Primary Failure Mechanisms and Long-Term Performance of a Remediated Crawl Space Foundation in a Large Building

Figley, S., D. Figley, D. Fugler

ABSTRACT

A large-scale CMHC funded research study was recently conducted as a retrospective investigation into the long-term durability and effectiveness of a number of previously implemented crawl space remediation strategies. The study reviewed more than 30 crawl space remediation projects and presented eight project summaries that were implemented in major buildings to address a number of primary crawl space failure issues. This paper provides a review of the initial in-situ performance deficiencies, re-design objectives and long-term performance improvements that were achieved in one of the crawl spaces that were included as part of the CMHC study: Development and Assessment of Crawl Space Remediation Strategies (Figley et al., 2007). The pre-remediation crawl space discussed in this paper is typical of many major building crawl spaces that are located throughout Canada and the post-remediation results are typical of those achieved in the other crawl space projects.

INTRODUCTION

The building complex is a single storey 16 unit senior citizens apartment development that was constructed during the mid-1970’s in central Saskatchewan (Photo 1). The crawl space area below the facility is approximately 1500m$^2$. The building has concrete perimeter grade beams that are supported by creosote treated driven wooden piles. Built-up lumber interior wood beams support the wood joists and plywood sub-flooring used for the main floor assembly. Prior to, during and following the remediation project, the tenant areas of the facility remained fully occupied and functional.

The building crawl space was originally designed as heated and conditioned space completely within the building interior. Due to basic design weaknesses and/or deficiencies and problems with the on-going maintenance, the crawl space had become a deteriorated, contaminated area that had significant impacts on the indoor environment and physical performance of the building. Since it was “out of sight and out of mind”, the fundamental purpose, relationship to the building as a system and performance requirements had not been maintained.

The remediation project goal was to clean up and repair the crawl space, and return it to a functional and durable space within the building. A number of innovative

---

1 S. Figley is a research associate with Figley Consulting Associates Ltd., Saskatoon, SK, Canada; D. Figley is the president of Figley Consulting Associates Ltd., Saskatoon, SK, Canada; D. Fugler is a senior researcher with Canada Mortgage and Housing Corporation, Ottawa, ON, Canada.
building materials and assemblies and remediation methods were used to enhance the integrity and durability of the crawl space and provide clean, functional space.

The results from the overall study group and this case study clearly demonstrate that well planned and implemented remediation projects that “get back to basics” can turn highly deteriorated crawl spaces into functional and durable building components which ensure the long term stability, performance and sustainability of the building.

FAILURE MECHANISMS

The crawl space presented with a number of issues in need of remediation. Basic problems included: ground and surface water control, microbial contamination (sewage leaks and mold growth), deteriorated piping components, the presence of asbestos materials, infestation by rodents, the presence of exposed creosote treated wood, the accumulation of debris throughout the space, inadequate ventilation and structural deterioration.

Chronic crawl space dampness caused by recurring ground/surface water entry, ventilation with un-conditioned outdoor air, an inadequate soil barrier and wetting caused by previous piping leaks resulted in significant microbial contamination on a number of building components. Although the building had a perimeter drainage piping system, poor construction practices rendered the system useless (Photo 2 and Photo 3). The water supply piping and sewer piping systems were deteriorated or defective and had leaked into the crawl space area (Photo 4). A large portion of the paper/foil jacketed glass fibre insulation on the cold water lines had been significantly damaged and showed visible mold (Photo 5). Many areas of the gypsum fire guard sheeting used on some of the main built-up wooden floor beams and smoke/fire separation walls showed visible mold and water damage.

The crawl space contained an accumulation of debris, including construction materials and other abandoned components. In some areas, erosion below the grade beam exposed the foundation drainage tile and allowed soil and straw (placed as “void form” below concrete) to enter the interior of the crawl space. The soil barrier on the floor showed extensive damage and was displaced or missing in many areas of the crawl space (Photo 6).

In the crawl space along the rim joist and concrete grade beam, rigid polystyrene (bead board) insulation had been originally installed; however the installation was in poor condition and not sealed (Photo 7). The exterior rim joist, floor joists, blocking below the floor joists and main beams were standard construction lumber. As a result of chronic wetting from condensation on cold exterior surfaces, a number of exterior perimeter areas of the rim joist, floor joist ends, blocking and beam ends were deteriorated and rotting. Initial wood moisture contents varied, however in areas around the perimeter, the wood moisture content ranged from 20% to greater than 28%. The extent of deterioration was variable around the exterior perimeter, however, in some areas as much as a 10 mm...
settlement of the beam and floor joists were noted, causing the structural integrity of the building to be compromised (Photo 8).

With the exception of the perimeter areas, other wooden floor components (beams, subfloor and joists) within the crawl space appeared to be in good physical condition. Several localized areas in the interior showed minor evidence of surface mold growth. These particular areas were attributed to events that resulted in pooled water in the crawl space and extended drying times.

The crawl space did not contain any building ventilation equipment. A number of manual open/close vents were installed in the perimeter rim joist to provide outdoor air ventilation into the crawl space. The vents had deteriorated years earlier and cold air, moisture and pests were able to enter the crawl space area (Photo 9).

More than 50 creosote treated wood piles extended approximately 0.5 to 1 meter above the soil surface (Photo 10).

**Photo 1:** Exterior of the building.
Photo 2: Perforated drainage piping sloping upwards to connect with solid drain pipe connected to sump. Water will not ever get to solid pipe section.

Photo 3: The defect noted in Photo 2 did not make much of an impact since sump pump piping was disconnected and drained water onto the crawl space floor. The concrete sump well never had an opening for foundation drainage piping to discharge properly.
Photo 4: Longitudinal crack in the sewer piping in the crawl space area repaired by wrapping with electrical tape. Obviously duct tape should have been used for a more professional job.

Photo 5: Deteriorated pipe insulation, leaking plumbing and piping in the crawl space.
**Photo 6:** Crawl space floor was sand/gravel. The floor was wet and covered with debris. The “floor barrier”, which consisted of sheets of polyethylene placed on and around the general floor area, was unsealed and incomplete.

**Photo 7:** Ends of the rim joists were rotted, moldy and deteriorated. Bead board insulation was present on the interior side of the exterior walls in the crawl space. The insulation was poorly installed, the edges were not sealed and many sections were missing.
**Photo 8:** Exterior concrete wall of the crawl space was dirty and stained. Extensive mineral deposits indicated chronic water entry. The wood joists were moldy and deteriorated.

**Photo 9:** Perimeter of building had poor landscaping. Soil was built-up to improve drainage but was above the appropriate level for the building configuration. Ground level vents were open and allowed entry of moisture and debris into the crawl space area.
Photo 10: Exposed creosote treated wood piles emit strong pungent odour after 35 years.

REMEDIATION STRATEGIES

The crawl space remediation project was started in February 2003 and completed in January 2005. A thorough visual inspection and air sampling were conducted as components of the final inspection.

The following is an overview of the major remediation completed on-site:

- Excavated the exterior, inspected and repaired the damp proofing membrane on the surface of the grade beam, installed 50 mm below grade service rigid polystyrene insulation, back filled, and re-graded with a well compacted clay layer, polyethylene and washed gravel surface ballast over the polyethylene. The removal of any plants from the area adjacent to the building eliminated the need for discharging water near the building.
- Installed exterior perimeter drainage system at the exterior of the grade beam and connected piping to new, covered and sealed sumps located inside.
- Provided durable downspout extensions to move water away from the crawl space exterior.
- Removed all interior insulation to expose the rim joists and grade beam.
- Removed all debris (garbage, construction materials, etc.) from the crawl space floor.
- Perforated or removed existing floor barrier membrane (removed all exposed polyethylene).
- Removed all surface molds using sanding, scraping, and brushing.
• Installed mechanical supports for beam ends. Due to the location of some components such as rotted rim joists, it was not possible to remove them. Some of these areas were scraped/cleaned as much as possible and then reinforced with additional preserved wood blocking that was tightly fitted and sealed to provide a clean, continuous and airtight interior surface. Periodic monitoring of the wood moisture content during the project confirmed that the wood moisture contents in all areas were well controlled and consistently remained below 10%.
• Re-graded the crawl space floor to provide a continuous slope to low points. Excavated to establish low points at sump openings.
• Installed a new continuous and well-sealed floor barrier (fire-retardant, 13 mil, two layer multi-axially oriented high-density polyethylene) attached at the exterior grade beam using sealant tape, pressure treated plywood battens and mechanical fasteners. All seams, joints and connections were carefully overlapped and sealed with a factory-supplied sealant. The top seams were taped with a vapor barrier tape to provide a smooth, finished surface. Temporarily removed support jacks on creosote wood piles, completely sealed and wrapped piles and installed new adjustable jacks.
• Conducted detailed cleaning using a HEPA vacuum and damp wiping of all interior surfaces. Although not required for mold clean-up, due to the rodent contamination the contractor had extensively spray-applied bleach to many interior surfaces.
• Installed thin rubber mats to establish pathways for inspection and maintenance personnel.
• Installed a dedicated crawl space exhaust fan to provide continuous depressurization and ventilation. Although somewhat unconventional in that no dedicated supply air was provided for the crawl space, air leakage through the floor assembly provided approximately 0.3 ach\(^{-1}\) of transfer air from the main floor at a crawl space depressurization of approximately 3 – 5 Pa. This level of air exchange occurred even after the initial detailed sealing of the main floor assembly during the isolation phase of the project and has been observed in all of the crawl space projects in wood frame buildings. Since the air transferred into the crawl space from the main floor was conditioned air from normal occupied areas, it provided a suitable ventilation and directional airflow control strategy. On-going monitoring within the crawl space (and others) confirms that the temperature and relative humidity conditions remain similar to the main floor areas, with no indication of elevated humidity or moisture management problems associated with the building envelope assembly.

LONG-TERM PERFORMANCE

The crawl space remediation project was completed in January 2005, at which time a visual inspection was conducted and air samples were taken to assess the outcome of the completed project. Site inspections have been conducted on a routine basis since the completion of the remediation project. In March 2007 a follow-up inspection of the crawl space area was conducted to assess the long-term results and durability of the overall remediation project.
The inspection indicated that the crawl space remediation was successful and that the crawl space was in very good condition. At the time of the inspection, 90% of the snow outside had melted yet the crawl space showed no indication of external water entry. The exterior modifications to the grading of the land near the building and proper downspouts proved to be effective in moving water away from the crawl space. The exterior metal flashing and exterior insulation appeared to be in good condition and properly attached.

On the interior of the crawl space a small amount of grit and debris (paper, wood scraps, light bulbs) was present at the entrance to the crawl space and in various locations on the floor barrier. The installation of a white floor barrier in the remediation project was helpful for indicating the history of leaks and the activity within the crawl space cavity. Many small stains on the floor barrier were observed directly under stained portions of the plywood sub-flooring, most likely a result of overhead piping leaks. Internal water entry did result in an accumulation of water under the floor mat near the crawl space entrance. The removable rubber floor mats provided a comfortable surface for movement within the crawl space and are easily moved for maintenance and cleaning. With the exception of the small stains, it was noted that the floor barrier was in excellent condition, the tape was well attached and the barrier material wrapping around the piles was in excellent physical condition.

The exterior crawl space walls showed no evidence of outside water entry and the batten boards at the exterior were solid. The structural supports that were added showed no signs of deterioration or staining. There was no evidence of mold re-growth on any of the wood surfaces within the crawl space. The bleaching method used as part of the cleaning of mold on the wooden components did not appear to cause damage or deterioration of the structure, electrical wiring or piping within the crawl space.

Rodent seed packets (poison) were found scattered within in the crawl space even though there was no indication of rodent activity.
Photo 11: Perimeter of the building has a graded landscape. Exterior walls of the crawl space are insulated from the exterior, covered with pressure treated plywood and capped with metal flashing. Eaves trough extensions and removal of planted materials eliminate the discharge of water against the perimeter of the building.
**Photo 12:** Clean, durable crawl space floor. Floor barrier is sealed at all connections and completely encloses piles. Black rubber floor mats provide floor barrier protection and are easily moved/removed for cleaning.

**Photo 13:** Mold from the floor joists has been physically removed by grinding, sanding and scraping followed by washing and HEPA vacuuming. Piping and pipe insulation have been repaired and properly sealed.
DISCUSSION

All of the remediation techniques were successful, and restored the function of the crawl space to a clean, durable area. Many of the techniques used to remediate this crawl space have since been used in many other remediation projects, due to their high quality results and long-term effectiveness. Successful remediation strategies used in this study included:

1. The white reinforced polyethylene floor barrier is much more durable and easier to visually inspect than regular polyethylene sheeting, and the overall cost difference for the complete project is small. Subsequent experiences with leaks confirm that that floor barrier provides a surface that is easy to inspect, clean and maintain.
2. The barrier attachment and sheet joining methods used have proven to be durable and secure.

3. The use of only direct exhaust for crawl space ventilation provides reliable and adequate ventilation and control of the temperature and humidity.

4. Bleaching had no advantage for removing mold or providing long-term performance. Although not observed in this crawl space, in several of the other crawl space projects, the use of bleach caused some damage to piping and electrical components. Basic physical cleaning provided good long-term performance. Due to the presence of rodents in some areas, the use of a disinfectant was required.

5. Regular crawl space inspections and maintenance are essential for keeping areas clean and in good condition.

6. Small problems need to be fixed immediately, to prevent them from becoming large/expensive problems.

7. Access and lighting improve personnel commitment to inspections and maintenance. Training on inspections and maintenance is required to ensure that these essential tasks are properly conducted.

8. Water drainage systems and sumps are necessary (sumps need to be maintained), although good exterior moisture management minimized the amount of water entering the interior foundation drainage and sump system.

9. Exterior landscaping and water management (including snow) is an important element in preventing basic moisture problems.

10. Written and enforceable procedures for crawl space activities are needed to prevent the “out of sight, out of mind” mentality, which results in neglect and deterioration.

11. It is possible to remediate highly compromised crawl spaces and return them to a high level of performance and durability.

12. Failure to address the basic performance requirements of conditioned crawl spaces results in conditions that compromise the indoor environment and threaten the continuing physical performance and usability of the building.
CONCLUSIONS

Overall, this crawl space remediation project was effective in resolving the past structural, microbial and water entry issues and has provided a durable and clean conditioned crawl space.

The overall results from the CMHC study clearly demonstrate that well planned and implemented remediation projects can turn highly deteriorated crawl spaces into functional and durable building components, which ensure the long term stability, performance and sustainability of the building. The study examined remediated crawl spaces (including a number that have been in service for almost a decade) and their overall performance was consistent with the outcomes observed for this case study crawl space. Many of these crawl spaces are owned/operated by a large social housing agency that has a regular crawl space inspection/assessment protocol included in their comprehensive facility management system. This crawl space and a number of others will continue to be monitored on a semi-annual basis to assess their on-going performance.

Since 2002, remediation costs for projects of this type have increased from $71-134/m² (Figley et al., 2002) to approximately $200/m² for this project. Although this may seem expensive, the remediation of this crawl space was an effective strategic investment in extending the overall life of the building, while ensuring that the crawl space did not compromise the indoor environment of the building.

ACKNOWLEDGEMENTS

The authors would like to gratefully acknowledge the assistance of Mr. Don Berton, Mr. Dennis McLain, Mr. Ray Sieber, P.Eng. and Mr. Bob Trafananko with the Saskatchewan Housing Corporation for their leadership, enthusiasm and support in developing and implementing the crawl space remediation program.

REFERENCES
