Demonstration of Cryogenic Ground Freezing Technology - Phase I. Site Selection and Development Plan Report

Reviewer 1 Comments:

- a. Page 1, pp1.0. Purpose of report is understandable, but purpose and scope of entire project is not described.
- b. Page 1, pp 2.1. Site selection does not address other sites that were investigated (if any) and why this site was selected. Does not state that this selected site meets all required criteria, or is good in some respects, or lacking in some desired parameter.
- c. General location of selected site is not clear. Here on page 1 it says Gallaher Road, yet page A-3 of Law Engineering says Gallaher Ferry Road. Since Fig.1 mentions Poplar Springs Road, I presume it is in the area shown on the attached copy of a section of a map of Gallaher/Poplar Springs Road area.
- d. Page 1. Figure 1 shows only approximate test location. It does not show contours and area surrounding test location, such that one has a feel for down hill drainage, proximity to neighboring houses (and wells), reservoirs, etc. Figure 2 is not dimensioned to property lines and corners, nor how far B-3 is from B-1 through B-6.
- e. Page 1, pp 2.2. More information on fill would appear to be important. When was fill placed? Where did it come from? Is it contaminated with anything? Why wasn't it tested (chemically) as part of site selection? Was fill compacted into place or just dumped. What is ground cover (i.e. grass, trees)? What is slope of surface? Will it require grading?
- f. Page 4 (Top) Was drilling contract only for determining moisture content, with one wet unit weight sample, at bottom of hole B-5? Why? Why weren't holes changed over to ground water wells, to investigate ground water table? Holes drilled on 8 and 9 Sept. Should one expect a high groundwater table in the Spring, or even a perched ground water (in fill)? What is permeability of fill and soils at greater depths?
- g. Page 4, pp3.0. Lacking specifics on purpose and scope of project its hard to evaluate why 56 x 56 and 33 x 33 ft were selected.
- h. Page 6, pp 3.1.1. Strange that Law Engineering report (Appendix A) did not mention stability of augured holes, with respect to proposed drilling for freeze pipe installation, i.e. will hole walls slough or otherwise fill with mud or water, etc.

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h. Page 6, pp 3.1.1. Strange that Law Engineering report (Appendix A) did not mention stability of augured holes, with respect to proposed drilling for freeze pipe installation, i.e. will hole walls slough or otherwise fill with mud or water, etc.

i. Page 6, pp 3.1.2. Appendix A does not provide any data on hydraulic conductivity. Soils are described as silty clays or clayey silt. If soils must be replaced by sand perhaps this was not the preferred site for the test to begin with. Discussion in section 4.2 does not provide real reason for sand.

j. Page 10, figure 7. Top connections very poorly drawn. Apparently no air bleed on annulus return, where air gets trapped on initial filling with brine. For inclined freeze/heat pipes it may be important to have wire or other centering devices to keep 1½ inch PVC pipe centered in 4½ inch pipe.

k. Page 13, pp 3.1.4 and elsewhere (Fig 10). Why not give manufacture's name and model of refrigeration units. No mention of unit to be used for heater.

l. Page 13, pp 3.1.5. This section does not describe instrumentation for the two bullets. Two bullets are really sections 3.1.6 and 3.1.7, on page 15.

m. Page 15, pp 3.1.6. Implies each refrigeration unit has the instrumentation. During test period must this information be recorded separately, or does all this data go to test computer? Will it be necessary to have personnel on site 24 hours a day to monitor refrigerators?

n. Page 17. Provide details of monitoring pipes. Are they steel or PVC, give diameter and whether filled with fluids, air, etc.

o. Figure 8 says only 1 flow meter on brine supply line. No details provided on manifolds of supply and return lines around site. If lines are split, rather than single loops, may need more than one flow meter to balance system. Same applies to heat system. Consideration should be given to installing RTD's to the outside of all freeze pipes, at some constant depth (10 - 20 ft), such that one knows that freeze pipe is indeed working and how it compares with others (i.e. colder or warmer).

p. Page, 17 pp 4.1. This is hardly a test, this and 4.1.1 and 4.1.2 are quality control and part of as-built. Will "testing" be done as each pipe is installed, or after all are installed? Will there be specifications on drilling as to position? What will size of augured holes be? Are they tight holes, or will slurry backfill be required. Is type of auger specified?

q. Page 19, pp 4.1.2 Is pressure test done with air or water?

r. Page 19, 4.2. Purpose overstates test. There are no planned instrumentation or wells to investigate if frozen barrier prevents passage of water-borne chemicals, other than in sand filled drainage way. There may be downward drainage, or through silty clay fill walls, even when frozen, or through some unfrozen spot in frozen bathtub. However it might take such chemicals many weeks or months to do this, depending on amount of water added and current groundwater conditions, lateral flow, diffusion, etc. Test duration may be too short to detect such leaks. Do not understand the use of sand through frozen barrier or around tank, nor the value of testing with first tracer (fluorescein). Is this first test to simulate a leaking tank before installation of the freeze pipe and does the sand simulate a sand backfill around tank and pipe trench? How will first tracer be released from buried tank? How much water, with first tracer, will be released?

s. Page 20, 3rd pp. Are monitoring wells equipped with well screens, perforated pipe, or solid? Note W1-A and W1-B have elbows and what appear to be slotted horizontal sections, which dump into pit at W1-C. Thus rate of filling and type of slots or holes important in dispersing tracers. How will flow rate and hydraulic gradient in fourth paragraph be determined? It's possible first tracer water is just slowly going down and laterally into silty-clay fill. Water levels measured outside frozen barrier may (will) be quite different from those inside frozen barrier. Why (5th pp) excavate only sand trench and observe frozen barrier?

t. Page 21, top pp. On previous page discussion was only about moisture content. Here we see saturation used. Is fill or soils at depth saturated or at some specific degree of saturation. This discussion, without long term water well observations, does not serve as basis for recommendation of not adding water to achieve full saturation at some specific depth.

u. Page 21, pp 4.4. If sand is not saturated it is possible that if dry frozen it may not contain dye. What is temperature of dyed water?

v. Page 21, pp 4.5. Ground temperature monitoring is very limited. Would recommend additional RTD's, taped to outside of freeze pipes, at one or two selected depths, to ensure that flow of brine through pipe is indeed occurring and at a balanced rate, compared to other pipes. Depending on manifold (details of which not provided) there could be warm or cold spots in frozen barrier.

w. Page 22, pp 4.6. Would suggest additional monuments on or near frozen well to the left of tank (Figure 12) opposite sand trench. Presume levels will be referred to non heaving benchmark, not just surface monument 20 ft. away. What are surface monuments?

x. Page 25, pp 4.8. See comment v, above.

y. Page A-17. Table of test results does not provide sample numbers (except 4). Text does not indicate where moisture content samples were taken. Presumably they were in interval of penetration test (see boring logs), yet here given as over 5 ft. intervals. How was single moist unit weight sample (no No.) in B-5 obtained and why wasn't dry unit weight also given?

aa. Pages A 18 thru A-21. Strange grain size distribution curves with very high percentages at 0.001mm size. While Atterberg Limits mentioned on page A-15 no data given for classification.

bb. Page B-3. Were soil temperatures measured during site investigation? Why is surface temp in Nov thru March the same as at depth?

cc. Page B-4. No soil ID for sand? No references cited for basis of data on density, specific heat, ice temps, etc. Should have had more undisturbed density samples. Weak link in analysis.

dd. Page D-2. No data on sand especially hydraulic conductivity testing at "dense state". Density data on sand also not provided. Figure 9 does not reflect 6 inch layer of sand under tank. Where (and why) will strain gages be attached to tank. If excavation fills with rain water won't tank float? Will excavation be protected from rain until clay cap is in place?

ee. Page D-3. Where (depth) will 5 ft well screens be positioned. Will holes be backfilled with sand or clay. Is screen size correct for this clay? Will water only be first added, then water with first tracer dye? Natural (?) communication may exist when water is first applied, but then in the weeks to follow, during freezing, the water in sand may just flow down and out through fill.

ff. Page D-4. Does initial tracer dye change the freezing point of soil moisture? Will it create a non-freezing zone in sand or clay? Will it cause a higher than normal unfrozen water content in the clay, at various below freezing temperatures? If 100 gallons will be withdrawn from well, how many gallons will be put in, near the tank? What happens to the 100 gallons, i.e. how disposed of ?

gg. Page D-4, pp 3.0. What if water level observations indicate water levels are dropping? What if there is not 800 - 1,200 gallons removed? How is this water from wells to be removed? Instructions appear to be repeating same step.

hh. Page D-5, pp 3.3. Why only for five (5) days? What is significance of barrier holding back dye for only 5 days? Why not look for dye after 30 days or more?

ii. Page D-5, pp 4.1. Why excavate only to a depth of 4 ft? How many holes, and where? What measurements will be taken (size of thaw/freeze zone)?

Will second dye inside frozen barrier be pumped down, or out, before digging excavations? Where is this dye disposed of? No mention of removing freeze/thaw pipes at end of test, nor of dye treated soil.

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Reviewer 2 Comments:

2. General Comments.

a. Since artificial ground freezing has been used for excluding water from subsurface excavations and stabilizing soil since before 1883, the ground freezing portion of the demonstration is well established. Then the main thrust of the subject demonstration is assumed to be directed toward determining the effectiveness of an artificially frozen soil barrier against the migration of contaminated materials through the barrier. Therefore, greater emphasis should be placed on the migration aspect of the demonstration.

b. Since the present plan is to test migration through sand, it is suggested that the frozen silty clay be tested also. One way to gather permeability data on the frozen clay barrier is to relocate piezometer PO-1 to a point near the center line of the TTC just outside of the vertical frozen silty clay barrier. This piezometer hole could serve also as a sampling point for the trace dye during the migration test. It's important to test the silty clay barrier, because frozen silt and clay soil contain considerable quantities of unfrozen water in the form of liquid films surrounding the soil particles. This unfrozen water would transmit contaminated solutions more readily than frozen sand. Also, at the proposed test site, the in situ soil is about 82% saturated and the water will be drawn to the freezing front leaving the soil between the frozen saturated soil columns deficient in ice and therefore more permeable than frozen sand. At the completion of the migration tests, the frozen silty clay barrier should be excavated and the soil tested in a manner similar to that planned for the frozen sand barrier.

c. The length of time allotted for the "Barrier Diffusion Test" should be increased to at least one year.

d. The surface drainage pattern is not shown in the report, however, it is important that the clay cover and the surrounding ground surfaces be graded to drain easily and quickly.

e. The heat pipes inside the test barrier are not necessary since heat removal from the frozen barrier can be controlled by adjusting the refrigeration system in response to temperature readings from the ground temperature sensors.

3. Specific Comments.

a. To reduce heat entrance into the frozen barrier at the ground surface, closed cell type insulation could be installed over the barrier but not on the unfrozen interior zone. It may be necessary to bury the insulation to avoid interfering with the drainage pattern of the ground surface.

Section 3.1 System Description.

b. In Figure 8, on the "View on X-X" TPV 11 and TPV 12 should be reversed to be consistent with the Plan View. Also, the view marks X-X on the plan should be moved backward to include TP-4.

c. On page 5, par. 3.1.1 states that freeze pipes, heat pipes and monitoring wells are to be placed in pre-bored holes. Pre-bored holes are acceptable where the soil is not contaminated but in contaminated areas the drill cutting must be handled with special care including special disposal. Driving the pipe into place would avoid this problem. It is suggested that consideration be given to driving the pipes as an installation method so this experience can be used in designing prototype barriers.

d. In the 3rd paragraph on the subject of monitoring pipes, it is suggested that the temperature sensors be mounted on plastic rods that can be removed for calibration and replacement of the sensors that malfunction. Also, since the sensor tubes are to be filled with brine, convection currents can develop if the inside pipe diameter is too large. If the sensors are mounted on a plastic rod as suggested, then the annular space around the rod should have a diameter of only one inch larger than the plastic mounting rod. If the sensors are suspended by their lead-in wire, then the inside diameter of the monitoring pipe should be 3/4" or less to avoid convection within the brine which would give false readings.

e. Paragraph 3.1.2. The clay cap must be well compacted and have a thickness greater than the depth of seasonal frost penetration to avoid loosening of the clay by frost action. The loosened clay can develop fissures thus allowing surface water to enter the simulated contaminated soil. The depth of maximum frost penetration should be determined at the site.

Section 4.1 Well Casing Installation.

f. Paragraph 4.1.2. Pressure Testing. It is assumed that a liquid will be used to pressure test the freeze pipes. In addition to a "visual indication of pipe leak tightness," a change in test pressure could be used to check on tightness by installing a valve and pressure gage to each pipe during the test and observe any drop in pressure over at least a period of a half hour with the valve closed.

Section 4.3 Moisture Addition Test.

g. On page 21, in the first paragraph there is a recommendation against adding water to the in situ soils for the demonstration of ground freezing. This recommendation is satisfactory

for the ground freezing process but water may be required to improve the imperviousness of the frozen silty clay barrier. Using the moist unit weight of the in situ soil as 109 lb/ft³, water content of 32% and specific gravity of the soil as 2.71, then the volume of soil voids is about 82% saturated. All of the boring logs shown in Appendix "A" state under remarks that, "No ground water encountered at the time of exploration." Since all the borings reached depths greater than 40 feet, it is reasonable to assume that the water table is quite low in this area. It is well established that during freezing soil moisture migrates to the freezing front. This fact raises the possibility that soil moisture will accumulate as ice around the freeze pipes, thus leaving soil between the solidly frozen soil columns unsaturated with little replenishment of water from the low water table. This condition would lead to an increase in the permeability of the frozen silty clay barrier.

APPENDIX B.

h. The table on page B-2 shows temperature at "Location 2" to reach temperatures down to -27.8°F; yet the table on page B-3 shows in situ Refrigerant Specification for "Temperature of Incoming Refrigerant" to be -22°F. This inconsistency in temperatures should be explained.

APPENDIX D.

Section 1.0. Installation Procedure: Barrier Diffusion Test.

i. Page D-3. Paragraph 1.4. The use of an open-standpipe piezometer for PO-1 which is to be installed in the in situ clay should be reconsidered since the ground water table apparently is lower than the bottom of the TTF. It is suggested that a pressure type transducer would be better suited for installation in the clay.

Section 2.0 Confirmation (initial) Test.

j. It is suggested that clear water be used initially to check the permeability of the sand fill. The sand fill is surrounded by relatively impervious clay and almost all the water should flow in the sand. Of course, the water flow and permeability could be determined in the same manner with piezometer readings. The advantage is that contamination of the soil with dye before the frozen barrier test is started can be avoided. If it is felt that the clear water test is not satisfactory, then the dye could be added later.

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Reviewer 3 Comments:

a. Purpose of Temporary Test Facility (TTF) design and testing strategy with respect to evaluation of full-scale design parameters is ambiguous. i.e. What are the design parameters and how will test results/data translate to full-scale design considerations? Report does little to address what questions will be answered by the study.

b. On page 4, the thickness of the frozen barrier is approximated as 10 feet. The radius of frozen soil surrounding each freeze pipe is stated to be about three feet. If the spacing in fig. 3 is applied, the frozen barrier thickness (perpendicular to the pipe) will systematically vary from 5.4 to 8.5 feet with a total domain of ten feet. The minimum distance across the frozen barrier will be only 1.9 feet. The representation in figures 5, 8, and 9 imply that the frozen perimeter will be uniform and planar. A non-planar frozen front will complicate the visual inspection described in paragraph 4.2, page D-6, particularly if the transport and diffusion is 2- or 3-D. Clarification of barrier thickness is therefore needed. The necessity of heat pipes for preventing inward barrier growth (section 3.0, page 4) needs explanation.

c. In section 3.0, page 5, the refrigeration capacity is listed as 2x40 tons. On page B-2, the largest predicted load requirement is 9 tons with zero losses for the analysis which is described. If 9 tons is comparable to the actual magnitude of heat transfer (rate) during the test, then significant losses will occur with the oversized refrigeration units. This will obscure the comparison of power consumption between the computer model and the field data (section 4.5, section 4.5).

The basis for the selection of refrigeration capacity should be explained. There is no indication in appendix B of a six to eight week process as stated at the top of page 5. Would have preferred to see analysis and discussion for the six to eight week freezing process along with time dependent dimensions of barrier.

d. With reference to section 4.1, page 17, recommend that maximum acceptable tolerances be specified on well placement/alignment and then adhere to specifications during installation.

e. With reference to section 4.1.2, page 19, while verification of piping integrity is important, it should not merit classification as a test since it will not generate data or provide usable information.

f. Provide details of the temperature monitoring pipes (material, diameter and schedule). It is unclear how the RTDs are installed and to what medium they are actually in contact. Suggest placing at least one RTD directly in sand for comparison.

g. The exact purpose and necessity of the first tracer needs further discussion. On page 19, statement is made that it will validate the test conditions. What does that mean? The indication on page 20 is that it is to verify hydraulic connection between the source and the sampling points. Why is a tracer necessary to do this?

h. Reason for sand trench needs clarification. Is it to evaluate high permeability soil, to decrease duration of test period, or to evaluate 1-D transport? If transport through sand only is being evaluated, the test facility is over-designed.

i. Ability to extrapolate short term data to long term transport phenomena should be scrutinized. In section 4.2, page 20, the expected results suggest that the barrier will be diffusion free. Section 3.3, page D-5, seems to imply that the test will only last five days. Time allowed for barrier diffusion test should be reconsidered. Test should emphasize the evaluation of rate of contaminant transport through the barrier as compared to unfrozen soil.