Heritage Engineering, P.C.
P.O. Box 255
Perkinsville, VT 05151
802-263-5400
heritageengineering@tds.net
www.heritageengineeringvt.com

Josh Arneson
Town Manager
Town of Richmond
P.O. Box 285
Richmond, Vermont 05477

Friday, January 03, 2025

Subject: Richmond – Cast-In-Place Concrete Potable Water Storage Tank – Visual Condition Assessment

Dear Josh Arneson,

You have asked Heritage Engineering, P.C. to review the Cast-In-Place Concrete Potable Water Storage Tank, an existing concrete tank and provide an engineering perspective to the interested parties to help inform the ongoing decision-making process. The tank was constructed by the contractor, S.D. Ireland Concrete Construction Co., between approximately August and December 2015. The tank is apparently not performing as expected. Town personnel report that there are visible cracks on the outside of the tank and leaking of the structure through some of these cracks. This document is intended to discuss the tank condition based on visual observations.

I have been provided access to the following project records.

1. A link to a shared file from Matt Bloomer via email dated 09/23/2024. Link included multiple project files.
2. A link to a shared file from Josh Arneson via email dated 10/9/2024. Link included videos and photos from inside the tank.

I visited the site on Wednesday, October 16th 2024. The Town had mowed the area surrounding the tank. I gained access onto the tank from the uphill side, where it is close to finish grade. A very small portion of the inside of the tank was observed briefly from the roof, looking downward to view only what could be seen through the access hatch opening. I did not enter the tank. It was seasonally cool during my site visit and the tank was moist/wet in some locations due to recent precipitation. This moist/wet condition is noted simply to clarify that, due to recent rain, it wasn't possible to conclusively distinguish between moisture from precipitation and active leaks of water out of the tank in all locations.

Steve Cote, the Richmond Water and Sewer Department Superintendent, met me at the site to introduce me to the project location and to answer my general questions about how the tank is used. Steve provided the following facts that I have included here for reference. The tank is generally "full;" that is, its normal service condition is to have the water level near the top, fluctuating within several feet of the top of the walls. The tank holds finished potable water that is piped for distribution into the municipal supply. In other words, the water has been treated and is ready to be consumed. There is trace chlorine in the water, with a general target concentration managed around 1.2ppm. The tank provides critical pressure to the water distribution system and provides flow quantity volumes to the system during periods of peak demand. Thus, it cannot be completely emptied and taken out of service for internal repairs without significant operating challenges. The exterior paint is approximately three years old. The masonry coating visible on the above-ground concrete tank surfaces was applied after cracks and leaks were noted to try to reduce the leaking and improve the visible aesthetics associated with the leaks.

Steve identified a few concerns about the tank which he was aware of that were not already identified as items for me to look at; 1. He expressed concern that the cracks were due to differential settlement of the tank resulting from settlement of the different supporting subgrade materials at construction; 2. He asked about a long-term management plan for the tank given presence of cracks and leaks; and, 3. He asked about the potential that existing metal form ties might rust through. Each of these additional items is included in this report.

The cast-in-place concrete tank is composed of four structural systems, which can be divided into these types:

A) The concrete walls, which are 24'-25' tall, 18" thick (north, south and west sides), 20" thick (east side). The walls form the sides of the tank and support the roof edges. See Section 1.1.
B) The concrete roof, a 9" thick concrete slab. See Section 1.2.
C) The concrete floor and foundation, a slab 12" thick, approximately 60'x95' in area, cast on the ground surface. There are thicker sections beneath the interior columns. The floor and foundation support the tank and water. See section 1.3.
D) The concrete columns, inside the tank, providing support for the interior portion of the roof. See Section 1.3.

Part 1 of this discussion will focus on specifics about the condition of the cast-in-place concrete.

Part 2 will discuss any obvious design or construction concerns noted during my review of the provided documents.

Part 3 will include a summary and discuss potential improvements to improve the tank's durability.

<u>Part 1: Visual Condition Assessment of Concrete Tank</u>

1.1 The Walls:

Most of the wall surface area is below grade. The tank is located on a sloping site and the grade varies around the tank, with approximately 15ft of wall exposed on the west (road) side, approximately 4ft of wall exposed on the east (uphill) side, and the north and south wall grades sloping between these heights. There are small cracks visible on all of the walls, many of which are associated with leaks. Because the tank is painted green, the white material deposited by the leaks is very distinct and prominent. There is a thin masonry layer applied over the above-grade sections of the walls.

1.1.1 Cracking in Concrete. Concrete cracking is a complicated subject, but there are general concepts about cracks that can inform this discussion. Most reinforced cast-in-place concrete that is well designed and constructed, with adequate reinforcement, can and will crack under normal service conditions, usually at an interval and size that does not compromise strength, function, or the service life of a structure. Concrete shrinks and swells in response to temperature change. It also shrinks as it cures. When any movement due to shrinkage is restrained by other structural components, the forces which develop during shrinkage can lead to cracks. Cracks can also develop from stress in the concrete member as it performs as a structural component. These stress-related cracks are most often present in the tension zone of structural concrete members that are acting as beams, because concrete has little strength in tension. As the member bends to support the load, cracks develop in the tension face. Once cracks form in concrete, either due to shrinkage or due to stress, the steel reinforcement restrains the cracks so that they do not become too large.

> 1.1.1.1 Temperature and Shrinkage Cracks. The shapes and patterns of cracking visible in these walls are consistent with the shrinkage component of temperature change during the life of the structure and with early stage curing-related shrinkage. The shape and location are consistent with what would be expected for the geometry and details of this tank. The cracks are mostly vertical, with many horizontal, and some diagonal. Cracks can be measured by their thickness, which is the gap across the crack. I took several measurements of cracks on the walls. All the cracks I observed on the outside of the tank walls were smaller than 0.003", which is a general performance criterion for concrete used to retain liquid. This is about the thickness where you can see the crack with the naked eye, but cannot see into it. The crack lengths varied from just discernable to many feet. Weathering of the edges of the cracks has begun to occur but is minimal.
>
> 1.1.1.2 Stress Cracks from Loads. Within the tank, based on the photographs taken by the divers, there appear to be cracks on at least two of the inside corners. These would be typical of the tension zone of the wall. Because the cracks appear distinct in the photos of the corners, they are likely slightly larger than the cracks measured on the outside. These cracks are likely the source of the leaks visible on the outside of the walls near the corners.

1.1.1.3 Construction Joints. The tank is constructed in sections. The joints between these sections are called construction joints and can resemble and behave like cracks, which is why they are discussed here. PVC waterstop is embedded in the concrete pours to span this joint and keep it water tight. The tank floor, wall, and roof were each constructed in six sections. The joints allow for large structures to be constructed in manageable sections. Also, these smaller sections reduce the shrinkage cracks that are exacerbated in long and highly-restrained concrete sections. The joints in this structure align, footing to wall to roof. The tank walls had some very fine leaks that aligned with half of the vertical construction joints, but they were almost imperceptible and would not likely be perceptible at all on warm, dry days.

1.1.1.4 Previous Repairs. There are several locations where cracks were repaired and are leaking again. There is a distinct orange, sticky substance outside these cracks, likely residue from the repair material. Distinct holes and plugs associated with the drilling to inject the sealer into the cracks are visible as well.1.1.2 Presence of Leaks and Water Movement Through the Concrete: At most of the concrete cracks there is evidence of water movement through the walls. Water movement is evidenced by physical observation of wetness on the concrete surface at cracks and by efflorescence, the white chalky-looking material visible at the leaking cracks. Efflorescence is a deposit of material that was solid in the concrete and is dissolved by moving water, or was already dissolved in the water and is then transported to the concrete surface where it precipitates into a solid (is redeposited) as the water in which it was dissolved evaporates.

The water moving through the walls is coming from three sources.

1.1.2.1 The first source of water is from within the tank, where water is moving from inside the tank all the way through the walls along cracks, emerging at the above-grade exterior surface. These leaks can be observed on most exterior above-grade tank walls. It is reasonable to conclude that the leaks are also present in the wall sections below grade.

1.1.2.2 The second most prevalent source of water is precipitation, from rain events and snow melt, where water enters the cracks in the top of the walls and at similar horizontal surfaces. This water travels into and through the wall via cracks, becoming visible at above-grade exterior surfaces. Example locations where precipitation is entering the wall can be observed at the top of the tank at the horizontal cracks in the roof, which have corresponding vertical cracks in the roof and wall.

1.1.2.3 A smaller but noteworthy source of water is condensation inside the tank, which occurs where the warm moist air inside the tanks comes in contact with the cooler concrete walls and roof. This moisture enters the walls near the top, behaves much like the precipitation discussed above, and is having a similar effect, although to a significantly lesser degree because it is a lesser quantity.

1.1.3 Effects of Water Movement Through the Concrete. Whether from water in the tanks or from water entering the concrete from the surrounding environment, the introduction of moisture into the concrete can reduce the service life of concrete structures. Deterioration of reinforced concrete can be associated with the combination of cracks and moisture because cracks expose the steel reinforcement to water. For those areas that are repeatedly wetted and dried, cracks also supply the air needed for rusting to occur. The weathering of concrete can also occur at cracks due to freezing and thawing action.

1.1.3.1 I did not observe any concrete material that appeared to be deteriorated due to moisture exposure and did not observe any signs of reinforcement decay. I did not observe any evidence of metal form ties rusting into or through the wall, although it is not even clear to me that there are permanent ties present (refer to project documents later in this section). The tank is generally full so where there are leaks of tank water through the walls, they are generally kept wet, which has a protective effect.

1.1.3.2 I did not observe any concrete material that appeared to be deteriorated due to freezing and thawing decay, other than some minor local weathering at the crack surface. I suspect this is because the walls are actively leaking relatively warm water, and the walls themselves are kept relatively warm by the large mass of water within the tank, providing a protective effect.

1.1.3.3 The structure of the tank walls appeared to be in average to good condition for their age, with the amount of cracking and leaking appearing to me to be slightly above average (more than would be expected). I did not observe any conditions that caused me to be concerned with the structural capacity of the tank walls.

1.1.4 Masonry coating. There is a thin masonry coating that covers the above-grade tank sections. It is no longer adhered to the tank walls where there are cracks that leak. Frost action between the concrete and the coating causes the coating to separate and bulge outward. Where the concrete has cracked, the masonry coating has also cracked, as it seems to be fairly brittle. Water moves behind and collects under the coating where it bulges. The coating exacerbates the appearance of the cracks. We can expect that larger areas of the coating will begin to break off in the near term.

1.2 The Roof:
A gently-sloping concrete roof covers the entire tank. The roof slope is approximately 1.7%, sloping 12" from east to west. There are small cracks visible on all of the roof sections, many of which are associated with leaks. There is a thin masonry layer applied over the above-grade sections of the roof.

1.2.1 Cracking In Concrete. As discussed in the narrative above, concrete shrinks and swells in response to temperature change, it shrinks as it cures, and it can crack due to tension stress.

1.2.1.1 Distinct cracks are present on the roof. The shapes and patterns are consistent with temperature- and curing-related shrinkage. The roof cracks are regularly distributed in patterns similar to the walls but also have distinct diagonal cracks at all four corners of the roof and at four of the individual poured segments. Because the roof was poured in six segments, the cracking is much worse at the panels that were installed with the most restraint already in place. In particular, one panel which was poured only attached to one wall (the middle westerly panel) has very little cracking. In contrast, one of the last pours, at a corner (the south westerly panel), is very cracked. These two examples demonstrate the effect that restraint has on the presence of cracks. I took several measurements of cracks on the roof. All the cracks I observed on the roof surface were smaller than 0.005", which is slightly higher than the general performance criteria for concrete used to retain, or in the case of a roof keep out, liquid. Weathering of the edges of the cracks is more distinct on the roof than on the walls, with the crack opening at the top now weathered to as wide as .01". These cracks can be seen easily with the eye. The crack lengths varied from just discernable to many feet. Within the tank, based on the photographs taken by the divers, many of the cracks visible on the exterior roof surface are also present on the interior roof surface. Several of the cracks in the roof extend onto and align with the cracks in the wall below.

1.2.1.2 Stress Cracks from Loads. Within the tank there are sections of the roof structure in tension. These tension zones would be typical between columns and between column and wall. On the roof top surface there are tension zones around the columns and around the perimeter. No cracks are attributed specifically to stress due to loads, although some of the diagonal cracking at the four roof corners may be made slightly worse by the tension forces in the top surface of the roof here. This item is included here more as a discussion point, because I attribute most of the cracking on the roof to shrinkage forces, not to stresses from loads. The roof spans appear relatively straight between points of support, meaning the roof does not meaningfully sag between supports, except for two small puddles along the westerly roof edge.

1.2.1.3 Construction Joints. The construction joints appeared to be functioning adequately and can be treated similarly to any of the other cracks.

1.2.1.4 Previous Repairs. There was no evidence of previous repairs on the roof.

1.2.2 Presence of Leaks and Water Movement Through the Concrete: At most of the concrete cracks, there is evidence of water movement through the roof. Water movement is evidenced by interior photographs taken by the divers that show an abundance of efflorescence, which is described above.

The water moving through the roof is coming from one main source, and a second minor source.

1.2.2.1 The most prevalent source of water is precipitation, from rain events and snow melt, where water enters the cracks in the top surface of the roof. Several of the cracks in the roof extend onto and align with the cracks in the wall below, introducing water into the wall.

1.2.2.2 A smaller source of water is condensation inside the tank on the underside of the roof, which occurs where the warm moist air inside the tanks comes in contact with the cooler concrete roof. This moisture is likely having little effect on the roof structure, but is listed here as a factor for any updates considered later.

1.2.3 Effects of Water Movement Through the Concrete. The introduction of moisture into the concrete can reduce the service life of concrete structures as described in Section 1.1. The weathering of concrete can also occur at cracks due to freezing and thawing action.

1.2.3.1 I did not observe any concrete material that appeared to be deteriorated due to moisture exposure, except for some shallow surface deterioration, and did not observe any signs of reinforcement decay.

1.2.3.2 I did observe that the cracks on the roof are beginning to decay due to freezing and thawing. The exposed corners at the crack edges are wearing down with frost action. The roof can get colder than the walls because it is not exposed to water from inside the tank; therefore, I suspect the roof service conditions are harsher and water in the cracks can freeze and thaw more readily.

1.2.3.3 The structure of the tank roof appeared to be in average to good condition, with the amount of cracking and leaking appearing to me to be more than average (more than would be expected). I did not observe any conditions that caused me to be concerned with the structural capacity of the tank roof at this time, but action should be taken in the near term to preserve this section of the structure.

1.2.3.4 Because the roof leaks, water from the roof can enter the tank. This could lead to entry by unfavorable material that gathers on the roof, as would be typical for any exterior flat surface in our area.

1.2.4 Masonry coating. The thin masonry coating that covers the roof is in very poor condition and no longer adheres to the tank roof in many locations. The frost action between the concrete and the coating is more pronounced than the walls and the coating is cracked, broken, missing in many locations and fairly brittle, similar but more pronounced than as discussed in section 1.1.4.

1.2.5 Settlement of Tank. During my site visit I took several measurements of the top surface of the tank, to look into Steve Cote's question about whether the cracks were caused by any apparent uneven settlement. There was a concern identified that the tank might settle more where it was supported by fill (the west side) than it would on native material. Looking for rotation of the tank in the uphill to downhill (east to west) direction my measurements indicate that the tank top surface is less than 3/4" off from mathematical correct expectation. That is, the east side of the tank is roughly 1ft higher than the west side of the tank, which is what is shown on the plans as the built in roof slope and is likely how it was constructed. Similarly looking for rotation of the tank along the long direction, there was little to no measureable difference, with 3/8" maximum difference in level from north to south. A 6ft level was placed on the westerly tall walls and they were relatively plumb. It is my opinion that the tank is not settling unevenly to any substantial degree.

1.3 The Floor and Foundation Slab and the Interior Columns.

The foundation slab and the interior columns cannot be observed during a regular visual site visit. There are photos and videos available that were taken previously by divers. I have looked through the provided diver photos and some of the videos. For this discussion, I believe it is reasonable to presume the foundation and interior columns are in similar, if not better, condition than the exposed concrete I observed directly, for several reasons. There are service conditions which are favorable to concrete performance for the foundation slab and columns. First, the foundation and columns are not subject to the same severe exposure conditions as the exposed parts of the tank, namely precipitation and the freeze and thaw cycle, therefore since they are composed of the same concrete mix the concrete material can be expected to perform similarly or better to that of the exposed concrete. Second, foundation pours are less restrained during the concrete curing process because they are not attached to as many items which would cause shrinkage stress to develop, so the foundation can shrink more readily than the other members during the curing process, and therefore generally tends to cracks less. Third, this concrete is not subject to the large temperature changes which cause changes in the concrete dimension and lead to cracks. Finally, constant exposure to water is also generally a favorable condition for concrete. Noting these favorable conditions, and after reviewing the photos, it is my opinion that the columns are thought to be in very good condition and the floor slab appears to be in good condition. The photos do show local concrete damage in the floor, apparently from installation of equipment supports. The photos also show cracks in the floor and therefore the comments discussed previously for concrete cracks are applicable for the floor.

Part 2 - Obvious Design or Construction Concerns Noted During My Review of the Provided Documents.

I have been provided access to the following available project records.

- A link to a shared file from Matt Bloomer via email dated 09/23/2024. Link included multiple project files.
- A link to a shared file from Josh Arneson via email dated 10/9/2024. Link included videos and photos from inside the tank.

Project Documentation Summary: The project files provided in the first link listed above appear to include most of the early water tank project planning, permitting, bid documents, design plans, project specifications, and some change order and payment requests. The documents taper off, become less thorough over time, and no project close out documents or correspondence are included that would help us understand how the final resolution of leak sealing and exterior surface coating issues resolved. The files also lack any documentation of project oversight that would have taken place during construction, commonly referred to as Quality Assurance (QA), that would include field inspections of fill placement, reinforcement inspection, concrete inspection, concrete testing, and any field inspection notes. Accordingly, we can't provide or discuss insights which may have been gathered from those documents. To the extent it is possible it would be prudent to look back over the Town's paper and digital files during 2015-2016 to see if more files can be discovered and archived for future reference. I understand that the project engineer, Green Mountain Engineering, Inc., is no longer in business, but it may be that structural engineer Carl A. Childs, P.E. has some relevant records and the contractor, S.D. Ireland Concrete Construction Co., may also have records they would share. Finally, the specifications on the plans required that an independent testing firm be employed for concrete testing. It may be that there is a reference somewhere to what firm did this work, as they are likely to have records.

Documents of Note:

The project files include documents that show that leaks were present in the early life of the tank, between approximately November 2015 when the last concrete was poured and sometime around June of 2016 when the Contractor requested a change order for more time to repair leaks. Leak repairs were ongoing and the change order was approved, providing time into July of 2016 for the repairs. Early leaks can occur from imperfections in joints and at form holes and are usually quite obvious when the tank is first filled. Other leaks, those typically associated with small cracks, take some time to form. I did not find evidence of a successful leak test in the project files. I also did not find any documents identifying why backfill was placed before the leaks were all remedied. The contract required that the leaks be fixed before backfill was placed. There is an interesting photo titled "042516 tank sealant application" which shows an excavated area with two cracks being repaired, indicating to me that the tank had been backfilled prior to elimination of all leaks. If the photo was taken on 04-25-16, with two active leaks within about 6ft of each other, numbered 3 and 2, presumably there was a #1 to fix and likely more to seal due to the request for more time to do so, as described in the change order above.

There is a report from Carl A. Childs, P.E. discussing the condition of the tank, dated July 14, 2020, along with conversation notes dated August 7, 2020 from a follow up phone call Don Morin had with Carl Childs regarding the tank condition. Childs originally designed the structure in 2015. The July 14, 2020 report summarizes Childs' observations of the tank at that time, specifically related to the cracks and leaks. The follow up conversation notes with Don Morin clarified and reiterated several points. I have read through the letter and the conversation memo. After having observed the tank in person, now a bit more than four years since Carl's visit, I can say that I generally agree with the findings he makes and the discussion points he provides. The two photos provided in the report showing leaks on the southerly wall can be matched to my current observations and the photos are nearly identical. Enough time has passed since his site visit that more wear has occurred and likely more fine cracks are present, particularly at the wall corners and on the roof. The green paint currently on the walls really highlights the leaks and the cement coating spreads the effect of the leaks out from the cracks themselves. While Childs' report does not discuss the condition of the roof, the report notes that the cracks and spalls on the roof coating will need to be patched. This does not appear to have been done. The masonry coating is now relatively ineffective and numerous cracks and leaks exist. See Recommendations in Part 3.

I have completed a brief desktop review of the plans and specifications for the tank design by looking through the drawing details and reviewing the reinforcement ratios which would be appropriate for this type of tank. This was not a comprehensive design review and I have completed only simple calculations to check the walls and roof for strength. This review is intended to see if I noted any concerns or proportions which should be investigated further.

- From my review of the plans and specifications, the reinforced concrete design seems reasonable and it appears that the roof and wall members are sufficient for strength. The plans show sufficient design information for construction and appear clear and nicely put together. I did not observe any specific design deficiencies that would lead me to suggest there were any structural safety concerns in the plan documents.
- Notes regarding the amount and spacing of reinforcement shown on the plans. Concrete cracking can be minimized in several ways. Cracks can be limited in size by reinforcement. Reinforcement is proportioned for the volume of concrete present. ACI 350 (06) Code Requirements for Environmental Engineering Concrete Structures and Commentary table 7.12.2.1 provides guidance for the minimum amount of reinforcing for concrete which is intended to be liquid-tight, with a ratio of reinforcement based on the cross sectional area of the concrete and the length between points of restraint. Concrete cracking and reinforcement ratios are a complex subject, so by providing the following I do not state absolutes; instead, I provide context to help explain what can be seen at the site. The longer roof and wall segments are approximately 35ft long. The minimum shrinkage and temperature reinforcement to anticipate crack widths conforming to the general design provisions of acceptable widths for this pour length would be between 0.004 and 0.005, depending on how the designer considers the joints.
  - (1) For the roof, the least reinforcement provided is a reinforcement ratio of 0.0057. Some areas in this roof provide nearly twice this amount, exceeding the minimum suggested.
  - (2) For the floor, the reinforcement provided is at a reinforcement ratio of 0.0061, which also exceeds the minimum suggested.
  - (3) For the walls, the least reinforcement provided is the horizontal reinforcement at a ratio of 0.0037. With a bar center to center spacing of 12" o.c., at the upper end of what is suggested. The walls are therefore perhaps slightly under-reinforced for water tightness. The vertical reinforcement bars are at a ratio of 0.0132, more than double the minimum ratio.
    - (a) This could help to explain, to some extent, why there is relatively consistent vertical cracking along the walls, since the stress due to temperature changes and concrete shrinkage is higher in the horizontal steel (because there is less of it). * See note 4.
  - (4) *It has been my experience that in areas where concrete is poured onto and connected to areas of high restraint such as walls onto footings and roofs onto walls, even when reasonable reinforcement ratios are provided, there will still be concrete that cracks. In a water tank structure these cracks, even though observed to be very small, will still leak. There is a balancing act in all designs between cost, feasibility, effectiveness, and strength. If, for example, one designs a structure this big, such that no concrete cracks, we have to use complicated joints and more joints, all of which can and often do leak. Also the project would require complicated construction techniques and materials, would be more expensive, take more time, and limit the contractors who could complete the project or even be interested in bidding the project.

ii) Cast-In-Place Concrete Materials. The project plan specifications define several concrete requirements. These include strength 4000psi, slump 3-5 inches, maximum water/cement ration of 0.45, air entrainment of 4%-6%, cement content, fly ash inclusion 10%-15%, water reducing admixture, and the inclusion of Xypex C-500 waterproofing admixture.
  - (1) The ACI 350 (06) document referenced previously provides guidance for concrete materials that are intended to be durable and have low permeability when exposed to water. The specified materials generally conform to these provisions. For the above-ground section of the tank, and perhaps for the roof, it might have been prudent to consider a slightly higher exposure condition, the next design category up to include exposure to "freezing and thawing in a moist condition". This would have adjusted the materials specifications to: the water-cementious (w/c) ratio of 0.42

(ACI 350) and a minimum concrete strength of 4500psi. It very well may be that the concrete has this strength but we do not have any tests to review.

(2) Cold Weather Concrete. The project specifications on the plans require that the concrete temperature during the first seven days be maintained between 50 and 90 degrees F. The time of year that the concrete was poured, into November, could have necessitated additional efforts by the contractor to maintain such temperatures. Absent field inspection records, there is no way to confirm conformance with this provision. Temperature could have been a factor in the latter roof pours as well, as this material is thinner and cools faster, making the work more temperature-sensitive.

(3) Steel Reinforcement Coating. The project plan specifications require ASTM A615, grade 60 reinforcement. This would be the typical reinforcement used for this application. There was an inquiry and some discussion about whether or not the reinforcement should be coated for corrosion protection. In other words, to determine whether epoxy-coated reinforcement would be used or required. The design engineer answers this question in item 6 of the Childs/Morin memo of their phone conversation August 7, 2020. Epoxy-coated reinforcement was not used. The designer did not specify the use of epoxy-coated reinforcement in this and similar tanks, because the tank is not exposed to salt solutions such as deicing chemical application typical for road work, or to other design limitations (such as shallow cover over reinforcement) that would require additional protection of the reinforcement. While ACI 350-06 does reference its use as one of the measures than can protect reinforcement from decay, it does not require it for all tanks. I read through the slide show written by Gene Gopenko, P.E. that is on the web, which was attached to the memo, that lists epoxy-coated rebar in one of the bullet points. However, I do not find the fact that it shows up in the slide show as a compelling argument that it is required for this tank. The chlorine content of this finish water is very low. No deicing chemicals are used on the tank. There was no evidence of reinforcement decay at the site (no spalling, rusting, bulging, decay). Accordingly, for this tank, it is my opinion that there is no merit to considering epoxy-coated reinforcement a necessity for this tank. The design engineer made a reasonable decision not to include it.

(4) Waterproofing Admixture. The plans specify the inclusion of a waterproofing admixture, Xypex-C-500. A substitution was made for Pentron Admix SB. It is not known if this change was approved and if the products are equivalent. The admixture literature states that the product is designed so that it will help provide a fully waterproof and permanently dry concrete structure, with self-healing capacity for cracks up to 0.5mm (0.0197”). I will note that even if the admixture was used, the cracks that are leaking are much smaller than the sales literature indicates will self-heal. If present the admixture t may be working to some extent but it is demonstrably not sealing many of even the finest cracks.

<u>Part 3: Summary - Next Steps - Potential Improvements to Improve the Tank’s Durability</u>

Summary:

The tank walls appear to be in average to good structural condition for their age, with the amount of cracking and leaking appearing to me to be slightly above average (perhaps more than would be expected). The tank roof appeared to be in average structural condition for its age, with the amount of cracking and leaking appearing to me to be more than average (more than would be expected). I did not observe any conditions that caused me to be concerned with the current structural capacity of the tank walls and roof. My review of the project documents to date has not identified any specific design deficiencies that would lead me to suggest there were any structural safety concerns.

The project files lack almost any information regarding the construction period specific to the concrete materials, concrete inspection and concrete testing, therefore any defect in these items is beyond the scope of this report. Additional testing may be warranted. See recommendation R6.

Because there is more cracking and leaking than we would like to see, it is my opinion that there are several reasonable repairs to purse, maintenance to perform and upgrades to consider that will improve the tank’s durability. The service life of the structure will be reduced if no actions are taken.

Recommendations:

Based on my site visit, the observed condition of the tank, and my review of the available documents, I provide the following recommendations for reasonable repairs to purse, maintenance to perform and upgrades to consider that will improve the tank's durability.

R1. Provide a roof membrane over the entire roof surface to seal the roof leaks. This will protect the water from contamination from roof leaks, preserve the concrete surface, and increase the service life of the tank's roof. In terms of benefit/cost this recommendation has a high value for the town, given that it will have a meaningful impact on the life of the structure and the potential of contamination. Crack sealing should be completed prior to installation of the membrane. Here the term membrane means a waterproof roof layer system that can accommodate some movement and still provide a watertight layer. The existing masonry coating is in very poor condition and is an impediment to the adhesion of a new roof membrane and associated crack repairs. Therefore I suggest the masonry coating be removed. Crack sealing is likely to include a combination of injection and hand applied epoxy products such as SikaFix HH LV. The roofing/waterproofing system is likely to be a roller-applied liquid roofing product such as Sikagard 62 high-build epoxy coating or similar. A levelling product may be needed to reduce or eliminate the puddles on the roof. Engage a design team to plan this work and a contractor to complete the work. Priority 1 – This recommendation should be pursued in the near term.

R2. Seal the cracks inside the tank, as it is feasible and reasonable to do so. For this discussion, it is presumed that the tank cannot be taken out of service and completely emptied for large scale internal repairs. Accordingly, develop a plan to seal the cracks that are easily located visually. The plan needs to be developed in coordination with the Town to understand at what water levels the repairs can be completed; that is, whether divers are needed or if the water level can be lowered to allow most work to occur above water. Crack sealing inside the tank is complex and not necessarily feasible. The sealing is likely to include a combination of injection epoxy, hand applied epoxy with small membrane tape, and injection of polyurethane and acrylate resins. Engage a design team to investigate the feasibility of the work, to plan this work and a contractor to complete the work. Priority 2 – This recommendation should be investigated further to better understand the potential scope, cost and complexity.

R3. Consider sealing the cracks outside the tank that are above grade and that leak. These are relatively easy to access and it is feasible to do this work with little specialized access equipment and relatively simple logistics. Develop a plan to seal the cracks that are easily located visually and that are leaking the most. Crack sealing these active leaking cracks is most successful using an injection epoxy system. Hand-applied surface sealing systems are not recommended, as they will likely be pushed off and detach from the crack, only to leak again. As stated in the Childs report, crack sealing of temperature and shrinkage cracks is frustrating and should not be considered a final or complete solution, but rather a maintenance activity undertaken to reduce the leaks and improve the long term durability of the walls. This activity is recommended as a consideration, but it would also be reasonable to allow the leaks to continue and accept the aesthetic downside and slightly reduced service life that may result. See notes in R5.

R4. Address the poor—and likely to worsen—aesthetics of the outside tank walls. The existing masonry coating is in very poor condition where it is adjacent to cracks and leaking, with the green paint color highlighting the leaks. While this report may provide some reassurance that the tank is safe, there will be an ongoing perception of the public and future Town officials that it is not. The coating will continue to break off, in larger segments over time, with the color disparity making it look much worse than it is. In the near term, the Town could consider painting the above grade tank walls a color more similar to the efflorescence. In the longer term, develop a plan to remove the masonry coating where it is damaged, perhaps all of it, and apply a coating that is more durable and colored to match the efflorescence. It may be worth considering a vegetated screen along the road, to screen the tank from the view by the travelling public.

R5. Investigate an insulation system with a permanent protective layer over the tank walls and roof. Shrinkage cracks associated with temperature change are identified above as a cause of some of the visible cracks and leaks. Freezing water on the roof surface cracks is also thought to be deteriorating the concrete. If the tank were insulated, even modestly, the dimensional changes it undergoes will be significantly less and future cracking would be reduced. The downside of this approach would be that it obscures the tank, impeding detection of future issues.

R6. Review the internal Town paper and digital files from 2015-2016 to see if additional relevant documents can be discovered and archived. Reach out to the parties involved with the project to request that they share their records of the construction period. I would start by locating the firm that completed concrete testing, then the contractor, S.D. Ireland Concrete Construction Co., and finally the structural engineer, Carl Childs. If no records can be found for the concrete material testing, because of the abundance of newer small cracks, I recommend that concrete cores be taken in several locations and the concrete tested for strength and material properties to assure there is no early stage deterioration.

I have included a selection of photos of the tank and sketches that depict the tank crack locations.

Thank you for the opportunity to work on this project. I am available to answer any questions as needed. Please let me know if I can help further.

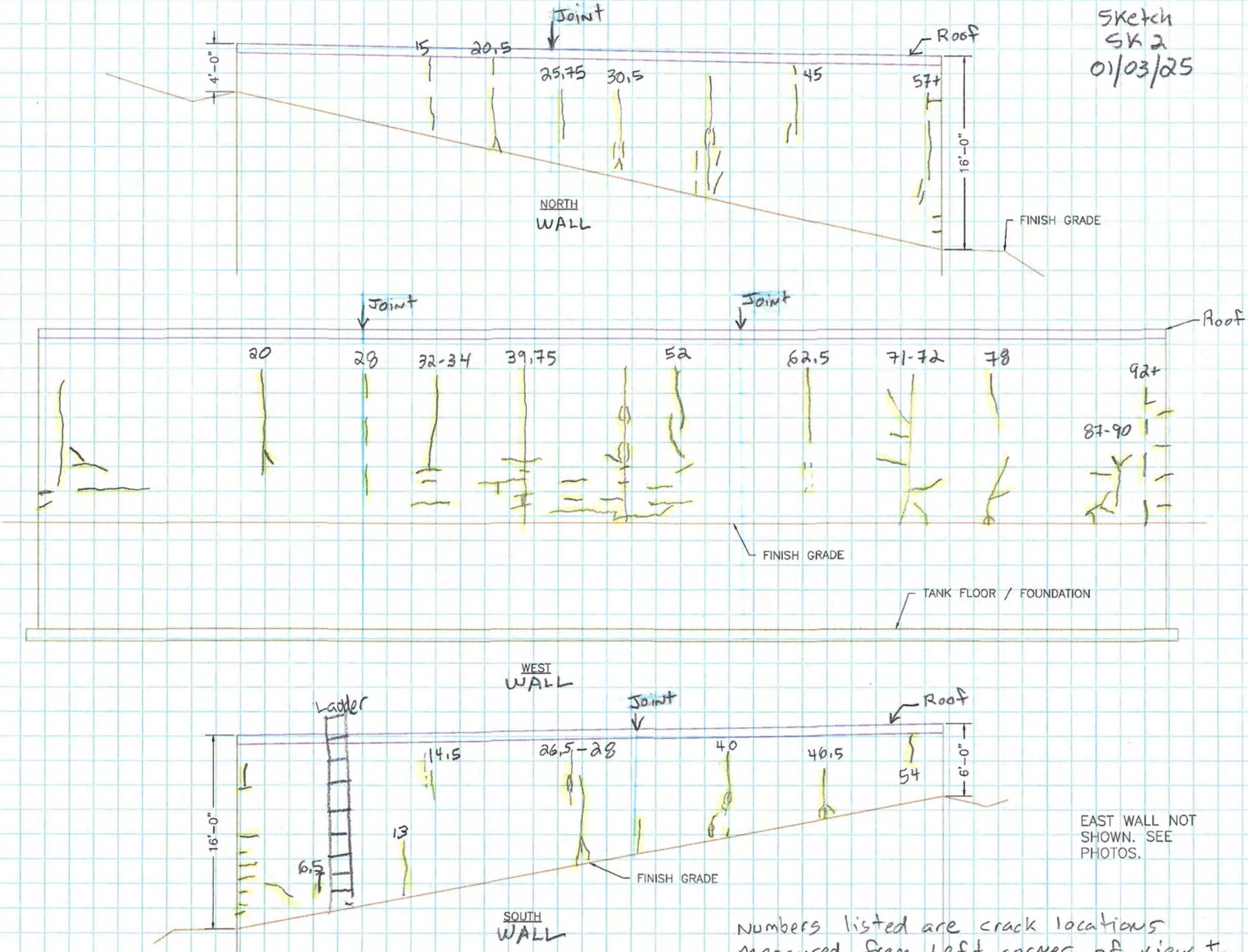
Richmond
STATE OF VERMONT
DAVID T. HINDINGER
01/03/25
NO. 8928
STRUCTURAL I
LICENSED
PROFESSIONAL ENGINEER
Water Tank

Sincerely,

David (Todd) Hindinger, P.E.

General crack patterns and Locations. Hand sketch only. These crack locations were not surveyed.

Sketch
SK 2
01/03/25



EAST WALL NOT SHOWN. SEE PHOTOS.

Numbers listed are crack locations measured from Left corner of view ±

OBSERVED EFFLORESCENCE LEAKS OR CRACKS

Tank Wall South – Right Corner

Tank Wall South – Middle


Tank Wall South – Left


Tank Wall West – Right Corner


Tank Wall West – Middle to Right Corner


Tank Wall West – Middle to Left Corner

Tank Wall West – Middle to Left Corner

Tank Wall West – Middle

Tank Wall West – Middle to Left Corner

Tank Wall West – Left Corner


Tank Wall North – Right Corner


Tank Wall North – Middle to Near Right Corner

Tank Wall North – Middle to Left Corner

Tank Wall North – Middle to Right Corner

Tank Wall North – Middle to Left Corner

Tank Wall East – Middle to Right Corner

Tank Wall East – First Control Joint to Right Corner

Tank Wall East – Middle to Left Corner


Tank Wall East – Left Corner


Roof – From Center Looking Southeast

Roof – From Center Looking Southwest

Roof – From Center Looking West

Roof – From Center Looking West-northwest

Roof – From Center Looking Northwest


Roof – From Center Looking North


Roof – From Center Looking Northeast

Roof – From Center Looking East

This is the end of the general photos intended to provide an overview of the visible portions of the tanks. The following section includes example photos of items discussed in the report at specific locations.

Crack and Leak Example Photos Exterior Wall Near Center of North Wall. Same Location both photos. Photo at left shows bulge of tank coating and leaks pushing through coating. Photo at right is after light tapping of coating showing concrete below and very small crack.

Crack and Leak Example Photo Exterior Wall – Middle of South Wall. Photos show same two locations depicted in Childs report from 2020. Leaks remain similar.

Crack and Leak Example Photos Exterior Wall Left Corner of West Wall. Same Location both photos. Photo at left shows leak, effervescence and yellowish color. Photo at right is after light tapping of the coating showing evidence of previous repairs (round drill holes or form tie holes that were plugged). Active leak.

Crack and Leak Example Photos Exterior Wall Middle of West Wall. Evidence of previous repairs that still leak. Horizontal and vertical cracking and leaking. This would have been one of the last walls poured = most restraint = most likely to crack due to concrete shrinkage.

Roof Crack Examples – Multiple locations of diagonal cracking at corners. Masonry coating is loose in many locations and does not seal or protect cracks.

Roof Cracks. Example photo on roof of a typical crack. Note relative size is very small. Handheld crack gauge and ruler in photo for reference.

Inside Tank – Diver Photo by Others - Note Efflorescence along diagonal crack. Water on Roof can leak into tank.

Inside Tank – Diver Photo by Others - Note Efflorescence along diagonal crack. Example location shown, other photos show that this event occurs in multiple locations.

Inside Tank – Diver Photo by Others – Distinct crack in wall. Location, other than wall inside tank, is not known. Other photos show that this event occurs in multiple locations. Likely source of water for leaks observed on outside.

Inside Tank – Diver Photo by Others – Distinct crack in wall Corner. Location, other than wall corner inside tank, is not known. Other photos show that this event occurs in multiple locations. This crack is likely not a shrinkage crack, but rather a stress crack as described previously. Helps to explain visible leaks at corners outside tank.


Example photos from an entirely different cast-in-place concrete tank. Provided to show that leaks and repairs can be relatively common. This tank is in VT. Photo at left shows previous injection process to repair crack and several cracks with some fine leaks. Photo at right shows a similar horizontal crack and efflorescence at a tank corner, similar to that occurring at the subject tank. This tank is not intended to be a model tank, just to help Owner understand leaks.

Photo from an entirely different cast-in-place concrete tank, much older but still full, not the same tank as previous photo. Provided to show that leaks and efflorescence are fairly common. This tank is also in VT. This tank is not intended to be a model tank, just to help Owner understand leaks.