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Analysis of a Fire Riser Failure below a Concrete Slab-on-Grade Foundation

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ABSTRACT

Pressurized water pipes such as fire risers are often installed below commercial building foundations. Hydrostatic pressure imparted on foundation slabs during a fire riser rupture often results in damage to building foundations, requiring a detailed evaluation of the foundation and substrate prior to performing repairs. In isolated cases, the introduction of moisture from a fire riser rupture to underlying expansive soils can initiate volumetric changes that impart additional pressures on the building components. The objective of this paper is to explain the investigative process and methodology used to determine the extent of damage and appropriate repair strategy for these types of failures. A case study is presented to illustrate the investigative methodology, involving a ruptured fire riser beneath a concrete (floating) slab-on-grade foundation in Texas. The investigation revealed that a distinct region of the slab-on-grade foundation was damaged as a result of the fire riser rupture and required replacement.

INTRODUCTION

During the summer of 2017, a fire riser underneath the reinforced concrete slab-on-grade foundation at a commercial facility in Texas ruptured, causing distress to the slab and interior contents, as well as a complete interruption of the structure's use until repaired. After performing multiple tests to evaluate the slab and exterior walls, the extent of damage was identified, and the slab was remediated by removing and replacing a portion of same, thereby returning the facility to service.

TYPICAL DISTRESS MECHANISMS

Fire riser ruptures can result in varying degrees and types of damages due to the different types and uses of buildings that utilize these systems. However, the resulting damage typically manifests due to three primary mechanisms: hydrostatic pressure, soil erosion, and/or volumetric changes in the underlying soils.

Hydrostatic Pressure & Soil Erosion

Concrete (floating) slab-on-grade foundations are often found in warehouses and are typically supported by only the underlying soils. As a result, the introduction of hydrostatic pressure from a below-grade pressurized fire riser rupture forces the slab upward as the pressure attempts to reach equilibrium with its surroundings. This upward deflection can result in fracturing and permanent vertical displacement of the affected portion of the slab, and may also cause an unsupported condition if the escaping water causes the erosion that results in a below-slab void. Figure 1 through Figure 3 illustrate the aforementioned mechanism with a conceptual before-and-after comparison.

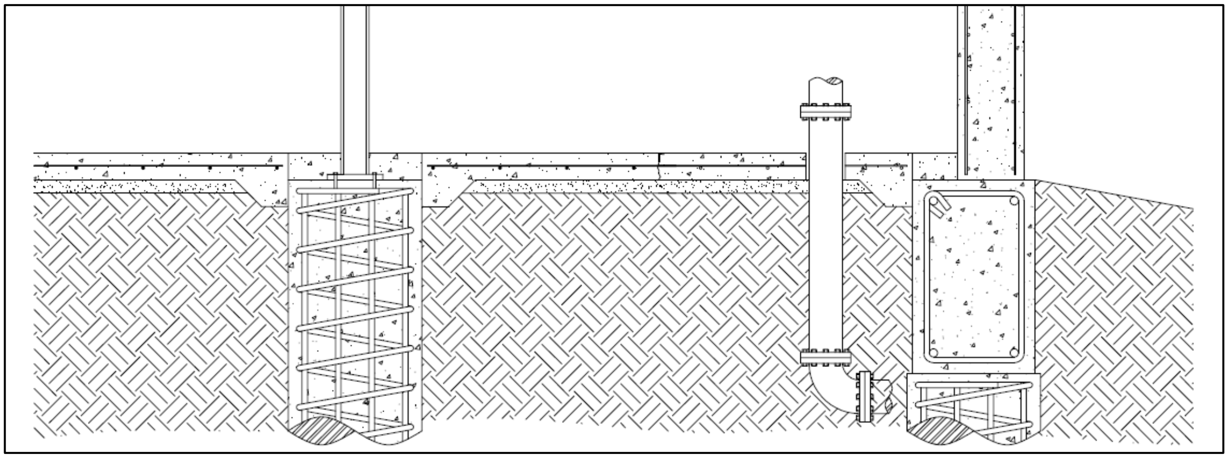

Figure 1: Representative view of a conventionally reinforced concrete (floating) slab-on-grade foundation prior to a fire riser rupture

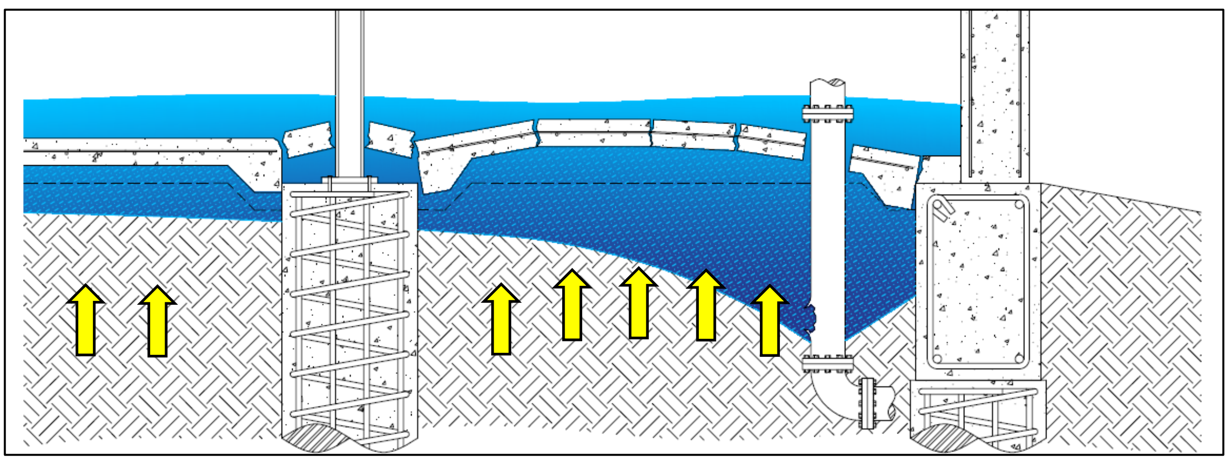

Figure 2: Representative view of the same foundation experiencing a net upward force (shown with yellow arrows) resulting from the fire riser rupture

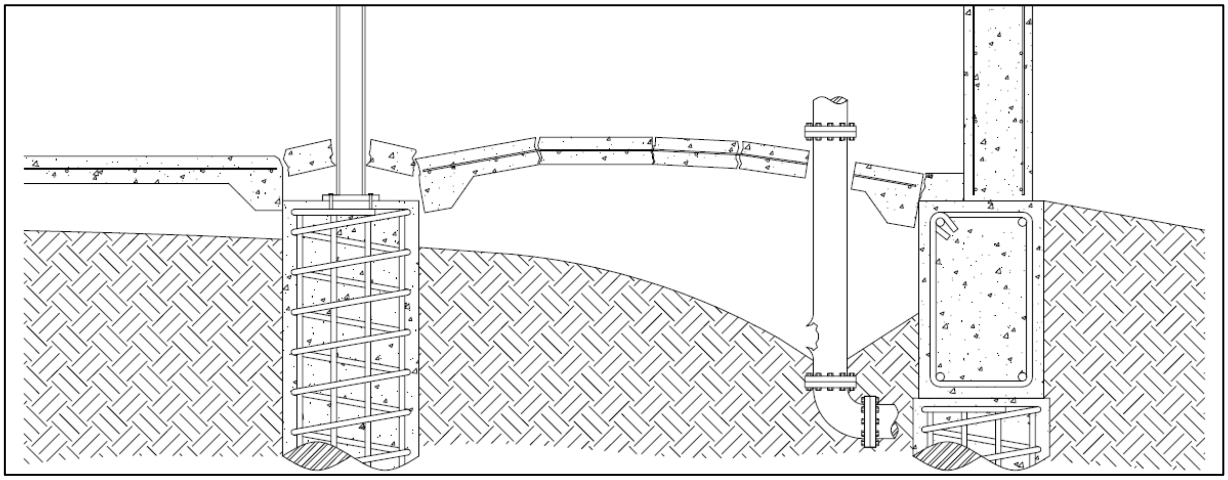

Figure 3: Consequential void underneath the displaced slab after the fire riser rupture

Volumetric Changes to Subgrade

The existence of expansive soils is a well-documented phenomenon, and may be a design consideration for new structures or foundation repairs. While steps are often undertaken to mitigate the reactivity of expansive soils to moisture, the introduction of a source of sufficient moisture, such as a below-grade fire riser rupture, can cause them to expand. Similar to the hydrostatic pressure previously discussed, this comparatively slower moisture-induced swelling can also result in an upward pressure from below a slab causing fracturing and permanent vertical deformation.

It is the experience of the authors that this mechanism rarely occurs as fire riser ruptures are often quickly mitigated and the amount of time that the soils are exposed to moisture is substantially reduced as compared to a slow below-grade leak that may influence the underlying soils for an extended period of time. Furthermore, expansive clay soils have a low hydraulic conductivity, which further increases the amount of time necessary for significant soil expansion (heave) to occur. This mechanism is presented conceptually in Figure 4 and Figure 5.

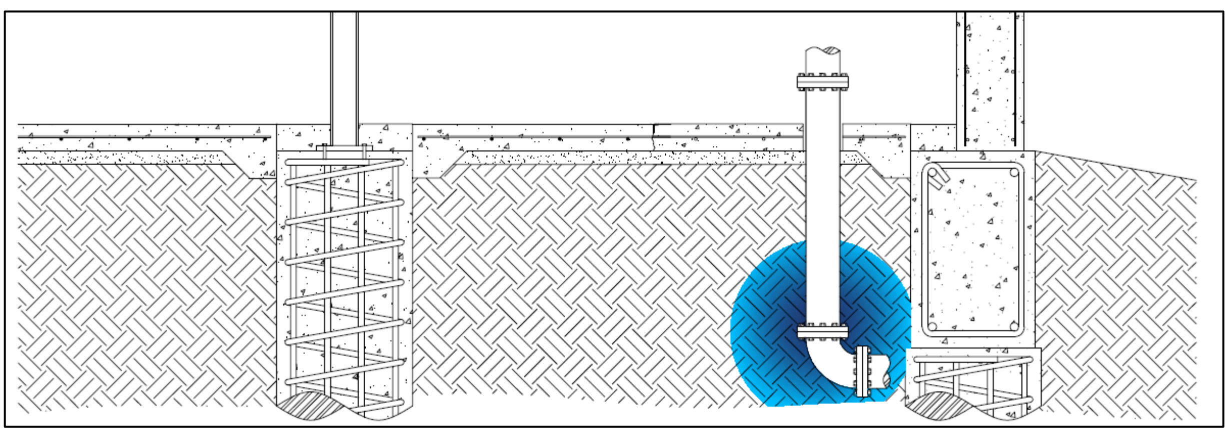

Figure 4: Immediately subsequent to a fire riser rupture, the surrounding clay soils with a low hydraulic conductivity begin to absorb the moisture

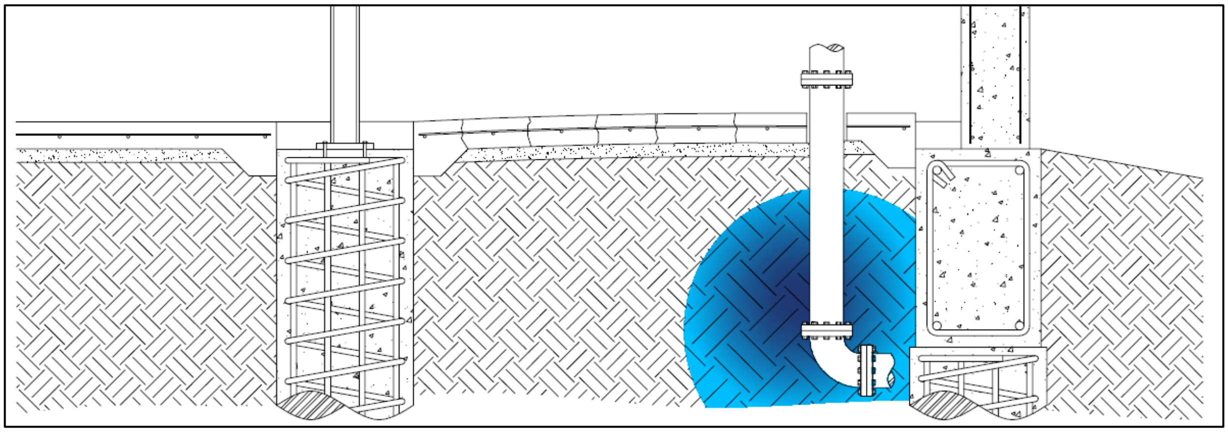

Figure 5: As time progresses, the surrounding soils expand from the excess moisture, resulting in minor damages to the slab

INVESTIGATIVE PROCESS AND METHODOLOGY

To determine the extent of distress resulting from the below-slab fire riser rupture and to provide appropriate repair recommendations, an investigative methodology following the Scientific Method is necessary. For the purposes of this example, the process can be described as follows:

1. *Document Review*
2. *Field Investigation*
    a. *Observations*
    b. *Hypothesis Formation*
    c. *Testing of Hypothesis*
3. *Analysis and Conclusions*
4. *Repair Recommendations*

Document Review

Occasionally, some limited information pertaining to the structure and the reported distress from the fire riser rupture is available for review prior to visiting the site. This information can include photographs taken by the occupants and/or reported information regarding the timeframe/extent of the fire riser rupture. In this case, the authors were notified by the contractor that the structure was a typical warehouse style structure that included a conventionally reinforced concrete (floating) slab-on-grade foundation and concrete tilt-up panels at the exterior walls. During this case study, the authors were informed that the recent fire riser rupture occurred at the south portion of the building (approximately 2' below the slab) resulting in associated distress to the slab and interior finishes. It was further reported that remediation, including partial removal of the floor/wall finishes, occurred prior to the author's initial site visit.

<u>Field Investigation</u>

Observations

Immediately upon accessing the location of the ruptured fire riser, the upward displacement of the slab was visible. This displacement visibly manifested as a convex feature, or dome, at the slab surface that increased in magnitude with proximity to the fire riser. At the riser, a portion of the concrete slab had previously been removed by others, and a visible void was present below the slab, as shown in Figure 6. Coincident with the vertically displaced portion of the slab were numerous concrete cracks exhibiting an absence of weathering and sharp, angular edges consistent with a recent condition (Figure 7).

Figure 6: Visible void below the concrete slab adjacent to the fire riser

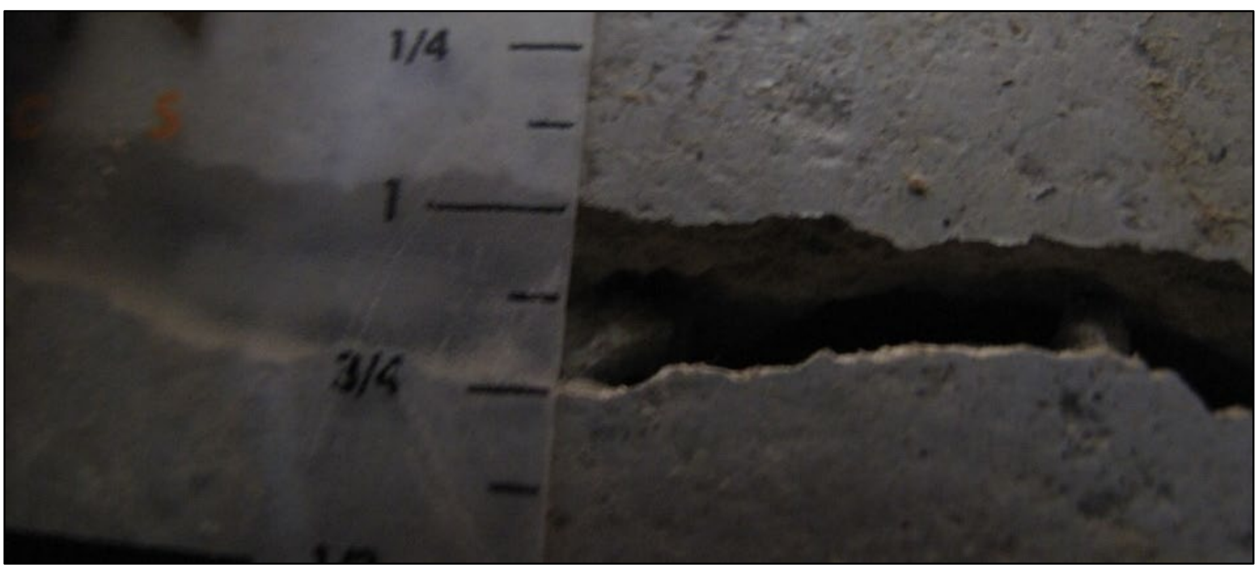

Figure 7: Concrete slab crack with sharp angular edges in close proximity to the fire riser

As is often present in older structures of similar construction, the authors observed numerous other concrete cracks in the slab that exhibited rounded and worn edges (Figure 8). These cracks were typically located farther away from the fire riser and were not indicative of a recent event.

Figure 8: Concrete slab cracks with rounded/weathered edges

In addition to the concrete slab distress, other observed distress included fractures at the gypsum board wall finishes (Figure 9), displaced and deformed ceiling grids, and buckled floor finishes, all of which are consistent with vertical displacement of the slab during the fire riser rupture. Additionally, this distress occurred in close proximity to the fire riser and further aided in determination of the extent of distress caused by the recent fire riser rupture.

Figure 9: Wall and ceiling distress in close proximity to the fire riser

Formation of Hypotheses

Based on the available information and the results of the authors' visual evaluation, it was hypothesized that the full extent of the concrete slab-on-grade was not damaged by the fire riser rupture, and that only a portion of the slab would require repair. Therefore, to verify or exclude this hypothesis, numerous additional tests were performed to accurately determine the extent of damage to the slab as well as to provide appropriate repair recommendations.

Testing

In addition to documenting the observed site conditions, the authors' performed multiple tests at the structure's concrete slab in order to test the aforementioned hypotheses and delineate the extent of distress attributable to the fire riser rupture. For discussion purposes throughout the remainder of this writing, the authors will refer to this extent as the zone-of-influence (ZOI). Testing performed as part of the investigation included a relative elevation survey of the slab surface to evaluate the levelness of the structure's slab, a ground penetrating radar (GPR) survey to identify potential below-slab anomalies, exploratory concrete coring to confirm the GPR survey results, and a plumbness survey of the exterior concrete tilt-up panels. These tests were performed sequentially over multiple site visits as the choice and execution of subsequent test methods were often contingent on the results of the prior test(s).

Relative Elevation Survey

The purpose of the survey was to document the levelness of the distressed areas in addition to the overall levelness of the structure's slab; thereby allowing assessment of any differential slab movement from the horizontal plane. The results of this survey revealed the extents of the vertical slab displacements caused by the fire riser rupture in relation to the entirety of the concrete slab.

The survey results indicated a discrete upward displacement measuring up to approximately 5" (in relation to the reference point) at the south end of the structure adjacent to the fire riser. This isolated area of upward displacement was further coincident with the locations of the more recent slab cracks. In addition, the survey results identified other areas of upward displacement in other locations of the structure. After reviewing the results of the relative elevation survey, it was determined that the recent rupture did not affect the entire portion of the slab, indicating that only a portion of the slab would need further GPR testing (shown in Figure 10).

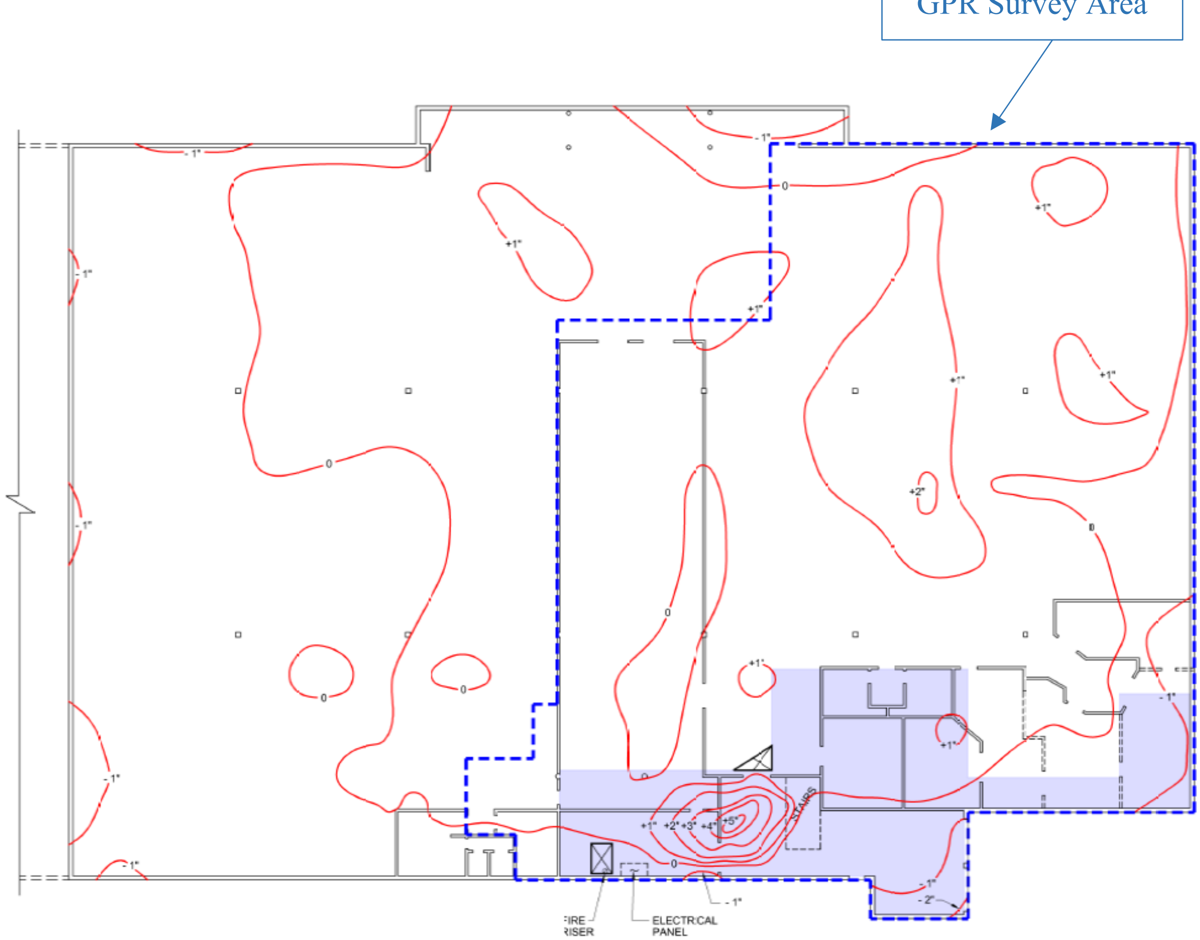

Figure 10: Illustration of the topographic contour map resulting from the relative elevation survey and the outline of GPR testing to be performed at the structure.

GPR Survey

After completion of the relative elevation survey, a GPR survey was performed in order to determine the extent of any below-slab anomalies potentially consistent with a void.

GPR functions by transmitting and receiving high frequency radio waves. When a transmitted radio wave is reflected by an object and received by the antenna, the GPR records the strength of the reflected wave (amplitude) as well as the elapsed time, then produces a graphic representation of this information (waveform). Using this tool, an experienced operator can identify features at the soil-to-slab interface that may indicate conditions such as trapped moisture or a below-slab void. Exploratory coring of the concrete slab at select locations is necessary to determine what these features (or anomalies) actually are, as well as their severity.

The results of the GPR survey indicated the presence of multiple anomalies that were consistent in pattern and appearance with below-grade voids emanating from the location of the fire riser and progressing towards the northeast portion of the structure. This pattern of void-like anomalies generally correlates with the topographic contour maps produced from the results of the relative elevation survey, as shown in Figure 11.

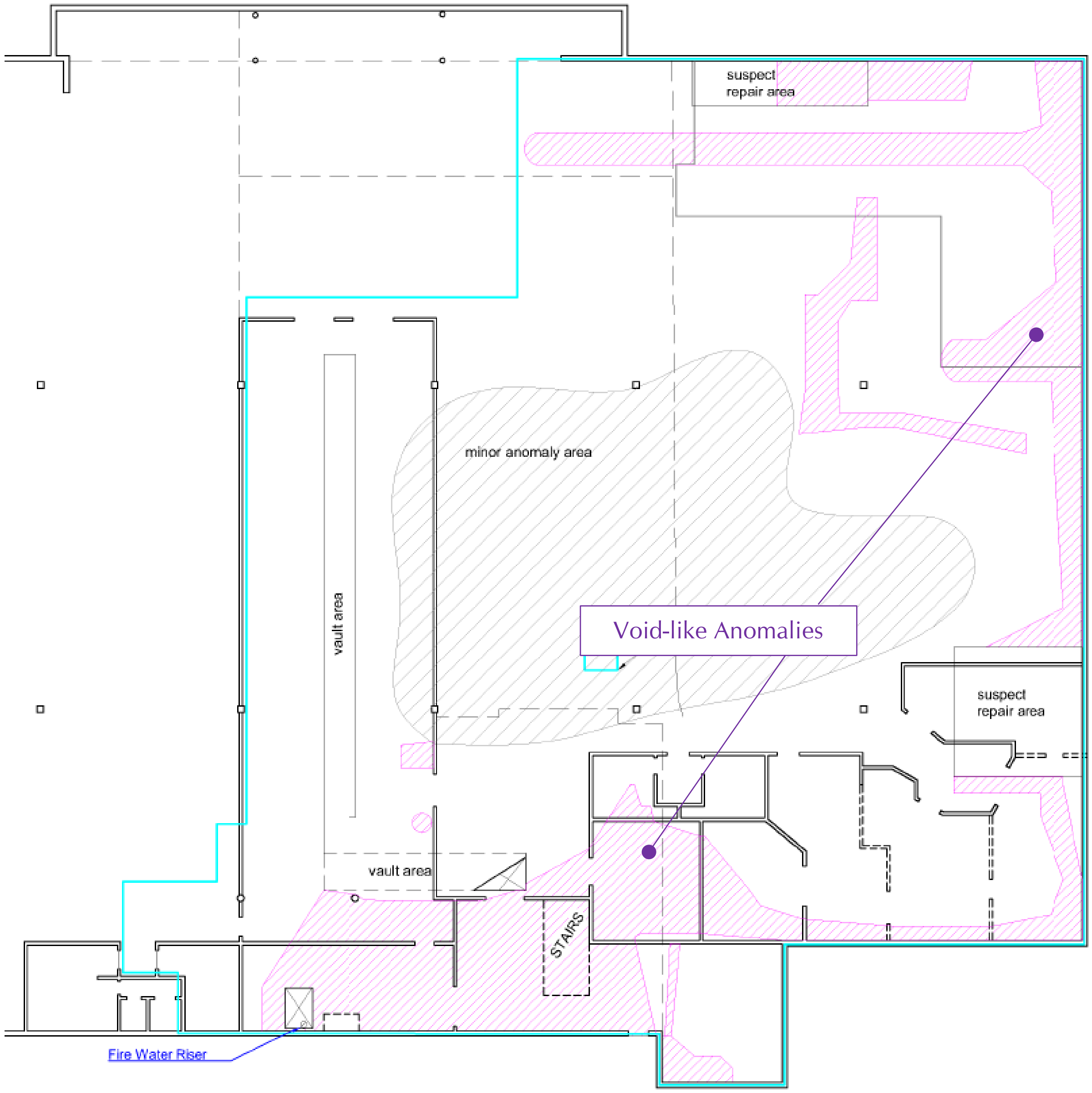

Figure 11: GPR survey results

Exploratory Concrete Coring

Exploratory concrete coring is necessary to confirm whether the observed anomaly is in fact a below-grade void. Therefore this destructive testing was conducted at multiple locations within the field of the slab. Specifically, 13 cores were extracted from the slab so that the soil-to-slab interface could be visually evaluated at locations both within and outside the areas where anomalies were identified. This testing revealed that seven core locations contained below-slab voids that measured up to 6" in depth as shown in Figure 12 and Figure 13. In addition, the majority of the cores taken within the anomalous regions had measurable voids, further corroborating the results of both the GPR and relative elevation survey.

Figure 13: Representative view at Core 4 with a measurable void of approximately 6"

Plumbness Survey

In order to assess the condition of the vertical elements of the structural framing, visual evaluation of the superstructure was complimented by obtaining plumbness measurements at the exterior concrete tilt-up panels with a digital level instrument. The plumbness measurements did not indicate a pattern of lean or permanent lateral deflection, and no recent distress was observed to these elements indicating that the superstructure was not affected by the recent fire riser rupture.

Analysis and Conclusions

After the testing procedures were completed, the authors were able to review and analyze the available data collected from the site visits and form conclusions based on same.

The relative elevation survey revealed a discrete upward displacement of the slab in the vicinity of the ruptured fire riser consistent with the anticipated effects of hydrostatic pressure acting on the underside of the slab during the event. The portion of the concrete slab cracks that exhibited sharp angular edges was concentrated at the location of the upward displacement, further defining the extent of distress to the slab at the surface level. In evaluating the soil-to-slab interface with GPR, the authors discovered that potential below-slab voids extended past the extents of the visible distress at the slab surface. The presence and extent of the voids were later confirmed by exploratory concrete coring.

In consideration of the observations, testing performed, and analysis of same, the authors were able to identify the extent of damage caused by the fire riser rupture (i.e., the ZOI) and confirm their hypothesis. The ZOI is shown conceptually in Figure 14.

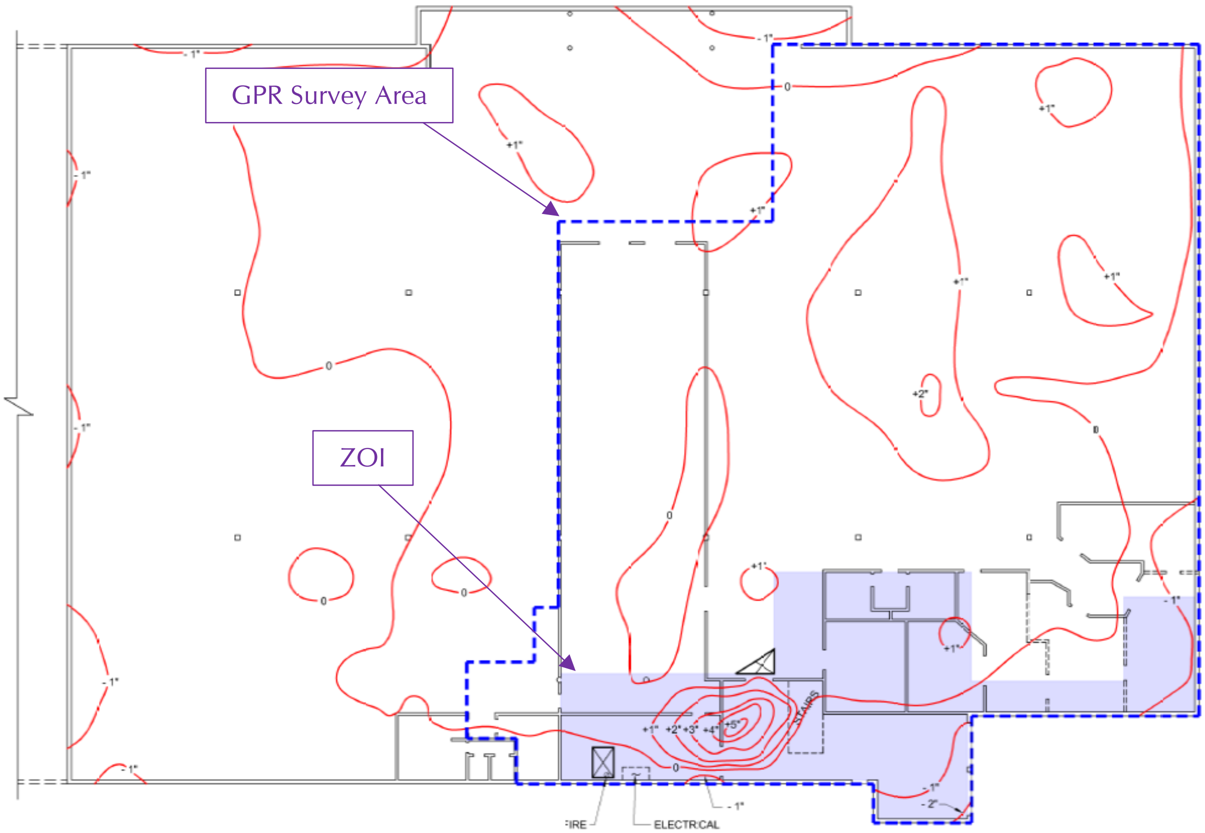

Figure 14: Outline of Final ZOI

Repair Recommendations

Multiple various options are available for repairing distress to a concrete slab-on-grade; however, the appropriateness of the repair is often defined by site-specific conditions at each location, such as structural configurations or geotechnical conditions. Due to the condition of the concrete slab-on-grade within the ZOI as well as the severity and extent of the below-grade void, the authors elected to recommend complete removal of the concrete slab within the ZOI so that the below-grade soils could be properly reinstated. The authors felt that this was necessary to ensure the long-term performance of the concrete slab moving forward.

CLOSING

The evaluation of fire riser ruptures and their effect on a building's structural system requires a detailed and methodological approach that includes a robust testing protocol. As shown with this case study, on-site observations are not sufficient to accurately determine the full extent of damage to a building's structural system as below-grade damage is often also present and concealed by the slab itself. Without conducting a thorough evaluation, appropriate repair recommendations cannot be provided.