Davis-BesseNPEm Resource

From: klbrowning@firstenergycorp.com
Sent: Tuesday, January 17, 2012 12:21 PM
To: Holmberg, Mel
Subject: remaining USBR procedures
Attachments: USBR 4907.pdf; USBR 4910.pdf

Attached are the remaining USBR procedures in response to question 12 for the Davis-Besse shield building cracking.

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Hearing Identifier: Davis_BesseLicenseRenewal_Saf_NonPublic
Email Number: 3332

Mail Envelope Properties (OF986A8972.34DD1B7C-ON85257988.005DB13E-85257988.005F458C)

Subject: remaining USBR procedures
Sent Date: 1/17/2012 12:20:36 PM
Received Date: 1/17/2012 12:24:18 PM
From: klbrowning@firstenergycorp.com

Created By: klbrowning@firstenergycorp.com

Recipients:
"Holmberg, Mel" <Mel.Holmberg@nrc.gov>
Tracking Status: None

Post Office: FirstEnergyCorp.com

Files	**Size**	**Date & Time**
MESSAGE	817	1/17/2012 12:24:18 PM
USBR 4907.pdf	1786717	
USBR 4910.pdf	1069817	

Options
Priority: Standard
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Sensitivity: Normal
Expiration Date:
Recipients Received:

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4907–92

PROCEDURE FOR

SPECIFIC HEAT OF AGGREGATES, CONCRETE, AND OTHER MATERIALS

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4907; the number immediately following the designation indicates year of original adoption or year of last revision.

1. Scope

1.1 This designation covers a procedure for determining the mean specific heat of concrete, aggregates, and other materials. While the description of this procedure mentions only concrete, it is applicable to any material that will fit in the calorimeter.

2. Applicable Documents

2.1 *USBR Procedures*:
4192 Making and Curing Concrete Test Specimens in Laboratory
2.2. *ASTM Standards*:
C 125 Standard Definitions of Terms Relating to Concrete and Concrete Aggregates[1]
C 168 Standard Definitions of Terms Relating to Thermal Insulating Materials[2]

3. Summary of Procedure

3.1 A sample of known mass is placed in a calorimeter, and a known amount of heat is then applied to calorimeter. The specific heat of the specimen is calculated from its temperature rise after applying corrections to heat input to calorimeter.

4. Significance and Use

4.1 Specific heat, which is the amount of heat required to raise the temperature of a unit mass of material by 1°, is expressed in this procedure as British thermal units per pound mass degree Fahrenheit and as joules per kilogram degree Celsius. This determination is made by measuring the net heat required to raise the temperature of a specimen by a given amount.

4.2 The temperature regime and resulting thermal stresses in mass concrete, during its early life, are a function of the rate of heat evolution produced by cement hydration, specific heat, thermal conductivity, and density of the concrete. Thus a knowledge of the thermal properties of concrete is necessary for establishing temperature control procedures during construction. Because aggregate comprises most of the volume of concrete, a measurement of the specific heat of the aggregate gives a good indication of the specific heat of the concrete.

5. Terminology

5.1 Terms used in this procedure are as defined in ASTM C 125 and C 168.

6. Apparatus

6.1 *Calorimeter*.–The calorimeter described in this procedure was designed for concrete, and uses an 8- by 16-inch (203- by 406-mm) cylindrical specimen cast with a 1.5-inch (38-mm) diameter hole extending the length of the specimen. However, the calorimeter can be used for any material where the test specimen can be adapted to fit.

6.1.1 The calorimeter shall consist of two containers separated by a layer of insulation. The inner container, which holds specimen and water, shall be made of stainless steel or copper. The outer container may be made of sheet steel. Specimen shall rest on a support that will permit circulation of water and minimize thermal conduction between specimen and calorimeter wall. A micarta base has been found to be satisfactory for this support.

6.2 *Stirrer*.–A brass stirrer capable of maintaining circulation of water through inner container of calorimeter.

6.3 *Heater*.–An immersion heater, with associated equipment to measure heat input, capable of raising temperature of inner container of calorimeter, including specimen and water, by 20 °F (11 °C) in 45 minutes.

6.4 *Thermometer*.–A thermometer graduated to 0.1 °F (0.06 °C), or a recording thermometer capable of being read to this same precision in the range from 32 to 150 °F (0 to 65.6 °C).

6.5 *Scales*.–Scales shall be capable of determining mass of sample within an accuracy of 0.1 percent.

NOTE 1.–The specific heat apparatus currently in use at the Bureau's Denver Office has been automated to include data

[1] *Annual Book of ASTM Standards*, vols. 04.02, 04.03.
[2] *Annual Book of ASTM Standards*, vol. 04.06.

acquisition, calculation, and control. Power to the immersion heater is measured by a watt-hour calibration standard reading to 0.0006 watt-hour. Temperature is determined using a platinum RTD (resistance temperature detector). The operation of this controlling and recording unit is described in section 12. Figure 1 shows an RTD with a calorimeter that has been found satisfactory for 8- by 16-inch (203- by 406-mm) cylinders. Figure 2 shows the propeller inside the calorimeter.

Figure 1. - Controlling and recording instrumentation for conducting tests to determine specific heat of concrete.

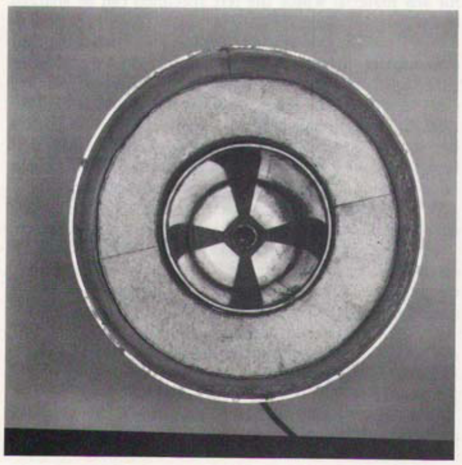

Figure 2. - Propeller.

7. Materials

7.1 Any material capable of being placed in the calorimeter may be tested.

8. Precautions

8.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

9. Test Specimens

9.1 While any shape specimen may be tested, the 8- by 16-inch (203- by 406-mm) cylinder with a 1.5-inch (38-mm) hole through the center provides excellent circulation of water and accurate results, see figure 3.

9.2 Concrete specimens shall be fabricated in accordance with the applicable provisions of USBR 4192.

Figure 3. - Mold and 8- by 16-inch (203- by 406-mm) cylinder with a 1.5-inch (38-mm) hole through the center.

10. Calibration and Standardization

10.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure or standard directly or by reference.

10.2 Determine the water equivalent of the calorimeter by substituting water for the test specimen and making a normal run. It is recommended that the average results of several runs be used.

11. Conditioning

11.1 No conditioning of the saturated specimen is necessary; however, if specimen temperature is about the same as the water bath temperature, initial equilibrium will be attained sooner.

12. Procedure

12.1 Initially, determine mass of specimen. The specimen should then be immersed in an accurately measured quantity of water in the inner container. Heater and propeller should then be inserted, cover placed on container, and heater connections made.

12.2 Start stirrer and continue stirring until equilibrium temperature has been reached as indicated by time-temperature curve becoming linear, as shown on figure 4. This may require 1 to 2 hours.

12.3 Read initial temperature T_i. Continue stirring for 30 minutes and then read temperature T_o. The temperature change during this 30-minute interval will be used in the calculations as a correction for heat loss or gain from calorimeter during test.

12.4 Turn on heater for 45 minutes or until a temperature rise of about 20 °F (11 °C) has occurred. Record total heat input.

12.5 Turn off heater, continue stirring, and make temperature readings until time-temperature curve is again linear. Record the temperature when curve is linear as T_n.

12.6 Continue stirring for 30 minutes and make another temperature reading, which is recorded as T_f. This final 30-minute interval will be used as a correction factor along with the initial 30-minute interval.

12.7 When using the automatic data acquisition and control unit to monitor and control the test, follow the steps in 12.7.1.

12.7.1 Connect the RTD to the data acquisition and control unit. The four-wire ohms technique is used to measure resistance of RTD. A computer controls the control unit and records temperature data from RTD. A high-order polynomial equation is used to convert RTD resistance to temperature. After initial equilibrium is reached, computer is instructed by operator to apply power to heater. The computer commands the control unit to close a relay, which in turn closes a solid-state power relay to apply power to heater. At this point, the watt-hour standard starts sending out pulses which are counted by control unit. The computer records the temperature and, when temperature has increased by 20 °F (11.2 °C), computer commands control unit to remove power from heater. The total pulse count is transferred to the computer and the apparatus is again allowed to reach equilibrium. At this point, computer calculates the specific heat and generates a graph of the temperature data. A block diagram of the apparatus and computer control is shown on figure 5.

12.8 Perform the test at each of two mean temperatures of about 50 and 140 °F (10 and 60 °C).

13. Calculations

13.1 When using the automatic data acquisition system described in section 12.7.1, the computer calculates the specific heat and generates a graph of the temperature data.

13.2 Calculations for a typical test are shown on figure 6. For this example test, 5-minute intervals were used; however, any interval can be used. For most automated procedures, such as the one described in 12.7.1, 1-minute intervals are used.

13.3 To calculate the true temperature rise, the test should be divided into three temperature periods: an initial period from T_i to T_o, heating period from T_o to T_n, and final period from T_n to T_f. The temperature rise is equal to $T_n - T_o + T_c$, where T_c is a calculated temperature correction. This correction is actually a summation, of opposite sign, of the temperature drifts per interval during the heating period calculated from drifts determined during the initial and final periods. The increase in temperature drift between the initial and any intermediate interval is to the increase in temperature drift between initial and final periods as the average temperature difference between initial and same intermediate interval is to the average temperature difference between initial and final periods. Mathematically, this proportion can be stated:

$$T_c = -nC_a - \left[\frac{C_b - C_a}{T_b - T_a}\right]\left[(T_1 + T_2 + \ldots + T_{n-1}) + \frac{T_o + T_n}{2} \quad (-nT_a)\right] \tag{1}$$

where:

T_c = temperature correction factor,
n = number of intervals during heating period (usually 1- or 5-minute intervals),
C_a = average temperature drift (algebraic) per interval during initial period,
C_b = average temperature drift (algebraic) per interval during final period,
T_a = average temperature during initial period,
T_b = average temperature during final period,
T_o = temperature at end of initial period and at start of heating period,
T_n = temperature at end of heating period and at start of final period, and
$T_1, T_2, \ldots T_3$ = temperature at intervals of heating period.

13.4 The specific heat of the concrete in British thermal units per pound mass degree Fahrenheit or joules per kilogram degree Celsius is equal to the total heat input minus the heat required to raise temperature of water and calorimeter divided by corrected temperature rise and mass of specimen (fig. 6).

13.5 Figures 7 and 8 are included to establish factors used in the example shown on figure 6.

13.6 The water equivalent of the calorimeter, as shown on figures 8a and 8b, must be reestablished for each calorimeter used. The water equivalent of the calorimeter currently used by the Bureau is shown on figures 8c and 8d.

13.7 When using the automatic data acquisition system described in section 12.7.1, the computer has been programmed to compute the factors internally to provide data similar to that shown on figures 7 and 8.

13.7.1 A computer printout utilizing the automatic data acquisition system described in section 12.7.1 is illustrated on figure 9.

13.7.2 A summarization of cycle runs for two specimens is shown in table 1 that generates the regression equations for the linear (straight line) versus parabolic curves illustrated on figure 10.

14. Report

14.1 Figure 11 shows a typical reporting form for the thermal properties, which consists of conductivity, diffusivity, and specific heat. The report shall include:

- Identification of constituents of sample.
- Mixture proportions, if concrete.
- Two average temperatures.
- Specific heat at each temperature.

15. Precision and Bias

15.1 The precision for this procedure has not been determined.

15.2 There is no known bias.

Table 1. – Summarization of cycle runs.

Specimen	Cycle No.	Start Temp., °F	End Temp., °F	Average Temp., °F	Specific Heat, Btu/(lbm • °F)
Specimen No. 2	1	31.08	50.01	40.46	0.378
9-25-85	2	49.80	67.94	58.97	.248
68.78 lbm	3	67.94	84.89	76.52	.254
	4	85.09	100.49	92.90	.260
	5	100.90	115.06	108.08	.266
	6	115.67	128.20	122.07	.270
	7	129.09	140.57	134.92	.278
	8	141.65	152.35	147.05	.291
Specimen No. 3	1	31.19	51.43	41.17	.325
9-25-85	2	51.14	70.80	61.07	.254
68.84 lbm	3	70.71	88.64	79.80	.256
	4	88.80	104.95	97.00	.262
	4	105.36	119.55	112.55	.276
	6	120.15	132.93	126.66	.280
	7	133.77	145.73	139.84	.284

Specimen No.	Average Temp. (T), °F	Specific Heat (S), Btu/(lbm • °F)
2	58.97	0.248
3	61.07	.254
2	76.52	.254
3	79.80	.256
2	92.90	.260
3	97.00	.262
2	108.08	.266
3	112.55	.276
2	122.07	.270
3	126.66	.280
2	134.92	.278
3	139.84	.284
2	147.05	.291

Specific heat equations:

$S = 0.221947 + 0.0004373\ T$, or

$S = 0.245342 - 0.0000588\ T + 0.00000243\ T^2$

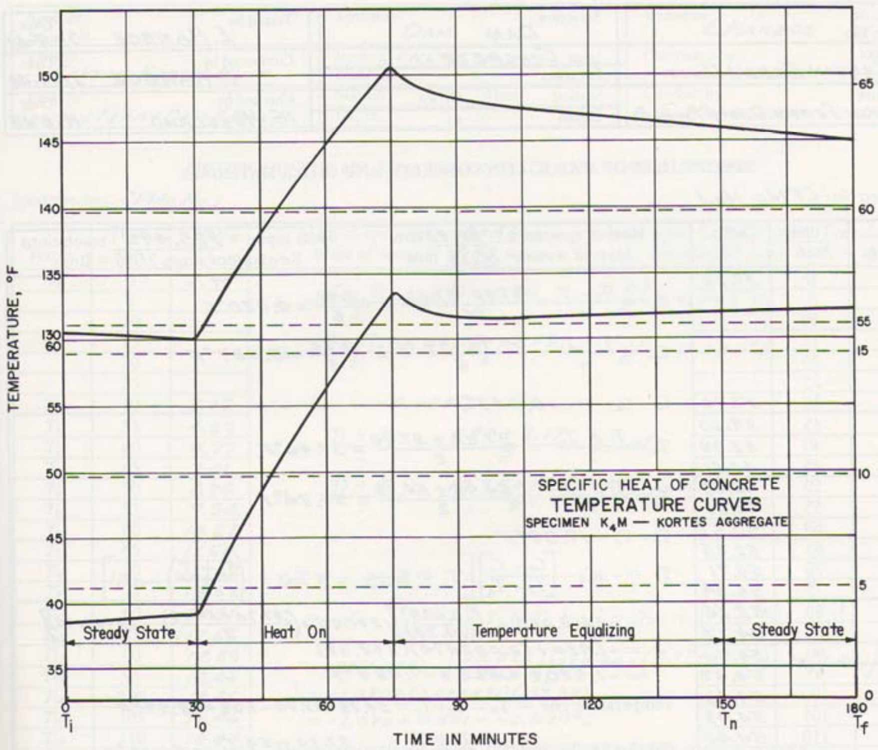

Figure 4. - Typical temperature curves during specific heat test.

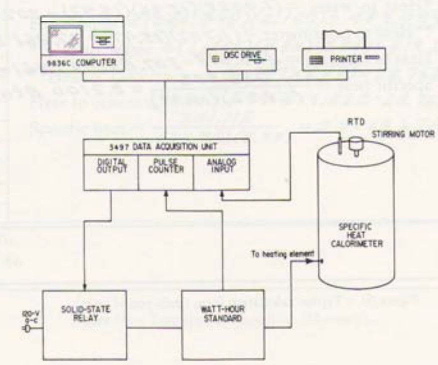

Figure 5. - Block diagram of data acquisition and control system.

Spec. or Solic. No.	Structure DAM	Tested by E. HARBOE	Date 11-8-48
Project CANYON FERRY UNIT	Item CONCRETE	Computed by E. HARBOE	Date 11-8-48
Feature CANYON FERRY DAM & PWR. PL.	Location	Checked by G. HOAGLAND	Date 11-8-48
	Station Offset		
	Depth to		

SPECIFIC HEAT OF AGGREGATES, CONCRETE, AND OTHER MATERIALS

Specimen No.: CFMo No. 1

Temp.	Time, min.	Temp., °F
T_i	0	37.22
	5	
	10	
	15	
	20	
	25	
T_o	30	37.70
T_1	35	39.60
T_2	40	42.38
T_3	45	44.61
T_4	50	46.83
T_5	55	48.81
T_6	60	50.67
T_7	65	52.85
T_8	70	54.71
T_9	75	56.34
T_{10}	80	55.24
T_{11}	85	54.77
T_{12}	90	54.56
T_{13}	95	54.47
T_{14}	100	54.43
T_{15}	105	54.43
T_{16}	110	54.44
T_{17}	115	54.47
T_{18}	120	54.50
T_{19}	125	54.55
T_{20}	130	54.58
T_{21}	135	54.62
T_{22}	140	54.65
T_{23}	145	54.69
T_n	150	54.73
	155	
	160	
	165	
	170	
	175	
T_f	180	54.95

Mass of specimen = 68.23 lbm
Mass of water = 12.96 lbm

Heat input = 225.495 revolutions
Revolutions times 2.056 = Btu's

$$C_a = \frac{T_o - T_i}{n} = \frac{37.70 - 37.22}{6} = \frac{0.48}{6} = 0.080\ °F$$

$$C_b = \frac{T_f - T_n}{n} = \frac{54.95 - 54.73}{6} = \frac{0.22}{6} = 0.037\ °F$$

$$C_b - C_a = -0.043\ °F$$

$$T_a = \frac{T_i + T_o}{2} = \frac{37.22 + 37.70}{2} = 37.46\ °F$$

$$T_b = \frac{T_f + T_n}{2} = \frac{54.95 + 54.73}{2} = 54.84\ °F$$

$$T_b - T_a = 17.38\ °F$$

$$T_c = -nC_a - \left[\frac{C_b - C_a}{T_b - T_a}\right]\left[(T_1 + T_2 + \ldots + T_{23}) + \left(\frac{T_o + T_n}{2}\right)(-nT_a)\right]$$

$$= -24(0.080) - \left[\frac{-0.043}{17.38}\right]\left[1201.20 + \left(\frac{37.70 + 54.73}{2}\right) - 24(37.46)\right]$$

$$= -1.920 + (0.002474)(348.38)$$

$$= -1.920 + 0.862 = -1.058\ °F$$

Temperature rise $= T_n - T_o + T_c = 54.73 - 37.70 - 1.06 = 15.97\ °F$

Average temperature $= \frac{T_o + T_n}{2} = \frac{37.70 + 54.73}{2} = 46.22\ °F$

Heat input $= (225.495)(2.056) = 463.618$ Btu

*Heat to water $= (1.0028)(12.96)(15.97) = 207.551$ Btu

**Heat to calorimeter $= (1.707)(15.97) = 27.261$ Btu

Heat to concrete $= 463.618 - 207.551 - 27.261 = 228.806$ Btu

Specific heat $= \frac{228.806}{(68.23)(15.97)} = 0.2100$ Btu/(lbm·°F)

* Obtain factor from figure 7a.
** Obtain factor from figure 8a.

Figure 6a. – Typical calculation form (inch-pound units).

Spec. or Solic. No.	Structure DAM	Tested by E. HARBOE — Date 11-8-48
Project CANYON FERRY UNIT	Item CONCRETE	
Feature	Location	Computed by E. HARBOE — Date 11-8-48
CANYON FERRY DAM & PWR PL.	Station — Offset	
	Depth — to	Checked by G. HOAGLAND — Date 11-8-48

SPECIFIC HEAT OF AGGREGATES, CONCRETE, AND OTHER MATERIALS

Specimen No.: CFMo No. 1

Temp.	Time, min.	Temp., °C
T_i	0	2.90
	5	
	10	
	15	
	20	
	25	
T_o	30	3.17
T_1	35	4.22
T_2	40	5.77
T_3	45	7.01
T_4	50	8.24
T_5	55	9.34
T_6	60	10.37
T_7	65	11.58
T_8	70	12.62
T_9	75	13.52
T_{10}	80	12.91
T_{11}	85	12.65
T_{12}	90	12.53
T_{13}	95	12.48
T_{14}	100	12.46
T_{15}	105	12.46
T_{16}	110	12.47
T_{17}	115	12.48
T_{18}	120	12.50
T_{19}	125	12.53
T_{20}	130	12.54
T_{21}	135	12.57
T_{22}	140	12.58
T_{23}	145	12.61
T_n	150	12.63
	155	
	160	
	165	
	170	
	175	
T_f	180	12.75

Mass of specimen = 30.95 kg
Mass of water = 5.88 kg

Heat input = 225.495 revolutions
Revolutions times 2.169 = kJ

$$C_a = \frac{T_o - T_i}{n} = \frac{3.17 - 2.90}{6} = \frac{0.27}{6} = 0.045\,°C$$

$$C_b = \frac{T_f - T_n}{n} = \frac{12.75 - 12.63}{6} = \frac{0.12}{6} = 0.020\,°C$$

$$C_b - C_a = -0.025\,°C$$

$$T_a = \frac{T_i + T_o}{2} = \frac{2.90 + 3.17}{2} = 3.04\,°C$$

$$T_b = \frac{T_f + T_n}{2} = \frac{12.75 + 12.63}{2} = 12.69\,°C$$

$$T_b - T_a = 9.65\,°C$$

$$T_c = -nC_a - \left[\frac{C_b - C_a}{T_b - T_a}\right]\left[(T_1 + T_2 + \ldots + T_{23}) + \left(\frac{T_o + T_n}{2}\right)(-nT_a)\right]$$

$$= -24(0.045) - \left[\frac{-0.025}{9.65}\right]\left[258.44 + \left(\frac{3.17 + 12.63}{2}\right) - 24(3.04)\right]$$

$$= -1.080 + (0.002591)(193.38)$$

$$= -1.080 + 0.501 = -0.579\,°C$$

Temperature rise = $T_n - T_o + T_c$ = 12.63 − 3.17 − 0.579 = 8.88 °C

Average temperature = $\frac{T_o + T_n}{2} = \frac{3.17 + 12.63}{2}$ = 7.90 °C

Heat input = (225.495)(2.169) = 489.099 kJ

*Heat to water = (1.1985)(5.88)(8.88) = 219.222 kJ

**Heat to calorimeter = (3.239)(8.88) = 28.762 kJ

Heat to concrete = 489.099 − 219.222 − 28.762 = 241.115 kJ

Specific heat = $\frac{241.115}{(30.95)(8.88)}$ = 0.8773 kJ/(kg·°C)

* Obtain factor from figure 7b.
** Obtain factor from figure 8b.

Figure 6b. – Typical calculation form (SI-metric).

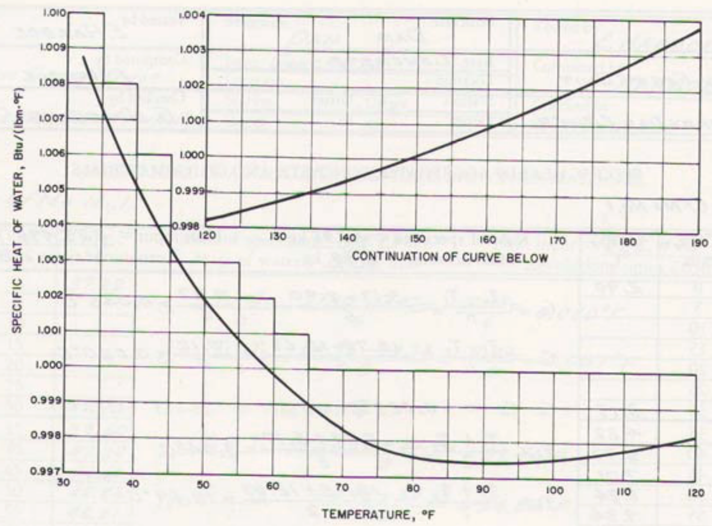

Figure 7a. – Specific heat of distilled water (inch-pound units).

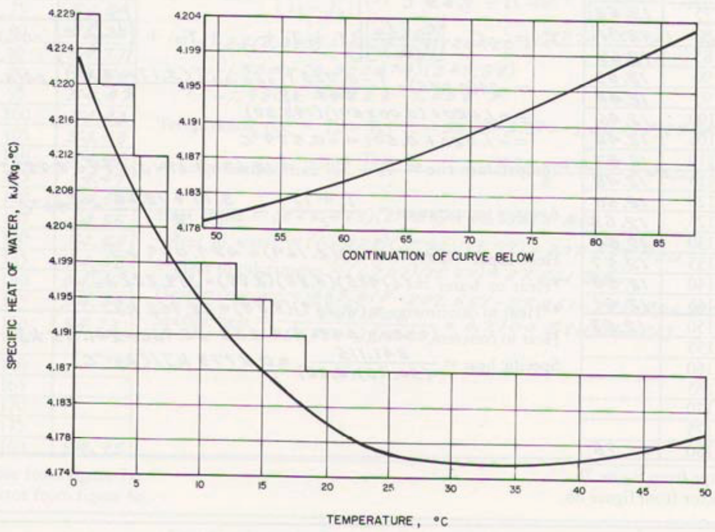

Figure 7b. – Specific heat of distilled water (SI-metric).

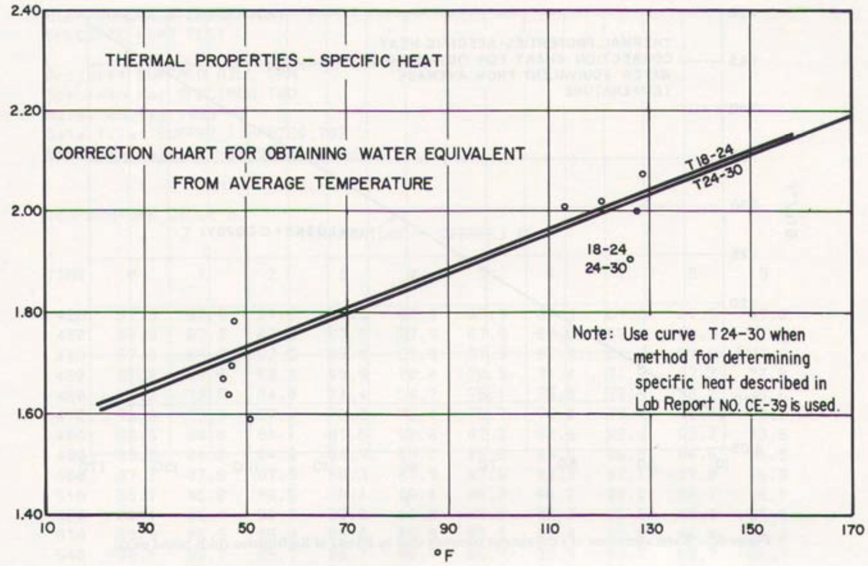

Figure 8a. – Water equivalent of a calorimeter (inch-pound units).

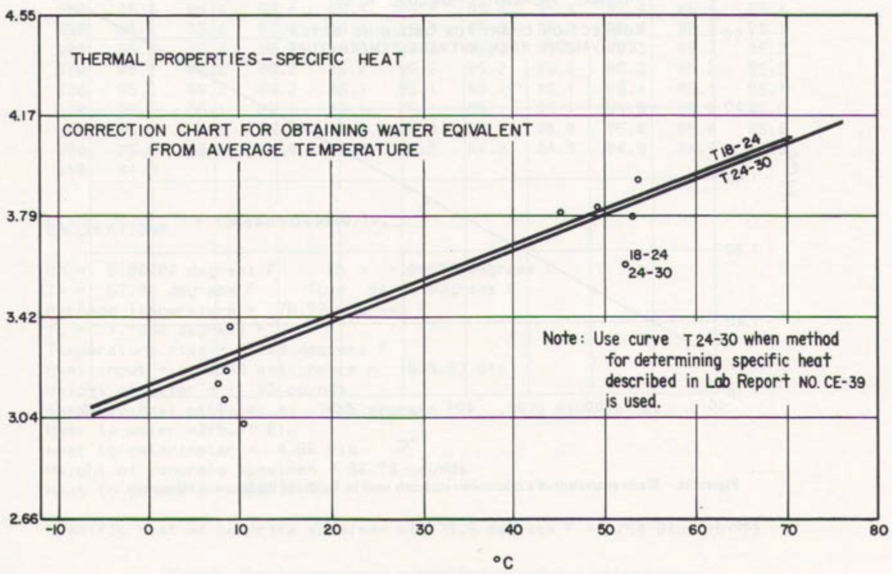

Figure 8b. – Water equivalent of a calorimeter (SI-metric).

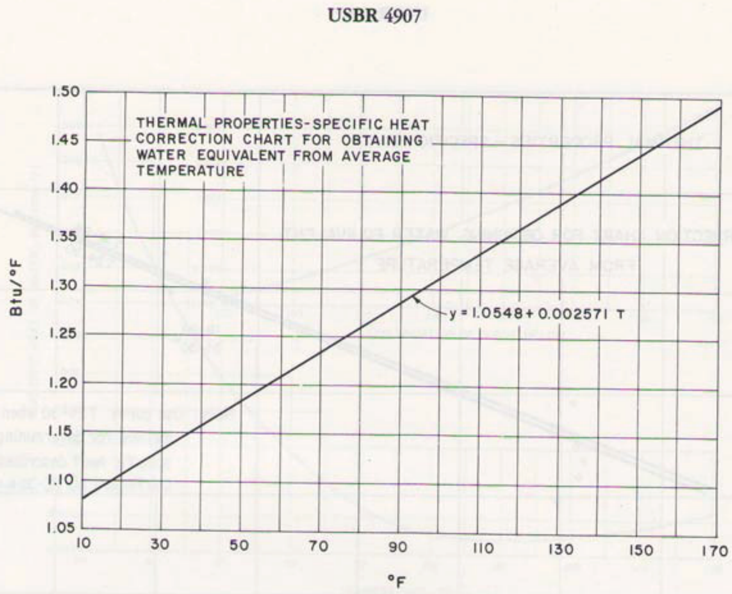

Figure 8c. – Water equivalent of a calorimeter currently used by Bureau of Reclamation (inch-pound units).

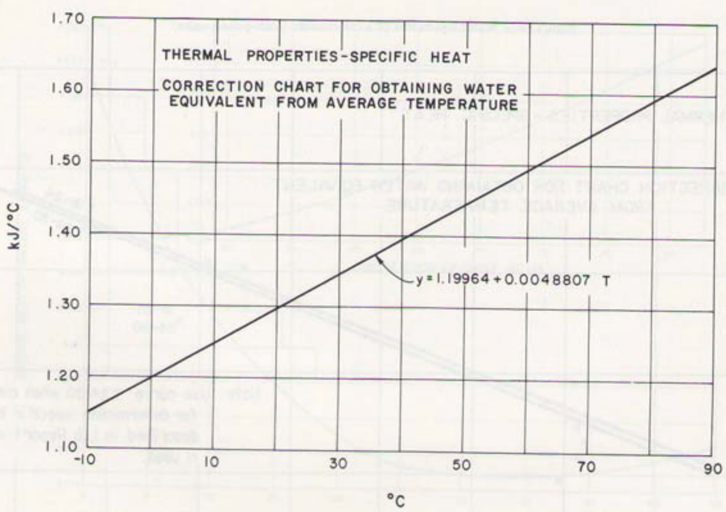

Figure 8d. – Water equivalent of a calorimeter currently used by Bureau of Reclamation (SI-metric).

USBR CONCRETE LABORATORY
SPECIFIC HEAT TEST

Project: BUFFALO BILL DAM
Specimen No: SPECIMEN TWO
Date: 25 Sep 1985
Data file: BUFFB2_1:HP8290,702
Specimen weight: 68.78 pounds

TEMPERATURE CYCLE 3

	TEMPERATURE - DEGREES F									
TIME	0	1	2	3	4	5	6	7	8	9
420	67.9	67.9	67.9	67.9	67.9	67.9	67.9	67.9	67.9	67.9
430	67.9	67.9	67.9	67.9	67.9	67.9	67.9	67.9	67.9	67.9
440	67.9	67.9	67.9	67.9	67.9	67.9	67.9	67.9	67.9	67.9
450	67.9	68.6	69.3	69.9	70.4	70.9	71.4	71.9	72.3	72.8
460	73.2	73.6	74.0	74.4	74.7	75.1	75.5	75.9	76.2	76.6
470	76.9	77.3	77.7	78.0	78.4	78.7	79.0	79.4	79.8	80.1
480	80.5	80.8	81.1	81.5	81.8	82.2	82.5	82.8	83.2	83.5
490	83.9	84.2	84.6	84.9	85.2	85.6	85.9	86.3	86.6	86.9
500	87.3	87.6	87.9	88.3	87.9	87.6	87.3	87.1	87.0	86.8
510	86.7	86.6	86.5	86.4	86.4	86.3	86.2	86.2	86.1	86.1
520	86.1	86.1	86.0	86.0	86.0	86.0	85.9	85.9	85.9	85.9
530	85.9	85.9	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8
540	85.8	85.7	85.7	85.7	85.7	85.7	85.7	85.7	85.7	85.7
550	85.7	85.7	85.7	85.6	85.6	85.6	85.6	85.6	85.6	85.6
560	85.6	85.6	85.6	85.6	85.6	85.5	85.5	85.5	85.5	85.5
570	85.5	85.5	85.5	85.5	85.5	85.5	85.5	85.5	85.5	85.4
580	85.4	85.4	85.4	85.4	85.4	85.4	85.4	85.4	85.4	85.4
590	85.4	85.4	85.4	85.4	85.3	85.3	85.3	85.3	85.3	85.3
600	85.3	85.3	85.3	85.3	85.3	85.3	85.3	85.3	85.2	85.2
610	85.2	85.2	85.2	85.2	85.2	85.2	85.2	85.2	85.2	85.2
620	85.2	85.2	85.2	85.1	85.1	85.1	85.1	85.1	85.1	85.1
630	85.1	85.1	85.1	85.1	85.1	85.1	85.1	85.0	85.0	85.0
640	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0
650	85.0	85.0	84.9	84.9	84.9	84.9	84.9	84.9	84.9	84.9
660	84.9									

CALCULATIONS

CA = 0.00000 degrees F   Cb = -.00681 degrees F
Ta = 67.94 degrees F   Tb = 84.99 degrees F
Average temperature = 76.52 degrees F
Tc = 1.1338 degrees F
Temperature rise = 18.29 degrees F
Heat input = 158.08 watt-hours = 539.53 Btu
Weight of water = 11.82 pounds
Specific heat of water at 76.5 degrees F = .9976 Btu/(lb·°F)
Heat to water =215.71 Btu
Heat to calorimeter = 4.65 Btu
Weight of concrete specimen = 68.78 pounds
Heat to concrete = 319.17 Btu

Specific heat of concrete specimen at 76.5 degrees F = .254 Btu/(lb·°F)

Figure 9. – Typical computer output generated from automatic data acquisition system.

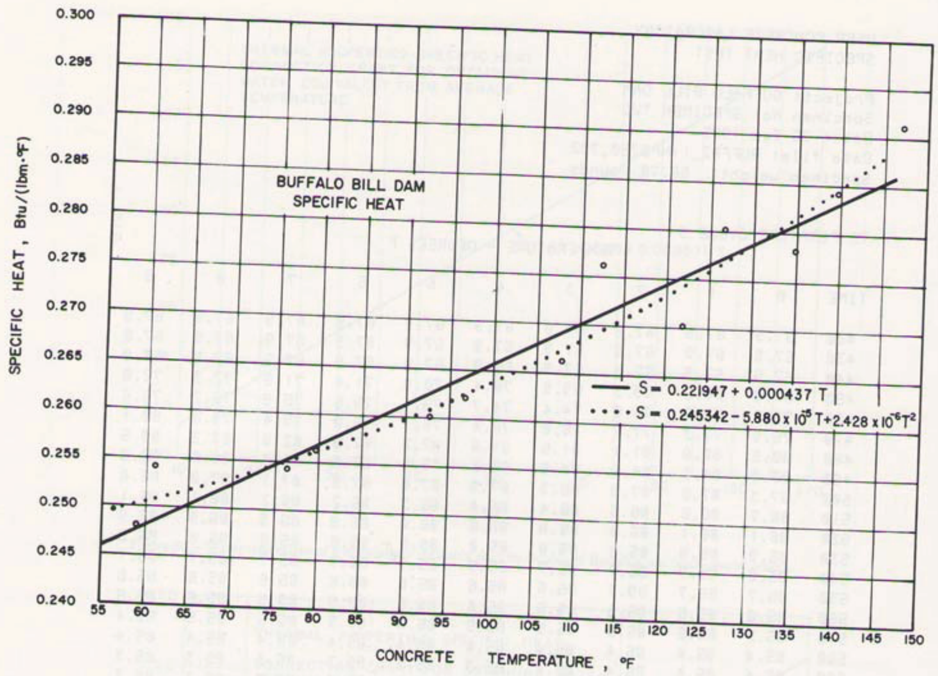

Figure 10. – Linear (straight line) versus parabolic curves plot of specific heat.

Spec. or Solic. No. DESIGN STAGE	Structure DAM MODIFICATION	Tested by M. PEABODY, M. CASH, D. ARNEY, F. TRAVERS	Date 9-10-85
Project SHOSHONE	Item CONCRETE MIX DESIGN Location E & R CENTER, DENVER	Computed by COMPUTER	Date 9-10-85
Feature BUFFALO BILL DAM	Station — Offset — Depth — to —	Checked by M. PEABODY	Date 9-10-85

SPECIFIC HEAT OF AGGREGATES, CONCRETE, AND OTHER MATERIALS

MIX DATA

	lbm	kg	mL
Water	160		
Type I/II cement	245		
Class F fly ash	105		
Fine aggregate	926		
Coarse aggregate	2,615		
Volume of air-entraining admixture, 5.5 oz/94 lbm (kg), $C+P$			605
Volume of water-reducing admixture, 4.0 oz/94 lbm (kg), $C+P$			490

Mineralogic makeup of aggregate: PRIMARILY LIMESTONE

THERMAL PROPERTIES

Concrete Temp. (T) °C	°F	Saturated density (P) lbm/ft³	kg/m³	Diffusivity (D) ft²/h	m²/h	Specific heat (S) Btu/(lbm·°F)	kJ/(kg·°C)	Conductivity (C) Btu/(ft·h·°F)	kJ/(m·h·°C)
	50	—		0.038		0.244		1.40	
	100	151.5		0.036		0.266		1.45	
	150	—		0.034		0.288		1.48	

NOTE: $D = 0.039636 - 0.0000396\ T$
$S = 0.221947 + 0.0004373\ T$
$C = PDS$

Figure 11. – Typical reporting form for thermal properties.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 4910-92

PROCEDURE FOR

COEFFICIENT OF LINEAR THERMAL EXPANSION OF CONCRETE

INTRODUCTION

This test procedure is under the jurisdiction of the Concrete and Structural Branch, code D-3730, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 4910; the number immediately following the designation indicates year of original adoption or year of last revision.

1. Scope

1.1 Most unrestrained engineering materials expand when heated and contract when cooled. The strain due to a 1°-temperature change is known as the coefficient of thermal expansion. This coefficient is approximately constant for a considerable range of temperatures, and generally increases with an increase in temperature. For a homogeneous, isotropic material, the coefficient applies to all dimensions in all directions. This test designation covers a procedure for determining the thermal coefficient of expansion for hardened concrete in a saturated, intermediate, or dry-moisture condition.

2. Applicable Documents

2.1 *USBR Procedures*:
4042 Obtaining and Testing Drilled Cores and Sawed Beams or Cubes of Concrete and Shotcrete
4192 Making and Curing Concrete Test Specimens in Laboratory

3. Apparatus

3.1 *Holding Tank*.–An insulated, copper-lined tank to hold circulating water.

3.2 *Water Tank*.–A water tank containing electric immersion heaters and refrigeration coils capable of maintaining circulating water at constant temperatures between 35 and 90 °F (1.7 and 32.2 °C).

3.3 *Recorder*.–A thermocouple recorder to record water temperature versus time.

3.4 *Refrigeration Unit*.–A freon refrigeration unit for lowering water temperature.

3.5 *Controller*.–A controller for regulating water temperature. Controller should automatically turn heater and refrigeration units on and off.

3.6 *Steel Frames*.–Invar steel, level frames for holding concrete test specimens as they are lowered into water (six required).

3.7 *Thermometer*.–A thermometer with a range of 35 to 90 °F (1.7 to 32.2 °C), and with an accuracy of 0.1 °F (0.16 °C).

3.8 *Transformers*.–For measuring length change during testing, six LVDT's (linear variable differential transformers) are required.

3.9 *Transducer Indicators*.–Two amplifier transducer indicators are required. These indicators are high-sensitivity, differential transformer, input modules for reading summation of length change occurring in three of the test specimens. The normal length change range selection for concrete is set so that a full scale division is 0.01 inch (0.25 mm); the scale is divided into 100 divisions.

3.10 Other types of sensing, controlling, and recording equipment and instrumentation can also provide satisfactory results. This system is being described somewhat in detail for the benefit of Bureau personnel who will be conducting the test with this equipment.

4. Precautions

4.1 This test procedure may involve hazardous materials, operations, and equipment, and does not claim to address all safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

5. Sampling and Test Specimens

5.1 Six concrete test specimens are sawed as 2- by 2- by 4-inch (50- by 50- by 100-mm) prisms obtained in accordance with USBR 4042, or cast as 2- by 4-inch (50- by 100-mm) cylinders made in accordance with USBR 4192. Invar buttons are then epoxied onto the ends of the specimens. The buttons are recessed to accommodate the tips of the holding frame during testing. Length measurements are made to nearest 0.01 inch (0.25 mm), and testing normally occurs in a 100-percent vacuum saturated condition, as close to zero load as possible.

5.2 In our previous test procedures, mass concrete has been tested at three different moisture conditions to determine difference in thermal coefficients at each state. These three conditions are 100 percent dry, 100 percent vacuum saturated, and 75 percent vacuum saturated. If testing by these conditions is requested, 12 specimens are prepared in 2 groups of 6 each. All specimens are oven dried at 190 °F (87.8 °C) to initiate testing under equal conditions.

5.2.1 During initial drying of first set of specimens, mass is determined until no loss of the mass is observed. Specimens are immediately dipped in heated paraffin wax to sustain this 100 percent dry condition.

5.2.2 After initial drying, second set of specimens are vacuum saturated and their mass determined until no increase in mass is observed. Specimens are immediately submerged in a water bath of constant temperature to sustain this 100 percent saturated condition.

5.2.3 The second set of specimens, which were previously tested in a fully saturated state, are also used for obtaining data in a partially saturated condition. The fully saturated specimens are dried and their mass determined until they reach a condition of 75 percent saturation. To remain in this state, specimens are immediately dipped in heated paraffin wax. The highest values for coefficient of thermal expansion are normally obtained in this 75 percent saturated condition.

6. Calibration and Standardization

6.1 The calibration and standardization of miscellaneous equipment or apparatus used in performing the tests listed under the Applicable Documents of section 2 are covered under that particular procedure.

6.2 The LVDT's are calibrated on the thermal expansion testing apparatus as follows:

Step 1.–Place test specimens in tank.

Step 2.–Set ABC selector switch to A of TAI (Transducer Amplifier-Indicator).

Step 3.–Set range selector to STANDBY. Adjust meter screw for zero reading.

Step 4.–Turn sensitivity to maximum (clockwise) and set zero knobs to center point (arrows point upward).

Step 5.–Repeat steps 1 through 4 for second TAI.

Step 6.–Turn range selector to NULL.

Step 7.–Unlock adjustment knob on frame and set LVDT for zero meter reading, lock LVDT, and adjust with "mechanical adjustment knob" to bring needle as close to zero as possible. Lock manual adjustment knob.

Step 8.–Fine adjust to zero with proper null screw.

Step 9.–If necessary, alternate mechanical and null adjustment to bring needle as close to zero as possible.

Step 10.–Set ABC selector switch to B, and repeat steps 7 through 9.

Step 11.–Set ABC selector switch to C, and repeat steps 7 through 9.

Step 12.–Turn second TAI range selector to NULL.

Step 13.–Repeat steps 7 through 11 for second amplitude.

Step 14.–Set range selector to 10.

Step 15.–Adjust zero for A with fine-zero controls. Repeat for B and C.

Step 16.–Check zero of A+B+C.

Step 17.–Repeat steps 14 through 16 with second TAI.

Step 18.–Set ABC selector switch to A.

Step 19.–Insert 0.01-inch (0.25-mm) shim between first LVDT and mechanical adjuster with a sawing motion.

Step 20.–Adjust sensitivity to bring needle to 100.

Step 21.–Set range selector to CAL and bring needle to 100 with CAL SET adjustment.

Step 22.–Bring range selector back to 10.

Step 23.–Set ABC selector switch to B. Insert shim.

Step 24.–Adjust needle to 100 with span B adjustment screw.

Step 25.–Set ABC selector switch to C. Insert shim.

Step 26.–Repeat step 24 with span C screw.

Step 27.–Check zero of A+B+C.

Step 28.–Repeat steps 18 through 27 with second amplitude.

Step 29.–With range selector at 10 and ABC selector switch at A+B+C, begin test by moving rheostat to about 55 and turning on all other switches. Turn recorder to "select-o-print."

Step 30.–Temperature is adjusted with knob on temperature controller.

6.3 Temperature control shall be verified as conforming with section 3 by adequate thermometers certified by manufacturer.

7. Conditioning

7.1 Tests should be conducted in a room environment where temperature change is held to a minimum. Other conditioning is covered under section 5.

8. Procedure

8.1 Test specimens in a fully dry, fully saturated, or partially saturated state are placed in their holding frames and lowered into a water bath of constant temperature 1 day prior to testing. This allows all components to reach a temperature equilibrium.

8.2 Fill in heading of Data and Computation Sheet (fig. 1) and begin test.

8.3 The initial time, water temperature, and amplified meter readings are taken and temperature controller is set to 70 or 80 °F (21.1 or 26.7 °C) depending upon initial room temperature.

8.4 When water reaches set temperature, hold temperature constant for 5 to 7 minutes while entries are made on data sheet of length changes, temperatures, and time.

8.5 Increase temperature to 90 °F (32.2 °C) and repeat data entries.

8.6 Lower temperature to 85 °F (29.4 °C) and read in 10 °F (5.6 °C) increments down to 35 °F (1.7 °C). Increase temperature to 40 °F (4.4 °C) and read in 10 °F increments back to the initial set temperature. In this manner, data points are obtained for every 5 °F (2.8 °C) interval between 35 and 90 °F as temperature is fluctuated.

8.7 Meter versus temperature readings are plotted and a linear curve is drawn (fig. 2).

9. Calculations

9.1 Figure 1 shows a typical data and calculation form.

9.2 Figure 2 shows the curve discussed in section 8.7. The length or projected meter readings are determined from the curve at the intersect point of 35 °F (1.7 °C) and 90 °F (32.2 °C).

9.2.1 Calculate the coefficient of thermal expansion as follows:

$$CE = \frac{y_2 - y_1}{0.55\,S} \qquad (1)$$

where:

CE = coefficient of thermal expansion, in (in/in)/°F $\times 10^{-6}$ or (cm/cm)/°C $\times 10^{-6}$;
y_1 = intercept of line at 35 °F (1.7 °C);
y_2 = intercept of line at 90 °F (32.2 °C); and
S = summation of gauge lengths, in inches (millimeters).

9.2.2 A more precise method of calculating the coefficient of thermal expansion is by the least squares method of calculation for determining the slope of a line (fig. 3):

$$CE = \frac{y_2 - y_1}{0.55\,S} \qquad (1)$$

$$y_1 = -c + 35b \qquad (2)$$

$$y_2 = -c + 90b \qquad (3)$$

$$c = a - \bar{y} \qquad (4)$$

$$b = \frac{\Sigma\,(x - \bar{x})\,(y - \bar{y})}{\Sigma\,(x - \bar{x})^2} \qquad (5)$$

$$a = \bar{x}b \qquad (6)$$

where:

a = constant derived from the average temperature multiplied by the slope of the line,
b = slope of line,
c = constant derived from a, minus the average meter readings,
x = temperature in °F (°C),
$\bar{x}$ = average temperature in °F (°C),
y = measurement in inches per inch (centimeters per centimeter),
$\bar{y}$ = average measurement in inches per inch (centimeters per centimeter), and
CE, S, y_1, and y_2 = as previously defined.

10. Report

10.1 A cover letter along with figures 1 and 2 or figure 3 should serve as a report for this procedure.

11. Precision and Bias

11.1 The precision and bias for this procedure have not been established.

Spec. or Solic. No. PRECONSTRUCTION STUDIES	Structure BUFFALO BILL DAM	Tested by D. ARNEY	Date 9-8-85
Project PSMBP	Item CONCRETE THERMAL EXP.	Computed by D. ARNEY	Date 9-8-85
Feature BUFFALO BILL DAM & SPILLWAY MODIFICATIONS	Location DENVER LAB; Station ~ Offset ~; Depth ~ to ~	Checked by E. HARBOE	Date 9-8-85

COEFFICIENT OF LINEAR THERMAL EXPANSION OF CONCRETE

Specimen: ☒ Prism ☐ Cylinder; ☒ Sawed ☐ Fabricated;
Aggregate Source: Coarse ALTHOFF CONST.* Fine ALTHOFF CONST. (26%) Nominal Size 2- BY 2-BY 4 inches ~~(mm)~~
MSA: 1½ inches ~~(mm)~~ 1½ TO 3-INCH CRUSHED
☒ 100% Vacuum Saturated ☐ 75% Vacuum Saturated ☐ 100% Oven Dried
Gauge Lengths: (1) 4 1/16 (2) 4.0 (3) 4.0 (4) 4 1/16 (5) 4.0 (6) 4.0 inches ~~(mm)~~ Summation: 24.125 inches ~~(mm)~~

Time	Temperature °F	Temperature °C	No. 1 Range 10 0.01 INCH x 100 Meter Reading	No. 2 Range 10 0.01 INCH x 100 Meter Reading	Average Meter Reading	Remarks
8:20	71.4		0	0	0	*3/8(15%), 3/4(25%), 1½(35%), 3(25%)
9:03	74.9		+5.2	+5.3	+5.3	
9:31	80.2		+10.7	+11.1	+10.9	
10:05	89.6		+20.5	+20.9	+20.7	
10:36	84.8		+15.2	+14.8	+15.0	
10:59	69.2		+0.7	+0.2	+0.5	
11:30	65.0		-4.4	-4.0	-4.2	
11:56	59.7		-11.7	-11.1	-11.4	
12:30	55.4		-14.0	-13.9	-14.0	
1:11	45.1		-24.1	-23.9	-24.0	
2:50	37.8		-31.5	-30.8	-31.2	
3:12	39.9		-29.9	-29.3	-29.6	
3:44	50.5		-20.3	-19.6	-20.0	

$$CE = \frac{y_2 - y_1}{0.55\,S} = \frac{20.3 - (-34.6)}{0.55(24.125)} = 4.138 \text{ millionths, inch/inch/°F}$$

Figure 1. – Typical data and calculation form for measurement of expansion.

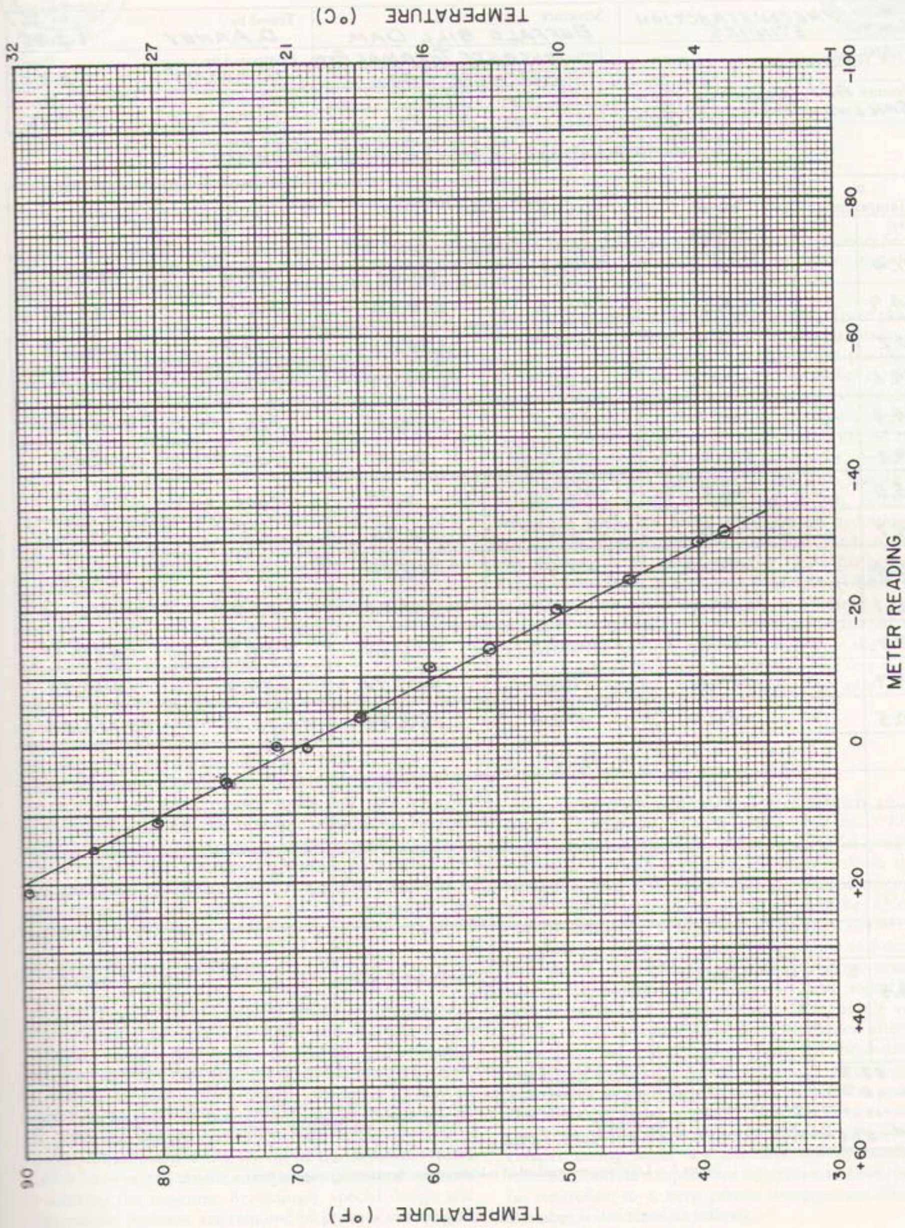

Figure 2. – Graph of meter versus temperature readings.

Spec. or Solic. No. PRECONSTRUCTION STUDIES	Structure BUFFALO BILL DAM	Tested by D. ARNEY — Date 9-8-85
Project PSMBP	Item CONCRETE THERMAL EXP. / Location DENVER LAB	Computed by D. ARNEY — Date 9-8-85
Feature BUFFALO BILL DAM & SPILLWAY MODIFICATIONS	Station ~ Offset ~ / Depth ~ to ~	Checked by E. HARBOE — Date 9-8-85

COEFFICIENT OF LINEAR THERMAL EXPANSION OF CONCRETE

x Temperature °F	x Temperature °C	y Meter Reading	$x-\bar{x}$	$(x-\bar{x})^2$	$y-\bar{y}$	$(x-\bar{x})(y-\bar{y})$
71.4		0	+8.1	65.61	+6.3	+51.03
44.9		+5.3	+11.6	134.56	+11.5	+133.40
80.2		+10.9	+16.9	285.61	+17.2	+290.68
89.6		+20.7	+26.3	691.69	+27.0	+710.10
84.8		+15.0	+21.5	462.25	+21.3	+457.95
69.2		+0.5	+5.9	34.81	+6.7	+ 40.12
65.0		−4.2	+1.7	2.89	+2.1	+ 3.57
59.7		−11.4	−3.6	12.96	−5.1	+18.36
55.4		−14.0	−7.9	62.41	−7.7	+60.83
45.1		−24.0	−18.2	331.24	−17.7	+322.14
37.8		−31.2	−25.5	650.25	−24.9	+634.95
39.9		−29.6	−23.4	547.56	−23.3	+545.22
50.5		−20.0	−12.8	163.84	−13.7	+175.36
Σ = 823.5	Σ =	Σ = − 82.4		Σ = 3,445.68		Σ = 3,443.71

$\bar{x} = 63.3$

$\bar{y} = -6.34$

$y_1 = -69.6 + 35(0.99943) = -34.6$

$y_2 = -69.6 + 90(0.99943) = 20.4$

$S = 24.125$ inches

$a = 63.3(0.99943) = 63.3$

$b = 3443.71/3445.68 = 0.99943$

$c = \bar{x} = 63.3 - (-6.34) = 69.6$

$CE = \frac{y_2 - y_1}{0.55\,S} = \frac{20.3 - (-34.6)}{0.55(24.125)} = 4.138$ millionths, inch/inch/°F

Figure 3. – Least squares method of calculation for determining slope of line.