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EXPANSION OF HANFORD CONCRETE

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October 1978

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PREFACE

High-level radioactive waste from the current waste management operation at Hanford is stored in underground reinforced concrete tanks with a steel liner on the sides and bottom. The removal of pumpable liquid results in a moist salt-cake of sodium salts that is relatively immobile compared to its original liquid state. Additional immobilization and isolation techniques are being studied to further improve waste isolation and containment. Retrieval of the waste and permanent disposal will be deferred until a permanent disposal mode and location is selected. The integrity of the storage tanks is of critical importance during this interim period.

Technical studies and laboratory tests have been performed to determine the effect of the stored waste's temperatures and chemistry on the reinforced concrete's strength and elastic properties. This work was performed for Rockwell Hanford Operations under the technical direction of the Pacific Northwest Laboratories at Richland, Washington by the Construction Technology Laboratories, a division of the Portland Cement Association, Skokie, Illinois.

Concrete is a stone-like material obtained by careful proportioning of cement, sand, gravel, and water. The aggregates (sand and gravel) occupy 70 to 75 percent of the volume of the hardened mass and have a significant effect on the strength and physical properties. A basic assumption in the design of a reinforced concrete structure is that "perfect" bonding exists between concrete and reinforcing steel.

The waste storage tanks have been subjected to temperatures as high as 350° F. The difference in the rate of thermal expansion of the reinforcing steel and the concrete could have a significant effect on the bond and consequently on the integrity of the tank. Specific data on the rate of thermal expansion of Hanford aggregate concrete was needed for a structural analysis of the effect of elevated temperature on tank integrity.

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EXPANSION OF
HANFORD CONCRETE

by

Michael Gillen

Submitted by
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EXPANSION OF HANFORD CONCRETE

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INTRODUCTION

This report presents results of measurements of thermal expansion of concrete cores from Hanford, Washington facilities, and concrete cast at the Construction Technology Laboratories of Portland Cement Association (CTL/PCA)⁽¹⁾**.

Thermal expansion was measured from room temperature to 1600F on 0.5 x 3.0-in. specimens heated at a rate of 10F/min.

Specimens were cored from concrete cylinders cast at CTL/PCA in 1975 and 1977, and from cylindrical cores taken from the Purex Building and Waste Tank Farms at the Hanford, Washington complex. A total of 14 specimens were tested: eight tests on CTL/PCA cast concrete, two tests on material from the Purex Building, and four tests on Waste Tank Farms concrete.

All tests were conducted using a commercially built dilatometer of high strain resolution. Work was done by the Fire Research Section at CTL/PCA.

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**Superscript numbers in parentheses refer to References at end of paper.

TESTING PROGRAM

Specimen preparation, test equipment, and procedures are described below.

Specimen Preparation

Specimens for thermal expansion studies were cored from concrete cylinders cast at the CTL/PCA in 1975 and 1977, and from cylindrical cores from the Purex Building and Waste Tank Farms facilities in Hanford, Washington.

Procedures used in preparing specimens from each group of materials are described in the following sections.

Concrete Cast at CTL/PCA

Dilatometer specimens from in-house concrete came from 6 x 12-in. cylinders cast at the CTL/PCA in May, 1975, (designated Phase II) and September, 1977, (designated Phase III). Cylinders were cast using materials and mix designs similar to those in Hanford structures. All cylinders had been conditioned continuously in a fog room maintained at 100% relative humidity (RH) and 73F prior to removal for fabrication of dilatometer specimens.

Cylinders 3K8-7, 3K9-18, 4.5K8-19, and 4.5K9-10, cast in 1975 and 3K14-12 and 4.5K12-12 cast in 1977, were used to obtain dilatometer specimens. Cylinders were cut into three 4 x 6-in. cylindrical sections. Next 1/2-in. diameter cores were obtained with a diamond-tipped core drill bit. Coring equipment is shown in Fig. 1.

Fig. 1 - Half-inch diameter core drill

Ends of these cores were then cut with a precision saw to a length of about 3 in. Finally, core ends were lapped plane to provide 0.5-in. diameter by 3-in. long cylindrical dilatometer specimens. Cores were then stored at 50% RH and 73F until tested.

Purex Building Concrete

Nineteen 4-in. diameter cores taken from the Purex Building were sent to CTL/PCA in 1977 to determine strength and elastic properties⁽²⁾. Material not used in mechanical testing was cut and cored to provide dilatometer specimens using methods previously described. Specimens were fabricated from core pieces marked SA-10W-7 and SA-17W-2. Specimens were stored at 50% RH and 73F until tested.

Waste Tank Farms Concrete

Irregularly shaped cores from Waste Tank Farms concrete were also sent to CTL/PCA for determination of strength and elastic properties⁽³⁾. Material not used in the original test program was cored to provide dilatometer specimens. Dilatometer specimens were obtained from concrete removed from Waste Tank Farms 241-A II and 241-T using procedures outlined above. Dilatometer cores were maintained at 50% RH and 73F until tested.

Test Equipment

Individual components of test equipment to measure thermal expansion of concrete specimens are described in the following sections. A photograph of the assembled test system is shown in Fig. 2.

(1) Electric Furnace	(4) Invar Bar
(2) Fused Silica Tube	(5) Dial Gage and LVDT
(3) Fused Silica Rod	(6) Recorder-Controller
Instrument
(7) X - Y Recorder	

Fig. 2 - Dilatometer and Recorders

Dilatometer

Thermal expansion of 0.5 x 3.0-in. cylinders was measured with a commercially manufactured dilatometer. This equipment consisted of an electric furnace capable of heating specimens to 1600F, and instruments for measuring resulting thermal strains. A schematic of the dilatometer system is shown in Fig. 3.

During testing the specimen was contained in the closed end of a fused silica tube that extended into the furnace. The open end of the tube was fixed to the support base by a large bracket.

Thermally induced movement of the specimen was transferred through a fused silica rod attached to an Invar bar that rode on ball-bearing pulleys. The end of the Invar bar rested against the plunger of a dial gage with a 0.0001-in. calibrated sensitivity. Pressure from the light spring of the dial gage kept the specimen in contact with the closed end of the fused silica tube.

The core of a linear variable differential transformer (LVDT) was mounted axially on the outer end of the dial gage plunger. Dial gage and LVDT housings were mounted on the base support of the assembly. Strain-measuring apparatus is shown in Fig. 4. In addition to lightly loading the specimen, the dial gage was also used to calibrate the LVDT.

Length changes measured by the LVDT included a component caused by thermal expansion of the fused silica rod and tube

Fig. 3 Longitudinal Section of Dilatometer

- (1) Invar Bar
- (2) Dial Gage
- (3) LVDT

Fig. 4 - Expansion Measuring Instruments

used to contain the specimen. Expansion of fused silica components was only about 5% of the length changes of the specimens. However, data were corrected for this effect.

Temperature Controller-Recorder

A commercial automatic instrument, actuated by one of the chromel-alumel thermocouples mounted inside the silica tube, controlled and recorded furnace atmosphere temperature. This instrument was set to change temperature at a rate of 10F/min.

X-Y Recorder

Thermal expansion of specimens measured by the LVDT, and temperature measured by a thermocouple were continuously recorded on an X-Y plotter.

Test Procedures

Specimens for thermal expansion testing were selected to avoid those with visible cracks, surface flaws, or air voids. Prior to test, each specimen was weighed and measured. Weight and dimensions are listed in Table 1.

Test specimens were placed in the fused silica tube of the dilatometer and the fused silica rod seated against the end of the specimen. Temperature was increased with the electric furnace at a rate of 10F/min. to 1600F. In two tests the maximum temperature was 1700F. Temperature was then returned to ambient, at a rate of 10F/min. Thermal movement and temperature were recorded with the X-Y plotter throughout the heat cycle. Output from a typical test is shown in Fig. 5.

After cooling specimens were weighed to determine weight loss resulting from heating. Values are reported in Table 1.

TABLE 1 - WEIGHTS AND DIMENSIONS
OF DILATOMETER SPECIMENS

Specimen	Test Number	Date of Test, Mo.-Day-Yr.	Weight at Test, lb	Length, inches	Diameter, inches	Weight after Test, lb	Weight loss, percent
3K8-7	1	8-24-78	0.0483	3.016	0.502	0.0447	7.42
3K9-18	2	8-30-78	0.0470	3.010	0.495	0.0435	7.54
4.5K8-19	3	8-31-78	0.0475	2.878	0.494	0.0441	7.16
4.5K9-10	4	9-1-78	0.0479	3.015	0.495	0.0444	7.36
241A II	5	9-6-78	0.0462	3.020	0.495	0.0429	7.20
241A II	5A*	9-7-78	0.0484	3.025	0.496	0.0451	6.83
241A II	5B*	9-8-78	0.0467	3.023	0.495	0.0437	6.41
241T	6	9-12-78	0.0519	3.026	0.496	0.0483	6.96
3K14-12	7	9-13-78	0.0512	3.019	0.494	0.0473	7.47
3K14-12	8	9-14-78	0.0479	2.958	0.497	0.0433	9.57
4.5K12-12	9	9-15-78	0.0512	2.985	0.497	0.0476	6.99
4.5K12-12	10	9-20-78	0.0513	3.000	0.496	0.0474	7.66
SA-10W-7	11	9-21-78	0.0489	3.013	0.495	0.0448	8.51
SA-17W-2	12	9-22-78	0.0495	3.018	0.494	0.0457	7.61

*Duplicate tests to verify test results.

FIG. 5 — TYPICAL OUTPUT FROM X-Y RECORDER. DILATOMETER TEST OF WASTE TANK FARM 241-T CONCRETE.

TEST RESULTS

Results of dilatometer tests on concrete cast at the CTL/PCA and concrete from the Hanford Purex Building and Waste Tank Farms are described separately below.

Concrete Cast at CTL/PCA

Concrete cylinders were cast at CTL/PCA in 1975 and 1977 using materials and mix designs similar to those used in construction of Hanford facilities. Thermal expansion of specimens fabricated from these cylinders are described below.

Phase II Concrete

Thermal expansion of specimens fabricated from concrete cast at CTL/PCA in May, 1975 (Phase II) is shown as a function of temperature in Fig. 6. Thermal expansion for each of the four specimens increased approximately linearly with temperature from 73 to 1000F.

At about 1000F, slopes of the expansion versus temperature curves increased rapidly for all specimens. The most probable explanation for this change is volumetric expansion of aggregate resulting from the inversion of quartz from the α - to β -form^(4,5). Temperature for this transition is usually reported as 1063F. The relatively large increases in expansion near this temperature indicate the presence of quartz in significant quantity in the aggregate.

No increase in thermal strain was observed for three of the four specimens from 1250F to maximum test temperature. This plateau in the expansion versus temperature curve has been reported by other investigators for siliceous aggregates^(4,5).

FIG. 6 — THERMAL EXPANSION OF PHASE II CONCRETE AS A FUNCTION OF TEMPERATURE

Thermal strain at maximum temperature ranged from a low of about 4000 millionths to a high of approximately 6700 millionths for these specimens. Expansion of concrete from 3K- specimens 3K8-7 and 3K9-18, was larger on average than that of 4.5K- specimens 4.5K8-19 and 4.5K9-10. Average thermal strain for 4.5- specimens was approximately 840 millionths at 400F, and 5180 millionths at 1400F.

Phase III Concrete

Thermal expansion of specimens fabricated from concrete cast at CTL/PCA in September, 1977, (Phase III) is plotted against temperature in Fig. 7.

Phase III concrete thermal expansion curves followed trends observed in Phase II concrete. Thermal expansion of Phase III concrete was on average slightly greater than Phase II concrete in the temperature range from 73 to 400F. Average thermal strain at 400F was approximately 1040 millionths. Between 400 and 1000F thermal strains for concrete of both ages were approximately equal.

At 1000F, the slope of expansion curves of Phase III concrete specimens increased more rapidly than was observed with Phase II specimens. The flattened portion of the expansion curve seen with Phase II specimens above 1170F is also present in plots of Phase III test results. However, for Phase III specimens this post-quartz inversion plateau appears to begin at a temperature of about ~1080F. This is lower than observed for Phase II specimens. In Test No. 8, the specimen contracted at temperatures above 1260F.

FIG. 7—THERMAL EXPANSION OF PHASE III CONCRETE AS A FUNCTION OF TEMPERATURE

Average thermal strain of Phase III specimens at 1400F was approximately 4600 millionths. As with Phase II concrete, average strains of 3K- concrete from Phase III were greater than 4.5K- concrete over most of the test temperature range.

Purex Building Concrete

Two specimens tested were from cores SA-10W-7 and SA-17W-2 of the Purex Building at Hanford, Washington. Variation of thermal expansion with temperature for these specimens is shown in Fig. 8.

Thermal expansion of Purex Building specimens was similar to Phase II and Phase III CTL/PCA cast concrete specimens from 73 to 400F. Average thermal strain at 400F was 858 millionths.

From 400 to 1000F, thermal expansion of Purex Building specimens increased at a slightly greater rate than Phase II and Phase III concrete specimens. At 1000F, expansion of Purex specimens exceeded that of CTL/PCA cast concrete specimens by approximately 900 millionths.

The sharp increase in expansion above 1000F, indicating the inversion of quartz from α - to β - form, was clearly visible in tests of both specimens.

Above 1200F, thermal strain of Purex specimens appeared to level-off. Further increases in temperature produced little or no additional expansion. In fact, the specimen obtained from Purex Building core SA-10W-7, Test No. 11, contracted approximately 1100 millionths when heated from 1250 to 1600F. However, no significant decrease in strain was observed for the second specimen, Test No. 12, in this temperature range.

FIG. 8-THERMAL EXPANSION OF PUREX BUILDING CONCRETE AS A FUNCTION OF TEMPERATURE

The specimen from core SA-17W-2 expanded more than its companion specimen from core SA-10W-7 from 300F to maximum test temperature. Differences in values for thermal expansion between specimens increased with temperature. For example, at 400F, strain values differed by approximately 150 millionths. At 1400F the difference increased to about 1570 millionths.

Thermal expansion of Purex Building concrete specimens was similar in magnitude to CTL/PCA cast specimens from room temperature to 400F. Above 400F, Purex Building specimens expanded at a slightly greater rate than CTL/PCA cast specimens. Though higher than the average for CTL/PCA cast concrete specimens, thermal expansion of Purex Building concrete specimens was within the limits of Phase II and Phase III test results.

Waste Tank Farms Concrete

Thermal expansion as a function of temperature was determined for two specimens fabricated from cores from Waste Tank Farms 241-A II and 241-T. Data from these tests are plotted in Fig. 9.

Response of these specimens to elevated temperatures differed in several ways from other concretes examined in this study. Thermal expansion of both specimens was on average smaller than either Purex Building or CTL/PCA cast concrete specimens over the entire temperature range investigated.

Thermal strain of Waste Tank Farms specimens was as low as one-half that of concrete of the other test series from ambient to 400F. Average thermal strain for these two specimens was

FIG. 9- THERMAL EXPANSION OF WASTE TANK FARMS CONCRETE AS A FUNCTION OF TEMPERATURE

only 550 millionths at 400F. Between 400 and 1000F, Waste Tank Farms specimens expanded more slowly than other concrete studied in the present program; however, differences in this range were smaller than at other temperature levels.

Near 1000F, increase in the rate of thermal expansion associated with the quartz α - to β - transition was observed. Neither the rate nor the amount of increase of thermal strain was as large for Waste Tank Farms specimens as it was for other specimens tested in this temperature region. Average thermal expansion for the two Waste Tank Farms specimens at 1000F was approximately 2750 millionths.

Above 1100F Waste Tank Farms specimens behaved differently than other concretes studied in the test program. For the specimen from Tank Farm 241-T, Test No. 6, increase in temperature from 1100F initially produced the post-quartz inversion plateau observed in tests of other concrete specimens. Beginning at 1260F, further heating resulted in contraction of the specimen that continued until maximum temperature was reached. Contraction over this interval was in excess of 1200 millionths.

Results from the test on concrete from Tank Farm 241-A II were more unusual. From 1100 to 1350F, thermal expansion continued to increase, though at a slowing rate. At 1350F however, thermal strain of this specimen abruptly decreased over 3500 millionths as temperature increased to 1500F. At 1500F, the specimen again began to expand until the maximum test temperature of 1600F was reached.

This behavior was so atypical that it was attributed some malfunction of the test apparatus. However, calibration of strain and temperature measuring instrumentation was checked and found to be in good order. Therefore, two additional Tank Farm 241-A II specimens were tested to determine if results were repeatable. These two additional specimens were tested to a maximum temperature of 1700F.

Results of tests of all three Waste Tank Farm 241-A II specimens are shown in Fig. 10. This figure shows specimen strain behavior both on heating and cooling from 73 to 1700F.

Comparison of the two additional Waste Tank Farm tests, Nos. 5A and 5B, with results of the original scheduled test, No. 5, shows similar trends during heating to 1600F. In particular, Test No. 5A closely followed thermal strain behavior of Test No. 5 over the entire temperature range.

Thermal expansion observed in Test No. 5B was somewhat greater than that measured for the other two specimens. Much of this additional strain resulted from a sharp increase in expansion near the quartz inversion temperature at approximately 1000F. Expansion of specimens from Test Nos. 5 and 5A was smaller near this temperature.

More importantly, the large contraction observed between 1350 and 1500F in Test No. 5 is clearly present in results of tests of both additional 241-A II Waste Tank Farms specimens. Strain reduction over this temperature range was on the order of 3500 millionths for each of the 241-A II specimens.

FIG. 10 - THERMAL EXPANSION OF TANK FARM 241-A CONCRETE AS A FUNCTION OF TEMPERATURE

Contraction ceased near 1500F and 241-A II specimens expanded slightly as temperature increased to 1600F. For those two specimens heated beyond 1600F thermal expansion increased rapidly from 1600 to 1700F.

Thermal strains of Waste Tank Farm 241-A II specimens on cooling are represented by dashed lines in Fig. 10. Contraction of all three specimens on cooling was similar. Decreasing temperature resulted in an almost linear reduction in thermal strain from maximum test temperature to 1100F.

From 1100 to 1000F, strain decreased at a greater rate, corresponding to the quartz inversion temperature region. Below 1000F, cooling specimens again contracted in a roughly linear manner to room temperature.

Final strain of cooled specimens was approximately 5500 millionths below their thermal strain values at maximum test temperature. In all cases, cooled specimens suffered a net reduction in length as a result of heating. Net contraction of specimens heated to 1700F, Test Nos. 5A and 5B, was less than half that observed for the single specimen, Test No. 5, heated to only 1600F.

Coefficient of Expansion

Thermal strain behavior is described completely only by curves such as those in Figs. 6 through 10. However, average coefficients of expansion are useful for calculations and comparison purposes. Average coefficients of test specimens for the range from 73 to 1000F are listed in Table 2.

TABLE 2 - AVERAGE COEFFICIENT OF THERMAL
EXPANSION, $\bar{\alpha}$, FROM 73 TO 1000F

Specimen No.	Test No.	Date of Test, Mo.-day-yr.	$10^{-6}/^{\circ}\text{F}$
3K8-7	1	8-24-78	3.79
3K9-18	2	8-30-78	3.60
4.5K8-19	3	8-31-78	3.84
4.5K9-10	4	9-1-78	2.63
241-A II	5	9-6-78	3.18
241-A II	5A	9-7-78	3.36
241-A II	5B	9-8-78	4.52
241-T	6	9-12-78	2.70
3K14-12	7	9-13-78	3.25
3K14-12	8	9-14-78	3.91
4.5K12-12	9	9-15-78	3.18
4.5K12-12	10	9-20-78	2.12
SA-10W-7	11	9-21-78	4.02
SA-17W-2	12	9-22-78	4.52

SUMMARY

A test program to measure thermal expansion of concrete from the Hanford, Washington Purex Building and Waste Tank Farms, as well as concrete cast at the Construction Technology Laboratories of the Portland Cement Association, was done. Thermal expansion was measured from room temperature to 1600F. Tests were conducted on 0.5 x 3.0-in. cylindrical specimens cored from the above materials. Specimens were heated at a rate of 10F/min., and resulting thermal strains measured using a commercially manufactured dilatometer.

Expansion of Hanford Purex Building specimens and CTL/PCA specimens cast in 1975 and 1977 followed similar trends over the entire temperature range investigated. Behavior of heated specimens can be characterized over four distinct temperature intervals.

Thermal expansion of Purex Building and CTL/PCA cast specimens heated from ambient to 400F displayed complex behavior. Most specimens expanded rapidly between 200 and 300F, but little or no additional expansion was observed from 300 to 400F. Thermal strain measured for these specimens averaged about 920 millionths at 400F.

Between 400 and 1000F, expansion of specimens was essentially a linear function of temperature. Average thermal strain at 1000F was approximately 3200 millionths.

Rate of thermal expansion increased sharply as specimens were heated from 1000 to 1100F. This increase in strain is

attributed to quartz in the aggregate undergoing inversion from the α - to β - form. This transition results in a discontinuous 2.4% volumetric expansion of quartz. Temperature for this transition is usually reported as 1063F. Average thermal strain for Purex Building and CTL/PCA cast specimens at 1100F was approximately 4600 millionths.

From 1100 to 1600F, most specimens exhibited little further increase. In several cases, thermal strain decreased slightly as temperature increased. This strain plateau, like the rapid increase in thermal expansion near 1063F, has been observed by other investigators for concrete containing quartz-bearing aggregate.

Thermal expansion behavior of Waste Tank Farms concrete specimens differed from specimens described above. Thermal strain of Tank Farms specimens followed trends similar to other specimens tested in the range from 73 to 1260F. However, magnitude of expansion was measurably lower at most temperatures. Thermal expansion of Tank Farms specimens averaged only 550 millionths at 400F and 2750 millionths at 1000F.

Above 1260F, the specimen of concrete from Waste Tank Farm 241-T contracted as temperature increased. Between 1260 and 1600F, strain in this specimen decreased approximately 1200 millionths.

Between 1100 and 1350F, the specimen of concrete from Waste Tank Farm 241-A II displayed the post-quartz inversion plateau observed with other specimens tested in this study. Beginning

at 1350F however, this specimen sharply contracted over 3500 millionths as temperature increased to 1500F. At 1500F, the specimen began to expand again.

Two additional Waste Tank Farm 241-A II specimens were tested and found to verify these results. Rapid decrease in strain near 1350F has been observed in rock containing dolomite^(4,5,6). However, a petrographic examination did not reveal the presence of this mineral in aggregates used in Waste Tank Farms concrete.

REFERENCES

1. Abrams, M. S., Proposal for Research, "Strength, Creep and Thermal Properties of Hanford Concrete," submitted to Battelle Northwest Laboratories from Portland Cement Association, Construction Technology Laboratories, March, 1978.
2. Abrams, M. S., Proposal for Research, "Evaluation of Shielding Wall of 202-A Purex Canyon Building," submitted to Atlantic Richfield Hanford Co. from Portland Cement Association, Construction Technology Laboratories, January, 1977.
3. Abrams, M. S., Proposal for Research, "Strength and Property Determination of Waste Tank Farms Concrete," submitted to Battelle Northwest Laboratories from Portland Cement Association, Construction Technology Laboratories, July, 1976.
4. Endell, K., "Influence of High Temperatures on Hardened Cement, Aggregate, and Concrete," Zement (Berlin), No. 45, 1926, pp. 823-929.
5. Soles, J. A., and Geller, L. B., "Experimental Studies Relating Mineralogical and Petrographic Features to the Thermal Piercing of Rocks," Mines Branch Technical Bulletin TB 53, Department of Mines and Technical Surveys, Ottawa, Canada, 1964.
6. Zoldners, N. G., "Thermal Properties of Concrete Under Sustained Elevated Temperatures," from Temperature and Concrete, American Concrete Institute Special Publication SP-25, 1971.

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