Above: Quebec Bridge, Canada

Contractual lessons from construction failures: part one

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This article reviews the lessons that can be derived from the failures of several large bridges during construction. One of these failures – that in respect of the Quebec Bridge – occurred more than a century ago, and the more recent failures – those of the West Gate Bridge in Melbourne and the Milford Haven Bridge in Wales – occurred within living memory. The first part of this article concerns the Quebec Bridge collapses; the second part, to be included in our March 2009 edition, will examine the West Gate and Milford Haven collapses and the lessons which can be learned from these collapses for construction law and its practice today.

Introduction

Collapses of buildings or structures almost inevitably generate disputes between the project participants. In addition, there is usually a substantial public interest dimension in such failures, particularly if death or injury results. The government response to significant failures is usually swift, and often takes the form of a public inquiry. The terms of reference of such public inquiries typically include determining the causes of the failure, and recommendations to avoid similar failures in the future. The reports of these inquiries are therefore much wider in scope than any report of the litigation between disputing parties involved in the failure, and form a valuable repository of lessons to be learned and guidance for improved practice in the future.

The lessons learned from the reports into the failures of the Quebec, West Gate and Milford Haven bridges are not only timeless, but are still relevant today and are ignored or forgotten at our peril. While these failures had a predominantly 'technical' cause in respect of inadequacies in the quality of design and/or construction, the focus of this article is on the contractual and procedural aspects of project execution (particularly time, cost and scope of work), and the extent to which these may have been contributing factors to the collapse.

The deaths resulting from these and other failures are, therefore, a salutary reminder that failure to implement the appropriate contractual procedures and execute the works in compliance with the requirements of the contract can have much more serious consequences than a dispute over which party is liable to pay damages.

Quebec Bridge, Canada (1907)

The Quebec railway bridge over the St Lawrence River is known for two separate failures which occurred during construction, the first in 1907 and the second in 1916, with the tragic death of 86 workers. After the first collapse, the Canadian Government immediately implemented a Royal Commission which reported on the cause, as well as the contractual matrix within which it was procured. The Commission of three civil engineers produced a very succinct five-page report, supported by 19 detailed appendices and 37 drawings. This report (the title of which is set out at the end of this article) has been studied by generations of engineers for its engineering lessons and is the source for the following comments.

The Quebec Bridge is a steel bridge of cantilever construction, the main span of 548 metres being the longest of this bridge type ever built. It was procured by the Quebec Bridge and Railway Company ('QBRC'), a company specifically incorporated in 1887 to finance, build and operate a toll bridge. Although the government passed appropriate enabling legislation, for a period of 13 years the company was unable to raise the necessary finance. The company's finances were only assured through government support in 1903.

Procurement of the bridge

Notwithstanding its precarious financial position, the company called lump sum design and construct tenders for the bridge on minimal documentation in September 1898, with a six-month tender period. The tender documents included a clearance diagram and specifications for a cantilever bridge with a main span of 488 metres (1,600 feet). Mr Theodore Cooper, an eminent American consulting bridge engineer, assessed the tenders submitted by four companies, and reported that the tender of the Phoenix Bridge Company (Phoenix) was the 'best and cheapest'. He advised, however, that further site investigation was necessary before letting a contract, and there should be provision for changing the specification in any contract that was entered into. Phoenix was not at that stage prepared to enter into a contract because of QBRC's weak financial position.

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Once favourable legislation was in prospect, QBRC awarded the contract for the main spans to Phoenix by an initial, brief agreement in April 1900. Phoenix executed the agreement on the understanding that it was not to become operative until the necessary legislation was enacted and satisfactory financial arrangements for payment had been made. However, it did agree to proceed with the design and drawings once formal approval of the government engineers had been obtained. In the event, only limited design work was undertaken before execution of the final contract in 1903. The initial agreement provided, not for a lump sum as tendered, but for the supply and erection of steel at a price per pound, apparently the result of Phoenix's tender qualification that its lump sum price was subject to modification for changes in specifications. Many such changes were subsequently made because of the insufficiency of the original plans and the preliminary work done by the QBRC.

After further site investigations and borings, Cooper recommended that the span be increased to 548 metres (1,800 feet), and an increase made in the allowable stresses in the steel, significantly above those in common use at the time. While the government engineers had to give their approval to these changes, it appears they had full confidence in Cooper and did not make any changes to his specification proposals, or interfere with

his technical control at any time. Some of that confidence may have been misplaced through a misunderstanding that Cooper would be engaged continuously on the work during construction, whereas Cooper did not actually have any responsibility for the critical erection phase.

Criticism of design and construct procurement

The Commission criticised the QBRC, a company of weak financial standing, for calling design and construct tenders on a general specification. For this large bridge at the limits of established practice, the Commission clearly preferred the traditional route of tendering for construction of a fully developed design prepared by engineers who had made a proper and thorough study of the whole project. It noted that most of the tenders submitted were prepared from immature studies based on insufficient data, including a faulty estimate of the weight of the structure in the successful Phoenix tender.

The contract

The final contract document consisting of 16 Articles of agreement was executed in June 1903. By today's standards this was a remarkably brief document for such a major project. Phoenix agreed to construct, deliver and erect the bridge to the satisfaction and acceptance of Cooper and the QBRC engineer. The contract provided for withholding ten per cent from progress payments until CAN$100,000 had been withheld together with security of CAN$100,000. As further security for proper performance by Phoenix, all of the plant and equipment was the property of QBRC until completion of the works. There was no requirement for insurance, but Phoenix was required to restore at its own cost all or any part of the work damaged or destroyed before its acceptance. Any variation not only required written authorisation by the engineer but approval of the QBRC board of directors!

Phoenix provisionally accepted the contract, subject to additional conditions precedent that the necessary legislation had to be in place, as well as satisfactory arrangements for payment. Phoenix did not guarantee completion by the specified date, but it did agree to pay CAN$5,000 per month in liquidated damages if the work was not completed by 31 December 1908. In February 1904, Phoenix advised that the conditions precedent were satisfied, and no further changes were made to the contractual arrangements. The Commission stated that there was nothing in the various contracts and agreements between QBRC and Phoenix that had a direct connection with the cause of the collapse. Nor was there any inappropriate action by the government, which maintained all its dealings exclusively with QBRC, which in turn was the only one who dealt with Phoenix.

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Cost issues

Notwithstanding the financial difficulties of QBRC and its view that design and construct was not the best method of procurement, the Commission did not consider that undue pressure on costs had any bearing on the ultimate failure. Cooper, although he clearly did not overlook costs, made his recommendations for technical reasons, and was not subject to pressure from QBRC. It is also apparent that letting the contract on a fixed price per pound of steel provided no incentive to the contractor to reduce the steel weight. Cooper's specification decisions on design loading and higher stresses than normal were no doubt made with the objective of achieving the best economy he believed was consistent with safe practice. The Commission considered that was an error of judgment, and did not take advantage of QBRC's improved financial situation.

Notwithstanding the Commission's view that undue pressure on costs did not have any bearing on the failure, it is difficult to avoid the conclusion that cost cutting in respect of the engagement of the consulting engineer had an adverse impact on the level of scrutiny to which the contractor's design was subject, and that this had an indirect bearing on the collapse. The Commission made trenchant comments about the consequences of the inadequate remuneration Cooper received for his services, which did not enable him to engage sufficient assistants or to spend sufficient time to investigate and detect the errors in the design prepared by Phoenix. Although

made 100 years ago, these comments have a timeless quality to them.

Engineering

Cooper was the engineer who approved all the designs emanating from Phoenix, and the chief engineer of QBRC was responsible for all other technical decisions. Cooper was only concerned with the bridge in its final constructed configuration, and had no involvement with the engineering for erection. He disclaimed any responsibility for inspection in the shop or in the field, and made no site inspections during construction. Although he assumed many of the duties of the chief engineer, he was not authorised to act in this capacity: his directions were advisory and not imperative.

The government was keen for the bridge to open in 1908, which the Commission considered was one factor which led to Phoenix hurrying the work of design and manufacture and resulting in errors. Phoenix made a significant error in not recalculating the dead weight of the bridge when it commenced the final design in 1903, after the three-year hiatus since its tender was accepted. Both QBRC and Phoenix overlooked this necessity in the rush to complete the final design, with the result that the bridge members would have been considerably overstressed after completion, an error sufficient to have condemned the bridge had it not collapsed owing to other causes. This error could have been detected had the time between 1900 and 1903 been used to prepare the design. The significance of the finding that the bridge would have been overstressed in service had it not collapsed during construction should not be overlooked. As with the much later West Gate Bridge failure in Melbourne (discussed in the forthcoming part two of this article), the tragic collapse during construction averted completion of a bridge which would not have been safe in service.

Cooper did not carry out any independent check on the dead load, and was not aware of the error until February 1906. At this time, a substantial part of the bridge had already been constructed, and Cooper permitted the work to proceed, believing that the increase in stresses were still within the limit of safety. The significance of this error in the calculated dead load was compounded by the high allowable stresses permitted, and the fact that the dead load stresses constituted approximately two-thirds of the stress in the main members.

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The Commission carried out its own studies and tests on the strength of latticed compression members of the type used, and concluded that the bridge collapsed because the secondary lattice members in the main compression members were too weak to carry the stresses to which they were subjected. The design of the latticed compression members did not breach any specific provisions of the specification. However, at that time there was no established theory for the design of such members. The design was based on the judgment of Phoenix's engineer, which in this case was erroneous. It could, however, have been checked by testing. Although considerable theoretical work on the design of large compression members was carried out after the Quebec Bridge, testing of major compression members was still regarded as prudent in structures designed in the 1920s such as the Sydney Harbour Bridge.

Erection

Although the Commission considered that the Phoenix erection staff was efficient, well trained and experienced, it did not have an experienced engineer on site responsible for erection. The Commission was also critical of the inadequate staffing of QBRC, and did not consider that the chief engineer was technically competent to direct the work on site.

There were warning signs of significant deformations in major structural members shortly before the collapse, but there was no engineer with the appropriate experience, knowledge and ability in charge of the site in a position to take decisive action. This lack of clarity in the engineering decision-making in QBRC was the subject of severe criticism by the Commission and the unquestioning reliance on Cooper was found to be a significant factor in the ultimate failure.

The Commission's conclusions

In the view of the Commission, and an engineer engaged by QBRC after the collapse to review the design, the failure was caused by an error of engineering judgment in respect of the design of the main compression members, on the part of both the contractor's design engineer and Cooper. Cooper's specifications for allowable stresses were unsatisfactory, and a grave calculation error was made in underestimating the dead load. Experimental studies and investigations that would have confirmed the design were not made. QBRC made a mistake in not appointing an experienced bridge engineer to the position of chief engineer, although the selection of Cooper and the confidence placed in him was warranted.

Lessons from Quebec Bridge

Based on the issues highlighted above, the following are some of the contractual and project execution lessons relevant to major engineering projects to be learned from the Royal Commission Report, and which, it is submitted, are still relevant to major projects today:

- the difficulties and time involved in raising finance for a project should not prevent sufficient time allowance for the preparation of initial studies, the design, tender documentation or for the execution of the works;
- unquestioning reliance on the skill and experience of an individual engineer may be misplaced without adequate peer review;
- a project owner requires adequately qualified and experienced technical staff with the appropriate authority for both the design and erection phases, even if it procures its project via a design and construct contract;
- the engineering design of a major project should be reviewed by an independent engineer, without reference to the designer's calculations;
- the scope of the engineer's engagement should include responsibility for both design and erection, with compensation commensurate with the proper execution of that scope;
- an owner with limited financial resources may be subject to cost pressures that result in inappropriate engineering decisions;
- the construction contractor needs to have an appropriately qualified and experienced erection engineer on site with an understanding of the design and full authority for the erection; and
- appropriate allowances should be made for the additional risks inherent in unusual structures or structures of a scale not attempted before, and this may require testing of components.

The full titles of the reports referred to in parts one and two of this article are as follows:

- Canada, Royal Commission Quebec Bridge Inquiry, *Report* (1908)
- Victoria, West Gate Bridge Royal Commission, *Report of Royal Commission into the failure of Westgate Bridge* (1971)
- Great Britain, Department of the Environment, Committee on Steel Box Girder Bridges, *Inquiry into the Basis of Design and Method of Erection of Steel-Box Girder Bridges: Interim Report* (1971)
- Great Britain, Department of the Environment, Committee on Steel Box Girder Bridges, *Inquiry into the Basis of Design and Method of Erection of Steel-Box Girder Bridges: Report of the Committee* (1973).

Donald E Charrett is a member of the Victorian Bar. This paper is based on two of the author's previously published papers: 'Lessons from Failures – Quebec Bridge' (2008) 119 Australian Construction Law Newsletter 14 and 'Lessons from Failures – West Gate Bridge' (2008) 30 Building Dispute Practitioners' Society News 4.