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External Research Program

Development and Assessment of Crawl Space Remediation Strategies

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Development and Assessment of Crawl Space Remediation Strategies

CMHC External Research Program (ERP) Project

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EXECUTIVE SUMMARY

Development and Assessment of Crawl Space Remediation Strategies

A retrospective field investigation was conducted to assess the long-term durability and effectiveness of crawl space remediation strategies. Over a number of years, the study authors have developed comprehensive crawl space remediation strategies and have supervised their field implementation in many major buildings. The study included the investigation and preparation of case study summaries of eight major building crawl spaces that had been remediated over a seven-year period. The report provides a summary of the key initial in-situ performance deficiencies, re-design objectives and long-term performance improvements that were achieved.

All of the crawl spaces discussed in this study were originally designed as heated/conditioned crawl spaces and should have been considered as conditioned spaces completely within the building interior. Due to basic design weaknesses and/or deficiencies and problems with the on-going maintenance, all of the crawl spaces had become deteriorated, contaminated areas that could potentially have significant negative impacts on the indoor environment and physical performance of the buildings.

Through a combination of design and use issues, these essential components of the building assembly had become deteriorated, but since they were “out of sight, out of mind”, their fundamental purpose, relationship to the building as a system and performance requirements had not been maintained.

Each of the buildings studied had received a major remediation project to clean up and repair the crawl space and return it to a functional and durable space within the building. A number of innovative building materials and assemblies and remediation methods were used to enhance the integrity and durability of the crawl spaces and provide clean, functional space.

The results from the 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.

RÉSUMÉ

Création et évaluation de mesures de remise en état des vides sanitaires

Une enquête rétrospective menée sur le terrain visait à évaluer la durabilité et l'efficacité à long terme des mesures de remise en état des vides sanitaires. Pendant un certain nombre d'années, les auteurs de l'étude ont mis au point des mesures complètes de remise en état des vides sanitaires et supervisé leur mise en application dans de nombreux bâtiments d'importance. L'étude comprend l'enquête et la rédaction de résumés d'études de cas consacrées au vide sanitaire de huit bâtiments d'importance qui ont fait l'objet de travaux de remise en état au cours d'une période de sept ans. Le rapport résume les principales lacunes de performance initiales, en plus des objectifs de réaménagement et des améliorations de performance à long terme qui ont été atteints.

Tous les vides sanitaires dont l'étude fait état avaient été conçus au départ pour être chauffés ou conditionnés, de sorte qu'ils auraient dû être considérés comme des aires conditionnées se trouvant complètement à l'intérieur des bâtiments. En raison des faiblesses fondamentales de la conception et/ou d'anomalies et de problèmes d'entretien continu, tous les vides sanitaires sont devenus des aires détériorées, contaminées, risquant de nuire au milieu intérieur et à la performance des bâtiments.

En raison de la combinaison de problèmes de conception et d'utilisation, ces éléments essentiels du bâtiment se sont détériorés, mais comme ils sont dissimulés, on a tendance à les oublier, de sorte que leur objet ou rapport fondamental avec le bâtiment considéré comme un système de même que leurs exigences en matière de performance n'ont pas été préservés.

Chacun des bâtiments à l'étude a fait l'objet d'importants travaux de remise en état destinés à assainir et à réparer le vide sanitaire pour lui restituer son caractère fonctionnel et durable à l'intérieur du bâtiment. Un certain nombre d'éléments, de matériaux de construction et de méthodes de remise en état ont servi à rehausser l'intégrité et la durabilité du vide sanitaire et ainsi en faire une aire propre et fonctionnelle.

Les résultats de l'étude montrent clairement que des travaux de remise en état bien planifiés et exécutés permettent de transformer des vides sanitaires grandement détériorés en éléments de bâtiment fonctionnels assurant ainsi à long terme la stabilité, la performance et la durabilité du bâtiment.

ABSTRACT

Development and Assessment of Crawl Space Remediation Strategies

This report presents an assessment of the long-term performance of crawl space remediation strategies that have been implemented over the past seven years in eight major building crawl spaces in Saskatchewan, Canada. Basic building science and indoor air quality design concepts were initially applied to assess the water damaged, deteriorated and contaminated crawl spaces. Remediation methods were developed and implemented to address performance deficiencies and return the crawl spaces to an acceptable and durable condition. The performance of the remediation methods has been regularly monitored over the life of the buildings.

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Introduction

This research study was conducted as a retrospective investigation of the long-term durability and effectiveness of crawl space remediation strategies that have been used in projects during the past seven years. Figley *et al.*[1] have previously discussed some background information pertaining to the basic issues related to the performance of building crawl spaces.

Study Overview

a) Background

The following case studies summarize the initial crawl space performance issues and follow-up measures enacted in each of the eight crawl spaces that are included in this study. The crawl spaces were selected from a large group of buildings that have been remediated to represent typical examples of various problems, remediation methods and performance outcomes. The crawl space assessments and intervention methods were developed by the study authors, who also supervised the field implementation of the remediation work.

Each of the study crawl spaces had been previously identified as having significant performance problems and had been subjected to a full engineering investigation. Based on the findings of the investigation, a comprehensive remediation plan was developed and implemented. The remediation plans were developed to provide a comprehensive building systems based solution, rather than to simply address one or several specific problems.

b) Pre-existing Building and Crawl Space Problems

All of the crawl spaces discussed in this study were originally designed as heated/conditioned crawl spaces and should have been considered as conditioned spaces completely within the building interior. Due to basic design weaknesses and/or deficiencies and problems with the on-going maintenance, all of the crawl spaces had become deteriorated, contaminated areas that could

potentially have significant negative impacts on the indoor environment and physical performance of the buildings.

Through a combination of design and use issues, these essential components of the building assembly had become deteriorated, but since they were “out of sight, out of mind”, their fundamental purpose, relationship to the building as a whole and performance requirements had not been maintained.

The purpose of the crawl space remediation project was to clean up and repair each crawl space and return it to a functional and durable space within the building. Although cleaned and repaired, the crawl spaces were configured to be isolated and ventilated independently of the building.

Many of the crawl spaces included in this study shared some common initial problems/issues related to moisture management, however many of the crawl spaces presented with one or more unique issue(s), which required different remediation strategies to be implemented. A summary of the major problems identified in the crawl spaces include:

1. Entry of exterior water due to improper landscaping or poor management of rain water and snow accumulation.

2. Entry of interior water due to sewer line failures, piping leaks or inoperable sump pumps. In some cases, the crawl space contamination was further advanced by the application of hydrated lime, bleach or other chemicals in an attempt by the building owners to control odours in the crawl space and adjacent building areas.

3. The lack of any “system” to provide an effective environmental separation for the crawl space floor assembly. At best, sheets of polyethylene were layered onto the excavation, without any detailed method for attachment or sealing of edges or penetrations. The addition of a surface layer of sand provided an ideal environment for the retention of moisture and contaminants and prevented any attempts at cleaning.

4. Interior insulation that did not control moisture or air leakage, resulting in significant surface condensation and moisture damage of rim joists and wood framing. In addition to extensive mold growth, rotting and structural deterioration occurred.

5. Contamination of the space by pests, including insects, mice, rats, bats, snakes and amphibians. The extensive placement of poison bait packages contributed to the accumulation of carcasses throughout the space and

the presence of poisonous materials scattered in the non-cleanable sand/soil floor surface.

6. Microbial contamination of the space due to mold growth on wetted paper, wood, food containers, air filters, packaging from repair parts and other debris. This was often highly compounded by piles of garbage left behind and sheets of cardboard or wood placed on the wet floor by service personnel who tried to avoid working on the wet, muddy floors.

7. Physical hazards due to the presence of broken glass, wood with nails, metal shards, abandoned repair parts and other garbage left during construction or by subsequent service personnel.

8. Poorly sealed mechanical equipment (air handlers, cooling/heating coils or fan coils) and ductwork which when located in a contaminated crawl space, provided a significant pathway for the transport of contamination. Air leakage from supply air ducts often resulted in pressurization of the crawl space relative to the main floor and contributed to air leakage from the contaminated crawl space.

9. Limited access, restricted movement and poor lighting contributed to difficult and dismal working conditions and reduced any worker commitment to maintaining or improving the space.

c) Remediation Plan Objectives and Actions

Some of the remediation methods had not been used in previous conventional clean-up projects, but were novel engineering innovations employed to experiment with component durability, cost, mold removal techniques or improve past techniques.

In all of the crawl space remediation projects, the comprehensive project plan included specific details related to:

1. Work area isolation to prevent the transport of contamination into adjacent building areas.

2. Providing appropriate worker personal protection.

3. Defining cleaning methods, work practices and components to be cleaned or replaced.

4. Establishing measurable objectives to determine the successful completion of the project.

Regardless of the basic performance deficiencies or clean-up and repair techniques that were used in each of the test-case crawl spaces, the final design objectives for all of the crawlspaces were to:

1. Control the primary sources of moisture.

2. Isolate the crawl space from the occupied areas of the building by sealing floor penetrations and ventilation components. During remediation, depressurization of the work area is provided by continuous exhaust with negative air machines.

3. Remove any debris and deteriorated or unnecessary components.

4. Repair or replace essential components.

5. Install a continuous and durable floor surface to provide a reliable environmental separation.

6. Conduct a thorough final cleaning of the space after the environmental separation has been completed.

7. Independently ventilate and continuously depressurize the crawl space with a dedicated exhaust fan system.

8. Control the access to the area.

9. Make the area easily accessible for inspection and maintenance.

Each crawl space remediation project included in this research study had been completed for a minimum of two-years (range 2-7 years). The remediation strategies and final outcomes of each case study have allowed conclusions and recommendations to be made based on successful remediation techniques.

This retrospective study is intended be used as a reference to provide a guideline for strategies used in future crawl space remediation projects.

The basic design and building performance issues identified in the study and the remediation methods employed also provide clear guidance for the design of new building crawl spaces. These methods and procedures have been successfully applied to a number of new crawl spaces and have consistently provided high quality performance.

d. Long-Term Performance of Remediation Strategies

1. All of the remediation techniques were successful, although some were better than others.

2. The white Permalon™ floor barrier is much more durable and easier to visually inspect than polyethylene, and the overall cost difference for the complete project is small.

3. The barrier attachment and sheet joining methods used have proven to be durable and secure.

4. Bleaching had no advantage for removing mold or providing long-term performance and caused some damage. Basic physical cleaning provided good long-term performance. Due to the presence of rodents in some areas, the use of bleach as 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.

13. Remediation costs have increased from the 2002 values[1] of \$71-134/m^2 to consistently over \$200/m^2.

References

Figley, D. and Sieber, R. (2002) Cleanup of Microbial Contamination in Major Building Crawlspaces. *Proceedings: Indoor Air 2002*. p. 739 – 7

CMHC Crawl Space Remediation Project

Case Study 1

Building Information:

The Building 1 complex is a 16 unit senior citizens apartment development that was constructed during the mid-1970's in central Saskatchewan. The crawl space area below the facility is approximately 1500m^2.

The entire facility has a heated, conditioned crawl space with an exterior concrete grade beam. The built-up wood interior beams and concrete grade beams are supported by driven wooden piles and the floor system is composed of wood joists and plywood sub-flooring.

Crawl Space Problems/Issues:

The crawl space in Building 1 presented with a number of issues in need of remediation. Building problems included: ground and surface water control, microbial contamination (sewage leaks and mold growth), deteriorated piping components, the presence of asbestos materials, rodents, accumulation of debris throughout the space, inadequate ventilation and structural deterioration.

Exterior work including installation of exterior insulation on the rim joist and grade beam, landscaping, grading, surface water control and rain water disposal were also addressed in this remediation project.

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. The water supply piping and sewer piping systems were deteriorated or defective and had leaked into the crawl space area. A large portion of the foil jacketed glass fibre insulation on the cold water lines had been significantly damaged and showed visible mold. Many areas of the gypsum fire guard sheeting (used in 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 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.

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. 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. 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, and this caused the structural integrity of the building to be compromised.

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 1: Deteriorated, leaking plumbing and piping in the crawl space.

Photo 2: Longitudinal crack in the sewer piping in the crawl space area (repaired by wrapping with electrical tape).

Photo 3: Deteriorated piping. Sump pump piping was disconnected and drained water onto the crawl space floor (note the concrete sump well never had an opening for foundation drainage piping to discharge properly).

Photo 4: Ends of the rim joists were rotten, 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 5: 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 6: Perimeter of building had poor landscaping. Soil built-up to improve drainage but was above the appropriate level for the building configuration. Ground level vents were open and allowed entry of debris into the crawl space area.

Photo 7: Crawl space floor is sand/gravel. The floor was wet and covered with debris. The "floor barrier", which consisted of sheets of poly laid around the general floor area, was unsealed and incomplete.

Remediation Strategies Employed:

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 remediations completed on-site:

- 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 mold using sanding, scraping, and brushing.
- Installed mechanical supports for beam ends. Installed pressure treated wood blocking at all rotted rim joists and sealed all edges.
- 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.
- Re-graded crawl space floor. Excavated to establish low points at sump openings.
- Excavated exterior and installed rigid polystyrene insulation, back filled, and re-graded with a well compacted clay layer, polyethylene and washed gravel surface ballast over the polyethylene.
- Installed a new Permalon™ PlyX 200FR floor barrier attached at exterior grade beam using pressure treated plywood battens and mechanical fasteners. Temporarily removed support jacks on creosote wood piles, completely sealed and wrapped piles and installed new adjustable jacks.
- Installed thin rubber mats to establish pathways for inspection and maintenance personnel.
- 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 a dedicated crawl space exhaust fan to provide continuous depressurization and ventilation. Although no deliberate air was supplied to the crawl space, air leakage through the floor assembly provided approximately 0.3 ach^{-1} at a crawl space depressurization of approximately 3 – 5 Pa.

Remediation Outcome:

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 done 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 bulb) 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 Permalon™ 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 (Hilti™ anchors) 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: no droppings or damage was observed.

Overall, the 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.

Photo 8: Clean, durable crawl space floor. Floor barrier is sealed at all connections and extends up the concrete piles. Black rubber floor mats provide floor barrier protection and are easily moved/removed for cleaning.

Photo 9: 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.

Photo 10: 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.

Photo 11: Floor barrier extends up and over the creosote treated wood piles. Floor barrier is properly sealed. Over time, contractors became more adept at taping without over-taping.

CMHC Crawl Space Remediation Project

Case Study 2

Building Information:

The Building 2 complex is a 24 unit senior citizens apartment development that was constructed during the mid-1970's in central Saskatchewan. The crawl space area below the facility is approximately 2500 m^2.

The entire facility has a heated, conditioned crawl space with an exterior concrete grade beam supported by a continuous concrete footing. The built-up wood beams are supported by steel screw jacks on concrete pads and the floor system is composed of wood joists and plywood sub-flooring.

Crawl Space Problems/Issues:

The crawl space below Building 2 required modifications to address a number of problems, some of which included: ground and surface water control, microbial contamination (sewage leaks and mold growth), deterioration of piping components, rodents and bats, accumulations of debris, inadequate ventilation and structural deterioration.

Exterior work including installation of exterior insulation on the rim joist and grade beam, landscaping, grading, surface water control and rain water disposal were also addressed in this remediation project.

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 and current piping leaks resulted in significant microbial contamination on the insulated water lines, gypsum board fire protective surfaces, exposed soil and other building components. Significant accumulations of rodent droppings were present in some of the crawl space areas and dead/live bats were present within the area.

The crawl space had a small accumulation of construction materials, abandoned components and other debris. The soil barrier on the floor of the crawl space was badly damaged, missing or displaced in many areas and the soil/sand above the barrier was contaminated.

A number of the water supply piping and sewer piping systems had become deteriorated or defective and had been leaking into the crawl space. A large portion of the jacketed glass fibre insulation on the cold water lines was badly damaged and moldy. Asbestos insulation materials were present on a number of elbows and pipe supports on the hot water heating system.

The crawl space did not contain any building ventilation equipment. A number of manual open/close damper vents had been installed in the perimeter rim joist to provide outdoor air ventilation into the crawl space. These vents were deteriorated and allowed the entry of moisture and pests as well as cold air that caused condensation problems.

Some of the main built-up wooden floor beams had gypsum fire guard. Many areas of the fire guard were water damaged and visibly moldy.

Rigid polystyrene (bead board) insulation was originally installed along the rim joist and on the concrete grade beam. The insulation was poorly installed and not sealed. Condensation on cold exterior surfaces resulted in chronic wetting of the rim joist, joist ends and beam ends that rested on or were imbedded in the concrete grade beams. These components were not pressure treated lumber and as a result of chronic wetting, a number of exterior perimeter areas of the rim joist, floor joist ends, blocking and beam ends were rotted and deteriorated. The extent of the deterioration was variable around the exterior perimeter (approximately 50% of the total exterior perimeter was affected), however, in some areas the deterioration resulted in up to 25 mm of settlement of the beams and floor joists.

The majority of the wooden floor members (beams, joists and subfloor) were, with the exceptions of the perimeter areas stated above, in good physical condition. Numerous localized areas in the interior had some visual signs of surface mold growth, which were due to incidents that resulted in pooled water and extended drying times.

Photo 1: Visible mold and discoloration on the subflooring and floor joists.

Photo 2: Debris (including garbage and deteriorated piping) was on the crawl space floor. In many areas, no floor barrier was present and the exposed sand/soil floor was damp.

Photo 3: Piping/plumbing within the crawl space area showed signs of extensive rusting and deterioration. Perimeter insulation was poorly installed or missing.

Remediation Strategies Employed:

The crawl space remediation project was started in March 2003 and was completed in January 2005. A thorough visual inspection and airborne fungi samples were conducted as components of the final crawl space inspection.

The following is a list of the remediation methods/tasks carried out:

- Removed all interior polystyrene 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 mold using sand blasting, sanding, scraping, and brushing. Sand blasting with commercial grit was used as the main method for bulk surface mold removal from the structure.
- Installed mechanical supports for beam ends. Installed pressure treated wood blocking at all rotted rim joists and sealed all edges.
- Installed perimeter drainage system and connecting piping to new, covered and sealed interior sumps.
- Provided durable downspout extensions to move water away from the crawl space exterior.
- Re-graded crawl space floor. Excavated to establish low points at sump openings.
- Excavated exterior, installed rigid polystyrene insulation, back filled, and re-graded with a well compacted clay layer, polyethylene and washed gravel surface ballast over the polyethylene.
- Installed a new Permalon™ PlyX 200FR floor barrier attached at the exterior grade beam using pressure treated plywood battens and mechanical fasteners. The floor barrier was sealed to all concrete piers, piping and other interior penetrations.
- Installed thin rubber mats to establish pathways for inspection and maintenance personnel.
- 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 a dedicated crawl space exhaust fan to provide continuous depressurization and ventilation.

Remediation Outcome:

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 was done

to assess the long-term results and durability of the overall crawl space 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 recent or previous 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, insects, wood scraps, dirt) was present at the entrance to the crawl space and in various locations on the floor barrier. It was noted that despite a thorough final cleaning at the project completion, sand blasting grit continued to fall onto the barrier for the first year. The installation of a white floor barrier was helpful in indicating locations where leaks had occurred 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. With the exception of the small stains, it was noted that the floor barrier was in excellent condition, the tape was well attached and mechanical connectors were solid. The removable rubber floor mats provided a comfortable surface for movement within the crawl space and are easily moved for maintenance and cleaning.

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 semi-aggressive bleaching method used for 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.

Overall, the crawl space remediation project was effective in resolving the past structural, microbial and water entry issues and has provided a durable and maintainable conditioned crawl space. Improved maintenance within the crawl space and in other building areas is required to ensure that the building performs adequately in the long-term.

Photo 4: Crawl space floor is dirty and shows evidence of water entry from the main floor.

Photo 5: Floor joists and plywood subfloor are in good condition and show no signs of mold re-growth.

Photo 6: Additional structural supports are in good condition and functioning properly.

Photo 7: Some downspout extensions are missing and water is not moved away from the exterior walls of the crawl space.

Photo 8: Exterior insulation and metal flashing are in good condition. The exterior landscaping and downspouts have been helpful in keeping water away from the crawl space exterior.

Photo 9: Floor barrier is well attached to the exterior walls and is sealed around all columns, piping and other floor barrier penetrations.

CMHC Crawl Space Remediation Project

Case Study 3

Building Information:

The Building 3 facility is a multi-unit apartment complex that was built as a senior's residence in central Saskatchewan in the 1970's. The crawl space area below the facility is approximately 1500 m^2.

Building 3 has several interconnected crawl space areas that were included in this remediation project. The crawl space areas have sand/soil floors that had an original polyethylene ground cover that was present, but in poor physical condition. The crawl spaces are located below wood framed floors with wood joists, steel beams and piles and concrete exterior walls. The crawl spaces contained some ventilation equipment and an extensive piping network of potable water, hot water heating and sanitary piping.

Crawl Space Problems/Issues:

The crawl space below Building 3 required modifications to address a number of problems, some of which included: ground and surface water control, microbial contamination (sewage leaks and mold growth), accumulations of debris, abandoned piping and inadequate ventilation. The local facility staff had attempted to control the microbial contamination and sewer odours by spreading hydrated lime throughout the crawl space, however, this resulted in significant contamination of the soil, structure and building services and deterioration of many of the metal components.

Chronic crawl space dampness caused by sewer discharges into the crawl spaces (caused by longitudinal and radial cracks in cast iron sewer piping) and some ground/surface water entry resulted in significant contamination of the soil floor, microbial growth on the insulated water lines (the cold water lines were primarily affected) and deterioration of the fire/smoke separation walls. Sewage escaped from the sanitary piping and had projected onto adjacent surfaces including piping and building components.

The main building air handling unit was located in the crawl space and the badly contaminated area around the unit was littered with dozens of used air filters and new air filters packed in water damaged and moldy cardboard boxes.

Exterior work including landscaping, grading, surface water control and rain water disposal were also addressed within the overall project scope.

Photo 1: Water markings and staining are visible on the wooden components in the crawl space area. The pipe insulation also shows evidence of water damage.

Photo 2: Water markings are visible on the subfloor and trusses.

Photo 3: Dirty, moldy furnace filters, along with light bulbs and pieces of insulation, were on the dirt/sand crawl space floor.

Remediation Strategies Employed:

The crawl space remediation project was started in November 2000 and was completed in September 2002. A complete visual inspection and airborne fungi sampling were conducted as components of the final crawl space inspection.

The following is a list of the remediation methods/tasks carried out:

- Removed all debris (garbage, construction materials, etc.) from the crawl space floor.
- Perforated or removed existing floor barrier membrane.
- Removed all surface mold using sanding, scraping, and brushing.
- Installed perimeter drainage system and connecting piping to new, covered and sealed interior sumps.
- Provided durable downspout extensions to move water away from the crawl space exterior.
- Re-graded crawl space floor. Excavated to establish low points at sump openings.
- In accessible locations excavated exterior, installed rigid polystyrene insulation, back filled, re-graded and landscaped. In areas where exterior insulation could not be installed, the grade beam and rim joist were insulated from the interior.
- Installed a new Permalon™ PlyX 200FR or 6 mil polyethylene floor barrier attached at the exterior grade beam using pressure treated plywood battens and

mechanical fasteners. The floor barrier was sealed to all concrete piers, piping and other interior penetrations.
- Conducted detailed cleaning using a HEPA vacuum and damp wiping of all interior surfaces.
- Installed a dedicated crawl space exhaust fan to provide continuous depressurization and ventilation.

Remediation Outcome:

The crawl space remediation project was completed in September 2002, 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 and in July 2007 a follow-up inspection was done to assess the long-term results and durability of the overall crawl space remediation project.

A thorough inspection indicated that the crawl space remediation was successful and that the crawl space was in very good condition. The crawl space showed no signs of external water entry. The exterior modifications to the grading near the building and installation of proper downspouts have been effective in moving water away from the exterior of the building and keeping water out of the crawl space area. The exterior metal flashing and protective cover installed over the foam plastic exterior insulation appeared to be in good condition and properly attached.

This crawl space had two different floor barrier materials installed during the remediation. In areas where maintenance personnel would frequently work (i.e. around sump pumps or under major ventilation or plumbing), Permalon™ was used as the floor barrier. Polyethylene was used in lower traffic areas (i.e. along the exterior walls of the crawl space) to reduce the cost of the overall remediation project. After five years, the Permalon™ floor barrier (although more expensive) is in excellent physical condition, whereas the polyethylene has needed repairs in many locations as a result of punctures and tears.

The white Permalon™ floor barrier is also a better surface for indicating stains from areas where water had been present. Small to moderate size stains on the floor barrier were observed directly under stained portions of the plywood sub-flooring or directly under overhead piping. The removable rubber floor mats provide a comfortable surface for movement within the crawl space and are easily moved for maintenance and cleaning. The rubber floor mats were in good condition and remained in the original installation location. With the exception of the small stains and the polyethylene areas, it was noted that the floor barrier was in excellent condition, the tape was well attached and the Permalon™ 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 and there was no evidence of mold re-growth on any of

the wood surfaces within the crawl space. The inspection showed no evidence of rodent activity in the crawl space.

Overall, the crawl space remediation project was effective in resolving the past structural, microbial and water entry issues.

Photo 4: The Permalon™ floor barrier and tape are in good condition and have not required significant repairs (see photo 6). The floor barrier extends up concrete piles and is sealed around each column.

Photo 5: Trusses are in excellent condition with no signs of mold re-growth.

Photo 6: Sections of the poly floor barrier have required extensive patching to repair punctures and tears.

Photo 7: New plumbing, piping and ventilation equipment has been suspended above the floor barrier. The insulation around piping and ducting is well sealed and in good condition.

Photo 8: Smoke control walls and fire dampers have been installed to separate various crawl space areas.

Photo 9: Landscaping and proper downspout attachments have prevented external water entry into the crawl space.

CMHC Crawl Space Remediation Project

Case Study 4

Building Information:

The Building 4 complex is a twelve unit senior citizen apartment development that was constructed in the mid-1970's in central Saskatchewan. The crawl space below the building is approximately 750 m^2.

The entire facility has a crawl space with an exterior concrete grade beam supported by piles. The built-up wood beams are supported by poured concrete piles and the floor system is composed of wood joists and plywood subflooring.

Crawl Space Problems/Issues:

The crawl space below Building 4 required modifications to address a number of problems, some of which included: ground and surface water control, microbial contamination (sewage leaks and mold growth), deterioration of piping components, rodents, accumulations of debris, inadequate ventilation and structural deterioration.

Exterior work including landscaping, grading, surface water control and rain water disposal had been addressed at this facility prior the crawl space remediation project.

Chronic crawl space dampness caused by recurring ground/surface water entry, an inadequate soil barrier and wetting caused by previous and current piping leaks resulted in significant microbial contamination on the insulated water lines, gypsum board fire protective surfaces, exposed soil and other building components. Significant accumulations of rodent droppings were present in some of the crawl space areas.

The crawl space had a small accumulation of construction materials, abandoned components and other debris. In some areas, erosion below the grade beam had exposed the base of the grade beam and drainage tile and allowed soil to enter the interior of the crawl space. The soil barrier on the floor of the crawl space was badly damaged, missing or displaced in many areas and the soil/sand above the barrier was contaminated.

Some of the water lines and most of the sewer piping had become deteriorated or defective and had been leaking into the crawl space. A large portion of the foil jacketed glass fibre insulation on the cold water lines was either missing or badly damaged and moldy. The canvas jacketed glass fiber insulation that was on the heating piping was missing or damaged in many places.

The crawl space did not contain any building ventilation equipment. A number of manual open/close damper vents had been installed in the perimeter rim joist to provide outdoor air ventilation into the crawl space. These vents were deteriorated and allowed for the entry of moisture and pests as well as cold air that caused condensation problems.

The main built-up wooden floor beams had gypsum fire guard cladding. Many areas of the gypsum board were missing, physically damaged, water damaged or moldy.

Rigid polystyrene (bead board) and/or glass fibre batt insulation was originally installed along the rim joist and on the concrete grade beam, however the insulation was poorly installed, not sealed and many sections were dislodged or missing. Glass fibre insulation without a vapour barrier was also installed along some sections the rim joist. Condensation on cold exterior surfaces resulted in chronic wetting of the rim joist, joist ends and beam ends that rested on or were imbedded in the concrete grade beams.

The exterior rim joist, floor joist, blocking and main beams were not pressure treated lumber. As a result of chronic wetting from condensation, a number of exterior perimeter areas of the rim joist, floor joist ends, blocking and beam ends were rotted and deteriorated. The extent of the deterioration was variable around the exterior perimeter, however, more the 50 percent of the building was affected to some degree.

Badly deteriorated paper forms were partially attached to the concrete piles.

The majority of the wooden floor members (beams, joists and subfloor) were, with the exceptions stated above, in good physical condition. Numerous localized areas in the interior had some visual signs of mold growth, which were due to incidents that resulted in pooled water and extended drying times.

Photo 1: Original crawl space floor showed extensive water damage and deterioration.

Photo 2: Crawl space floor was littered with debris and garbage.

Photo 3: Exterior walls were insulated from the interior side of the crawl space. Joist ends were moldy and deteriorated.

Photo 4: Exterior walls were insulated from the interior side of the crawl space.

Photo 5: Crawl space floor is sand/gravel. Concrete piles were wrapped in deteriorated paper.

Photo 6: Old, corroded piping within the crawl space area.

Photo 7: Visible mold and deterioration on the rim joists and ends of the floor joists.

Photo 8: Old, corroded piping was the source of some water entry into the crawl space.

Remediation Strategies Employed:

The crawl space remediation project for Building 4 was started in January 2005 and was completed in November 2005, at which time a visual inspection and air samples were taken to assess the outcome of the completed project.

The following is a list of the remediation methods/tasks carried out:

- Removed all interior polystyrene 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 surface mold using sanding, scraping, brushing and bleaching.
- Installed mechanical supports for beam ends. Installed pressure treated wood blocking at all rotted rim joists and sealed all edges.
- 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.
- Re-graded crawl space floor. Excavated to establish low points at sump openings.

- Previously, the exterior was excavated, rigid polystyrene insulation was installed, the area was back filled, and re-graded with a well compacted clay layer, polyethylene and washed gravel surface ballast over the polyethylene.
- Installed a new Permalon™ PlyX 200FR floor barrier attached at exterior grade beam using pressure treated plywood battens and mechanical fasteners. The floor barrier was sealed to all concrete piers, piping and other interior penetrations.
- Installed thin rubber mats to establish pathways for inspections and maintenance personnel.
- In this building a detailed final cleaning was not conducted and the crawl space continues to be considered as a contaminated area. Although not approved, the contractor had extensively spray-applied bleach to many interior surfaces.
- Installed a dedicated crawl space exhaust fan to provide continuous depressurization and ventilation.

Remediation Outcome:

The crawl space remediation project was completed in November 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 July 2007 a follow-up inspection was done of the crawl space area 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 good condition. At the time of the inspection there was no evidence 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, insect carcasses) were present 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 moderate to large stains on the floor barrier were observed directly under the suspended crawl space piping, which was indicative of piping leaks. The installation of removable rubber floor mats allowed them to be moved for maintenance and cleaning, and provide a more comfortable surface for moving throughout the crawl space. With the exception of the stains, it was noted that the floor barrier was in excellent condition, the tape was well attached and the Permalon™ 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 (including the Hilti™ anchors) were firmly attached, maintaining an airtight seal of the floor barrier. 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, although the semi-aggressive bleaching method

used for the cleaning of mold on the wooden components appeared to leave some residual staining/markings on some sections of the floor joists.

There was no evidence of rodent activity (carcasses, droppings, floor barrier damage) within the remediated the crawl space.

Overall, the crawl space remediation project was effective in resolving the past structural, microbial and water entry issues and has provided a durable crawl space. The ceiling and direct exhaust from the crawl space are maintained continuously to ensure that contaminated crawl space air does not enter the occupied areas of the building.

Photo 9: Floor barrier, tape and rubber mats are in excellent condition. Floor barrier extends up the concrete piles and is sealed to enclose the base of each column.

Photo 10: Plywood subfloor and floor joists are in good condition and show no evidence of mold re-growth.

Photo 11: Some floor joists show signs of staining, which is most likely residual bleach.

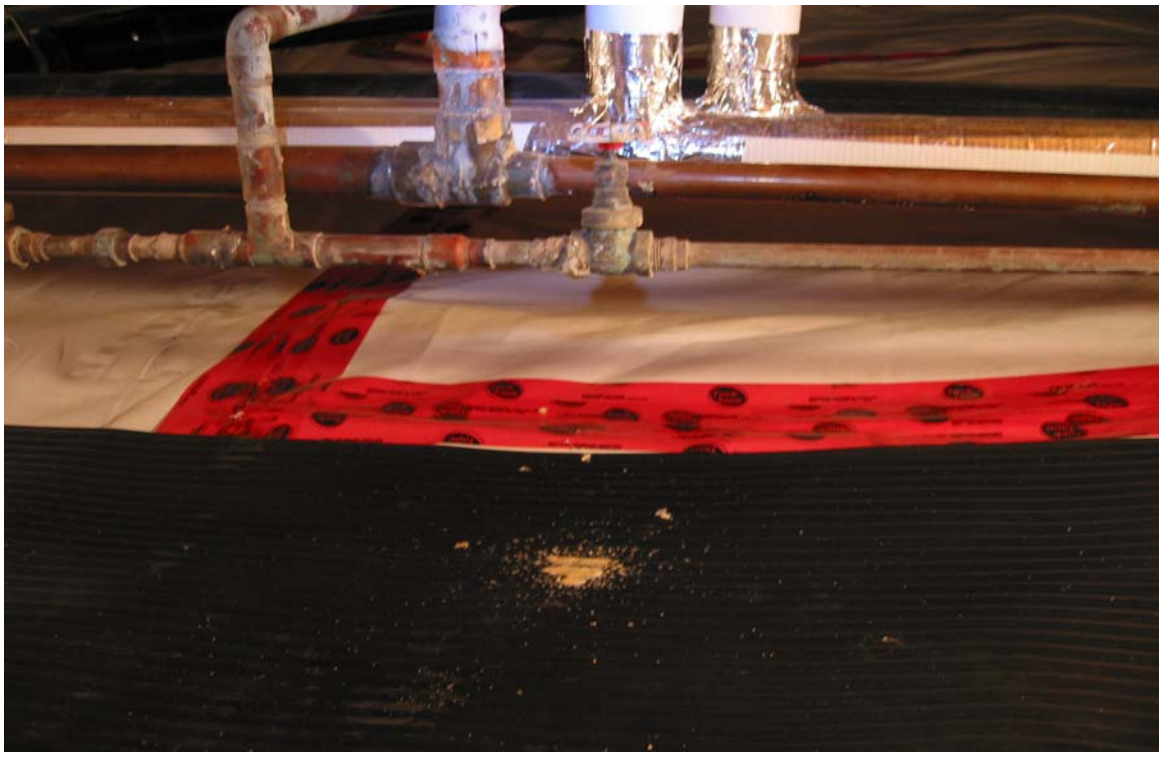

Photo 12: Water and sewer lines are suspended off the crawl space floor. The rubber mats and white floor barrier are helpful in identifying the location of leaks.

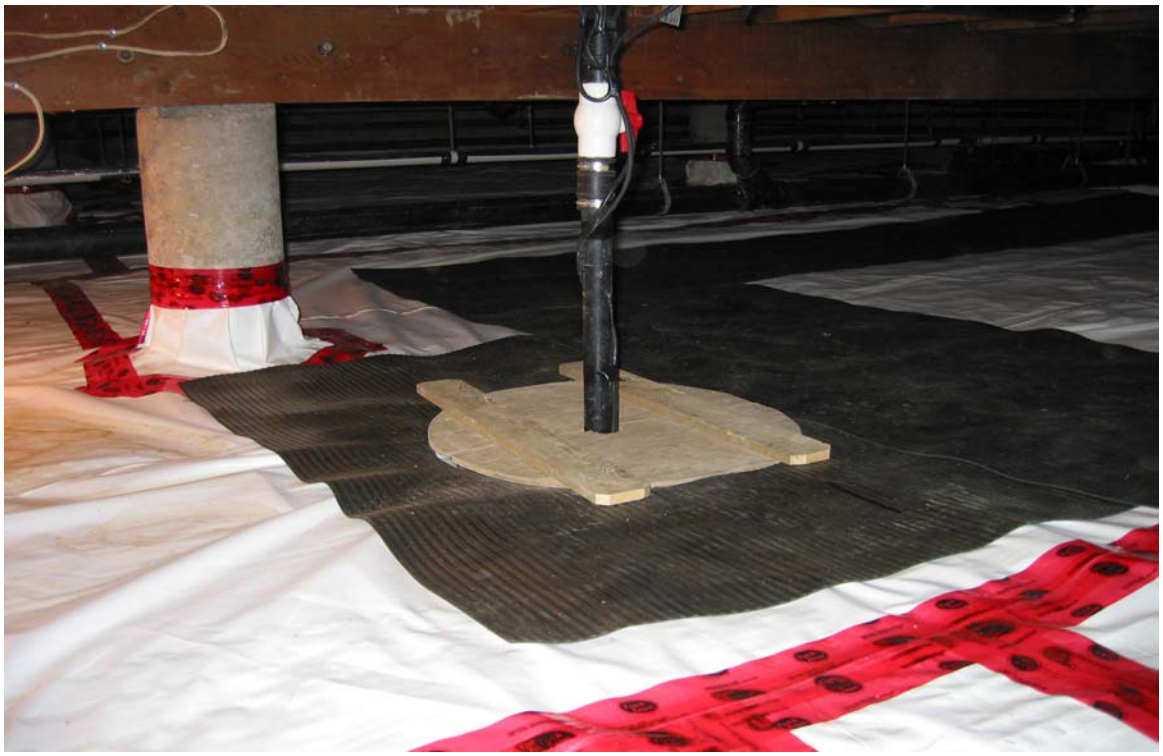

Photo 13: New sump pump installed at a low point in the crawl space.

CMHC Crawl Space Remediation Project

Case Study 5

Building Information:

The Building 5 complex is an 800 m^2, multi-storey apartment facility for senior citizens. It was constructed during the early 1980's and is located in central Saskatchewan. The building is one of six similar structures located on the site, all of which were remediated using the same methods and materials.

The entire facility had an exterior concrete grade beam and concrete pile crawl space foundation with two interconnected crawl space areas. The crawl space areas included a basic excavation below wood beams, floor joists and a plywood subfloor.

Crawl Space Problems/Issues:

The crawl space below Building 5 required modifications to address a number of problems, some of which include: ground and surface water control, microbial contamination (sewage leaks and mold growth), deterioration of piping components, rodents, accumulations of debris, and inadequate ventilation.

Exterior work including landscaping, grading, surface water control and rain water disposal were not included in the crawl space remediation, but were concurrently addressed as a separate project.

Chronic crawl space dampness caused by recurring ground/surface water entry, an inadequate soil barrier and wetting caused by previous and current piping leaks resulted in significant microbial contamination on the insulated water lines, gypsum board fire protective surfaces, exposed soil and other building components. Rodent droppings were present in some of the crawl space areas.

The crawl spaces had a small accumulation of construction materials, abandoned components and other debris. The soil barrier on the floor of the crawl space was badly damaged, missing or displaced in many areas and the soil/sand above the barrier was contaminated.

A number of the water supply piping and sewer piping systems had become deteriorated or defective and had been leaking into the crawl spaces. Numerous soldered joints in copper pipes were corroded and leaking and a number of cast-iron sewer pipes had radial and longitudinal cracks that were allowing contaminated water to leak into the crawl space areas.

The crawl spaces did not contain any building ventilation equipment. Each crawl space had a dedicated, thermostatically controlled outdoor air supply/exhaust fan system that was initially designed to intermittently ventilate and de-pressurize the crawl space.

It appeared that several changes had been made to the original crawl spaces. Some of the main built-up wooden floor beams had gypsum fire guard sheeting that was not indicated on the original building plans. A number of additional beam and support systems had been placed in various areas, presumably to reinforce the main floor against deflection or excessive bouncing. Some plumbing repairs had been undertaken, but were insufficient. Several areas of the polyethylene floor barrier had a second layer added over the original sheeting. Some of the crawl space exhaust fans/intakes were missing or incomplete.

The paper forms used for the piles had not been removed and were highly water damaged and moldy.

The rim joist cavities had been insulated with glass fibre batt filled plastic bag “pillows” that were stuffed into the cavities. Since the edges were not sealed, moisture had condensed behind the insulation and caused significant long-term wetting and rotting of the wood.

The grade beams were insulated with glass fibre batt insulation covered with a polyethylene barrier.

Photo 1: Existing sump pump was dirty and rusted and was not covered or sealed.

Photo 2: Longitudinal cracks were visible on some piping components. Piping was old, deteriorated and rusty.

Photo 3: Debris and water were present on the surface of the existing polyethylene floor barrier.

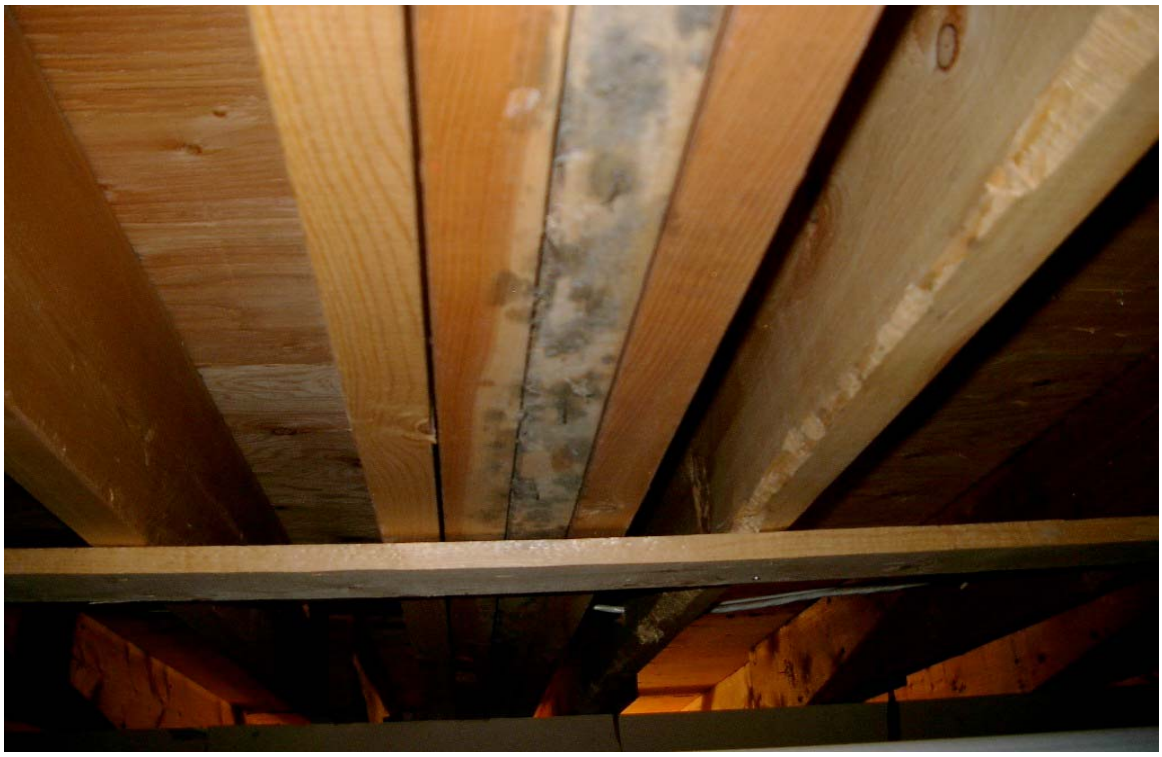

Photo 4: Mold was visible on some of the wooden components within the crawl space area.

Remediation Strategies Employed:

The crawl space remediation project for Building 5 was started in September 2002 and was completed in June 2004, at which time a visual inspection and air samples were taken to assess the outcome of the completed project.

The following is a list of the remediation methods/tasks carried out:

- Removed all interior insulation to expose the rim joists. The grade beam insulation system was retained.
- 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 mold using sanding, scraping, and brushing. Baking soda blasting was initially used, but abandoned due to excessive airborne dust and the immediate plugging of the negative air machine filters with caked soda.
- Installed perimeter drainage system at the interior 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.
- Re-graded crawl space floor. Excavated to establish low points at sump openings.

- Removed all gypsum board fireguard and replaced with new Densglass Gold™ material.
- Installed a new Permalon™ PlyX 200FR floor barrier attached at exterior grade beam using pressure treated plywood battens and mechanical fasteners. The floor barrier was sealed to all concrete piers, piping and other interior penetrations.
- Installed new foil faced rigid mineral fibre insulation in the rim joist cavities and sealed the edges.
- Installed thin rubber mats to establish pathways for inspection and maintenance personnel.
- Conducted detailed cleaning using a HEPA vacuum and damp wiping of all interior surfaces. Although not approved, the contractor had spray-applied bleach to many interior surfaces.
- Installed a dedicated crawl space exhaust fan to provide continuous depressurization and ventilation.
- Installed a two zone Humidiguard™ system to monitor crawl space humidity and detect adverse humidity events.

Remediation Outcome:

The crawl space remediation project was completed in June 2004 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 May 2007 a follow-up inspection was done to assess the long-term results and durability of the overall crawl space remediation project.

The inspection indicated that the crawl space remediation was successful and that the crawl space was in very good condition. The crawl space showed no indication of recent or previous 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.

On the interior of the crawl space a small amount of grit and debris (paper, insects, wood scraps, dirt) was present at the entrance to the crawl space and in various locations on the floor barrier. The installation of the white Permalon™ floor barrier was helpful in indicating locations where leaks had occurred within the crawl space cavity. With the exception of the small stains, it was noted that the floor barrier was in excellent condition, the tape was well attached and mechanical connectors were solid. The removable rubber floor mats provided a comfortable surface for movement within the crawl space and are easily moved for maintenance and cleaning.

There was no evidence of mold re-growth on any of the wood surfaces within the crawl space. The bleaching method used for 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.

Overall, the 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.

Photo 5: Dedicated crawl space exhaust fan provides a continuous negative pressure relative to the main floor of the facility. Fan discharge is ducted to a roof mounted exhaust hood through well sealed and insulated round metal ducting. Humidiguard™ humidity and temperature reference sensor located downstream of each crawl space zone to assess crawl space environment conditions.

Photo 6: Floor barrier is in good condition and tape is well attatched. Concrete piles are wrapped to provide a continuous barrier between the crawl space area and the soil. Densglass Gold™ gypsum fireguard installed on main built up beams.

Photo 7: Foil faced insulation installed on the exterior rim joists. The plywood subfloor and the floor joists show no signs of mold re-growth or deterioration. Floor barrier is well attached and sealed to the existing glass fibre insulation system at the exterior wall.

Photo 8: Rubber mats provide a pathway for maintenance personnel. Sump pumps are covered and sealed and are functioning properly. Piping is suspended off the floor and the pipe insulation is in good condition.

CMHC Crawl Space Remediation Project

Case Study 6

Building Information:

The Building 6 complex is a multi-unit senior's residence that was constructed in the mid-1970's in southern Saskatchewan. The crawl space area below the facility is approximately 1400 m^2.

The entire facility has a heated, conditioned crawl space with an exterior concrete grade beam supported by concrete piles. The built-up wood beams are supported by concrete piles and the floor system is composed of wood joists and plywood subflooring. The crawl space contains a number of ventilation system ducts and potable water and sanitary piping components.

Crawl Space Problems/Issues:

The crawl space below Building 6 required modifications to address a number of problems, some of which included: ground and surface water control, microbial contamination (sewage leaks and mold growth), rodents, accumulations of debris, abandoned piping and inadequate ventilation.

Exterior work including landscaping, grading, surface water control and rain water disposal were addressed as a concurrent project.

Chronic crawl space dampness caused by recurring ground/surface water entry, an inadequate soil barrier, ventilation with unconditioned outdoor air and wetting caused by previous and current piping leaks resulted in significant microbial contamination on the insulated water lines, exposed soil and other building components. Rodent activity and carcasses were evident within the crawl space. The crawl space had an accumulation of construction materials, abandoned components and other debris. The soil barrier on the floor of the crawl space was badly damaged, missing or displaced in many areas and the soil/sand above the barrier was contaminated.

The majority of the duct systems for the facility were routed through the crawl space. In some cases, the ducts were for supply air and had foil faced glass fibre insulation on the exterior. A number of the supply air ducts had discharge points into the crawl space. In other cases, the ducts were for return air or exhaust air and were not insulated or sealed.

The crawl spaces had two dedicated outdoor air exhaust systems that attempted to ventilate and de-pressurize the crawl spaces. Although the air exhaust systems were quite large (the flow was not measured), the supply air discharged into the crawl space and exterior crawl space grilles prevented the fans from effectively depressurizing the crawl space area with respect to the main floor.

Photo 1: Ventilation ducting in crawl space area. Non-insulated sections of piping. Duct sealing was conducted as a final step in sealing and isolating the crawl space before other remediation was initiated.

Photo 2: Rodent activity in crawl space area. Crawl space floor was dirty.

Photo 3: Interior batt insulation on the exterior walls of the crawl space was not sealed or covered. Floor joists are visibly moldy.

Photo 4: Old, corroded piping was a source of water entry into the crawl space.

Remediation Strategies Employed:

The crawl space remediation project was started in November 2001 and was completed in March 2003. Upon completion of the project, a visual inspection and airborne fungi sampling were conducted as components of the final inspection.

The following is a list of the remediation methods/tasks carried out:

- 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 (remove all exposed polyethylene).
- Removed all surface mold using sand blasting, sanding, scraping, and brushing. Sand blasting with commercial grit was used as the main method for bulk surface mold removal from the structure.
- Installed mechanical supports for beam ends. Installed pressure treated wood blocking at all rotted rim joists and sealed all edges.
- Installed exterior perimeter drainage system at the exterior of the grade beam and connect piping to new, covered and sealed sumps located inside.
- Provided durable downspout extensions to move water away from the crawl space exterior.
- Re-grade crawl space floor. Excavated to establish low points at sump openings.
- Installed foil faced mineral fiber insulation on the rim joist and grade beam and sealed all joints.
- Installed a new Permalon™ PlyX 200FR floor barrier attached at exterior grade beam using pressure treated plywood battens and mechanical fasteners. The floor barrier was sealed to all concrete piers, piping and other interior penetrations.
- The large and uneven pile tops (no forms were used in drilled holes) were "wrapped" since cleaning the piles and sealing the floor barrier to the piles was difficult.
- Installed thin rubber mats to establish pathways for inspection and maintenance personnel.
- Conducted detailed cleaning using a HEPA vacuum and damp wiping of all interior surfaces.
- Installed a dedicated crawl space exhaust fan to provide continuous depressurization and ventilation.

Remediation Outcome:

The crawl space remediation project was completed in March 2003, 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 July 2007 a follow-up inspection was done of the crawl space area to assess the long-term results and durability of the overall remediation project.

A thorough 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, the crawl space showed no indication of external water entry, despite the excessive amount of rain that had fallen in the previous weeks. The exterior modifications to the grading of the land near the building and proper downspouts proved to be successful in moving water away from the crawl space perimeter.

On the interior of the crawl space a small amount of grit and debris was present 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 to moderate stains on the floor barrier were observed directly under stained portions of the plywood sub-flooring or directly under crawl space plumbing pipes. With the exception of the localized staining, it was noted that the floor barrier was in excellent condition, the tape was well attached and the Permalon™ wrapping around the piles (although visually crude looking) was in excellent physical condition. The removable rubber floor mats provided a comfortable surface for movement within the crawl space and are easily moved for maintenance and cleaning.

The exterior crawl space walls and floor barrier showed no evidence of outside water entry, although the sumps were filled with water and were actively pumping water that was draining from below the barrier. The batten boards at the exterior (Hilti™ anchors) were solid. The interior foil faced insulation appeared to be in very good condition. 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 sand blasting method used for the cleaning of mold on the wooden components did not appear to cause damage to surrounding building components and was effective in permanently removing the mold from the wood surfaces.

Overall, the 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.

Photo 5: Landscaping around the building has been modified to move water away from the building perimeter.

Photo 6: Floor joists and sub-flooring are in excellent condition after sand-blasting.

Photo 7: Exterior foil faced wall insulation is in good condition.

Photo 8: Tape is in good condition and has not detached from the floor barrier. The Permalon™ wrapping around the concrete piles is in excellent condition. Although crude looking, the wrapping of the piles provided a durable and well sealed system to isolate the piles.

Photo 9: Crawl space area is clean, dry and easily accessible.

CMHC Crawl Space Remediation Project

Case Study 7

Building Information:

The Building 7 facility is a multi-unit apartment complex that was built as a senior's residence in central Saskatchewan in the 1970's. The crawl space area below the facility is approximately 550 m^2.

The facility has two interconnected crawl space areas. The crawl space areas have sand/soil floors that had the original polyethylene ground cover sheet and sand cover in place. The crawl spaces are below wood framed floors with open web wood joists, glue laminated interior support beams, concrete beams and piles.

Crawl Space Problems/Issues:

The crawl space below Building 7 required modifications to address a number of problems, some of which included: ground and surface water control, microbial contamination (sewage leaks and mold growth), accumulations of debris and inadequate ventilation.

Chronic crawl space dampness caused by ground, surface and potable water entry and inadequate ventilation resulted in significant contamination of the soil floor, microbial growth on the insulated water lines and ventilation ducts, and mold growth on the pile forms, wood framing and wood subfloor. A separate structural assessment was conducted (by others) and provided recommendations on issues related to the structural performance of the glue laminated beams used in the floor system. Due to the chronically elevated and highly variable crawl space humidity levels, the glue laminated beams had cracked and delaminated.

The crawl spaces contained supply and return air ducts, ventilation equipment, an extensive piping network of potable water, hot water heating and sanitary piping and equipment to provide some outdoor air exchange within the crawl space.

Exterior work including landscaping, grading, surface water control and rain water disposal were included in a separate concurrent project.

Remediation Strategies Employed:

The crawl space remediation project was started in April 2001 and was completed in September 2002. A complete visual inspection and airborne fungi sampling were conducted as components of the final crawl space inspection.

The following is a list of the remediation methods/tasks carried out:

- Removed all debris (garbage, construction materials, etc.) from the crawl space floor.
- Perforated or removed existing floor barrier membrane.
- Removed all surface mold using sanding, scraping, and brushing.
- Installed perimeter drainage system and connecting piping to new, covered and sealed interior sumps.
- Provided durable downspout extensions to move water away from the crawl space exterior.
- Re-graded crawl space floor. Excavated to establish low points at sump openings.
- Installed a new Permalon™ PlyX 200FR or 6 mil polyethylene floor barrier attached at the exterior grade beam using pressure treated plywood battens and mechanical fasteners. The floor barrier was sealed to all concrete piers, piping and other interior penetrations.
- Installed plywood platforms to establish pathways for inspection and maintenance personnel.
- Conducted detailed cleaning using a HEPA vacuum and damp wiping of all interior surfaces.
- Installed a dedicated crawl space exhaust fan to provide continuous depressurization and ventilation.

Remediation Outcome:

The crawl space remediation project was completed in September 2002, 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 and in July 2007 a follow-up inspection was done to assess the long-term results and durability of the overall crawl space remediation project.

A thorough inspection indicated that the crawl space remediation was successful and that the crawl space was in good condition, although it required a moderate amount of maintenance to address general cleaning and repair issues.

The crawl space showed no signs of external water entry. The exterior modifications to the grading near the building and installation of proper downspouts have been effective in moving water away from the exterior of the building and keeping water out of the crawl space area.

The crawl space had two different floor barrier materials installed during the remediation. In areas where maintenance personnel would frequently work (i.e. around sump pumps or under major ventilation or plumbing), Permalon™ was used as the floor barrier. Polyethylene was used in lower traffic areas (i.e. along the exterior walls of the crawl space) to reduce the cost of the overall remediation project. After five years, the Permalon™ floor barrier (although more expensive) is in excellent physical condition,

whereas the polyethylene has needed repairs in many locations as a result of punctures and tears.

The white Permalon™ floor barrier is also a better surface for indicating stains in areas where water had been present. Moderate to large stains on the floor barrier were observed directly under stained portions of the plywood sub-flooring or directly under overhead piping. The plywood platforms that were installed as pathways were helpful in protecting the floor barrier in high-traffic locations, however the platforms themselves were uncomfortable to use. The thin rubber mats used as pathways in other crawl space remediation projects can be easily moved, unlike the plywood platforms, for cleaning and maintenance, and they still provide extra protection of the floor barrier while offering a more comfortable surface for movement within the crawl space. The plywood platforms showed signs of water markings but were in good condition. With the exception of the stains observed and one specific location of the floor barrier that had been penetrated and not resealed by a maintenance personnel (see photo below), the floor barrier was in good condition and the tape was well attached.

The exterior crawl space walls showed no evidence of outside water entry and the batten boards at the exterior were solid. There was no evidence of mold re-growth on any of the wood surfaces within the crawl space and there was no evidence of rodent activity in the crawl space.

Overall, the crawl space remediation project was effective in resolving the past structural, microbial and water entry issues, however, continuous maintenance and cleaning is requiring in order to protect the crawl space area from deteriorating.

Photo 1: Floor barrier surrounding a new piping installation has not been sealed. Debris from the installation has not been removed and is scattered on the floor barrier.

Photo 2: Wood pathways were installed for inspections and maintenance personnel, but are uncomfortable to kneel on and difficult to move for maintenance and cleaning. The floor barrier shows debris and a history of water entry.

Photo 3: Extensive sweating on cold water pipes has caused stains on the floor barrier and has affected attachment of the tape.

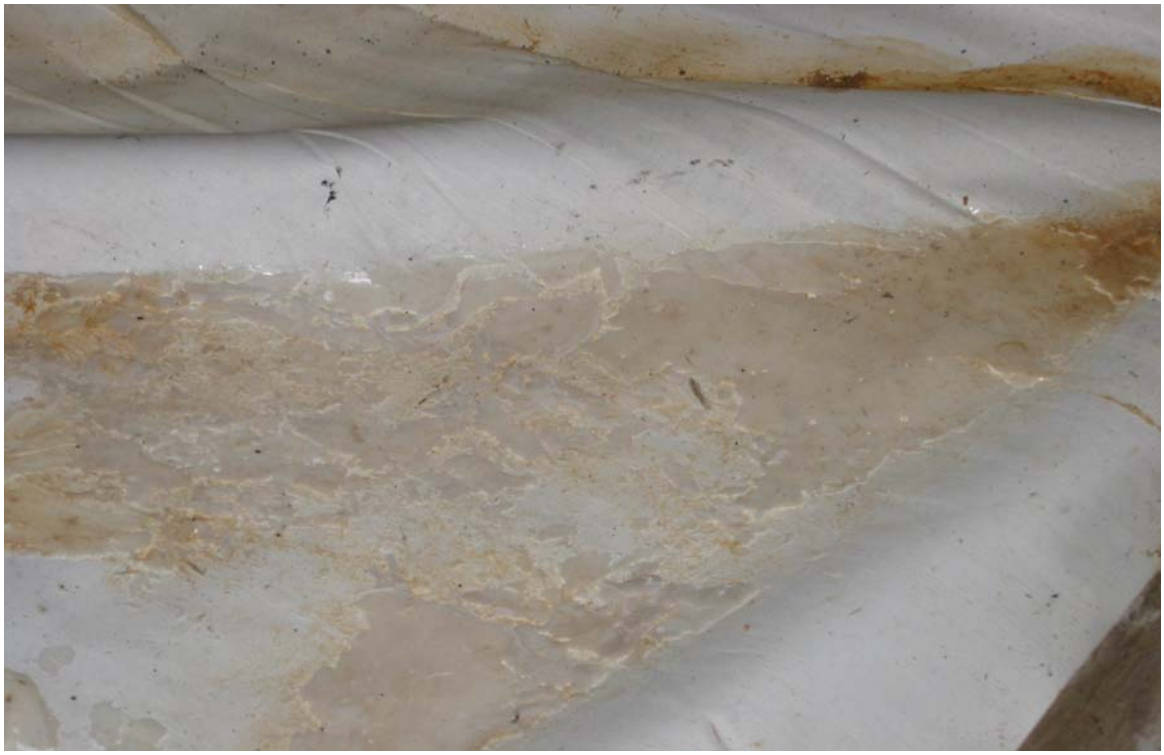

Photo 4: White crystals (either bleach residue or mineral deposits) are found on the floor barrier.

Photo 5: The floor barrier, with the exception of the stains and specifically damaged areas, is in good physical condition. The floor barrier is a mixture of Permalon™ and polyethylene.

Photo 6: Exterior landscaping and downspouts have been effective in moving water away from the exterior of the building.

Photo 7: The crawl space has a dedicated exhaust fan installed to provide a continuous negative pressure in the area relative to the main floor. The fan discharge is ducted to a roof mounted exhaust hood through well sealed and insulated round/rectangular metal ducting.

CMHC Crawl Space Remediation Project

Case Study 8

Building Information:

The Building 8 complex is a multi-unit senior's residence that was built in the mid-1980's in southern Saskatchewan. The crawl space area below this facility is approximately 1300 m^2.

The entire facility has an exterior concrete grade beam and concrete pile crawl space foundation with two interconnected crawl space areas. The crawl space areas include a basic excavation below wood/steel floor trusses and an OSB subfloor. The crawl space contains a number of duct system and potable water/sanitary piping components.

Crawl Space Problems/Issues:

The crawl space below Building 8 required modifications to address a number of problems, some of which included: ground and surface water control, microbial contamination (sewage leaks and mold growth), rodents, accumulations of debris, and inadequate ventilation.

Exterior work including landscaping, grading, surface water control and rain water disposal were not included in the crawl space remediation, but were addressed in a concurrent project.

Chronic crawl space dampness caused by recurring ground/surface water entry, an inadequate soil barrier, ventilation with unconditioned outdoor air, and wetting caused by previous and current piping leaks resulted in significant microbial contamination on the insulated water lines, smoke/fire separation walls, exposed soil and other building components. Rodent activity and carcasses were evident within the crawl space.

The crawl spaces had a small accumulation of construction materials, abandoned components and other debris. The soil barrier on the floor of the crawl space was badly damaged, missing or displaced in many areas and the soil/sand above the barrier was contaminated.

The majority of the supply and return air and crawl space ventilation duct systems and components for the facility were located in the crawl space. The return fan for the building ventilation system had a discharge point in the crawl space.

The crawl space had a dedicated outdoor air supply system that was designed to ventilate and pressurize the crawl space, and the system relied on passive relief vents for exhaust. The system had been reversed to provide a continuous exhaust (up through the existing outdoor air "supply" duct) and the existing "relief" air duct had been sealed off. The changes to the system exhausted air from the crawl space, but due to duct/equipment air

leakage from the ventilation system components, the crawl space was operating under a positive pressure with respect to the main floor.

Remediation Strategies Employed:

The crawl space remediation project was started in December 2001 and was completed in August 2002. As components of the final inspection, airborne fungi samples were taken following a thorough visual inspection.

The following is a list of the remediation methods/tasks carried out:

- Removed all interior insulation to expose the rim joists.
- Removed all debris (garbage, construction materials, etc.) from the crawlspace floor.
- Perforated or removed existing floor barrier membrane (removed all exposed polyethylene).
- Removed all surface mold using sanding, scraping, brushing and bleaching.
- Installed interior perimeter drainage system at the base 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.
- Re-graded crawl space floor. Excavated to establish low points at sump openings.
- Installed foil faced mineral fiber insulation on the rim joist and sealed all joints.
- Installed a new Permalon™ PlyX 200FR floor barrier attached at exterior grade beam using pressure treated plywood battens and mechanical fasteners. The floor barrier was sealed to all concrete piers, piping and other interior penetrations.
- Installed thin rubber mats to establish pathways for inspection and maintenance personnel.
- Conducted detailed cleaning using a HEPA vacuum and damp wiping of all interior surfaces. Although not approved, the contractor had extensively spray-applied bleach to many interior surfaces.
- Installed a dedicated crawl space exhaust fan to provide continuous depressurization and ventilation.
- Replaced/repaired the moldy type x gypsum board smoke/fire walls with new pressure treated lumber and plywood smoke separations.

Remediation Outcome:

The crawl space remediation project was completed in August 2002, 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 July 2007 a follow-up inspection 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, the crawl space showed no indication of external water entry, regardless of the large amounts of rain that had fallen in the weeks prior to the follow-up inspection. 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.

On the interior of the crawl space a small amount of grit and debris (insulation, wood shavings) were present on the floor barrier throughout the crawl space area. The installation of a white floor barrier in the remediation project was helpful in indicating the locations 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 or the crawl space piping.

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 Permalon™ wrapping around the piles was in excellent physical condition. The installation of removable rubber floor mats allowed them to be moved for maintenance and cleaning and also provided extra protection of the floor barrier.

The exterior crawl space walls and floor barrier showed no evidence of outside water entry, although the sumps were filled with water and were actively pumping water that was draining from below the barrier. The batten boards at the exterior (Hilti™ anchors) were solid. The foil faced insulation installed on the rim joist was in good condition and showed no signs of water damage or deterioration. There was no evidence of mold re-growth on any of the wood surfaces within the crawl space. The semi-aggressive bleaching method used for the cleaning of mold on the wooden components did cause some deterioration to the galvanized metal ducting in the crawl space, and bleach crystals are still present on the floor barrier throughout the crawl space.

Overall, the 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.

Photo 1: Exterior landscaping allows water to be moved away from the building exterior.

Photo 2: Bleaching of the wood joists has caused damage to the galvanized metal ducting within the crawl space area.

Photo 3: Crystallized bleach remains on the crawl space floor barrier from the bleaching method used for mold removal.

Photo 4: Crawl space floor barrier and tape is in good condition. The installed rubber floor mats, which can be moved for cleaning and maintenance, are useful in enhancing the durability of the floor barrier.

Photo 5: Floor barrier is clean and in excellent physical condition. The Permalon™ floor barrier extends part way up the exterior crawl space wall and merges with poly sheeting, which covers the remaining exterior walls. Wooden joists show no signs of mold re-growth or deterioration from extensive bleaching methods.

Photo 6: Rust is present on many of the crawl space piping components as a result of the use of bleach for mold removal.

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