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The repair of Arctic structures damaged by thaumasite

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Abstract

The reinforced concrete foundations of two buildings in the Arctic were severely damaged by thaumasite formation within two years of construction. Repairs to the piers supporting one building were successfully made by jacketing them with steel-encased silica-fume grout. The column foundations and slabs on grade of the other building were repaired using a polymer concrete formulated to cure at low temperature. These repairs were incompetently made and the resulting concrete had inadequate strength and resistance to freeze–thaw action and chemical attack. These foundations were replaced under strict supervision and control with successful results. Both types of repair are described. The quality control procedures and test results are reported.

Keywords: Polymer concrete; Pull-out tests; Quality control; Silica-fume grout; Thaumasite

1. Introduction

The Polar Continental Shelf Project is a Federal Government base for scientific expeditions in the Arctic. It is situated at Resolute on Cornwallis Island at approximately 75 degrees North. A barren place, with winter temperatures as low as −49°C, there is a brief period during the summer when the surface layer of the permafrost thaws during the day.

The facility consists of a motel-like living accommodation and a converted hangar for equipment and laboratories. The living accommodation is supported on short piers founded on footings in the permanently frozen permafrost. The concrete in the hanger consists of a slab-on-grade and individual column footings founded on concrete piles.

Construction was completed in 1988, but within two years there was clear visual evidence of severe deterioration of concrete components. Investigation identified thaumasite formation as the cause of deterioration [1]. Typical damage is shown in Figs 1–4.

In 1993 a repair contract was let and carried out that summer. It was subsequently found that the repairs to the hanger had been improperly made. These repairs were re-done in 1995 by the same contractor at no expense to the owner.

2. Repairs to accommodation building

The piers supporting the accommodation building were 300 mm in diameter. Typical damage is shown in Figs 1–4. The soil around these piers was excavated to below the permanent frost line and all deteriorated concrete removed. Each pier was then jacketed with a steel tube fabricated in two halves as shown in Figs 5 and 6. The steel jackets had a grout inlet at the bottom and an outlet at the top.

Fig. 1. Sulphate-laden water on ground surface. Note deterioration of third column from the right at ground level.

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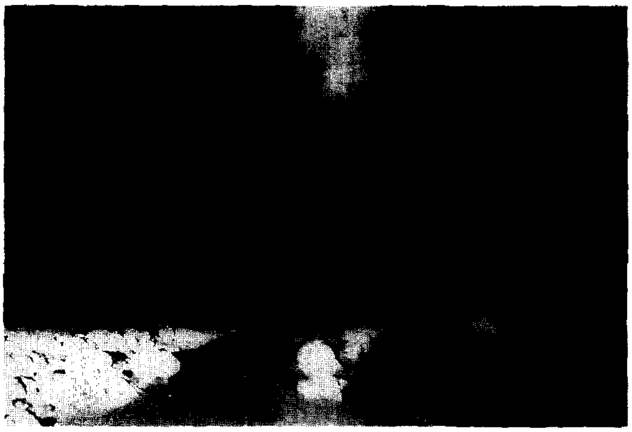


Fig. 2. Initial sign of deterioration. Expansion at ground level.

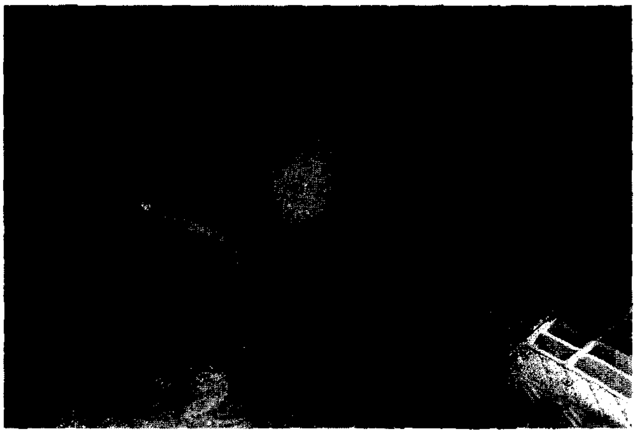


Fig. 3. Cracked pieces can be removed by hand. Mud-like material at ground level.

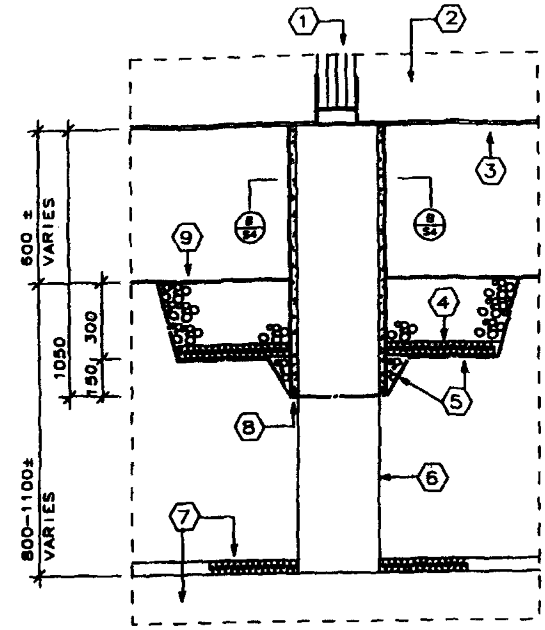
Fig. 4. Advanced deterioration. All of the lower part of the pier now mud-like material.

The annulus between the tube and pier was then filled with a silica-fume grout developed for grouting post-tensioned structures. The soil was then backfilled to original ground level. As the lower part of the piers is in permanently frozen ground, the piers are now isolated from further sulphate attack.

The grout used comes pre-bagged and requires only the addition of water. Tests for flow and bleeding were made each day and 50 mm cubes were made for compression tests. Specified strength was 40 MPa.

Twenty-eight day test results were as follows:

Sample	Compression strength (MPa) (average of three specimens)
1	87.8
2	87.4
3	89.6
4	80.8
5	93.1
6	74.5
7	79.1
8	62.5
9	51.4
Mean	78.5
Standard deviation	13.8
Coefficient of variation	17.6%



① BUILT-UP BEAM OVER (SIZE VARIES)
② EXISTING CRAWL SPACE FRAMING
③ UNDER SIDE OF CRAWL SPACE FLOOR SHEATHING
④ 50MM RIGID INSULATION AROUND, MINUMUM 450MM WIDE
⑤ EXCAVATE AND BACKFILL AS NECESSARY TO INSTALL CASING AND RIGID INSULATION
⑥ EXISTING CONCRETE PIER SIZE VARIES. (SEE SCHEDULE). PRIOR TO INSTALLATION OF SLEEVES REMOVE LOOSE AND SPALLED CONCRETE
⑦ EXISTING CONCRETE FOOTING PLUS RIGID INSULATION BELOW
⑧ SEAL
⑨ EXISTING GRADE

Fig. 5. Elevation of typical pier repair, accommodation building.

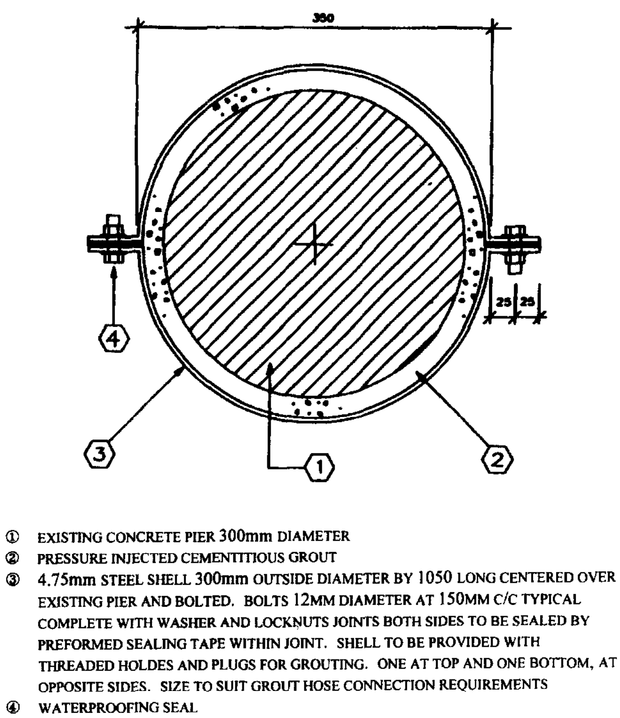


Fig. 6. Cross-section of pier showing repair details.

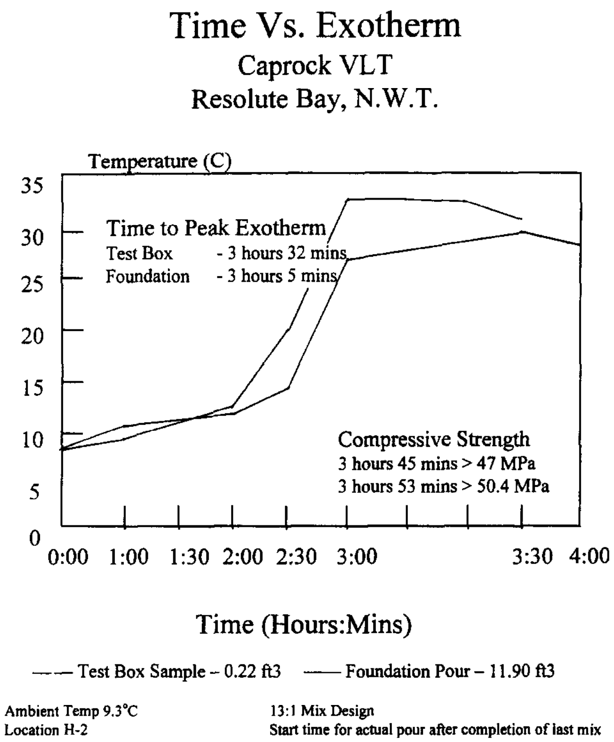


Fig. 7. Curing characteristics of resin concrete.

Table 1
Compressive strength results

Specimen no.	Compressive strength (MPa)
A-2-1	112.0
A-2-2	111.1
A-3-1	114.0
A-3-2	114.2
A-4-1	114.0
A-4-2	111.7
A-5-1	110.1
A-5-2	109.5
A-6-1	124.2
A-6-2	124.8
H-2-1	115.7
H-2-2	116.0
H-3-1	129.7
H-3-2	125.7
H-4-1	112.9
H-4-2	112.5
H-5-1	121.5
H-5-2	121.0
H-6-1	123.8
H-6-2	118.7
Mean	117.2
Standard deviation	6.0
Coefficient of variation	5.2%

3. Repairs to hangar

The repairs to the hangar slab on grade and column footings consisted of the removal of all damaged concrete and replacement with a proprietary resin concrete formulated to cure autogenously at very low temperatures. This material had a long track record of satisfactory performance and was considered to be the most suitable for this application, where adequate curing of conventional concrete would be difficult and no suitable natural aggregates were available. The resin concrete is immune to all forms of sulphate attack.

This resin concrete consists of a resin, a benzoyl peroxide hardener and a high-quality natural gravel coarse aggregate. Accurate batching, thorough mixing and a clean mixer are prerequisites to the successful use of this material.

Table 2
Splitting tensile strength results

Specimen no.	Splitting tensile strength (MPa)
A-4-1	18.9
A-4.2	18.9
A-2-1	16.4
A-2-2	16.9

The resin concrete improperly batched and mixed in 1993 was removed at each location and replaced with correctly prepared concrete.

Although the quantities of grout and concrete required for these repairs were small, the materials had to be flown to the Arctic and site working conditions were difficult. Consequently the repairs were very expensive. The second resin concrete repairs, involving the removal and replacement of about 4 m^3 of concrete, were estimated to have cost approximately $100,000.

Because the first resin concrete repairs had been improperly executed, it was the requirement of the rectification of them that a principal of the firm supplying the resin concrete materials be resident on site. It was also, to the author's dismay, the client's requirement that he be resident for the contract.

In the event Mr Ray Crowne of Cappar Ltd. controlled the measurement, mixing and placing of each batch and the removal of all defective material. He also carried out various ad hoc physical tests to confirm the satisfactory exothermic reaction and hardening of each batch. A typical plot of the exothermic reaction is shown as Fig. 7.

Each column had to be supported by a temporary frame while the foundation was removed and replaced. Only one support frame was available. Pull-out tests were made on samples of resin concrete cast into boxes. This confirmed compressive strengths in excess of 50 MPa at about 3 to 4 hours after casting. This accelerated construction from one column foundation a day to two. This accelerated the completion of the repairs and the return of the construction team to civilization.

Test cylinders 75 mm diameter and 150 mm long were made from resin concrete placed in each foundation. These were tested at approximately 28 days after casting. The test results are shown in Tables 1 and 2.

4. Discussion and conclusions

The contractor who carried out the repairs had a bid price significantly below the estimated price for the contract and those of the other bidders. The total cost including the extensive additional investigation needed as a result of the improper installation of the resin concrete and the cost to the contractor of rectifying this work was well in excess of the estimated price.

The grouting of the accommodation building piers was successful, although the variability of the strength test was somewhat higher than it should have been.

The installation of the resin concrete repairs when carried out in strict conformance with the manufacturer's instructions produced a dense, highly-sulphate-resistant concrete with very high and uniform strength characteristics.

The role of pull-out testing to accelerate construction was demonstrated. The importance of quality control in the successful use of the resin concrete was also demonstrated.

Acknowledgements

The client was the Canadian Federal Department of Public Works. The tremendous help of Mr Ray Crowne of Cappar, who worked 14 hours a day to ensure the successful use of his product is also acknowledged.

References

[1] Bickley JA, Hemmings RT, Hooton RD, Balinski J. Thaumasite related deterioration of concrete structures. American Concrete Institution Proceedings, Concrete Technology, Past, Present and Future, Special Publication SP 144, 1994:159–75.