SECTION II

Causes of the Collapse

The evidence before this Commission is clear that the waterproofing of the roof failed virtually from the outset. The logical course of action would have been to undertake early and effective remedial measures to protect a valuable asset. Successive owners neglected to do so, and the consequences of that neglect were tragic.

CHAPTER 3

Causes of the Collapse

Overview: A rusted weld lost its strength

On June 23, 2012, at 2:18 p.m., a portion of the parking deck level of the Algo Mall collapsed into the retail space below. Following the collapse, the Ontario Provincial Police (OPP) began a criminal investigation and retained NORR Limited (NORR) to carry out a forensic investigation into the cause.[1] NORR is a multidisciplinary firm composed of architects, engineers, and planners.

The NORR team was asked to provide a picture of the condition of the Mall before and at the time of the collapse. In its final report, NORR also commented on the previous reports and inspections that had been carried out by various engineering firms throughout the life of the building. This chapter will not look at its findings and opinions on the adequacy of those inspections and reports but, rather, will consider the conclusions it arrived at in its determination of the cause of the collapse. The Commission did not retain its own expert to determine the cause of the collapse.

In order to fulfill its mandate, NORR assembled a team of in-house professionals which included the following experts:

- Hassan Saffarini, P. Eng., PhD, structural engineer and team leader;[2]
- Michael de Raaf, master of applied science, structural engineer;
- Christopher Hughes,[3] bachelor of environmental studies, member of the Royal Architectural Institute of Canada, member of the Ontario Association of Architects, architect and building envelope specialist; and
- Christopher Pal, P. Eng., electromechanical engineer.

NORR also retained external experts in concrete, metallurgy, and corrosion: Pouria Ghods[4] of Giatec Scientific Inc. (Giatec), Aaron Dinovitzer[5] of BMT Fleet Technology (BMT), together with the National Research Council of Canada (NRC).

In addition to preparing an extensive report, four of the experts involved in the investigation testified as a group before the Commission to explain their findings.[6] During their testimony, these experts, who will be referred to at various points in the Report as the NORR Panel, also addressed the alternative theories advanced by some of the other Participants. The members of the NORR team were accepted by the Commission as highly qualified professionals and experts in their respective fields (engineering and architecture). None of the other Participants challenged their expertise.

As part of their investigation, some of the members of the NORR team visited the site of the collapse between July 21 and July 29, 2012. By the time they arrived, the area of the collapse had been partially cleared and demolished during the rescue operations to facilitate access to the two victims and to secure and stabilize the building. The NORR team did not participate or assist in the demolition.[7]

To help illustrate the events of the collapse, the NORR team produced an animated video, which was shown during the hearings. The narrative heard on the video provided the following account:

> The Mall was beset with a chronic leaking problem from the day it opened. This went unabated due to the lack of a proper continuous waterproofing membrane at the parking level. Every owner addressed the leakage problem by attempting to seal and reseal cracks where leakage was observed. Water leaked onto the structural steel, carrying with it the de-icing salt that accelerated corrosion rates to levels only found in marine environments. Corrosion progressed likely since the Mall was built, until there was so little material left in one particular connection that it could no longer support the weight of the parking deck. On June 23, 2012, failure occurred in this steel connection which is located just below the deck

> opposite the roof top hotel entrance. Without support, the concrete panels collapsed into the upper mall adjacent to the food court. The impact of the hollow core panels killed two people and caused a second connection failure in a steel beam supporting the pre-cast panels of the upper mall. A portion of the upper mall framing then collapsed into the ground level. The failure initiated in the welded connection between two steel angles and a column. By the time of failure, it is estimated that more than 85% of the original weld capacity of the failed connection had been lost to corrosion.[8]

Description of the collapse

In its final report, dated March 8, 2013, NORR described how the collapse occurred:

> On June 23, 2012 a portion of the parking deck level of the Algo Centre Mall collapsed into the retail space below. The collapse initiated due to a failure of a beam to column connection supporting the parking deck HCS [hollow core slab]. The steel framing for the extent of the area affected by the collapse at the parking deck level is provided in Figure 3-1. The connection which failed consisted of two steel angles bolted to the web of the W24x110 beam running along gridline16 and welded to the flange of the column at gridline intersection G-16. The failure occurred in the welded connection between the steel angles and the flange of the column.[9]

NORR also provided two diagrams of the failed beam-to-column connection and the location where the failure occurred (see figures 1.3.1 and 1.3.2).

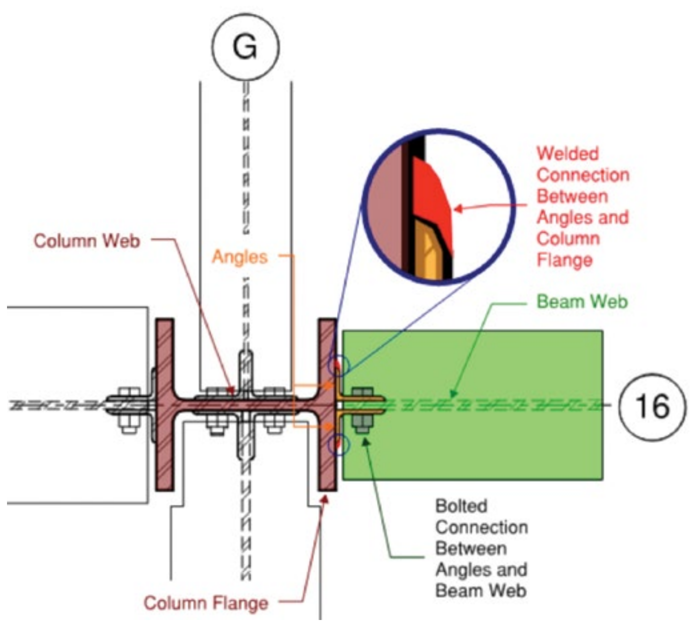

Figure 1.3.1 Plan detail of the beam-to-column connection where the initial failure occurred

Source Exhibit 3007

The actual failed connection, which was ultimately tested and examined by BMT, had been removed from the site before the arrival of the NORR team. It had been stored at the police station in an environmentally controlled location.[10]

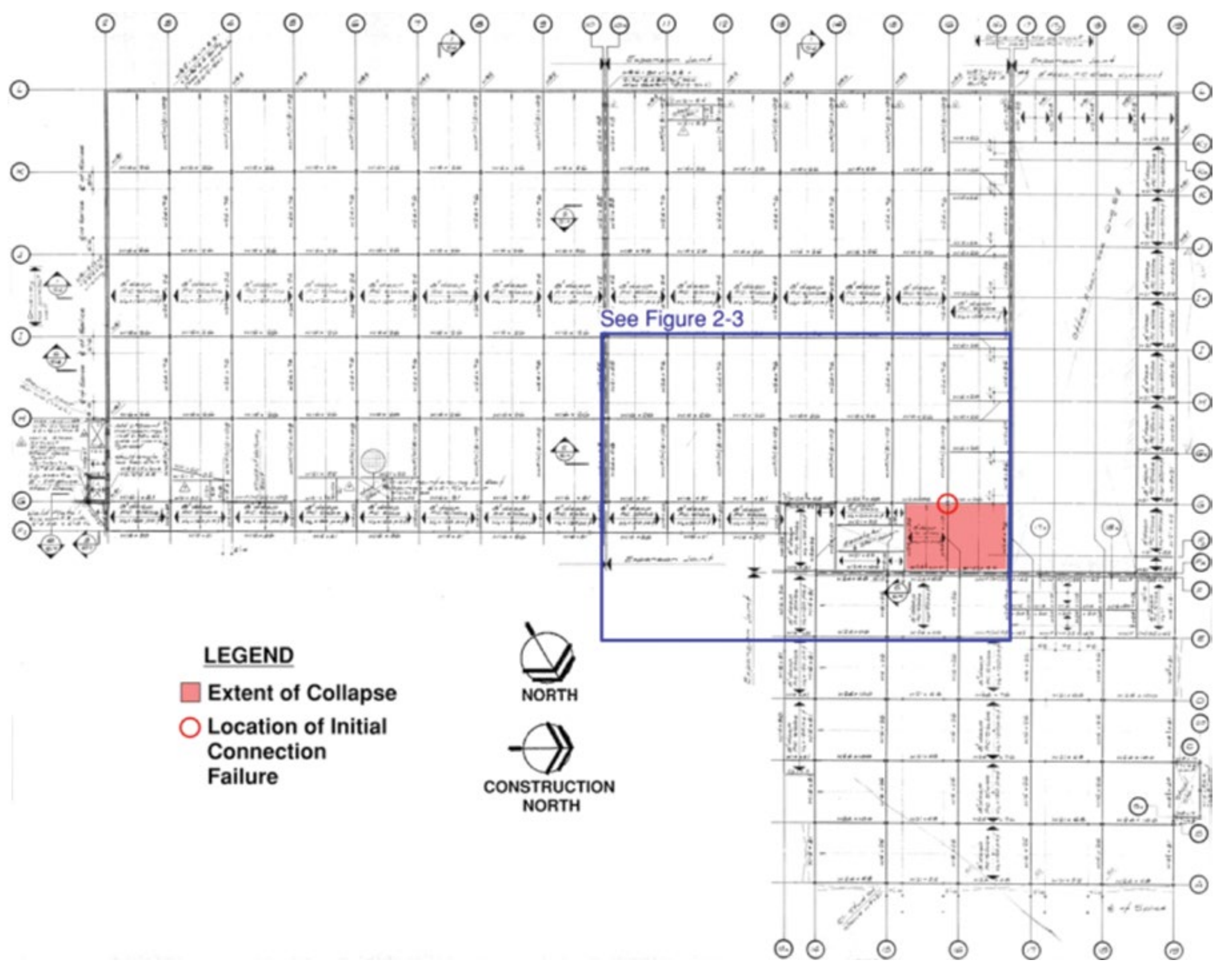

Figure 1.3.2 Roof parking level framing plan (identifying area of collapse)

Source Exhibit 3007

The design of the Algo Mall met the requirements of the 1975 Ontario *Building Code*[11]

NORR identified two key shortcomings and a number of design deficiencies

During its investigation, NORR reviewed the original drawings that had been prepared and used during the construction of the Algo Mall, as well as a number of other documents that had been preserved and maintained over the years in the files of the first owner, Algocen Realty Corporation (Algocen). The history of the construction of the Mall is outlined and reviewed extensively in Chapter 4, 1979–85: Construction and Early Years.

In its review of the original design and construction of the Mall, the NORR team identified two key shortcomings: the first was "the placement of a parking lot on the roof of a mall without providing sound waterproofing"; the second was the "structural insufficiency of the hollow core slabs" used in the construction of the deck of the parking deck.[12]

NORR also identified deficiencies in the design and construction of the rooftop parking, including

- lack of detail of the roof drains in the drawings;
- specifying the installation of what appeared to be custom-built expansion joints, which would have to rely on "perfect performance from sealants";
- a slope in the roof which was so low that, if designed today, its intent would likely be to retain water for prolonged periods; not surprisingly, photographic evidence showed standing water present on the roof;
- the presence of expansion joints that compounded the effect of the low slope of the roof; and
- flashing detail around the base of the hotel walls which ignored the fact that the roof was doubling as a parking lot; the flashing was too low on the wall, and the lower wall was not adequately protected against vehicular impact or snow and ice buildup.[13]

The design prepared by the engineer, John Kadlec, met the requirements of the 1975 Ontario *Building Code*

The structural drawings and the steel specifications were prepared by the structural engineer, John Kadlec of Beta Engineering. NORR reviewed Mr. Kadlec's work and found that the structural drawings showed a "level of preparation, information and details" that appeared to "reflect the industry standards at the time of their production."[14] NORR also concluded that the specified superimposed "live" and "dead" load of 120 pounds per square foot (psf) on the drawings for the rooftop and the interior appeared to be in general conformity with the 1975 Ontario *Building Code*.[15]

NORR also undertook a close examination of the steel beam that fell in the collapse. It determined that the beam had the necessary capacity to resist the loads specified in the drawings, though there were some design deficiencies in the beam due to "an apparent assumption by Beta Engineering of uniform loading[,] which was not the case."[16] The beam was found to be carrying approximately 13 percent more weight than it was designed for, resulting in a reduction in the margin of safety typically assumed by design codes. NORR determined, however, that this diminished factor of safety had no bearing on the final collapse.[17] It confirmed, despite these design deficiencies, that the beam involved in the collapse did not fail. Rather, what triggered the collapse was the failure of the beam's connection to the column.[18]

In brief, NORR concluded that the design of the beam that collapsed was sufficient and that the design of the structural steel did not contribute to the collapse.[19]

The original as-built condition of the welds in the Mall met and exceeded the requirements in the specifications

In conducting its inspection and analysis, the NORR team considered whether the original welds had been deficient and could have contributed or led to the collapse. The shop drawings for most of the steel framing, including the failed connection, were not available for review by NORR or by the Commission. NORR therefore looked at similar connections in the Mall which were not corroded in order to gain insight into what would have been their original as-built condition.[20]

NORR was able to locate a connection in the Mall that showed almost no signs of corrosion (the "reference weld").[21] Although this connection was significantly larger than the one that failed, the NORR team determined that it could use it for comparison purposes.[22] Mr. Dinovitzer of BMT was responsible for determining the likely as-built condition of the way the steel angle had been welded to the column of the failed connection.

The BMT report,[23] which is an appendix to the final NORR report, outlined both the process followed to compare the welds and the indicators used to determine the likely as-built condition in 1979–80 of the failed weld. The BMT report contains complex and detailed information on the process and the comparisons undertaken in this attempt. It explained that, during the welding process, the heat required to weld the metals together creates a heat-affected zone that can be seen through metallographic examination.[24] The contours of the heat-affected zones (also described as a "halo" in the BMT report) were used to determine the geometry (shape and size) of the original weld (see figure 1.3.3).

By comparing what would have been the geometry of the original weld to the other connections in the Mall, NORR determined that it was more than likely that the failed weld had been constructed in a manner similar to the reference weld (see figure 1.3.4).

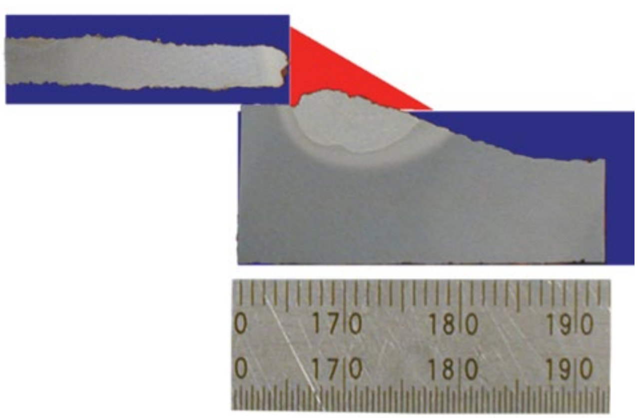

Figure 1.3.3 Metallographic examination showing geometry of the weld at the time of failure, and red triangular background to illustrate the nominal weld size considered to have been used at the time of original construction

Source Exhibit 3015

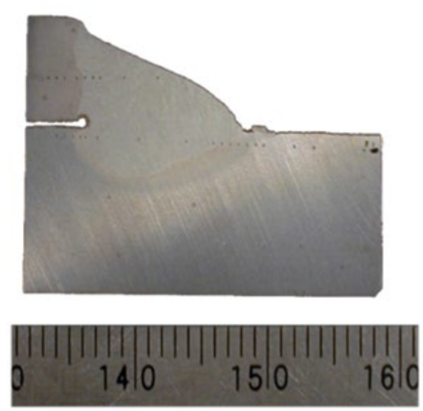

Figure 1.3.4 Reference weld used to determine nominal weld size at the time of original construction

Source Exhibit 3015

BMT concluded that the weld of the failed connection in its original state would likely have been consistent with the Code requirements at the time of construction.[25] It found that, compared with today's standards, the original weld was generous and would have been using only 60 percent of the capacity for which it was designed. In other words, it was stronger than what had been specified, so there was a higher margin of safety. If the weld had not been corroded, there would have been no issue of its capacity.[26]

In light of the testing and analysis performed by NORR, its conclusions on the likely as-built condition of the weld, and its finding that the "as-built nominal capacity" of the weld "was significantly higher than that specified by design simply as a result of generous weld geometry by the original installer,"[27] I find that the connections and welds in the Mall, including the weld at the failed connection, had likely been properly constructed at the time of original construction.

Despite the shortcomings identified by NORR, the hollow core slabs did not contribute directly to the collapse

The building was constructed with steel beams, columns, and pre-stressed precast hollow core concrete slabs that rested on the beams and served as the floor and roof of the parking deck. The engineer specified in the structural drawings that the hollow core slabs should be 8 inches thick and capable of carrying a superimposed load of 120 psf without a composite topping. In its report, NORR stated that this size was insufficient. Dr. Saffarini testified that the supplier, Coreslab, could have advised the engineer during the design stage that it would not be able to achieve the requirements of the specifications with the size of slab identified in the drawings. It could have suggested an alternative, such as supplying a 10-inch slab or adding a composite topping to the 8-inch slab.[28]

NORR reviewed the load tables published by Coreslab, which indicated that an 8-inch slab with a 31-foot span could not support 120 psf. NORR concluded that, in order to achieve the design requirements, a properly bonded concrete topping was required; without this topping, the hollow core slabs installed on the rooftop parking deck would have been structurally insufficient.[29] The analysis and findings of NORR on the structural sufficiency of the hollow core slabs are explored in greater detail in Chapter 4, 1979–85: Construction and Early Years.

The compressive strength of the hollow core slabs was tested and found to have met or exceeded the specified values they were designed for. The same test was conducted on the concrete topping, and its strength was also found to be above the design specifications. NORR had no issues with the strength of the concrete used in the construction of the Algo Centre.[30]

Although the concrete (both the slabs and the topping) met or exceeded the specifications, the concrete topping was found to have been extensively contaminated with chloride, presumably from the use of de-icing salts in the winter months. The chloride concentration in the concrete samples was well above the level where corrosion would begin in the steel mesh inside the concrete.[31]

Despite NORR's conclusion that the hollow core slabs were structurally insufficient, the team nevertheless concluded that the inadequacy of the hollow core slabs did not contribute directly to the collapse. Rather, their limited capacity had an indirect effect by improperly skewing the early attempts to stop the leaks and the corrosion that ultimately led to the collapse.[32]

During the Inquiry, it quickly became clear that the structural capacity of the precast slabs was a distraction and an excuse during the life of the Mall. All the Mall owners used the uncertainty about the capacity of the slabs to justify and rationalize their failure to take any meaningful steps to fix the leaks.

The design of the proposed waterproofing for the rooftop parking of the Algo Mall narrowly met the requirements of the 1975 Ontario *Building Code*[33]

As early as August 1981, leaks were discovered along gridline 16, in front of the escalator, over the beam that ultimately collapsed. This leak was the first documented evidence at the Inquiry of a problem at this location, and continuing leaks there caused the corrosion of the weld that led to the collapse.[34]

NORR examined the building envelope design (the waterproofing) of the Algo Mall to determine if it complied with the 1975 Ontario *Building Code*. At that time the Code was not explicit in describing the type of waterproofing system which would be acceptable for an occupied building. It required only that roofing be installed to shed or drain water effectively. In NORR's opinion, that result was not achieved.[35] Mr. Hughes, the architect on the NORR team, testified that it was his responsibility to examine the condition of the concrete roof and the building envelope. While focusing on the specific location of the collapse and the rooftop parking deck, he had looked at three main components on the roof: the condition of the concrete, the various attempts to seal the cracks, and the condition of the drains and expansion joints installed there.[36]

As early as August 1981, leaks were discovered along gridline 16, in front of the escalator, over the beam that ultimately collapsed. This leak was the first documented evidence at the Inquiry of a problem at this location, and continuing leaks there caused the corrosion of the weld that led to the collapse.

The roof deck parking of the Mall had been designed as a flat roof. Mr. Hughes testified that flat roofs can be designed to have water sit on them, providing that the roof is waterproof. He noted that the roof of the Algo Mall was supposed to drain water as quickly as possible, but in fact that did not appear to have happened.[37]

Mr. Hughes reviewed the architectural drawings to determine if the design was compliant with the Ontario *Building Code* requirements. He noted that the details were not consistently shown throughout the drawings. There was no indication, for instance, of what the "waterproofing sealer" was to be. The requirement in the 1975 Code simply provided that "a roof should shed or drain water effectively." The first question therefore became whether the waterproofing sealer was actively shedding or draining water effectively. Mr. Hughes testified that, because the building was known to be leaking from the day it opened, it was fair to state that the waterproofing sealant had never functioned properly.

The second question was whether the architectural drawings complied with the *Building Code*. Mr. Hughes testified that, in the most narrow sense, he would have to say that the design did comply, but only inasmuch as the architect was relying entirely on the material – the waterproofing sealer – to act as a waterproofing membrane.[38] Mr. Hughes noted that the sealer did not shed water effectively, even though the design assumed that it would do so. Mr. Hughes concluded that the design narrowly met the expectations of the Code, but only in principle.[39]

Mr. Hughes explained that the decision on whether the architectural design was in compliance with the Ontario *Building Code* would have been made at the building permit review stage, when the drawings were submitted in order to obtain the building permit. After this stage, if the materials do not perform as anticipated by the design, the issue becomes one of warranty and maintenance.[40] NORR, and in particular Mr. Hughes, concluded that, notwithstanding the noted deficiencies or shortcomings in the design of the roof, the design could still be said to "narrowly meet the requirements of Part 4 of the OBC (1975) but relies entirely upon the 'WATERPROOFING SEALER' material."[41]

In the end, I am of the view that no plausible evidence was presented at the Inquiry leading me to conclude that the design and construction of the Algo Mall (excluding the application of the waterproofing system on the rooftop parking) was the direct cause of the collapse. Dr. Saffarini confirmed this same conclusion in his testimony when he indicated that NORR did not believe that the design had contributed to the actual collapse of the parking deck.[42]

It was abundantly clear from the evidence, however, that although the "design" of the waterproofing system met the requirement of the Ontario *Building Code* "in principle," it never achieved the intended performance of the design. The application of the system enabled water and chlorides to leak into the interior space of the Mall. These leaks, which were allowed to continue unabated, caused the corrosion that led to the collapse.

Corrosion at the Algo Mall

The Mall had extensive corrosion throughout and would have required retrofitting in order to remain operational

The NORR team investigated the extent of corrosion at the Mall. Dr. Saffarini testified that the inspection of the steel was conducted over three days, when the team collected and tested samples of rust materials and corrosion product.[43]

One of the purposes of investigating the general state of the corrosion at the Mall was to determine whether the failed connection was an isolated instance. Was it only the failed connection that, for some combination of reasons, had suffered the level of corrosion observed, or was it a more widespread type of corrosion that was affecting the entire Mall or substantial parts of it?[44]

In order to obtain a fair representation of the state of corrosion at the Mall, NORR first did a visual inspection of the steel in 45 randomly selected locations, without the advantage of tools to actually scrape off the corrosion product. This process was designed to mimic someone doing a visual inspection without tools. In addition to this initial inspection, Dr. Ghods of Giatec inspected those same locations using a more detailed method to determine loss of section.[45]

During the Inquiry, the term "loss of section" was often used. NORR explained that this term describes what occurs when corrosion results in a reduction of the original steel material, which in turn leads to a decrease in the thickness of the material itself (be it the web, flange, bolt, weld, connection angle, or some other part). The reduction in the thickness of the material is deemed a loss of section that will affect the load-carrying capacity of the structure.[46]

As a point of reference, NORR opted to use the Ontario Structure Inspection Manual (OSIM), the standard used by the Ministry of Transportation, to evaluate the level of corrosion found in the Mall. Dr. Saffarini noted that, because there is no standard or guideline in Ontario for evaluating the level of corrosion in buildings and civil structures, they turned to this manual. Although the OSIM is generic and primarily intended for highway structures and bridges, it nevertheless provided a yardstick for classifying the corrosion observed at the Mall.[47]

Dr. Saffarini explained that the OSIM classifies corrosion into four conditions. For the purposes of the Algo Mall investigation, NORR grouped the classifications into three conditions:

- The first two, "excellent" and "good," were classified as "good," which included those areas which had surface rust only or were found to be completely unaffected.
- The second classification was "medium" or "fair," which included conditions where some level of corrosion had progressed, and there was some section loss calculated at 10 percent or less.
- The third classification was "severe," which included conditions where the corrosion had resulted in more than 10 percent of section loss. At more than 20 percent of section loss, NORR classified loss as "very severe," but for the purposes of the Algo Mall inspection, "severe" and "very severe" were lumped together into one classification.[48]

Dr. Saffarini explained in his testimony that a condition noted as "fair" would mean that the inspecting engineer would have to raise an alarm and advise the owner to monitor the situation, but nothing would need to be done immediately to make repairs or reinforcement.[49]

In order to obtain the measurements of the loss of section, Dr. Ghods testified that he first cleaned the corroded steel down to shiny metal and used a digital caliper to measure the remaining section. The difference between the remaining section and the original size of the section being measured, which was obtained from the design specification, provided the basis for calculating the percentage of loss of section. Dr. Ghods explained that he conducted a detailed condition assessment of approximately 20 out of the 45 locations that had been selected for visual inspections.[50]

Dr. Ghods explained that, following the completion of his detailed assessment, he found that the top flange of the beams was generally in a worse condition than the bottom flange. This result was not surprising, given that the top flange had greater exposure to the leakage of chloride-contaminated water. He also found that the beams were slightly worse than the columns. The welds and other components of the connection in more than 40 percent of the locations inspected had severe to very severe corrosion. NORR deemed the general condition of the structure of the Mall to be poor. Corrosion was a widespread issue that affected significantly more than the connection that ultimately failed.[51]

NORR identified a number of other locations within the Mall which exhibited signs of very severe corrosion. The team considered them to be critical locations that cried out for immediate repairs to the structural members or connections.[52] NORR explained that signs of moderate to severe and very severe corrosion of the beams and connections were found in two locations selected at random: one of them showed no signs of leakage before the suspended ceiling tiles at gridline C-14 were removed; at the other, at gridline B-12, no indications or reports of problematic leakage had been received in the past.[53]

In areas such as the Dollarama Store at gridline C between gridlines 17 and 18, where there were obvious signs of previous water leakage, the inspectors noted severe corrosion of the beam as soon as the ceiling tiles were removed. In this location they found that the fireproofing had fallen off the underside of the bottom flange and a portion of the web, and they observed several layers of corrosion product and scaling on the beam. After they removed the corrosion product and measured this beam, they found that the remaining metal had an 18 percent loss of section in its flanges. An inspection of the connections of this beam revealed a similar level of corrosion in the steel angles and welds.[54]

Figure 1.3.5 Severely corroded connection at the pedestrian walkway located at gridline E-13x

Source Exhibit 3007

In addition to the interior of the Mall, the NORR team also inspected the pedestrian walkways located at the exterior perimeter. After removing the exterior cladding, the inspectors found some of the most severe corrosion there. In its report, NORR stated: "Beam flanges and stiffeners were reduced to almost nothing in some locations and more penetrations were uncovered through members."[55] The team's concerns were demonstrably and starkly illustrated by a significant number of photographs presented during the Inquiry showing the condition of the Mall. Any neutral observer of such egregious deterioration must be troubled by its logical implications. It speaks of glaring inattention, neglect, and lack of proper maintenance by the owners of the Mall during its lifetime (see figure 1.3.5).

NORR noted in its report that the team had no difficulty during its inspection at the Algo Mall in finding signs of very severe corrosion. Team members observed corrosion in the majority of locations inspected, though the degree of corrosion varied from location to location. NORR determined that a number of critical areas would have required immediate attention.[56]

The rate of progression of corrosion at the Mall was similar to that found in the ballast tank of a ship

Mr. Dinovitzer of BMT estimated that the corrosion of the structural steel in the Mall had progressed at a rate of 0.1 mm/year – a rate he said was similar to that found in a "marine environment" where moisture and chlorides are also present.[57] He testified that he used this term to try to convey the difference between a building-structure environment (which is typically dry, without the presence of chloride) and the Mall environment, which was humid and wet with moisture containing a lot of chloride. This type of environment would enhance or accelerate corrosion. When asked, he confirmed that he did not mean that the conditions were as though the Mall had been underwater in the ocean.[58]

In his testimony, Mr. Dinovitzer expanded on this comment and explained that the level of corrosion noted at the Algo Mall is uncommon in a building structure. He stated that it was difficult to find statistics on rates of corrosion for enclosed buildings, so he had turned to an industry that recorded such information – in particular, the Tanker Structure Cooperative Forum, an organization that conducts research related to ships and offshore structures. In looking at its data, Mr. Dinovitzer found that the estimated corrosion rates at the Algo Mall were similar to those observed in a ship's ballast tank, where water and chlorine are present in quantity. He testified that the chemical analysis performed on the corrosion products had found that abundant chloride was present, presumably from the de-icing salts used on the roof and also dripping from cars. As previously noted, chloride had also been observed in the concrete as well. Mr. Dinovitzer said that leaking made the Mall a humid environment. If the Algo Mall had been a dry environment, as might be expected for a building, the corrosion rate found there would have been much less.[59]

In measuring the corrosion rate at the Mall, Mr. Dinovitzer assumed that the components were uniformly subjected to corrosion. No evidence was presented to dispute or discredit this assumption. During cross-examination, Mr. Dinovitzer acknowledged that there would have been events during the life of the Mall that would have accelerated or decreased the rate of corrosion. The NORR team, however, was not able to identify any specific moment or event that would have influenced the rate of corrosion. I accept the team's conclusion that it was reasonable, based on the information and data before it, to use the assumption that the rate of corrosion was uniform over the course of the years.

The assumption that the components were uniformly subjected to corrosion also took into account the evidence that, at the time of construction, the structural components were coated. Mr. Dinovitzer expected that this coating would have played a role in delaying the onset of corrosion, and he determined, based on factors enumerated in the BMT report, that, during the first five years of the life of the Algo Mall, the coating on the components did assist in resisting corrosion.[60]

On the day of the collapse, the weld of the failed connection was so depleted by the effects of corrosion that it could no longer support half its design load

NORR stated that the constant wetting and drying, combined with the presence of chlorides, led to the corrosion of the steel framing and the failed connection. Over time, these conditions weakened the connection to a point where it could no longer support the weight of the parking deck, resulting in the failure of the welded connection. The end of the beam, along with the overlying hollow core slab of the parking deck level, then collapsed into the upper level of the Mall. The impact of the hollow core panels initiated a secondary collapse of a portion of the upper-level Mall framing.[61]

Although BMT assisted Giatec and NORR in estimating the rate of corrosion at the Mall, its main focus was the connection detail that was suspected of precipitating the collapse.[62] BMT was provided with the section of the column flange of the failed connection as well as with its beam and bolted angles. The separation of the connection occurred at the welds joining the two angles to the column flange (see figure 1.3.6).

Figure 1.3.6a Column flange of failed connection

Source Exhibit 3015

Figure 1.3.6b Top view of the failed beam connection showing that the angle and bolted connection were severely corroded

Source Exhibit 3015

NORR determined that the weld suffered a "two-stage" failure, likely separated by several months, but probably not by several years. Two elements were significant in determining how the collapse occurred: the presence of pitting and black oxide in the surface of the failed connection. This combination indicated that the initial failure had occurred along a portion of the weld some months before the final separation.[63]

The metal loss in the assembled weld connection suggested that a significant amount of material was lost because the corrosion process continued after the weld fracture. BMT noted in its report that the last piece of the connection to fail was the upper end (corner) of the angle section. The conclusion that the collapse occurred as a result of a two-stage failure was supported by several factors, including the evidence of rotation (or prying) of the remaining corner piece of the angle section from the column flange and the absence of corrosion pits on the failure surface of the corner of the angle section which had been pried away from the column flange.[64]

When members of the NORR team examined the angle of the failed connection, they noted that a small triangular piece of the angle had remained on the column face. By examining the material under a microscope, they were able to observe that the angle was pried off the flange, suggesting that the angle section fracture was the last element of the connection's failure.[65]

Mr. Dinovitzer explained that, if one takes a piece of material and pulls on it in an effort to break it, the first thing to happen before it breaks is that the micro-structures of the material will deform. When he examined the material under a microscope, he was able to see that the steel grains were deformed. This "plastic deformation," as it is known technically, indicated to him that the material had been stretched. He looked at the other failure surfaces next and noted that there were no signs of stretching. That difference suggested that the corrosion on these surfaces had consumed or absorbed the little bit of stretching that would have occurred at the fracture surface at the time of the initial failure. On this and other evidence, NORR determined that there had been a two-stage failure of the connection.[66]

BMT also carried out microscopic examination of the path of the fracture in an attempt to identify the mode of failure as well as the contributing factors. During the course of this examination, BMT was able to make the following observations:

- The failure of the surface on the column flange was entirely within the weld.
- Pits along the failure surface suggested that this surface had been exposed to a corrosive environment for a significant period of time; in addition, corrosion deposits were seen in the pits.
- The failure surface revealed no observable grain deformation, indicating that there had been no stretching or pulling of the metal and therefore no rotation or prying of the metal before the failure (other than the deformation referenced above).
- The failure surface of the welded connection on the beam did not display weld metal; that fact, together with the first point above, meant that the fracture path followed the weld fusion line – the border between the weld metal and the base material at the angle.[67]

On close examination of the failed connection, then, NORR determined that no weld metal had been left between the angle and the column flange. They were separated. The corrosion had progressed to a state where it had eaten away the entire weld. Corrosion had similarly caused a very significant amount of reduction in the weld in another location.

Mr. Dinovitzer testified that they could see that the angle was corroding from both sides, though the weld was corroding predominantly from one side. They also observed that the fracture (or failure) surface at the end of the angle had pitting, which meant that it had been exposed to the environment for a significant period of time.[68] BMT noted that the connection detail that failed had experienced a significant level of corrosion degradation, thereby reducing its load-carrying capacity.[69]

Figure 1.3.7 Face of the column flange at gridline G-16 and the beam and angle that were connected to the column flange before failure

Source Exhibit 3007

From NORR's perspective, the cause and mechanism of the collapse were evident. The connection of the beam to column G16, on gridline 16 between gridline Fx and G, failed in shear because of the loss of section of the weld. NORR specifically noted: "In fact the remaining weld after years of corrosion is so small that justification for the ability of the beam to support its own and the concrete above was subject of further testing and analysis." The condition of the column flange and the steel angles at the beam end as they existed at the time of the collapse is depicted in figure 1.3.7.

NORR determined that the force applied to the connection at the time of failure was approximately 50 percent of the design factor load. The team concluded that, on the day of the collapse, the welded connection was depleted to the extent that the car seen driving in the video footage over the area in the seconds before the collapse was the proverbial "straw that broke the camel's back." The connection could no longer carry any more weight, and the remaining weld sheared, leading to the immediate and sudden collapse. NORR determined that the portion of the weld which remained in place immediately before the collapse had only 13 percent of its original capacity.[70]

Dimitri Yakimov, an Algo Mall employee, had observed movement – rocking and clunking – of the precast panels in 2009 in the area of the ultimate collapse. I accept that evidence. I also accept NORR's findings that the observations made by Mr. Yakimov were likely not a sign that the first failure occurred in 2009, but rather that the two-stage failure identified by NORR was separated by a period of months, not years. Mr. Yakimov's evidence and the apparent lack of remedial action* was further evidence of the failure by the owners and by the engineers retained by them to investigate properly the concerns brought to their attention during the life of the building.

* Engineer Robert Wood of M.R. Wright and Associates testified that, although he was taken to the area by Mr. Yakimov, he observed no such rocking or clunking sounds as cars passed over the area. Even if he had witnessed such an occurrence, he stated, it would not have been unusual: Wood testimony, June 6, 2013, pp. 13327–8.

The actions of the owners contributed to the collapse

The attempts to repair the leaks never worked

The parking deck was constructed with a 3-inch concrete topping above the precast hollow core panels. Over the years, this deck was described as having several visible cracks that corresponded to joint locations between the precast panels immediately below the topping. It is clear, as I explain below, that salt-laden water entered the interior space of the Mall through the parking deck. The witnesses were consistent in their evidence that, throughout the life of the Mall, the favoured method of repair was to apply sealant to the cracks in an attempt to stop the entry of water into the retail space below. The NORR team members confirmed that they saw evidence of this practice. Following their review of photographs as well as the history of reports and correspondence, they concluded that the crack-sealant methods used by the various owners over the years did not prevent the infiltration of water through the parking deck.[71]

No evidence was provided to the Commission to show that the practice of sealing cracks was an effective means of stopping the leaks. At best, it stopped some leaks for a finite (usually short) period. The witnesses testifying on behalf of the Mall's second owner, Retirement Living, and its counsel, through re-examination and cross-examination, attempted to convince the Commission that its methods of sealing were more effective at stopping the leaks than those used by the first owner, Algocen, and the third owner, Eastwood Mall Inc. However, ample evidence was presented to the contrary. The documentary and oral evidence presented satisfies me that the Mall continued to leak unabated during Retirement Living's ownership, supporting the conclusion reached by NORR that the crack-sealant methods employed by *all* the owners over the years were inadequate to prevent water infiltration through the parking deck. I accept NORR's conclusion on this issue.

Retirement Living could have saved the Mall by installing a membrane

Dr. Saffarini stated that, on the basis of the information obtained by NORR, if Retirement Living had installed a membrane and asphalt wearing course on the rooftop parking deck when it purchased the Algo Mall, the leaks would have stopped. He was also comfortable in expressing the opinion that, despite a degree of uncertainty relating to the condition of the Mall at the time of purchase, if the leaks and the resulting corrosion had been stopped in 1999, the structure likely would have endured without any strengthening being required.[72] I accept this conclusion.

Eastwood Mall would have had to do more: Install a membrane *and* strengthen the steel

Dr. Saffarini testified that the building would have reached a point (before the collapse) where, even with the application of a waterproof membrane and asphalt wearing course, some retrofitting / strengthening of the structure would have been required. He could not point to an exact time when this threshold would have been reached; however, he postulated that the threshold had been attained sometime in the early 2000s. Based on his evidence, it would appear that, even if a waterproof membrane and asphalt wearing course had been applied on the rooftop parking of the Algo Mall in the early 2000s, the owner – NorDev or Eastwood Mall – would have also been required to undertake some retrofitting / strengthening of the structure in order to address the depleted capacity.[73]

No other plausible theories were presented to explain the cause of the collapse

Mr. Wood, the last engineer to inspect the Mall before its collapse, explored alternative theories to explain the cause of the collapse. Although these alternative theories were suggested through cross-examination by his counsel, no requests were made on his behalf for leave to enter additional expert reports in support of his positions. Some of these theories were put to the NORR Panel during its testimony.

Dr. Saffarini testified that the NORR team sought to determine if there were other possible causes or contributing factors to the collapse and the failure of the beam:

> We considered or we reflected on any possibilities – as we have said, in terms of looking at the design and any contributing factors. The fact that in this particular case, as I have said yesterday, it was very evident that the connection was completely deteriorated, that the capacity that remained in the connection was so low – it was not very difficult to correlate the cause of the collapse with that diminishing strength of that connection, pointed us in this direction, but we nevertheless explored the strength and design capacity and so on, of all of the members.[74]

The column did not buckle before the collapse

Counsel for Mr. Wood pointed out that, in one of the photographs presented by NORR, the column to which the collapsed beam had been attached appeared to be buckled. Dr. Saffarini explained that what was seen in the photograph was not evidence that the column had buckled. Rather, during the demolition that followed the collapse, the column had been bent as it was torn out of the building.[75]

The "clunking" noticed by Mr. Yakimov was not a result of an early partial failure of the connection

During its investigation, NORR looked at whether the reports by Mr. Yakimov in 2009 of the rooftop panels rocking as cars passed over the area of the eventual collapse could have been an indication of a partial collapse at that time. It found that a number of reasons could explain the movement and clunking noises observed by Mr. Yakimov and ultimately concluded that an early partial failure of the connection from the corrosion was the least likely explanation for the phenomenon.

It was more likely that the noise and movement was a result of an uneven bearing of the precast panels, caused by the deterioration of the Masonite bearing pads placed between the panels and the steel beams at the time of construction. These bearing pads are used to ensure that the hollow core slabs are sitting properly on the beam, with no gaps between the bottom of the slab and the top flange of the steel beam. The entry of water through the rooftop parking would have deteriorated the Masonite (a hardboard that is not waterproof), resulting in the hollow core slabs not sitting evenly on the beams. This irregularity would have led to the movement and noise observed by Mr. Yakimov.[76]

The collapse at the Algo Centre Mall was not a progressive collapse

Counsel for Mr. Wood, through cross-examination of a number of witnesses, suggested that the collapse was a "progressive collapse" – a result of the hollow core slab not having been properly restrained at the time of construction. He explored this theory during the evidence given by the NORR Panel. Dr. Saffarini, answering on behalf of the panel, dismissed this theory in its entirety:

> I think the collapse that did occur was not a progressive collapse, in the sense that it did not expand beyond the failure of the connection. And the failure below is a direct impact of the failing panels onto the upper mall panels and directly failing them. A progressive collapse would be where there is a loss of – say, a column that led to a loss of a group of members, which eventually led to a wave of loss of adjacent columns and more members, where the entire structural or substantial part of the structure would have failed. But in this particular case, this is localized – and the only progress in it is the actual impact of the dropped panels into the upper mall.[77]

The freeze–thaw cycles experienced at the Algo Mall did not cause the collapse

Dr. Saffarini testified that he disagreed with the suggestion made during cross-examination by counsel for Mr. Wood that the freeze–thaw cycle or the variation in temperatures had any role in the deterioration of the hollow core slabs. He explained that the cycle of temperature changes would have an effect on the stresses and forces in the structure (both the steel and the concrete), but that this cycle was not something that the NORR team considered to be key or of significance in the collapse.[78]

Dr. Saffarini disagreed with the further proposition suggested in cross-examination by Mr. Wood's counsel that the change in the design, which saw the placement of the insulation underneath the hollow core slabs as opposed to on top, contributed to the collapse. Counsel for Mr. Wood suggested that this change placed the slabs outside the building envelope and caused or contributed to the collapse by putting the structural steel below the slabs under stress at various times during the course of the year. However, Dr. Saffarini testified that the impact of temperature on the precast slabs and on the steel was not significant in terms of determining the cause of the collapse.[79]

Conclusions

A section of the Algo Mall collapsed as a result of a failed connection. The connection at gridline G-16 did not fail because of a construction defect. It failed because of exposure over the years to constant wetting and drying conditions in the presence of chlorides, which leaked from the rooftop parking deck unabated for more than 30 years. I am content with the findings made by NORR: I agree that the collapse occurred because the weld connecting the angle to the column had become so depleted from corrosion that it was no longer able to hold even half its designed load.

The design of the roof deck parking was permitted by, and met the requirements of, the 1975 Ontario *Building Code*. NORR's evidence was to that effect: individually, the various design elements that made up the structure of the Algo Mall – specifically, the structural steel, the hollow core slabs, and the waterproofing system – all met those requirements.

A section of the Algo Mall collapsed as a result of a failed connection. The connection at gridline G-16 did not fail because of a construction defect. It failed because of exposure over the years to constant wetting and drying conditions in the presence of chlorides, which leaked from the rooftop parking deck unabated for more than 30 years.

However, the waterproofing system was never able to provide a watertight roof to the Mall. Clearly, the roof was far from ideal, considering the climatic conditions in Elliot Lake. It was also costly and difficult to repair and maintain. This factor operated as a powerful disincentive to the owners to take any meaningful steps to remedy the constantly leaking roof.

Those design inadequacies (including, in particular, the lack of a waterproof membrane as part of the original design or as a later addition), and an unwillingness to address leakage in a meaningful way, led inevitably to the exceptional corrosion that precipitated the collapse.

The evidence before this Commission is clear that the waterproofing of the roof failed virtually from the outset. The logical course of action would have been to undertake early and effective remedial measures to protect a valuable asset. Successive owners neglected to do so, and the consequences of that neglect were tragic.

The evidence presented to the Commission showed that the materials that made up the waterproofing system failed very early on, if not immediately. When the first owner, Algocen, saw that the system was not meeting the design intent, it could have taken the next logical step of replacing the entire waterproofing system in order to stop the leaks and protect its asset. None of the owners of the Mall took any real steps to stop the leaks, as the cost to do so would have jeopardized their bottom line.

Notes

1 Exhibit 3007, p. 278.
2 Exhibit 5157.
3 Exhibit 5156.
4 Exhibit 5155.
5 Exhibit 5154.
6 On May 29 and 30, 2013, Dr. Hassan Saffarini and Christopher Hughes of NORR, together with Dr. Pouria Ghods from Giatec and Aaron Dinovitzer of BMT, testified as a panel of experts before the Commission.
7 NORR Panel testimony (Saffarini), May 29, 2013, pp. 12187–8.
8 Exhibit 3141.
9 Exhibit 3007, p. 333.
10 NORR Panel testimony (Saffarini), May 29, 2013, p. 12188.
11 O Reg 925/75.
12 Exhibit 3007, p. 279.
13 Exhibit 3007, pp. 348–52.
14 Exhibit 3007, p. 356.
15 Exhibit 3007, p. 358.
16 Exhibit 3007, p. 281.
17 Exhibit 3007, p. 363.
18 Exhibit 3007, p. 362.
19 NORR Panel testimony (Saffarini), May 29, 2013, pp. 12249–50.
20 Exhibit 3007, p. 363.
21 Exhibit 3011, p. 705.
22 Exhibit 3007, p. 363.
23 Exhibit 3015.
24 Exhibit 3015, p. 174.
25 Exhibit 3007, p. 363; Exhibit 3015, pp. 173–80; NORR Panel testimony (Dinovitzer), May 29, 2013, pp. 12295–6.
26 NORR Panel testimony (Saffarini), May 29, 2013, pp. 12250–1.
27 Exhibit 3007, p. 411.
28 NORR Panel testimony (Saffarini), May 29, 2013, pp. 12252–3.
29 Exhibit 3007, p. 279.
30 NORR Panel testimony (Ghods), May 29, 2013, p. 12313.
31 NORR Panel testimony (Ghods), May 29, 2013, pp. 12313–14.
32 Exhibit 3007, p. 325.
33 O Reg 925/75.
34 Exhibit 3007, p. 300; Exhibit 541.
35 Exhibit 3007, pp. 281–2.
36 NORR Panel testimony (Hughes), May 29, 2013, p. 12214.
37 NORR Panel testimony (Hughes), May 29, 2013, pp. 12227–9.
38 NORR Panel testimony (Hughes), May 29, 2013, pp. 12236–42.
39 NORR Panel testimony (Hughes), May 29, 2013, p. 12243.
40 NORR Panel testimony (Hughes), May 30, 2013, p. 12517.
41 Exhibit 3007, p. 352.
42 NORR Panel testimony (Saffarini), May 29, 2013, p. 12247.
43 NORR Panel testimony (Saffarini), May 29, 2013, pp. 12232, 12234.
44 NORR Panel testimony (Saffarini), May 29, 2013, pp. 12258–9.
45 NORR Panel testimony (Saffarini), May 29, 2013, p. 12260.
46 Exhibit 3007, pp. 391–2.
47 NORR Panel testimony (Saffarini), May 29, 2013, p. 12261.
48 NORR Panel testimony (Saffarini), May 29, 2013, pp. 12262–6.
49 NORR Panel testimony (Saffarini), May 29, 2013, p. 12264.
50 NORR Panel testimony (Ghods), May 29, 2013, pp. 12273–4.
51 NORR Panel testimony (Ghods), May 29, 2013, pp. 12280–1; Exhibit 3007, pp. 389–91.
52 Exhibit 3007, p. 392.
53 Exhibit 3007, p. 393.
54 Exhibit 3007, pp. 395–6.
55 Exhibit 3007, p. 401.
56 Exhibit 3007, p. 404.
57 Exhibit 3007, p. 280.
58 NORR Panel testimony (Dinovitzer), May 30, 2013, pp. 12669–79.
59 NORR Panel testimony (Dinovitzer), May 29, 2013, pp. 12304–6.
60 Exhibit 3015, p. 195.
61 Exhibit 3007, p. 336.
62 Exhibit 3015, p. 152.
63 Exhibit 3015, p. 198.
64 Exhibit 3015, p. 198.
65 Exhibit 3015, Appendix H, p. 187.
66 NORR Panel testimony (Dinovitzer), May 29, 2013, pp. 12308–10.
67 Exhibit 3015, p. 180–1.
68 NORR Panel testimony (Dinovitzer), May 29, 2013, pp. 12300-1; Exhibit 3015, p. 180.
69 Exhibit 3015, p. 198.
70 Exhibit 3007, p. 406–7.
71 Exhibit 3007, p. 334.
72 NORR Panel testimony (Saffarini), May 30, 2013, pp. 12570–2.
73 NORR Panel testimony (Saffarini), May 30, 2013, p. 12573.
74 NORR Panel testimony (Saffarini), May 30, 2013, pp. 12547–8.
75 NORR Panel testimony (Saffarini), May 30, 2013, pp. 12541–4; Exhibit 3015, figure 2.1, p. 11.
76 Exhibit 3007, pp. 408–10.
77 NORR Panel testimony (Saffarini), May 30, 2013, pp. 12539–40.
78 NORR Panel testimony (Saffarini), May 30, 2013, pp. 12519–20.
79 NORR Panel testimony (Saffarini), May 30, 2013, pp. 12528–9, 12537–8.