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SUMMARY OF CORE SUPPORT GRAPHITE AND CARBON RESEARCH AND DEVELOPMENT TEST PROGRAMS FOR THE FORT ST. VRAIN REACTOR PLANT

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INTRODUCTION AND SUMMARY

The core-support graphite components provide the vertical support and the lateral restraint for the reactor core and reflector in the Fort St. Vrain reactor plant. The assembly consists of 37 core-support blocks of hexagonal cross-section, each approximately 37 in. between the parallel prism faces. Surrounding these blocks are 24 reflector support blocks keyed to the hexagonal blocks under the core and to the core barrel. Each of these graphite blocks is supported by three graphite posts with spherical ends to permit them to rock and accommodate the differential expansion between the various parts of the assembly.

Under normal operating conditions the core-support graphite blocks will be subjected to the weight load of the core and the differential coolant pressure, which together will be equivalent to a load of about 30,000 lb on each block. The support posts (in compression) transfer the vertical load from the core support block to the floor below. The components operate at temperatures between room temperature and 1470°F (800°C) maximum in a dry helium gas atmosphere (<10 ppm H₂O) during normal operating modes.

The reactor is designed for 30 years operation. During this time it is expected that the components will maintain their characteristics and function satisfactorily under the specified environmental conditions. In order to evaluate the reliability of the components and materials, an eight-part test program was initiated.

The first two test programs were initiated to determine the load capacity of a graphite structure. These tests are described in Parts I and II of this report.

A third test program was conducted to determine whether cracks would develop on the core-support post ends or graphite post seats because of cycling Hertz stresses resulting from applied loads. This test is described in Part III.

The fourth test program is described in a separate report, GAMD-8374.* In this program, which was intended to test the friction and wear characteristics of the graphite and carbon materials that were selected as candidates for the PSC core-support structure, commercial graphite friction couples PGX versus PGX, MHLM versus MHLM, ATJ versus ATJ, and H359 versus H205 were rubbed with oscillating motion 2500 or 5000 in. in dry helium (~2 ppm H₂O) at room temperature, 400°, and 800°C. Loads of 17.7 lb were used to produce nominal contact pressures of 250 to 500 psi. The PGX and MHLM couples were also rubbed under

*O. M. Stansfield, Friction and Wear in PSC Carbon and Graphite Core Support Materials, USAEC report GAMD-8374, Gulf General Atomic Incorporated, December 7, 1967.

a 4.3-lb load (60 to 120 psi). A baked carbon (B-205) and MoS₂-impregnated graphite (TS835) were rubbed on A-537 Grade B steel 250 in. in dry helium at room temperature, 100°, and 200°C under a 35.3-lb load (500 psi contact pressure). Friction and wear was correlated with rubbing distance, temperature, load, pretreatment of PGX surfaces, and surface roughness of the A-537 Grade B steel.

The fifth test program, which determined the physical and mechanical properties of the selected graphite and carbon materials, is described in GAMD-8371.[†] Several PSC core-support candidate graphites and one baked carbon were evaluated for selected physical and mechanical properties and were compared within each component group. Mechanical testing consisted of tensile, compressive, and flexural tests at room temperature to measure ultimate tensile strength, ultimate compressive strength, modulus of rupture, modulus of elasticity, and density. The coefficient of thermal expansion and thermal conductivity were measured over the temperature ranges of 22° to 1000°C and 22° to 800°C, respectively.

A sixth test program was conducted to determine the wear and operational characteristics of a full-scale core support block and post assembly when subjected to a series of cyclic movements simulating PSC core-support conditions in a dry helium environment. This test is described in Part IV.

A seventh test program was conducted to test the load capacity of the final design of the core-support structure. This test is described in Part V.

The eighth and final test program conducted was to determine the modes and magnitudes of lateral displacements of the core-support block assembly during various operational conditions that were simulated. A 1/5-scale two-dimensional model that was built for this test is described in Part VI.

A summary of the conclusions reached as a result of the PSC core-support graphite and carbon research and development test programs described in this report follows:

1. The selected core-support graphite and carbon components as designed are satisfactory and will withstand all anticipated loading conditions.
2. No cracks developed in either the spherical ends of the graphite posts or seats after cycling such an assembly at the design load for the design life of the components.
3. The friction and wear characteristics of the selected graphite and carbon materials are not expected to adversely affect the performance of the core-support components.
4. The physical and mechanical properties of the selected graphite and carbon materials meet the minimum specified requirements.
5. Negligible wear and no dimensional changes occurred on a full-scale graphite block and post assembly as a result of the simulated thermal

[†]C. Meyers and K. Koyama, Evaluation of Candidate Graphites (and Carbon) for PSC Core-support Application, USAEC report GAMD-8371, Gulf General Atomic Incorporated, February 6, 1968.

cycling test, which was performed at operational load conditions in a helium environment.

6. Clearances and tolerances of the core-support blocks as designed are satisfactory to permit displacements and rotational movements due to differential thermal expansion and seismic conditions.

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Part I

FAILURE TEST OF 3/4-SCALE MODEL CORE-SUPPORT BLOCK AND POST

1. PURPOSE OF TEST

The purpose of this test was to determine the load at failure and what the mode of failure would be on a 3/4-scale model of the graphite core-support block and posts.

2. SUMMARY

A 3/4-scale model of the core-support block and three support posts was fabricated and placed in a test fixture. Instrumentation was provided for recording bellows pressure, loads on the support posts, and the vertical displacement of the test specimen. A pressurization system with an accumulator was used to apply a controlled load to the bellows system in 25-psi increments. The test specimen, test fixture, and pressurization systems are shown in Fig. 1.1.*

The test was conducted by placing the test fixture in a 400,000-lb Baldwin testing machine (see Fig. 1.2).

The load at failure as measured by the testing machine was 135,600 lb, as measured by the load cells on the support posts 141,900 lb, and as measured by the bellows system 136,800 lb. A description of the method of determining the load from the pressure in the bellows system and the load cells on the support legs is discussed in a later section. Since the Baldwin testing machine and load cells were adjusted for a zero reading after the test fixture was placed in the machine, the loads given above do not include the weight of the test specimen and bellows system. The total displacement of the test specimen was 0.134 in. at failure.

The mode of failure is shown in Figs. 1.3 through 1.13. The model core-support block and posts were designed to support a vertical load of 16,875 lb. The failure appeared to have initiated at two of three support post seat recesses in the area of the graphite retaining screw holes. Cracking of the block may be seen in the photographs. All three core-support post upper seats cracked together with the fracture of one core support base (see Fig. 1.4). The actual position of the test specimen with respect to the fixture is shown on Fig. 1.14.

3. TEST CRITERIA

The criteria for testing called for applying a vertical load to failure of the test specimen, which would simulate the load on a full-size core support

*Figures will be found at the end of each part of this report.

block and posts in the reactor. The test specimen would be positioned $3/4$ in. laterally from its true vertical position. Because it was necessary to determine the mode of failure, an important part of the test criteria was to accurately simulate the loading on the full-size block in the reactor. Considerable effort was put into the pressurized bellows system that was used. This system applied a uniform load at the seven independent areas around the coolant holes and thus simulated the loads on the full-size block in the reactor.

The failure load was measured by the Baldwin testing machine, using load cells under each of the three support posts and the hydraulic bellows system. A record was also made on an X-Y plotter of the pressure in the bellows system versus the vertical deflection of the test specimen.

The lateral displacement of the specimen was restricted by four vertical keys that were to be set up with 0.64 in. (times the length of the key) contact engagement area. A clearance of 0.20 in. was specified between the block and the key on the side opposite the contact surface.

4. DESCRIPTION OF TEST FIXTURE AND FACILITY

The test fixture (see Fig. 1.1) is a structure to support the $3/4$ -scale core-support block standing upright (offset $3/4$ in.) on its three support posts with vertical keys to maintain the lateral position. A bellows assembly was placed on top of the support block to facilitate progressive and uniform loading. The final position of the support block with respect to the test fixture is shown in Fig. 1.14; the final lateral displacement was $23/32$ in. The test specimen and fixture were then placed in the 400,000-lb testing machine (see Fig. 1.2).

5. TEST PROGRAM AND RESULTS

A vertical compression load was applied to the seven independently loaded pads centered over the coolant holes in the block. The bellows system, filled with oil and manifolded to an accumulator, allowed the pressure to be raised in 25-psi increments. This increased the total load by approximately 7000 lb per increment, or 1000 lb per pad.

Flow was restricted in the hydraulic system with a preset ball valve to prevent rapid movement of the bellows system should the test specimen fail suddenly. Tests were conducted on the bellows and hydraulic system to determine the optimum setting of the valve.

The load on the support posts was measured with load cells and recorded on a strip chart recorder (see Figs. 1.15 and 1.16). A pressure transducer was installed in the hydraulic line and recorded on the X axis of an X-Y plotter (Y axis as presented on the record). The vertical displacement of the assembly was measured with a linear-motion potentiometer and recorded on the Y axis of the X-Y plotter (X axis on the record). This resulted in a pressure (load) versus displacement plot of the test specimen (see Fig. 1.17).

Failure occurred at a pressure of 496 psi in the bellows system and a deflection of 0.134 in. (see Fig. 1.17). The load on each support post as measured by the load cells was 47,300 lb (see Figs. 1.15 and 1.16). The total load as measured by the Baldwin testing machine was 135,600 lb.

6. DISCUSSION OF DATA

1. Determination of the Failure Load from the Load Cells on the Support Posts

- a. The maximum load at failure was recorded to be 47,300 lb on load cell No. 6 and identically the same on load cell No. 3 (see Fig. 1.14). A recorder failed during the test and no data were obtained for load cell No. 1.
- b. Since there are three support posts, if it is assumed that the load was equal to all posts, the total load is $47,300 \times 3 = 141,900$ lb. During a subsequent test on the individual posts (discussed in Part II), it was discovered that the output of the load cells was non-linear, even though the original calibration was linear. This was due to a slight bending of the bearing plate on the load cells when loaded with the carbon base and graphite seat (see Tables 1.1 and 1.2 for load-cell recalibration data).

2. Determination of the Failure Load from the Bellows System

- a. The load on the test specimen, as measured from the bellows system, is equal to the pressure in the bellows times the effective area minus the load required to extend the bellows.
- b. The pressure in the bellows system at failure was 496 psi. The bellows manufacturer stated that each bellows has an effective area of 39.9 in.^2 , which results in a total area of 39.9×7 or 279.3 in.^2 . The pressure load was 496×279.3 , or 138,500 lb. The pressure load was checked by placing the bellows system in the Baldwin testing machine and measuring the load as the system was pressurized. The result was linear (see Fig. 1.18) and the slope of the pressure versus load plot is approximately 292 lb/psi. Therefore at 496 psi the pressure load was approximately 144,800 lb (see Table 1.3 for pressure transducer calibration data).
- c. The spring constant of one bellows was given by the vendor as approximately 7000 lb/in. The total spring constant of the bellows system was measured (see Fig. 1.19), and for low deflection it was 60,000 lb/in. Since the test specimen deflected 0.134 in. before failure, the load required to extend the bellows system was $60,000 \times 0.134$ or 8040 lb.
- d. The load on the test specimen as measured by the bellows system is $144,800 - 8040$, or 136,800 lb.

Table 1.1

LOAD-CELL RECALIBRATION DATA FOR CHANNEL NO. 4
(Load Cell No. 3)

Load (10 ³ lb)	Recorder Deflection Change (in.)		
	Plain	Correction Factor	Final
0	0	1.017	0
10	0.395	1.017	0.402
20	0.800	1.017	0.814
30	1.220	1.017	1.241
40	1.632	1.017	1.660
50	2.070	1.017	2.105
40	1.628	1.017	1.656
30	1.225	1.017	1.246
20	0.808	1.017	0.822
10	0.400	1.017	0.407
0	0	1.017	0

NOTE: The plot of load versus recorder deflection is linear. The slope of the plot is 50K/2.105, or 23.8 lb/in. of recorder deflection.

Table 1.2

LOAD-CELL RECALIBRATION DATA FOR CHANNEL NO. 5
(Load Cell No. 6)

Load (10 ³ lb)	Recorder Deflection Change (in.)		
	Plain	Correction Factor	Final
0	0	1.017	0
10	0.380	1.017	0.386
20	0.825	1.017	0.839
30	1.225	1.017	1.246
40	1.650	1.017	1.678
50	2.050	1.017	2.085
40	1.650	1.017	1.678
30	1.250	1.017	1.271
20	0.830	1.017	0.844
10	0.40	1.017	0.407
0	0	1.017	0

NOTE: The plot of load versus recorder deflection is linear. The slope of the plot is 50K/2.085, or 24.0K lb/in. of recorder deflection.

Table 1.3

CALIBRATION OF PRESSURE TRANSDUCER

Recorder Deflection (in.)	Pressure Dead Weight Tester (lb/in. ²)	Recorder Deflection (in.)	Pressure Dead Weight Tester (lb/in. ²)
0	0	5.755	550
0.495	50	5.214	500
1.015	100	4.695	450
1.575	150	4.180	400
2.100	200	3.670	350
2.616	250	3.145	300
3.145	300	2.627	250
3.670	350	2.100	200
4.180	400	1.575	150
4.695	450	1.050	100
5.214	500	0.518	50
5.755	550	0	0
6.280	600		

NOTE: The plot of pressure versus recorder deflection is linear.
The slope of the plot is $600/6.280$ psi/in. (i.e., 95.5 psi/in.).

7. CONCLUSIONS AND OBSERVATIONS

The data as measured by the Baldwin load machine and pressure in the bellows system are in close agreement:

$$\frac{136,800 - 135,600}{136,800} \times 100 = 0.88\%$$

Since one recorder failed on the load cells measuring the load on the support posts, all three loads were not measured. In addition, the output of the load cells was nonlinear when loaded on the carbon base and graphite seat, thus causing a slight error. The total load at failure was therefore 136,000 lb.

The safety factor of the system as determined by the 3/4-scale test specimen is 136,000/16,875 or 8.06.

8. ADDITIONAL TESTS

A test was conducted on one 3/4-scale support post and associated components in a vertical position in the 360,000-lb Baldwin testing machine to determine the failure load and deflection at failure. No failure occurred at the maximum capacity of the machine of 60,000 lb. The deflection of the test specimen was 0.135 in. at this load.

Fig. 1.1. Test specimen, test fixture, and pressurization systems

Fig. 1.2. Test specimen and fixture in 400,000-lb Baldwin testing machine

Fig. 1.3. Underside view of failed support block

Fig. 1.4. View of failed carbon base

Fig. 1.5. Failed carbon base (left) and core support post seat

Fig. 1.6. Side view of failed core support block at location of post seat insert

Fig. 1.7. Side view of failed core support block

Fig. 1.8. Top view of failed core support block (removed from fixture)

Fig. 1.9. Top view of failed core support block

Fig. 1.10. Failed core support block

Fig. 1.11. Bottom view of failed core support block (removed from fixture)

Fig. 1.12. Bottom view of failed core support block

Fig. 1.13. Top view of failed core support block

* NOTE: Dimensions given are dimensions between the key and the graphite block at the top and bottom

Fig. 1.14. Position of test specimen with respect to test fixture

Fig. 1.15. Strip chart record for load cell 3

Fig. 1.16. Strip chart record for load cell 6

Fig. 1.17. X-Y plotter record of pressure transducer signal versus specimen deflection

Fig. 1.18. Δ load versus Δ pressure for bellows

Fig. 1.19. Load versus deflection for bellows system

Part II

FAILURE TEST OF A 3/4-SCALE MODEL CORE SUPPORT POST AND CARBON BASE

1. PURPOSE OF TEST

The data required from this test program was the failure load of a single support post and carbon base. The support post, graphite seat, and carbon base used in this program was a 3/4-scale model similar to the test specimens described in Part I.

2. SUMMARY

The first test included a support post, graphite seat, and carbon base. The carbon base failed at a load of 121,300 lb.

The second test was similar to the first, but did not include the carbon base. In this test the support post failed at a load of 171,300 lb. Pieces from the post struck and broke the graphite seat.

3. TEST CRITERIA AND DESCRIPTION OF TEST SETUP

The criteria for the test was to place the test specimens in the 400,000-lb testing machine and load them to failure. A record of the load versus deflection of each test specimen was required.

The installation of the first test specimen in the testing machine is shown in Fig. 2.1. The second test specimen (no carbon base) is shown in Fig. 2.2.

The X-Y plotter used in the testing was the same instrument used on the tests of the core support block described in Part I. For the testing of the single support posts the X-Y plotter was set up to record the actual load on the post versus the deflection instead of the pressure versus load, as was done previously on the support block test.

The deflection transducer was a Lockheed Electronics Model WR-8B with a range of ± 2 in. The transducer was held to the base of the testing machine with two large magnets, and the end of the wire was fastened to the testing machine crosshead with a smaller magnet (see Figs. 2.1 and 2.2).

The load cell utilized was one of the three Sigma System transducers that were used to measure the load on the support posts of the core support block test. These load cells have a rated capacity of 300,000 lb. They were originally designed to measure tendon loads on the PCRV models. The

1-in.-thick plates on the top and bottom of the transducer were used to distribute the load evenly over the unit. A slight nonlinearity of the load cell output resulted from a small bending of these plates.

4. TEST PROGRAM AND RESULTS

The first post tested has been previously loaded to 60,000 lb without any indication of failure, on the Gulf General Atomic testing machine (see Fig. 2.3). When this specimen was set up, the full-scale range of the X-Y plotter was 110,000 lb. When the load reached the full-scale range of the recorder, the test was discontinued (see Fig. 2.4).

On the second run of specimen No. 1 the recorder full scale was adjusted for 180,000 lb and the test specimen was loaded to failure which occurred at a load of 121,300 lb (see Fig. 2.5).

The second test specimen (which had not been previously loaded and was set up with no carbon base) was loaded to 131,250 lb, when the recorder reached the maximum range on the X-axis (deflection measurement). The test was discontinued, and the resulting plot is shown in Fig. 2.6. The range of the X-axis was extended to 0.6 in. maximum, and the test specimen was loaded to failure. The failure load was 171,300 lb, and the plot is shown as run No. 2 on Fig. 2.6.

As shown in the photograph in Fig. 2.1, the first test specimen was tied to the crosshead to prevent it from being damaged by a fall in case of a failure of the carbon base. When the base failed, however, the post tore loose and was chipped when it fell to the floor. Figure 2.7 shows both specimens after failure. During the testing of the second specimen, when the post failed, half of the post was left hanging from the tiedown to the crosshead. The pieces of the post of specimen No. 2 are shown in Fig. 2.8. A reassembly of the lower seat and bottom of the support post of specimen No. 2 is shown in Fig. 2.9. The pieces of the lower seat and carbon base of specimen No. 1 are shown in Figs. 2.10 and 2.11.

5. CONCLUSIONS AND OBSERVATIONS

The weak point in the support post assembly is the carbon base. Since the full-scale post is designed to hold 10,000 lb, the design load for the 3/4-scale model is 5,630 lb. The safety factor of the support post system is $121,300/5,630$ or 22. It was established in Part I that the safety factor of the core support block was 8. The carbon base, therefore, is not the weak point in the complete system.

The safety factor of the support post is $171,300/5,630$ or 30. The support post failed in shear, and pieces from the post caused the failure of the seat.

The calibration of the load cell indicated that the load versus recorder deflection was nonlinear. With the calibration data and the data from the

X-Y plotter record, a correction curve was plotted (see Fig. 2.12). Corrected plots of the data are presented in Figs. 2.13, 2.14, and 2.15.

The curve in Fig. 2.3, which shows the first load on specimen No. 1, and the curve in Fig. 2.14, which shows the corrected curve of first load on specimen No. 2, are very similar in shape and are quite nonlinear at loads below 10,000 lb. A cracking noise was heard during the first loading on both specimens in the area of 40,000 to 60,000 lb. The permanent set on the first loading of the second test specimen was significant. These facts apparently indicate that the graphite exhibits a work-hardening characteristic.

Fig. 2.1. Specimen No. 1 support post loaded in testing machine

Fig. 2.2. Specimen No. 2 support post loaded in testing machine (carbon base removed)

Fig. 2.3. Load versus deflection for specimen No. 1;
Test discontinued at 60,000-lb capacity of
testing machine

Fig. 2.4. Load versus deflection for specimen No. 1, run No. 1; test discontinued at 110,000 lb, full-range of recorder

Fig. 2.5. Load versus deflection for specimen No. 1, run No. 2; testing to failure

Fig. 2.6. Load versus deflection for specimen No. 2

Fig. 2.7. View of two post specimens after failure

Fig. 2.8. Pieces of post of specimen No. 2

Fig. 2.9. Reassembly of lower seat and bottom of support post of specimen No. 2

Fig. 2.10. Specimen No. 1, lower seat

Fig. 2.11. Carbon base, specimen No. 1

Fig. 2.12. Error curve for support post failure test

Fig. 2.13. Corrected plot of load versus deflection for specimen No. 1, Run No. 2

Fig. 2.14. Corrected plot of load versus deflection for specimen No. 2, Run No. 1

Fig. 2.15. Corrected plot of load versus deflection for specimen No. 2, Run No. 2

Part III

FATIGUE TEST OF A 3/4-SCALE MODEL CORE SUPPORT POST

1. PURPOSE OF TEST

The purpose of the testing was to determine whether any cracks developed on the support post ends or spherical seats due to cycling Hertz stresses and to measure dimensional changes, if any, resulting from applied loads.

2. SUMMARY

Visual inspections were conducted using acetone before starting the test and at various intervals through the conclusion of the test. No cracks were found on the specimen components. Maximum vertical deflection at 43,000 lb was 0.109 in. The dimensional changes, which were negligible, are shown on three inspection checkoff lists, Tables 3.1, 3.2, and 3.3.

3. TEST CRITERIA

The criteria for testing called for setting up a 3/4-scale graphite core support post, base, and post seats and applying a load from 0 to 43,000 lb for a total of 1000 cycles.

Loading on the first 500 cycles was to be applied at a uniform rate to full load over a period of 1-1/2 min/cycle. From 501 to 1000 cycles the loading rate was to be reduced to 1 min/cycle. Continuous recordings of vertical loading and deflection versus time were planned.

Visual inspections of the post ends and spherical seats utilizing acetone were to be made before testing began, at 415, 500, 600, and 700 cycles, and at the conclusion of the test. In addition, pre- and post-test dimensional checks of specimen components were to be made.

4. DESCRIPTION OF TEST SETUP

To provide accurate loading of the specimen, the 60,000-lb Baldwin testing machine was used.

The graphite support post with the upper and lower spherical seats were assembled and placed on top of a type B load cell.

A steel adapter machined to the same dimensions as the support post seat recess in the support block was fitted to the cross arm on the stress machine.

To measure compression (vertical linear motion) of the specimen, a Lockheed Electronics position transducer model No. 1166 was clamped to the load bed with the spring loaded cable attached to the cross arm (see Figs. 3.1 and 3.2).

Excitation to the load and position transducer was provided with a Hewlett Packard model 721A power supply, the excitation voltage being set at 15.0 v. Continuous recordings were made on the Moseley model 7100B dual-channel strip-chart recorder (see Figs. 3.3 and 3.4).

5. TEST PROGRAM AND RESULTS

After initial dimensional measurements and visual checks, the post, base, and seat were installed in the load machine and vertical alignment was accomplished using a bubble level. The load was applied in steps to calibrate the deflection of the recorder channels versus load and deflection.

Readings from the large load machine dial and deflection from a dial indicator gave the proper readings versus deflection of the recorder channels. The load was measured on channel No. 1 with 1-in. deflection equal to 10,000 lb. The deflection was recorded on channel No. 2 with 1 in. indicating 0.100 in. of vertical compression of the specimen (one thousand cycles were performed with required visual inspections at proper intervals).

Post-test dimensional checks were performed by inspection and recorded.

6. CONCLUSIONS AND OBSERVATIONS

The cycling Hertz stresses did not produce any cracks or chips in the post ends or spherical seats.

The dimensional changes due to the 1000 load cycles were negligible.

The maximum vertical deflection (in compression) was 0.109 in., with a 43,000 lb load producing no noticeable permanent set of the graphite components.

The design of the post was based on a total of 415 cold and warm shutdown cycles and was tested to 1000 cycles. This gives a design safety factor of: $1000/415$, or 2.41.

Table 3.1
INSPECTION CHECK-OFF LIST

PART NAME Post - 3/4 Scale Core Support

PART NUMBER 90-SK-972-1

B/P DIM./CHARACTERISTIC	ACTUAL DIM./CHARACTERISTIC	
	BEFORE TESTING	AFTER TESTING
1/4R	.235/.240	.235/.240
4.500 R	4.50/4.50 R	4.500/4.500
4 1/2 dia +1/32 - 0	4.508/4.509	4.508/4.509
4.495 + .000 - .005	4.4953/4.495	4.4950/4.4945
4 1/2	4.490(1)/4.480(2)	4.485/4.480
30.94	30.936	30.934

Table 3.2
INSPECTION CHECK-OFF LIST

PART NAME Upper seat- 3/4 Scale Core Support Post

PART NUMBER 90-SK-974-2

B/P DIM./CHARACTERISTIC	ACTUAL DIM./CHARACTERISTIC	
	BEFORE TESTING	AFTER TESTING
6.375 dia	6.379	6.379
6.00	6.00	6.00
4.500 + .005 -.000	4.499 .002 gage under middle, .002 feeler	
4.734R	4.733R	4.733
1.125	1.120	1.119
1/8R	.120	.120
1.68	1.675	1.674
3.56	3.566	3.5665
.562	omitted	
5.625 +.000 -.002	5.6255	5.626
1/16R	1/16ID 1/32OD	1/16ID 1/32OD
1/8 x 45°	125 x 45°	.125 x 45°
1/2 x 13 UNC 3/4 dp	omitted	
1/16 x 45	.067 x 45°	.067 x 45°

Table 3.3
INSPECTION CHECK-OFF LIST

PART NAME Lower Seat - 3/4 Scale Core Support Post

PART NUMBER 90-SK-972-2

B/P DIM./CHARACTERISTIC	ACTUAL DIM./CHARACTERISTIC	
	BEFORE TESTING	AFTER TESTING
5 5/8 dia	5.627	5.6275
2.562	2.565	2.565
1.28	1.28	1.28
3/32 x 45°	.092 x 45°	.092 x 45°
7/8	.872/.873	.871/.873
-.010-A-	.0005	.0005
1.50	1.505	1.508
3/32 x 45° top	.110 x 45°	.110 x 45°
3/16 x 45° t	.198 x 45°	.198 x 45°
4.734R	4.734R	4.734
1/8R	1/8R	1/8R
3 1/2"	3.494	3.495
.562 +.002 -.000	.562	.562
C' sk 90° 3/4" dia	90° .76	90° .760/.756
3° 30'	3° 45"	3° 45"
4.500 +.005 -.000	4.499 .002 feeler under middle	.002 feeler
⊥ -A- .002	.002	.002
⊥ -A- .002	.001	.0015

Fig. 3.1. Setup for measuring compression, position transducer clamped to load bed

Fig. 3.2. Setup for measuring post compression

Fig. 3.3. Strip chart record of core support post fatigue test

Fig. 3.4. Strip chart record of core support post fatigue test

Part IV

SIMULATED THERMAL CYCLING TEST OF A FULL-SCALE CORE SUPPORT BLOCK AND POST ASSEMBLY

1. PURPOSE OF TEST

The purpose of this part of the test program was to determine the wear and operational characteristics of a full-scale specimen of a graphite core support block and post when subjected to a series of cycling movements simulating PSC core support conditions.

2. SUMMARY

Measurements of all graphite test components were made by inspection before testing. The dimensions were again checked after the first 55 cycles, after the next 360 cycles, and at the completion of the following 10,000 cycles. Since the wear was negligible, no further checks were made during the following 30,000 cycles, but they were performed at the completion of the test of 40,000 cycles. No significant changes in dimension were found at the completion of 40,000 cycles, and no cracks or chips developed.

3. TEST CRITERIA

The criteria for testing called for a full-size PSC core support block and three post assemblies to sustain a vertical load of 30,000 lb, which represents the supported core weight and core pressure drop.

Facilities for loading the specimen and for maintaining a helium environment of less than 10 ppm moisture were to be used. The load was to be monitored by a load cell placed under each of the three posts.

The block was to be displaced horizontally to simulate the calculated movements in the reactor resulting from thermal expansion during heatup and cool down at different power levels.

Keys and keyways to simulate core support blocks adjacent to the test specimen were to be installed. Individual hydraulic actuators were to supply the force required to move the keys.

Horizontal displacement of the block was to be made on two planes. One plane was to be across the flats of the block and the other at 90° to this position or across the corners perpendicular to a line across the flats. The direction of horizontal displacement was to be changed after completion of one half of the required number of cycles for each step.

Linear motion potentiometers with output signals to a visicorder was to give a means of monitoring the key and keyway travel. Hydraulic pressure was to be provided for the horizontal displacement of the block and the relative motion of the keys and keyways. Sequential selection of the hydraulic pressure was to be controlled by a specially constructed timing unit that selected a pre-programmed solenoid valve to perform the two different functions. Figures 4.1, 4.2, 4.3, and 4.4 show schematics of the electrical and hydraulic systems.

4. DESCRIPTION OF TEST SETUP

The test fixture components that were fabricated included the graphite core support block post seat inserts, posts, post seats, and carbon bases.

Figures 4.5, 4.6, and 4.7 show the test specimen and associated components installed in the test fixture. Figure 4.8 is a diagram of the core support test fixture.

The core support block was mounted in the test fixture on its three support posts. These were mounted in the lower seats and on top of the carbon bases, which were supported by three specially constructed load cells.

Pressure-proof electrical connectors were installed in 8-in.-diameter pipe flanges surrounding the load cells and carbon bases. Helium purge and fill lines and hygrometer sample lines were also fabricated into the flange.

Housings 8 in. in diameter for the support post were bolted to the flanges. Each post housing was equipped with two 8-in.-diameter bellows having eight convolutions to allow lateral motion of the oscillating assembly.

The post housings, with bellows, were welded to the oscillating assembly which formed a helium-tight containment for the post, open to the large containment.

Two hinge plates supported the oscillating assembly and were made to operate in two different positions. One position was for horizontally displacing the support block along a line through two opposite corners of the block. The other position was at 90° to this position for horizontally displacing the block along a line across two opposite flats bisecting the line between two corners.

A 6-in.-diameter hydraulic actuator was attached to an upright support and connected to the oscillating assembly to effect the horizontal displacement. This also provided restraint to hold the oscillating assembly in a center or neutral position during periods of assembly and disassembly.

In order to simulate the core support blocks adjacent to the test specimen, keys and keyways representing the portion of adjacent blocks that would normally be in contact with the test specimen block were fabricated and mounted on friction-free, precision linear-motion bearings attached to the oscillating assembly. These were so positioned that the keys and keyways

mated with their respective faces on the test specimen and could be moved outward and away from the specimen on their bearings.

A load plate was mounted on top of the test specimen block and fitted with a steel shaft running down through the block and attaching to a 6-in.-diameter hydraulic actuator. The actuator shaft measured 2-1/2 in. in diameter. The effective area of the actuator was thus 23.3653 in.² By applying a pressure of 1284 psi, a load of 30,000 lb could be exerted on the test specimen. The load pressure was supplied by an independent system using a pneumatic/hydraulic accumulator, with the pneumatic side controlling the load pressure.

To maintain a pure helium environment for the test specimen, a dome approximately 60 in. in diameter and 1/2 in. thick was fabricated. Three observation points were provided on top to view the interior in the area of the keys and keyways.

The dome attached to a flange on the oscillating assembly and was sealed with an O-ring and graphite-impregnated asbestos gasket. It was retained by a 62-in., three-piece Marman clamp. Six 1-in.-diameter studs with brackets welded to the dome and on the oscillating assembly were used to prevent the dome from deforming should accidental overpressurization occur.

Six 1000-w strap heaters were mounted to the outside of the dome to raise the internal temperature and speed up purification of the helium environment.

Actuators to move keys and keyways were mounted on brackets near the top of the dome.

Arms with a center pivot point were mounted vertically on the dome. One end was connected to the actuators and the other connected to rods that bolted to small bellows assemblies and connected internally to their respective key and keyway frame (see Fig. 4.5).

The pressure to the six key and keyway actuators was supplied by the same hydraulic supply as for the block lateral motion system. However, a separate regulator maintained pressure to the six actuators at a sufficiently low level to avoid bending the actuator arms and yet maintain cycle speed.

The lateral motion of the block was achieved by the use of an actuator identical to the one used for loading; however, the pressure was raised only enough to move the actuator through a cycle in the time required by the sequence timer.

One cycle (with the keys in their outward or withdrawn position) consisted of the bed or oscillating assembly moving laterally and returning, followed by the six keys moving in and out. The rate of cycling was 2 cpm for the 55-cycle and 360-cycle tests. For the last test phase the cycle rate was increased to 4 cpm.

The sequence timing unit used a 1-rpm (and later a 2-rpm) motor and was equipped with cams that actuated micro switches. The switches operated directional control valves regulating flow to the actuators.

Measurements taken with the instrumentation setup for this test are shown below:

Measurement	Transducer	Channel	Recorder
Post No. 1	Load cell	1	Moseley Strip Chart No. 1
Post No. 2	Load cell	2	Moseley Strip Chart No. 1
Post No. 3	Load cell	1	Moseley Strip Chart No. 1
Load pressure	Press. pot.	2	Moseley Strip Chart No. 1
Bed motion actuator	Lin. pot.	5	Minn. Honeywell Visicorder
Load actuator	Lin. pot.	6	Minn. Honeywell Visicorder
Key No. 1	Lin. pot.	7	Minn. Honeywell Visicorder
Key No. 2	Lin. pot.	8	Minn. Honeywell Visicorder
Key No. 3	Lin. pot.	9	Minn. Honeywell Visicorder
Key No. 4	Lin. pot.	10	Minn. Honeywell Visicorder
Key No. 5	Lin. pot.	11	Minn. Honeywell Visicorder
Key No. 6	Lin. pot.	12	Minn. Honeywell Visicorder

Twelve channels of bridge balance were supplied with a regulated power supply for each six channels.

A patch-panel setup allowed easy trouble shooting of the system as well as rapid channel or measurement changeover. All measurements were plainly marked on the patch panel as were the resistance calibration points for the load cells.

The linear motion potentiometers were calibrated in position using shims of known thickness. The sensitivity or deflection of the recorder trace was controlled by adjusting the individual excitation control potentiometers. Once these were adjusted, no further adjustment was required. Mechanical zero for all measurements was not affected by changing the distance of the strokes of the hydraulic actuators. The deflection changed on the recorder, since this was proportional to the movement of the position potentiometers.

Two Moseley dual-channel strip-chart recorders were used to measure the load cells and load pressure transducer. A twelve-channel Visicorder monitored all position potentiometers (see Fig. 4.1).

A different pattern on the recorder was observed for the same load cell, when displacing the block horizontally from the two different directions (see discussion in Section 5, below).

The graphite components were inspected after the completion of different phases of testing. In general, data were taken for the following measurements:

1. Envelope of movement, i.e., with the keys and keyways in their initial IN position (steel dowel pins were installed to prevent the key and keyway frame from moving from the reference position) the movement of the block in all directions was measured.
2. Distance across the face of keys.
3. Distance between the sides of keys.
4. Length of support post.
5. Levelness of block.
6. Depth of keys and keyways.
7. Wear of post seats.
8. Visual inspection for cracks, chips, and points of excessive wear.

5. TEST PROGRAM AND RESULTS

Three simulated sets of conditions were used in this test. The conditions were as follows:

1. 100% power to complete shutdown, 1-in. total movement of block, 1/2-in. relative movement of keys in keyways, for a total of 55 cycles.
2. 100% power operation to warm shutdown, 7/8-in. total movement of block, 7/16-in. relative movement of keys in keyways, for a total of 360 cycles.
3. Load change from 100% to 25% power, 3/8-in. total movement of block, 3/16-in. relative movement of keys in keyways, for a total of 40,000 cycles.

Since the horizontal movement of the block could normally be in any direction, two limits were imposed: the block was first cycled for one-half the required number of cycles (for each set of conditions) along a line through two opposite corners of the block, and then for the second half of the required number of cycles (for each set of conditions), along a line bisecting two opposite flats.

To more accurately measure the wear of the simulated adjacent core support blocks relative to the wear on the test block, the levelness and envelope of movement (the keys and keyways were equipped with repeatable reference points) were measured before the test was started. They were again measured at completion of 55 cycles (step No. 1), 360 cycles (step No. 2), 10,000 cycles (25% of step No. 3), and at 40,000 cycles or at the completion of the test. Helium purity requirements called for less than 10 ppm moisture.

Initial preparations for the test required assembly of the fixture with test components having been measured as previously described. With the dome sealed in place, a vacuum pump was used to pump the pressure down to approximately 40 to 50 μ m.

After isolating the vacuum pump, the containment was back-filled with helium from the purification system and heat applied with the strap heaters.

When a purity level of less than 10 ppm moisture was attained, a load of 30,000 lb was applied to the support block. This was monitored by means of the three load cells and a pressure transducer installed in the hydraulic line to the load actuator. Signals were displayed on the two Moseley 7100B dual-channel strip-chart recorders. After a warmup period for the hydraulic oil in the horizontal displacement and key actuator system, the sequence timer unit was turned on and cycling started. Position potentiometers mounted on all actuators displayed their signals on a 12-channel Visicorder and were recorded periodically.

At the completion of one-half the total required cycles for a given set of conditions, cycling was halted and the horizontal actuator and hinge plates were moved 90° to their position for the remainder of the required number of cycles.

Inspection of graphite components was called for at 55 cycles, 360 cycles, 10,000 cycles, and at the completion of the test (40,000 cycles). Each inspection was performed at the completion of a set of conditions, i.e., horizontal displacement and key motion. This required disassembling the fixture, inspection, reassembling the fixture, and reestablishing the environment each time.

At the completion of 10,000 cycles, photographs were taken of small deposits of graphite on the key frames and oscillating assembly (see Fig. 4.9).

The helium purity for the entire test was monitored and abbreviated curves (presented in Fig. 4.10) were plotted from the purification recorder. Difficulty was encountered in obtaining the required purity level because of the gradual outgassing of the specimen and fixture. Three measures were introduced to alleviate this situation:

1. Six 1000-w strip heaters were added to the outside of the containment dome.
2. Baffles were added around the support posts ports of the oscillating assembly to divert the helium flow from the purifier supply line.
3. Helium fill and purge lines and purity sample points were added to the third leg or support post to allow helium to go in leg No. 1 and out leg Nos. 2 and 3.

While small areas of wear or friction were evident on some graphite components, no significant changes in dimensions were measured. There were no chips or cracks observed as a result of testing. Figures 4.11, 4.12, 4.13, and 4.14 showing support posts and seats are typical of the slight wear resulting from the test.

6. OBSERVATIONS

During the test a slight "popping" sound was heard at cycle 1745. Investigation at disassembly showed evidence of the support post riding over on the slope of the edge of the post seat and sliding down to the bottom of the recess in the seat. The noise continued for the duration of the first 10,000 cycles. It was again observed for the next 10,000 cycles, which concluded the required number of cycles for horizontal displacement of the block along a line through two opposite corners.

When the horizontal displacement actuator was moved 90° to this position, the noise was not detected. No excessive wear was produced by this action.

Two different patterns of trace oscillation were recorded from the load cells for the two different directions of horizontal displacement. This resulted from the orientation of the load cells in relation to the direction of horizontal movement of the block. The vertical load of the block produced a slight side load when the block was displaced. The variation in trace pattern did not result from any unusual loads or moments being applied to the test specimen.

Fig. 4.1. Electrical systems

Fig. 4.2. Actuator systems and plumbing

Fig. 4.3. Actuator sequence timing unit for core support test

Fig. 4.4. Hydraulic control for core support test

Fig. 4.5. Test specimen and associated components installed in test fixture with containment raised

Fig. 4.6. Test specimen and associated components installed in test fixture with containment raised

Fig. 4.7. Test specimen and associated components installed in test fixture with containment raised

POTENTIOMETER INSTALLATION
TYPICAL 2 PLACES

Fig. 4.8. Core support test fixture

Fig. 4.9. View showing deposits of graphite on key frames and oscillating assembly

Fig. 4.10. Helium purity versus number of cycles

Fig. 4.11. Top ends of support posts at completion of test

Fig. 4.12. Bottom ends of support posts at completion of tests

Fig. 4.13. Post seat inserts at completion of test

Fig. 4.14. Post seats at completion of test

Part V

STATIC FAILURE TEST OF A 3/4-SCALE MODEL CORE SUPPORT BLOCK AND POST ASSEMBLY

1. PURPOSE OF THE TEST

The purpose of the static failure test of the 3/4-scale model was to determine the static load capacity of the redesigned core support block and post assembly. It was very similar to the test described in Part I.

2. SUMMARY OF TEST RESULTS

Because of loading restrictions, a 3/4-scale model was used for these tests. The testing was conducted in three stages:

1. Loaded on three posts to five times design load.
2. Loaded on two posts to five times design load.
3. Loaded on three posts to failure.

The ultimate failure load of 138,000 lb, 8.15 times the design load, exceeded the specimen failure load of 136,000 lb described in Part I, not withstanding a crack that developed in the block during the loading tests on 2 posts. The ultimate failure occurred in this region. No failure was sustained by the posts or lower seats of the test specimen during this series of tests.

3. TEST CRITERIA

The three tests, as described in the summary, were performed with the block displaced 3/4 in. from a true vertical position and a clearance of 0.400 in. between the block and two keys on one side of the block; see Fig. 5.1 for the actual location of the block with respect to the fixture and keys. The distances between the keys and block noted on Fig. 5.1 were deviations from a true bearing contact.

The first test required was performed on three posts, and the criterion was to produce a vertical load on the specimen. The load required was to be five times the design load of 16,875 lb, or approximately 85,000 lb. If the specimen passed the first test without damage, it was to be loaded in a similar manner but with one of the posts removed. If the specimen did not fail as a result of the test on two posts, it was to be loaded to failure on three posts as a final run.

4. DESCRIPTION OF TEST FIXTURE AND FACILITY

The test fixture and associated equipment are shown on Fig. 5.2; the setup in the structures laboratory is shown on Fig. 5.3. Because of the redesigning of the core support specimen and the test requiring it to be loaded on two posts, the test fixture was modified, and new key assemblies were used.

The test specimen was taller than the specimen used for the tests described in Part I, and this resulted in larger moments on the fixture keys. In addition, the moments were considerably higher than the ones experienced during the Part I test because of the requirement that this test be conducted on two posts.

The bellows assembly on the top of the specimen was pressurized with oil and produced a load closely simulating the condition on a full-size core support block. In the actual reactor, the load on the full-size block is due to the weight of the fuel elements and the pressure drop of the helium across the core.

The test specimen, installed in the fixture, was placed into the 400,000-lb testing machine (see Fig. 5.3).

The pressurization system consisted of a nitrogen bottle, air-oil accumulator, and associated regulators and valves. A flow restrictor valve was used on the main pressurization line to prevent a sudden movement of the bellows system in case of a specimen collapse. Rods were used around the bellows assembly with adjustable nuts on the top to provide a mechanical stop for the bellows. The pressure was measured in the bellows assembly with a strain gage pressure transducer. A calibration of the transducer, utilizing a dead-weight tester, was performed on the X-Y plotter. The deflection transducer was also calibrated at the same time, and the results of the calibration are given in Fig. 5.4.

The load cells were calibrated before the test, and shunt-resistance calibration values established for them at a load of 60,000 lb.

5. TEST PROGRAM AND RESULTS

The first test, loaded to five times the design load on three posts, was performed on November 15, 1967 with no indication of failure. The X-Y plotter and strip-chart records of this test run were replotted and are given in Figs. 5.5, 5.6, and 5.7. The testing machine load was 90,700 lb. The load as indicated by the sum of the loads on the load cells was 91,100 lb. The effective area of the bellows system is 279.3 in.², and the average spring constant of the system is 56,000 lb/in. (see Part I, Fig. 1.19 for a more precise curve of the deflection versus load). The pressure in the bellows system, as indicated by the X-Y plotter record, was 370 psi and the deflection of the specimen was 0.129 in. The load due to the pressure was 103,300 lb. Subtracting the load required to deflect the bellows assembly 0.129 in. results in an over-all total load of 95,300 lb.

No indication of damage was evident after the test, and post A (see Figs. 5.1 and 5.8) was removed for the second test.

The first run on test two was terminated when it became evident that the load axis on the X-Y plotter was moving off scale. It was also noted that the pressure versus deflection curve became nonlinear at a deflection of 0.15 in. This was an average deflection, and because the block was supported on two posts, it was tilting, causing the point near the post that had been removed to deflect considerably more. At this time the nonlinearity was attributed to the tilting of the block. The scale was reset on the pressure axis of the X-Y plotter and the test rerun. The X-Y plotter and strip-chart records for the first run of test two are given in Figs. 5.9 and 5.10.

The second run was terminated when an increase in pressure, on the air side of the piston in the air-oil accumulator, did not produce an increased load on the testing machine. Investigation revealed that the deflection of the test specimen had increased considerably for the same load that had been experienced on the test on three posts. As a result of this increase in deflection, the capacity of the air-oil accumulator was not sufficient to pressurize the system. In addition, the investigation revealed that the mechanical stops on the bellows system were restricting the motion of the assembly in the area of maximum deflection, or around the missing post. These stops were readjusted for the third run on test two. The results of the third run indicate that the nonlinearity of the pressure versus deflection records was a result of the restriction of the motion of the bellows assembly by the mechanical stops. The X-Y plotter and strip-chart records for the second and third runs of test two are given in Figs. 5.11 through 5.13.

The third test was performed after a larger air-oil accumulator was installed. The results on strip-chart recorder and X-Y plotter were replotted and are included in Figs. 5.14 through 5.16. The testing machine indicated a load of 87,000 lb, and the sum of the measured loads on the load cells was 81,200 lb. The load as indicated by the pressure in the bellows, minus the spring constant load, was 95,700 lb. Note that the load indicated by the load cells was lower than that indicated by the testing machine, whereas the pressure load was higher. The test fixture was warped as a result of test two, and this became evident when the setup for test three was started. The horizontal component of the vertical load would be large to warp the fixture. The horizontal loading would create large friction forces between the block and keys, and would thus produce lower loads on the posts of the specimen. The block tilted considerably during this test on two posts, resulting in a tendency for the upper plate on the bellows assembly to tilt. This upper plate is guided by four rods, and if it became cocked during assembly, it would bind and not move. This binding would be present during the test when the upper plate was tilted. The pressure force required to load the specimen and overcome the binding would be greater than that indicated by the testing machine.

The load on the specimen during test two was 87,000 lb if the friction forces on the keys are taken into account, or 81,200 lb if the friction forces are ignored.

Examination of the test specimen the day following the test revealed a crack between the keyway and the removed post support area. Figure 5.8 shows the setup before completion of test two, and Figs. 5.17 and 5.18 show the crack in the block after test completion.

An examination of the bottom of the keyways and keys on the block revealed cracks around all four that were loaded. The cracks around the keys near the two posts supporting the specimen were small, however, and did not show up well in the photographs.

The test specimen for test three failed at a load of 138,000 lb on the testing machine, 138,200 lb indicated load on the load cells; the corrected load, as indicated by the pressure in the bellows system, was 137,100 lb. To correct the load as measured by the pressure in the bellows, it was not only necessary to subtract the spring constant load due to the deflection of 0.15 in. of the bellows but also to add the preload of the testing machine, which was not reflected as a pressure in the bellows. The amount of this period can be obtained from the strip-chart records. The preload was necessary to seat the testing machine properly on the test fixture after the latter had been warped from the test performed on two posts.

Photographs of the mode of failure of the block are shown in Figs. 5.19 through 5.25. A visual survey of the posts and seats did not reveal any damage. When the block was removed from the test fixture and placed on the floor it was cracked, but not separated. It was necessary to exert a force of about 20 lb to separate the broken corner (see Figs. 5.21 and 5.22).

6. CONCLUSIONS AND OBSERVATIONS

The test specimen performed well and failed at a load higher than the specimen described in Part I. The load at failure for this redesigned test specimen was 8.15 times the design load, even though the block had been cracked in several places on the bottom near the post seats before it was loaded to failure.

The specimen was cracked at a load of 53,000 lb when it was loaded on two posts. The crack was caused when the block was wedged between the two keys on the test fixture, near the bottom of the block in the area of the removed post. The deflection of the block at this point is estimated to be 0.624 in., or 0.514 in. below the opposite edge. The angle of tilt of the block at a load of 87,000 lb (5.18 times the design load) can be estimated as $\sin^{-1} (0.514/28)$, or 1.05° .

DISTANCE BETWEEN FRONT
FACE AND SIDE OF BLOCK,
AND SIDE OF KEY AND BLOCK,
TOP AND BOTTOM = .000

1. DISTANCE BETWEEN FRONT
FACE AND BLOCK
TOP = .004, BOTTOM = .005
2. DISTANCE BETWEEN SIDE OF
KEY AND BLOCK
TOP = .000, BOTTOM = .000

Fig. 5.1. Offset location of block with respect to test fixture

Fig. 5.2. Static test specimen and associated equipment

Fig. 5.3. Static test setup

Fig. 5.4. Deflection transducer calibration; pressure versus deflection

Fig. 5.5. Strip chart record of load on Post A load cell versus time; Test 1

Fig. 5.6. Strip chart record of load on Post B and Post C load cells versus time; Test 1

Fig. 5.7. X-Y plotter record of bellows pressure versus specimen deflection;
Test 1, 3 posts loaded

Fig. 5.8. Test setup on two posts

Fig. 5.9. Strip chart record of load on Post B and Post C load cells versus time; test 2, Run 1, Post A removed

Fig. 5.10. X-Y plotter record of bellows pressure versus specimen deflection;
Test 2, Run 1, Post A removed

Fig. 5.11. Strip chart record of load on Post B and Post C load cells versus time; Test 2, Run 2, Post A removed

Fig. 5.12. Strip chart record of load on Post B and Post C load cells versus time;
Test 2, Run 3, Post A removed

Fig. 5.13. X-Y plotter record of bellows pressure versus specimen deflection; Test 2, Runs 2 and 3, Post A removed

Fig. 5.14. Strip chart record of load on Post A load cell versus time; Test 3, loaded on three posts to failure

Fig. 5.15. Strip chart record of load on Post B and Post C load cells versus time; Test 3, loaded on three posts to failure

Fig. 5.16. X-Y plotter record of bellows pressure versus specimen deflection; Test 3, loaded on three posts to failure

Fig. 5.17. Crack in bottom of static test specimen as a result of loading on two posts

Fig. 5.18. Bottom view of crack in static test specimen

Fig. 5.19. Top view of block in test machine after failure of specimen

Fig. 5.20. Test specimen on floor after removal from machine

Fig. 5.21. Block specimen with piece removed

Fig. 5.22. Alternative view of failed static test specimen

Fig. 5.23. Bottom inside view of crack in static test specimen

Fig. 5.24. Side view of failed test specimen

Fig. 5.25. Test specimen components after removal from test fixture

Part VI

LATERAL DISPLACEMENT TEST OF A 1/5-SCALE MODEL CORE SUPPORT BLOCK ASSEMBLY

1. PURPOSE OF TEST

The purpose of this test program was to determine the modes and magnitudes of the displacements that are possible as a result of the thermal growth of the core barrel and the key/keyway clearances. A 1/5-scale, two-dimensional model of the core support and reflector support blocks was fabricated in order to determine these characteristics.

2. SUMMARY OF RESULTS

Rotational movement of the six trapezoidal blocks revealed that contact occurs with their adjacent outer support blocks at the outer peripheral corners of the blocks. This condition occurred in both the hot and cold positions.

The maximum movement of any one hexagonal block with the others unrestrained from movement was 0.52 in. in the cold position and 0.61 in. in the hot position. The maximum differential radial movement between any two adjacent blocks during earthquake conditions was 0.25 in. in the cold position and 0.39 in. in the hot position. The maximum radial movement from cold to hot, including the movements allowed during earthquake conditions, amounted to 0.48 in. The radial displacement required of the outer support blocks to cause disengagement of all the blocks was 7-1/4 in.

3. TEST CRITERIA

The criteria for this test were that the modes of displacement of the core support plate model be observed and the magnitude of displacements be determined. The total plate movement and the relative movement of the keys in the keyways was determined. These movements were used in the simulated thermal cycling test of a full-scale core support block described in Part IV.

4. DESCRIPTION OF TEST FIXTURE

Since the core support plate model was built to 1/5 scale, all measurements were multiplied by 5 in order to be representative of actual conditions. The test assembly is shown in Fig. 6.1, and the details of a typical hexagonal plate are shown in Fig. 6.2. The numbering schedule for the plates and the directions in which the plates were moved are shown in Fig. 6.3.

The hot position of the plates was simulated by removing the pins that positioned the outer plates to the base plate and placing them in holes that are located 0.200 in. radially outward from the cold position holes. The 0.200-in. location was established by taking one-fifth of the expected radial core barrel expansion of 1.0 in. The outer core support blocks were keyed to the core barrel and would move radially outward as the core barrel expanded as a result of thermal growth.

The instrument used to determine the movements was a Bausch & Lomb Stereozoom Microscope Model No. SVB-73 with a 30X magnification. The reticle eyepiece disk used was a Bausch & Lomb, Catalog No. 31-16-08. Each least-division value on the reticle is 0.001 in. The light source used with the test was a Bausch & Lomb, Catalog No. 31-33-53. The setup used for the measurements is shown in Fig. 6.4.

5. TEST PROGRAM AND RESULTS

The tests were performed in a clean room, with the assembly set on a precision level table.

The total movement of the center plate was determined in the x and y directions in both the simulated cold and hot position. The adjacent six plates were held in their nominal positions. A magnifying glass was used to assure that the plates had not moved at the time the readings were taken. The total movement was found to be 0.012 in. in both the x and y directions in the cold condition and 0.010 in. in both the x and y directions in the hot condition (see Table 6.1). These measurements amount to 0.060 in. and 0.050 in., respectively, for the full-scale setup.

The rotational movement was so small as to not be measurable.

The total movements of all the plates located on the x and y axes were determined in both the simulated cold and hot positions. These "earthquake" movements were simulated by pushing the matrix of plates to the desired direction (left, right, up, or down) and measuring with the microscope the amount of displacement from the nominal cold position that had been scribed on the base plate. These movements are shown in Table 6.1. It was found that the six trapezoidal-shaped plates could be rotated so that the outer corners came in contact with the adjacent outer plates.

The total distance required to radially displace the outer plates to the point of disengaging the keys and keyways of all the plates was measured as 1.447 in.; on the full-scale structure this distance would be approximately 7-1/4 in.

6. CONCLUSIONS AND OBSERVATIONS

It was concluded that due to the contact between the outer support plates it would be necessary to incorporate keys and keyways on the sides of the six trapezoidal-shaped blocks with corresponding keyways and keys on the adjacent outer support blocks.

The entire matrix of the hexagonal core support plates interacted in a satisfactory manner during movement from the cold to the hot position and also during simulated earthquake conditions. The center plate exhibited the greatest amount of movement as a single plate. The greatest amount of differential movement between any two adjacent plates occurred between the outer plates and the adjacent inner ring of hexagonal plates.

The outer support plates required a radial displacement of 1.447 in. to disengage all the plates, which occurred simultaneously. Translated into full scale, this means that the core barrel would have to expand radially a distance of approximately 7-1/4 in. adjacent to the graphite support blocks in order to permit the blocks to become disengaged. There is no credible mechanism that would cause such an expansion of the core barrel.

Table 6.1

PLATE MOVEMENT OBSERVATIONS*

A. Movement of Center Plate Only:

Cold

"X" Direction (Total Movement) = 0.012 in.

"Y" Direction (Total Movement) = 0.012 in.

Rotation not measurable.

Hot

"X" Direction (Total Movement) = 0.010 in.

"Y" Direction (Total Movement) = 0.010 in.

Rotation not measurable.

Table 6.1 (continued)

B.1. Total Movement for "X" Axis "Earthquake"

a. Cold

Plate No.	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇	X ₈	X ₉
Plates Moved Left	+0.004	-.007	-.026	-.033	-.042	-.039	-.027	-.007	+0.002
Plates Moved Right	+0.004	+0.023	+0.040	+0.052	+0.055	+0.060	+0.045	+0.028	+0.002
Total Movement	.000	.030	.066	.085	.097	.099	.072	.035	.000

	Plate No.	Y ₁	Y ₂	Y ₃	Y ₄	Y ₅	Y ₆	Y ₇	Y ₈	Y ₉	Y ₁₀	Y ₁₁	Y ₁₂	Y ₁₃
"Y" Direction Displacement	Plates Moved Left	.000	-.005	+0.005	-.002	-.005	.000	.000	.000	.000	.000	+0.002	+0.002	+0.006
	Plates Moved Right	.000	-.005	-.005	-.002	-.002	-.005	-.002	-.002	-.002	-.003	.000	+0.002	+0.005
	Total Movement	.000	.000	.010	.000	.003	.005	.002	.002	.002	.003	.002	.000	.001
"X" Direction Displacement	Plates Moved Left	-.020	-.034	-.035	-.040	-.040	-.042	-.043	-.035	-.037	-.035	-.030	-.030	-.010
	Plates Moved Right	+0.019	+0.050	+0.053	+0.055	+0.060	+0.055	+0.060	+0.056	+0.060	+0.057	+0.051	+0.052	+0.030
	Total Movement	.039	.084	.088	.095	.100	.097	.103	.091	.097	.092	.081	.082	.040

- *NOTES: 1. See Fig. 6.3 for position of numbered plates.
 2. "+" indicates displacement to the right (or up) from the nominal position.
 3. "-" indicates displacement to the left (or down) from the nominal position.

Table 6.1 (continued)

B.2. Total Movement for "Y" Axis "Earthquake"

a. Cold

Plate No.	Y ₁	Y ₂	Y ₃	Y ₄	Y ₅	Y ₆	Y ₇	Y ₈	Y ₉	Y ₁₀	Y ₁₁	Y ₁₂	Y ₁₃
Plates Moved Up	.000	+.025	+.023	+.040	+.041	+.039	+.047	+.043	+.040	+.037	+.023	+.022	+.007
Plates Moved Down	.000	-.024	-.024	-.042	-.050	-.051	-.050	-.046	-.047	-.038	-.022	-.021	+.007
Total Movement	.000	.049	.047	.082	.091	.090	.097	.089	.087	.075	.045	.043	.000

	Plate No.	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇	X ₈	X ₉
"Y" Direction Displace- ment	Plates Moved Up	-.015	+.035	+.039	+.042	+.045	+.040	+.031	+.002	-.005
	Plates Moved Down	+.007	-.032	-.042	-.050	-.050	-.045	-.037	-.030	+.015
	Total Movement	.022	.067	.081	.092	.095	.085	.068	.032	.020
"X" Direction Displace- ment	Plates Moved Up	.000	.000	.000	+.005	+.010	+.008	+.006	+.005	+.002
	Plates Moved Down	+.002	+.005	+.007	+.012	+.012	+.012	+.005	+.007	+.002
	Total Movement	.002	.005	.007	.007	.002	.004	.001	.002	.000

Table 6.1 (continued)

B.2.

b. Hot

	Plate No.	Y ₁	Y ₂	Y ₃	Y ₄	Y ₅	Y ₆	Y ₇	Y ₈	Y ₉	Y ₁₀	Y ₁₁	Y ₁₂	Y ₁₃
"Y" Direction Displace- ment	Plates Moved Up	+.205	+.175	+.165	+.130	+.095	+.092	+.055	+.010	+.008	+.045	-.107	-.105	-.200
	Plates Moved Down	+.205	+.114	+.117	+.047	-.010	-.007	-.050	-.097	-.095	-.150	-.180	-.182	-.200
	Total Movement	.000	.061	.048	.083	.085	.099	.105	.107	.103	.105	.073	.077	.000
"X" Direction Displace- ment	Plates Moved Up	+.012	+.007	+.062	+.027	-.002	+.050	+.015	-.015	+.050	+.014	-.022	+.055	+.014
	Plates Moved Down	.000	-.035	+.048	+.005	-.022	+.035	.000	-.020	+.030	+.007	-.010	+.032	.000
	Total Movement	.012	.042	.014	.022	.020	.015	.015	.005	.020	.007	.012	.023	.014

	Plate No.	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇	X ₈	X ₉
"Y" Direction Displace- ment	Plates Moved Up	-.022	+.060	+.054	+.045	+.055	+.045	+.045	+.052	-.010
	Plates Moved Down	+.017	-.062	-.057	-.057	-.050	-.045	-.045	-.050	-.020
	Total Movement	.039	.122	.111	.102	.105	.090	.090	.102	.010
"X" Direction Displace- ment	Plates Moved Up	-.205	-.178	-.105	-.042	+.015	+.085	+.145	+.190	+.205
	Plates Moved Down	-.205	-.170	-.110	-.053	.000	+.062	+.115	+.175	+.205
	Total Movement	.000	.008	.005	.011	.015	.023	.030	.015	.000

Table 6.1 (continued)

B.1.

b. Hot

Plate No.	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇	X ₈	X ₉
Plates Moved Left	-.205	-.191	-.154	-.105	-.057	.000	+.070	+.162	+.208
Plates Moved Right	-.210	-.165	-.070	.000	+.065	+.120	+.175	+.205	+.212
Total Movement	.005	.026	.084	.105	.122	.120	.105	.043	.004

	Plate No.	Y ₁	Y ₂	Y ₃	Y ₄	Y ₅	Y ₆	Y ₇	Y ₈	Y ₉	Y ₁₀	Y ₁₁	Y ₁₂	Y ₁₃
"Y" Direction Displace- ment	Plates Moved Left	+.210	+.155	+.155	+.102	+.042	+.047	.000	-.047	-.050	-.095	-.155	-.157	-.190
	Plates Moved Right	+.210	+.145	+.155	+.095	+.045	+.041	.000	-.049	-.050	-.095	-.150	-.143	-.200
	Total Movement	.000	.010	.000	.007	.003	.006	.000	.002	.000	.000	.005	.014	.010
"X" Direction Displace- ment	Plates Moved Left	-.032	-.080	-.024	-.055	-.082	-.025	-.057	-.077	-.017	-.040	-.065	-.015	-.018
	Plates Moved Right	+.030	+.034	+.095	+.062	+.032	+.091	+.065	+.032	+.102	+.065	+.037	+.095	+.035
	Total Movement	.062	.114	.119	.117	.114	.116	.122	.109	.119	.105	.102	.110	.053

Fig. 6.1. Test assembly for lateral displacement test

Fig. 6.2. Typical hexagonal plate

Fig. 6.3. Numbering schedule for plates and directions of movements

Fig. 6.4. Setup used for test measurements