CONSTRUCTION FAILURES—HAVE WE LEARNED THE LESSONS OF HISTORY?

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Only rarely will we learn from our successes. Even if the failures are ones which we fondly think we would not cause, nevertheless there are likely to be similarities which should cause us to re–examine the work which we are doing.[1]

Disaster is most likely when new designs are based purely on successful precedents and the basic lessons of the past failures are ignored.[2]

INTRODUCTION

Failures of buildings or engineered facilities which involve collapse of structures or result in loss of life (referred to herein as construction failures) are usually scrutinised in a public inquiry such as a Royal Commission or Committee of Inquiry. This paper reviews some past public inquiries into construction failures, and highlights the lessons that, in the author's opinion, still have contemporaneous value in respect of contractual issues that were found to have relevance to the failure.

The theme of this paper is that the lessons to be learned from construction failures are not confined to the technical quality of the engineering and construction, but include the contractual, organisational and managerial aspects of project execution. Unlike most construction disputes which, at their heart, are about money and who pays how much to whom, most of the public inquiries considered here had the further dimension that the construction failure resulted in significant (and sometimes substantial) loss of life. This should be a salutary reminder to construction law practitioners that the engineer's 'art of directing the great sources of power in nature for the use and convenience of man'[3] in every project carries with it attendant execution risks which, if they materialise, can involve significant injury and loss of life.

VALUE OF STUDYING CONSTRUCTION FAILURES

Engineers have long recognised the value of studying past construction failures in order to learn their lessons so as to avoid such failures in the future. In 1856, the President of the Institution of Civil Engineers, Robert Stevenson observed:

Nothing is so instructive to the younger members of the profession as the record of accidents in large works, and the means employed in repairing the damage. A faithful account of those accidents, and of the means by which the consequences were met, is really more valuable than a description of the most successful works. Older engineers have derived their most useful store of experience from the observation of those casualties which have occurred to their own and to other works, and it is most important that they should be faithfully recorded in the archives of the Institution.[4]

The significance of studying construction failures is recognised in the engineering specialty of forensic engineering, and the conferences, journals and books devoted to dissemination of the results of forensic engineering investigations.[5] The importance of studying construction failures and learning the lessons inherent in them is aptly summed up on the Institution of Structural Engineer's website:

The concept of failure is central to understanding engineering, it has as its first and foremost objective the obviation of failure. Design, even structural design, is a human endeavour and thus is subject to error. Due to this, some designs are destined to fail. This can lead to a loss of life which itself is tragic, but a deeper unforgivable tragedy exists when the lessons of failure are understood and allowed to occur again.[6]

Determining the cause is at the heart of every inquiry or dispute about a construction failure, since it is essential to know the cause of failure before the responsibility for the failure can be allocated, and legal liability (if any) determined. The causes of failure have been classified in different ways by different authors. For example, McKaig considers that 'usually buildings fail through men's ignorance, carelessness or greed'.[7] A number of authors have observed that construction failures are frequently not the result of only one cause, but more frequently are the result of a combination of causes. The prevalence of a number of claims and counterclaims in individual construction disputes supports this statement.

It is suggested that the following classification of the primary causes of construction failures is conceptually useful, as it may assist in determining which party (or parties) is causally liable for the failure. Clearly this is not necessarily determinative of legal causation, although this may be apparent in certain cases. The suggested classification of the primary causes of construction failures is:

• unforeseen event caused by an 'act of God' (or terrorist);

• unforeseen failure resulting from inadequate engineering knowledge of structural behaviour or materials;

• failure to prepare an appropriate design;

• failure to construct or use materials in accordance with the design; or

• failure to operate and maintain the facilities in accordance with appropriate requirements.

Apart from the two categories of 'unforseen' failures, the underlying reason for a particular construction failure could be inadvertence because of a failure to take reasonable care, reckless because of a lack of concern for the possible consequences of a course of action, or wilful because of a conscious choice of a course of action, such as failure to comply with regulatory or other normative requirements. Whatever the cause behind a particular construction failure, the project procedures (including the provisions of the contract(s) and the quality assurance procedures) have not averted the failure.

Lack of the required quality in design or construction is usually a major issue in construction failures, and this is typically a 'technical' issue. Failures in the form of collapse always have a 'technical' cause, but the reason for that technical cause may be procedural and/or contractual. This paper focuses on the extent to which non–technical issues contributed to the failures examined, particularly the significance of the relevant contractual provisions.

PUBLIC INQUIRIES AND ROYAL COMMISSIONS INTO FAILURES

These have a number of unique features that make them an especially valuable resource for construction law. Although only conducted for a small number of high–profile failures, inquiry reports are often of far broader significance than their conclusions on the particular failure.

In contrast to the judicial enquiry a judge makes in litigation, a Royal Commission is an administrative enquiry, in which the findings are not binding on individuals. It is suggested that this and the following are some of the significant features of Royal Commissions and public inquiries which contribute substantially to the value of their reports on construction failures:

• often chaired by a judge, retired judge or lawyer who is widely experienced in the conduct of adversarial proceedings and the relevant laws of evidence;

• the Commission may have relevant technical expertise in the form of one or more technically qualified and experienced Commissioners;

• the Terms of Reference enacted by the legislature are subject to public scrutiny and Parliamentary debate;

• the Terms of Reference can be widely drawn to enable the Commission's comprehensive consideration of the relevant issues that resulted in the failure, in contrast to the narrow focus of the parties to a dispute (who are normally only concerned with legal liability as between themselves);

• the findings in a Royal Commission Report provide a comprehensive resource of all the causes of the failure determined, typically with recommendations for remedial measures to avoid similar failures in the future;

• the public nature of such a Royal Commission Report puts pressure on the Government to implement remedial legislation of appropriate measures (or, in some cases, implement prosecutions of persons found to have breached the law).

The practice of holding public inquiries into construction failures has a long history in the common law world. For example, in 1876 the Ohio State legislature appointed a joint committee to investigate the causes of the failure of the iron railroad Ashtabula Bridge that failed after 11 years in service (resulting in over 80 fatalities), in parallel with a coroner's jury which appointed an engineer to investigate the causes of collapse. The bridge failed under the load of a train during a winter snow storm.

The joint committee concluded that the cause of the disaster was fatigue failure in an iron casting that had not been detected because of inadequate inspection. This failure bolstered the call for standard bridge specifications and highlighted the unreliability of iron castings (which were explicitly prohibited in specifications 10 years later).[8]

The United States has formalised investigations of building failures by enactment of the National *Construction Safety Team Act 2002* (USA) (NCST). The stated purpose of the Act is:

... to provide for the establishment of investigative teams to assess building performance and emergency response and evacuation procedures in the wake of any building failure that has resulted in substantial loss of life or that posed the potential for substantial loss of life.

The National Institute of Standards and Technology (NIST) is authorised to establish teams to investigate building failures, with the technical focus of improving the safety and structural integrity of buildings.[9] These investigating teams are modelled after those of the National Transportation Safety Board (NTSB) for investigating transportation accidents.

To date, NIST has conducted two major construction safety investigations under the NCST: a building and fire safety investigation of the 11 September 2001 World Trade Centre fire and building collapses,[10] and a 2003 fire at a nightclub in Rhode Island. It remains to be seen whether NIST will ultimately adopt the broad approach of also considering the impact of nontechnical issues on the causes of failures in the way that the NTSB does for aircraft accidents.[11]

The following case studies derived from the reports of public inquiries are presented to illustrate the way in which they have revealed shortcomings in contracts, procedures and practices in the implementation of construction projects that have been contributing causes of failure.

RONAN POINT APARTMENTS, LONDON (1968)

Failure and inquiry

Ronan Point was a 22 storey tower block of flats in East London that suffered a collapse of one corner of the building following a gas explosion in May 1968. The explosion occurred early in the morning when most of the demolished rooms were unoccupied, however four people were killed.

The structure was typical of many high–rise system built buildings erected in England in the 1960s. The building was constructed from factory prefabricated wall, floor and stairway concrete panels, cast offsite and bolted together on–site. This new method of construction was intended to overcome the shortage of skilled building labour which was constraining the construction of badly needed housing. The system of load bearing walls used at Ronan Point was developed in Denmark for low–rise buildings up to six floors, but was applied virtually without change to multi–storey buildings in England, apparently without further development or design. Neither the building regulations nor the existing UK Codes of Practice specifically contemplated construction of such load bearing multi–storey buildings.

The day after the collapse the Minister of Housing and Local Government appointed a Panel (comprising a QC and two engineers) to conduct a public inquiry into the collapse, under provisions of the Local Government Act. Less than three months after it was appointed the Inquiry reported to the Minister its concern about the possibility of progressive collapse in buildings designed similarly to Ronan Point. The final report, issued five months after the collapse, detailed the immediate causes of the failure, but perhaps more importantly analysed the deficiencies in the design and made recommendations in respect of the assessment of existing buildings as well as for the design of future buildings.[12] The inquiry led to the government implementing measures to avoid similar collapses, including a requirement for buildings with reticulated gas to be able to resist an explosive pressure of 5 psi. Existing buildings had to be able to resist 2.5 psi, provided the gas supply was disconnected.

Progressive collapse

Perhaps the most important aspect of the Inquiry findings (and the reason that Ronan Point is still remembered by structural engineers) was a finding of the importance of guarding against progressive collapse:

The extent of the collapse subsequent to the explosion was inherent in the design of the building. The collapse has exposed a weakness in the design. It is a weakness against which it never occurred to the designers of this building that they should guard. They designed a building which they considered safe for all normal uses; they did not take into account the abnormal. They never addressed their minds to the question of what would happen if for any reason one or more of the load bearing members should fail. ... The designers of Ronan Point were not alone in the attitude they adopted; it is significant that we have not been referred to any English publication which has *drawn attention to the need to think of tall system buildings as civil engineering structures requiring alternate paths to support the load in the event of the failure of a load bearing member. It appears to us that there has been a blind spot among many of those concerned with this type of construction and it would be wrong to place the blame for the failure to appreciate the risk of progressive collapse upon the shoulders of the designers of this building alone. They fell victims, along with others, to the belief that if the building complied with existing building regulations and Codes of Practice it must be deemed to be safe. Experience has shown otherwise'.*[13]

In the years since the collapse of Ronan Point, the importance of design to avoid progressive collapse has been re–emphasised by terrorist attacks which have resulted in the collapse of major buildings such as the World Trade Centre[14] and the Federal Building in Oklahoma. In the Oklahoma Federal Building, whilst only 4% of the building was destroyed by the bomb blast, a further 38% was subsequently destroyed by progressive collapse.[15]

The inquiry concluded that there was no evidence that the design of Ronan Point did not broadly comply with the byelaws and Codes of Practice.[16] However, in subsequent litigation against the designers and constructors, the judge and the Court of Appeal found that the design failed to comply with the relevant Codes of Practice because there was insufficient reinforcing steel at the joints to tie the various units together positively, and the failure to follow those Codes had thus resulted in a breach of the building byelaws.

The designers were found not to have been liable in negligence, but because of the failure to comply with the byelaws, the contractor was liable for the costs of rectification as a consequence of its breach of contract.[17]

It is significant that it was the weakness of these non–complying joints that caused the building to have inadequate resistance to progressive collapse. Thus, although the cause of the collapse was, arguably, inadequate engineering knowledge, it was also contributed to by failure to comply with the contract and normative requirements.

The inquiry stated that it had painstakingly investigated the standards of both workmanship and supervision. Although it identified two cases in which it found that the workmanship fell below the desired standard, it stated:

... in general the standards of workmanship and supervision are satisfactory, and it must be emphatically stated that no deficiency in either workmanship or supervision contributed to or was in any way responsible for, this disaster.

The two cases of unsatisfactory workmanship were related to the design, and concerned the external wall joint to the floor, and tie plates intended to tie the wall panels and floors together. The inquiry found that the design wind pressures used, although complying with the current Code of Practice, were substantially less than could be expected during the 60 year life of the building. It found that Ronan Point :

... has little or no margin of strength if a speed of 105 m.p.h. is reached. We think also that parts of the structure, particularly at the lower H.2 joints in the flank walls, might develop undesirable deformations under the repeated action of less extreme high winds.

THE AFTERMATH

Notwithstanding the strengthening of the building that was carried out in response to the findings of the inquiry, there were continuing concerns over the building's structural integrity, which eventually led to its demolition in 1986.
It was dismantled floor by floor so that the joints could be studied. The architect responsible for investigations during this demolition commented:

I knew we were going to find bad workmanship—what surprised me was the sheer scale of it. Not a single joint was correct. Fixing straps were unattached: levelling nuts were not wound down, causing a significant loading to be transmitted via the bolts: panels were placed on bolts instead of mortar. But the biggest shock of all was the crucial H–2 load bearing joints between floor and wall panels. Some of the joints had less than 50% of the mortar specified.[18]

The finding of such poor workmanship in Ronan Point resulted in many of the remaining tower blocks constructed using the same system being demolished in the 1980s and 1990s. Despite the availability of Building Research Station reports on the assessment of such buildings, some councils apparently did not assess the integrity of all buildings they were responsible for. In 1999 it was found that over 300 such buildings in Birmingham did not meet the 5 psi pressure criterion, and still had a piped gas supply. It has been queried whether the large panel system buildings owned by the London Borough of Southwark have adequate strength to resist a 5 psi explosion.[19]

A team which investigated the Packington Estate in Islington in 2004 warned that it was in real danger of progressive collapse, because appropriate strengthening work was never carried out. The floor slabs had inadequate strength to resist 2.5 psi, and despite replacement of all gas cookers, some residents were still using gas canisters for cooking.[20]

Robustness

Since Ronan Point, the UK and other Building Codes have explicitly addressed the technical need for 'robustness' of structures, i.e. their fundamental property of resistance to disproportionate (progressive) damage. The UK has had a progressive collapse standard since 1968.[21] However, robustness of structures has been a matter of ongoing concern to the Standing Committee on Structural Safety (SCOSS), which considers the regulatory and contractual framework within which decisions on robustness are made to be 'somewhat unsatisfactory'. In a paper delivered to a workshop on robustness held in 2005, SCOSS noted that its concern extended beyond just the physical means of achieving adequate robustness in the design, construction and operation, but included procurement matters. These contractual issues which SCOSS consider relevant are:

- competency of those organisations procured;
- 'best value' tendering;
- clear lines of responsibility and authority;
- clear reporting protocols;
- adequate information for planning and pricing the construction phase;
- adequate specification; and
- inclusion of adequate monitoring procedures (avoidance of self certification approaches).[22]

In addition to relevant factors in procurement, design and construction of a building, SCOSS identifies the importance of subsequent maintenance in ensuring the continuance of robustness, since alteration or refurbishment works have the potential for disturbing it. It is noted that although the Construction (Design and Management) Regulations 1994 (CDM) require a 'health and safety file' to be created, this is focused on personal risk rather than risk to the structure, and although legally required, may not even exist. SCOSS suggests that a building 'logbook' would be worthwhile, but this currently has no legal status or universal acceptance.[23]

HYATT REGENCY HOTEL WALKWAYS, KANSAS CITY (1981)

In 1981 after a year in service, the walkways in the atrium of the Hyatt Regency hotel in Kansas City collapsed when they were packed with spectators watching a dance competition on the floor below. 114 people died, and over 200 were injured. The National Bureau of Standards (now NIST) carried out an investigation into this collapse.[24] The original design for the walkways' hanging supports was found to be capable of carrying only 60% of the required load under the relevant building code, and only just able to support the dead load. A detail change to the connections of the hanging rods to the support beams made by the steel fabricator during construction doubled the load on the supporting fourth floor walkways, making failure inevitable under full load. The significance of this change was not picked up by the designers.

The investigators of the collapse concluded that the basic problem was a lack of communication between the designers and the steel fabricators. In particular, the sketch drawings prepared by the designers were taken as final drawings by the fabricators.

The designers accepted the fabricator's detail change (which was implemented to overcome an impractical detail) without carrying out basic calculations which would have revealed the doubling of load on the fourth floor support beams.[25] Shepherd lists the following non technical lessons learned from this tragedy:

Clearly, there is a need for all parties to understand their responsibilities and to perform their assignments competently. The structural engineer's responsibility for overall structural integrity, including the performance of the connections, was firmly established in this case. This failure also lends credibility to the practices of project peer review and constructability review.[26]

The designers were convicted of gross negligence, misconduct and unprofessional conduct, and lost their engineer's licenses. At least $140 million was paid out to victims and their families in compensation.

L'AMBIENCE PLAZA, CONNECTICUT (1987)

The structural frame and slabs of what was to be a 16 storey apartment building collapsed during lift slab construction, killing 28 construction workers. An investigation into the failure was conducted by the Centre for Building Technology for the Occupational Health and Safety Administration (OSHA). Several technical factors in the design and construction were identified as contributing to this catastrophe. In addition, it was considered that the convoluted and fragmented project delivery system also contributed, as responsibility for ultimate structural safety was confused by unclear relationships among the engineer of record, the lift slab contractor and the designer of the shear heads.[27] One significant outcome of this failure was a change in the law relating to the method of construction known as the 'lift slab' technique.[28]

It is interesting to note that alternative dispute resolution was used to resolve all pending litigation following the collapse within 20 months of the disaster, a process that involved five judicial bodies, more than 44 plaintiffs, approximately 40 potential defendants, several government agencies, and nearly 200 attorneys.[29] The settlement techniques used in resolving these disputes are discussed by Schwarzer *et al*.[30] One result of the somewhat controversial early settlement was that the various theories on causes of the failures were discussed thoroughly in the engineering literature sooner than is typically the case.[31]

BURNABY SUPERMARKET PARKING DECK, BRITISH COLOMBIA (1988)

Part of a rooftop parking deck of a one story regional community centre collapsed on opening day. The Government appointed a Commissioner to investigate the failure, and his report detailed the probable technical cause of the collapse and also reviewed the many procedural deficiencies that allowed a design deficiency to cause failure.[32] The numerous contributing procedural and contractual problems identified included:

- competitive bidding for design services;
- unclear assignment of responsibilities;
- inadequate involvement of designers during the construction phase;
- poorly monitored changes during construction;
- incomplete peer review; and
- inadequate professional liability insurance.

The Commissioner's report contained 19 recommendations to avoid similar failures in future, including:

- independent project peer review funded by increased permit fees;
- special examinations for structural engineers and mandatory professional liability insurance;
- the development of a manual that would clarify the responsibility of all parties in the construction process; and
- a minimum fee schedule for design services.[33]

Similar recommendations on the desirability of independent peer review have been made in response to other failures. For example, the collapse of a hotel building in Singapore in 1986 resulting in 33 deaths, led to a legislative requirement for all building works to be reviewed by an 'accredited checker'.

The efficacy of this approach to preventing avoidable failures was, however, put in question by the collapse of the roof of a building under construction in 1999, killing seven workers. The engineer and accredited checker were fined the maximum for their breaches of the legislation.[34]

DE LA CONCORDE OVERPASS, QUEBEC (2006)

The inquiry in Canada into the collapse of the de la Concorde overpass illustrates the principles behind, and the public benefits that can come from an inquiry established to determine the truth and to make recommendations to avoid a repetition of future failures. The de la Concorde was a pre–stressed concrete bridge over Autoroute 19 in the province of Quebec, built in the early 1970s, and designed and constructed generally in accordance with the standards prevailing at that time. In 2006 a span collapsed under light traffic load, killing five people.

The Government of Quebec established a Commission of Inquiry, comprising an attorney as President, and two engineers as Commissioners. The Commission conducted its inquiry in accordance with the principles defined by the Canadian Supreme Court.[35] The Commission concluded that, whilst there were a number of defects and shortcomings, both technical and procedural, none of those by itself would have caused the collapse which resulted from a chain of causes.[36]

The technical reason for failure of the overpass was a shear failure in a reinforced concrete cantilever slab, the concrete of which had deteriorated over the years. The reinforcement design satisfied the code requirements at the time, but would not do so now, nor would the detailing of the reinforcement be regarded as satisfactory today. The weakness of the detail was due to errors in placement of the reinforcement (a quality–control failure during construction), and low quality concrete that was not suitable to resist freeze–thaw cycles (arising from ambiguity in the specification). There were further contributing causes that the thick slab was not watertight (the specified waterproof membrane had apparently not been installed either originally or during subsequent refurbishment), and refurbishment work in 1992 caused damage that was not evaluated. In respect of procedural failures, the Commission identified the following:

- failure of the consulting engineer for not fulfilling its contractual obligation to exercise full–time supervision of the construction of the overpass, and thereby not preventing the faulty installation of the reinforcement that resulted in the structure not complying with the drawings and specifications;

• failure of the contractor to meet its legal contractual obligations;

• failure of the principal subcontractor to adequately the control the quality of the work and thereby incorrectly install the reinforcement;

• the Ministry responsible did not rigorously and effectively use all the means at its disposal to properly evaluate the condition of the overpass despite numerous signs of deterioration, and did not maintain adequate records for the guidance of inspectors and maintenance workers.[37]

The Commission recommended that the Government review the legal framework for the design, construction and construction supervision of all new structures and for major rehabilitation work along the following lines:

• use a transparent process for selecting consulting engineers based on competency and past performance, with cost only considered for those firms meeting the competence criteria;

• validation of the concept, drawings and calculations of structural designs by a responsible engineer;

• prequalification of contractors on the basis of their ability for the type of structure to be built, with cost only considered for contractors meeting the competence criteria;

• when awarding contracts for consulting engineering or construction, ensure that the key personnel on which prequalification was based will be available for the duration of the work;

• subcontracting requirements be identified in bids, and contractors required to produce a work quality control plan for their own and subcontract work;

• on completion, an engineer certify that the structure was built in accordance with drawings and specifications and all the documents associated with the work and structure be assembled and kept during the entire life of the structure to assist with inspection and maintenance programs; and

• owners of structures evaluate the performance of consulting engineering firms and contractors on completion of a project, and the evaluations be kept on record.[38]

The Commission made far reaching recommendations not only on the organisation and responsibilities of the Ministry, but also on the investment needed by the Province of Quebec to rehabilitate its bridges to a satisfactory standard, comparable with other provinces and the USA. The Commission considered that annual investment of $500 million would be required for each of the next 10 years to bring the percentage of bridges in good condition from the 2005 level of slightly more than 50% to an acceptable 80%.[39]

CONCLUSION

The details of the failures discussed above, and as revealed by the reports of the public inquiries that ensued, highlight many issues relevant to the contracts and the execution of those contracts. In each case the direct 'technical' causes of failure were accompanied by contractual and project execution deficiencies that did not prevent or detect the onset of disaster before it was too late. No doubt all of the disasters discussed above had their genesis in human failings, generally and perhaps invariably in a combination of individual failures. Whilst no contract or procedure can prevent human error, it is suggested that clearly expressed agreements in which people are expected to function in known, logical and acceptable ways are at least a good starting point.

In some cases discussed above the lessons have apparently been well learned because of the remedial measures subsequently implemented to avoid a repetition of the same type of failure. However, it is submitted that some of the causes of past failures revealed by public inquiries are still operative today, and reconsideration of such lessons from the past may assist in avoiding future failures from similar causes.

The importance of history was stated long ago by Cicero:

History is the witness that testifies to the passing of time; it illumines reality, vitalizes memory, provides guidance in daily life and brings us tidings of antiquity.[40]

Has the importance of history really changed in the last 2000 years?

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