to be appropriate here.) The 'Target Risk' is most easily defined as that part of the insured property that is judged to be at risk of damage in the loss scenario being considered. It is best illustrated by several examples:-

- For a construction project consisting of a single building, the Target Risk is simply the building itself, unless that building is effectively sub-divided, as there is nothing else that is insured under the policy that the fire can spread to.

For an explanation of the term 'sub-divided' see the last paragraph of this section.

- For a construction project consisting of a number of separate buildings, what is included in the Target Risk is determined by the degree of separation between those buildings, from the point of view of fire spreading.

The simplest form of separation to see and understand is the distance between the buildings. If they are far enough apart, the fire will not spread from one to another. Authoritative guidance on separation distances presented in a concise and easy-to-apply form is hard to find, so a standard commonly used in Construction Risk Engineering is 10 metres. This figure is consistent with the recommended separation distance for temporary buildings and the building under construction set out in "The Joint Code of Practice on the Protection from Fire of Construction Sites and Buildings Undergoing Renovation", and with much general Property Conservation guidance on adequate separation distances in city and town centre locations.

The figure of 10 metres has to be treated with caution, however, as a number of features of buildings under construction can erode or even negate what at first appears to be an adequate separation distance. Examples of such features are:-

- Scaffolding on the outside face of buildings
- Temporary buildings placed between buildings being worked on
- Storage of combustible materials, combustible waste, plant, fuel/oil, gas bottles etc. in the gaps between buildings
- Buildings with high inherent fire loads – e.g. timber-framed buildings – have been shown by experience not to be adequately separated when placed 10 metres apart (reference the fire in Colindale in 2006). For this type of building a minimum separation distance of 20 metres is indicated.

So, for a project comprising a number of separate buildings, all of similar size and construction, all having adequate separation, the Target Risk is simply the most expensive amongst them.

For a project comprising a number of separate buildings with adequate separation but with different forms of construction and/or of different sizes, it may be necessary to consider each one individually with regard to the extent and value of likely damage; but the separation distance means that each one can be considered as being independent of the others.

For a project comprising a group or groups of buildings that do not have adequate separation distance between them, the Target Risk is the group that would produce the largest loss in the scenario being considered. Several calculations may be needed to establish which of the blocks forms the Target Risk, if it is not obvious from inspection of the layout, building size, building construction, value etc.

Another form of erosion of separation distances is the existence of common basements beneath groups of buildings that, above those basement levels (from ground floor upwards), do have adequate separation. This is becoming increasingly common on large developments – of offices and apartments mainly. In this case, the presence of the basement has to be carefully considered. Some of them, by virtue of the location, or lack, of lift shafts, staircases and service risers (i.e. not connecting directly with the buildings above) can be considered to be separate from the buildings above them. Others, where lift shafts, stair wells etc. lead directly up into the buildings above them, cannot be considered as separate unless there is certainty that there will be no continuity in fire load between basements and superstructures, thus making it very unlikely that fire will be able to spread upwards from one to the other.

Effective sub-division within a building can only be achieved by the presence of a properly-constructed and maintained compartment wall and/or compartment floor, with no openings at all in either one of them. Definitions of what these are and the standards they must comply with are contained in the Loss Prevention Council (LPC) Building Construction Design Guides, National Fire Protection Association (NFPA) Standards and other authoritative guidance on fire protection. Neither one is very likely to be encountered on a construction site. Compartment walls are almost never seen, and floors on construction sites will almost always have openings in them, until immediately before the date of Practical Completion and handover.

(2.3) What is it Worth?

Answering this question allows the value of the Target Risk to be determined.

The figure the Underwriter or Construction Risk Engineer determines at this stage is the overall construction cost of the Target Risk, as given by the figures available at the time. This represents the largest possible loss that can be incurred from the Target Risk. This figure will be adjusted downwards to become the largest probable loss, and therefore the PML, in the final stage of the assessment. The figure thus produced represents the material damage PML, which Underwriters then amend by adding other costs, as determined by the applicable insurance policy, to arrive at the final PML figure. Other costs cover factors such as debris removal, inflation, price escalation and others. They are not dealt with in this paper.

The quality of information provided on values of buildings under construction can be variable. Sometimes there is almost none at all and estimates have to be made to fill in the gaps. Sometimes there is far too much, making analysis of the cost of various parts a time-consuming exercise. Quite often the amount provided is reasonable, making the exercise of determining the value of the Target Risk reasonably straightforward.

The best place to find the information that is needed is the cost breakdown for the project. This is a brief presentation (on no more than a few sides of A4, normally) of the overall costs for significant elements of a building or project. A typical (simple) example might be as set out below:-

<u>Block</u>	<u>Item</u>	<u>Cost</u>
A	Foundations & substructures	£ xxxxx million
	Superstructure	£ xxxxx million
	External cladding	£ xxxxx million
	Internal walls	£ xxxxx million
	Roof coverings	£ xxxxx million
	M&E plant & services	£ xxxxx million
	Internal finishing – floors, ceilings etc.	£ xxxxx million
	Internal fixtures & fittings	£ xxxxx million
B	Foundations & substructures	£ xxxxx million
	Superstructure	£ xxxxx million
	External cladding	£ xxxxx million
	Internal walls	£ xxxxx million
	Roof coverings	£ xxxxx million

	M&E plant & services	£ xxxxx million
	Internal finishing – floors, ceilings etc.	£ xxxxx million
	Internal fixtures & fittings	£ xxxxx million
Site wide	Demolition and site clearance	£ xxxxx million
	Enabling works	£ xxxxx million
	Service diversions	£ xxxxx million
	External works/landscaping	£ xxxxx million
	Preliminaries	£ xxxxx million

More detailed information might be provided in a costed bill of quantities, from which a more accurate assessment of the PML might be compiled, but the type of information set out above is normally adequate for purpose.

Addressing the answer to the question ‘What is it worth?’ for the example outlined above leads to the following:-

Assuming that Blocks A and B are separate, and that A is identified as the more expensive of the two and is therefore the Target Risk, the following sets out the means of determining the value of the Target Risk:-

- The cost of Block A’s foundations and substructures can be omitted from consideration, as they are unlikely to be damaged by a fire
- The cost of Block A’s superstructure, external cladding, internal walls, roof coverings, M&E plant & services, internal finishings, fixtures and fittings are all included for consideration as they are all intimately involved in and with the fabric of the building and are therefore at risk of damage in a fire
- The cost of demolition and clearance of the site is a one-off initial cost that would not need to be repeated. (Underwriters will add in an amount to allow for removal of debris (following the fire) during their consideration of the PML.)
- The costs of the enabling works and service diversions are one-off initial costs that would not be repeated, as the works covered by them would not be damaged by a fire in the building. They are therefore omitted from consideration.
- The cost of external works and landscaping are omitted from consideration as the works they cover are external to the building and would not be damaged by a fire within it.
- Preliminaries are normally omitted from consideration as they frequently represent one-off site mobilisation and set-up costs that would not need to be repeated after the fire. It is possible, however, that they also contain some repeatable elements, such as temporary building hire, running and maintenance costs. The view normally taken is that that these costs are small compared with the overall values being considered so, unless specific information is available to the contrary, they can normally be omitted. Alternatively they can be added in once the other construction costs have been apportioned as ‘included’ in and ‘excluded’ from the value of the target risk – pro-rata those values.

The sum of the figures denoted for inclusion in the lists set out above therefore gives the overall value at risk in the Target Risk. An example of the use of this process is included in Section (2.5.1) of this document.

If Blocks A and B were not found to be separate, the calculation outlined above would have been done with the value of the relevant parts of Block B included.

Aggregations

Whilst an Insurer's construction risks and property risks are normally insured separately, the possibility of a construction PML scenario event involving surrounding property does need to be considered so that the overall exposure from the same event can be considered by Underwriters. This is not discussed in detail in this document.

(2.4.) How much of it is likely to be damaged, and to what extent?

This is the stage at which the PML Scenario and the cost information are combined to produce the material damage PML assessment. It is where an assessment has to be made of the likely extent of damage. Section 2.5 describes the development of a method for producing consistent calculations of the material damage PML for buildings under construction and undergoing refurbishment.

The reader's attention is drawn to the "General Conditions" applying to the use of this method of evaluating the likely extent of damage. Buildings deviating from these conditions will require special consideration as it is likely that they will represent higher levels of risk and the potential for a greater extent and value of damage. These considerations are discussed in the Appendices at the end of this document.

(2.5) Development of the calculation method

(2.5.1) Part 1 – Low-rise Buildings

The following General Conditions apply to the basic calculation. Later Appendices to this document provide information on extending the method to situations that do not comply with the conditions. These are highlighted in the relevant places.

- This method considers a single building in isolation. See Appendix C for information on dealing with situations where the Target Risk contains more than one building.
- The PML scenario being considered in all cases is a fire at a late stage in the construction process, when the value of the work done is at or approaching a maximum, but when the features/systems/procedures that will afford protection to the finished product are either not present, not completed, not commissioned or not working.
- The contractor in control of the site is of known or assessed quality: known or shown at survey to have good management standards and procedures; in particular:-

- A good level of compliance with “Fire Prevention on Construction Sites, the Joint Code of Practice on the Protection from Fire of Construction Sites and Buildings Undergoing Renovation” or an equivalent standard
 - Good hot work controls
 - Good housekeeping standards/procedures
 - Good security standards/procedures
- Non-combustible construction for the building fabric, with adequate passive fire protection i.e. new-build, complying with legislative standards/requirements, or refurbishment where structural fire protection is being upgraded to modern standards*
 - A low volume of combustible materials incorporated in fixtures and fittings installed during fit-out stage*
 - Adequate response from the fire brigade and adequate fire-fighting water supplies
 - Good subdivision of the building horizontally by solid floors with a limited number and size of openings, and no atria*

** Buildings with significant volumes of combustible materials incorporated in the structure, or high volumes of combustible materials in fixtures and fittings, or having atria inside them, or with poor/inadequate levels of passive fire protection are all special cases and need to be considered individually.*

With these conditions satisfied, the extent of the fire and the degree of damage sustained is defined as follows:-

- Fire breaks out on one floor and spreads upwards to the floor above. The floors directly affected by fire are referred to as the ‘Fire Floors’.
- Direct damage due to fire is equal to 100% of the value of the two Fire Floors
- Damage due to smoke to the value of 50% of the floor immediately above the fire
- Damage due to fire-fighting water to the value of 50% of the floor immediately below the fire

Note - This is not necessarily the way the damage would be distributed in a real fire, but is presented as a means of arriving at a figure representative of the extent and value of that damage.

Collapse of the whole structure is not considered to be a likely occurrence, except:-

- In the case of single storey buildings, where fire resistance of the structure is generally not required.
- In the case of two storey buildings, where the collapse of the unprotected structure of the upper storey is likely to subject the lower storey of the building to loads it is unable to withstand.

In such cases the estimated loss is already set at 100% of the superstructure value, so the risk of collapse is automatically allowed for.

As the building increases in height it is likely to become more robust and more able to withstand failure of the structure of the roof framing without being at risk of catastrophic failure. At three storeys, four storeys etc. the proportion assumed to be lost decreases progressively. See Section 3

of this document for a discussion of the reasons why collapse is not considered to be likely in bigger buildings.

Where the value of the floors is known not to be equal, the location of the fire can be moved up and down the height of the building in order to maximise the loss.

Assuming that the cost of the building is equally distributed on all floors, the cost of the damage to the building superstructure can be stated generally as follows for buildings of different heights:-

<u>Building height</u>	<u>Extent of damage (% of superstructure value)</u>
Single-storey	100
Two-storey	100
Three-storey	83
Four-storey	75
Five-storey	60
Six-storey	50
Seven-storey	43
Eight-storey	38
Nine-storey	33

As building height increases, the extent of the damage decreases. This is judged to be reasonable, up to a point, as experience shows that there is a certain base fire load involved in constructing any building and that, as the building size increases, the fire load becomes more thinly spread, making fire spread less likely and fire fighting easier. The point at which this becomes unreasonable is when the building reaches a size where its height begins to impede the ability of the Brigade to fight the fire. This is generally accepted to be when the building reaches 6 storeys above ground level. Section (2.5.2) deals with High-rise Buildings.

The final part of this section presents an example of the determination of the value at risk for a single building. Cost breakdowns provided by Clients and Brokers typically give the construction cost for the major elements of the building being worked on. These can be used to compile a list of those items that are likely to be involved in the PML scenario fire and those that are not, as set out below. The 'included' items are those that would need to be repeated in a rebuilding process if the building were to be completely lost in a fire. For example, site preparation would not need to be repeated and is therefore excluded, nor would the foundation construction, basement excavation or basement structures. Clearly there would be damage and loss to items such as floors, ceilings, internal walls, external cladding, windows, services etc., so their costs are included.

<u>Item</u>	<u>Included (£m)</u>	<u>Excluded (£m)</u>
Site preparation	-	0.48
Piling	-	1.41
Basement excavation & concrete	-	9.31
Superstructure	10.00	-
Envelope	16.61	-
Mechanical & Electrical installations	17.13	-
Internal walls & linings (& ceiling)	6.35	-
Fit-out (residential)	7.00	-
Lifts (residential)	1.36	-
Builders' work in connection with services	0.45	-
Fit-out (hotel)	5.13	-

Specialist leisure	0.59	-
Lifts (hotel)	1.14	-
Contingency (all included)	9.47	-
Enhanced fit-out	4.00	-
External works	-	2.50
Design development	0.50	-
Interim totals	79.73	13.70
	(85%)	(15%)
Site preliminaries (pro-rata)	3.40	0.60
Site staff (pro-rata)	5.00	0.87
Totals	£88.13m	£15.17m

The percentage extent of damage figures set out above are applied to the figure determined as 'included' in the PML scenario fire. So in this case, if the building was single-storey or two-storey, the loss would be £88.13 million. If it was three-storey the loss would be 83% of £88.13 million i.e. £73.1 million. If it was four-storey the loss would be 75% of £88.13 million i.e. £66.10 million, and so on.

(2.5.2) Part 2 - High-rise Buildings

The approach adopted for high-rise buildings aligns with that used by the Property Conservation discipline.

The same conditions apply here as for low-rise buildings.

The extent of damage in the PML scenario fire is defined as follows:-

- Fires on floors up to and including fifth floor are assumed to be dealt with satisfactorily by the local fire brigade/fire department.
- Fires above the fifth floor are assumed to be too high up the building to be dealt with effectively and to run away up the building, out of control, until they either reach the roof or reach a floor that is free of any combustible material and will therefore act as a fully effective fire break. This latter situation is rare during construction, and so is not normally taken into account.

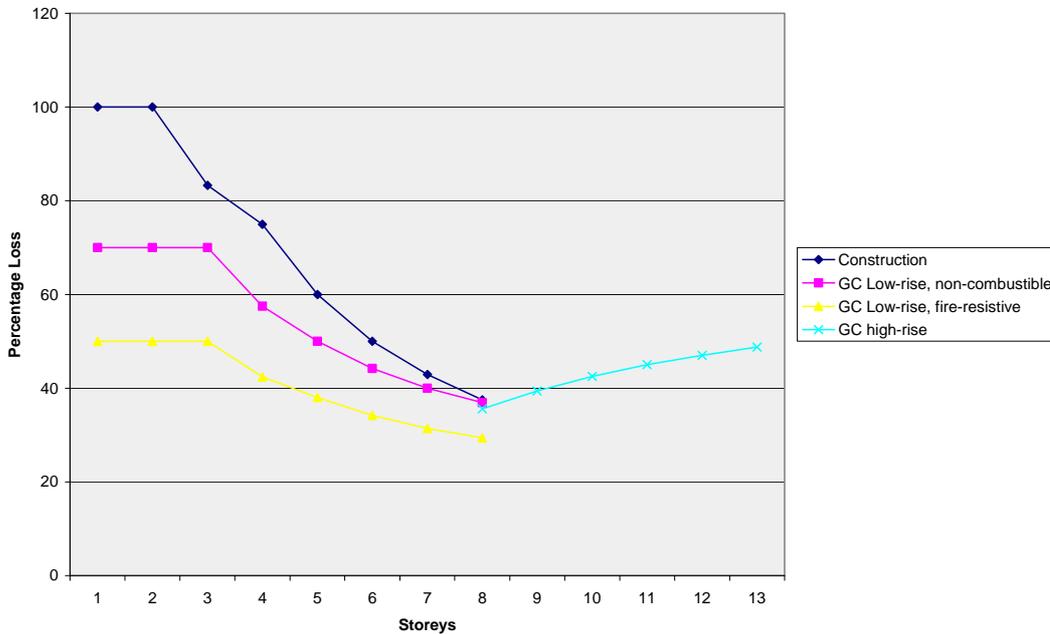
Damage is assessed as – 70% of the value of all Fire Floors, plus
15% of the value of all floors below the fire for water damage

This gives the following extent of damage to superstructure:-

Six-storey -	24%	
Seven-storey -	31%	
Eight-storey -	36%	
Nine-storey -	39%	OR For all above 5:- $(70 \times (N-5) + (15 \times 5)) / N\%$
Ten-storey -	42%	- where N = number of storeys
Eleven-storey -	45%	(tends to 70% when N = infinity)
Twelve-storey -	47%	
Thirteen-storey -	49%	

(2.5.3) The calculation method applied to low- and high-rise buildings

When the results obtained for low-rise and high-rise buildings are combined and expressed graphically, the result is as shown below:-



The graph presents four lines. These are:-

- (A) Dark blue –)
this is the line for low-rise buildings under construction) These two are the most
- (B) Turquoise –)
this is the line for high-rise buildings under construction) relevant of the four
- (C) Yellow –)
this is the line for the Property discipline, low-rise buildings,)
fire-resistive construction) The relevance of these
- (D) Purple –)
this is the line for the Property discipline, low-rise buildings,)
non-combustible construction) lines is explained later

The interesting and useful feature is the approximate meeting of three of the plotted lines at the eight-storey building height

- the Construction curve (Version 1 of this method)
- the Property low-rise, non-combustible curve
- the High-rise curve

This offers the opportunity to adopt and use a numerically consistent method for buildings of all heights, by adopting the Construction curve for buildings up to and including eight storeys in height, and the High-rise curve for those that are taller than eight storeys.

The Construction curve used for low-rise buildings predicts a greater extent of damage than the equivalent Property discipline curves. This seems logical on the grounds that buildings under construction generally have more unprotected floor and wall openings than the same buildings will have when they are completed.

Adopting the finished building curve for high-rise buildings under construction can also be defended, using the argument that, although the same floor openings, wall openings, service risers etc. exist inside them, the fire load is far more thinly spread than in smaller buildings, and its density is far lower than will be present once the work is finished and the building is handed over.

For information and completeness, the Low-rise Property discipline curves were derived as follows:-

- Low-rise buildings, non-combustible construction, with conditions similar to those set out for the construction method:-
 - fire damage on three floors to 70% of the value of each of those floors, plus
 - smoke damage on the two floors above the fire to 20% of the value of each of those floors, and 10% on the rest
 - water damage on all floors below the fire to 15% of the value of each of those floors

The location of the fire floors is varied to maximise the extent of damage if that was appropriate e.g. if floor values were known and were different from one another.

Assuming that all floors are equally valued, this gives the following extent of damage to superstructure:-

Single-storey –	70%
Two-storey -	70%
Three-storey -	70%
Four-storey -	58%
Five-storey -	50%
Six-storey -	44%
Seven-storey -	40%
Eight-storey -	37%
Nine-storey -	34%

- Low-rise buildings, fire-resistive construction, with conditions similar again:-
 - the same as for the non-combustible version, but with direct damage due to fire restricted to 50% to reflect the better fire performance of the structure.

This gives the following extent of damage to superstructure:-

Single-storey –	50%
Two-storey -	50%
Three-storey -	50%
Four-storey -	42%
Five-storey -	38%
Six-storey -	34%
Seven-storey -	31%
Eight-storey -	29%
Nine-storey -	28%

Section (2) – Summary

Provided that the conditions set out in Section (2.5.1) are met, the PML for a single building under construction can be calculated as follows:-

- For buildings up to and including 8 storeys in height above ground level – 100% of the value of two floors – direct damage due to fire

50% of the value of the floor above the fire – smoke damage
50% of the value of the floor below the fire – water damage
The Fire Floors should be located such that the value of the damage is maximised

- For buildings greater in height than 8 storeys above ground level –
70% of the value of sixth floor and above
15% of the value of all floors below the sixth for water damage.

(3) Why is Collapse Not Considered to be Likely?

(3.1) General

Building collapse in fire does occur occasionally, but is too infrequent to be regarded as probable in the context of Probable Maximum Loss estimation. This conclusion is supported by research carried out for the National Institute for Standards and Technology (NIST) in America (Contract Number NA 1341 -02-W-0686) by J J Beitel and N R Iwankiw, both of Hughes Associates Inc. after the terrorist attacks on New York's World Trade Centre in 2001. The report of this research is entitled "Historical Survey of Multi-Storey Collapses Due to Fire". This was a search of historical data, looking for evidence of collapse of buildings during fires. Its data was drawn from records dating back to the 1950s, mainly from North America.

Table 1 of the report of this research lists 22 case of collapse or partial collapse over that time period. Of these, four are World Trade Centre, New York, buildings and so can be discounted due to the exceptional circumstances that prevailed in that location at the time – see later text in this section on that subject. One was the partial collapse of part of The Pentagon building, on the same day, caused by fire following aircraft impact. Two involved the collapse of wooden-framed buildings that are clearly outside the scope of this method. Eleven were partial collapses of varying degrees, the extent of damage described being judged to be within the extent that would have been predicted by the application of this method. That leaves four cases that were total collapses that were attributable just to fire (and with further investigation it might be shown that two of these (at least) were outside the scope of this method due to the form or materials of their construction). The report also states that annual occurrences of fire in buildings of 7 storeys or more exceeds 10,000. If that is true, then over the study period, assuming it encompassed the 45 years from 1957 to 2002 and covered just the USA (which it clearly did not) then those four cases represent a rate of collapse of 1 in 112,500 of the buildings that suffered a fire. To calculate the absolute probability of collapse, that figure would have to be modified to allow for the probability that any particular building would suffer from a fire, making the probability of collapse even smaller. Is this within the bounds of what is probable when considering PML estimates? Probably not.

Moving on now to some specifics:- collapse of a building frame will occur when its structure is exposed to a fire that weakens it to the point where it can no longer support the loads that are applied to it. The two types of building frame we are primarily concerned with here are reinforced concrete and structural steel.

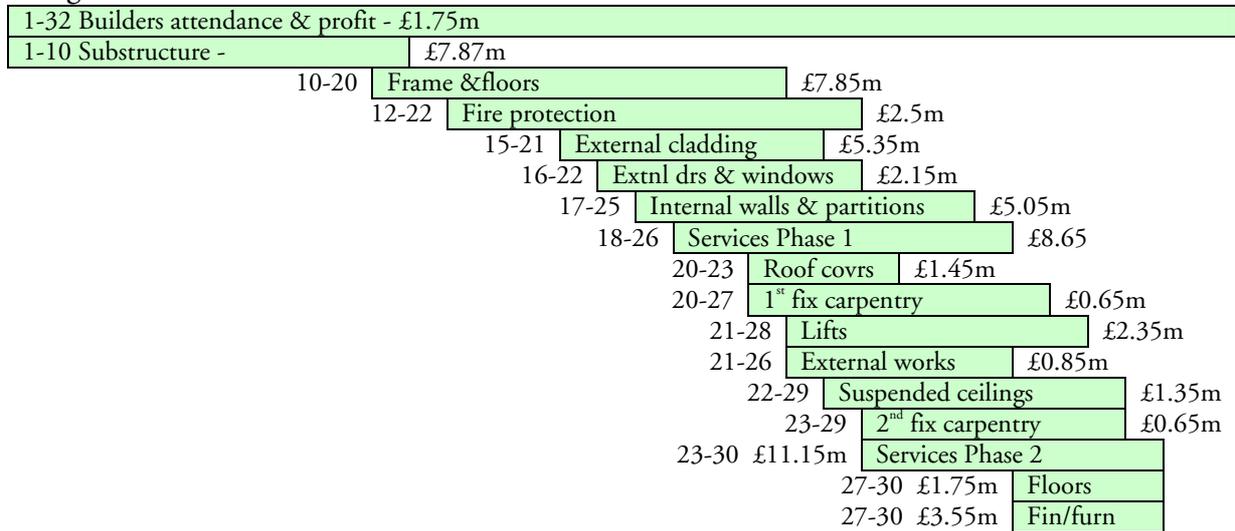
Reinforced concrete has inherent fire resistance built into it by virtue of the thickness of the concrete covering the steel bars that reinforce it. It is inherently 'fire-safe', therefore, as soon as it is cast and has cured.

Steel is protected by adding protective layers in the form of intumescent paint, sprayed-on fire protection or fire-resistant boarding. Intumescent paint is normally applied at the steel fabrication works and so is present on the frame components when they are delivered to the site.

The others are added to the steelwork at an early stage after its erection on site, as they cannot easily be added once other work inside the building has commenced. The effect of this is best illustrated by considering a case-study dealing with the construction of a new laboratory building.

Details of the laboratory building construction process are set out below, in graphical form.

Programme – months



The fire protection is applied to the building frame very soon after the erection of any given floor, and is complete at every level before that level is enclosed by the cladding and before there is any appreciable volume of combustible materials included inside the building at that level.

The material damage PML assessment for this ten storey building is as follows:-

Sum at risk = £64.89m - £7.87m (substructures) - £0.85m (external works) = £56.17m

Damage percentage = (70% x 5/10) + (15% x 5/10) = 42.5%

Material damage PML = 0.425 x £56.17m = £23.8m

Analysis of the cumulative spending curve for the project shows that this figure is reached during the twenty-first month of the project, by which time almost all of the fire protection is in place, but the work in progress is still dealing at that time with essentially non-combustible materials. So, even if was possible for a fire to trigger a collapse at an early stage, before the fire protection was in place, the sum at risk would be very unlikely to equal or exceed the sum calculated as the PML for the later fire scenario.

The view that collapse is improbable is also supported by the available anecdotal evidence on fires in multi-storey buildings from around the world, both from construction projects and from buildings post-completion. Collapses have occurred, and these are sometimes held up as proof that such buildings are not capable of surviving such fires. Close examination of the available evidence proves the point the other way, however.

(3.2) Fires in completed buildings

The World Trade Centre, New York

The most prominent case(s) of collapse of large buildings during fires in recent years involved buildings 1, 2 and 7 on the World Trade Centre (WTC) site in New York in 2001. All three collapsed in full view of the world's media and were initially held up by some as providing proof that steel-framed buildings were not as safe in fire as they had been thought to be up to that point in time. Others, the so-called 'conspiracy-theorists', use the fact that no other large buildings have ever collapsed solely due to fire as the primary reason for promoting their theories that the buildings were deliberately brought down by demolition charges.

In the years that have followed the terrorist attack on the WTC, the National Institute of Standards and Technology (NIST) in America has been investigating the collapses to establish, as best they could, the sequence of events that led to them happening. The circumstances surrounding the collapse of WTC 1 and WTC2 were broadly similar, with some differences in detail that led one building to collapse before the other (in a shorter time after impact of the aircraft). The final report of this investigation has been published and is commented on below. The investigation into the collapse of WTC7 was not complete when this paper was written. The comments made below on this building are based on preliminary reports that are thought to reflect broadly what will appear in the final report when it is published, some time in 2008.

WTC1 and WTC2 were both struck by fast-moving, heavily-laden airliners on the morning of November 11th 2001. These were deliberately flown into the buildings, presumably in the hope that they would bring the buildings down. On impact with the buildings, a number of things happened:-

- The aircraft substantially disintegrated, with most of the debris coming to rest inside, but with a number of major components - notably wheels and the main shafts of the engines - passing straight through and falling to ground or onto the roofs of buildings on the other side.
- The initial impacts with the face of the buildings severed a number of outer steel columns, and severely damaged others, leaving those faces of each structure considerably weakened.
- The remains of the aircraft, mainly small pieces carrying high energy, spread over a wide area and a number of floors inside the buildings causing considerable internal damage including:- severing of a number of steel columns in the cores and causing severe damage to others; causing parts of several floors on the impact side to collapse onto the floors below; removing the sprayed fire protection from the steel trusses supporting the floor slabs over a wide area on a number of floors. In WTC2, one of the very heavily-loaded corner columns in the core was severed by the 'off-centre' impact of the aircraft that hit it, a major contributory factor leading to the collapse of this building first, although it was the second to be hit. The high-energy debris also stripped away most or all of the fire-protective boarding in the cores on the impact floors, leaving the steelwork there exposed to the fires that would follow. This was a key factor in the collapse of both buildings.
- Jet fuel spilled both inside and outside the buildings and was ignited, by the friction and heat of the impact, by the hot components in the aircraft and by other sources of ignition - mainly electrical equipment - inside the buildings. NIST have estimated that the fireballs seen as the aircraft impacted the buildings constituted only a proportion of the fuel on board,

with the rest travelling into the building interiors. Some of this was atomised and involved in the vapour cloud explosions. The rest was deposited as liquid to burn and ignite the building contents.

- The fires that followed consumed both the aviation fuel and the building contents. The columns and beams of the building frames and the trusses supporting the floors, all stripped of their fire protection, began to heat up. This led to a transfer of load from the perimeter columns to the columns in the core via a stiff structure at each roof level referred to as the 'hat-truss'^{*}, as temperature differentials caused the core columns to expand more rapidly than the perimeter columns did. This effect was exacerbated by the load redistribution that had already occurred between the outside faces of the buildings as they coped with the loss of structural integrity at the impact sites.

* The hat-truss was a substantial steel structure built into the top section of each building to allow it to carry the load of a television tower on its roof, by distributing its load evenly to all perimeter and core columns. The presence of these trusses made the buildings more robust than they would otherwise have been, and are thought to have increased the time they remained standing between impact and collapse.

- As the fires continued to burn, the exposed steel grew progressively hotter and began to lose strength. Large loads and high temperatures caused the core columns to shorten, shedding load back out to the perimeter columns via the hat-trusses. The floor slabs, where they were still attached to the core and perimeter columns, were sagging and beginning to pull the perimeter columns inwards – a deflection of around 1.4 metres has been estimated from photographs of part of the external wall of one of the buildings shortly before final collapse began. As this process continued, the perimeter columns on the deflected sides failed by buckling inwards, triggering rapid progressive failure of the rest of the structure at that level.
- When this progressive collapse occurred, the section of each building above that level began to move downwards. WTC2 fell first, despite being the second to be struck, because the loss of the corner column in its core accelerated the load transfers that led to its final collapse. In both cases, the section of the building above the impact floor was intact, so when it fell it carried a huge store of energy with it, that the structure of the building below the level of impact was not strong enough to arrest and stop once it had begun to move.
- Although some details of the way the progressive collapse began were different in each case, both buildings fell in more or less the same way, with the top section falling down through the rest of the structure, 'peeling' the outer walls open as it went. The forces produced were so great that the concrete of the floor slabs was crushed and turned into the huge dust cloud that accompanied each collapse. The perimeter steel frames were almost completely destroyed, as were the core columns and beams.
- Once started, the rate of fall was rapid – not very much slower than the rate of free-fall under the effects of gravity. This is not judged to be, as the conspiracy-theorists have stated, an indication that explosive demolition was used to 'assist' the collapse, but more a measure of the huge energy contained in the falling sections, above the impact floors, measured against the small resistance offered to the collapse by the structure below it.

WTC7 stood a short distance away from WTC1. It was not hit by an aircraft, but was hit and damaged by large pieces of debris – thought to be sections of the perimeter wall – when WTC1

fell. This caused damage to the building of an unknown extent and started fires inside it in a number of places and at a number of levels. Some time later the building completely collapsed in a manner that has been likened to that observed in a collapse triggered by controlled demolition. Once again, the conspiracy-theorists have claimed that controlled demolition was used, while others have claimed it as the first collapse of a major building caused solely by a fire. In reality it is neither of these, as the preliminary investigation results show and as the final report will probably show. Yes, it did collapse because there was fire inside it, but that was not the only cause, so to attribute it just to the fire is not correct.

Interest in the collapse of WTC7 centres on an area inside the building between the 5th and 7th floors, directly below the eastern rooftop plant room where the final collapse was first seen to be happening. At this level there was a transfer structure, used to convert one column layout, used below this part of the building, to another, used above. This was included in the design of the structure for two reasons:-

- (1) The building was constructed in two phases, with a time delay between the two, and
- (2) To allow a substation to be incorporated within the building

The two construction phases involved the foundations and substructures (first) and the superstructures (afterwards). As is sometimes the case with this type of development site, the foundations and substructures were built speculatively, with later bespoke design and construction of the rest of the building on top of them. As is also sometimes the case, the column layout of the building when it was finally designed did not suit the foundation layout as built, so there was a need to incorporate a transfer structure of some kind within it. This was combined with the need to install the substation, and a design compatible with both needs was developed.

The transfer structure as-built included a row of deep steel beams with long spans and cantilevers transferring offset column loads along one side of the building, plus three two-storey truss systems doing a similar job in two locations at its heart. Also in this part of the building there were a number of diesel-powered generator sets forming part of the back-up power supply system, along with their associated fuel tanks and pumps. It is suspected that the collapse of the building was caused by a chain of events triggered by the terrorist attacks on WTC1 and 2, the main elements of which are as follows:-

- The collapse of WTC1 and/or WTC2 cut the incoming power supply to the building, causing the diesel engines powering the back-up generators to start up and run, in order to maintain power to computers etc. inside it. One or more of these pumps is thought to have been connected to a UPS system.
- When WTC1 collapsed, WTC7 was hit in several places by debris from its outer walls. WTC7 was damaged, and several fires broke out inside it.
- Fire-fighting response and water supplies were severely impaired due to the size and severity of the problems in the area at the time, so the fires in WTC7 received less attention than they otherwise would have done.
- A number of hours after WTC1 collapsed, the roofline of the eastern plant room on WTC7 developed a 'kink' where previously it had been straight. Within a fairly short space of time afterwards, that plant room disappeared into the building, followed by the adjacent western

plant room, indicating that a substantial internal collapse was underway. As this was happening, a deformity was seen to develop in the outside wall of the building, immediately below where the eastern plant room had been. This ran rapidly down from the top of the wall to the ground and was followed by total progressive collapse of the building.

The main finding of the preliminary report on the collapse is that when the building was struck by the falling debris, one or more of the fuel lines serving the diesel engines was ruptured or cracked, allowing diesel oil to spill out in the area where the large transfer trusses were located. The pump or pumps on that line, being supplied with power from one of the generators that kept running or, as is considered more likely, being fed by the UPS, kept pumping, either fuelling a fire that had already broken out, or creating a reservoir of spilt diesel oil that was ignited later. Whichever it was, that oil fuelled a fire that heated, weakened and eventually caused the failure of a key item of structure in the heart of the building, below or almost below the eastern rooftop plant room. Failure of that element then led to a progressive collapse that caused the building structure to fall in on itself from the bottom upwards, pulling the outer walls inwards as it did, in the manner often observed during controlled demolitions, where the structure being pulled down has been pre-weakened to ensure that it collapses in just this way.

From a structural point of view this is a completely feasible explanation of the observed mode of failure, consistent with the fact that

- American structural codes do not require designs to combat the risk of progressive collapse.
- The scenario outlined could easily have led to the collapse of a major structural element supporting, on its own, a significant area of floor through the full height of the building.
- The steelwork above the area of the collapse would have been bolted or welded together in a way that would allow it to transmit some tensile forces without failing, but not to withstand the total loss of support caused by the failure of one of the major transfer trusses between 5th and 7th floor levels. This could easily have resulted in what was actually seen – the building falling in on itself in the manner observed.

The extraordinary circumstances surrounding the collapse of these three buildings ‘disqualifies’ them from consideration as collapses due simply to fire. This point is clearly made by the NIST final report on WTC1 and 2, when it deals with the as-built condition of the buildings and discusses the likelihood that a similar collapse could have been triggered by a fire started by ‘normal’ means i.e. accidental (or ‘normal’ deliberate) ignition of combustible materials with passive fire protection still in place. In fact this section of their report contains a commentary on just such a fire in one of the towers, a number of years ago, in an area that had no sprinklers in it at the time. That fire spread to affect a large part of one floor and burnt for some time before being brought under control, without placing either the floor above it or any part of the structure as a whole at risk of collapse. This section of the NIST report concludes, after considering both an ‘academic’ study of the protection in place, and examination of the anecdotal evidence, that a normal building fire could not have caused any of these collapses to occur, without the extraordinary circumstances that applied at the time. In terms of the PML assessments this document concerns itself with, these circumstances are:-

- Removal of passive fire protection from large areas of steelwork, particularly in the seats of the fires. The buildings we are considering here for PML assessment will all be fully protected to modern standards at the pertinent time.

- The presence of abnormal fuel loads to assist the growth and duration of the fires – aviation fuel in WTC1 and WTC2; a continuous supply of diesel oil in WTC7.
- The disrupted fire-fighting effort in place at the time.

The Windsor Tower, Madrid

The second case-study of a completed building fire is that involving the Windsor Tower in Madrid, which suffered partial collapses and was later demolished after a serious fire in February 2005.

This building, originally constructed in the 1970s, was undergoing a major renovation programme at the time that the fire occurred and was still at least partly occupied. It had a heavy fire load in the occupied areas. It had no sprinklers in or above the area where the fire started as they were being fitted as part of the work being done during the renovation project.

The building structure comprised a reinforced concrete core, with reinforced concrete floor slabs spanning from the core walls onto steel columns positioned on the building perimeter. At the time of building, there was no requirement for the steel columns to be fire-protected, no requirement for the gaps between floor edges and the external cladding to be fire-stopped, and no requirement for sprinklers to be installed. All of these 'deficiencies' (when compared with modern standards) were being addressed during the refurbishment programme. At the time of the fire, the refurbishment work, which was being carried out on a floor-by-floor basis, had reached the seventeenth floor.

The fire broke out on the twenty-first floor and travelled in both directions – upwards and downwards - eventually engulfing the whole building down to the fourth floor level during the twelve or so hours the fire burned before it was extinguished. After five hours, the floors above the seventeenth suffered a progressive collapse when the unprotected steel columns failed. The floors folded downwards against the face of the reinforced concrete core, which remained standing. The floors below the seventeenth, where the steel perimeter columns had been fitted with passive fire protection, also remained standing. Eventually the whole building was demolished as it was judged to have been damaged beyond economic repair.

The cause of the fire was found to be an electrical fault on the 21st floor. Fire was able to spread laterally in an uncontrolled way due to the fire load present on this occupied, open-plan floor and the lack of sprinklers installed on this un-refurbished floor. Fire spread upwards easily due to lack of fire-stopping between the cladding and the floor slab edges. Fire spread downwards in the upper section, above the refurbished floors, for the same reason and because windows broke from exposure to heat and through impact with falling debris. Below the seventeenth floor, where the refurbishment had been completed, downward fire spread was also from window to window. There is also a suggestion that the cladding moved away from the slab edge due to thermal expansion of its framing, rendering the newly-installed fire-stopping ineffective.

Structural collapse was confined to areas above the seventeenth floor, due to the presence of passive fire protection to the steel perimeter columns below that level and the lack of it above. If the passive fire protection had been in place on the steel perimeter columns through the rest of the height of the building it is very likely, judging from their performance on the lower floors, that the collapses would not have happened. If the collapses had not happened it appears likely,

from the evidence obtained from other large building fires (see following examples) that demolition of this building would not have been thought necessary.

One New York Plaza, New York

This fifty-storey high tower caught fire in August 1970, not long after it was completed. The fire burned for more than six hours. Some partial collapses were experienced where sprayed fire protection, then newly introduced, had failed to adhere to the steel members it was intended to protect and fell off. No widespread collapse occurred, however, and none where the fire protection remained in place. The building was repaired and re-occupied.

First Interstate Bank, Los Angeles

This sixty-two storey building caught fire in May 1988 and burnt for three and a half hours before being brought under control by the fire department. Four and a half floors were completely gutted. The floors above the fire suffered smoke damage. The floors below the fire suffered massive water damage. In spite of the total burnout of four and a half floors, there was no damage to the main structural members and only minor damage to one secondary beam and a small number of floor pans. It was noted during the recovery operation that the quality of the sprayed-on fire protection was particularly good. Property loss was estimated to be some \$200 million, including both building and contents. The building was repaired and re-occupied.

One Meridian Plaza, Philadelphia

This was a thirty-eight storey office building that suffered a large fire in February 1991. Fire broke out on the twenty-second floor and burnt for 18 hours, reaching the thirtieth floor where it was controlled by the presence of sprinklers. The frame of the building was steel, cased in concrete as fire protection. Damage was extensive but there was no collapse, and the building was repaired rather than being demolished. Property loss was estimated to be some \$100 million, including both building and contents.

Parque Central, Caracas, Venezuela

In October 2004, twenty-six floors of this fifty-six storey building were damaged by a fire that lasted for more than seventeen hours. Fire-fighting efforts were reported to have been impaired by inadequate supplies of water, so the fire lasted longer and caused more damage than would otherwise have been the case. No collapse was caused by the fire and the structure was repaired and put back into use.

(3.3) Construction Site Fires

The London Underwriting Centre, Mincing Lane, London

August 1991. Fire broke out in this seven-storey building during the course of fitting-out. Fire spread upwards from the lower levels via the escalators that had been installed in the atrium, temporarily protected by combustible packaging and covering. Repair costs are reported to have been approximately £105 million. There was no collapse of structure.

Fortune Tower, Jumeirah Lake Towers, Dubai

January 2007. Fire broke out on the upper levels of this thirty-seven storey tower during the course of its construction. The reinforced concrete frame was complete, and work was in progress on internal fitting-out and installation of the external cladding. There was no serious damage to the structure, although two workers were killed.

Shanghai World Financial Centre, China

August 2007. Fire broke out around forty storeys up in this one hundred and one storey tower while it was being fitted out and work was in progress on installation of its external cladding. The fire was put out relatively quickly and no serious damage was sustained by the structure.

APPENDIX A

Material Damage PML Assessments for Buildings Under Construction

Use the method outlined on the following sheet for buildings that meet the following criteria:-

- This method considers a single building in isolation. Further consideration of potential accumulation risk is required when several buildings are involved on a single site, or where adjacent sites are at risk by exposure to one another – see Appendix C of this document for details
- The PML scenario being considered in all cases is a fire at a late stage in the construction process, when the value of the work done is at or approaching a maximum, but when the features/systems/procedures that will afford protection to the finished product are either not present, not finished, not commissioned or not working.
- The contractor in control of the site is of known or assessed quality: known or shown at survey to have good management standards and procedures; in particular:-
 - A good level of compliance with the Joint Code of Practice, Fire Prevention on Construction Sites (JCOP) or an equivalent standard
 - Good hot work controls
 - Good housekeeping standards/procedures
 - Good security standards/procedures
- Non-combustible construction for the building fabric, with adequate passive fire protection i.e. new-build, complying with legislative standards/requirements, or refurbishment where structural fire protection is being upgraded to modern standards*
- A low volume of combustible materials incorporated in fixtures and fittings ‘imported’ during fit-out stage*
- Adequate response from the fire brigade and adequate fire-fighting water supplies
- Good subdivision of the building horizontally by solid floors, and no atria*

** Buildings with significant volumes of combustible materials incorporated in the structure, or high volumes of combustible materials in fixtures and fittings, or having atria inside them are all special cases and need to be considered individually.*

(1) For buildings up to and including 8 storeys in height above ground level:-

Assume that fire breaks out on one floor and spreads upwards to the floor above.

The extent of damage will be:-

100% of the value of each of the fire floors

50% of the value of the floor immediately above the fire for smoke damage

50% of the value of the floor immediately below the fire for water damage

Single storey and 2-storey buildings will suffer a loss of 100% of the value of their superstructure*

3-storey buildings will suffer a loss of 83% of the value of their superstructure**

4-storey buildings will suffer a loss of 75% of the value of their superstructure**

***Assuming they have no basements – see Appendix B for modifications due to the presence of basements*

In 5-storey to 8-storey buildings with unequal floor values, the position of the fire floors etc. can be positioned to maximise the extent of the damage.

The extent of the damage (% of the value at risk) is then multiplied by the value at risk to obtain a figure for the PML.

(2) For buildings of 9 storeys above ground level and higher***:-

Assume that fire breaks out on the sixth floor above ground level and spreads upwards unchecked to the full height of the building.

The extent of the damage will be:-

70% of the value of each of the fire floors

15% of the value of each of the floors below the fire for water damage

This can be summarised as follows:-

$$\text{Extent of damage} = (70 \times (N-5) + (15 \times 5)) / N\%$$

- where N = number of storeys

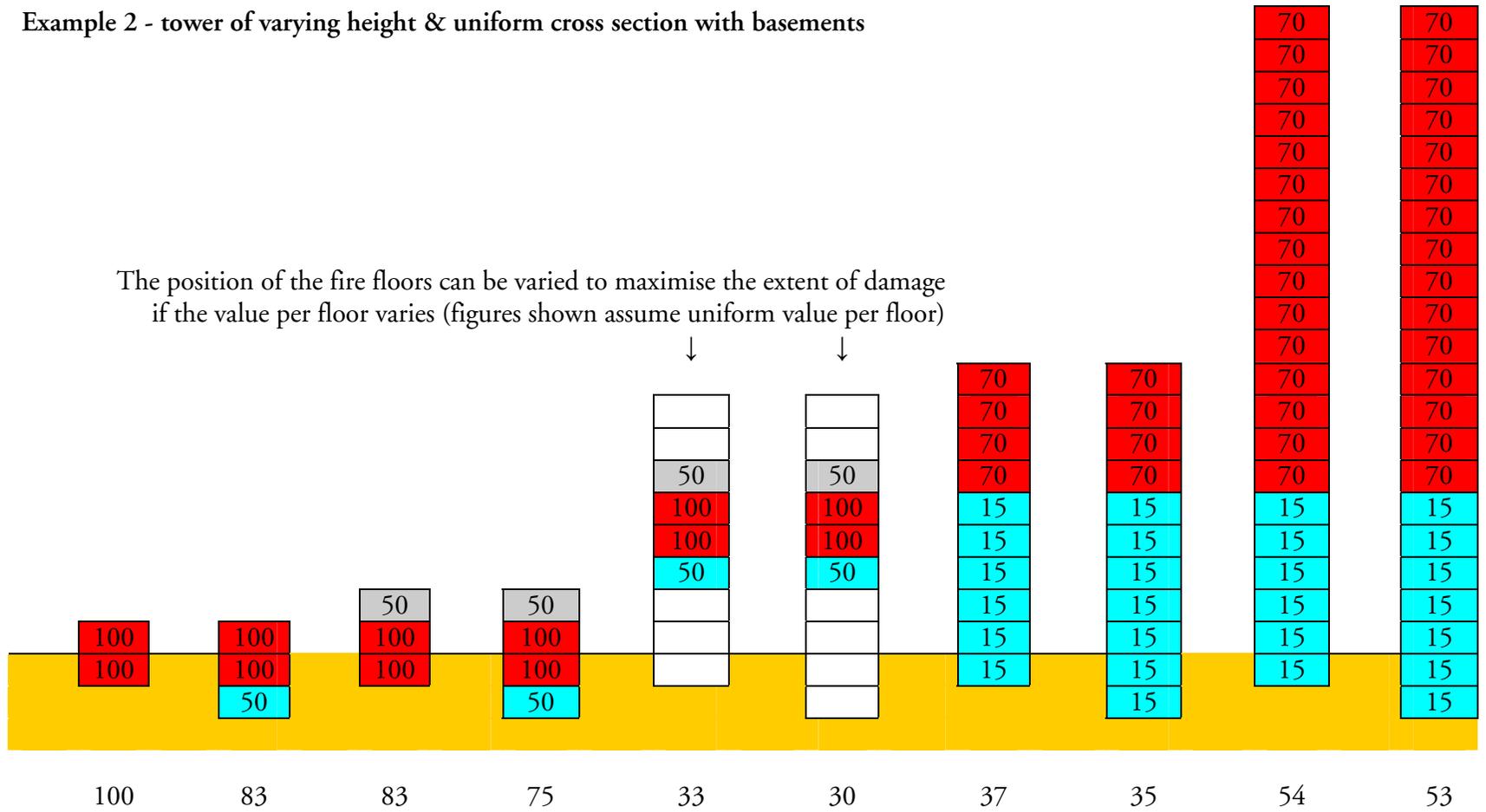
(tends to 70% when N = infinity)

**** This applies without modification if all floors are of the same (or approximately the same) area. Where the building has a low-level podium of a larger area per floor, consideration will have to be given to the possibility that a scenario of the type outlined above in (1) in the podium will produce a larger PML estimate.*

The extent of the damage (% of the value at risk) is then multiplied by the value at risk to obtain a figure for the PML.

Example 2 - tower of varying height & uniform cross section with basements

The position of the fire floors can be varied to maximise the extent of damage if the value per floor varies (figures shown assume uniform value per floor)

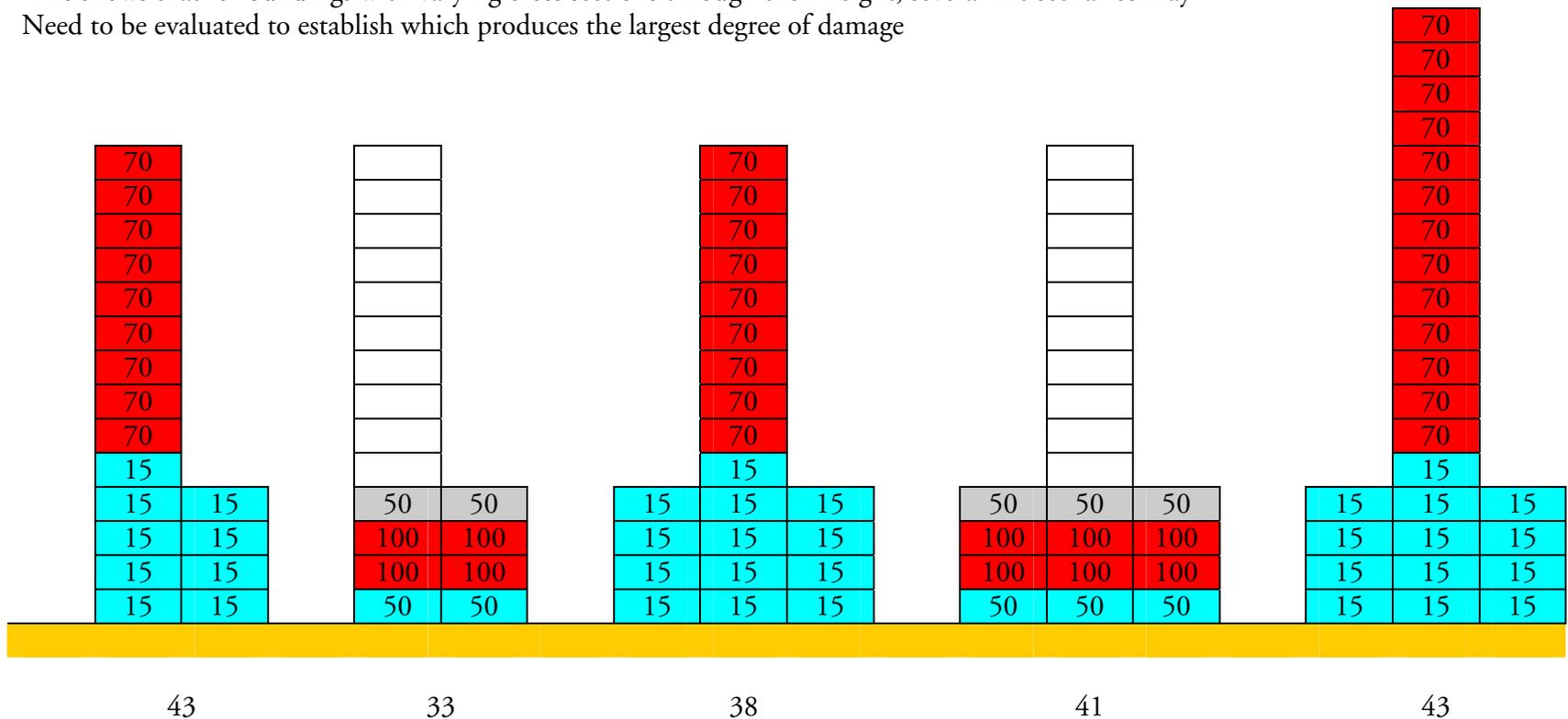


Example 3 – buildings having uneven cross section through their height

This example illustrates the relationship between tower height and the size of a 'podium' at low level

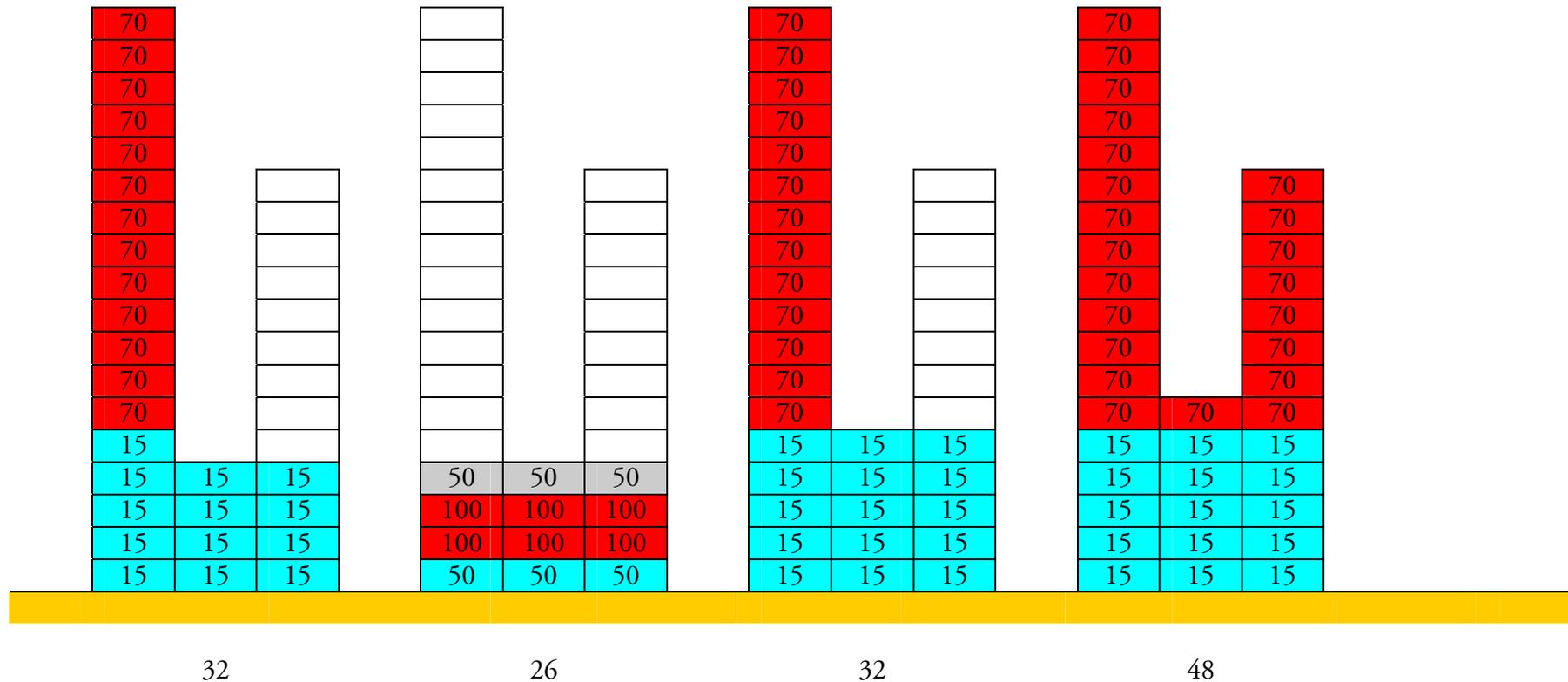
- In the first building shown, a fire in the tower is the dominant feature
- In the second, with a larger podium and same tower height, fire in the podium becomes the dominant feature
- In the third, the tower is taller and once again becomes the dominant feature of the building

This shows that for buildings with varying cross sections through their height, several fire scenarios may need to be evaluated to establish which produces the largest degree of damage



Example 4 – showing the influence of podium height

- In the building with a four-storey podium, fire in the tall tower dominates (32% versus 26% for fire in the podium)
- The same applies to the building with the five-storey podium, as the fire ‘mechanism’ confines the fire to one tower only
- When the podium reaches six storeys the fire mechanism changes and both towers are affected – with an increase in damage (in buildings with shorter towers the fire in the podium may be the dominant feature – see previous example)



APPENDIX C

Application to sites with more than one building

So far, this method has only been applied to single buildings in isolation. Many projects involve the construction of multiple buildings standing close to one another, so this must be considered when assessing PMLs. This section deals with the issue of how that might be done.

When considering such sites, the risk that fire will spread from one building to another must be taken into account. This is done by ensuring that they are far enough apart to prevent the easy spread of fire. Three things should be considered:-

- (1) The physical distance between the subject buildings
- (2) The likely presence of any temporary buildings or other structures that could 'bridge' the gap and carry fire from one to the other
- (3) The likely presence of any temporary works, materials or equipment storage that might render the gap ineffective as a fire-break and carry fire from one to the other

Considering point (1):-

The question of what is and what is not adequate separation between buildings is a complex one, with a number of methods having been developed, requiring the input of specific information such as fire loads, compartment sizes, the area of external wall penetrations expressed as a percentage of the overall area of the exposed walls etc. Much of this is not available at the Underwriting stage, and much of it varies with time over the cycle of construction.

For the purposes of construction PML assessment this is judged to be too complex, due to the complexity of the construction process and the factors outlined above. Instead, a simplistic approach has been adopted, which states that, for those buildings to which the method applies, a nominal separation distance of 10 metres is adequate. This is based on two things:-

- 10 metres is the separation distance that was deemed to be adequate for multi-storey buildings in city/town centre locations in the property insurance PML evaluations used by the Property Conservation discipline
- 10 metres is stated as the ideal separation distance between temporary buildings and buildings being constructed/renovated in "Fire Prevention on Construction Sites, the Joint Code of Practice on the Protection from Fire of Construction Sites and Buildings Undergoing Renovation". The thinking here is that the combined fire load of a 'standard' temporary building (one that is not compliant with the requirements for enhanced fire resistance etc. set out in the Joint Code) and its contents is likely to be more intense (or dense) than the fire load of/inside a building that falls within the scope of this method. As that is the case, and as a separation distance of 10 metres is judged to be adequate in that case, it is judged to be adequate in this context also.

Considering point (2):-

Where temporary buildings or other structures are positioned between the buildings being considered, a judgement must be made on whether fire is likely to be able to spread from one of those subject buildings to the other via the intervening building(s)/structure(s). Normally it would be prudent to assume that only structures comprising non-combustible materials – concrete, steel, glass, aluminium etc. – would fit this description, and that any combustible structures and/or temporary buildings, whether they comply with the enhanced requirements of the Joint Code or not, would be likely to carry fire from one of the subject buildings to the other.

Exceptions to this ‘rule’ may need to be considered however; if, for example:-

- The temporary buildings were positioned between the subject buildings for a short period only at the start of a project and were to be removed before there was a significant build-up of value or combustible content in the subject buildings. Where this is the case, two loss assessments might have to be made – the first with two buildings exposed at part full value – the other with only one exposed at its full value (assuming the programmes for construction of the two are similar – see below for further information on phased handovers).

Considering point (3):-

Other features of the site/construction process can serve to decrease effective separation distances between subject buildings; for example:-

Scaffolding; materials stores; combustible waste storage areas; equipment stores; fuel tanks; anything, in fact, that could carry fire from one part of the site to another.

This is possibly the most difficult part of the process to evaluate, as it has to be based on an appreciation of how the construction process is to develop and how well it is likely to be managed; which is why the conditions that apply to the application of the method refer to knowledge of and familiarity with the contractor.

Again, the presence of such conditions may be a temporary feature, relating to a particular phase of construction work and, as a result, several loss assessments may need to be made to establish which of them represents the PML for the project.

APPENDIX D

Treatment of special cases

Special cases are all cases that do not comply with the conditions set for application of the 'standard' method. The conditions, and a commentary on how cases that do not comply might be dealt with, are set out below:-

- Condition:-
The standard method considers a single building in isolation

Commentary:-
Appendix C of this document shows how it might be adapted/applied to sites with more than one building

- Condition:-
The PML scenario being dealt with here is fire

Commentary:-
There are other possibilities – hurricane, typhoon, earthquake, but they are outside the scope of this document and other guidance must be sought when dealing with them

- Condition:-
The contractor is in control of the site and is of known or assessed quality

Commentary:-
These firms can be relied on to have good controls on fire inception risks – hot work, smoking, security against arson etc. – and on the volume of fuel available to fires – waste control, good storage arrangements for materials and the like.
Other contractors are unknown quantities and may represent a greater degree of risk by not exercising good controls in these key areas. This may make the likelihood of a fire greater and may increase its extent and the value of damage it is likely to cause. The standard method does not deal specifically with likelihood, but does deal with extent and value, both of which could be increased to allow for the higher levels of risk associated with unknown contractors.

- Condition:-
Non-combustible construction for the building fabric, with adequate passive fire protection in place at the time of the PML scenario fire.

Commentary:-
Deviation from either of these is likely to have a dramatic effect on the degree of damage the structure is likely to suffer. At the extreme, timber-framed buildings are likely to suffer 100% losses through their full height, as the frame is likely to burn away completely in a fire, leading to a total loss of the building. Unprotected steelwork, unless it is part of a deliberately fire-engineered solution, is likely to suffer

collapse if exposed to fire for a protracted period, with large extents of damage suffered as a result. Normally, only the steelwork of the upper storey and roof is left unprotected (there being no requirement to protect it in most country building standards/codes) so only this part is at risk, but if late installation of fire protection on lower floors is accompanied by high fire loads, more extensive collapse could be the result.

- Condition:-
A low volume of combustible materials incorporated in fixtures and fittings 'imported' during the latter part of the construction phase and/or the fit-out stage

Commentary:-

Combustible fixtures and fittings – furniture and the like – could allow rapid fire spread through open doorways, vertical shafts etc. left/wedged open for access or snagging or completion of commissioning of services etc. This would serve to make the extent of fire spread and damage greater than predicted by the standard method and should be allowed for where it is known to be likely.

- Condition:-
Adequate response from the fire brigade/department, and adequate supplies of fire-fighting water available

Commentary:-

Where one or both of these is lacking, the spread of fire is likely to be greater than that predicted by the standard method. Collapse may be indicated, but experience tends to suggest that structures with good passive fire protection in place would successfully be able to survive burn-out of normal construction materials

- Condition:-
Good subdivision of the building horizontally by solid floors, and no atria

Commentary:-

Some penetration of floors by stairs, lifts, service ducts and risers is envisaged, but not the more substantial holes left by atria and the like. Where those features are present, the fire should be 'allowed' to spread upwards freely inside the atrium to affect all floors that open into it, with 70% damage caused on all floors affected.

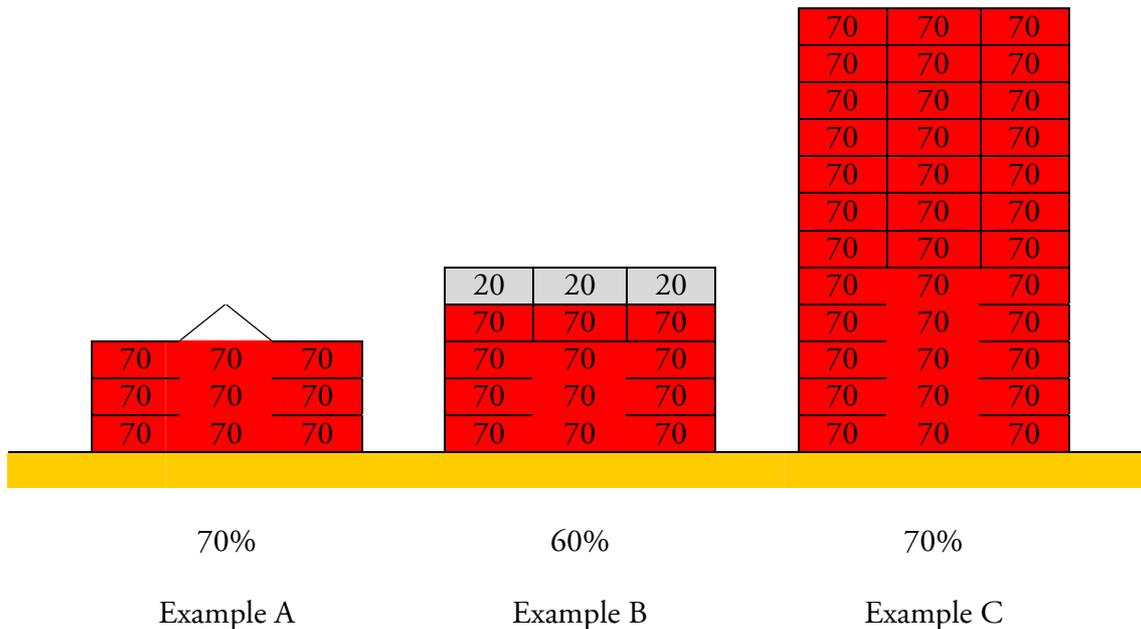
Where an atrium extends up to the roof, so does the fire – see example A below.

Where the atrium is 'capped' by a solid floor slab, fire spread can be limited to the height of the atrium plus one floor above – see example B below – unless by applying this 'rule' the fire reaches the sixth floor above ground level, in which case the fire must then be 'allowed' to burn upwards in an uncontrolled way to affect the full height of the building, as per the standard high-rise method – see example C below.

In applying this 'rule' for atria, the damage to the building is to be assessed as:-

- 70% of the value of each floor directly affected by the fire, plus
- 20% of the value of the two floors directly above the fire and 10% of all floors above that for smoke damage, plus
- 15% of the value of all floors below the fire for water damage

Collapse is still not considered to be likely, for the reasons stated previously.



The results produced by this analysis should be considered in conjunction with the results obtained for the same building by using the standard method.

Consider, for example, a low-rise building with a full-height atrium. Using the ‘rules’ set out above the degree of damage would be predicted as 70% of the superstructure value, whatever the building height. For buildings having 1, 2, 3 and 4 storeys, however, the standard method predicts 100%, 100%, 83% and 75% respectively. In these cases the larger figure should be used. At five storeys the standard method predicts 60% but the ‘atrium method’ predicts 70%, so the presence of the atrium dominates.

‘Special cases’ not covered by the ‘General Conditions’ applicable to the method (set out in Section 2.5.1):-

- Sites containing buildings with ‘inadequate’ separation distances. Use the method outlined in the paper, but use the full value of the Target Risk in the calculation, rather than the value of just one building.
- Buildings having combustible materials in the frame or fabric.
Where the combustible elements are spread throughout the building, then the size of the loss must be expanded to become 100% of the value at risk in the Target Risk.
Where the extent of those materials is more limited, the areas containing them should be rated at 100% and their value added to the figures calculated for the non-combustible part in the standard manner.
If, however, the non-combustible part is supported by the combustible part (unlikely) then a 100% loss of the whole structure is likely, to allow for the risk of complete collapse.
- Buildings having high volumes of combustible materials incorporated in the fixtures and fittings.
The same considerations apply as outlined in the preceding paragraph.

- Lack of adequate response from the fire brigade (defined as brigade attendance not likely within 15 minutes of call-out) or lack of adequate fire fighting water supplies. The fire must be assumed to spread uncontrollably and cause a full-value loss in the Target Risk.
- Lack of adequate subdivision between floors inside the building i.e. presence of significant floor openings like atria.
In such circumstances the method outlined above for buildings containing atria.

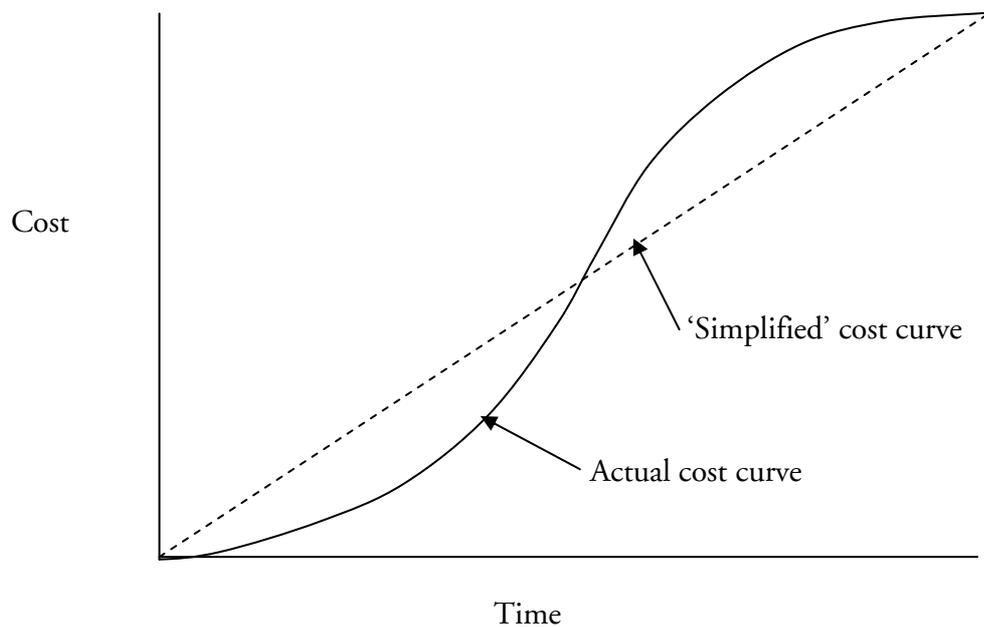
It is acknowledged that the methods set out in this document vary from current practice in the Property Conservation discipline, mainly in respect of floor openings, which exist on every construction site through most of the duration of the construction programme, and would be seen in the Property discipline as a certain route for the passage of fire from one floor to another. In the Construction Insurance discipline the presence of a certain number of floor openings of limited size is seen as being acceptable, provided the 'General Conditions' set out in Section (2.5.1) of this paper are complied with. This reflects the fact that most modern construction sites have a much lower fire load in most areas than an equivalent finished and occupied building does. In Construction we therefore rely on the lack of continuity of fire load on the sites we insure to protect them from fire spread, rather than solid, unbreached compartment walls or floors.

APPENDIX E

The Effect of Phased Handovers

On many projects, parts of the building(s) are completed and handed over to the Construction Client while other parts are still being built. This can have the effect of reducing the overall value at risk, and lowering the PML. In order to determine the effect of phased handovers the flow of money through a project must be considered, in the form of a cumulative spending curve.

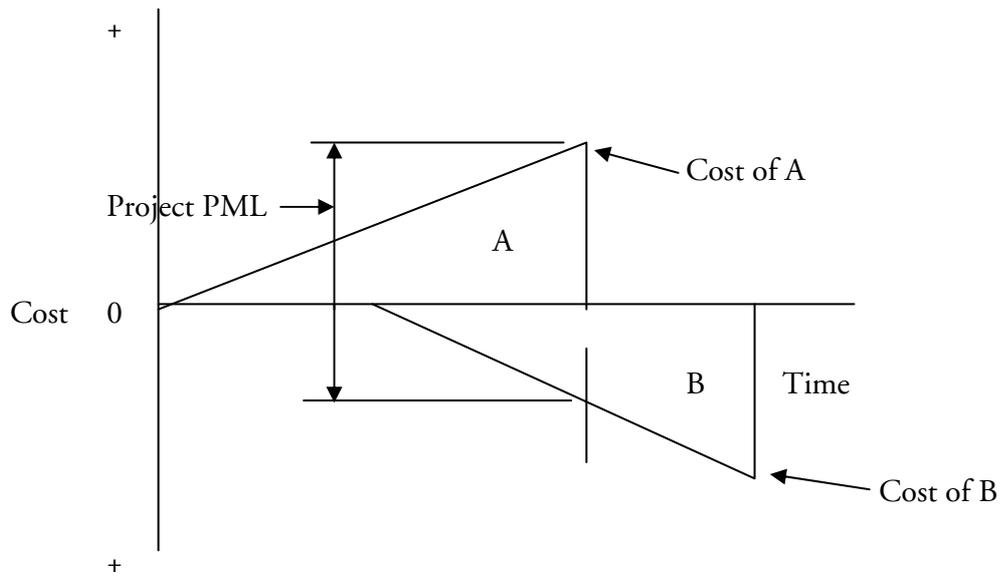
Experience shows that the typical curve for the construction of a building is as shown below:-



The spending typically follows an S-shaped curve, commencing at a slow rate while the job is in the ground, accelerating through frame construction, installation of external cladding and waterproofing and construction of internal walls, accelerating further as services installations and first-fix finishes go in, then slowing down as testing, commissioning and finishing stages are reached.

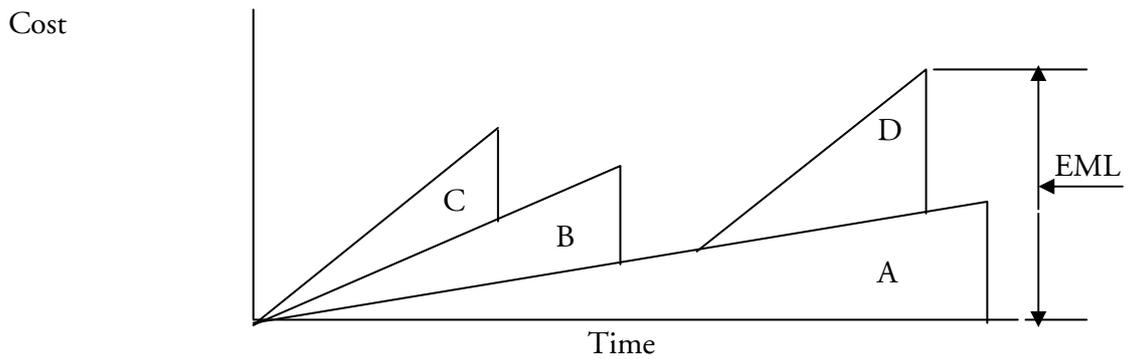
For our purposes, a straight-line approximation of this curve is sufficient when carrying out PML assessments. It does lead to an over-estimate of the spending in the early stages of the project and an under-estimate in the latter stages but, in reality, it is nowhere near as pronounced as is suggested by the graph above and is judged to be within the normal margins of error for the method employed.

The use of this simplified 'curve' allows us to examine the effect on the PML of planned early completions and phased handovers. Consider the case of the two buildings used in the example earlier in this module, Block A and Block B. Suppose that Block A was begun first and Block B some time later, and that Block A was due to be completed and handed over some time before Block B was finished. A graphical representation of that situation would appear as shown below:-



The project PML for this case is the value of Block A at handover, plus the value of Block B at the same time, as predicted by the graph of rate of spending on the project.

Using this method of presentation, it is possible to analyse quite complex projects with multiple handovers on multiple dates:-



In this example, Blocks A, B, C and D are judged to be sufficiently close to one another to be regarded as all being within the Target Risk. Construction of Blocks A, B and C begins concurrently, each one of them having a different duration. C is finished first and handed over. B is finished some time after that and is also handed over. Construction of Block A continues. Block D is begun some time after Blocks B and C have been finished, perhaps relying on the sale or rental income derived from B and C to provide its funding. D finishes before A and is also handed over.

The value at risk, as shown by the graph, fluctuates through the contract period, rising from nothing at the start to a first 'peak' immediately before the handover of Block A, then falls back. It rises to a second, lower, peak immediately before the handover of Block B, then falls back again. The PML for the project, as shown on the graph, is generated by the full value of Block D, plus the proportion of the value of Block A that has been spent/installed at the time of the handover of Block D.

APPENDIX F

Calculating EMLs for Buildings Undergoing Alteration or Refurbishment

The Works

The calculation of a PML for the works in a building undergoing alteration or refurbishment essentially follows the process outlined above, but with the important proviso that the nature, condition and role played by the existing structure has to be considered as a factor. The extent and influence of that factor is best illustrated by two examples, at opposite ends of the spectrum:-

- Example 1

Consider a project involving the demolition of the whole of the structure of an existing building, except the brick and stone façade on one of its sides, which is to be retained and incorporated in the new scheme. The new works consist of the construction of a new building, on new foundations, to which the existing façade will then be connected in order to provide it with its lateral restraint.

In this example, the characteristics of the new works will dominate the PML calculation, and all of the processes outlined above will apply to the new construction. The presence of the existing structure will be a minor consideration and will only be relevant if it has some feature which, in the opinion of the Underwriter or Risk Engineer, enhances the risk presented by the PML scenario – if it was constructed entirely or mostly from combustible materials, for example, it would play a major role in development of the PML scenario and therefore development of the PML assessment.

- Example 2

Consider a project where the work involves the refurbishment of an old tea warehouse and its conversion into open-plan offices. The existing building has solid brick external walls, timber floors throughout, supported internally on exposed cast iron columns and beams. Construction works comprise:-

minor structural repairs to brick work, lintels and some of the cast iron elements; replacement of a limited amount of rotted timber – mainly in the roof structure; installation of new services throughout; installation of new toilet and kitchen facilities and the installation of a new lift in the existing lift shaft.

In this example, the characteristics of the existing building will dominate the PML calculation. The presence of the timber floors means that, in a fire, the whole of the building would be lost. As the insured works are likely to be spread throughout the building, the PML here would almost certainly be 100%.

The Existing Structure

The method to be used here is broadly similar to that outlined above, but with additional considerations to be taken into account.

As was stated in Module 10 (Existing Structures), the extent of the insurance cover for this class is varied – sometimes being provided on an ‘all risks’ basis, and sometimes only for specified perils. When calculating an PML for existing structures, the Underwriter or Risk Engineer must take into account the scope and extent of cover provided, in the context of the work that is being done on the site. To illustrate the principles involved here, the two examples set out above will be used again.

- Example 1

Consider a number of possible scenarios:-

- If the cover was on an ‘all risks’ basis, then all aspects of the work being done on the site would need to be considered, including vibration damage from demolition activities, the strength and suitability of the temporary works providing lateral restraint while and after demolition was carried out, any risk presented by foundation works – either directly on the façade itself, or for the new building behind it, the likely effect of fire etc.
- If the cover was limited, to, say, just storm, then the only aspect to be considered would be the temporary works providing lateral restraint, and its ability to withstand the loads imposed by high winds.
- If the cover was ‘all risks’ and the new building had a reinforced concrete or fully protected steel frame, then the risk of collapse of the retained façade would be very low, as the risk of collapse of the new building would be judged to be similarly low, and the façade’s restraint would be maintained.
If, however, the frame of the new building was to be constructed from timber, then the risk of collapse of the façade in a fire would be high, and the PML would probably be set at 100%.

These examples are intended to show that in this case it is the features and properties of the work being done that affects the risk to the existing structure, rather than the nature of the existing structure itself.

- Example 2

In this case it is the features and properties of the existing structure itself that dominates the risk, rather than the nature of the works being done in or to it. The presence of the high fire loads the timber floors and roof structure represents automatically makes the PML scenario fire and leads to the calculation of a high PML.

APPENDIX G

LIMITATIONS

Lateral Fire Spread

Everything set out above deals only with vertical fire spread, but does not address the issue of lateral spread, which is also important. In the Property Conservation discipline, fire is considered to spread laterally without restraint, until it reaches either the outer edge of a building from which it cannot spread further (due to the existence of adequate separation distances to the next building) or a satisfactory fire-break wall. This is based on the reasonable assumption that, in an occupied building, there will be a continuous fire load in all throughout the compartment or building being considered.

In construction it is reasonable to use the same assumptions when either the compartment or building being considered is small, or when there is, or is likely to be, a continuous fire load throughout. There are cases, however, when it would be unnecessarily onerous to calculate PMLs on that basis, and a less conservative approach is warranted. Features that are associated with buildings where this approach (i.e. less conservative) can be taken are set out below. Realistically, for this approach to be applicable, all or most of these features would need to be present at the same time.

- Buildings that are 'long' in comparison to their width, so that fire can only effectively spread in one direction, making it easier for the brigade to set up a place where its spread can be stopped
- Buildings that are being finished to shell and core stage only, with little or no finishing works being done on the floors outside the service cores, or where finishes on the floors are limited to non-combustible materials only i.e. plastered walls, metal ceiling tiles in metal grids, metal tile raised floors with no finishes (carpet) etc.
- Buildings with no temporary buildings or temporary accommodation placed inside or within 6 metres of their outside walls
- Buildings with no significant storage of combustible materials or combustible waste inside them
- Buildings with no storage of gas bottles – full, part-full or used – or flammable liquids of any kind inside them

In other words, long, thin buildings with no identifiable continuous fire loads or high-hazard areas inside them.

Another example of such a building might be one which consists of a number or series of discrete 'blocks' with more than 10 metres separation between each of them, that are connected together by 'links' – corridors or walkways. In theory, these links, from the PML point of view, connect the separate blocks together and make the whole development the Target Risk. If, however, the links are to be constructed entirely from non-combustible materials – concrete, brick, concrete block, steel, glass etc. – and will be kept clear of combustible materials, waste etc. during the construction process, there is

merit in considering the argument that fire will be unlikely to be able to spread from one block to another, so they can be treated as being separate.

If this option to calculate a 'reduced' PML on the basis of restricted lateral fire spread is selected, it should be remembered that 'links' and large open areas, although they might not be regarded as likely to allow fire to spread, will almost certainly contain and conduct smoke into other parts of the building. Due allowance should be made for this in calculating the PML, on the basis of 10% of the value of all of the areas judged likely to be affected.