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THE SPECTRUM OF HAZARD AND RISKS IN CONSTRUCTION

> It is only by risking our persons from one hour to another that we live at all.
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> (Williams James, 1897)

> No Risk is the Highest Risk of All.
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> (A.Wildavsky, *American Scientist,* 1979)

The ideas captured by the above quotations have formed the pivotal factor in many aspects of human life. In insurance, the 1601 Marine Insurance Act of the English Parliament is an example.[1] In law, voluntary assumption of risk results in contributory responsibility, see page 14, and it may be observed in many authoritative works on sociology and philosophy. Nevertheless, few people involved in construction perceive its importance within the work done by the parties involved. It should be perceived that the risks inherent in construction should be specifically allocated in the contract(s) between the parties involved and that they may also be offloaded from one party to another by agreement. They may also be offloaded to a third party such as an insurer or a banker but that choice has to be based on proper principles relevant to the transaction and should also be referred to in their contract(s). The agreements made must be based on clarity and understanding of the respective risks, responsibilities and liabilities which are allocated to each. It is who bears the risk that is important.

As a party enters into contractual obligations freely, it accepts certain risks that are allocated to it and promises to bear these risks if and when they eventuate. In this way, the contracting parties are able to plan ahead with calculable certainty their schemes and arrange their business affairs. There are, however, specific risks that are beyond the capacity of a party to accept. In such circumstances, it would be better to name these risks and specify the method of dealing with and managing them.

In this chapter an attempt is made to classify the risks inherent in construction in such a way that a spectrum may emerge identifying the risks that one might expect.[2] If these expectations are clearly understood, attention may then be focused on which risks should be expected on a particular project and how they could or should be dealt with.

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1 See page 4 above.

Classification based on chronology

In order to produce as wide a spectrum as possible, the classification used in this chapter is that based on chronology as expressed in Figure 2.3. Of course, any other classification could be utilized, but then a different spectrum would emerge. Figures 2.3, 3.1 to 3.3, 3.6, 3.9 and 3.11 are drawn as flow diagrams which arrange, in chronological order, the various stages of a construction project and list in general terms the risks considered important. As it is most difficult, if not impossible, to perceive all possible risks and thus present a complete spectrum, the figures referred to above show a wide but not complete range to which others could be added once a project is accurately defined or new risks are envisaged.

The spectrum of risks in construction

Figure 2.3 on page 46 above displays the spectrum of risks by showing that the risks included are those affecting, in principle, the construction trinity of owner, professional team and contractor and, in certain circumstances, the community at large. It then divides the spectrum, in a chronological manner, into seven stages, allocating to each stage the relevant risks. Figure 3.1 deals with the feasibility stage and Figure 3.2 with the design stage. Figures 3.3, 3.6 and 3.9 refer to the construction stage and Figure 3.11 to the post-construction stage.

E.1.1

Risks associated with the feasibility stage (Figure 3.1)

Figure 3.1 shows the risks in the feasibility stage during which the idea of a particular project on a specific site or in a certain area is born and a decision is then made to either proceed with it or abandon it. In some cases, the choice of a professional team precedes the choice of the site. In others, it is the other way round, relieving the professional team of the responsibility of site selection. For the purposes of this spectrum, we shall assume the first situation whereby the professional team is selected first and the choice of site is decided upon with assistance drawn from that team's recommendation. In the following sections, an example of each of these envisaged risks is given from real life.

E.1.1.1

Owner's choice of professional team and advisers

On 27 March 1981, the reinforced concrete roof of the Harbour Bay Condominium in Cocoa Beach, Florida, collapsed during concreting operations, bringing down with it the whole building and resulting in the death of eleven construction workers and the injury of twenty-three others. The building, a five-storey structure, was 242 ft long×58 ft wide and designed as a cast in *situ re*inforced concrete flat slab and columns by two retired structural engineers. One of the two engineers was employed as a consultant by the contractor to carry out design calculations, prepare documents and inspect the construction as it proceeded. The second

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[2] 'The Spectrum of Risks in Construction', FIDIC's Annual Report of the Standing Committee on Professional Liability, June 1985.

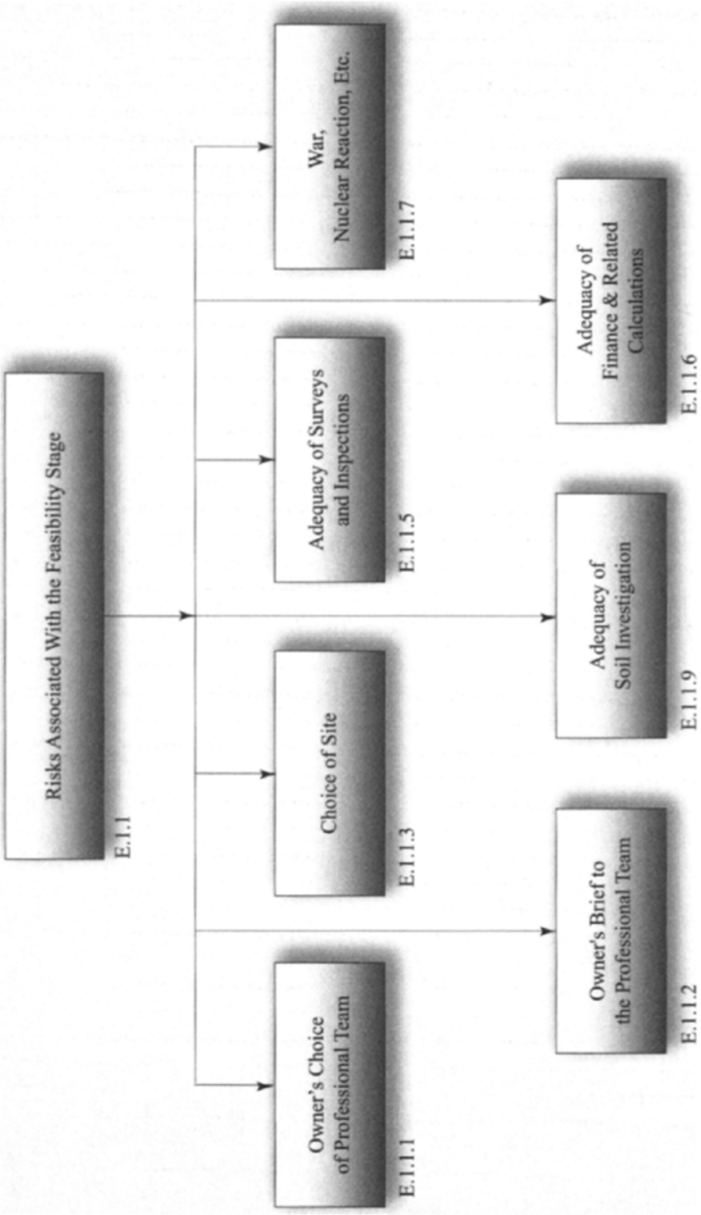

Figure 3.1 Risks associated with the feasibility stage.

was brought in by the first engineer as a sub-consultant to carry out the necessary calculations. Out of the seventy-nine sheets of calculations submitted to the Cocoa Beach Buildings Department only one was done by the first engineer.

The cause of the collapse was attributed to punching shear forces around the columns, which is a feature of flat slab design.[3] Despite the fact that it is a basic item of calculation in this type of design, the engineers did not consider it in their calculations. At full loading, the stresses exceeded those allowable by 469%. Even at dead load alone, the shearing stresses significantly exceeded the allowable stresses at all but two of the columns and were sufficient to cause the collapse.

The investigations that followed the collapse showed a variety of design and construction errors, some of which were extremely serious. For example, the weight of the external masonry walls was not taken into account in the calculations for weights on foundations. The columns as constructed were much smaller than designed but, even if they were not, they would have been too small to carry the load safely. Slab deflections were neither calculated nor checked against those permissible in similar type design.

This case serves to show the importance of selecting the right consultant for the particular project or even for the particular discipline.

E.1.1.2

Owner's brief to the professional team

The owner's brief is one of the most important documents and yet that to which the least attention is generally paid. It is a document which sets out the basic definition of the project and the boundary within which it must evolve. It is sometimes referred to as the terms of reference (TOR) and should include such topics as would be necessary for the particular project. They would, however, refer to geographical, financial and technical limits; objectives, capacities and key components; period of service, life span of project and level of input.

Misunderstandings in this area have caused and continue to cause failures in the construction field. Examples include failures due to:

1 Change in use of the project not envisaged by the designer and yet contemplated by the owner;
2 TOR of the mechanical consulting engineer not including the design of a ventilation system capable of handling the corrosive atmosphere in a particular environment; and
3 Greatly differing understanding by the owner and the designer of their duties and responsibilities.

E.1.1.3

Choice of site

A school was recently planned in a mountainous area of the United States of America where many feet of snow are a normal, annual, winter event.[4] The site designated for this project was located at the base of several large mountains and in a bowl-shaped hollow.

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[3] Professional Liability Loss Control Program prepared by National Program Administrator Inc. in cooperation with Simcoe & Erie General Insurance Co., Canada, Bulletin No. 57, January 1982.

Designs were made and contract documents were prepared for a very costly school. The contract for the construction was entered into and work on the foundations proceeded satisfactorily, until the spring when the snow started to thaw. Large quantities of run-off water accumulated in the hollow chosen as the site for the school, forming a shallow but large lake submerging the foundations. The architect who had participated in the selection of the site was blamed and his professional liability insurer had to step in to rectify the situation.

Similar problems exist all over the world wherever natural hazards exist. When a site is chosen for a certain project, its natural characteristics must be investigated. The professional team should not depend on the owner's undertakings or assurances as to the suitability of the site. The defendants in the case of *Bowen v. Paramount Builders* in New Zealand relied on such an assurance from the owner/employer, but they were still held liable to a third party who purchased the property which subsequently suffered from subsidence due to unsuitability of the site.[5]

The site may also be unsuitable due to subsoil conditions, as in the case of *W.C. Kruger and Associates v. Robert D.Krause Engineering Co. and Albuquerque Testing Laboratory, Inc.,* in New Mexico.[6] The facts of the case are that an architect retained a structural engineer to design the structural elements of a post office facility. He also retained a soil-testing consultant to perform a soil investigation based on a proposal which failed to include a partial basement with footings substantially below the depth of the soil investigation made. The soil consultant submitted his report making the recommendation that further settlement computations should be carried out.

The additional computations were not made and the work progressed. During excavations, it was discovered that the site was not suitable for the foundation design recommended by the soil consultant. An additional investigation had to be performed and the foundation had to be redesigned resulting in an additional cost of $54,363. The architect settled the claim made by the owner and brought an action to recover from the structural engineer and the soil consultant on the basis of negligence.

The trial court found that, had the computations recommended by the soil consultant in his report been carried out, the problem that was encountered would not have arisen. On this basis, the court held that the architect, the structural engineer and the soil consultant were all negligent in allowing the work to progress without performing the additional settlement computations. The court, however, rejected the architect's claim against the structural engineer and the soil consultant and did not permit any recovery on the basis that he had contributed by his own negligence to any damages suffered.

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4 *Guidelines for Improving Practice,* a publication of Victor O.Schinnerer & Co., Inc., in cooperation with the American Institute of Architects, The National Society of Professional Engineers in Private Practice and CNA Insurance, Washington, DC, USA, vol. 11, no. 5.

5 *Bowen v. Paramount Builders [1977]* 1 NZLR 394.

6 *Guidelines for Improving Practice,* op. cit., see note 4, vol VI, no. 1.

E.1.1.4
Adequacy of soil investigations

Having established the risks to which the site is exposed from nature, perhaps the most controversial, widely litigated and arbitrated subject revolves around what lies below the surface of the ground. One of the reasons is that matters of opinion before construction become matters of fact afterwards and those involved tend to make judgment with the benefit of hindsight. On the other hand, another reason may be that there are many questions of a technical, economic and legal nature which keep changing and developing with time and location. These questions may take the form of:[7]

> …to what extent does the employment of 'professional' site investigators entitle the owner to say that he has reasonable grounds to believe that their report was true, even when it proves to be quite misleading?
>
> Is there a difference between an owner who chooses site investigators of good reputation, supervises their work properly and gives tenderers the full information received from them (or perhaps from a series of site investigations over many years) and an owner who employs the cheapest investigators that can be found, with an inadequate brief, and provides only a part of their conclusions?
>
> …Conclusions about the site drawn from a few boreholes may be worded as fact, but are based not only on the factual results in the columns of ground that have been bored, but on the opinion that those results are typical of the ground between the bores.

Is this a reasonable assumption?

There are also questions about who should bear the responsibility for this risk. Since no two projects or sites are alike, the terminology used in conditions of contract is by necessity quite vague, in order to resolve part of this problem. Clauses 12 of three sets of Conditions of Contract are quoted below which differ slightly in detail but both use the words 'physical conditions', 'artificial obstructions', 'reasonably', 'foreseen', 'experienced contractor' and 'Unforeseeable'.[8]

ICE, 7th edition

> 12 (1) If during the carrying out of the Works the Contractor encounters physical conditions (other than weather conditions or conditions due to weather conditions) or artificial obstructions which conditions or obstructions could not in his opinion reasonably have been foreseen by an experienced contractor the Contractor shall as early as practicable give written notice thereof to the Engineer.[9]

FIDIC, 4th edition of the Red Book

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[7] 'Risk Management', by Max W.Abrahamson, [1984] ICLR 241. It was also a paper presented at the International Construction Law Conference organised by the Master Builders Federation of Australia, held in Sydney, October 1982.

[8] 'Unforeseeable' is a defined term in the New Red Book of 1999. It is defined as 'not reasonably foreseeable by an experienced contractor by the date for submission of the Tender'.

> 12.1 If, however, during the execution of the Works the Contractor encounters physical obstructions or physical conditions, other than climatic conditions on the Site, which obstructions or conditions were, in his opinion, not foreseeable by an experienced contractor, the Contractor shall forthwith give notice thereof to the Engineer with a copy to the Employer. On receipt of such notice, the Engineer shall, if in his opinion such obstructions or conditions could not have been reasonably foreseen by an experienced contractor….[10]

FIDIC, The New Red Book

> 4.12…If the Contractor encounters adverse physical conditions which he considers to have been Unforeseeable, the Contractor shall give notice to the Engineer as soon as practicable.
>
> This notice shall describe the physical conditions, so that they can be inspected by the Engineer, and shall set out the reasons why the Contractor considers them to be Unforeseeable. The Contractor shall continue executing the Works, using such proper and reasonable measures as are appropriate for the physical conditions, and shall comply with any instructions….
>
> If and to the extent that the Contractor encounters physical conditions which are Unforeseeable, gives such a notice, and suffers delay and/or incurs Cost due to these conditions, the Contractor shall….[11]

Following an interesting Australian case in 1972, it could be construed that, where the owner did not accept the task and therefore the responsibility of providing full and accurate information about the site and the contractor had not therefore relied upon such information, the risk was the contractor's.[12] The contract was to deepen a harbour using blasting operations which proved to be slower than the contractor expected. This was attributed to the existence of underground mine workings which were assumed to dissipate the effect of blasting. The contractor alleged that the owner knew of the existence of these mine workings but did not make it known in the tender documents. It is no wonder that even eminent authors, arbitrators and judges do not seem to agree on what to do with this risk.[13]

It may, however, be interesting to quote from actual case histories concerning site investigation. It seems that, in 1826, the responsibility of a designer in respect of carrying out his own investigations was established through the case of *Moneypenny v. Hartland*.[14] The designer, in that case, accepted the results of borings taken by someone else who had been

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9 ICE Conditions of Contract and Forms of Tender, Agreement and Bond For Use in connection with Works of Civil Engineering Construction, Measurement Version, 7th edition, The Institution of Civil Engineers, London, 1999.

10 Conditions of Contract For Works of Civil Engineering Construction, 4th edition, Federation Internationale Des Ingenieurs-Conseils, Lausanne, 1987.

11 Conditions of Contract for Construction for Building and Engineering Works Designed by the Employer, 1st edition, Fédération Internationale des Ingenieurs-Conseils, Lausanne, 1999.

12 *Dillingham Construction Pty. Ltd. & Others v. Downs* (1972), 13 BLR, Supreme Court of New South Wales.

previously engaged by the owner. The design based on these borings was found later to be inadequate and the designer failed to recover his remuneration.[15]

In 1981, in *Eames London Estates Ltd. and Others v. North Herts District Council and Others,* the judge stated:[16]

> I consider it normal practice for an architect to draw his client's attention to the need for ground conditions to be investigated. Also, that the client be advised of the possible need to carry out a detailed site investigation, if the architect was uncertain in any way of the type and bearing capacity of the ground.

Commercial decisions on the type of investigation to be carried out or the type of foundation to be designed carry with them responsibility. The owner/employer must, therefore, be involved in those decisions if he were to take part of the risk that might benefit him financially. This was illustrated in the case of *City of Brant ford v. Kemp & Wallace-Carruthers & Associates Ltd.*[17] Another view of the relationship between architect, engineer and owner was treated in the case of *District of Surrey v. Church* in Canada where the engineer was appointed by the architect rather than by the owner.[18] The engineer recommended to the architect that a soil investigation be carried out but the latter refused to accept the recommendation due to lack of money in the budget and the presumption that the owner would not approve such an investigation and that he would accept the building to be designed to a certain bearing pressure. Neither the architect nor the engineer approached the owner to verify these statements. It was contended that, had such an approach been made, the owner would have approved the required soil investigation which would have revealed that a layer of marine clay below the surface did not have the necessary bearing capacity to support the building.[19]

In the particular circumstances, serious differential settlement occurred and the owner sued both the architect and the engineer who were held jointly and severally liable to the owner. The architect was held liable for breach of contract and the engineer in tort (since he had no contract with the owner) as he was held to have had a duty of care to inform the owner directly of the need for deep soil investigation, notwithstanding the lack of a contractual link.

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13 See judgments referred to in the article quoted in note 3 above.

14 *Moneypenny v. Hartland,* 1826, 2 C. & P. 378.

15 *Hudson's Building and Engineering Contracts,* by I.N.Duncan Wallace, 11th edition, Sweet & Maxwell, 1995, London.

16 *Eames London Estates Ltd. and Others v. North Herts District Council & Others* (1981) 259 EG.

17 *City ofBrantford v. Kemp & Wallace-Carruthers & Associates Ltd.* (1960) 23 DLR.

18 *District of Surrey v. Church,* 1977, 76 DLR.

19 Ibid., See *Guidelines for Improving Practice,* op. cit., see note 4.

E.1.1.5

Adequacy of surveys and inspections

There is no substitute for actually visiting the site and physically walking between its extremities and even beyond, keeping one's eyes open for any sign which might require special attention.

In *Balcomb and Another v. Wards Construction (Medway) Ltd and Others,* the engineer was held liable to his client, the builder in this case, for failing to exercise professional skill which would have alerted him to the presence of trees on the site in the immediate past.[20] He was also found liable in tort to the owners of the house which, in this case, was damaged by the heave of the clayey subsoil.

This principle of site inspection goes beyond the boundary of the actual building site, as happened in the case of *Batty and Another v. Metropolitan Property Realisation Ltd. and Others.* [21]

A development company and a builder had inspected land on the side of a valley. They both passed the site as suitable for development, but had they looked across the valley and on adjoining property, they would have seen what should have alerted them to the necessity of carrying out a soil investigation. In the event, three years after the construction of a house on one of the plots, which was located over a steep slope, a landslide occurred below the garden of the house damaging the fence and part of the garden. Although the house itself was undamaged on that occasion, the Court of Appeal in England held that it was doomed to failure and in imminent danger. The developer and builder were held liable to the house owner in tort and, in addition, in contract between him and the developer.

E.1.1.6

Adequacy of finance and related calculations

Getting paid for work done without any strings attached is a real risk. The construction industry cannot function if John Heywood's quotation given below is frequently applied:

> Let the world slide, let the world go; A fig for care, and a fig for woe! If I can't pay, why I can owe, And death makes equal the high and low.

However, in some cases, the calculations made of what is reasonable to pay to complete a project may be erroneous and the finance allocated may prove to be insufficient. In other cases, unforeseen events may result in the owner becoming incapable of honouring his commitments. Thus it is always wise to consider this risk and the consequences which may flow from its occurrence. A few of the most spectacular occurrences of cost overrun are listed below:

The Concorde Project: In 1959, the project was estimated to cost £95 million. The total development cost was finally £1,140 million.

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[20] *Balcomb and Another v. Wards Construction (Medway) Ltd and Others, and Pettybridge and Another v. Wards Construction (Medway) Ltd and Others* (1981) 259 EG 765.

[21] *Batty and Another v. Metropolitan Property Realisation Ltd and Others* 1978 2 All ER 445.

The Sydney Opera House: The Sydney Opera House was originally estimated in 1967 to cost $A6 million and, when it was completed in 1973, the cost had risen to $A100 million.

The North Sea Oil Fields: The cost of 20% of North Sea fields was up to 200% overrun; 30% of North Sea fields were up to 100% overrun and 50% of North Sea fields were up to 50% overrun.

The Channel Tunnel: The Channel tunnel, which is one of Europe's largest infrastructure projects ever, is 31 miles long and, on average, 150 ft under the seabed, started at an estimated cost of £4 billion and ended in the mid 1990s at £15 billion.

E.1.1.7
War, nuclear reaction, etc.

The consequences of hazards such as war, nuclear reaction and such similar events are so devastating, if a project is exposed to them, that the owner must consider them on their own. The risk in such a hazard materialising must be assessed by experts in the relative field or ignored completely. The decision to proceed with a project must be taken by the owner once the balance of probability is considered by him.

E.1.2
Risks associated with the design stage (Figure 3.2)

Once a project passes from the feasibility stage to the design stage, the decision-maker, amongst other things, must have assessed the implications of the various risks indicated in Figure 2.1 and passed them as acceptable.

Lord Edmund-Davies said in the House of Lords case of *Independent Broadcasting Authority v. EMI Electronics & BICC Construction,* the following:[22]

> …The project may be alluring. But the risks of injury to those engaged in it, or to others, or to both, may be so manifest and substantial and their elimination may be so difficult to ensure with reasonable certainty that the only proper course is to abandon the project altogether. Learned Counsel for BICC appeared to regard such a defeatist outcome as unthinkable. Yet circumstances can, and have at times arisen, in which it is plain commonsense and any other decision foolhardy. The law requires even pioneers to be prudent.

Assuming that there are no changes in the identity of the professional team, the first risk that must be considered during this stage is that of inappropriate conceptual design and its suitability, not only in respect of the project itself but also for third parties and for society in general.

Statistics based on an analysis of 10,000 building defects in France during a period of ten years indicate that, where design faults are concerned, conceptual design is responsible for

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[22] *Independent Broadcasting Authority v. EMI Electronics and BICC Construction* (1980) 14 BLR 1.

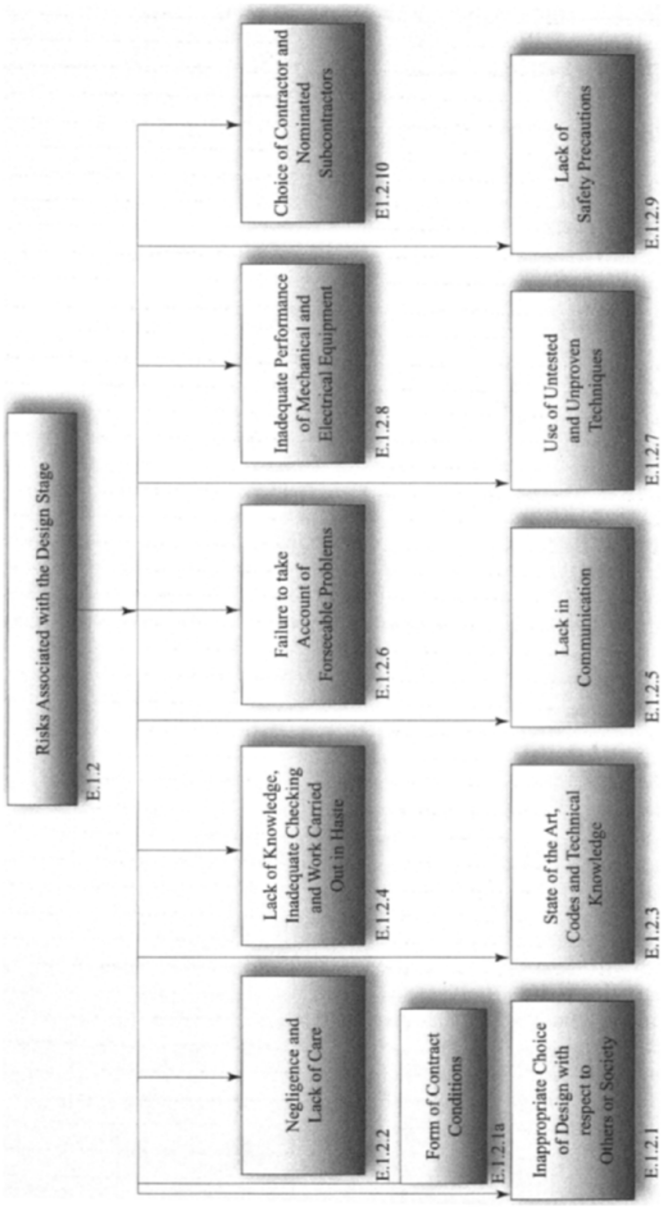

Figure 3.2 Risks associated with the design stage.

18% of all causes in terms of cost and 14% in terms of frequency of occurrence.[23] It was also shown in that analysis that the major culprit in design faults was poor detailing. It accounted for 59% of all causes in terms of cost and 78 % in terms of frequency of occurrence.

Errors in calculation, to the surprise of some, were only responsible for 13% of design faults in terms of cost and only 3% in terms of frequency of occurrence. The last category of causes was unsuitable material which accounted for 10% of all causes in terms of cost and 5% in terms of frequency of occurrence.

The statistical evidence in respect of the cost and frequency of poor detailing demonstrates that not only is architecture an art but so, too, is engineering. Dr. Peter Miller, in his presidential address to FIDIC stated:[24]

> Somewhere down the track, I think engineering took a wrong turning. It allied itself with Science in public perception when, in fact, it is very much more of an art form. Very few structures have ever failed because of stress analysis faults. They mostly fail because of detailing faults, and detailing is a process in which an engineer applies his experience I suggest to you, his art.

The high number of defects due to poor detailing as compared with defective calculations shows also that, where design is concerned, it is more difficult to master art than science. The following quotation is of interest in this context.[25]

> However, in the rush to master that field (science) we must not lose sight of the difference between the function of the engineer and that of a scientist. The latter's function is to know, but the function of the former is more extensive in that it is not only to know but more importantly, it is to do.
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> …
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> The scientist adds to the reservoir of knowledge; the engineer brings this knowledge to bear on the practical aspects of problem solving….

Let us now look at the risks in their individual capacity.

E.1.2.1
Inappropriate choice of design with respect to others and to society

If the design carries a risk of it being injurious to the environment, or to others living in the vicinity, or, in some circumstances, even in faraway places, the risk must be assessed carefully before it can be passed as acceptable. If not acceptable, the design should be altered or changed completely. Examples of such issues, which have become topical in recent years, are acid rain and dumping of nuclear waste. In a similar vein, an example of what can happen occurred in Bhopal, the capital of the State of Madhya Pradesh in Central India, on 2 December 1984.

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[23] 'The Structural Engineer in Context', A.C.Paterson, Presidential Address to the Institution of Structural Engineers, 1984, *The Structural Engineer,* November 1984.

[24] 'The Future', Peter O.Miller, a presidential address to the International Federation of Consulting Engineers, Annual Conference, Florence, Italy, 1983.

[25] 'The Civil Engineer—A New Role in an Old Industry', Nael G.Bunni, The Institution of Engineers of Ireland, Special Conference entitled 'A Future for the Civil Engineering Industry', November 1984.

In 1975, the Indian Government granted Union Carbide, an American-based company, a licence to manufacture pesticides. The plant was located in Bhopal which had, at that time, a population of 900,000 and has since increased by a further 100,000. The site chosen for the plant was on the outskirts of Bhopal, despite its proximity to the densely populated areas of the city and despite an existing local regulation requiring that manufacturing plants producing dangerous substances should be sited at least 15 miles outside populated areas.

The original design of the plant was based on producing the pesticide by the use of an extremely effective imported material called methyl isocyanate (MIC) to produce sevin carbaryl. However, in 1980, in accordance with India's industrial self-sufficiency policy, the plant was modified to produce MIC itself. Thus, carbon monoxide was mixed with chlorine to form the deadly phosgene gas which was in turn combined with methylamine to produce the methyl isocyanate.

At around 2 a.m. on 2 December, 1984, a massive leak occurred in one of the three storage tanks, each holding 40 tonnes of MIC. Due to its very low boiling point, the chemical, which is stored in liquid form, turned into gas as it leaked into the atmosphere.

The needle of the tank's pressure gauge had moved into the danger zone before it was noticed by the night-shift worker. He notified his supervisor who sounded the alarm but it was already too late. The noxious white gas had started to escape from the tank and was spreading with the northwesterly winds in cloud formation towards the densely populated areas of Bhopal. In the thirty minutes which elapsed before the tank was sealed, 5 tonnes of the gas had escaped. With a safe content of only two parts per million, the gas cloud was a deadly one.

The alarm sounded by the supervisor activated the plant's siren and, thinking that a fire had started, hundreds rushed towards the plant straight into the path of the deadly gas.

Methyl isocyanate is so unstable and so dangerous that even professional toxicologists are reluctant to study it in the laboratory. It belongs to a family of toxins for which there is no antidote and no treatment. But the first effect of exposure is watering of the eyes and damage to the cornea rendering its cells opaque. Subsequent effects resemble those of nerve gas. When inhaled, it reacts with water in the lungs, often choking the victim to death instantaneously. It can be just as lethal when absorbed through the skin. The survivors may be left with permanent disabilities such as blindness, sterility, kidney and liver diseases, tuberculosis and brain damage.

The catastrophe in Bhopal is probably the worse industrial accident in history causing the death of over 2,500 and injuring as many as 100,000. Bhopal, in minutes, had turned into a city of corpses. Muslims were piled on top of each other in hurriedly dug graves and Hindu funeral pyres burned around the clock because of fear of a cholera epidemic.

Besides the human toll, the tragedy of Bhopal is without precedent in terms of insurance and financial implications. Some lawyers, in the tradition of champerty, travelled without delay to Bhopal and initiated and filed suits in the US District Court in Charleston, W. Va., for $5 billion in punitive damages on behalf of 'all injured and deceased residents'.

Another aspect of unacceptable design occurs if there is an infringement of patent such as took place in the following case, whose ending was not a typical outcome of similar cases:

An engineer was retained by an owner to design a water treatment plant.[26] When the designs and documents were completed, tenders were invited for the supply and installation of the special equipment from contractors experienced and capable in this field of activity.

The contract was awarded to the lowest tenderer A and the others, including tenderer B, were informed accordingly.

When the fabrication of the equipment was half-completed, Company B advised the owner that the equipment as designed infringed its patents. The owner in turn claimed from the engineer and the latter claimed from contractor A who advised him that fabrication would be discontinued until the matter was resolved and he (contractor A) was fully indemnified against patent infringement. The building contractor could proceed no further and he joined the battle and brought the project to a halt.

The engineer's design so closely matched the features depicted in Company B's bulletin that performance by Company A of its contract with the owner involved infringement if Company B's patent was valid. The engineer faced delay claims by the building contractor, plus either Company A's damages for breach of contract should the owner decide to take such proceedings against Company A for non-performance, or payment to Company A for modifications to avoid patent infringement. Alternatively, the engineer had the choice to pay damages to Company B for the infringement.

However, the engineer was satisfied that his design did not constitute an infringement because there was no such allegation at the tendering stage. He obtained a copy of Company B's patent in order to either establish invalidity, or design some modifications to avoid the infringement.

The patent had been applied for on 4 May 1956 which meant that, in order to invalidate it, it was necessary either to establish a use of its content prior to that date anywhere in the world, or to show that the content was obvious to anyone skilled in the art as of 4 May 1956.

A search of the *American Waterworks Journals* showed that a similar device to the subject of the patent had been used as far back as 1939. With this information, the patent for the earlier device was obtained and, when compared with that of Company B, it was found to be sufficiently close to make a strong case for making Company B aware of the consequence of their intended action. Faced with that risk, Company B withdrew their claim and indicated that they did not intend to pursue the allegation.

E.1.2.2

Negligence and lack of care

Negligence of a professional person has been defined in common law jurisdictions through various legal decisions. In *Bolam v. Friern Hospital Management Committee,* Mr Justice J.McNair stated:[27]

> How do you test whether this act or failure is negligent? In an ordinary case it is generally said that you judge that by the action of the man in the street. He is the ordinary man. In one case it has been said that you judge it by the conduct of the man on the top of the Clapham omnibus. He is the ordinary man. But where you get a situation which involves the use of some special skill or competence, then the test as to whether there has been negligence or not is not the test of the man on top of the Clapham

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[26] 'Investigate, Don't Capitulate', Report of the Standing Committee on Professional Liability, FIDIC, Item 3.2.1., 1984, Switzerland.

> omnibus, because he has not got this special skill. The test is the standard of the ordinary skilled man exercising and professing to have that special skill. A man need not possess the highest expert skill; it is well established law that it is sufficient if he exercises the ordinary skill of an ordinary competent man exercising that particular art.

The courts have since relied on this test. In the recent case of *QV Ltd and QV Foods v. Fredrick F.Smith and Others,* this test of an ordinary competent skilled building designer was applied to show the standard of care owed by the first defendant in carrying out the design of the building in question.[28]

To whom can one be negligent? This is an important consideration. In most legal systems, the law of negligence has developed to such an extent that the risk is of major importance, and one may be liable not only in contract but also in tort. The construction trinity may, therefore, be liable to each other and also to third parties who have no interest in the construction project. The length of the period during which one is exposed to liability has also been extended through the tort net. Specialist reference books in the relevant jurisdiction should be consulted when answers to these questions are sought.

E.1.2.3

State of the art, codes and technical knowledge

Innovation and technological advancement in all facets of construction must continue in order to improve standards and reach beyond present achievements. The results, if successful, can be expressed in terms of either cost benefit or the production of something new for the benefit of human existence or luxury. If the results prove to be unsuccessful and cause loss or damage, then as the risk of such an event occurring is high, it is only just that it should be borne by those benefiting, providing they were given the opportunity to decide for themselves whether or not the innovation was to be pursued.

This principle in common law can be traced back to 1853 in the case of *Turner v. Garland and Christopher* where a designer was asked to prepare plans for the erection of model lodging houses, using a new patent concrete roofing which was cheaper than the alternatives available.[29] The patent concrete roofing was not a success and had to be replaced. The owner claimed in negligence from the designer but the judge told the jury that, although failure in an ordinary building was evidence of want of competent skill, yet if, out of the ordinary course, a designer is employed in some novel concept in which he has no experience and which has not the test of experience, failure may be consistent with skill.

In more recent times, however, another design at the frontier of professional knowledge ended in collapse and was the subject of a court case with a different outcome. It was the case of *Independent Broadcasting Authority v. EMI Electronics Ltd. and BICC Construction Ltd.* (quoted in note 22). The case was decided in the United Kingdom by the House of Lords in 1982, but the events occurred in 1969 when, on 19th March, the 1,250 ft high cylindrical

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[27] *Bolam v. Friern Hospital Management Committee* [1957] 2 All ER 118.

[28] (1) *QV Ltd (formerly Holbeach Marsh Co-operative Ltd.);* (2) *QV Foods Ltd (formerly QV Ltd.) v.* (1) *Fredrick F.Smith (Trading as Fredrick F.Smith Associates);* (2) *D.A. Green & Sons Ltd (Defendants) and Eternit UK Ltd. (Formerly Eternit TAC Ltd) (Third party),* (1998) QBD Official Referees' Business.

television mast at Emley Moor in Yorkshire collapsed. The collapse occurred after a flange at a height of 1027 ft. above ground level fractured due to vortex shedding induced by wind and the asymmetric loading of ice on the mast and the stays. The cause of the fracture was attributed to defective design, which at the time was accepted as being at and beyond the frontier of professional knowledge. The designers had assumed that excessive deposits of ice would crack and fall away in the wind and this did not happen.

The statement quoted below is relevant to the discussion here:

> What is embraced by the duty to exercise reasonable care must always depend on the circumstances of each case. They may call for particular precautions: *Redhead v. Midland Railway Co.* (1869). The graver the foreseeable consequences of failure to take care, the greater the necessity for special circumspection: *Paris v. Stepney Borough Council* (1951). Those who engage in operations inherently dangerous must take precautions which are not required of persons engaged in the ordinary routine of daily life: *Glasgow Corporation v. Muir* (1943). The project may be alluring. But the risks of injury to those engaged in it, or to others, or to both, may be so manifest and substantial and their elimination may be so difficult to ensure with reasonable certainty that the only proper course is to abandon the project altogether. Learned Counsel for BICC agreed to regard such a defeatist outcome as unthinkable. Yet circumstances can, and have at times arisen, in which it is plain commonsense and any other decision foolhardy. The law requires even pioneers to be prudent.

Had the owner been informed of the features of the design, would the above statement have been different?

E.1.2.4
Lack of knowledge, inadequate checking and work carried out in haste

Although a professional may be qualified and experienced to carry out the design of a certain project, he may still lack knowledge of a particular aspect of the design. The problem is that if he does not realise his limitation, he may proceed without executing his duties properly. This occurred in the case of a firm of consulting engineers commissioned to design a steam power station for which the various pieces of equipment were ordered directly from the manufacturers who supplied, independently of each other, in accordance with the specification.[30] Unsuitable relays were, however, ordered and installed for the safety and protection system of the generator of a 32 MVA turboset. During commissioning, it failed to operate and respond properly when a fan blade broke accidentally and was thrown into the stator winding head. The blade fragments caused an earth and short circuit with arcing. The unsuitable relays in the safety devices responded but only after a thirty-second delay causing considerable damage to the whole turboset.

Due to either economic restraints or shortage of time, this type of risk increases, reaching unacceptable levels and situations, which may produce problems later during construction.

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29 *Turner v. Garland and Christopher* (1853), *Hudson's Building Contracts,* 4th edition, vol. 2, page 1.

The level of this type of risk also increases if economic restraints or shortage of time exist. This may occur during construction as in the following example.

An engineer was engaged for the design of retaining walls as part of a site stabilisation plan for a large city building.[31] A system of ground anchors was chosen to stabilise the retaining walls, and due to the short period allocated to the construction, the engineer permitted work to proceed without carrying out preliminary tests to establish the load capacity of the anchors. It was not until the work was well advanced that stressing of the anchors was first attempted; it was discovered then that their capacity was below the design load. Work on the contract came to a halt until the matter was resolved by adding further anchors throughout the whole wall.

The owner, who had to pay for the delay and the additional anchors, started to prepare a case against the engineer who, in allowing the work to proceed, was only giving the owner a commercial advantage and benefit.

It was fortunate for the engineer in this case that, by virtue of a sympathetic and reasonable report by an independent consulting engineer, the claim was averted.

E.1.2.5

Lack of communication

Communication has been identified as the most important requisite of success, and lack of it is perhaps the most significant factor in human failure. Its recognition as a cause of failure goes back to the first construction project, that of Babylon, as recorded in the Revised Standard Version Common Bible, Genesis, Chapter 11, which reads:

> Now the whole earth had one language and few words. And as men migrated from the East they found a plain in the land of Shinar and settled there. And they said to one another, ‘Come, let us make bricks and burn them thoroughly.’ And they had bricks for stone and bitumen for mortar. Then they said, ‘Come let us build ourselves a city and a tower with its top in the heavens and let us make a name for ourselves lest we be scattered abroad upon the face of the whole earth.’ And the Lord came down to see the city and the tower which the sons of men had built. And the Lord said, ‘Behold they are one people and they have all one language; and this is only the beginning of what they will do; and nothing that they propose to do will now be impossible for them. Come let us go down and then confuse their language, that they may not understand one another’s speech.’ So the Lord scattered them abroad from there over the face of all the earth and they left off building the city. Therefore its name was called Babel.

On a more recent note on communication or lack of it, a number of disputes would not have arisen had the parties involved explained to each other, in clear language, what risks and responsibilities each has been allocated; see Chapter 2.

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30 *Schaden Spiegel,* a publication of the Munich Reinsurance Company, No. 1, 1982, Munich.

31 ‘Lessons to be Learnt’, FIDIC Standing Committee on Professional Liability Report, 1983, page 14, Switzerland.

E.1.2.6

Failure to take account of foreseeable problems

An engineer advised a city water authority to close certain valves in its water supply system to allow leakage tests to take place.[32] During the tests and whilst the valves were closed, a fire broke out in a factory and the water pressure in the system was not sufficient to fight the fire.

The court ruled that the engineer, as an expert, was aware that closure of the valves in one district would reduce the water pressure in the adjacent district and greatly increase the risk of fire damage. The engineer was held liable for the fire damage sustained by the factory.

E.1.2.7

Use of untested and unproven techniques

Robert C.McHaffie Ltd recommended the use of a material to produce lightweight concrete, which material proved to be unsuitable.[33] The court in the case of *Sealand of the Pacific v. Robert C.McHaffie Ltd* held that the respondents should not have relied on manufacturer's literature in recommending the material for use. Further-more, if they wanted to use the material, they should have carried out their own tests and examinations. Accordingly, they were held liable.

E.1.2.8

Inadequate performance of mechanical and electronic equipment

More and more designers are using the electronic equipment readily available in today's design offices for analysis, design and drafting. In doing so, they are using hardware equipment designed and manufactured by others and software written and checked by yet another party. In order to guard against unauthorised use of copying, the software is secured in such a way that the user cannot check or disassemble the steps used in the design of the software. He is, therefore, unaware of the assumptions made and the methods utilised in the solution of the problems. The risk of incorporating incorrect computer results in construction is a very real one and can only be mitigated by meticulous and critical checking using common sense and experience.

E.1.2.9

Lack of safety precautions

An employee of a seed grain drying plant went to sweep up grain around the hatches on top of one of the grain bins.[34] He fell through a hatch and was fatally injured. His widow was awarded US$280,000 by the courts which held that the designers of the plant and the builders were jointly liable. The fact that there were no code recommendations concerning such hatches did not absolve the designer and the builder of the responsibility to protect users.

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[32] 'Lessons to be Learnt', op. cit., see note 31.

[33] *Sealand of the Pacific v. Robert* C.*McHaffie Ltd* (1974) 51 DLR, Canada.

E.1.2.10

Choice of contractor and nominated subcontractor

There is an implied warranty in a construction contract that good material and workmanship will be used. The risk that defective material and workmanship are used in a construction contract can only be mitigated through careful selection of the contractor and any subcontractors to be named in the contract.

E.2.1

Risks during construction associated with the site of the project and its location (Figure 3.3)

Statistics based on an analysis of 10,000 building defects, recorded through the decennial liability insurance in France between 1968 and 1978, showed that construction faults ranked highest in frequency of occurrence.[35] The analysis showed that 51% of all faults were due to construction, 37% to design, 7.5% to faulty maintenance and 4.5% to defective material.

In terms of cost of repair, the analysis showed that design faults and construction faults each accounted for 43% of the total cost of repair. Faulty maintenance accounted for 8% and defective material for 6% of the cost.

These faults did not all occur during the construction period. In fact Figure 3.4 shows the distribution of when faults occurred or were detected against time, indicating that only 11 % occurred during the construction period. The figures may be different if civil engineering or if building defects in another country were to be considered.

But let us look first at examples of the risks commonly referred to as ‘Acts of God’.

E.2.1.1

Excessive Rainfall

Water pipeline in Africa: Trenching had already been completed for the entire 60 km pipeline that was to be joined with couplings.[36] Some of the pipes had already been laid in their final position. However, the couplings, for which adequate room between the pipes had been left, were still not available. When sudden, intensive rainfall started, the ditch was flooded and the pipes became filled with mud. During the repair operation, it was found that only some sections of the pipes could be salvaged by cleaning. The rest had already been rendered useless by the solidified mud, causing a total loss of DM 1 million. This example demonstrates how important it is to limit the length of open trench. (Figure 3.5)

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[34] ‘Lessons to be Learnt’, op. cit., see note 31, page 25.

[35] ‘The Structural Engineer in Context’, op. cit, see note 23.

[36] *Schaden Spiegel,* op. cit., see note 30.

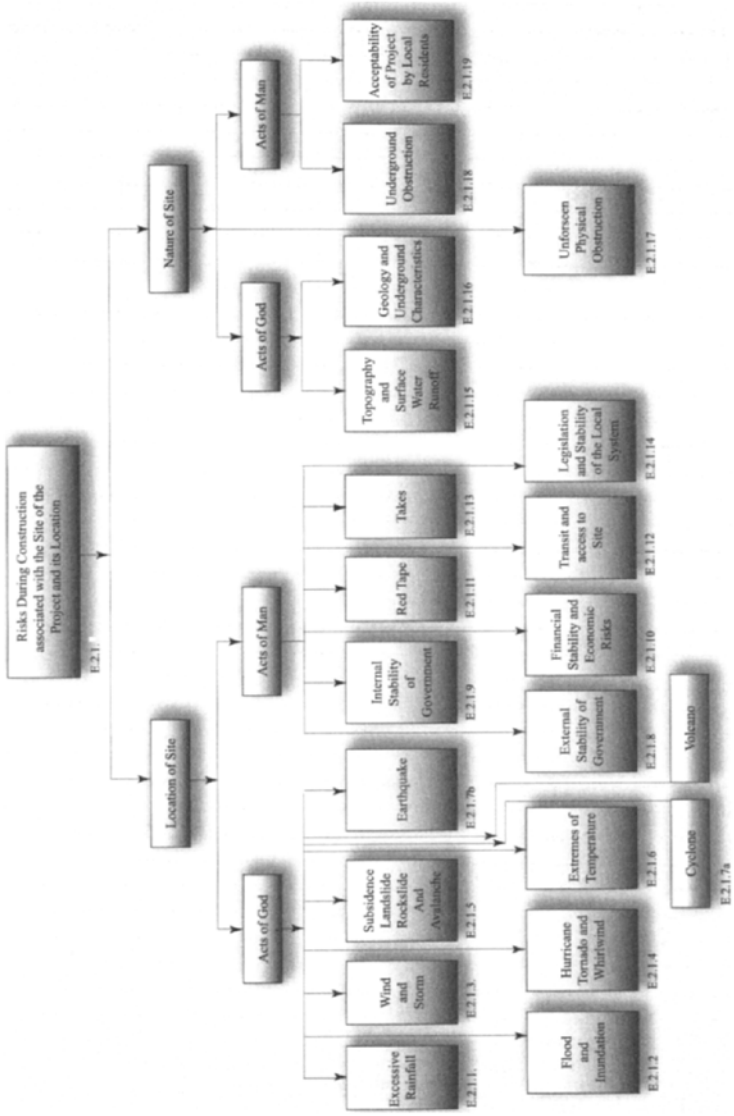

Figure 3.3 Risks during construction associated with the site of the project and its location.

E.2.1.2
Flood and inundation

It is well recognised that projects exposed to the effect of water may encounter some of the most hazardous conditions during construction. Damage can result in any of the following modes:

A Inundation and/or damage caused by rainfall;

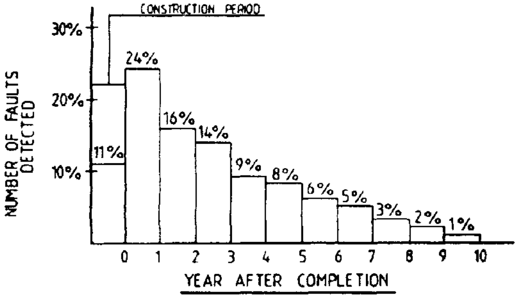

Figure 3.4 Building defects occurring or detected in the first ten years.

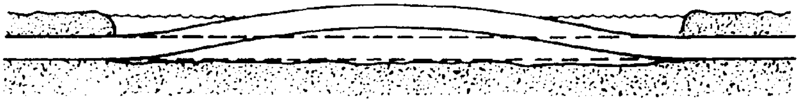

Figure 3.5 Flotation of a pipeline due to rainfall.

B Flooding caused by excessive surface run-off either immediately after rainfall or consequent upon melting snow;
C Flooding due to failure of water conduits or storage structures;
D Flooding and inundation due to a combination of natural forces such as wind-storms, tides, etc;
E Inundation due to underground water.

The damage which may occur due to this risk can be summarised as one or more of the following:

(a) Damage due to erosion and wasting away.
(b) Damage due to under-design of temporary works because of their short period of exposure.
(c) Damage due to lack of, or insufficient, flood warning in areas with certain topographical properties.
(d) Damage due to non-compliance with the construction programme.
(e) Damage due to insufficient waterway.
(f) Damage due to improper organisation which includes method of execution, arrangement of storage space, etc.
(g) Damage caused directly by rainfall.

There are many examples of damage relating to these risks during construction. Perhaps the more spectacular are those involving bridges and dams, but the most unexpected are floods occurring in the deserts. The following accident took place on a road project under construction, 105 km long, in a desert area where a 1,000 m high mountain range had to be crossed.[37] The topography of the mountains made it necessary for the road to follow the course of a wadi over a distance of 35 km. In this section of the road, thirty-one prefabricated viaducts had to be built as well as a number of retaining walls and culvert structures for side wadis.

The tender specifications did not contain much information on the amount of rainfall to be expected, as this desert area was only just being developed and, so, no statistics were available. During the two-year period of road construction, unexpected and heavy rainfalls occurred which flooded the wadi nine times. The floods lasted only one to two hours each but reached flow velocities of nearly 40 km/h and water discharge rates of up to 1000 m^3/h.

The highest flood lasted about 45 minutes. Within the first two minutes the water rose by 1 m. The maximum of 4 m was reached after 15 minutes. The quick rise of the flood and the vast amount of water caused severe damage on the construction site. All nine floods caused extensive damages, including:

- Construction equipment, such as a screening and crushing plant, was destroyed or washed away.
- Excavators, bulldozers, loading gear, etc. which could not be removed from the wadi in time, filled with mud or silt.
- Culverts were washed away or clogged.
- Falsework and formwork material were lost or damaged.
- Foundations for abutments, piers or retaining walls were covered with mud. Slopes and benches were scoured.

E.2.1.3
Wind and storm

The strength and lateral stability of an uncompleted structure are in most cases much lower than those 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, as the next example demonstrates.

A project for a gas liquefying plant in the Middle East included the erection of nine tanks for the storage of final liquefied products: butane and propane.[38]

The tanks were erected by the usual method: pre-curved plates were welded together one after the other around the entire tank circumference. Thus, the tank grew in height ring by ring. Seven tanks had been completed in this way. When the workers were welding the top section of the eighth tank 30 m above ground, a hailstorm occurred with hailstones measuring 1 cm in diameter and wind velocities up to 100 km/h. The storm lasted for about 10 minutes. There was no time to secure the tank with guys, as had always been done before extended breaks and during the night.

As the tank had not yet been covered by its mushroom-type roof, suction forces were created inside the tank in addition to the great pressure forces applied by the storm on the outside. As a result, an area of 400 m^2 imploded. The working platform around the top tier of the tank was

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37 Ibid., July 1977.

torn from its mountings and crashed to the ground. Under the influence of these forces, the buckled side of the tank was lifted off the foundation, leaving a gap of 10 cm at the bottom.

The first repair operation was to pull out the imploded section using winches and tractors. Then material samples from the buckled areas were examined in the Ismaning Institute's laboratory to see which plates could be reused and which had to be replaced. The damage was unforeseeable, since the storm had arisen within a few minutes. Fortunately, through a careful and well-conceived repair programme, the storage tank was slowly put back into horizontal alignment on its foundation which made possible a successful repair, thus avoiding a total loss. The total amount of the damage was accordingly limited to US$750,000.

E.2.1.4

Hurricane, tornado and whirlwind

As in the previous hazard of wind, the low strength and lateral instability of uncompleted structures make this type of hazard devastating in its effect. Hurricanes, by definition, have a speed greater than 120 km/h.[39] Whirlwinds, which are basically a column of air rotating rapidly with low atmospheric pressure at its centre, can be of three types: the tropical storms which develop in tropical sea areas having large diameters; the dust devils which develop in desert regions having much smaller diameters; and tornadoes which are the most destructive, reaching a velocity of 400 km/h and perhaps more. At that velocity, lightweight structures and industrial buildings would be completely demolished, whilst reinforced concrete and steel framed structures could suffer serious damage.

The Midwest part of the United States is the area most exposed to tornado activity and the Wichita Falls/Mexico tornado of 10 April 1979 produced one of the most expensive single tornadoes on record with about US$200 million of insured damage.

E.2.1.5

Subsidence, landslide, rockslide and avalanche

Subsidence is one of the risks the causes of which are extremely complex to assess. This is basically due to the inexact nature of the science of soil mechanics, which covers the problem of subsidence. Subsidence may occur due to any of the following reasons or a combination of them:

- Lack of or insufficient site investigation;
- Incorrect assumption of distribution of stresses in or under foundations and the supporting soil layers;
- Improper support to sides of excavations;
- Changing the properties of the surrounding soil;
- Deterioration of the foundation material due to presence of aggressive substances in the soil such as sulphate salts, etc.;

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38 Ibid., no. 2, 1981.

39 Ibid., no. 2, 1981.

- Inferior properties of the foundation soil;
- Defective design of the foundations.

Catastrophic accidents have occurred because of this type of peril. In many ways, it is connected with the previous hazard and therefore it is sufficient to add that instability of soil strata can only be averted by very careful handling of the design and construction of projects which are dependent, in one way or another, on the soil. Even then, accidents will happen.

E.2.1.6
Extremes of temperature

The effect of extremes of temperature on some materials and processes can be demonstrated by the following incident, which occurred during the erection of a plant for the production of coffee extract. A loss occurred in the most important section which houses the deep-freezer room where coffee is quick frozen at a temperature of—45°C and then it is ground and screened.[40] This room was insulated with 30 cm thick, expanded polystyrene slabs. Four suspended air coolers were installed to produce the low temperature required for the freezing process. The automatically controlled defrosting units attached to the coolers were designed to be operated at intervals of 24 hours for approximately 8 minutes.

The loss occurred during installation of the defrosting units. When the wiring had been completed, the defrosting units (each having a power input of 15 kW) were switched on manually for testing purposes. At the beginning of their lunch break, the workers left the deep-freezing room and shut the door, without switching off the units. A technician happened to re-enter that deep-freezing room only 20 minutes later. The room temperature had already risen to more than 60°C and around the coolers it was even higher. The entire polystyrene insulation had shrunk considerably; at certain exposed areas the material had even become liquid and was dripping off. The damage was so extensive that the insulation had to be replaced throughout the upper third of the deep-freezing room and new lamps, switches and cables were required.

If the technician had not discovered the error when he actually did, the damage would have been even more extensive as the temperature would have increased further and the air coolers suspended from nylon elements would have fallen down into the expensive coffee preparation plant.

This loss shows that, in the case of erection projects, it is imperative to obtain permission from the site management for any commissioning or testing operations, even if only minor plant items are involved. In fact, it is only in this way that it is possible to cope with the hazards inherent in the provisional operation of individual plant sections prior to completion of the entire project.

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[40] Ibid., October 1976.

E.2.1.7a
Cyclone

Cyclones pose a threat to nearly all coastal areas. An example of the devastating effect of such an event occurred on 9 June 1998, at the relatively sparsely populated peninsula of Kathiawar in the north-west Indian state of Gujarat when it was hit by a tropical cyclone (Cyclone 03A) with peak wind speeds of 170 to 180 km/h. On the coast there was a storm surge with a height of 2 to 4 m. The toll was as follows:[41]

- probably more than 10,000 fatalities and 30,000 homeless;
- economic losses of about US$ 1.7 billion; of which
- the insured losses exceeded US$ 400 million.

Cyclone 03A developed on 6 June 1998 from a tropical low pressure system in the south-east of the Arabian Sea and steadily gathered in strength on its way north. On 8 June, the storm attained its maximum intensity with peak wind speeds of 240 km/h, but was already much weaker when it finally hit land on 9 June. Judging by the wind speeds and the duration of the storm, the waves must have been 5 to 6 m high. The astronomic tide reached its maximum that day about three hours after the eye of the cyclone had passed. If these two events had occurred simultaneously, the water levels would have been even higher.

In the cyclone track there were two refineries under construction some 20 to 30 km from each other and in one of which the erection work was in full swing. The total investment value of these two plants exceeded US$ 1.7 billion. Both of these refineries had erection all risks insurance cover. One of them was also insured for advance loss of profits. There were about 50,000 workers at one of these two construction sites in June 1998, making it one of the world's largest construction sites in the industrial sector at that time.

The severest damage was to the temporary installations like the site offices, workers' barracks, stores and the power supply.

The cyclone tore off roofs and hurled the corrugated metal sheets through the air like sheets of paper. Brick walls were smashed down. As a result of the rain that followed, there was considerable damage to office equipment, including computers and stored materials. The damage to the tank farm was likewise catastrophic. More than a quarter of the 200 tanks, up to 92 m in diameter, were damaged or destroyed. The damage mainly affected tanks that were in the course of being erected and were therefore not sufficiently secured.

Installations directly on the coast were also destroyed. A pumping station, which had been built to provide seawater for desalination and supply the refinery itself with cooling water, was destroyed by barges that had broken loose and had to be rebuilt. This proved to be particularly critical for the advance loss of profit insurance cover. However, it was not only on land that Cyclone 03A left its mark of devastation but also at sea. Total losses and partial damage to over fifty ships off the coast of Gujarat generated marine insurance losses totalling hundreds of millions of dollars.

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[41] Taken from a paper by Andreas Gerathewohl, Martin Jenne, Ernst Rauch, Werner Teichert, published in *Schaden Spiegel,* op. cit., see note 30, No. 1 1999.

E.2.1.7b
Earthquake

Earthquakes occur much more frequently than most people realise and on average ten potentially catastrophic earthquakes occur per year around the world. In addition, many hundreds occur causing serious local damage, many thousands can only be felt and modern seismographs record even a larger number.

Between 1974 and 1984, thirty-three major earthquakes occurred in twenty-two countries with a magnitude greater than 6 on the Richter scale. The number of resultant fatal injuries depends largely on the density of population in the affected area and varied between five dead in Guerrero (Mexico) and 242,000 in Tangshan (China). The property damage in the latter quake was estimated at US$5600 million. The heaviest property damage during that period occurred in Irpina in Italy on 23 November 1980, reaching an estimated amount of US$7200 million and resulting in the death of 3,114 persons.[42]

The total injury and damage that has resulted in the ten-year period is 330,000 dead and US $25.5 billion loss.

Despite the obvious catastrophic nature of this hazard, the risk of exposure to earthquake damage can be reduced through knowledge of its facets.[43] These are:

1 Zone

Site location determines the probability of occurrence of earthquake and, whilst it is not easy to generalise, one may observe that 80% of all earthquakes occur in the Circum-Pacific belt which follows the west coast of South America, Central America, North America, the arc of islands in the northern part of the Pacific, Japan, Taiwan, the Philippines and a section of Indonesia.

About 17% of earthquakes are observed in a belt which extends from the Azores in the Atlantic to the southern part of Europe and part of North Africa, Turkey, the Near East, including Iran, part of Arabia, Afghanistan, Pakistan, India and Burma. The probability of occurrence of earthquakes obviously varies greatly for each of the regions within these belts.

2 Subsoil conditions

The type of subsoil and its stratification, the depth of layers and the position of the water table determine to a large extent the resultant effect. As a general rule, the harder the subsoil material on which a structure is founded, the smaller is the damage. Groundwater and sloping ground increase the damage.

3 Building materials

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[42] *Schaden Spiegel,* op. cit., see note 30, No. 1, 1984.

[43] ‘S.R. Focus—A Short Guideline to Earthquake Risk Assessment’, a publication of the Swiss Reinsurance Company, 1982, Zurich (H.Tiedemann).

It is usual that various materials are used in any one building, each of which responds differently to earthquake forces. Therefore, the relative and cumulative response of these materials must be considered carefully. Elastic materials such as steel respond better than brittle materials. Stiff design incorporating shear walls capable of resisting bending moments is more effective in resisting earthquake than soft design. Prefabricated elements are in general more prone to damage due to earthquake forces than cast *in situ* parts.

4 Shape of buildings

The shape of buildings plays an important part in the type of response displayed. Deviations from absolute symmetry introduce different oscillations and vibrations which increase the probability of damage.

5 Sensitivity of machinery and plant

Most machinery and plant are usually susceptible to damage by falling debris, tilting bases and cracking foundations. The behaviour of the building elements and the type of damage they are expected to sustain due to earthquake forces are important factors for consideration when the building is designed to house machinery and plant.

6 Tolerances:

Permissible deviations from acceptable standards of design, material and workmanship are much lower in circumstances where earthquake forces are to be accommodated.

E.2.1.8 to E.2.1.14 Acts of man as related to location of site

These are a group of risks connected with the political, financial, sociological and status of the country in which the site is located. They can be enumerated as follows:

- External stability of government;
- Political risks;
- Internal stability of government;
- Financial stability and economic risks;
- Red tape;
- Transit to site and condition of infrastructure;
- Taxes; and
- Legislation and stability of the legal system.

E.2.1.15

Acts of God in relation to nature of site—topography and surface water run-off

'See E.2.1 Risks'.

E.2.1.16
Adverse geological and underground characteristics

The hazard of adverse geological and underground characteristics and the risks attached to it form a major topic in engineering, particularly when these conditions are not foreseen and not discovered during soil investigations that are carried out prior to construction.

Unforeseen adverse ground conditions have been described in an interesting article on this topic as one of the most notorious causes of disputes under engineering contracts.[44] Their incidence may have far-reaching effects on the course of the works and their resolution can often have a most serious effect on the economic balance under the contract. Given their importance, one would expect to find a rational scheme of transfer and placement of this risk, but unfortunately, experience suggests that the effect of the relevant provisions in standard forms of contract is anything but rational. This is perhaps due to the fact that these provisions pose a test which is related in part to what has immediately occurred, but is also dependent on conditions which existed at the date of the tender, and which are likely to be obscure and highly susceptible to dispute at the date of the occurrence. The important point is that the contract terms make no attempt to define the occurrence of risk in terms which can be applied directly or readily.

In the article quoted above, John Uff explains that unforeseen conditions typically produce large contractual claims, which could remain in dispute even after completion of the project. The principal reasons for this are, first, the lack of any clear criteria for determining whether the relevant events are established, and second, the qualified right to be reimbursed in respect of all additional cost if the event is established. The effect of these clauses in practice is, therefore, not to transfer risk but to provide a vehicle for making a claim for additional payment in the event that the relevant facts can be established subsequently. Indeed, it may be said that the contractual provisions embody two risks namely:

1 that circumstances will arise which allow the contractor to bring a claim; and
2 that an arbitrator might subsequently find the claim proved.

The article concluded that a risk event should not be regarded as equivalent to a claim situation created at the will of one of the parties. While the contractor may legitimately expect proper compensation for variations and imposed delays, risks should be dealt with so as to preserve a proper incentive to minimise their incidence.

The tunnel collapse in September 1994 of the second phase of Munich's U-Bahn U2 underground extension is a dramatic example of an incident resulting from an unforeseen adverse ground condition. Two people died and thirty were injured when a crowded bus was sucked into a large hole that suddenly opened up in the middle of a main suburban road.[45]

The Munich area has a high water table, just 4 m below ground level. The tunnel was being driven with a cover between 3 m and 1.5 m of marl above the soffit, but it appears that the drive hit an unforeseen local depression in the marl stratum after less than 50 m of progress,

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[44] 'Contract Documents and the Division of Risk', by John Uff, part of a book entitled *Risk, Management and Procurement in Construction,* published by the Centre of Construction Law and Management, Kings College London, edited by John Uff and A.Martin Odams, 1995.

prompting the collapse. It was reported that the collapse was preceded by an influx of water at the tunnel face and caused by a breach of the tunnel soffit.

Workers in the tunnel had enough warning to escape before the tunnel was flooded with tonnes of water and gravel for 20 m along its length, but nothing could prevent the crowded bus from plunging into the void that was created. The collapse also undermined the foundations of an adjacent apartment block and a shop, which were temporarily stabilised after the hole was plugged with concrete and supported with crushed stone fill. The bus, which became partially embedded into the concrete that was poured in, was later cut in two and lifted by a crane.

E.2.1.17
Acts of man in relation to nature of site— underground obstructions

Underground obstructions in the form of man-made cables, pipe ducts, and other conduits are susceptible to damage causing not only physical loss but also consequential damage which in many cases exceeds the cost of repair to the items directly affected. An investigation into the causes of damage of underground cables and pipes in the course of construction work carried out in a European country revealed the following statistics which give an insight into the risk: [46]

- In 30% of all cases, the contractor had not procured any plans showing the positions of telephone and electric cables or gas pipes.
- In 11% of the cases concerned, the plans received by the contractor were not available at the construction site.
- In 10% of these cases, the plans submitted to the contractor were incorrect.
- The telephone office was not notified in 40% of all cases in which its cable network had been damaged; the gas works in 18% and the electricity supply company in 13% of these cases.
- 84% of the cases were accounted for by construction machines.
- 60% of the cases occurred outside built-up areas.

The above findings can probably be regarded as generally valid in other countries also.

Due to the severity of this risk, some insurers recommend the inclusion of the following clause in covering major earthwork contracts:

> The Insurers shall indemnify the Insured only in respect of loss of, or damage to, existing underground cables and/or pipes or other underground facilities if, prior to the commencement of works, the Insured has inquired with the relevant authorities as to the exact position of such cables, pipes or other underground facilities. The indemnity shall in any case be restricted to the repair costs of such cables, pipes or other underground facilities, any consequential damage being excluded from the cover.

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[45] *New Civil Engineer,* Magazine of the Institution of Civil Engineers, London, 29 September 1994.

[46] *Schaden Spiegel,* op. cit., see note 30, No. 2., 1981.

There are many examples of this type of hazard of man-made obstructions. In February, tunnelling work on the Jubilee Underground Line extension in London caused Blackwall Tunnel to sink 3 mm. The incident occurred when preparation for the chamber for the tunnel-boring machine was being carried out by hand digging. The workmen hit a pocket of peaty ground, which caused water to gush out into the westbound tunnel on the £71 million contract. Three miners were lucky to escape injury.[47]

The construction of the underground tube line at the Black wall Tunnel in 1966 had included a steel sheet piled cofferdam to enclose the peaty soil that was encountered rather than remove it. The Jubilee tunnel required to be cut through the cofferdam and breaking through it released the retained soft material and pore water causing it to fall into the pit leaving a huge void. The existence of the cofferdam was known, but its purpose was unclear.

Excavation work was stopped immediately. Emergency procedures were then employed, and frantic remedial measures, including an immediate injection of grout into the ground to stabilise the weak material, averted a major ground collapse.

E.2.1.18
Acceptability of project by local residents

A concrete sewage pipeline had to be laid, extending 700 m into the sea.[48] The complete pipeline was assembled and laid on land ready to be dragged into the sea. It was then that overzealous environmental protectionists paid a visit and ignited three explosive charges destroying over 150 m of pipeline. The cost of repair amounted to DM800,000.

E.2.2
Risks during construction associated with the technical aspects of the project (Figure 3.6)

E.2.2.1
Extended duration of construction

It is evident that the longer the period of construction, the greater is the probability of occurrence of the hazards to which a project is exposed. However, in certain circumstances, there are seasonal hazards which occur at specific times of the year and thus require special consideration if the period of construction is to be extended. These hazards include rainfall, temperature changes, flood, storm and wind. To illustrate this point, the example of Diyala Bridge in Iraq may be cited. Designed as a prestressed concrete multi-span structure, it crossed a river known to flood during the month of April. The bridge was constructed using closely spaced formwork supported on the riverbed. The prestressing operation of the deck was scheduled to be completed prior to the flood season, but due to the permitted tolerances in the deck level being exceeded by the contractor in construction, the prestressing operation was delayed. The contractor attempted to rectify the levels, but in doing so he spent more time

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[47] *New Civil Engineer*, op. cit., see note 45, 16 February 1995.

[48] *Schaden Spiegel,* op. cit., see note 30, September 1975.

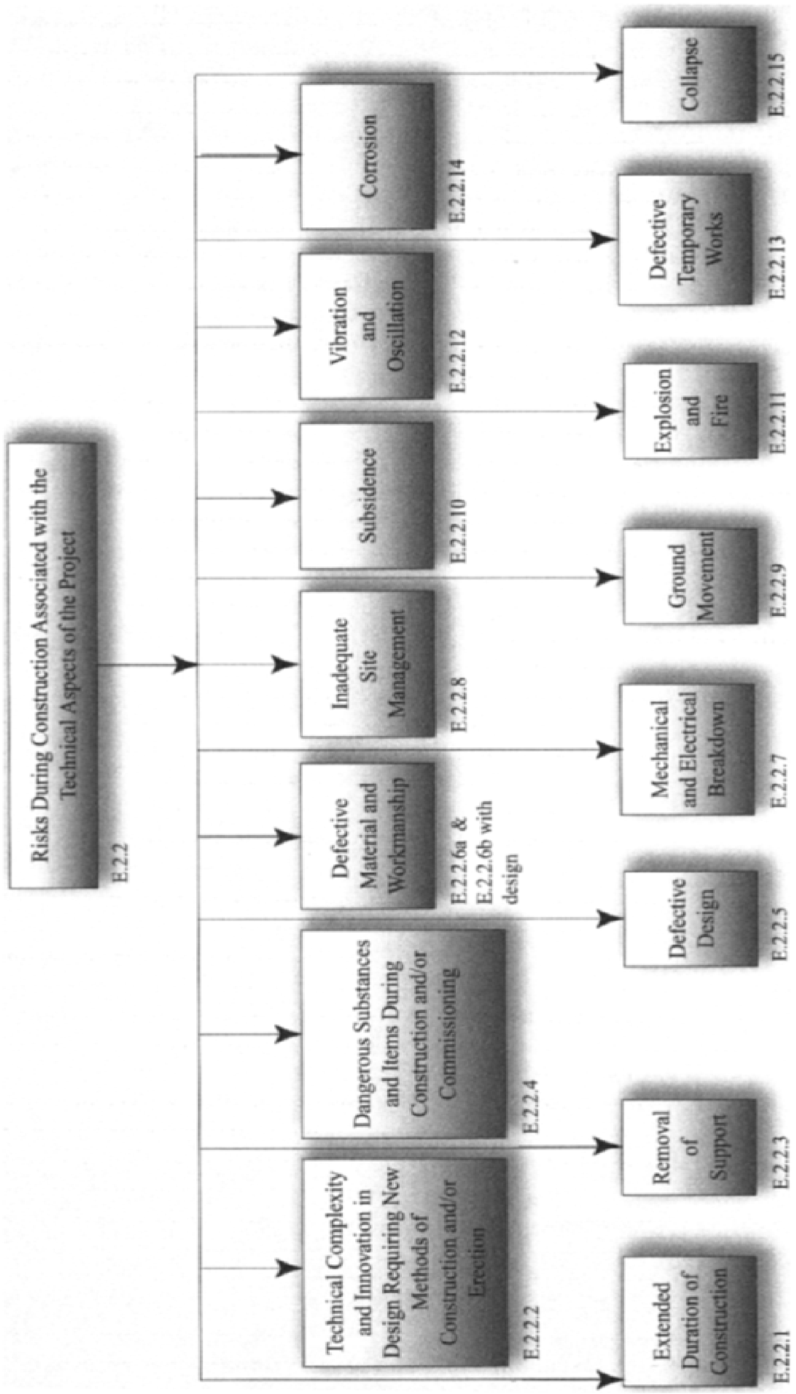

Figure 3.6 Risks during construction associated with the technical aspects of the project.

than he originally allocated for the construction of the deck. When the floodwaters finally arrived at the site, the restricted area of the river caused increased water velocities under the bridge, which resulted in severe erosion below some of the formwork supporting members under the end span of the bridge. In a very short period of time, the floodwaters swept the formwork downstream of the river. The end span collapsed into the riverbed. As usual, there were other factors that contributed to the occurrence of this episode, nevertheless one could focus on the issue related here as being the main cause.

E.2.2.2

Technical complexity and innovation in design requiring new methods of construction and/or erection

When traditional materials or methods are used in construction, the familiarity of those involved with the design or the work itself may permit an occasional ambiguity in the drawings or specifications without them being misinterpreted. It may even provide correction of a mistake. However, in a novel or relatively new design, material or construction method, what is needed is precise and thorough communication between the designer, manufacturer or contractor, as the case may be, and others involved in the construction process.

Examples cram the literature on failures. The brittle fracture of high tensile structural steel to British Standard 968:1962 was little known in the construction industry until load-bearing members designed for the Kleinwort-Benson building cracked one day in September 1965 as they lay on the ground in the fabricator's welding yard.[49] It was fortunate that this phenomenon was discovered at an early stage of using this material before a major disaster could take place. The most disturbing aspect of brittle fracture is that the metal breaks without warning at very low stresses with cracks spreading at a speed of 1,000 metres per second and often one may find it associated with welding.

In the precast concrete industry in the United Kingdom, the roof collapse of Camden School for Girls and of the reading room in Leicester University, within hours of each other, in June 1973, showed that the bearing distance between precast members and their supports must be of a minimum dimension greater than that allowed for in these two buildings.[50] This minimum distance must be chosen not only for practical reasons of placement of steel reinforcement but also for accommodating movements in the various elements of the structure and for their lateral stability. These two buildings were in fact built in 1956 and 1965, respectively, prior to compilation of codes of practice in respect of the use of such precast concrete sections. However, the reading room in Leicester University was built after the collapse of four precast concrete buildings under construction in the United Kingdom and one of the reasons given in the technical statement made by the Building Research Station was 'Bearing area of beam to column inadequate'.[51]

Another serious consequence of the use of new materials and methods is that such use may create a problem in another area of design as is the case in high-rise buildings. The fire risk increased dramatically in the 1950s and 1960s due to the use of new materials in their construction. Prior to that period the infill elements of old skyscrapers were much more fire-

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[49] 'How the Umbrella Technique Failed', *Sunday Times,* 4 July 1965, London.

[50] 'Hundred Schools Checked after Roof Fall', *Sunday Times,* 17 June 1973, London.

resistant and their masonry was non-combustible. There were no large glass surfaces which, when burning, would have permitted a fire to spread to other storeys from the outside.

Catastrophic fires were the result of the use of the aluminium curtain walls, plastic façade elements, large areas of glass, suspended fitted ceilings concealing large undivided areas and finally the use of synthetic materials. An example in this context is the large fire which occurred in São Paulo in a thirty-one storey building in 1972.[52]

E.2.2.3
Removal of support

The risk of removal of support has usually very serious consequences, even in minor parts of the work, as can be seen from the following example.

A four-man gang was engaged in backfilling a trench excavated to lay a 229 mm diameter saltglazed pipe as part of a contract for kerb laying and surface water drainage on a road project. The side walls of the trench where the pipes were to be laid were supported by 19 mm-thick plywood sheeting held in position by crossstruts. As the men prepared to take a mechanical roller along the bottom of the trench, they removed the cross-struts holding the plywood in place. Once the struts were removed, part of one of the walls collapsed, burying one of the labourers. The 21 year old worker died.[53]

E.2.2.4
Dangerous substances and items during construction and/or commissioning

The following example from Japan highlights the effect of such substances on construction work. Shortly after commencement, the construction of a water reservoir had to be stopped when the concrete cubes cast for testing purposes did not meet the required compressive strength and neither the concrete nor the cement manufacturers were able to give any explanation for the failure of the test cubes.

The mystery was solved when it was discovered accidentally that the blossom and leaves of nearby Jacaranda trees had fallen into the concrete aggregate.[54]

Usually, concrete reaches 90% of its compressive strength within 28 days after manufacture. In this case, however, certain substances contained in the Jacaranda trees, although of minor concentration, apparently retarded the curing of the concrete. In another series of tests carried out later the compressive strength of the test cubes proved to be satisfactory.

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51 ‘Technical Statement by The Building Research Station of the Department of Scientific and Industrial Research on the Collapse of a Precast Concrete Building under Construction’, 19 December 1963, United Kingdom.

[52] *Schaden Spiegel,* op. cit., see note 30, October, 1974.

[53] *New Civil Engineer,* op. cit., see note 45, 30 November 1978.

[54] *Schaden Spiegel,* op. cit., see note 30, October 1976.

E.2.2.5
Defective design

In September 1994, a ship-to-shore walkway in the Port of Ramsgate in the United Kingdom collapsed, killing six people and seriously injuring a further eight. The contractor was responsible for the design and construction of the walkway, but the cause of the accident was seen to be relating to the design of the steel structure.

The walkway structure was hinged at the shore end and spanned two intermediate vertical supports fixed to a floating pontoon. The third span connected the walkway to the vessel. The construction of the walkway was in three sections, which were shipped to the site along with hinges and other fixing materials, where the whole structure was then assembled. The support bearings had to accommodate vertical and lateral movement caused by tidal changes, vessel roll and motion of the pontoon. It was reported that the two shore-end bearings and a third corner bearing at the first internal support allowed longitudinal movement along the direction of the span and rotation around a pin.[55] The bearings on the fourth corner had two pins, one vertical and one horizontal, allowing rotation about two axes. Thus, the vertical pin at the fourth bearing provided the only restraint against longitudinal movement.

The accident occurred when the horizontal pin joint failed, thus disconnecting the bearing, and leaving no restraint to prevent horizontal movement. The structure's integrity relied on a single 55 mm diameter steel pin, a 5 mm butt weld and a 7 mm fillet weld, one of which failed causing the bearing to fail.

E.2.2.6a
Defective workmanship and material

The warranty of incorporating or using only good workmanship and material is implied in construction contracts. Despite that warranty, one finds that as long as quality means perpetual care and high cost, this risk of defective workmanship and material will always exist. Even the smallest defect can sometimes cause a disastrous effect, as happened in the case described below.

The main distillation column of a new oil refinery became a total loss in an accident which occurred during erection.[56]

The column, which was approximately 50 m in height and weighed over 120 tonnes, had been shipped by a cargo vessel from the factory to the refinery pier. It was moved to the erection site on low loaders. Two cranes with a capacity of 250 tonnes and 200 tonnes, respectively, were used to hoist the column into a vertical position and place it on its foundation.

During the initial phase of the joisting operation a third crane guided the base of the column. The foundation had been covered up with wooden planks to protect the anchor bolts while lifting work was in progress. When the column was suspended vertically a few centimetres clear of the foundation, the plank cover was removed. At this point the column made a slight turn, shifting out of position and sagging a little.

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[55] *New Civil Engineer,* op. cit., see note 45, 22 September 1994,

[56] *Schaden Spiegel* op. cit., see note 30, No. 1, 1980.

A weld in the cross-strut in the top section of the jib of the 250 tonne crane had failed, causing the failure of the welded joint and ultimately of the strut. The jib became distorted causing the column to turn and sag as described.

The operator of the 200 tonne crane, warned by the sudden movement, released the brake for the hoisting cable which deposited the column on the platform but leaning to one side. As a result, the 250 tonne crane was unable to carry the additional load and both cranes and the column crashed on to the ground sustaining irreparable damage. Other equipment on the site suffered damage which, when added to the cost of the column and cranes, amounted to $1.2 million. This collapse resulted from failure of the weld in the cross-strut of the crane.

Sometimes, however, such defects arise out of lack of knowledge rather than lack of care or intentional acts, as happened in the following incident. Aggressive material was shipped in 5, 000 plastic sacks each containing a weight of 50 kg.[57] The sacks were heat-sealed at one end but, when they arrived at their port of destination, they were found to have burst open.

The cost of salvage and removal operations was very expensive due to the aggressive nature of the material being shipped. The sacks were examined and found to be made of a plastic material of a thickness of 0.25 mm. They were loaded on pallets with up to twenty sacks on top of each other. A chemical analysis carried out with the help of an infra-red spectroscope revealed that the sacks were made of polyethylene film with a density of 0.94 g/cm^3. A tensile strength examination showed that near the heat-sealed ends the strength of the material was between 20% and 40% lower than elsewhere. This phenomenon, which is well known in the packaging industry, is caused by the fact that the films grow thinner in the area around the seams due to the heat-sealing.

The next step was to examine the way the sacks had been loaded on top of each other in the light of the above-mentioned inherent weakness. Calculations showed that, with twenty sacks placed on top of each other, the reduced tensile strength around the seams would already be exceeded under static load conditions. Considering the shocks and bumps hardly avoidable during loading and unloading, not more than a maximum of ten sacks should have been placed on top of each other.

E.2.2.6b
Defective design, workmanship and quality control

During the construction of the rail link from London's Paddington Station to Heathrow Airport, the Heathrow Express line, three partly built station tunnels caved in during the early hours of Friday 21 October 1994 and continued to collapse over a number of days. Fortunately, no one was injured or killed in the accident, but the failure, which was estimated to have cost Heathrow Airport operator BAA around £50 million, brought chaos to the heart of the airport.[58]

The station complex was to comprise three large caverns 9 m in diameter which form the central concourse area and two up-and-down-running platforms together with a complex network of tunnels and escalator shafts to link the station to the surface and to the main airport terminals.

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[57] Ibid., October 1976, Munich.

At about 1 a.m. on the morning of the collapse, ground-monitoring equipment measured movements ‘of the scale’ which alerted workmen in the down-platform tunnel to the impending disaster. Twenty-five people were evacuated to the surface moments before the roof of the new station complex collapsed. Chaos ensued as the contractor’s and consultant’s engineers tried to contain and arrest the collapse and prevent further damage.

It was discovered that the collapse started at the base of the main shaft at the connection to the down-platform. With overburden material pouring into the fractured tunnel the semi-complete cavern was severely breached and the ground above swiftly sank. As the ground around the shaft slid into the down-platform, abnormal stresses were induced in the linings of both the concourse and the up-platform tunnels. These quickly began to fold up around the junction with the main shaft, causing further movement in the ground above.

To prevent further damage, the first task was to secure the stability of the main shaft. Structural concrete, at a rate of 27 truckloads per hour, was pumped into the shaft. This formed a 9 m plug at the bottom covering the tunnel accesses completely. Despite this, and despite pouring thousands of cubic metres of structural and light-weight foamed concrete, the ground was still sinking into the hole and eventually the site headquarters building tilted on its foundations and crumpled towards the hole.

Some 24 hours later, a rotary piling rig was employed to drill from the surface into the concourse and the down-platform caverns and more concrete was pumped through these shafts to plug the failed area. Access was gained to construct concrete bulkheads to seal the damaged tunnels. The flow of concrete into the hole continued the whole time until ultimately these measures were successful and ground movement around the failed area was stabilised. It was stated that by the end 18,500 cu m of concrete was pumped in.

The designers of the tunnel and the contractors were prosecuted under the Health and Safety Act in England for failing to ensure that their conduct during the construction of the tunnel did not expose the construction workers and members of the public to risk. The contractors pleaded guilty after an expert report, which was carried out for them in 1998, showed that a weak tunnel invert resulting from poor construction was the cause of the collapse. During the 27-day trial, it transpired that various warnings of an impending collapse were given, but these warnings were not heeded.

The final report of the Health and Safety Executive, published in 2000, referred to the accident as the worst civil engineering disaster in the UK in the last quarter of the twentieth century resulting from a catalogue of design and management errors, poor workmanship and quality control.[59] The Executive claimed that the designers were responsible for monitoring the behaviour of the lining during construction and failed in their duty to issue warnings when data from their monitoring instruments showed that a collapse was imminent in the weeks preceding the collapse. The designers claimed that an ‘unpredictable and unpreventable’ landslide in the clay above the tunnels triggered the collapse and that even with a defective lining caused by poor workmanship, the tunnels could not have collapsed without an outside influence.

The report also stated

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58 ‘HEX Collapse Report Slates Poor Risk Management’, report by Anthony Oliver, *New Civil Engineer International*, 1 August 2000, UK. See also various earlier reports in the *New Civil Engineer,* 27 October; 3 November; 10 November; 1 and 8 December 1994; and 26 January 1995.

> Such accidents must be prevented through effective risk management. The industry cannot simply rely on good fortune. Risk assessment should be a fundamental step in the procedures adopted by all parties: it is inappropriate wholly to leave the control of risk to contractors.

The jury found both the designers and the contractors guilty of the charges against them. The judge in the case, Mr Justice Cresswell stated that the contractors should bear the greater responsibility for the collapse, as they fell seriously short of the 'reasonably practicable' test. He stated that it was a matter of chance whether death or serious injury resulted from the breaches committed. The contractors were fined £1.2 million, whereas the designers were fined the lesser sum of £500,000 for their 'less culpable role'.

A material factor in the collapse was the nature of the contractual arrangements, the contract management, and all engineering questions relating to the New Austrian Tunnelling Method (NATM) process in soft ground being devolved to the contractor with self-certification as part of a competitive contract.

E.2.2.7

Mechanical and electrical breakdown

Site operations are becoming more dependent on plant and equipment, the breakdown of which forms a major risk element. An interesting study was made of 409 failures of diesel and natural gas engines reported in the period from 1975 to 1979 with damage amounting to or exceeding US$2500. The study covers only such cases where the cause and development of the failure were clearly determined.[60] Failures due to 'unknown causes' were not included in the study.

Table 3.1 shows the distribution of failure in terms of the application to which the engine is used. Table 3.2 shows the distribution in terms of the component mainly affected and Table 3.3 in terms of primary cause.

In some cases, the damage to the piece of equipment or machinery is minor when compared with the damage or risk of damage to the project itself, as occurred in the following case where the loss amounted to DM1.7 million.

A 2.3 km underwater pipeline with a diameter of 0.6 m was to connect a refinery on land with a planned tanker jetty.[61] The pipeline was winched out from the shore by means of a steel cable. The winch stood on a moored pontoon. Then the cable became entangled and the winch was ripped apart. The pipeline, already partly under water, had to be salvaged. A cyclone then caused a tidal wave which pushed the pipeline some 200 m from its correct position to where it could be brought back only after a great deal of effort. Apart from this, construction equipment was also damaged. While a second attempt was being made to tow out the pipeline, the winch broke. At that point a length of pipeline measuring 1.3 km was in the water. The

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59 *The Collapse of* NATM *Tunnels at Heathrow Airport,* [2000] published by HSE Books, UK, which could be viewed from www.hse.gov.uk web site.

60 *Schaden Spiegel,* op. cit., see note 30, No. 2, 1981.

Table 3.1 Distribution of failures of diesel and natural gas engines by fields of application

Application	*Number*	*% of total*
Earthmoving machines	209	51.1
Power generation	58	14.2
Watercraft	42	10.3
Construction site vehicles	32	7.8
Fork-lift trucks	29	7.1
Railbound vehicles	19	4.6
Compressors, pumps	11	2.7
Other	9	2.2
	409	100.0

Table 3.2 The principal failure areas in diesel and natural gas engines

Failure areas	*Number*	*% of total*
Pistons and connecting rods	191	23.3
Crankshafts	138	16.8
Bushings	132	16.1
Bearings	123	15.0
Casings	81	9.8
Cylinder heads	63	7.7
Controls	48	5.9
Other	45	5.4
	821	100.0

resistance caused by friction on the seabed had obviously been underestimated. It was not possible to repair the winch in the country itself and a reserve machine was not available.

Following this, tugs belonging to the harbour authority were used to tow the pipeline. Only approximately 400 m had been positioned in this way before the tugs were forced to give up. The next attempt was made with the help of a 16,000 tonne tanker used to tow the pipeline on its own. This also failed as, when the heavy ship started to move, the cable was torn by the force of the sudden jerk and the pipe sprang back and bent over.

These constant misfortunes led to a considerable delay in the laying operations. In addition, assembly became more difficult when the monsoon period began. The pipeline was finally towed with the original winch which had meanwhile been repaired abroad.

E.2.2.8
Inadequate site management

A company contracted to build a section of motorway procured the necessary stones from a nearby quarry.[62] The rock was blasted into fragments and loaded onto dump trucks. The hydraulic excavator had a loading shovel with a capacity of 4.5 cu m and was driven by a 500 hp (DIN) diesel engine.

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61 Ibid., September, 1975.

Table 3.3 Primary causes of damage in diesel and natural gas engines

Product faults	*Number*	*% of total*
Faulty assembly	23	5.6
Faulty design	20	4.9
Faulty material	17	4.3
Faulty repair	13	3.3
Poor workmanship	12	2.9
	85	21.0
Operational faults	*Number*	*% of total*
Maintenance faults	177	43.2
Faulty handling	102	24.8
	279	68.0
Outside influences	*Number*	*% of total*
Foreign bodies	25	6.1
Sabotage and other extraneous causes	20	4.9
	45	11.0
Total	409	100

During operation, fire (probably caused by a short circuit in the 24 volt electrical system) broke out in the excavator. The flames consumed 1,000 litres of diesel fuel and an equal quantity of hydraulic oil in two tanks at the rear of the excavator.

Although fire brigades from the neighbourhood quickly reached the scene, it took an hour to extinguish the fire. The losses amounted to US$300,000. The fire could well have been brought under control at the outset if adequate fire-fighting equip ment (manual fire extinguishers) had been available. The loss, in that case, would have been minimal.

E.2.2.9
Ground movement

Ground movement could take place from a number of causes, including landslides, frost heave, earth slips and ground pressure leading to collapse. Two examples are given here. The first occurred in a sewerage plant which was damaged during construction by an earth slip.[63] Due to heavy rainfall the earth on the slope above the building site slipped down 10 m. The soil pressed against a shaft structure made of precast concrete elements until it collapsed. Consequently, surface water and silt were able to get into a sewer at the point where it had been connected to the shaft. The sewer had already been completed and was ready for use but then became filled with mud along a length of 2500 m.

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62 Ibid., October 1976.

The second incident occurred during construction work for new loading and landing piers which included the driving of steel sheet pile walls into about 8 m deep water and anchoring the walls on the landside by steel anchors. These anchors were held by a smaller sheet pile wall driven about 20 m further inland. When the driving operation was completed, the space between the two sheet pile walls was gradually filled with liquid soil. At the same time steel piles were driven along the waterside of the outer sheet pile wall, which were to be connected later by a solid concrete slab to form the final quay.

The ultimate fill height had nearly been reached when the inland sheet pile wall started to move. Deprived of its backward anchoring, the sheet pile wall on the waterside also gave way and collapsed over a length of 100 m pulling the inland sheet pile wall with it. Large amounts of fill material poured into the bay, tearing down several steel piles standing in the water.

The damage amounted to about US$2 million.[64]

E.2.2.10
Subsidence

In 1975, an international consortium of contractors were awarded the contract for the construction of the terminus station in Hong Kong Island for the Hong Kong Mass Transit Railway Corporation.[65] The station, basically a large underground concrete box, almost half a kilometre long and approximately 27.5 m deep, was built in the central business district only a few metres away from surrounding properties. One of these buildings was the premises of the Supreme Court of Hong Kong which was built around 1910 on wooden piles in very poor ground.

During the diaphragm wall construction and after the sides of the excavation has been stabilised with bentonite, unexpected ground behaviour and dewatering influences caused the building to subside and tilt. Serious cracks appeared and in July 1978, when the learned judges had become concerned at lumps of plaster falling on their heads, the building was evacuated.

In 1984, the loss, which was calculated to be well into seven figures, was settled out of court, by the insurers. A single insurance policy had been arranged to cover the employer, contractor, subcontractors, and ‘all other parties engaged to provide goods or services’. No subrogation recovery procedures were initiated and the insurers accepted responsibility.

E.2.2.11
Explosion and fire

Even the best-organised construction sites are, by their very nature, prone to fire hazards. Inflammable construction materials such as timber, shuttering, packing material, plastic foils, fuel, paints and other hazardous material are generally found on site. The temporary nature of

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63 Ibid., October 1974.

64 *Schaden Spiegel,* op. cit., see note 30, special issue, 1998.

65 ‘Settlement at Court or Why the Judges Sought an Adjournment!’, *Risk Review,* a publication by Stewart Wrightson, Insurance Brokers, No. 9, October 1984.

many items on site such as camps, stores and temporary heating and cooking facilities adds to the fire hazard. Moreover, only a few sites maintain complete and efficient fire-fighting equipment and many civil engineering projects are remote from public firefighting facilities. A project concentrated in one location can be threatened in its entirety by fire and the risk involved increases with the progress of construction.

Welding operations in an enclosed environment constitute a major fire risk both during and after the welding operation. The following incident of a fire that occurred during welding illustrates what could happen. An amusement park under construction within a hotel and shopping complex was almost completely destroyed by fire.[66] The roof of the multi-storey 'theme park' was to be spanned by a 200 m×60 m glass dome. Among the attractions was a presentation of the Arabian tale of Sindbad the Sailor. The artificial rock walls used for the show consisted of glass-fibre reinforced polyester resin and were covered with a refractory coating on the front side only. The fire broke out during flame-cutting operations on pipework situated under the ceiling. It was thought that welding beads must have dropped on to the back of the artificial rock walls, which were at the time unprotected, and they caught fire immediately.

The workmen tried to combat the fire with portable extinguishers, but dense smoke and the toxic gases it contained soon forced them to give up. Large amounts of combustible material and the presence of a great many shafts for transporting installations, lifts, and escalators between the individual storeys accelerated the spread of the fire up to the glass dome.

Several hours elapsed before the fire brigade managed to extinguish the fire. Four of the approximately 300 workmen present in the building when the fire started suffered minor injuries. The fire caused considerable damage to the interior of the building, including its structural components, surfacing slabs, wall panelling and floors. Protective coatings covering the steel structure were affected by the heat and smoke and serious damage was inflicted to the mechanical and electrical installations, to lifts and to loudspeaker systems. The panels of the glass dome had to be cleaned or replaced. The material damage covered by CAR insurance amounted to the equivalent of about US$3 million.

In a similar incident, fire caused severe damage to a thermal power station designed to house three 400 MW units. The fire occurred many hours after the end of a day's work.[67] At the time of the accident, the structural steelwork of the 29 m high machine hall was nearing completion and the equipment for the first unit was being installed. Concreting work for the third unit was under way. The foundations and steel columns had been completed and work was concentrated on the completion of the reinforcements and scaffolding for the turbo-generator platform. Concrete was to be poured the following morning and completion work continued late into the night.

In the early hours of the morning, a watchman on an inspection round discovered flames coming from the formwork. He triggered the fire alarm and fire engines were called from a nearby industrial area and the nearest town. The works fire brigade and another seven fire engines fought the fire, which was finally brought under control after one hour.

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[66] Taken from an article by H.Maier, published in the Special issue of *Schaden Spiegel,* op. cit., see note 30, 1998.

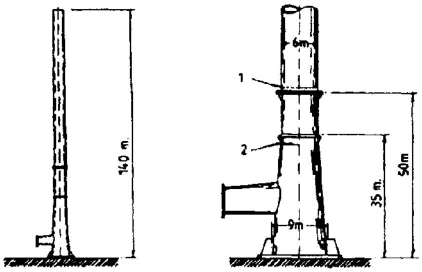

Figure 3.7 Brittle fracture in a steel chimney due to oscillation.

The turbo-generator platform was completely destroyed. The flames lashing up high and the enormous heat had caused serious damage to the turbine house and a neighbouring building. The entire roof structure and two cranes parked above the fire area had to be replaced.

The damage amounted to about US$3.5 million, some 10% of the sum included for the removal of debris. As no cause for the fire could be established, it was assumed that the accident was caused by flying sparks from the welding of steel reinforcement, which ignited timber and combustible wastes.

E.2.2.12

Vibration and oscillation

A serious loss amounting to DM3.5 million occurred during the erection of one of the world's largest blast furnaces with a daily output of 8,800 tonnes of pig iron.[68]

A self-supporting steel-plate, brick-lined chimney with an overall height of 140 m was to be erected for discharging the waste gases. The lower section of the chimney was 35 m high and cone-shaped, tapering from 9 m to 6 m in diameter. The upper chimney section consisted of a cylindrical tube having a length of 105 m and a diameter of 6 m. The material used for the steel plate was mild steel and the thickness of the plate varied from 12 to 30 mm. After the two chimney sections had been erected, the brick lining work was started. When the lining had reached a height of only a few metres, technicians discovered a crack, measuring 1 m in length, around the periphery of the chimney. The crack was at a height of 35 m, just below the joint between the lower conical section and the upper cylindrical section (see Figure 3.7). Within a period of seven hours, the crack extended to a length of 8 m. The prevailing wind at the time was force 6 on the Beaufort scale and the risk of the chimney toppling over and crashing down on to the furnace air preheater unit could not be ignored. It was decided, therefore, after consultation with the insurers, to blast off the chimney approximately 15 m above the crack. This was done successfully, but how had the crack originated?

When checking the fracture and the design of the chimney, it was found that, due to severe oscillation of the structure, excessive stress had been exerted at the point where the conical and cylindrical sections met.[69] Eventually, this had resulted in a brittle fracture of the steel

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67 *Schaden Spiegel,* op. cit., see note 30, No. 1., 1982.

68 Ibid., October 1976.

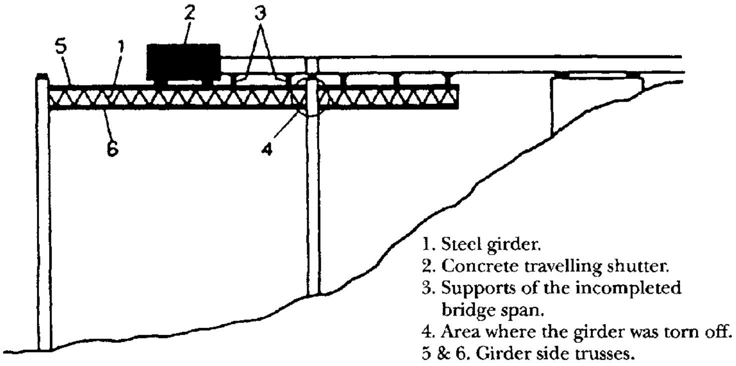

Figure 3.8 Defective design of a temporary girder.

plate. Wind tunnel tests, which could have uncovered the weakness, had not been carried out during the design stage.

E.2.2.13
Defective temporary works and their design

A steel girder, used as falsework to support formwork, and incomplete bridge span sections, collapsed during construction of the second span of a six-span 300 m long continuous, prestressed concrete box-girder railway viaduct (Figure 3.8).[70]

At the time of the collapse, all piers and one span had been completed. The steel girder was supporting the completed span and the moving formwork for the concrete box-girder into which approximately 40 cu m of fresh concrete had been placed for the first 10 m length of the second span. The form work was felt to drop suddenly and buckling was noticed in the web members of the lattice trusses which made up the steel girder. Buckling progressed slowly over a period of 30 minutes until the concrete box-girder section, which was two-thirds of its final length, was torn off near the pier and collapsed, together with the formwork. The completed piers and span were undamaged by the collapse.

The cause was traced to buckling of tubular web members in the steel girder side trusses. The girder, imported from overseas, had been originally designed to position and support precast concrete bridge sections slung beneath it. It had been substantially redesigned for use on the viaduct project, which necessitated a different construction method with the girder mounted under the viaduct span, and involved heavy loads and long spans. The affected side truss web members had not been strengthened and were loaded beyond their safe limit. There were no injuries in the collapse, but the financial loss sustained was approximately DM250, 000.

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[69] Ibid., October 1976.

[70] Ibid., October 1976.

E.2.2.14
Corrosion

A 63 mm stop valve was connected to a fire water supply line by means of an aluminium flange with a screw thread about 80 mm in length. The stop valve had a brass body of the material $CuZn_{39}Pb_2$ whilst the flange was made of aluminium alloy $G\text{-}AlSi_{10}Mg$. The quality of each of the two materials by itself was not in question, but when used together they result in galvanic corrosion when in contact with moisture and therefore leakage. This is precisely what happened on this project.

The water leaked through the localised corrosion in the joint and saturated the wall in the basement. To repair the damage, the soil outside the wall had to be removed and then filled in again afterwards. The wall also had to be dried and painted.

The loss, for which the water damage insurer paid, amounted to approximately US$15,000 and could only have been prevented by an electrochemical separation of the materials inside the valve. However, since as the valve could not be constructed in such a way, a different material should have been chosen for the flange. In this case, recourse action was taken against the plumbing firm responsible for this configuration.[71]

E.2.2.15
Collapse

Total collapse is the most catastrophic of all hazards. It rarely gives any warning and it therefore carries with it the risk of injury. Such an event occurred in Kuwait in 1976 when twenty-one workers were killed.[72] The chain reaction, which resulted in the total collapse of a garage building under construction, lasted for just five seconds. Six parking levels collapsed like a house of cards. While the slabs fell on to each other to form a ‘sandwich’, the columns broke like sticks at each level and all that remained was a pile of wood, steel and concrete. What had happened? The formwork and reinforcement for the sixth floor of the building had already been completed. As a total of more than thirty floors had already been made in the same way, concreting seemed to be just a routine affair. The pouring of concrete for the sixth floor was thus started half an hour before midnight. The concrete was being pumped up through a riser. Some 70% of the slab had already been concreted around 6 a.m. when the timber structure supporting the formwork suddenly collapsed. As a result, the concrete, some of which had cured but other areas had not yet hardened, fell on to the slab below from a height of 3.5 m. The mass of falling concrete weighed no less than 450 tonnes.

The floor slab below had only been completed fifteen days earlier, but the form-work had already been removed. The floor was not able to support the weight of the collapsed floor and the dynamic load of the collapsing concrete masses. The columns buckled, and both floor slabs fell to the next level together. This induced a chain reaction, causing all of the six floor slabs to collapse right down to the basement level. The accident occurred while some workers for the next shift were still asleep on the lower floors and were thus crushed to death underneath

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[71] Ibid, No. 2, 1998.

[72] Ibid., October 1976.

the rubble. The workers doing the concreting fell to the ground together with the collapsing structure.

The investigations that followed indicated that the lateral support of the form-work of the floor slab being concreted was insufficient. In fact, the timber structure used for this purpose had been previously used a number of times and was worn considerably and did not have sufficient stability. Moreover, additional horizontal forces were exerted on the weakened structure by the riser through which the concrete was being pumped up. The actual reason for the collapse was, without doubt, the fact that there was not enough sound timber material in the formwork used. So, used and reused parts were patched together to serve as supports, but these were no longer able to bear the imposed loads. In addition, the specification for concrete curing was disregarded. There can be no doubt that tough competition and piecework contracts often force contractors to make full use of the materials they have at their disposal and to really exploit their schedules to the utmost. However, once economic limits and sound practical engineering are reached and sometimes even exceeded, the failure of just one minute detail may be sufficient to cause a disaster. The loss described above amounted to a total of about DM3 million, not to mention the loss of life. However, it is unusual for one single cause to be identified with such a collapse. More usually, one particular factor can be found to have contributed most in bringing about the final collapse.

E.2.2.16
Collapse of temporary works

On 5 August 1999, the £300 million Grand Bridge in South Korea partially collapsed and thirty-seven precast concrete bridge segments from one partly complete and two completed spans crashed to the ground.[73]

The collapse occurred during construction of the 5.82 km section of the precast concrete segmental twin box girder southern viaduct. The viaduct, with 60 m long spans, was founded on twin 2.5 m diameter *in situ* concrete piers. The accident occurred as work was approaching the fifty-fifth pier and the 80 tonne deck segments were being assembled.

The segments were precast on site and transported along a previously completed bridge-deck before being positioned on a steel launching truss, which spanned adjacent piers and supported the segments making a span until all the segments were in position. Epoxy adhesive was then applied to the segment faces and external posttensioning was carried out stressing the segments together. The launching truss then slid forward to span the next pair of piers.

It was thought that the launching truss failed causing the incomplete span to collapse and to over-load the two preceding spans, causing their collapse. It was fortunate that no one was killed or injured in the collapse.

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[73] *New Civil Engineer,* op. cit., see note 45, 19 August 1999.

E.2.3
Risks during construction associated with Acts of Man (Figure 3.9)

E.2.3.1
Human error

It is now generally accepted that human error is in some way or another the cause of a large percentage of the accidents in the industry in the sense that actions by people either initiated or contributed to the accident or that people might have acted better to avert them. Recent data indicate that approximately 80% of industrial accidents, 50% of pilot accidents and 50–70% of nuclear power accidents are attributable to human error.[74]

Construction is part of these statistics. In particular, such accidents result in accidental death, personal injury, property damage or combinations of them. Workers may feel that safety measures, such as wearing protective equipment, are cumber-some or it is not manly to follow them. A person may rationalise the idea of risk, believing that it would not happen to him/her, or deviate from safety procedures to gain some personal benefit. In the context of the intense time pressures typical of construction work, workmen may even cut corners in the belief that they are acting in the interests of their employer in finishing a particular task earlier or on time. However, simply put, the truth is that to err is human, and humans are fallible and liable to make mistakes or behave unpredictably for many reasons.

It has been suggested that modern technology has advanced to the point at which improved safety can only be achieved through attention to human error mechanisms.[75] Therefore, human control must remain and must be exercised to intervene when unplanned events occur. In fact, there is evidence to suggest that introducing safer technology can lead to more risky behaviour because people feel uncomfortable with the 'low' level of risk they experience and try to 'compensate' for this by behaving in an unsafe manner, often referred to as risk compensation.

The importance of the human element in reducing the risk in construction projects means that there ought to be a successful management of construction workers' occupational health and safety (OHS) behaviour. It is therefore important to understand the psychological processes which result in behaviour that leads to mistakes and accidents. Although detailed study of this topic is outside the scope of this book, it is interesting if not important to understand the types of error that may occur. The Health and Safety Executive in the United Kingdom classified the types of error in the following manner.[76]

(a) Lapses of attention

Intentions and objectives are correct and the proper course of action is selected but a slip occurs in performing it. This may be due to competing demands for attention. Paradoxically, highly skilled operatives may be more likely to make slips because they are not used to carefully thinking about every minor detail.

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[74] *Human Reliability Analysis,* E.M.Dougherty, and J.R.Fragola, John Wiley, 1988, New York; *'Human Factors',* R.S.Jensen 1982, 'Pilot judgment: Training and evaluation', 34, 61–73; and *Cognitive Systems Engineering,* J.Rasmussen, A.M.Pejtersen and L.P. Goodstein, John Wiley, 1994, New York.

[75] *Human Error, J.* Reason, Cambridge University Press, 1990, Cambridge.

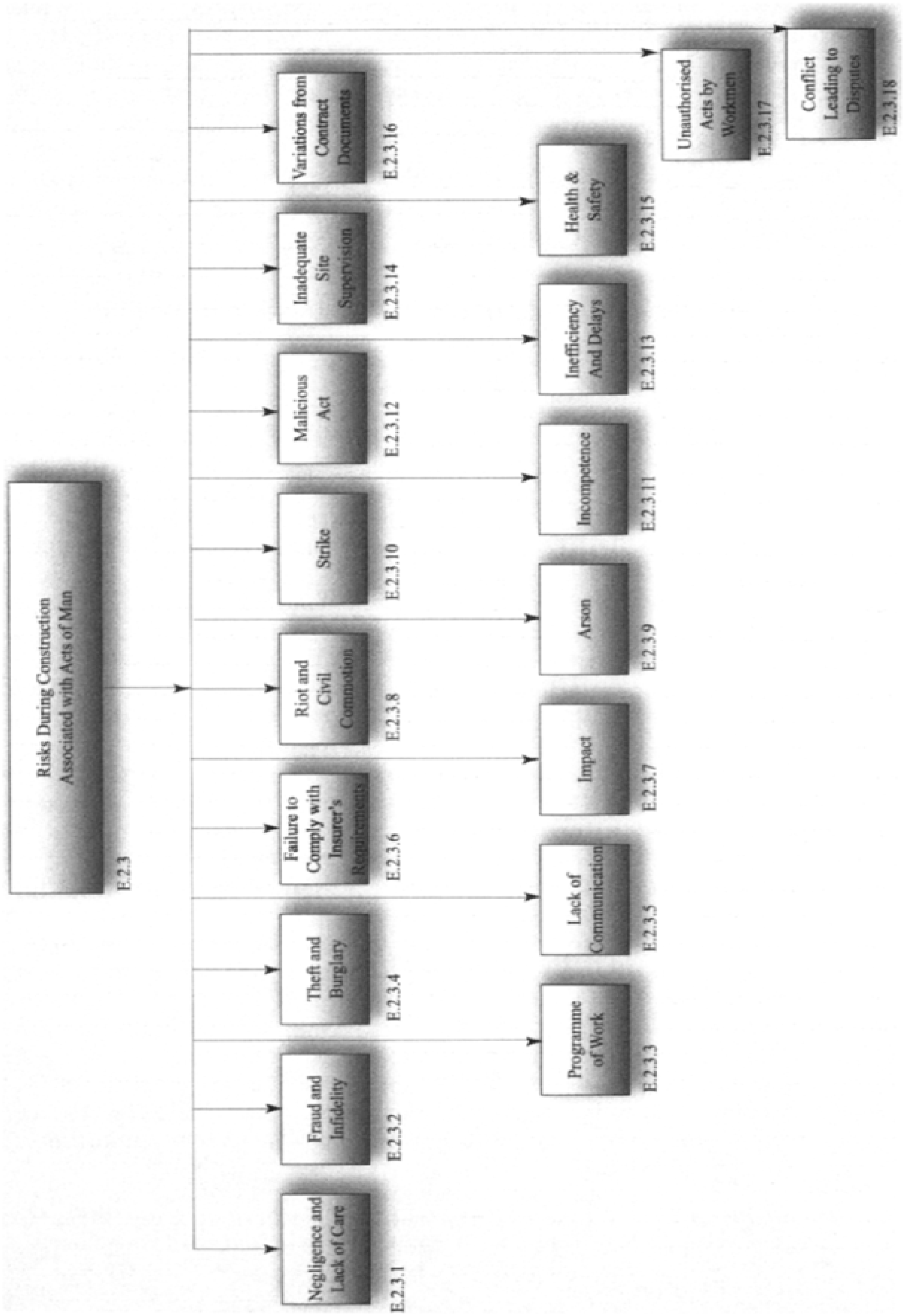

Figure 3.9 Risks during construction associated with Acts of Man.

(b) Mistaken actions

Doing the wrong thing under the impression that it is right. For example, the individual knows what needs to be done but chooses an inappropriate method to achieve it.

(c) Misperceptions

Misperceptions tend to occur when an individual's limited capacity to give attention to competing information under stress produces 'tunnel vision' or when a preconceived diagnosis blocks out sources of inconsistent information.

(d) Mistaken priorities

An organisation's objective, particularly the relative priorities of different goals, may not be clearly conveyed to, or understood by, individuals. A crucial area of potential conflict is between safety and saving cost or time. Misperception, described above, may be partly intentional as warning signs are ignored in the pursuit of competing objectives. Where top management's goals are not clear, individuals at any level in the organisation may superimpose their own.

(e) Wilfulness

Willfully disregarding safety rules is rarely a primary cause of accidents. Sometimes there is only a fine line between 'mistaken priorities' and 'wilfulness'. Managers need to be alert to the influences that, in combination, persuade employees to take and condone 'cutting corners' where safety rules and procedures are concerned, in the belief that the benefits outweigh the risks.

An example of a human error of the penultimate type, which could have easily been fatal, is the incident that happened during excavation works at Heathrow Express trial tunnel project. A truck driver escaped death when his 30 tonne vehicle plummeted down the access shaft to the tunnel. Four men who were working at the bottom of the shaft escaped injury by pressing themselves against the side of the 10.67 m wide and 25 m deep shaft as the truck landed, roof first, on a protective steel mesh 3 m from the bottom.[77]

The driver, who had to be cut from the wreckage, explained that he lost traction in deep mud and his laden truck plummeted down the shaft. The shaft perimeter was only protected by a pedestrian barrier consisting of scaffold tubes. The Health and Safety Executive stated there were no regulations stipulating the installation of vehicle barriers, but the standard practice is to protect the top of such shafts with lining segments, which were to be added on the next day.

An example of a human error of the last type, which did end in a fatal accident, occurred on a road in the Far East during asphalting operations.[78] The asphalt, which had to be mixed with a diluting substance to increase its viscosity, was heated in batches to a temperature of between 110 and 135°C in a special tank lorry. The tank had a built-in churning device, which stirred the contents until they had formed a homogeneous mixture which was then carried to the laying point by the lorry.

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76 *Human factors in industrial safety,* UK Health and Safety Executive, HSE HS (G) 48, 1989, London: HMSO.

The diluting substance when used on site should normally be a non-volatile hydrocarbon with a high boiling point. In this case, however, the mistake was made by using, on a site operation, kerosene—a volatile hydrocarbon with a low boiling point with similar properties to petrol.

On the day of the loss event some of the asphalt/kerosene mixture suddenly spilled over the edge of the opening, ran down the outside of the tank, and ignited immediately upon contact with the heating elements. The flames surged back into the tank and within seconds the fire had engulfed both the tanker and a forklift truck next to it that was used to carry the kerosene from the storage area. An unsuccessful attempt was made to extinguish the fire using CO2 extinguishers. The local fire brigade was alerted, but in spite of arriving on the scene almost immediately, it could not assist in the fire fighting because the only extinguishing agent it had was water, which is not suitable for fighting hydrocarbon fires.

Ultimately, the fire was extinguished by throwing earth and sand onto the flames using shovel dozers. Two workers died in the fire and the material damage totalled more than US $110,000.

E.2.3.2
Negligence and lack of care

For the extension of a power plant, a 500 m pipeline with a diameter of 1.7 m was needed to supply additional cooling water from a nearby lake.[79] Owing to the very gradual slope of the lake shore and the great fluctuation in the water level, the pipeline was to be laid in a trench both on land and under water. The method chosen for laying was to weld together the 6 m pipe lengths on land into several lengths of pipeline and temporarily seal them. The sections were then floated into position by means of pontoons and were mechanically coupled. In order to ensure even lowering of the pipeline, the inside was fitted with sealing discs dividing the pipes into separate chambers, each chamber having its own valve. Thus, it was possible to flood the chambers individually, giving maximum control over the rate of sinking.

After the complicated sinking procedure had been completed and the pipeline lowered into its channel, the temporary partition walls between the pipe section were to be removed by specially installed tackle lines. One of the walls then jammed as it was being extracted. A diver was engaged to rectify the problem. To make work easier for him, it was decided to let some air into the pipeline. Unfortunately, too much air was pumped in and the pipe began to lift. A whole section of the pipeline was pushed to the surface, but its ends had already been secured by anchorages. Consequently, the pipeline fractured and sank back into the water. The damaged pipeline was useless and not worth salvage. A new ditch was prepared parallel to the original one and a second pipeline had to be laid. The loss amounted to DM1.9 million.

Another instance of lack of care during construction can be taken from the mechanical engineering field when, after completion of the construction of a modern iron plant containing

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77 *New Civil Engineer*, op. cit., see note 45, 10 February 1994.

78 An article by Maqbul Ahmad, Dacca taken from *Schaden Spiegel,* op. cit., see note 30, No. 2, 1997.

[79] *Schaden Spiegel,* op. cit., see note 30, September 1975.

a 74 m long, 4.6 m diameter, rotary kiln, it found that the pneumatic clutch of one of the two 35 kW auxiliary drive motors had not engaged properly.[80]

The coupling discs between the two main reduction gearboxes and the spur-gear drive shafts were found to be fractured near the key slots. Investigation of the damage revealed that the auxiliary drives, which were both connected to the two main reduction gearboxes, had acted in contra-rotating directions, thus causing the 1,400 tonne kiln to lift by a couple of millimetres fracturing the coupling discs and then failing down on its bearings.

The impact also caused the dislocation of bricks of the refractory lining of the kiln which had to be removed and rebuilt. The entire kiln bearings had to be checked, gears and drive shafts had to be dismantled and checked, and the drive shafts were found damaged in the key slots. The total claim was estimated to be DM100,000.

According to the electrician, all power cables were connected in the same sequence of red/white/blue, on the motor side as well as in the switch room. It was found, however, that whilst the connection for the right auxiliary drive motor had been changed in the switch room to red/blue/white to give the motor the correct direction of rotation, the connection for the left auxiliary drive motor had remained unchanged. This was noted neither during individual testing of the motors nor during testing of the auxiliary drives by rotating the kiln.

E.2.3.3
Fraud and infidelity

Although these risks are not common, they are nevertheless real, albeit in some cases rare, possibilities. This risk is best illustrated by the legal case of *Applegate v. Moss* which went to the English Court of Appeal in December 1970.[81]

The facts of the case were that in February 1957, Mr Moss, an estate developer, agreed to build for Mr Archer and Mr Applegate two houses already in the course of construction. He had employed a builder, Mr Piper of Piper Ltd, to build the houses in accordance with plans and specifications approved by the local authority, on condition that the foundation should be a reinforced concrete raft with a specific concrete mix. The reason for this condition was that the site formed a sloping ground on wet clay soil.

Messrs Applegate and Archer occupied the houses towards the end of 1957. In 1965, when one of them tried to sell his house, experts for the would-be purchasers found serious cracking. On investigation, it was found that there was no foundation raft but instead only a simple concrete footing of inadequate dimensions and concrete strength. The cracks were so serious that the houses were deemed unsafe, uninhabitable, beyond repair at a reasonable cost and only fit for demolition. They were, therefore, evacuated in 1966. Both Mr Applegate and Mr Archer sued Mr Moss for breach of contract despite the fact that they were outside the limitation period of six years. Mr Moss denied liability, basing his denial on an exclusion of liability clause in the original contract and also on the assumption that the action was time-barred. In reply, Messrs Applegate and Archer claimed that their rights of action were concealed by the fraud committed. The judge in the case, Paull J., held that both the builder

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[80] Ibid., October 1974.

[81] *Applegate v. Moss and Archer v.* Moss [1971] 1 All ER 747.

and the developer had concealed the right of action by fraud and thus the action was not time-barred. He awarded as damages the cost of the houses in 1957, plus interest from that date.

The case went to the Court of Appeal. The developer appealed against the finding of concealment by fraud, and a cross-appeal was made by the owners as to the date from which damages should be assessed. The appeal was dismissed and the cross-appeal was allowed, awarding damages of the value of the house when the problem was discovered in 1965 and interest from the date the houses were evacuated.

It is interesting to note that the exemption of liability clause was considered to be inapplicable to a situation created by a fundamental breach of contract and fraud, of which this case was a good example.

E.2.3.4

Programming the work

As an example of this risk, see page 81, Risk E.2.2.1.

E.2.3.5

Theft and burglary

On large sites, this risk can be quite substantial particularly if events lead to losses of a repetitious nature. Housing schemes present a good example of projects exposed to this risk.

E.2.3.6

Lack of communication

Lack of communication during the construction period can be a major risk no matter how small the project. Inaccurate communication, or lack of it, can also be a cause of misunderstanding between the various members of the professional team and also between members of the team and either the contractor or the owner. An example of this risk can be shown in the English case of *Sutcliffe v. Chippendale* where an architect was held liable to the owner for certifying payment in respect of defective work.[82] The contractor subsequently went into liquidation and could not make good the defective work. The cause of the problem in this case was a failure of communication between the architect and the quantity surveyor who drew up the certificates on behalf of the architect. The architect knew that the work was defective but he simply did not pass that information to the quantity surveyor.

However, one of the most catastrophic examples of poor communication and organisational failure during construction and erection of an engineering project occurred on 28 January 1986 when the space shuttle *Challenger* was given the clearance for ignition.[83] The space-shuttle-rocket-booster exploded after lift-off and all seven crew-members perished. The flight began in the late morning at 11:28 and ended 73 seconds later in an explosive burn of hydrogen and oxygen propellants that destroyed the external fuel tank and exposed the space shuttle to severe aerodynamic forces that caused complete structural break-up. Although the technical cause of the *Challenger's* explosion was the result of a faulty design of the O-ring seal, which failed at the launch, the Presidential Commission, which was established to investigate and enquire into the cause of the disaster, found that the underlying cause 'was rooted in organisational failures and poor communication'.

The explosion was found to have been caused by hot combustion gases that escaped from a booster via a failed field-joint seal. The design of the joint included two O-rings that did not function correctly at launch due to the low ambient temperature that prevented them from responding correctly to the rising pressure after ignition and rotational movement within the joint.

For a number of years prior to the tragedy, engineers had been concerned about the behaviour of the seals at low temperatures and such temperatures were forecast for the morning of the launch. Analysis of the records, showed that of the previous twenty-three launches in which the field-joints had been examined following booster recovery and where data was held, seven showed damage to the O-ring seals.[84] This damage had only occurred at ambient temperatures below 24°C and it occurred in all cases where the temperature was below 18°C. The lowest recorded temperature was 12°C. However, various factors, including the management structure of the project, and ultimately time pressures to maintain the space shuttle programme, created a situation where launch proceeded despite technical advice to the contrary and at an ambient temperature near to freezing, where seal damage was likely to occur.

The Presidential Commission Report (Bermingham 1999, pers. Comm.) traced the technical cause of the accident to hot gas escaping, known as *blow-by,* following the failure of the O-ring pressure seal in a joint of the casing of the booster. The failure was due to a faulty design, which was unacceptably sensitive to a number of factors, including the effects of temperature, physical dimensions, the character of the seal materials, as well as the reaction of the joint to dynamic loading. The shuttle's solid rocket boosters were made up of several sub-assemblies; the nose cone, solid rocket motor, and the nozzle assembly. Marshall Space Flight Centre was responsible for the solid rocket boosters, while Morton Thiokol was the contractor for the solid rocket motors. The boosters are one of a set of 'elements' that make up the complete craft.

Prior to the launch of this flight, the procedures of the Flight Readiness Reviews (FRR) were carried out in accordance with normal procedures. However, concerns of Level III NASA personnel, and element contractors, regarding the joint seals of the Solid Rocket Motors were not adequately communicated to the NASA Level I and II management responsible for the launch. The management structure of the Shuttle Programme had four levels: Level I was responsible for policy, budgetary and top level technical matters; Level II was responsible for overall supervision of the Shuttle programme; Level III was responsible for development, testing and delivery of hardware to launch site; and Level IV was responsible for design and production of hardware. The managers at Levels I and II were unaware that the O-rings had been designated a 'Criticality 1' feature—a term denoting a failure point, without back-up, that could cause a loss of life or vehicle if the component fails. This component had previously

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82 *Suttcliffe v. Chippendale and Edmondson* (1971), 18 BLR, 149.

83 Quoted from *Management of Engineering Risk,* by Roger B.Keey, Centre for Advanced Engineering, University of Canterbury, New Zealand, April 2000.

84 *Engineering Ethics: Balancing Cost, Schedule and Risk,* by R.L.B.Pinkus, L.J.Shumann, N.P.Hummon and H.Wolfe, Cambridge University Press, Cambridge, 1997.

been designated ‘Criticality 1R’—the R implying redundancy. The R was removed when it became understood that the secondary O-ring was unlikely to seal if the primary O-ring failed.

The managers at Levels I and II were also unaware that since July 1985 a launch constraint had been imposed and then for six consecutive flights waived. The crucial factor seems to have been that *neither the management of Thiokol nor the Marshall Level III manager believed that the O-ring blow-by and erosion risk was critical.* The testimony and contemporary correspondence show that Level III believed that there was ample margin to fly with the extent of O-ring erosion that was being experienced, provided the leak check was performed at an increased pressure. The fact that the increased test pressure was a contributor to the increased failure rate in service seems not to have been recognised. *What is clear is that the NASA Level III managers, and Thiokol management, had no such understanding or a least bad a different perspective of the failure mechanism to that held by Thiokol’s engineers.*

The Mission Management Team (MMT) postponed the launch scheduled for 27 January due to high crosswinds. The MMT met again at 14:00 on that day and concerns were raised about the effect of the forecast low temperatures on such facilities as drains, eye wash and shower water, and fire suppression systems, but not about the O-rings. When the situation was relayed to the engineers at Morton Thiokol they were adamant about their concerns over the low temperature: ‘…way below our database and we were way below what we qualified for…’ They contacted Morton Thiokol’s liaison officer at the Kennedy Space Center, expressed their concern, and requested more forecast temperature data. He recognised the significance of the concerns and ensured that a teleconference was set up. This was in turn followed by a second.

At the second teleconference Morton Thiokol engineers presented the history of O-ring erosion and blow-by. Their recommendation was not to launch until the O-ring temperature reached 53°F (12°C). A long-detailed, and reportedly, not acrimonious discussion followed. Thiokol’s Vice-President of Engineering was asked for a recommendation and he replied that he could not recommend launch. The Deputy Director, Science and Engineering at Marshall, was reported to have said he was ‘appalled’ at the recommendation not to launch. The Manager SRB (Solid Rocket Booster) Project at Marshall was said to have asked, ‘My God, Thiokol, when do you want me to launch, next April?’ Under this pressure, Thiokol management asked for a recess to consider their recommendation further and a Thiokol management-level discussion took place. One of the managers is said to have remarked that he ‘took off his engineering hat and put on his management hat’. The Thiokol managers seem to have concluded that, although blow-by and erosion was to be expected, there was not sufficient evidence to predict joint failure. In the absence of such evidence Thiokol engineers described it:

> This was a meeting where the determination was to launch and it was up to us to prove beyond a shadow of a doubt that it was not safe to do so. This is in total reverse to what the position usually is in a pre-flight conversation or a flight readiness review

and the launch subsequently took place, with fatal results.

E.2.3.7

Failure to comply with insurer's conditions and requirements

All insurance policies are based on full disclosure by the insured of any relevant information to the insurer and almost all insurance policies make it a condition that the insured is to abide by any other conditions of the insurance contract. *Williamson and Vellmer Engineering v. Sequoia Insurance Company* is a case that illustrates the importance of this risk.[85]

A mechanical and electrical services consulting engineer received a quotation valid for thirty days for professional indemnity insurance through his broker on 15 May 1973. Because of financial problems he did not act on or respond to the quotation until 2 August 1973 when he sent to the broker a cheque for the quoted premium. During the intervening period, problems arose in connection with the mechanical design of an air conditioning, heating and ventilating system in the library project which was designed by him in 1968.

The insurer, upon receipt of the premium, requested a new application form to be completed and submitted by the consulting engineer. The broker copied the original application and sent it to the engineer with instructions to return it noting any changes. The engineer returned the application without change and the insurer issued a one-year insurance policy effective from 10 August 1973.

In 1974, the design problems in the library project resulted in a legal case against the engineer who turned to his insurer for indemnification. The insurer refused to defend or indemnify the engineer. The legal action initiated by the engineer against his insurers failed and the case was appealed to the California appellate court which affirmed the original judgment. Reference was made to the pertinent questions in the application form which asked the applicant to describe any claim made against the applicant and to set out whether he is aware of any circumstances that could result in a claim against him. The engineer's response to these questions gave no indication of problems with the library project.

In contrast with the aforementioned case, the insurer may unjustly fail his insured, using this condition as a basis for his refusal to defend or pay a claim. An example of this occurred in Canada where one firm of consulting engineers was refused coverage by their insurer under their professional indemnity policy. The insurer refused to defend a claim made against the insured firm alleging late notification of the claim and failure to disclose relevant information. The firm faced with this dilemma had to, in the end, defend the claim and pay the legal costs. The defence was successfully made and the insured firm pursued the insurer for the legal costs it paid in defending the claim. It was awarded judgment against its insurer by the trial court. The insurer still refused to honour the insurance contract and appealed against the judgment. The appeal court dismissed the appeal and approved the judgment, ordering the insurer to pay the legal costs incurred in the defence of the original claim as well as the non-legal costs incurred in defending the claim, and the legal costs of the actions, trial and appeal.[86]

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85 *Guidelines for Improving Practice,* op. cit., see note 4, vol. VIII, No. 1.

E.2.3.8
Impact

As part of construction work for a quay, 30 m long reinforced concrete piles were driven into the seabed.[87] They were to be connected by a solid reinforced concrete platform. During a windstorm, a 350 GRT pontoon, moored some hundred metres away from the construction site, broke away from its moorings and drifted against the piles. As these were still standing free and unconnected, they were unable to absorb any appreciable horizontal force, so two rows of piles were bent over in the impact. A number of piles had to be removed and replaced. In order to provide the necessary access for the pile driver, even undamaged piles had to be extracted and redriven, which considerably increased the cost of repair. The damage was estimated at DM300,000.

E.2.3.9
Riot and civil commotion

Riot is defined as a tumultuous disturbance of the peace by three or more persons assembled together without lawful authority, with intent to assist each other, if necessary by force.

Civil commotion may be defined as public disorder. Riot or civil commotion may occur within the boundary of the construction site or outside it, and it may involve the employees of the contractor or members of the public or both. The responsibility for the risk in these different circumstances is assessed differently and thus may be allocated to different parties.

E.2.3.10
Arson

Arson may be defined as the wilful and malicious damage to or destruction of property by the setting of a fire.[88] Experience has shown that the following are the usual causes:

- Vandalism;
- Covering up a crime or diverting suspicion;
- Greed for profit, insurance fraud;
- Terror, intimidation, sabotage;
- Mental defects.

It has been established that the target of arson is usually unattended and isolated premises with little or no security. Construction projects during construction or after completion fit that description and are often the target.

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86 ‘Insurance, An Ultimate Solution or a Failing Expectation’, by Gerald Beaumont, Workshop on Risks and Liability, FIDIC Annual Conference, Vienna, 1985. The case referred to by Mr.Beaumont was *Stevenson et al. v. Simcoe & Evie General Insurance Company* (1982) *Insurance Law Reporter* 5462, Alberta Court of Queen’s Bench, upheld by the Alberta Court of Appeal by judgement dated October 1982.

[87] *Schaden Spiegel,* op. cit., see note 30, July 1977.

E.2.3.11
Strike

Strike is the usual term given for a simultaneous and concerted cessation of work by an employer's employees, or a substantial group of them, normally in pursuance of an industrial dispute. Strikes, however, may be political aimed at coercing the government.

Damage to property or injury to people may occur as a result of a strike action within the site involving the employees of the contractor or outside the site involving others. Allocation of responsibility for these two different risks is usually established in the General Conditions of Contract.

E.2.3.12
Incompetence

Mistakes are sometimes made by the most qualified and experienced of people. However, more frequent by far are the mistakes made by those who have not previously had the experience of similar work. This risk becomes more acute in rapidly developing countries where many projects of a wide variety are under construction without the necessary level of expertise either on the drawing board or on site.

E.2.3.13
Malicious acts

A 14 km pipeline with a diameter of 900 mm was laid to convey water between a reservoir and waterworks.[89] The bitumen-lined steel pipes were to be laid in a shallow trench and backfilled after testing. However, prior to the testing and backfilling of a section of the pipeline, it was exposed with one end remaining open.

Unknown persons emptied into the trench a 200 litres barrel of diesel oil which flowed into the open end of the pipeline. The manner in which this had been carried out indicated an act of sabotage. The diesel oil caused a chemical reaction with the bitumen and the lining was ruined. Forty-two pipes, each 9 m long, had to be replaced and the repair, necessitating electric welding, was extremely expensive. It was necessary to separate the pipes from one another, give them a new lining, re-weld them and then lay the section of pipeline once again. The loss amounted to DM300,000.

E.2.3.14
Inefficiency and delays

Time is money, with the exception that one cannot help spending it. Inefficiency and delays cost time and in the end additional expenditure in one form or another, directly and indirectly. This risk is recognised as one of the major factors in most project overruns and in

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[88] Arson, a publication of the Munich Reinsurance Company, Munich, 1982.

[89] Schaden Spiegel, op. cit., see note 30, September 1975.

essence it can also apply to other cost overruns experienced by the contractor and the design professional.

E.2.3.15
Inadequate site supervision

This is a multi-faceted risk affecting all the parties to a construction contract. The owner should realise the importance of full-time site supervision and allocate sufficient funds to provide for a suitable and qualified individual, or a team of inspectors and supervisors. If the project is the owner's first and he is unaware of the importance of this risk, then it is up to the professional adviser to acquaint him with the problems and benefits. He should understand that if inexperienced, poorly trained and underpaid personnel are employed on site, they would be no match for the contractor's team and in most cases they would not earn the essential respect and cooperation.

The contractor also has to supervise his own workers and ensure that they carry out the work properly and to the requirements of the contract documents.

The professional designer is also expected to carry out his part of the supervision, which can be best explained by quoting from the document prepared by the International Federation of Consulting Engineers (FIDIC) for the purpose of assisting individuals discussing the subject of the various aspects of supervision. It is entitled 'FIDIC Policy Statement on the Role of the Consulting Engineer During Construction', and states in part the following:[90]

> A full professional service by a Consulting Engineer to a Client for a project comprises five main stages, as follows:
>
> (1) investigation and report,
> (2) detailed design and preparation of contract documents,
> (3) arranging a contract,
> (4) services during construction,
> (5) acceptance of Works, commissioning of systems, and resolution of final account.
>
> …
>
> A Consulting Engineer who undertakes only some of the services comprised in a full professional service, is not in a position to take responsibility for the performance or consequence of those which are not entrusted to him.
>
> …
>
> Therefore, FIDIC recommends as follows:

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[90] 'FIDIC Policy Statement on the Role of the Consulting Engineer During Construction', a FIDIC Policy Statement, 1984, Lausanne Switzerland.

> (1) The Consulting Engineer should recommend to his Client the advantages of a full professional service providing continuity from inception to completion of a project.
>
> If the Client does not accept this recommendation, the Consulting Engineer should analyse and agree with his Client, before accepting an appointment for partial services, on the allocation of responsibilities for the different services respectively, and the procedures to be adopted for any independent checking or repetition of previous services that may be required.
>
> (2) The Consulting Engineer undertaking services-during-construction should recommend to his Client the advantages of the Consulting Engineer undertaking entire services-during-construction with delegated authority to exercise comprehensive powers under the construction contract, as the agent of the Client, and authority to act as independent arbiter on matters properly referred to the Consulting Engineer for decision under the construction contract.
>
> If the Client does not accept this recommendation, the Consulting Engineer should analyse and agree with his Client, before proceeding with the services, on the allocation of responsibilities for the various duties respectively, between the Client and the Consulting Engineer, between the Client and the Contractor, and between the Consulting Engineer and the Contractor, all of which should be recorded in writing.
>
> (3) Remuneration for services-during-construction should comprise two main parts:
>
> (i) payment for all services other than resident site staff, on the basis of a retainer per month, or on the basis of a percentage of the cost of the Works.
> (ii) payment for resident staff at man-month rates plus mobilisation payments.
>
> In addition, payment to the Consulting Engineer should include reimbursement of…

This risk is so intense that the technical publications are full of horror stories relating to the inspection of work which is either carried out improperly or not at all. The extension of the law of negligence in the past decade or two has made the parties involved in the construction contract, and others too (see Chapter 5), responsible to third parties for any lack of care or negligence in the process of supervision. Some design professionals have already decided to lessen their exposure to this risk either by not undertaking the task of supervision at all, or by withdrawing from the site. Some lawyers, cultivating this risk, are advocating the idea that the professional involved in supervision should not be the same person responsible for design. Such an idea can only multiply the number of disputes and increase the magnitude of this risk because, if a problem arises during construction, the person best qualified to deal with it is the designer.

The American Society of Civil Engineers, concerned with the problem of construction inspection, established in 1967 a task committee on inspection. The Committee gathered a wealth of information through replies to two questionnaires; the first was sent to owners and their representatives and the second to contractors. The replies showed the following problem areas as being conducive to claims and extra payments:[91]

- Inspectors who are too young and inexperienced;

- Personality conflicts with contractors' personnel;
- Unfamiliarity of the owner's representatives with the plans and specifications;
- Poor documentation;
- Owner's representatives directing the contractor's operations;
- Demanding a higher quality of work than is necessary;
- Owner's representatives exceeding their authority;
- Unnecessary delay by contractors;
- Unfamiliarity with construction practices.

One example of this risk eventuating can be taken from the case of the *Governors of the Peabody Donation Fund v. Sir Lindsay Parkinson and Co. Ltd and Others.*[92] Architects and engineers were retained to design a housing complex of 245 houses on a hillside site in inner London. The owners, Peabody Donation Fund, were required, under the London Government Act 1963, to install a suitable drainage system for the development. The system was to be to the satisfaction of the local authority and had to conform to the requirements of the drainage by-laws.

The site, being hilly, presented problems and had to be terraced. The subsoil was London clay which tends to expand and contract seasonally, thus giving rise to movement. For this reason, the professional team of architects and engineers designed the drainage system using flexible joints.

Early in 1973, the contractor, Sir Lindsay Parkinson & Co. Ltd, was ready to start work on the drainage system. The architect's representative on site was a young trainee architect who was responsible for supervision of the works. The local authorities instructed a drainage inspector to carry out inspections of the drainage works and on 2 February 1973 he met on site the trainee architect supervising the work and agreed with him to abandon the planned flexible jointing system in favour of a rigid pipe jointing system. The latter accordingly instructed the contractor, whose agent had attended the meeting on site. However, neither the inspector nor the trainee architect informed their respective principals of the change in design to which they had agreed.

Tests carried out in late 1975 and early 1976 revealed that many of the drains laid with rigid joints had failed. Reconstruction was necessary at a cost of £18,000 and the completion of the development was delayed for about three years with consequent loss of rents for the owner, who was also faced with substantial claims by the contractor for additional payments.

The owner started legal proceedings against the contractors for faulty workmanship, against the architects for failing to supervise properly and for the change in the design of the joints, and against the local authorities for knowing that rigid joints were being installed yet failing to require that they be flexible.

In the event, the case against the architects was compromised but it continued against the contractor and the local authorities. It was held that,

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[91] Report on Construction Inspection, ASCE Paper No. 9192, Summary Report, published in the Proceedings of the America Society of Civil Engineers, September 1972.

[92] *Governors of the Peabody Donation Fund v. Sir Lindsay Parkinson & Co. Ltd. & Others* [1984] 3 All ER 529.

> although there had been some faulty workmanship on the part of the contractors, this was not the cause of the failure of the drains, and that the cause of the failure was the design change, instructed by the supervising trainee architect, from flexible joints to rigid joints.

The court did not have to deal with the claim against the architects since it was settled. The local authorities were judged liable in damages to the owner on the grounds of failure to take steps to ensure that the drainage system, as installed, complied with the design originally approved by them.

The local authorities appealed against the latter part of the judgment. The Court of Appeal allowed the appeal and reversed the decision of the trial judge. Subsequently, the owner appealed, though without success, to the House of Lords.

This decision was followed in the case of *Investors in Industry Commercial Properties v. South Bedfordshire District Council & Others.*[93] The defendants appealed the earlier decision of the court's finding of negligence in the defendant's approval of plans and inspections of two warehouses with inadequately designed foundations. It was held that the local authorities owed no duty of care in its supervisory powers to the original building owner, who had the advice of architects, etc.

E.2.3.16

Variations front contract documents

On a Friday evening in July 1981, over one thousand people were crowded on to the main floor of the lobby of the Hyatt-Regency Hotel, in Kansas City, USA and on three walkway bridges spanning it, to watch and participate in a dancing contest. Shortly after 7 p.m., a loud cracking noise was heard and the fourth-level walkway was seen to buckle and fall on to the second-level walkway two storeys below, causing it to collapse and dump some 60 tonnes of debris, along with the spectators from both walkways, on to the crowded dance area. The death toll was 111, and 188 were injured.

Lawsuits were quickly launched, seeking compensation damages exceeding US$1 billion and punitive damages of more than US$500 million. Legal fees involved were estimated to be in the order of US$100 million. Several technical investigations were undertaken, including one by several consultants retained as engineering counsel on behalf of the steelwork fabricator.

The technical facts of the case are altogether simple. The failure initiated in the fourth-level walkway at the hanger rod connections to the floor beams. Each floor beam consisted of a pair of light channels joined together, toe to toe, with weld beads placed along the outside of the joints only, except for inside passes 30 mm long at each end. Such welds have no code status. Figure 3.10 shows the general arrangement of the walkway steelwork.

Investigations showed that the as-built steelwork was different to that shown on the original design drawings. The original connection detail showed each of the 32 mm steel hanger rods passing continuously from the ceiling through the fourth-level floor beam and terminating at

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[93] *Investors in Industry Commercial Properties v. South Bedfordshire District Council & Others* [1986] 1 All ER 787.

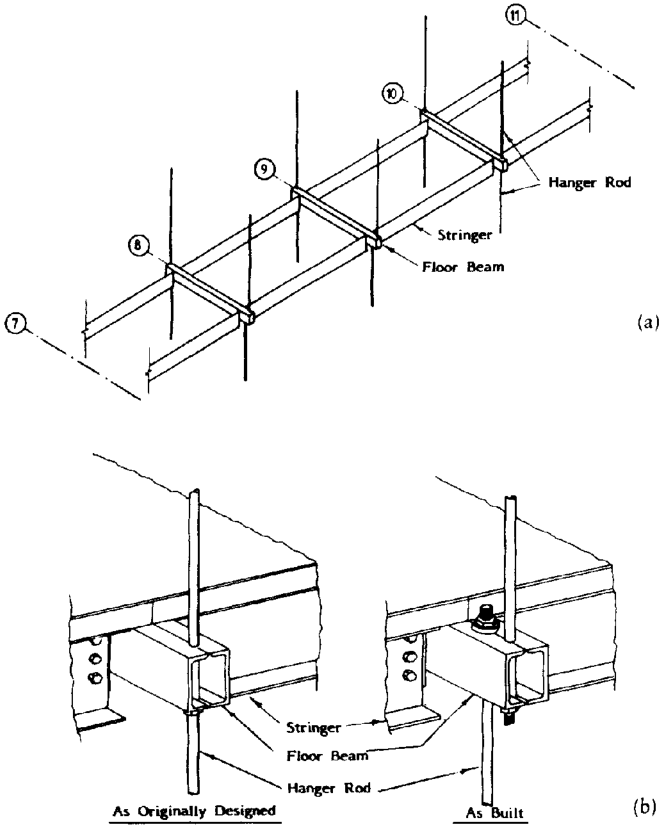

Figure 3.10 (a) General arrangement of framing of the walkway; and (b) Floor beam detail of the Hyatt-Regency Hotel, Kansas City, USA.

the second-level floor beam, with an ordinary round washer and a nut at each floor beam bearing point. In order to simplify fabrication and erection, the fabricator submitted an alternative detail, Figure 3.10, incorporating two half-length hanger rods, each terminating at the fourth-level floor beam. The fabricator's shop detail drawing showing this hanger rod connection detail was seemingly reviewed and authorised by the design engineer as attested by his stamp. The hanger rod connection failed.

The change in detail of the connection resulted in doubling of the load applied against the lower flange of the upper floor beam. The walkway failure cycle began when one of the upper hanger rods pulled through the bottom flange of a fourth-level floor beam.

It is interesting and significant to note that whilst the original hanger rod connection detail at the upper floor beam was adequate to support the loading subjected at the time of the collapse, its capacity was far below that required by the Kansas City Building Code.[94] Furthermore and in comparison, the as-built connection detail that failed reached its capacity under the weight of only the dead load.[95]

E.2.3.17
Illegal activities

A shopping mall in Donguan in the Chinese province of Guangdong collapsed as workers were engaged in illegally adding two floors to the single-storey reinforced concrete-framed building. The disaster occurred on Friday 1 December 2000, as a result of which eleven people were killed, 40 were injured and 120 were trapped for a number of hours. It was thought that the weight of the additional floors caused the building to collapse.[96]

E.2.3.18
Risks associated with dispute resolution

Construction contracts are prone to disputes, the resolution of which is highly uncertain as to duration, costs and outcome. In particular, these elements cannot be known in the early stages of the dispute resolution proceedings and risk management is of the utmost importance if optimum results are to be achieved.

Experienced construction lawyers and specialists, however, can usually provide very preliminary, but realistic estimates by drawing up a step-by-step schedule of activities of the dispute resolution mechanism. Important dates should be laid down, for example, dates for the exchange of witness statements; dates for the exchange of expert reports; and hearing dates. The duration and costs of these activities should then be assessed together with the amount of the outcome on the basis of probabilities of optimistic and pessimistic boundaries. Risk strategy can then be developed for each of these boundaries.

This process should be continued throughout the dispute resolution mechanism to provide a continued assessment and flexibility of reaction.

Of course, it should be noted that in arbitration, the arbitrator in consultation with the parties sets the above-mentioned dates, which are unknown at the early evaluation stages. In order to evaluate fully the extent of the risks involved in arbitration, as well as the objectives sought, sufficient information should be continually examined, including the following:

(a) An assessment of the estimated or likely sum recoverable if the case proceeded to a hearing and an award;
(b) An estimate of the percentage of costs that is likely to be recoverable if a party is met with success or failure at arbitration; and
(c) Whether or not an offer of settlement is made.

The answers to the above are combined to form compound figures for decision-making in relation to the risks involved in dispute resolution.

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94 'Hyatt-Regency Walkway Collapse: Design Alternatives', by George F.W.Hauck, ASCE *Structural Engineering,* vol. 109, No. 5, May 1983.

95 'Some Liability Aspects of Steelwork Design and Construction', by Jackson Durkee, The IABSE Henderson Colloquium on Liability, Cambridge, 1984.

[96] *New Civil Engineer,* op. cit., see note 45 above, 7 December 2000.

E.3.1

Risks associated with the post-construction stage (Figure 3.11)

A project is born with the completion of the construction period and it is then expected that it should carry out whatever functions for which it has been conceived. Accordingly the risks to which a project is exposed during the post-construction stage differ from those which exist prior to its completion. They can be categorised however, as shown in Figure 3.11, under the following headings:

- Safety
- Serviceability
- Resistance to fire and arson
- Resistance to natural and other hazards
- Resistance to man-made hazards
- Fitness for its purpose
- Operation
- Resistance to wear and tear during its designed life span.

There is little difference between the risks during the Defects Notification period, and those in the period that follows. The difference mainly lies in the fact that the contractor may be present on the site of the project during the earlier period in fulfilment of his obligations under the contract. Each of these risk categories is discussed separately. The term 'maintenance period' has been renamed as the 'Defects Notification Period' in the new suite of FIDIC Forms of Contract published in September 1999 and the 'Defects Correction Period' in the old Red Book of FIDIC and the ICE forms of contract. In this book, the term Defects Notification Period will be used.

E.3.1.1

Risks associated with safety

The combined quality and performance of the design of the project, the material used and the workmanship employed in its construction makeup the level of its safety. If one considers each in a scale where white represents perfection and black represents fault, then there are as many combinations as there are shades of grey. Lack of safety in construction projects continue to cause concern all over the world, but naturally more in some parts than in others. The concern in the United States about the apparent increase in the number of structural failures in the 1980s prompted the US House of Representatives Committee on Science and Technology to investigate these failures. The Committee's report, submitted in February 1984, discusses the findings and provides some recommendations as a result. Part of the report is quoted here for its relevance to the problem of safety:[97]

> The Committee found six significant factors that are critical in preventing structural failures. The Subcommittee also found five factors to be of heavy-to-moderate impact and eleven factors to be of lesser significance.
>
> The six critical factors are:

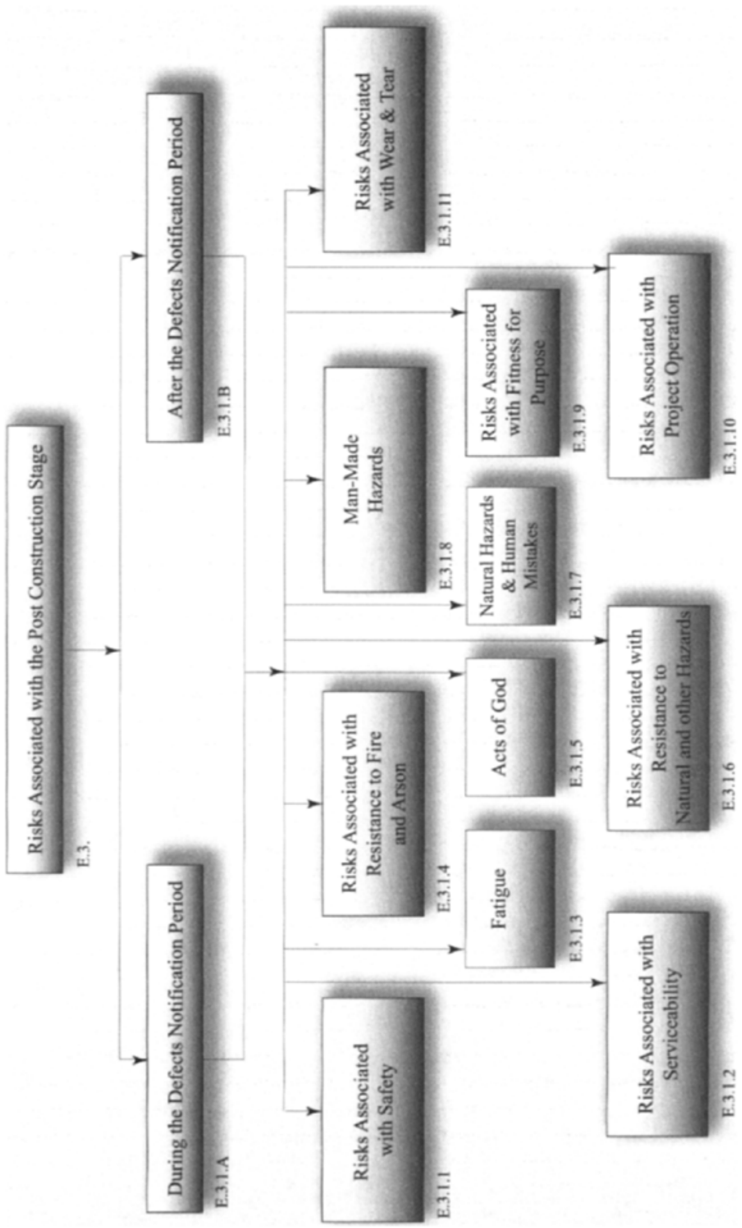

Figure 3.11 Risks associated with the post-construction stage.

(1) communications and organisation in the construction industry;
(2) inspection of construction by the structural engineer;
(3) general quality of design;
(4) structural connection design details and shop drawings;

(5) selection of architects and engineers; and
(6) timely dissemination of technical data.

The five moderately significant factors are:

(1) overall accountability for structural integrity;
(2) impact of ‘cost cutting’ on design;
(3) impact of ‘cost cutting’ on construction;
(4) potential for improving quality during construction; and
(5) selection of construction contractors.

The eleven least significant factors are:

(1) adequacy of building codes;
(2) impact of higher strength materials;
(3) adequacy of state and municipal design reviews;
(4) increased use of speciality contractors;
(5) support by testing laboratories;
(6) certification of buildings;
(7) role of lending institutions;
(8) adequacy of seismic codes;
(9) impact of construction manager type Organisation;
(10) impact of fast track scheduling; and
(11) need for legislative changes.

The Subcommittee also made formal findings and recommendations for the six factors which it concluded as being of critical importance to structural failures. The subcommittee believed that ‘these factors warrant the greatest and most immediate attention by both government and the building industry’.

The Subcommittee then elaborated on the six critical factors as follows:

(a) Communications and Organisation in the Construction Industry

> There is no set pattern for organising design/construction projects. Virtually all projects are different, and the companies involved have different capabilities. The data received by the Subcommittee, however, through its hearings and investigation strongly indicate the existence of loosely structured organisations, unclear definitions of responsibility, and poor lines of communication between the participants in construction projects, all of which can contribute to the occurrence of a structural failure.

(b) Inspection of Construction by the Structural Engineer

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97 *Structural Failures in Public Facilities,* Report by the Committee on Science and Technology of the United States House of Representatives, United States Government Printing Office, Washington, 1984.

For a variety of reasons the structural engineer of record or his designee is often not present on the job site during the construction of principal structural components. The absence of the structural engineer has permitted flaws and changes on site to go unnoticed and uncorrected. One reason for the structural engineer's absence is the possibility that he or his firm could be subject to lawsuits which have no relationship to their project responsibilities.

(c) General Quality of Design

The quality of design is being compromised by client desire to speed construction and reduce overall project costs. This can lead to the subsequent elimination of essential engineering services, such as peer reviews, that provide an important check on the commission of errors in the design process and help ensure that high quality designs are produced.

(d) Structural Connection Design Details and Shop Drawings

Structural connections, which are critical components of structural design, are often not designed by a structural engineer. Instead, they are frequently left to persons who do not have a sufficient understanding of the interaction of all stresses between structural members. Moreover, shop drawings are not sufficiently reviewed by the structural engineer. As a result, errors in design can be made and go unnoticed.

(e) Selection of Architects and Engineers

The selection of architects and engineers is generally made on a 'low bid' basis. Even when peer reviews, design scope, and on-site inspection are included in the bid request, there is a tendency to unrealistically reduce the price when price is known to be the primary basis for the contract award. Nearly exclusive use of this 'low bid' procedure has frequently resulted in insufficient funds allocated to a project to adequately verify the accuracy of design and to thoroughly check plans before construction. In other words, selection of an architect or engineer solely on a price-competition basis provides the potential for reductions in quality due to initial underestimation of the costs and resources required to adequately perform the work.

(f) Need for a National Board to Investigate Structural Failures

The records in many cases of litigation involving structural failures have been closed to public review as a result of settlement agreements between the parties. Consequently, little information has been made public about the technical causes of several recent major structural failures. Structural engineers and others have thus often been prevented from learning from the experiences and mistakes of others. This failure to disclose information provides the opportunity for others to commit the same mistakes in the future. A national investigative body is needed to obtain information about structural failures and provide individuals involved in the building industry with much needed data on failures around the country.

Examples of the risk of failure in safety are plentiful and some have been quoted earlier in this chapter. Others can be seen in the technical press and those which are dramatic have been the subject of investigation by various committees formed in various parts of the world for that purpose.

E.3.1.2
Risks associated with serviceability

Serviceability is the second essential and basic performance requirement of any construction project throughout its intended life span.

The serviceability requirement can be very stringent in that it restricts the acceptable and yet inevitable movement and deformation of the various elements of a project to a maximum limit. Such limit is usually fixed so that any movement or deformation is within a boundary beyond which the intended use of the project is rendered less effective.

The movement and deformation may take any of the following forms:[98]

- Settlement of foundations
- Deflections due to loads including wind
- Strain and creep deformation
- Temperature and shrinkage movement
- Movement due to varying moisture content
- Movement due to natural forces such as those resulting from earthquakes
- Cracking
- Vibration

The most dramatic examples of serviceability failures are perhaps due to the first type of movement, i.e. settlement of foundations. The building for the Société Minoteries Tunisiennes at Tunis is but one example of such failure with others easily located in the technical press.[99]

E.3.1.3
Risks associated with fatigue

In June 1989, a 90 m diameter radio telescope at Green Bank, Virginia, USA, collapsed after twenty-six years of service. It collapsed due to fatigue following progressive cracking and then failure of a key joint. The fatigue was caused by very high cyclic loading derived from secondary forces as the radio telescope swept back and forth across the sky.[100]

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[98] 'Guide to the Performance of Building Structures', a publication of the Institution of Structural Engineers, December, 1984, London, UK.

[99] *Building Failures,* Thomas McKay, McGraw-Hill Book Co., 1962, page 114.

The shallow dish consisted of a light aluminium surface supported on a bolted steel frame of matching shape, all supported on a diamond shaped truss. The collapse was precipitated by failure of a gusset plate on one side of the diamond truss at a connection between three main members. A crack spread from two punched bolt-hole positions to extend over the whole 1.2 m width of the plate. Secondary cracking was found around the rogue boltholes, indicating that 'severe working produced by the punch could have left an initiating small crack'. Cracking was also found on corresponding gusset plates.

E.3.1.4
Risks associated with fire and arson

A construction project should be capable of containing a fully developed fire within a restricted and prescribed area and in such a way that it does not spread to adjacent compartments. Furthermore, it is a requirement in many parts of the world that collapse should not occur as a result of fire before a prescribed period of time has elapsed which depends on the type of the project.

Examples of fire disasters can best be studied from the files of insurance and reinsurance companies and the following is one of these examples. A 114-year-old department store in Singapore, one of the landmarks of the city, was destroyed by a large fire on 21 November 1972.[101] Nine people were killed, the property damage and consequential loss amounting to about DM18 million.

The three-storey building was of brick, masonry and timber construction with a tile roof. The whole department store covered an area of about 8,000 sq m which was not separated into individual fire compartments and not protected by sprinklers. The building was air-conditioned and had three passenger lifts.

On the day when the fire occurred, the store opened at 9 a.m., as usual. Shortly afterwards, the air-conditioning system was put into operation by an electrician. At 9.45 a.m., some employees on the ground floor noticed a smell of smoke which they thought had been caused by a short circuit. The electrician was called and, as he arrived on the ground floor, all the lights suddenly went out. Just as repairs at the main switchboard were to be started, the fire alarm rang and, shortly afterwards, fire was noticed at the rear of the ground floor. At first, some employees tried to bring the fire under control using portable extinguishers. However, they soon gave up as fire and dense smoke spread very rapidly from the ground floor and also took hold of the upper storeys of the building.

When the fire brigade arrived at the scene, the fire had already reached such proportions that they had to limit their action to protecting the adjacent buildings.

The building, where about 300 employees worked, had several staircases but these were difficult to find, especially for the customers. In addition, the lifts were inoperative due to the failure of the power supply and the combination of these unfavourable factors led to the loss of nine lives.

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[100] *New Civil Engineer,* op. cit., see note 45, 8th June 1989.

[101] *Schaden Spiegel,* op. cit., see note 30, October 1974.

The risk of fire in certain structures, such as grain mills, forms part of their function. Grain mills and silos are essential structures for human food programmes. To guarantee sufficient food supplies for the world's population, the main needs are grain, powdered milk, and oil seed. In order to store and provide these basic substances, harbours and areas with intensive, large-scale grain production are all equipped with silos, trans-shipment terminals, and facilities to store grain for export and import.

Dust explosions in mills and grain elevators occur frequently despite the accumulated knowledge of their cause and devastating effect. In the 1960s and 1970s, for example, the Corn Belt in the United States was frequently the scene of devastating dust explosions. Major incidents then occurred in the harbour at Bremen in 1979 and in the harbour at Metz in 1982, with many fatalities in each case.

One of these explosions happened recently in France.[102] In the harbour area of a small town a mighty dust explosion destroyed the silos used to store wheat, barley and maize. It was not until the dust cloud settled that the rescue teams realized the total extent of the catastrophe:

- 29 of the 44 silos had vanished completely, together with the conveying equipment installed on top;
- The head house, 52 m in height, had buried offices, a grain-loading station, and the packing unit beneath it;
- The maize drier in the rear section was badly damaged;
- The oil and soda containers at a neighbouring tank farm were riddled with holes; and
- Eleven persons died.

The fire brigade, which took only three minutes to arrive on the scene, could do nothing but fight a relatively small fire and make the ruins safe. A close watch was kept on the three remaining parts of the structure so that a timely warning could be given if there was any likelihood of them collapsing.

It was assumed that the explosion originated in the central dust extractor because of its large-scale destruction. Mechanically induced sparks, friction heat or self-ignition could have triggered the event.

The mechanism of such an explosion is well known. Grain seeds rub against each other during transportation and release extremely fine dust. Unlike the grain itself, this organic dust is highly inflammable and can burn so fast that there is an explosion. Such a sudden combustion can only be caused by finely dispersed combustible dust, such as a dust cloud, coming into contact with oxygen in the air and an ignition source, which may be, for instance, an electrical discharge or a hot piece of metal.

The initial explosion usually swirls up further dust clouds, which ignite on the first flame front and release a much larger explosion. The chain reaction continues until such time as there is no dust left.

The energy released in this sudden combustion manifests itself just as suddenly in an expansion of gases. The expanding gases finally produce a shock wave. In this incident, the shock wave was so strong that it was able to pulverise solid concrete, hurl large elements into

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[102] An article by Robert Schmid, Munich, taken from *Schaden Spiegel,* op. cit., see note 30, No. 2, 1999.

the harbour basin, and catapult a car some 50 m through the air. Subsequent explosions led to the collapse of the head house.

Obviously, risk prevention measures are taken very seriously in such structures. In principle, atmospheric oxygen and combustible materials are always present in any silo. Risk prevention therefore primarily involves eliminating ignition sources and limiting combustible grain dust as far as possible, which means, in practical terms, sucking it off.

E.3.1.5

Acts of God in relation to nature of site—topography and surface water run-off

On 9 October 1963, one of the worst reservoir disasters in history, killing nearly 3,000 people, took place when over 240 million cubic metres of hillside slid into the Vaiont Reservoir in Italy.[103] The dam 265.5 m, then the world's highest thin arch, survived.

The dam, completed in 1960, blocks the Vaiont gorge, a mile above its confluence with the Piave, in the Italian Alps, 90 km north of Venice. The disaster was entirely caused by dangerous geological conditions, accentuated by groundwater changes due to the filling of the reservoir.

The area consists of a thick succession of sedimentary rocks, dominantly lime-stone with frequent shaley partings and sequences of thin limestone and marl, ranging in age from Lias (Lower Jurassic) to Senonian (Upper Cretaceous). These strata are folded into a syncline, the valley coinciding with the axis, and the north limb of the syncline (right bank) is cut by a fault bringing Upper Cretaceous against Dogger (Middle Jurassic). Minor faulting and close jointing have created blocky rock masses, and solution cavitation of the limestones has occurred.

Topographically, the reservoir area consists of an outer U-shaped glaciated valley and an inner steep-sided post-glacial gorge. Morainic deposits occur in the outer valley, and on the rock surface of both valleys there are accumulations of talus, slope-wash and old landslide material. Large-scale landslips are common in the Vaiont Valley.

The rocks of the outer valley are affected by an older set of stress-relief joints parallel to the surface, and a younger set occur parallel to the walls of the inner gorge.

The dam itself is built on the Middle Jurassic, which contains some thickly bedded massive limestone.

The events before the disaster were that in 1960 a slide of some one million cubic metres occurred on the left bank of the reservoir near the dam; a pattern of cracks developed upslope from the slide and continued eastwards.

In 1960–1, a 2 km by-pass tunnel was driven under the right wall to enable water from upstream to reach the outlet works of the dam in case of future slides. As a further precaution the top water level (TWL) was limited to 680 m, about 40 m below the dam-crest, and a grid of geodetic stations installed throughout the potential slide area. Drill holes and an adit did not detect a major slide plane, but an analysis after the disaster showed that they were too shallow. Gravitational creep continued to be observed during the 1960–3 period.

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[103] *Case Histories in Engineering Geology,* by J.G.C.Anderson and C.F.Trigg, Elek Science, London, 1976. This case is reported here almost as it appeared in the Dams and Reservoirs section of this book.

During the spring and summer of 1963, scattered observations of the eventual slide area showed an average creep movement of 1 cm per week. About mid-September, numerous geodetic stations were moving at 1 cm a day, but it was believed that only individual blocks were involved, not the whole area.

Heavy rains, beginning about 28 September and continuing until after 9 October, increased groundwater recharge and run-off, and the reservoir TWL rose to 690 m. Early in October, the Mayor of Casso, a town above the right bank, posted a warning to the townspeople. About 8 October, engineers realised that all the geodetic stations were moving on an unstable mass, and on that date they began to lower the water level through two outlet tunnels, although heavy run-off reduced effectiveness.

On 9 October, accelerated movement was reported and in spite of the open gates, the reservoir level rose; movement must by that time have been reducing reservoir capacity.

The disaster occurred late in the evening of 9 October when over 240 million cubic metres of the hillside slid from the left bank into the reservoir in less than 30 seconds. The speed of the mass movement was 15–30.5 metres per second. Over a length of 2 km, the entire reservoir piled up as a vast curving wave for ten seconds. A terrific updraft of air created by the slide and accompanying the wave sucked water and rocks up to about 270 m above reservoir level. Both the blast and the subsequent decompression added to the destruction. The water swept over the dam to a height of some 100 m above its crest. A wave 70 m high over-whelmed Longarone, 1.6 km down the Vaiont Valley from the dam, at the confluence of the Vaiont and Piave. Two kilometres up the latter valley, the wave was still 5 m high, and the main volume swept for many miles downstream. Nearly 3,000 people perished.

Seismic (L waves only) tremors were recorded as far away as Vienna and Brussels. The records showed that these were entirely due to the kinetic energy of the sliding mass and that no tectonic earthquake triggered the movement.

It was established that the Vaiont disaster was caused by a combination of adverse geological conditions (dip slope of tectonically jointed Mesozoic lime-stones affected by later relief joints and inter bedded with weaker shale), change in environment due to the reservoir itself and excessive groundwater recharge from heavy rain. Geological assessment, not only of a dam site, but of a whole reservoir area, should be directed not only to present conditions but to past events (e.g. former sliding in the Vaiont Valley) and to likely future changes. Rock masses in a changed environment can weaken rapidly, particularly once creep (for which there is often surface evidence) gets under way; acceleration to collapse can occur very quickly.

E.3.1.6
Risks associated with natural hazards

Natural hazards are many. By the very function they perform, construction projects are exposed to the effects of natural hazards such as wind, hurricane, typhoon, landslide, earthquake, rainfall and flood. The degree of protection afforded by a particular design to a specific project depends on the probability of occurrence beyond which the project is expected to be unaffected. Where the hazard is of a probability of occurrence lower than that for which the project is designed, damage would be expected to occur. Table 3.4 provides a list of loss to property, which resulted from natural hazards within the period of 1970 to 1980, and shows the extent and the disastrous nature of these hazards.[104]

Since 1980, many natural hazards have occurred, some of which would be more appropriately designated as natural catastrophes. In particular, the more significant of these natural catastrophes with devastating effects include: storms, typhoons, hurricanes, floods, tornadoes and last, but not least, earthquakes. Examples of the latter include the earthquake in Armenia on 7 December 1988, where 25,000 people died and 65,000 were injured; in Kobe, Japan, on 17 January 1994, where 1,000 people died; in Los Angeles in January 1994; in Istanbul, Turkey on 17 August 1999, where 30,000 people lost their lives; and in Gujarat, India, on 26 January 2001, where 100,000 people lost their lives.

It is noteworthy that there seems to be an upward trend in the number and the devastation caused by these natural hazards. The number has increased by a factor of 2.3 when comparing the 1980s with the 1960s; and by a factor of 3.3 when comparing the 1990s with the 1960s. The economic losses suffered have increased by a factor of 2.8 when comparing the 1980s with the 1960s; and by a factor of 8.6 when comparing the 1990s with the 1960s. The insured losses, which form only a small portion of the economic losses, have increased by a factor of 3. 6 when comparing the 1980s with the 1960s; and by the huge factor of 17.0 when comparing the 1990s with the 1960s.[105]

Insured losses form a superior basis for analysis of these natural hazards since they can be established precisely. When the insured losses resulting from a single event pass the significant threshold of US$1 billion, there would usually be a large number of people killed, and even larger number made homeless. A list of insured losses exceeding that threshold is quoted below in Table 3.5 for the years between 1980 and 2001.[106] The figures given represent the original losses recorded without taking into account inflation.

In construction, as explained below, the worst effects occur when natural hazards are combined with standards of construction that are lower than acceptable.

E.3.1.7
When risks of natural hazards are added to human mistakes

The earthquakes in India and Turkey provided examples of such disasters where the number of casualties is usually highest. In Turkey, many buildings collapsed because of 'soft storey' failure after walls in the ground floor were removed to accommodate shop fronts. This reduces the stiffness of the lower floors and weakens the structural resistance to torsion leading to shear failure at the beam to column connection or at the base of the column. Much of the destruction in the nearby Golcuk was through liquefaction, where whole floors disappeared into the ground, since the water table is so close to the ground level that the

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[104] *Reinsurance Principles and Practice,* by Dr Klaus Gerathewohl, Verlag Versicherungs-wirtschaft e. V., Karlsruhe, vol. II, 1982, page 114.

[105] 'Annual Review: Natural Catastrophes 2001', Munich Re Topics 2001, published by the Munich Re Group, Munich, Germany, 9th year 2002, page 15.

[106] The list is reproduced from page 17 of the previous reference marked Copyright to 2002 Munich Re NatCatSERVICE'.

Table 3.4 List of loss to property from natural hazards within the period 1970 to 1980

Date	*Location*	*Approximate overall value of the loss*
May 1970	Earthquake/Chimbote, Peru	US$510m
Aug. 1970	Hurricane Celia	US$450m, of which US$330m is an insurance loss
Oct. 1970	Flood/Northern Italy	US$200m
Feb. 1971	Earthquake/California, USA	US$535m, of which US$50 m is an insurance loss
June 1971	Flood/India	US$530m
June 1972	Hurricane Agnes/east coast of USA	US$3,100m, of which US$100 m is an insurance loss
July 1972	Flood/Philippines	US$35m
Nov. 1972	Winter gale/Lower Saxony/ Central Europe	US$420m, of which US$200 m is an insurance loss
Dec. 1972	Earthquake/Managua, Nicaragua	US$800m, of which US$100m is an insurance loss
Jan. 1973	Lava from the Helgafjell volcano/ Iceland	US$200m
April 1973	Flood/St Louis, USA	US$500m
Jan. 1974	Tornado Wanda, floods/Australia	US$300 m
April 1974	Tornadoes/USA	US$1,000m, of which US$20m is an insurance loss
Sept. 1974	Hurricane Fifi, floods/Honduras	US$500m, of which US$20m is an insurance loss
Dec. 1974	Tornado Tracy	US$500m
Jan.–Aug.1975	Severe rainfalls/Japan	US$400m
Sept./Oct.1975	Typhoons Phyllis, Rita and Cora/Japan	US$360 m
Sept. 1975	Hurricane Eloise/Florida, USA	US$420m
Jan. 1976	Winter gale Capella/Europe	US$1,300m, of which US$500m is an insurance loss
Feb. 1976	Earthquake/ Guatemala	US$1,100m, of which US$55m is an insurance loss
May 1976	Earthquake/Friuli, Italy	US$2,000m
May 1976	Typhoon Pamela/ Guam, Pacific	US$120m, of which US$66m is an insurance loss
March 1977	Earthquake/Rumania	US$800m
June 1978	Earthquake/Japan	US$1,800m, of which US$2m is an insurance loss
Aug. 1979	Hurricane David/ Caribbean and USA	US$2,000 m, of which US$250 m is an insurance loss
Sept. 1979	Hurricane Frederi/USA	US$2,300m, of which US$750m is an insurance loss
May 1980	Volcanic eruption, Mt St Helens/ USA	US$2,700 m, of which US$27 m is an insurance loss
Aug. 1980	Hurricane Allen/ Caribbean and USA	US$1,400 m, of which US$50 m is an insurance loss
Oct. 1980	Earthquake/Algeria	US$3,000m
Nov. 1980	Earthquake/Italy	US$10,000m, of which US$40m is an insurance loss

buildings could be considered as floating. Where buildings were engineered properly, only a small amount of damage occurred.

In the Indian earthquake, poor construction, poor supervision, and lack of adherence to design codes, were at the heart of the disastrous consequences. Eighty percent of Gujarat city

Table 3.5 List of insured losses from natural hazards after 1980 of US$ 1 billion and above

Rank	*Year*	*Event*	*Region*	*Insured losses US$m*	*Economic losses US$m*
27	1983	Hurricane Alicia	USA	1,275	3,000
10	1987	Winter storm	Western Europe	3,100	3,700
6	1989	Hurricane Hugo	Caribbean, USA	4,500	9,000
5	1990	Winter storm Daria	Europe	5,100	6,800
26	1990	Winter storm Herta	Europe	1,300	1,950
15	1990	Winter storm Vivian	Europe	2,100	3,250
25	1990	Winter storm Wiebke	Europe	1,300	2,250
4	1991	Typhoon Mireille	Japan	5,400	10,000
18	1991	Oakland forest fire	USA	1,750	2,000
1	1992	Hurricane Andrew	USA	17,000	30,000
20	1992	Hurricane Iniki	Hawaii	1,650	3,000
19	1993	Snow storm	USA	1,750	5,000
33	1993	Flood	USA	1,000	16,000
2	1994	Earthquake	USA	15,300	44,000
11	1995	Earthquake	Japan	3,000	100,000
29	1995	Hail	USA	1,135	2,000
22	1995	Hurricane Luis	Caribbean	1,500	2,500
16	1995	Hurricane Opal	USA	2,100	3,000
21	1996	Hurricane Fran	USA	1,600	5,200
28	1998	Ice storm	Canada, USA	1,200	2,500
34	1998	Floods	China	1,000	30,000
24	1998	Hail, severe storm	USA	1,350	1,800
7	1998	Hurricane Georges	Caribbean, USA	4,000	10,000
30	1999	Hail storm	Australia	1,100	1,500
23	1999	Tornadoes	USA	1,485	2,000
14	1999	Hurricane Floyd	USA	2,200	4,500
8	1999	Typhoon Bart	Japan	3,500	5,000
13	1999	Winter storm Anatol	Europe	2,350	2,900
3	1999	Winter storm Lothar	Europe	5,900	11,500
12	1999	Winter storm Martin	Europe	2,500	4,000
32	2000	Typhoon Saomai	Japan	1,050	1,500
31	2000	Floods	Great Britain	1,090	1,500
17	2001	Hail, severe storm	USA	1,900	2,500
9	2001	Tropical Storm Allison	USA	3,500	6,000

was reduced to rubble within two minutes. The estimated costs of rebuilding the city are over £3.5 billion.

E.3.1.8
Risks associated with man-made hazards, including political risks

The twentieth century has witnessed great wars and disastrous destruction, as well as very significant progress in science and technology, which has not only increased the quality of human life and the respect for human rights and the freedom of the individual, but also unfortunately permitted the possibility of more sinister atrocities. Acts of terrorism and acts of force against the rights of individuals or of a whole nation are but only two of the hazards that have emerged and face humanity as a whole. Construction artefacts are in particular vulnerable to these two types of risk.

No example of the first of these two risks, terrorism, can be more striking in atrocity than the events that took place on 11 September 2001 in New York, USA. The events are lucidly counted in an insurance publication on these events.[107]

On 11 September 2001, an American Airlines Boeing 767 flew right across the Manhattan peninsula at low altitude, heading southwards. The aircraft had a wingspan of almost 48 m, weighed approximately 180 tonnes, and had 92 passengers and crew on board. The aircraft had taken off in Boston shortly before and was hijacked en route to Los Angeles. At 8:45 it slammed into the North Tower of the World Trade Centre, between the 96th and 103rd floors. A major explosion immediately followed the impact, and the entire building was shrouded in black smoke. The steel columns of the façade were severed over a width of roughly 50 m. The heavy aircraft probably also severed a number of steel columns in the inner core. The aircraft had an almost full complement of fuel, so that over 90,000 litres of kerosene poured into the interior of the building, ran down through the vertical elevator shafts to the storeys below and ignited.

A second Boeing 767, operated by United Airlines, with 65 people on board was also hijacked en route from Boston to Los Angeles. This aircraft approached the World Trade Centre in a long drawn-out curve from the seaward side and struck the South Tower at an angle roughly between the 73rd and 77th floors at 9:03, little more than a quarter of an hour after the first impact. Whether by coincidence or through perfidious planning, the kerosene in the wing tanks was distributed over several storeys by the oblique impact of the 48 m wide aircraft, thus accelerating the fire with fatal consequences. A huge fireball on the outer façade and dense black smoke from the building's interior heralded its imminent demise.

Both towers were now ablaze. Before long, the fire reached temperatures of over 800°C and as much as 1,400°C according to some experts. The fireproof coating of the steel trusses in the core area was designed to withstand at best a local fire, such as burning archives. At temperatures of only 600°C, steel loses around 75% of its strength. Despite their coating, the columns consequently gave way or melted completely.

In the case of the South Tower, the aircraft had struck the building lower down and also severed the columns of the outer façade near one of the edges. Due to the higher load of the thirty-five or so floors above, reputedly around 100,000 Mp, the upper half of the tower initially buckled. Then, at 10:02, almost exactly an hour after the collision, the tower completely collapsed in a huge cloud of dust.

Although the North Tower had been struck first, the aircraft hit the building higher up and the fire raged longer there before the weakened steel columns in the floors finally caved in abruptly. Due to the dynamic force of this sudden failure of the load-bearing structure, the upper storeys hit the undamaged floors below with their full weight. The lower floors were not designed to withstand such loads and likewise collapsed. As a result, the North Tower caved in like a telescope at 10:28, almost an hour and three-quarters after the collision.

The third building to succumb was the 47-storey 7 World Trade Centre on Vesey Street. Severely damaged by flying debris from the twin towers, it collapsed floor by floor, almost in slow motion, at 17:40. Subsequently the other four buildings of the World Trade Centre collapsed one after the other too.

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[107] '11th September 2001', Central division: Corporate Communications, Munchener Rückversicherungs-Gesellschaft, 2001.

It was estimated that up to 50,000 people worked in the two towers every day and that the number of visitors could exceed 100,000 on peak days. The number of parties affected by the attack is therefore high. Those directly affected include, in addition to the owners and lessees of the towers, above all the firms domiciled there: telecommunications companies, banks, insurance companies, brokers, hotels and public authorities. The interruption or even discontinuation of their business activities has led to considerable losses of rental value as well as loss of business income and extra expense.

However, as an indirect consequence, the collapse of the two towers following the outbreak of fire resulted in another fifty buildings being severely damaged or even collapsing in Manhattan, with its dense concentration of high-rise buildings. This is not surprising, considering the dynamic force and energy released during the collapse of the two towers, the resultant pressure waves, and the masses of falling structural components and flying debris that were spread over the district.

The entire area of Lower Manhattan was closed off as a result of the catastrophe. Over 3,000 people lost their lives. Over 150,000 people lost their jobs temporarily or permanently because thousands of smaller businesses and offices were forced to close due to limited access. This in turn led to a breakdown of the entire infrastructure. Bridge and tunnel operators are suffering from the loss of toll fees, whilst subways, ferries and other public transport companies have had to suspend operations, and there are no passengers for the taxis.

The second act of flagrant disregard for human rights is the economic embargo against a whole nation by a certain group in response to the acts of one person or a group of people from that nation. Examples of this type of political risk that affect the maintenance and care taking of all types of construction and engineering projects are beyond the scope of this book, but must be mentioned.

E.3.1.9

Risks associated with fitness for purpose

Although it is unusual, there is always the risk that when a construction project is completed, it is found to be unfit for a specific purpose, either because the purpose was not made clear to the designer prior to the design stage or by virtue of some changes in circumstances.

The latter situation can be illustrated by the example of the sewage sludge incineration plant, which was completed in 1975, but never used and abandoned by the owner.[108] It was found to be too expensive to run and the decision to abandon the project was taken despite the fact that it cost £2.5 million to construct. This risk has assumed particular importance recently since the introduction of standard forms of contract that placed the responsibility for design on the contractor. The new suite of contracts introduced by FIDIC in September 1999 include such contract forms where the level of liability for design is that for fitness for purpose.

E.3.1.10

Risks associated with project operation

Investigations have shown that in mechanical and electrical plant, operational faults form the largest number of incidents causing failure and damage. In combustion engines, 68% of all incidents are attributed to operational faults.[109] In construction projects, due to their nature, operational faults are not as significant as other considerations. However, the following incident is an example of what can happen.

The rain continued to fall in the Brazilian province of São Paulo and, in the forty hours preceding the morning of 21 January 1977, 230 mm fell down in a storm of a probability of occurrence of one in ten thousand.[110] The runoff swelled the Rio Pardo, a tributary of the Rio Grande and exposed four dams to risk. The uppermost dam, Graminha, was saved by opening the gates. The nearby 60 m high earth fill Caconde dam also survived. The release from the Graminha resulted in a rise of 7 m in the flow of the Rio Pardo above its normal level. This flood wave struck the Euclides da Cunha, another 60 m high earth fill dam, 40 km downstream, overtopping its embankment. The flood destroyed about one-third of the dam and filled the machine hall with water, wrecking the generating equipment and so locking the gates in their part-opened position.

The flood wave thus continued its course and struck the lower 41 m high Armando Salles de Oliveira dam, 10 km downstream and destroyed half of its length and the power house. The two dams held 13.6 and 25.4 million cubic metres of water respectively. Further downstream, the flood waters destroyed a small village and inundated several towns. It was reported that 4,000 homes were washed away and the loss was estimated at $40.5 million.

It was understood that the dam operators hesitated over instructions to open the gates of the lower two dams because they were afraid to flood downstream farmland. When failure of the two dams occurred by overtopping, the gates were only part open.

E.3.1.11

Risks associated with wear and tear during the project's designed life span

The life span of materials and components incorporated in construction projects is limited and inversely proportional to the deterioration, wear and tear which take place usually for many reasons; some are natural and others are artificial. To increase the life span, one must reduce the deterioration, wear and tear and increase the durability of the various elements. Such a result could only be achieved by a strict programme of inspection and maintenance.[111]

The risk of lack of or faulty maintenance programme is a grave one and could affect not only the owner of the project but also others involved in its execution. The latter event usually occurs when things go wrong and the liability for any injury or damage is then held to be shared between the owner and others.

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108 *New Civil Engineer,* op. cit., see note 45, 1 January 1976.

109 *Schaden Spiegel,* op. cit., see note 30, No. 2., 1981.

110 *New Civil Engineer,* op. cit., see note 45, 27 January and 3 February 1977.

111 'Guide to the Performance of Building Structures', Institution of Structural Engineers, London, December, 1984.