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Structural Failure – Case Study

By

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Introduction

This Case Study involves the structural failure of concrete and reinforcing bar due to corrosion. The structure was also compromised by most of the reinforcing bar not being of a structural grade steel, and the structure itself was likely not up to code at the time of construction. The concrete slab on the main garage level was supported by four un-reinforced masonry walls and an H-beam running laterally across the center of the garage. When the house and garage were constructed, the Building-Code had been adopted in the county, but there were no inspections being done.

Site Examination

Figure 1 – Garage Location

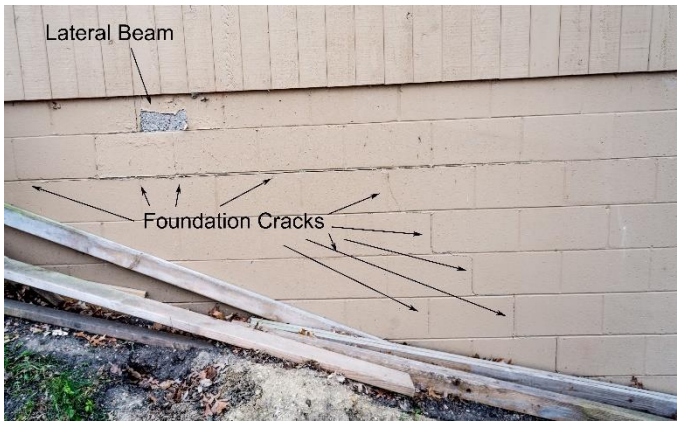

Figure 2 – Cracks in Foundation Mortar Joints

Figure 1 shows the location as viewed from the south. The garage floor had the structural damage. The drainage on the property was away from the house and garage, and was not a factor in the damage.

Figure 2 shows cracks in the garage east foundation wall mortar joints. The cracks in the mortar joints indicated that there had been settling in the garage side of the foundation over the years. This is also apparent in the cracking along the masonry joint between the house and the garage foundations, which met on the northside, Figure 3. It appeared that the garage had settled.

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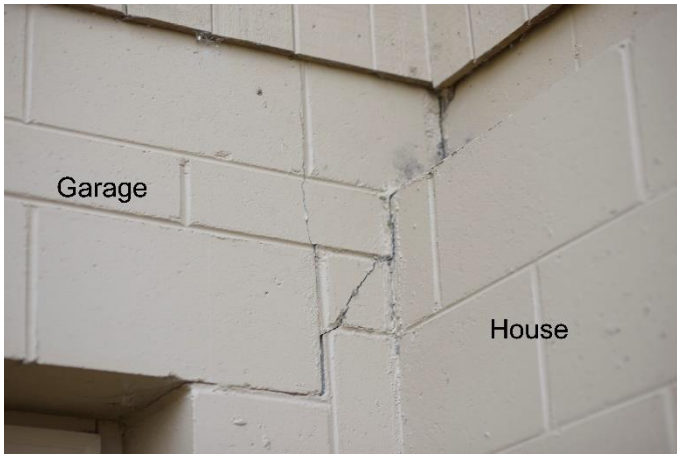

Figure 3 – Cracking in Foundation Joint Between House and Garage

Figure 4 – Open Cores in Foundation Block

Figure 4 shows open cores in the masonry foundation at the front of the garage. The garage floor slab at this location was supported by the inside edge of the block.

Figure 5 – Location of Garage Floor/Ceiling Collapse

Figure 6 – Tipped and Broken Block

Figure 5 shows the collapsed section of the basement ceiling side of the garage floor. The cause of the collapse was the corrosion of the reinforcing bar and concrete by road salt that had infiltrated from above. Another contributing factor was the tipping and cracking of the masonry block along the front of the garage/basement. Broken and tipped block is shown in Figure 6.

Samples of reinforcing bar were removed for further evaluation. Figure 7 shows Reinforcing Bar Sample 1, and Figure 8 shows Reinforcing Bar Sample 2.

The site examination showed that there had been extensive corrosion of the reinforcing bar and concrete used in the garage floor/ceiling, that there was settling of the east and north masonry block walls which caused the top row of blocks on the south wall to break, and that the cores in the block used in the south wall had not been filled with concrete.

Figure 7 – Reinforcing Bar Sample 1

Figure 8 – Reinforcing Bar Sample 2

Laboratory Examination of Samples

Concrete Sample

A sample of concrete was examined for chloride and sulfate ions, that are corrosive to both concrete and steel. The chemical analysis showed that the chloride content was 1600 part per million, and that the sulfate content was 62 parts per million. The concentration of these two ions is high enough to corrode both concrete and steel.

Reinforcing Bar

Reinforcing Bar Samples 1 and 2, Figures 7 and 8, were examined by energy dispersive x-ray analysis to determine the cause of corrosion. The results of the analysis are given in the table that follows and in Figures 9 and 10. The analysis showed the presence of sufficient chlorine and sulfur to explain the corrosion of the reinforcing bar.

Chemical Analysis Rebar Surface
(Percentage by Weight)

Element Location	Rebar (1)	Rebar (2)
Carbon	2.2	2.1
Oxygen	32.2	31.6
Sodium	0.3	0.3
Aluminum	0.1	0.2
Silicon	0.1	
Sulfur	0.3	0.4
Chlorine	0.9	0.8
Calcium	0.1	0.1
Manganese	0.4	0.6
Iron	63.4	64.1
Spectrum	Figure 9	Figure 10

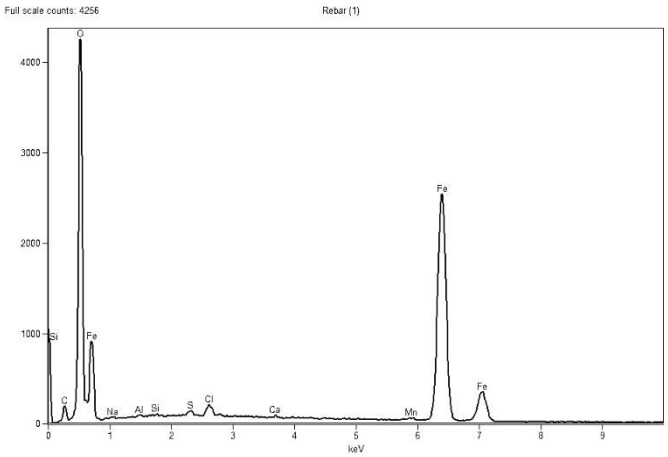

Figure 9 – Spectrum of Rebar Sample 1

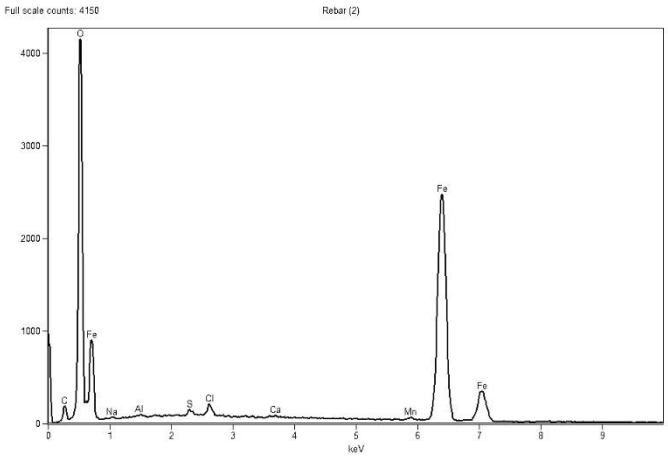

Figure 10 – Spectrum of Rebar Sample 2

Metallographic Examination

Figure 11 – 100X Corrosion in Reinforcing Bar Sample 1

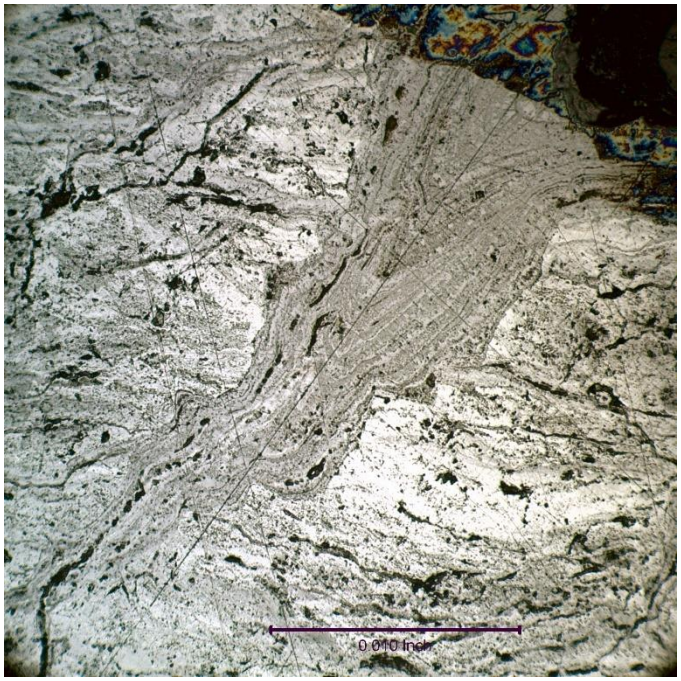

Figure 12 – 200X Corrosion and Cold Working in Reinforcing Bar Sample 1

The black areas shown in Figures 11 and 12 are portions of Sample 1 reinforcing bar that had been corroded. The steel used in the reinforcing bar was cold worked. Cold working leaves a residual tensile stress in the steel, making it susceptible to stress corrosion. Chlorides cause stress corrosion in cold worked carbon steel. Figure 12 shows a highly cold worked section of the reinforcing bar. Therefore, because of corrosion associated with cold working, the strength of the bar was reduced to almost zero. **It should be noted that during the late 1970's and much of the 1980's, low carbon steels were cold worked to achieve strength levels to meet only the minimum strength requirements of ASTM structural grade steels.** Most of the reinforcing bar used for the garage floor was of this type.

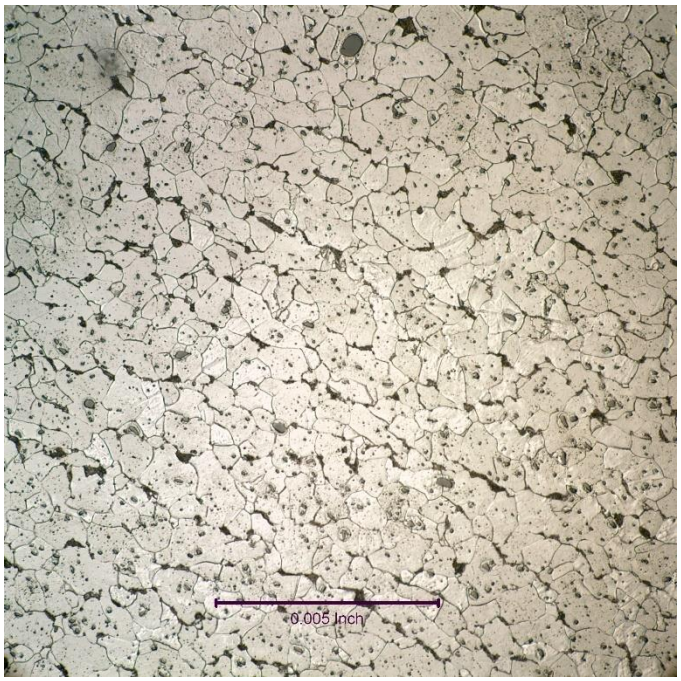

Figure 13 – 400X Microstructure of Sample 2

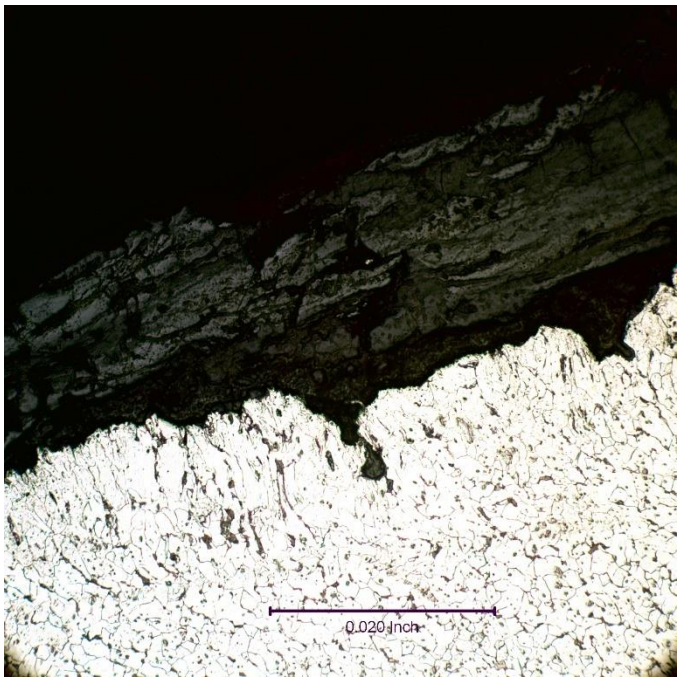

Figure 14 – 100X Pitting Corrosion – Sample 2

The microstructure of Reinforcing Bar Sample 2 is shown in Figure 13. The microstructure consisted of ferrite (light colored), which is pure iron, and pearlite (black). The grain size was very fine, indicating that the bar was hot rolled structural steel. The hardness of the steel was 144 Brinell Hardness Number, indicating that the tensile strength was 72,000 psi. The microstructural and hardness indicated that this reinforcing bar was made from ASTM A36 grade structural steel.

Figure 14 shows pitting corrosion on the surface of Sample 2. Pitting corrosion is normal for structural steel in the presence of chlorides and sulfates. The uncorroded steel retains its strength.

Opinion

It is my professional opinion to a reasonable degree of scientific certainty based on the information available and discussed in this report that the following conditions resulted in the deterioration and collapse of the garage floor/ceiling:

1) Use of nonstructural grade reinforcing bar which failed by stress corrosion in the presence of chlorides.
2) Settling of the north and east support walls.
3) Failure to fully support the floor/ceiling slab along the south wall.
4) Corrosion of the concrete by chloride and sulfate ions.