GROUND FREEZING TO SUPPORT HISTORIC BUILDINGS WHILE TUNNELING BELOW

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ABSTRACT

Tunneling below the three Russia Wharf buildings in downtown Boston for a light rail passenger line required support to prevent damage to the timber pile-supported structures. It included cutting off the timber piles as the tunnel advanced and transferring support to the tunnel structure. Ground freezing provided tunnel face stability and prevented groundwater flows. The analysis demonstrated that temporary support of one of the buildings on the frozen ground was not feasible due to limited clearance. The second building was temporarily supported on the frozen ground using jacks to maintain the column level. Underpinning using mini piles included a system of transfer girders and jacks to maintain consistent support for the buildings during expected ground heave from the ground freezing and to compensatefor any movement during tunneling. While earlier publications described this project, this paper describes the soil types, frozen ground test results, analysis that demonstrated that using only ground freezing for temporary support was not feasi ble without provisions to relevel building columns, the underpinning procedure, the method of monitoring movement and the project results.

KEYWORDS

Tunneling, ground freezing, frozen soil testing, ground heave, settlement, underpinning, historic buildings

INTRODUCTION

The route selected for this light rail tunnel extended beneath the adjacent Fort Point Channel and below two historic five-story structures, the Russia Wharf and the Graphic Arts Buildings, supported on timber piles and immediately adjacent to a third building. The buildings are shown in Figure 1. The path of the tunnel is illustrated in Figure 2. The Program Manager was DMJM-Harris. The tunnel designer was Dr Sauer Corporation, who originally proposed the tunneling method, including using ground freezing beneath these buildings to stabilize the ground and to re-support the buildings on the tunnel lining using the stub ends of the original wood piles. Mueser Rutledge Consulting Engineers, PLLC were the frozen ground engineers and designers of the underpinning and building protections system. Details of the final construction plan were a collaboration between the engineers, the transit authority, the building owners, the general contractor, and the freezing subcontractor after the contract was awarded.

Figure 1. Russia Wharf Buildings, facing east.

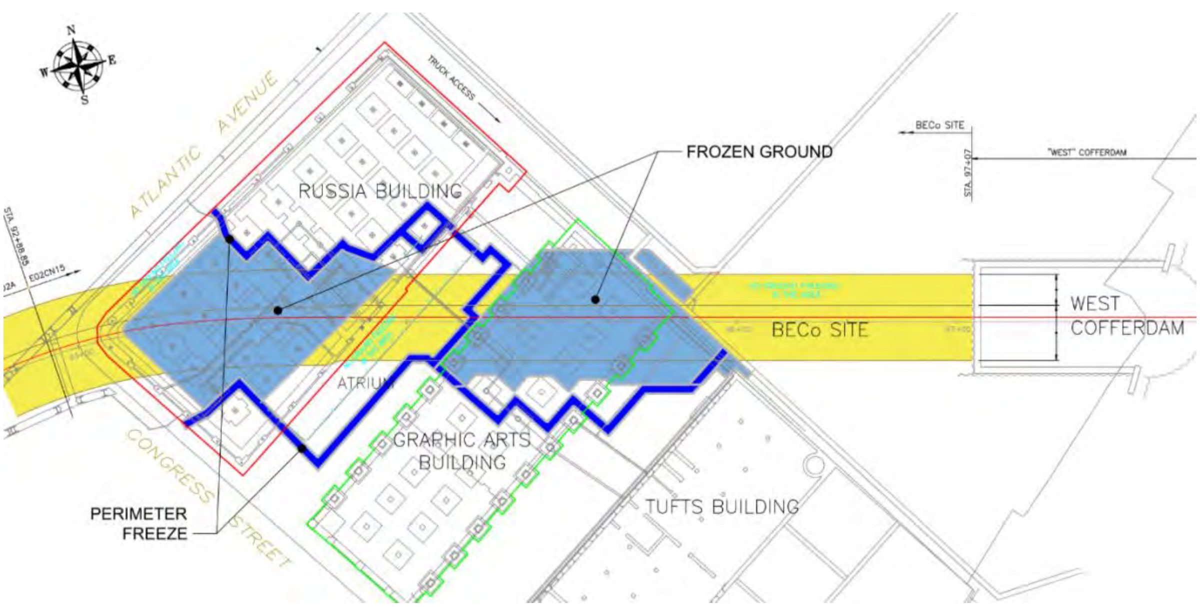

Figure 2. Site plan.

SUBSURFACE CONDITIONS

The buildings are underlain by miscellaneous fill placed during the 19th century over organic silts and peat. The soils below consist of silty marine clay slightly desiccated near the top. The base of the tunnel profile extends into a very dense, silty, sandy glacial till at the west end. Figure 3 shows the soil profile.

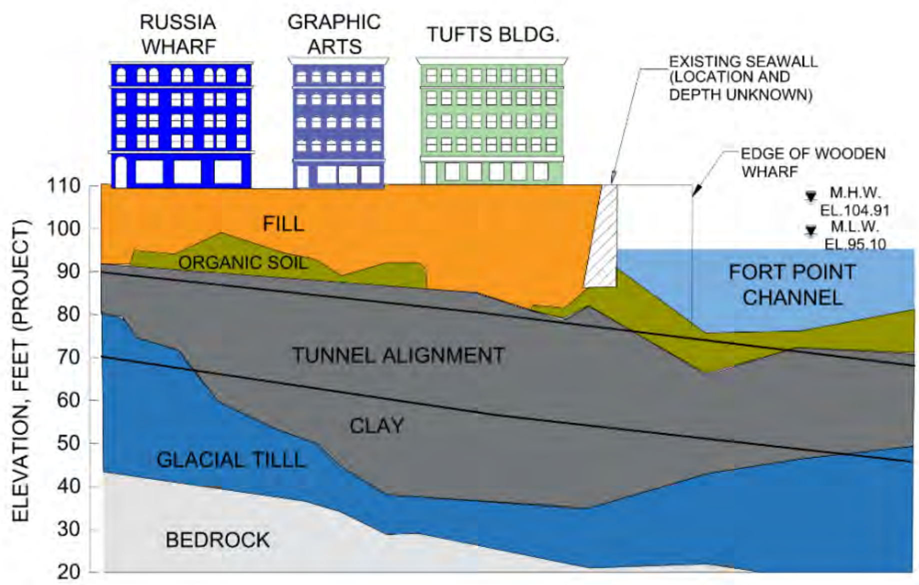

Figure 3. Soil profile along tunnel alignment.

FROZEN GROUND TESTING

Seven borings and frozen soil testing was performed, including nine samples of marine clay, six of organic clay, two of peat and four of granular fill. The test program consisted of 12 unconfined compression tests, four creep strength tests, three unfrozen water content tests, six thermal conductivity tests and two freeze-thaw tests.

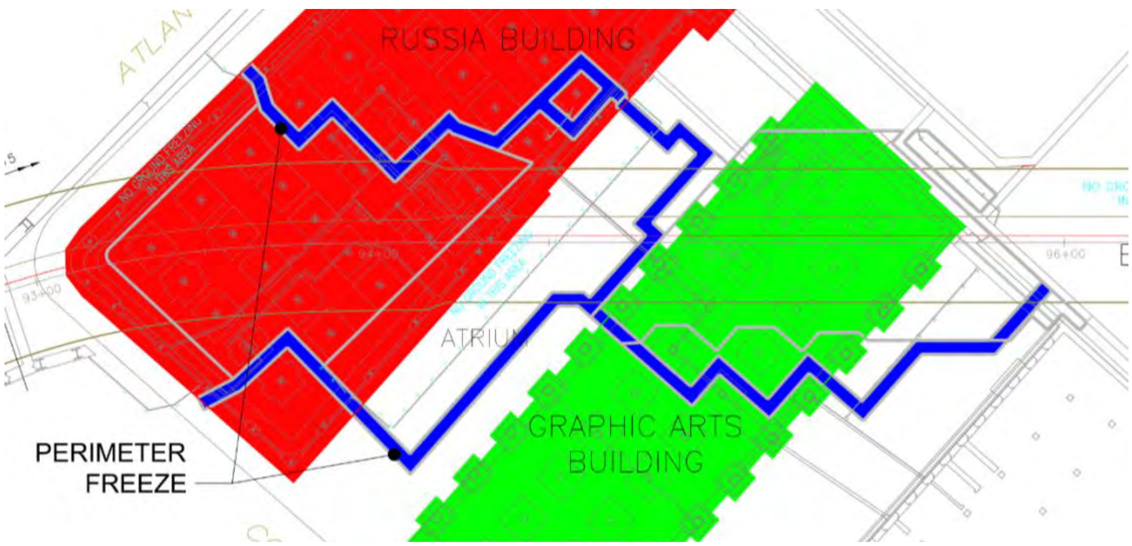

Figure 4. Perimeter freeze.

The natural water content of the marine clay varied from 28.4 to 37.4%, while the organic clay varied from 46.3 to 70.1%. The peat samples had natural water contents between 214.3 and 346.7%. After the frozen samples were thawed, there was little change in water contents except two of the peat samples experienced a modest decrease in water content.

DESIGN OF THE BUILDING PROTECTION

Russia building

Analysis indicated that too little cover was present between the tunnel crown and the basement to permit the use of ground freezing for temporary column support. Therefore, perimeter ground freezing was used to permit the removal of the basement floor and to excavate below the groundwater level sufficiently to use low-headroom drill equipment for micropile installation along the edges and in the center wall of the planned tunnel. Transfer girders were then installed beneath the granite pile caps for the permanent underpinning of the affected columns in this building.

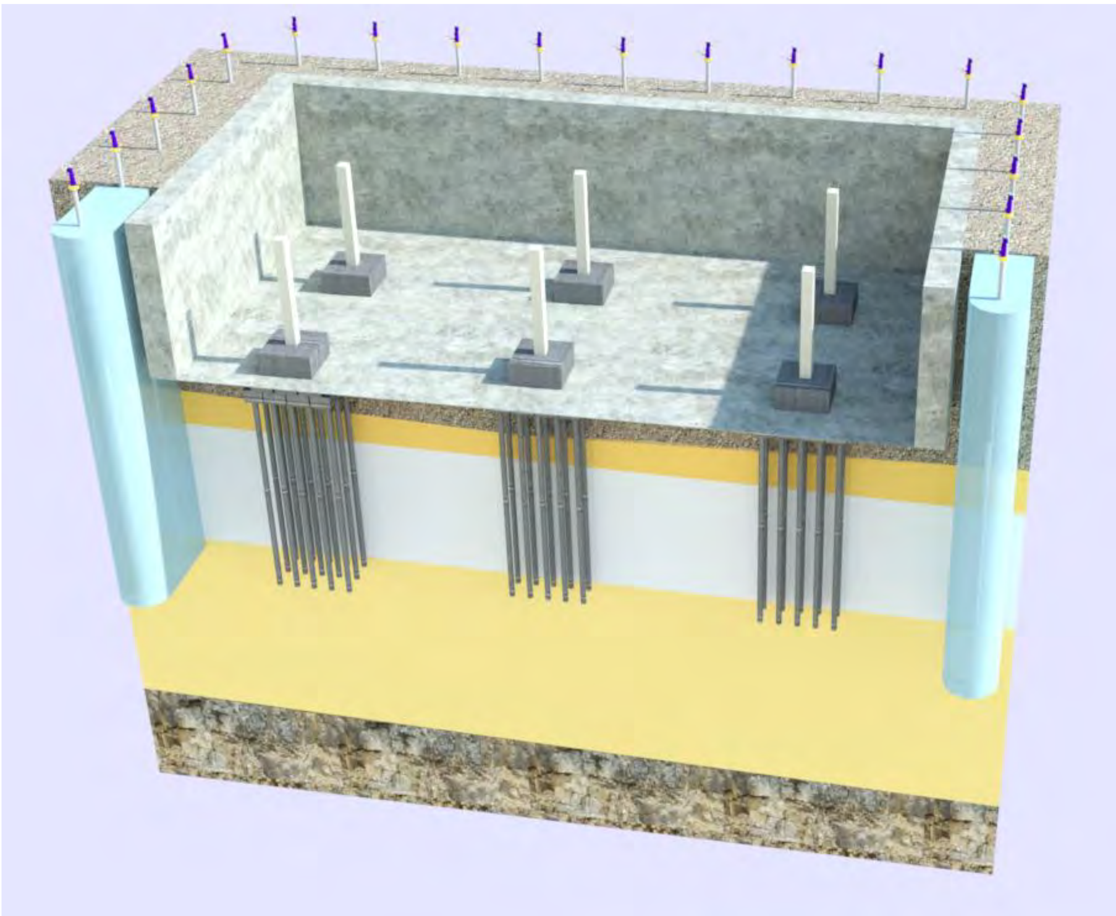

Figure 5. Russia Wharf excavation

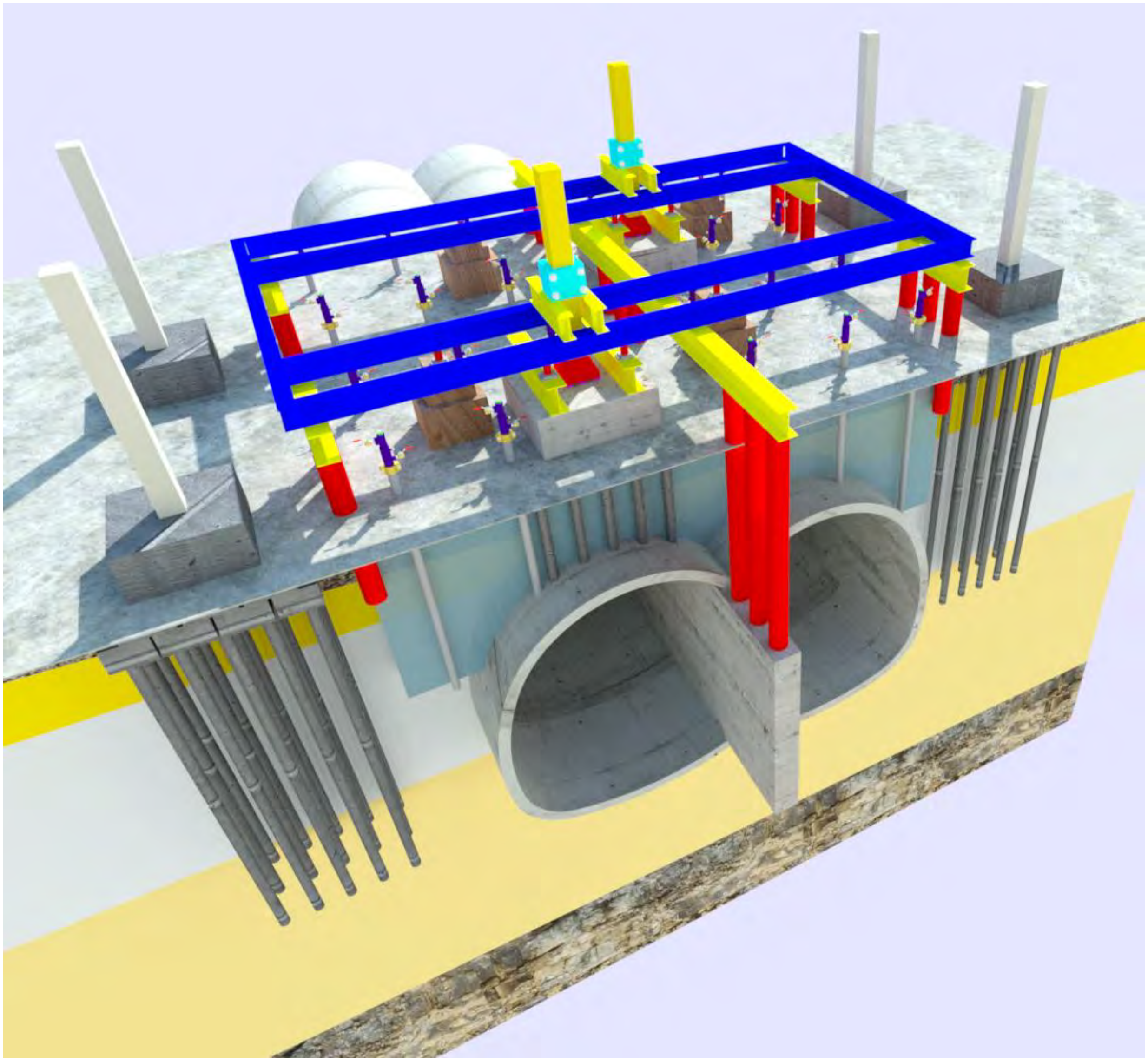

Figure 6. Micropiles and connection to columns

Graphic arts building

Analysis indicated that the building columns could be temporarily supported on the frozen ground using transfer girders located at the base of the column as shown in Figure7. Column levels were adjusted as the ground expanded during freezing and as settlement occurred during tunneling due to creep and elastic deformation of the frozen ground until the initial tunnel lining gained sufficient strength.

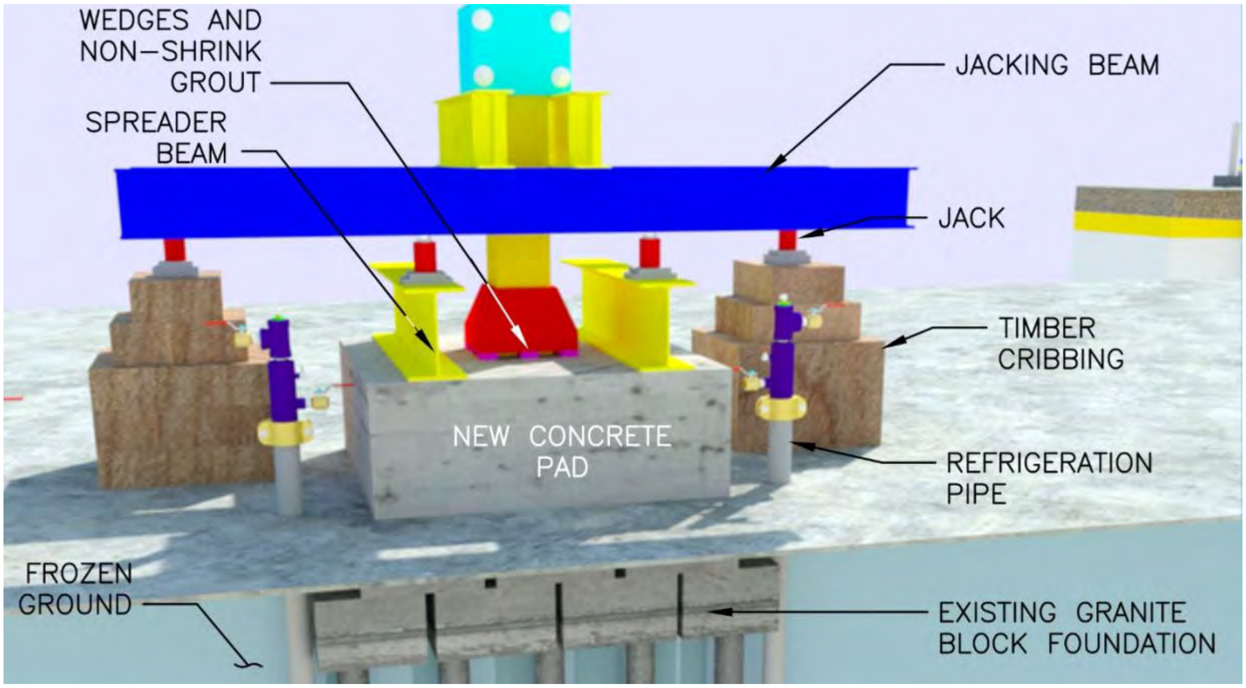

Figure 7. Temporary column support at Graphic Arts Building.

Test ground freezing at the graphic arts building

Early in the ground freezing design of this building, it was proposed to do a full-scale ground freezing demonstration to evaluate:

- vertical and lateral ground expansion
- impact of staged ground freezing
- impact of drainage wells within the frozen mass and pumping of the wells before all the soil was frozen plus the effect of heat applied at the drainage wells.

Stage 1 of the test freeze lasted 45 days. It was comprised of four freeze pipes being turned on around each of three adjacent pile caps within the Graphic Arts Building.

Two pipes were installed through the three granite pile caps to provide drainage of excess pore pressure during freezing. Pumping from these drains continued until all the organic and marine clay below these pile caps was frozen to reduce the heave of the pile cap. Drains were also installed midway between the pile caps to permit the dissipation of pore excess pressure. Heat pipes installed in the pile cap drains prevented the drains from freezing. Convergence gauges were used to measure the biaxial movement of the columns and those adjacent to those subject to the test freeze. It was found that after 45 days of Stage 1 freezing that no measurable vertical or horizontal movement was observed in the test columns.

Stage 2 extended an additional 20 days and included activating additional freeze pipes located between the pile caps. The purpose of the Stage 2 test freeze was to determine whether the additional freezing would adversely affect the adjacent columns that had been influenced by the Stage 1 test freezing.

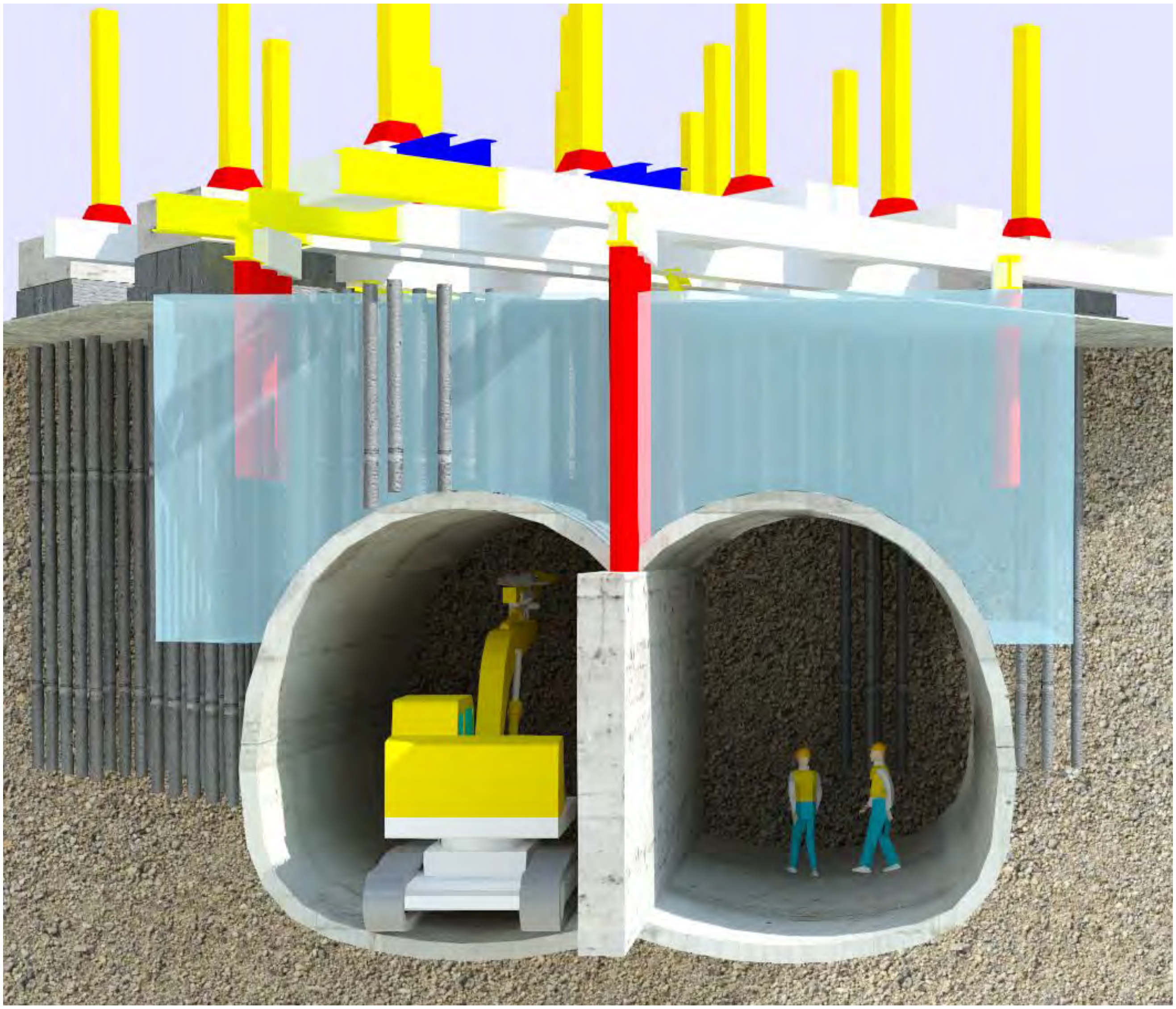

Figure 8. Tunnel mining under Russia Building

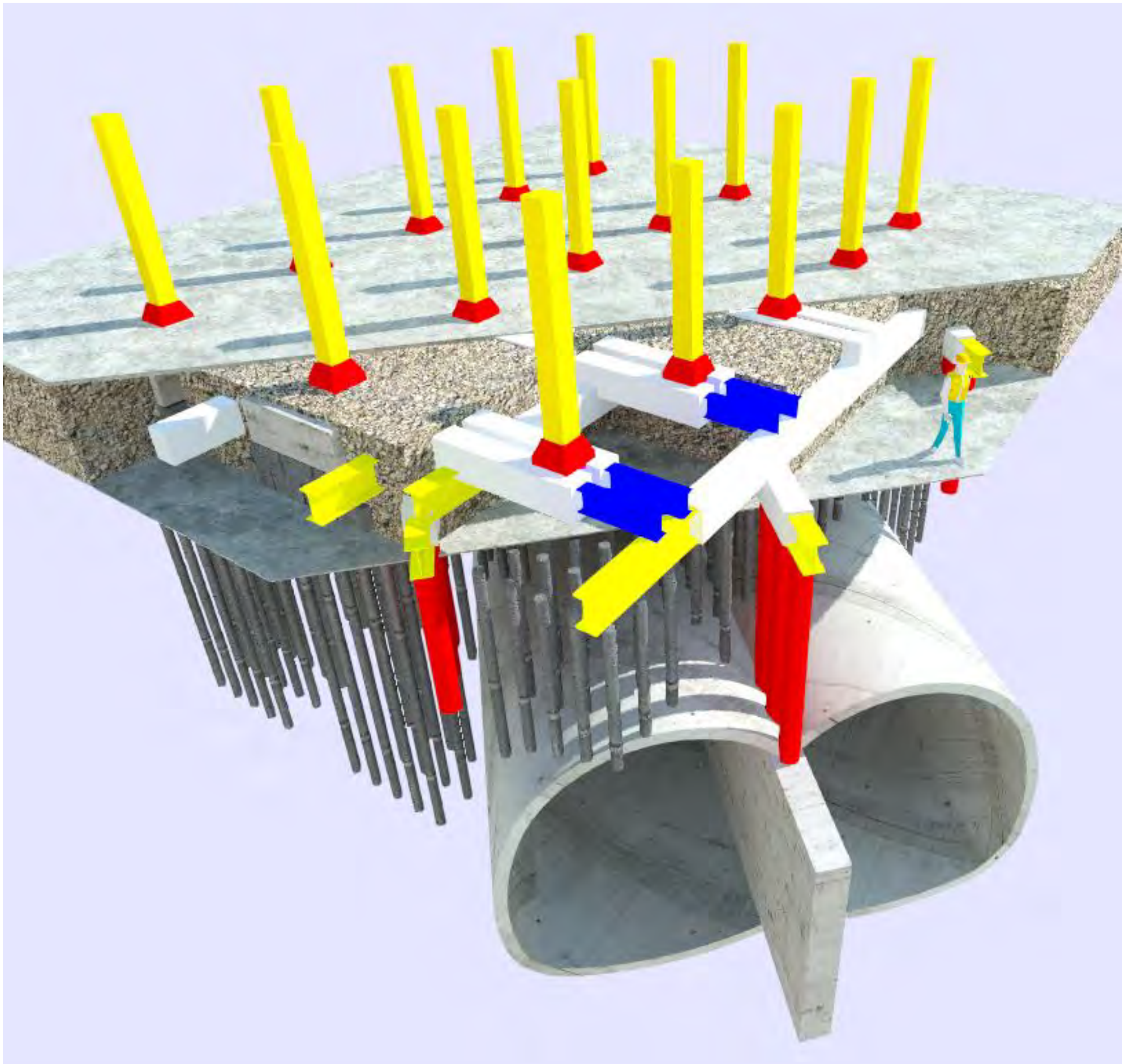

Figure 9. Piles bearing on tunnel lining.

Results of test freezing

No measurable heave, lateral expansion or column distress was observed during the Stage 1 and Stage 2 freezing. Temperature measurement was sufficient to determine the extent of freezing, indicating that the fill froze before the clay. The 45 days of Stage 1 freezing was reasonable for individual freeze pipes to develop circular frozen columns beneath each test pile cap and merge with each other, as predicted. A test of turning off the heat pipe for 24 hours in the pile cap drain and monitoring temperature change indicated a temperature drop of 60 °C. During the 20 days of Stage 2 freezing, monitoring showed a drop from -2 °C to -6 °C, indicating sufficient freezing between the test columns.

Conclusions from the test ground freezing

- The test freezing successfully demonstrated that staged freezing with the drainage system is beneficial for controlling volume expansion.
- The columns in and around the test freezing area experienced no measurable heave or lateral movement. It was concluded that ice expansion occurred in the least resisting lateral directions and was absorbed within the unfrozen soil mass without significant lateral column movement.
- Temperature monitoring demonstrated that the estimated 45 days of Stage 1 freezing was enough to solidify the soil below the columns.
- Stage 2 freezing did not adversely affect the already frozen Stage 1 test freezing columns.
- Pile cap pumping during freezing below the pile caps appears to be an important factor in reducing heave directly beneath pile caps.
- It was recognized that the test freeze did not consider the much longer period of freezing during tunnel construction or in potential impacts of a much larger area being frozen.

The freeze pipes for the Graphic Arts Building were installed at the time of installation of the cut-off and area freeze pipes for the Russia Building. The test ground freezing at the Graphic Arts Building occurred concurrently with the freezing for the cutoff at the Russia Building. The general area freezing at both buildings proceeded at the conclusion of the test freeze program to keep construction on schedule and budget.

GROUND MOVEMENTS DURING TUNNELING COMPARED WITH PREDICTIONS.

Measured cumulative heave in the Graphic Arts Building varied from none to 46 mm with a pattern that is difficult to explain (Lacy et. al. 2004), Frequent adjustments to the column levels (as much as twice a month) was necessary to minimize building distortion to less than the 1:200 permitted. Most distortions were less than 1:700. Settlement during tunneling was between 5 and 8 mm and did not require column adjustment. Predicted ground heave during ground freezing demonstrated that staged freezing and drains between freeze pipes appeared to be effective in reducing the heave of the ground below and around the pile caps.

REFERENCES

Lacy, H. S., Boscardin, M. D, Becker, L. A. *Performance of Russia Wharf Buildings During Tunneling,* North American Tunneling 2004