First Floor Slab Evaluation

Northfield Fire Station

93 Main Street

Northfield, MA

Prepared for:

The Town of Northfield

69 Main Street

Colrain, MA

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TABLE OF CONTENTS

1. DESCRIPTION OF PROJECT

This report is a structural evaluation of the first floor slab and the supporting walls and beams for the fire station located at 93 Main Street, Northfield, Massachusetts.

The evaluation was based a visual survey of the buildings when visited on August 28 and September 11, 2019 and a review of the drawings by James E. Britton, A.I.A., dated 8/15/53.

No selective demolitions, such as cutting or drilling holes into floors, walls or ceilings, were performed. No excavations were made at the foundation perimeter.

Photographs were taken depicting various conditions. They are included in Appendix C. Some measurements were taken to confirm the dimensions depicted on the Britton drawings.

A copy of a portion of the structural drawings depicting the first floor slab layout is attached as Appendix A, page 11. Refer to the layout plan for slab panel and beam nomenclature.

The fire station is a two story building constructed with concrete block and brick veneer walls built on a concrete foundation (cover photo.) The roof is wood framed.

The lower slab, accessed at grade on the back side of the building, was referred to as the basement level in the Britton drawings, and the upper slab referred to as the first floor slab. This report uses the same nomenclature. The basement slab was not evaluated, although it appeared to be in good condition with some oil stains. It should be sealed with concrete sealer every few years to keep it in good condition. Slabs constructed on solid soil may crack and deteriorate, but they do not fail because of the continuous support of the soil.

It was reported that an evaluation of the first floor slab was conducted sometime in the 1970's. The report was not available at the time of this report. Apparently, at the time there was concern about water that had been seeping through a construction joint that ran longitudinally through the two center bay panels. The report recommended that panels 3 and 6 be retrofitted with an expansion joint to be cut along the construction joint to provide a groove for caulking. The expansion joint was cut and the caulking installed.

2. USE GROUP AND BUILDING CLASSIFICATION.

The following information was included to assist in considerations that involve the future use of the building:

The relevant Massachusetts State Building Codes are the International Building Code, the International Existing Building Code and the Massachusetts Amendments to those codes. The code requires that a building be classified under one of several categories.

The classification information is necessary when considering a Change of Use for a building or a portion of a building. When making such a change, the building code requires that the changed area be altered to meet the building code requirements for the new use. Typically, the building inspector will require that the owner commission a formal code review to determine the requirements.

The use group of an existing building is based upon to the actual use of the building or portion thereof. The fire station is a Mixed Use building.

Use Groups:

Training Room/Offices: Group B, Business

Apparatus Parking Bays: Group S-2, Low Hazard Storage

The Type of Construction needs to be determined when a change of use is considered. This classification has to do with the fire resistance capacity of the construction materials used in the floors, walls, and ceilings.

Construction Type: IIIB, exterior and interior walls and floors are non-combustible, roof framing is combustible material, wood.

The Risk Category is based on the use of the building relative to the hazard to public safety if he building should fail. The Risk Category is used in structural analysis and design. Fire Stations are classified as Risk Category IV, Buildings or Other Structures Designated as Essential Facilities. Business buildings are in category II.

When considering alternative uses for the first floor, the capacity of the floor needs to be considered. The following are some of the building code minimum load requirements for various uses:

1. Passenger vehicles:	40 psf. or 3,000 lbs. concentrated load
2. Manufacturing, heavy:	250 psf. or 3,000 lbs. concentrated load
3. Manufacturing, light:	125 psf. or 2,000 lbs. concentrated load
4. Offices:	50 psf. or 2,000 lbs. concentrated load
5. Assembly areas with moveable seats:	100 psf.
6. Assembly areas with fixed seats:	60 psf.
7. Library stack rooms	150 psf or 1,000 lbs. concentrated load
8. Restaurants	100 psf.

Based on the Recommendations (see Section 8), the first floor (once repaired) would have the capacity to support any of the listed uses, except for heavy manufacturing.

3. DISCUSSION OF CONCRETE SLABS AND BEAMS.

The main concern about the building's condition involve the condition of the first floor slab and supporting beams in the middle bay. A discussion of the performance of concrete slabs and beams under loads is presented to assist in understanding the evaluation.

The first floor slab and the concrete beams were poured monolithically. The slab and the beams are tied together by the steel reinforcing system. If a portion of a slab and beam system is weakened, the entire system is weakened.

When a load is applied to the top of a beam, the beam bends downward. At the point of application of the load, the bending is at its maximum, which results in tensile stresses in the bottom of the beam and compressive stresses in the top.

Concrete is very strong when compressed, so the concrete alone is designed to resist the compressive stresses.

Concrete is about 1/10th as strong in tension, so steel rebars are placed in the lower portion of the beam to resist the tensile stresses. In order for the rebar to take tensile the stress, the concrete has to exceed its' tensile capacity, whereupon the concrete cracks. Once the concrete cracks, the steel rebar is engaged to take the tensile stress. By design, the concrete tension cracks are limited to a less than 0.0014 in. (about 0.036 mm.) If the cracks exceed 0.0014 in. in width, the steel rebars are taking more stress than the designer intended. If that occurs, an additional load could cause failure on the concrete.

For slabs, the same principles apply, except that the tensile stresses are in the top of the slab at the support beams and at the walls. The tensile stress is in the bottom of the slab over most of the span.

In the Britton drawings, the slab in the office side is labeled as panel 1. Panel 1 is described as a one way slab. That indicates that the slab reinforcing is designed to resist the load by spanning the distance between supports in one direction, in this case north/south.

The slab panels (panels 2-7) in the garage areas are labeled as two way slabs. Two way slabs are designed with reinforcing running in both directions. The reinforcing is balanced to share the load and transfer it to the supporting beams/ walls. The two way slab is able to support a greater load than a one way slab of equal thickness.

It is important to note that tensile cracks that exceed 0.0014 in. wide, whether on the top or bottom side of a concrete beam or slab, indicate that the beam or slab has been loaded beyond the capacity of the beam or slab.

The tension side cracks in concrete beams and slabs were measured to determine if they are within the allowable range.

Spalling occurs when a portion of concrete breaks away from the slab. It can be caused by impact from a falling object, corrosion of rebar in the slab, weathering of the concrete due to water absorption and freeze/thaw cycles, and de-icing compounds absorbed by the concrete. The cause of spalling in a specific area cannot always be determined.

In areas where pieces of the concrete have spalled off and the rebar is exposed and rusted, water absorption was the cause. Water in the concrete causes the rebar to rust. When steel rusts, it expands up to 7 times the original steel thickness with a pressure of up to 9,000 psi. which exceeds the tensile capacity of the concrete, therefore, the concrete breaks. The exposed steel still has some capacity to support loads, but the lack of concrete cover over the rebar and the reduction in the cross section of the rebar disallow the use of the methods used to calculate the strength of a concrete member. Therefore, the capacity is unknown.

4. SLAB ANALYSIS.

For design purposes, the American Association of State Highway Transportation Officials (AASHTO) has established standard truck loading criteria for highways and bridges (See Appendix 2.) At the time of the fire station design, the 1944 AASHTO standards were in use. The same loads were used in design of heavy vehicle garage floor slabs at the time.

An analysis of the first floor slab was performed based on the information provided in the structural drawings (S.1 and S.2 by Britton.) The analysis was based the procedures established in the American Concrete Institute's design manual titled Building Code Requirements for Buildings and Other Structures (ACI-318.) The current method for design and analysis of concrete structures (Ultimate Strength Design) is more complex that the method (Working Stress Design) used in used in 1953. Nevertheless, the current method was used for the analysis.

From the calculations, it was concluded that the garage bay slabs were designed for 24,000 lbs. axle load. This corresponds to AASHTO's H15-44 or HS15-44 design load requirements for a 15 ton vehicle. The H15 load corresponds to a two axle truck and the HS15 corresponds to a three axle truck. Either way, the maximum design load was 24,000 lbs. per axle.

The slab panels were also analyzed for uniformly distributed load capacity. They were designed for the wheel load, so the capacity varied widely for the various garage panels, but in general, the garage slabs were designed to support at least 300 lbs. per square foot (psf.)

In the middle bay, Panels 3 and 6 were modified when the expansion joint was cut into the center of the panels (photos 4, 7.) Those two panels were analyzed with the slab depth reduced to 5 in. The result was that, as modified, the slab capacity was somewhat reduced, yet still capable of supporting the 24,000 axle load. However, the cracking and spalling of the concrete and the exposed rebar on the underside of the slab (due to water infiltration) are evidence that the slab is no longer intact and is incapable of supporting the design load (see Recommendations for Slab Loading, below.) The current safe loading capacity is unknown.

Panel 1, in the office area, was analyzed as a one-way slab. The slab capacity was calculated to be 160 lbs. (psf.)

5. BEAM ANALYSIS.

The beams, columns, and walls supporting the slab (in the basement) were examined to determine if there was evidence of excessive stress. In general, the cross beams, columns, and the walls did not show cracks or spalling.

The one exception is beam #5, spanning north/south under the middle bay (photos 10 - 14.) It was assumed that this beam was compromised by the leak at the expansion joint. It is cracked in the middle (0.016".) It is no longer capable of safely supporting the design load. Its current safe loading capacity cannot be determined by calculation.

The concrete beams over the lower level overhead doors (Beams 1, 2, and 3) did exhibit excessive cracking and spalling (photos 14 - 18.) An analysis of these beams was performed which indicated that the lintels were designed to support the wall and roof above and the load from the slab relative to the 12,000 lbs. axle load. However, the degree of cracking in all three beams indicates that the beams have been overstressed. Because of their exposure to weather and the spalled concrete in the middle beam, it was assumed that rusted rebar was the cause of the cracks. Again, the current capacity is something less than the design load.

6. OBSERVATIONS.

A. FIRST FLOOR SLAB

The slab in the office area was in good condition.

In the three parking bays, there was evidence of some surface cracking and spalling at the door openings and at several places in the field (photos 1 - 9.) The spalls at the door openings were due to water absorption. At other locations, the spalls may be due to standing water absorbed at low points, road salt, impact from dropped equipment, or overloading. The capacity of the slab was not impacted by the top surface spalls.

In the center bay, the expansion joint caulking was observed to be dried and shrunken, and no longer effective at preventing water from entering the slab (photos 4, 7.) In the basement, there was cracking and spalling of the underside of the slab and six exposed rebar directly under the expansion joint (photos 10 - 14.)

The slab was supported by interior beams running both north/south, and east/west. The top of the slab is cracked above both of the east/west running beams (between bays1 and 2, 2 and 3) (photo 7.) The width of the cracks varied from 0.007 in. to 0.04 in., exceeding the maximum of 0.0014 in. These cracks are a concern. They indicate that the slab has been loaded beyond its capacity.

B. BASEMENT OVERHEAD DOOR LINTELS.

The three concrete beams that span across the overhead door openings exhibit vertical cracks on the outside face as well as horizontal cracks on the underside (photos 15 - 21.) The center bay exhibits spalling of the concrete and exposed rebar. The cracks are consistent with beams that have exceeded the design capacity. Expansion of water entering the cracks exposed to freeze/thaw cycles has likely increased the width and depth of the cracks. The analysis indicated that the three beams should have been able to support the axle loads from the slab.

D. BASEMENT BLOCK WALL.

The concrete block wall between the boiler room and the adjacent parking bay exhibits a vertical crack along the mortar joint running from floor to ceiling (photos 22, 23). The crack is most likely caused by settlement of the soil beneath the footings. It is not a danger, but it should be repaired as recommended below.

E. FIRST FLOOR BLOCK WALLS.

The concrete block walls on the north, east, and south sides of the parking area are all exhibiting cracking of the mortar joints (photos 24 - 28.) On the north and south sides, the cracking is most likely due to settlement of the foundation. They do not present a danger, but they should be repaired as recommended below.

On the east side, the cracks are more extensive. They are due to the stress in the wall resulting from the overstressed beams below at the overhead doors.

F. CHIMNEY.

The brick chimney exhibited some spalling of the bricks and some deterioration of the mortar joints of the bricks (photos 29, 30).

G. NORTH WALL.

The north wall exhibited some cracking behind the antennae tower and at the edge of the window (photos 31 -34.) Also, there was some damage at the northeast corner that had been repaired with caulking. The caulking should be removed and the wall patched as described in the Recommendations.

H. EXTERIOR STAIRS.

At the northeast corner, there is a broken-down set of concrete stairs (photo 35.) The stairs are in poor condition and are a safety hazard. They should be removed. If replaced, the new stairs need to meet the Building Code Requirements for commercial building stairs.

7. RECOMMENDATIONS FOR REPAIRS.

The following recommendations are for repairs to prevent further deterioration of the slab, beams and walls. The repairs will maintain the reduced capacity of the slab, but will nor restore it to its former capacity.

The products recommended are expensive and require very specific preparation and application procedures as described in the manufacturer's instructions. Application should be performed by an experienced concrete repair contractor. An engineer should be employed to verify the products and construction methods. Substitutions should only be used if approved by an engineer.

The following repairs are recommended:

1. Patch the top of the first floor slab where damaged with Silpro Feather Spread RPS concrete repair mortar.
2. Seal the slab to prevent further water infiltration (Silpro Silocks Plus, SuperSeal25.)
3. Repair the underside of the floor slab. Remove loose concrete. All rusted rebar will need to be exposed on all sides and cleaned to bare metal. Concrete edges will have to be saw-cut with an undercut and deteriorated concrete will have to be removed. Patch with Silpro's SilproRepair™ VOH.
4. Repair the concrete beams over the lower level overhead doors using Silpro's SilproRepair™ VOH.
5. Repair Beam #5 using Silpro's SilproRepair™ VOH.
6. Where cracked, repair the concrete block walls in the basement and first floor levels with Quikwall Surface Bonding Cement (manufactured by Quikrete) or similar product.
7. Remove the caulk from the expansion joint and re-seal with elastomeric joint filler.
8. Re-point the chimney where needed and replace any spalled bricks.
9. Patch the cracks in the exterior concrete wall on the north side with Simpson Strong-Tie's ETI Injection Epoxy.
10. Patch the spalled concrete at the northeast corner of the foundation wall with SilproRepair™ VOH.
11. Replace the exterior stair and retaining wall in the northeast corner.

Simpson Strong-Tie's FX-263 Rapid-Hardening Vertical/Overhead Repair Mortar may be substituted for SilproRepair™ VOH.

Consideration was given to possibly restoring the slab to a 24,000 lbs. axle load capacity by removing the middle bay slab and support beam (Beam #5) and installing a new floor system in that area. Beams #1, #2, and #3 would also have to be either replaced or reinforced.

This is an impractical solution because the slab and beams were designed and built to act together. Cutting and removing the middle section of the slab would reduce the capacity of the adjacent bays because of the discontinuity of the concrete. Therefore, those slabs would also need to be reinforced which would increase the load on the support beams, most likely requiring reinforcing for the entire floor system. As a consequence, the basement ceiling height would be reduced. This would be a very expensive solution to design and implement.

8. RECOMMENDATIONS FOR FIRST FLOOR SLAB LOADING.

The extent of the rust on the (concealed) rebars in the slab, Beam #5, and the overhead door beams is unknown. Whether the slab was ever loaded with a vehicle that exceeded the 24,000 lbs. axle load is also unknown. The cracking of the concrete does indicate that the safe load capacity of the slab and beams was exceeded.

At this time, the capacity of the slab is reduced due to the cracking and corroded rebar. The repairs will prevent further deterioration, but will not restore the capacity of the slab and beams to the original value. There is no way to numerically determine the remaining safe load capacity.

Given that the capacity is unknown and that failure could mean sudden collapse of the floor, a conservative judgment was made regarding the future use of the second floor. It is recommended that after repairs are made, the first floor slab be limited to Class 3 Light-Duty Trucks with a GVWR of 14,000 lbs. or less.

Additionally, future uniformly distributed loads on the repaired slab should be limited to a maximum of 150 psf. which would permit all the Use Groups listed above, except for Heavy Manufacturing.

Truck Classification	GVWR* (lbs.)
Light-Duty Trucks	
Class 1	0-6,000
Class 2	6,001 – 10,000
Class 3	10,001 – 14,000
Medium-Duty Trucks	
Class 4	14,001–16,000
Class 5	16,001–19,500
Class 6	19,501–26,000
Heavy-Duty Trucks	
Class 7	26,001 to 33,000
Class 8	Over 33,001 pounds
	*Gross Vehicle Weight Rating

9. CONCLUSION

The first floor slab is no longer capable of safely supporting the heavy trucks for which it was intended. The recommendation is to limit the use of the first floor to parking vehicles weighing less than 14,000 lbs. The recommended repairs should be made to prevent further damage to the structure and to insure the continued safety of the people that use the building.

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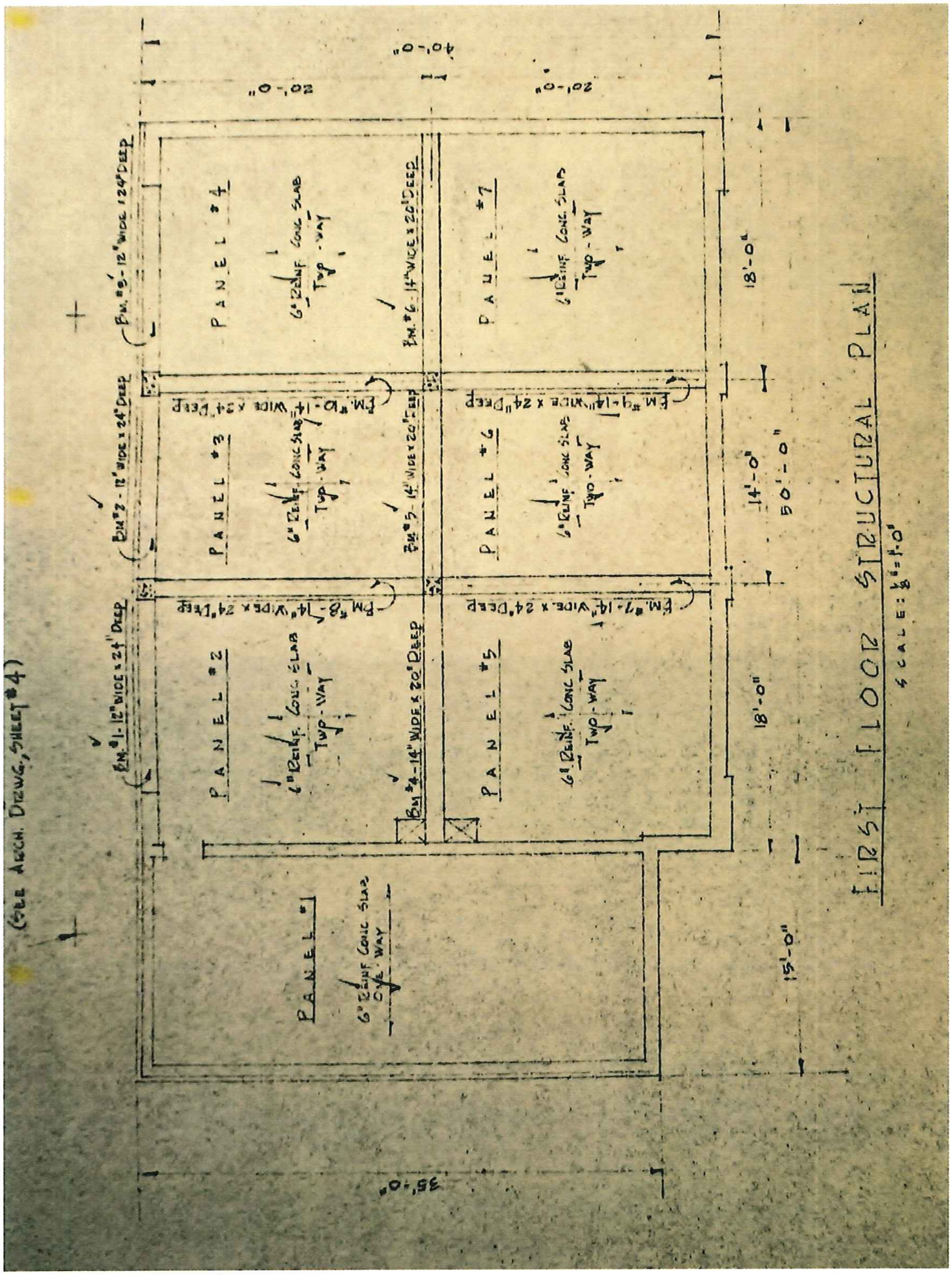
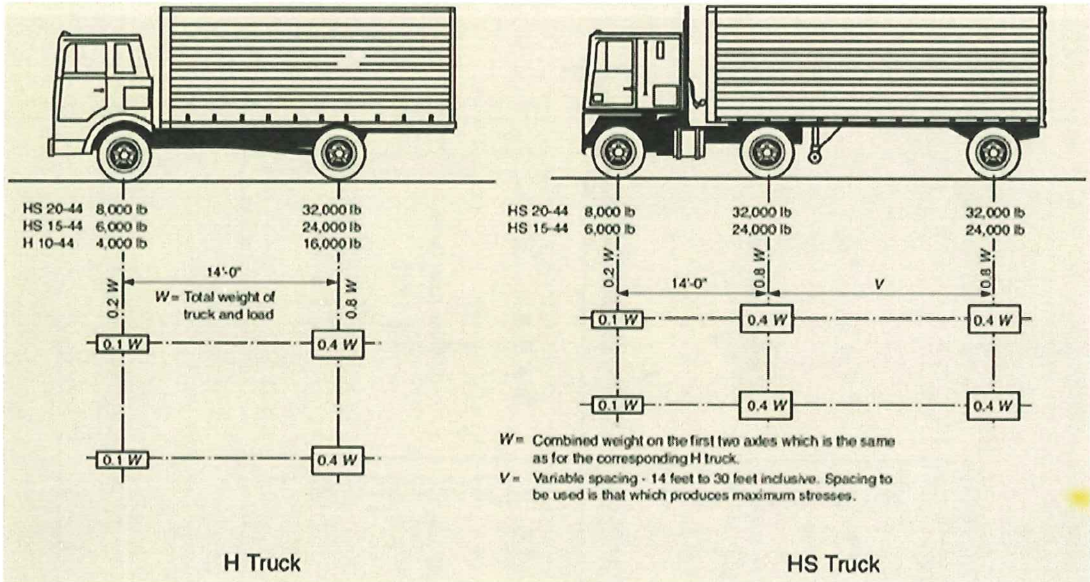
APPENDIX A – SLAB LAYOUT



First Floor Slab Plan – copied from 1953 drawing S-2, James A. Britton, A.I.A.

APPENDIX B – AASHTO DESIGN TRUCK LOADS



APPENDIX C – PHOTOS

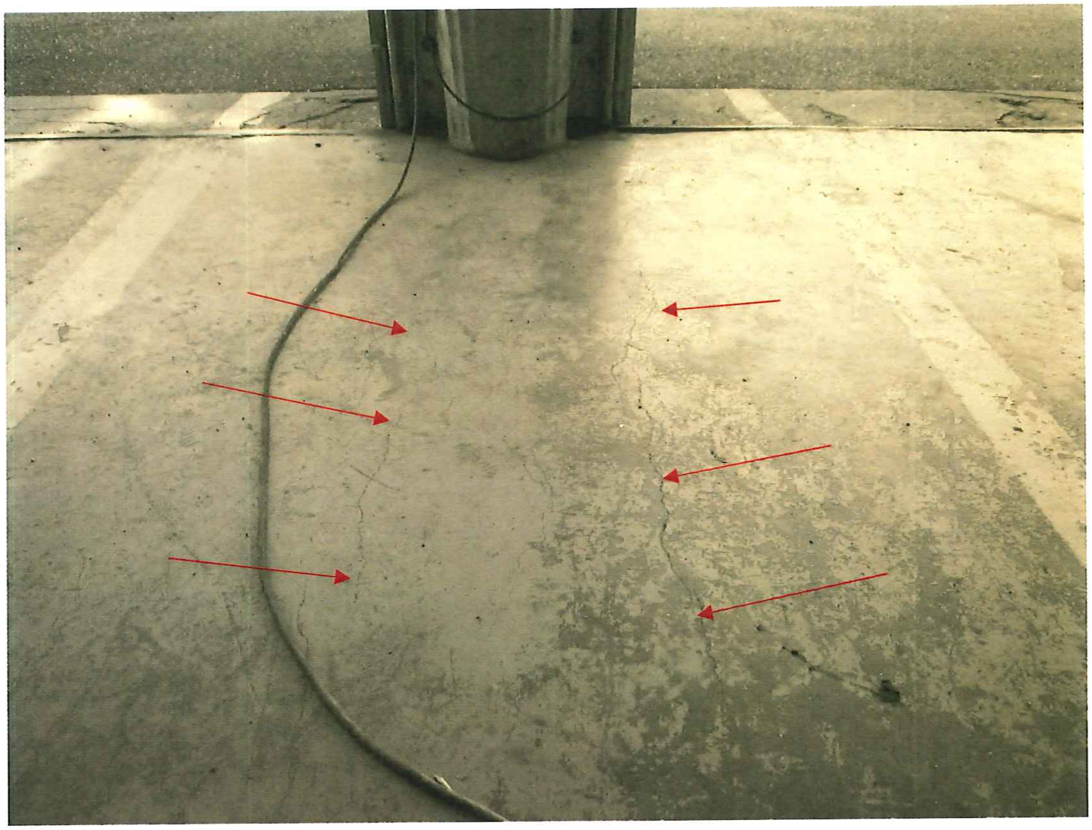
1. First Floor, Bay 1 slab. Spalls at apron and front of slab.

2. First Floor, Bay 1 slab. Enlarged spalls at apron and front of slab.

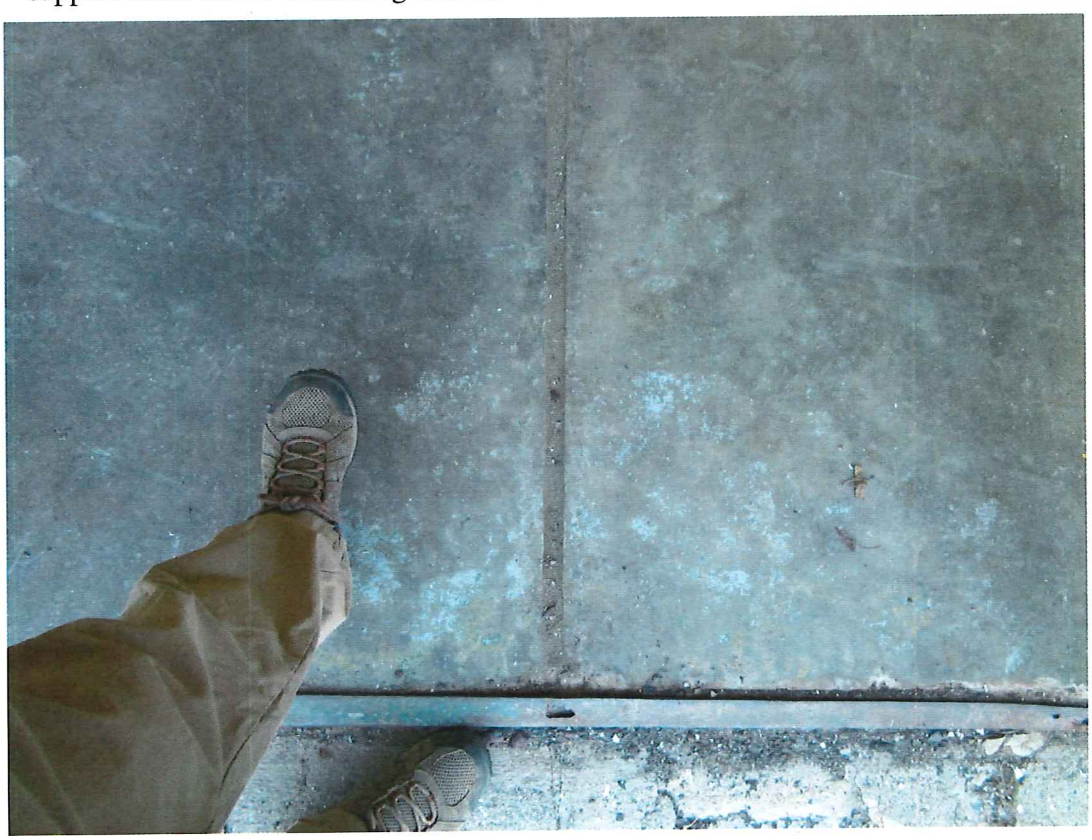
3. First Floor, Bay 1 slab. Surface spalls.

4. First Floor, Bay 2 slab. Surface spalls at apron and front of slab. Expansion joint.

5. First Floor, bay 2 Slab. Surface spalls.

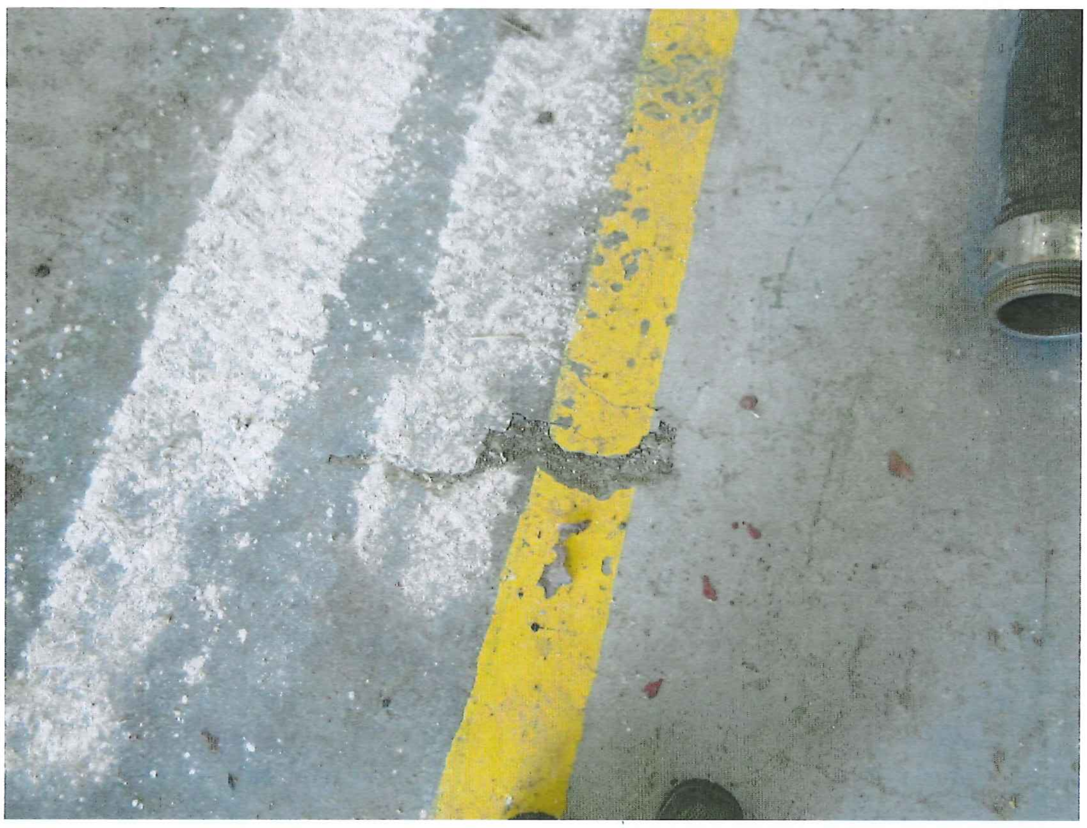


6. First Floor, between bay 2 and bay 3. The parallel cracks are right over the edges of the support beam below indicating that the slab has been overstressed.

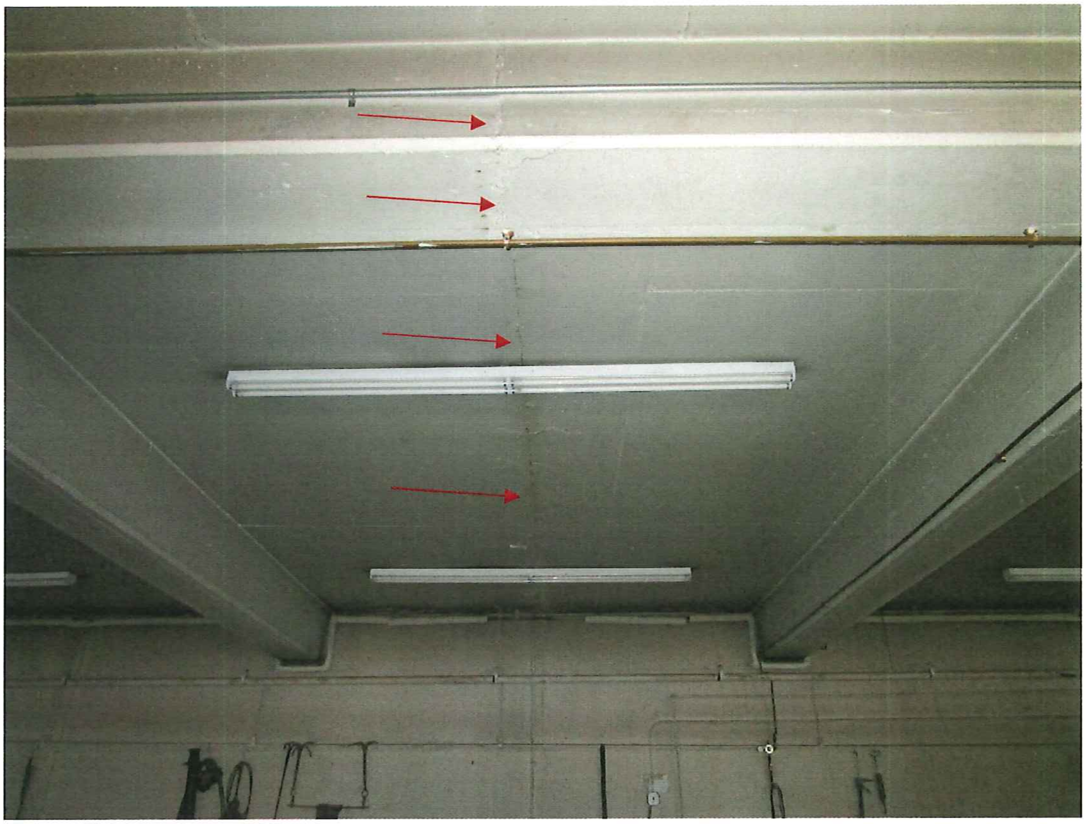


7. Bay 2 Slab. Expansion joint. Caulking is dried out and shrunken.

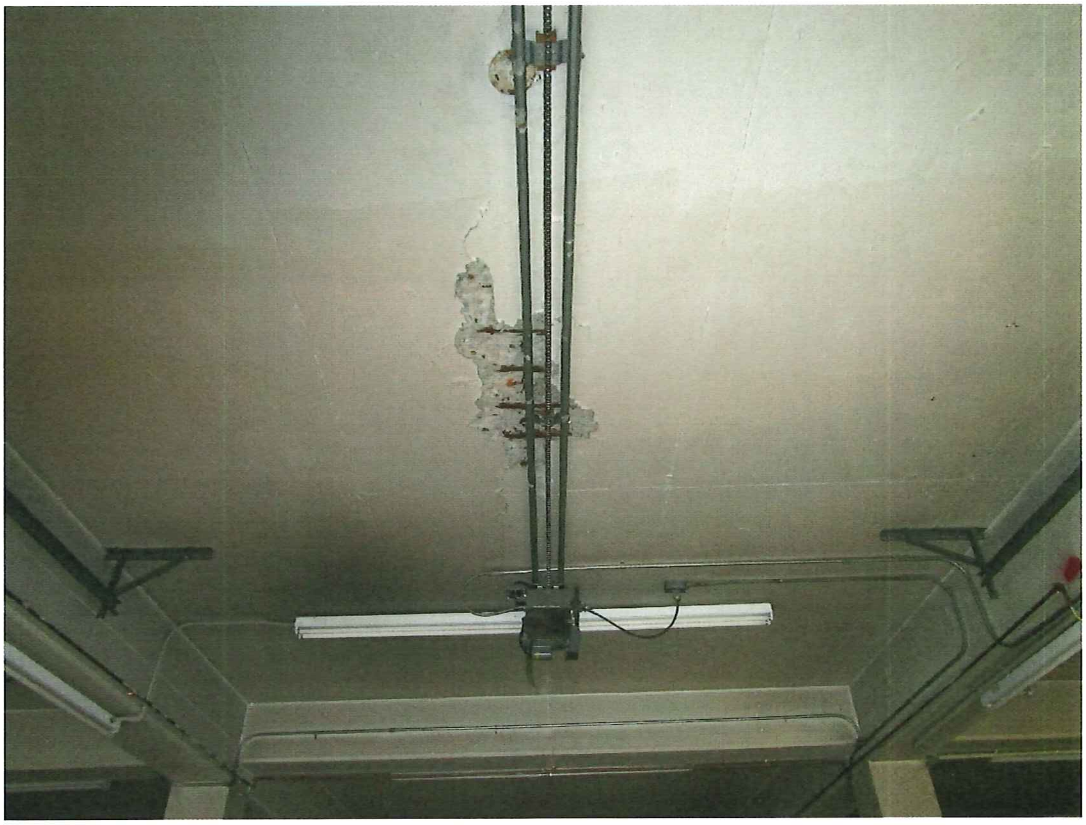
8. Bay 3 Slab.



9. Bay 3 Slab. Surface spalls.

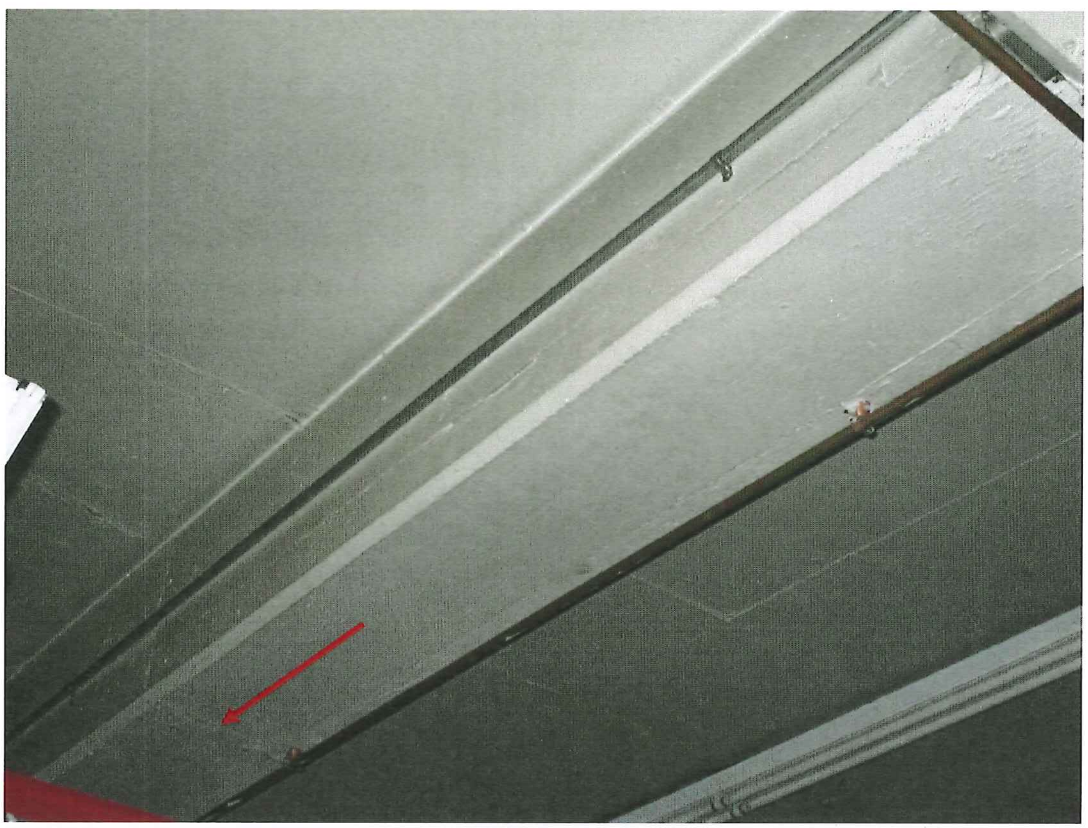


10. Bay 2 Slab, underside, Panel #6. Cracks in slab and beam.

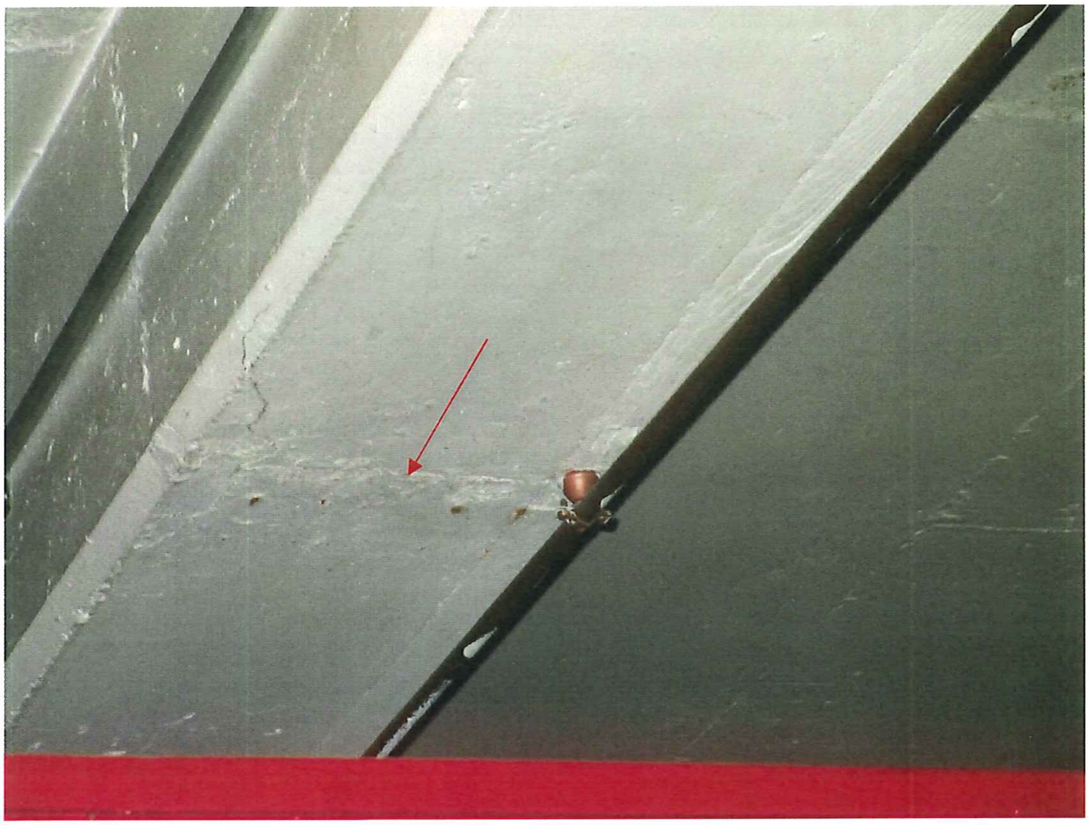


11. Basement, bottom of first floor slab, center bay, Panel #3. Spalled concrete and rusted rebar.

12. Basement, bottom of first floor slab. Close-up of rebar.



13. Basement ceiling. Cross beam, middle bay, cracked.



14. Basement, ceiling. Cross beam. Crack.

15. East side, Concrete lintel above overhead door openings.

16. East side, concrete lintel, middle bay.

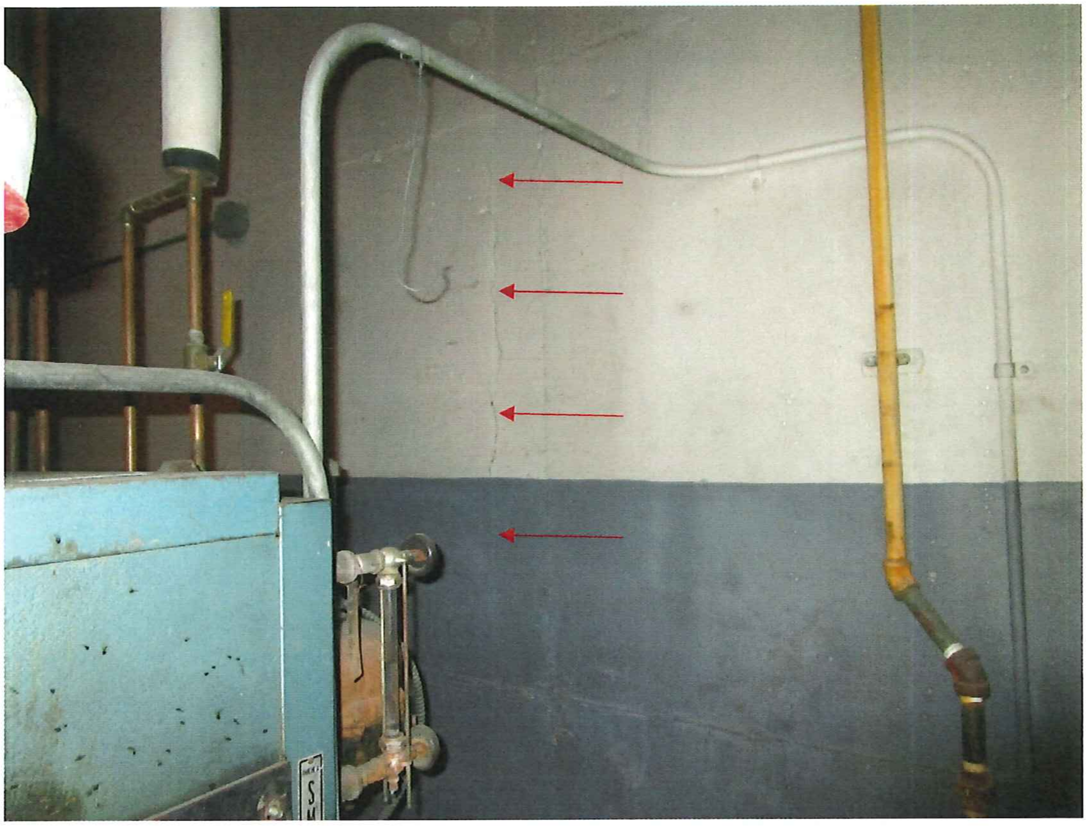
17. East side, concrete lintel, close-up.

18. East side, concrete lintel, close-up, vertical crack.

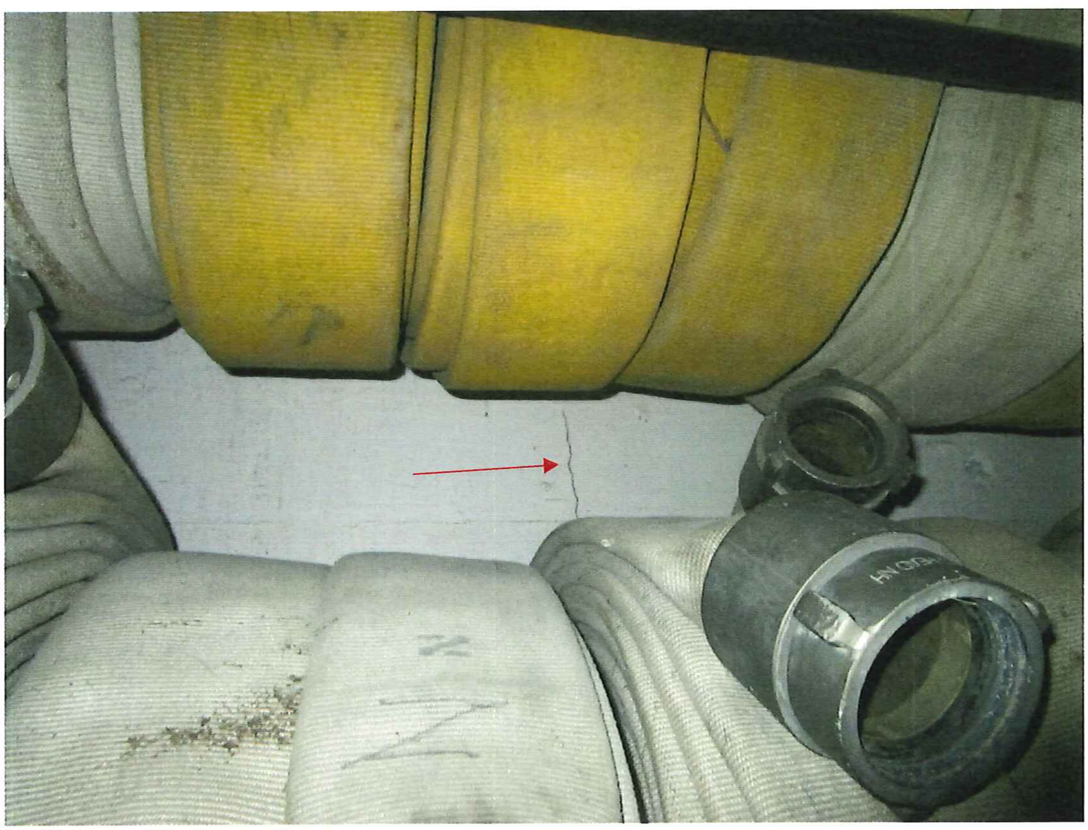
19. East side, concrete lintel, close-up bottom side crack, exposed rebar.

20. Beam #3. Cracked.

21. Beam #3. Cracked.

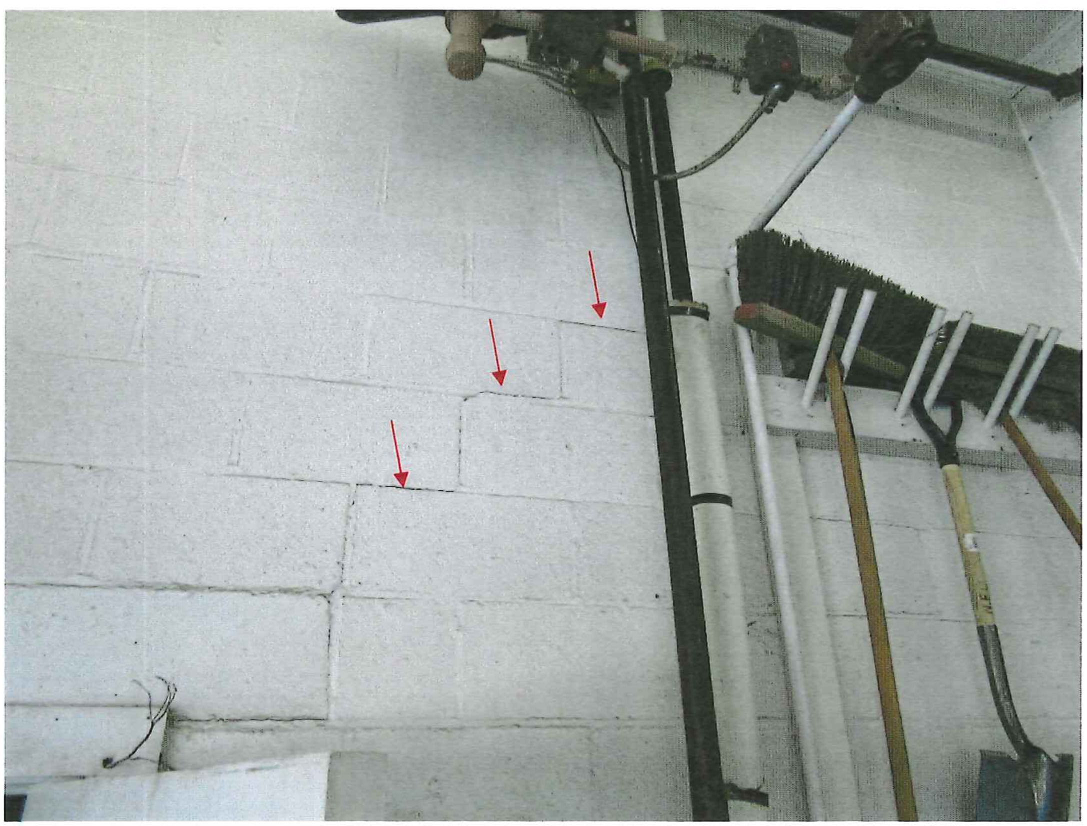


22. Basement, concrete block wall between boiler room and garage cracked.



23. Basement, concrete block wall crack, garage side.

24. First floor, concrete block wall between office and garage. Cracked mortarjoints.



25. First floor, concrete block wall between office and garage. Close-up, cracked joints.

26. First floor, back wall. Block wall cracked.

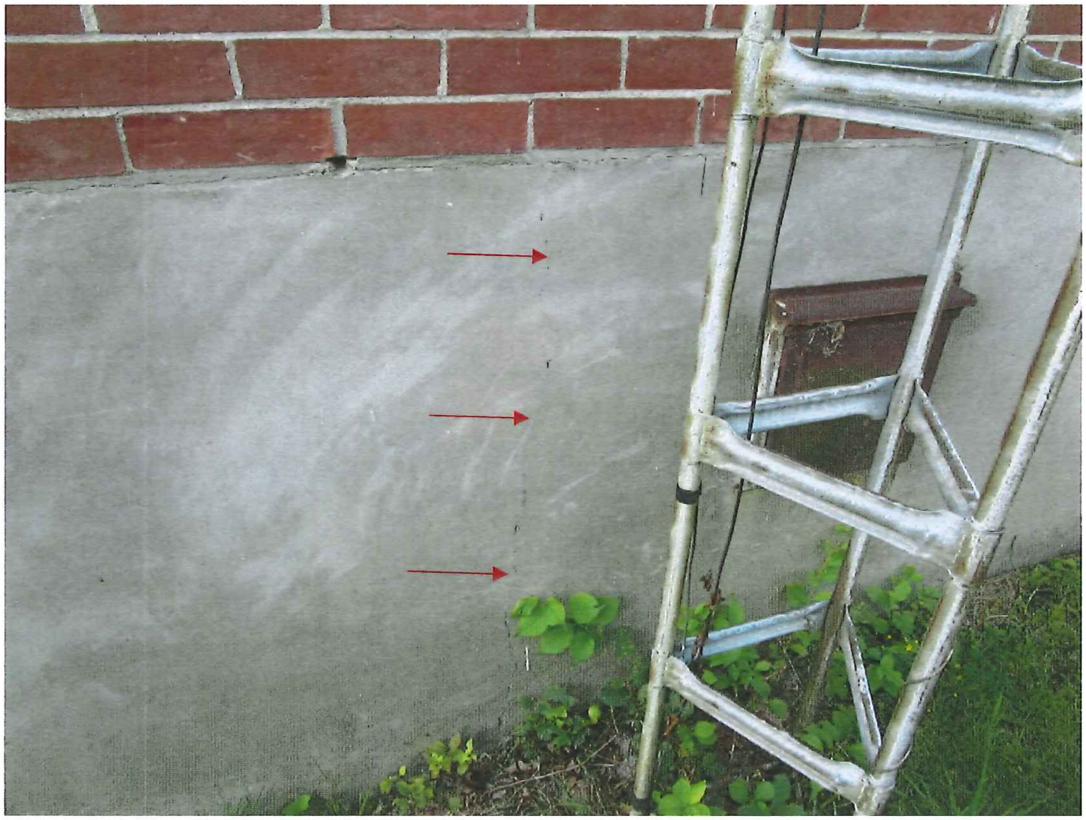
27. First floor, back wall. Block wall cracked.

28. First floor, south wall, southeast corner. Block wall cracked.

29. Chimney, south and west sides. Spalled bricks.

30. Chimney, south and east sides.

31. North side.



32. North side. Cracked foundation wall.

33. North side. Cracks at window edges.

34. North side. Cracked concrete.

35. Northeast corner. Stairs are in unsafe condition.