GENERAL ATOMIC

GA-A13539
UC-77

REFLECTOR DOWEL STRENGTH TEST FORT ST. VRAIN

by
D. W. DOLL

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Prepared under
Contract E(04-3)-633
for the San Francisco Operations Office
U. S. Energy Research and Development Administration

GENERAL ATOMIC PROJECT 1900

DATE PUBLISHED: OCTOBER 31, 1975

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1. SUMMARY

The strength of the 44.45 mm (1.75 in.) diameter Fort St. Vrain (FSV) reflector dowel for loads directed radially inward toward the center of the element was measured. For a statically applied load, the strength exceeded 5783 N (1300 lb) in direct shear. This strength remained after load cycling 100 times to 4448 N (1000 lb), 10 times to 4893 N (1100 lb), 10 times to 5338 N (1200 lb), and two times to 5783 N (1300 lb). Typically, the deflection to ultimate failure was ~ 1.0 mm (0.04 in.). At about 3316 N (750 lb) and 0.20 mm (0.008 in.) deflection, one of the webs between the dowel and a coolant hole cracked, apparently redistributing the load. No further failure occurred up to the ultimate load of 5783+ N (1300+ lb).

2. INTRODUCTION

When the orifice flow valve is in the near fully closed position and the reactor is at maximum power, the pressure drop across the valve and plenum can reach 72,400 pascals (10.5 psi) (Ref. 1). This pressure difference surrounds the entire region and tends to hold the columns within a region together. Because of thermal expansion differences between graphite and metal, the surfaces of the reflector and plenum elements are not in direct contact throughout the full operating cycle from startup through operation to refueling. This allows forces to build up on the dowels as the pressure tends to force the columns inward. The geometry of the threaded connection between the dowel and the reflector element is complex and difficult to model analytically. A strength test was performed to establish the load capacity of this feature.

Tests of dowel strength were performed on the large [44.45 mm (1.75 in.) diameter] dowels in FSV fuel blocks (Ref. 2). The results showed failure loads that ranged from 4252 N (956 lb) to 5832 N (1311 lb). In each case failure occurred in the threaded socket. The presence of the fuel holes around the dowel reduces the amount of supporting material for shear loads. For this reason, the results of the fuel element tests are not applicable to a reflector element that does not have the fuel holes. The tests reported herein are aimed at measuring the dowel strength of a reflector element with coolant holes.

3. TEST APPARATUS

The test apparatus consisted of dowels cemented into sections of a fuel block, a fixture for holding the sections, a simulated socket, and a tensile testing machine.

3.1. DOWEL TEST SAMPLES

Three dowel test samples were assembled. Each consisted of a 254.0 mm (10 in.) thick section of a standard fuel block with one 44.45 mm (1.75 in.) diameter dowel cemented into a threaded socket. The sections were removed from the undamaged end of a rejected production fuel block. Threaded sockets were machined into the exposed surfaces in the same manner and in the same location as the original single dowel (see Fig. 1). Standard production dowels as shown in Fig. 2 were used.

In order to simulate a reflector block using a fuel block, the fuel holes surrounding the dowel were plugged with standard fuel hole plugs stacked one on another and cemented (Fig. 3). After plugging the holes, the dowels were installed. Curing was done in the conventional manner as specified in the fuel specifications.

3.2. Test Fixture

The test fixture consisted of a clamping arrangement that held the block section and a frame with a dowel socket attached. Two types of socket were used: one socket was machined from 6061-T6 aluminum and the other from type H-451 graphite. The socket inside diameter was 45.47 ± 0.13 mm (1.79 ± 0.005 in.).

Fig. 1. Standard fuel element hole layout and dowel installation detail

Fig. 2. Detail of large dowel for FSV fuel elements

Fig. 3. Dowel installation

The clamping frame was attached to the base of a Baldwin universal testing machine [type SO 640-2632; 266,893 N (60,000 lb) capacity] and the frame holding the dowel was attached to the crosshead. The deflections were measured on a Baldwin extensometer (type PD-1-M) and recorded on a Microformer recorder, which read out load versus deflection directly (without chart speed conversion). The assembly is shown in Fig. 4.

HT98815

HT98813

Fig. 4. Test apparatus

4. TEST PROCEDURE

Three assembled dowels were tested to their ultimate strength in direct shear. A crosshead speed of ~ 0.76 mm (0.003 in.)/min was maintained for all tests (control was hand operated). The first sample was loaded using a graphite socket in order to simulate a reflector-to-reflector connection. The second was loaded using the metal socket to simulate the connection between the plenum and the reflector elements. In both cases the load was applied until evidence of failure was observed.

The third sample was mounted in the same manner as the second sample using the metal socket. The load was applied up to 4448 N (1000 lb) and released for 50 cycles. The sample was removed, inspected, reinstalled in the fixture, and loaded 50 more times up to 4448 N (1000 lb) for a total of 100 cycles. The load was increased by 445 N (100 lb) increments and cycled to zero 10 times at each load. This was repeated until failure. The sample was then removed and inspected.

5. RESULTS

In this series of tests the ultimate strength of the large 44.45 mm (1.75 in.) diameter dowels used in upper reflector elements was measured. The loads applied were in direct shear perpendicular to the dowel axis and toward the center of the block. The ultimate loads are summarized in Table 1 and the load at the first indication of failure is summarized in Table 2. The load on one sample was cycled to investigate the possible effects of fatigue.

5.1. GRAPHITE SOCKET - SAMPLE 1

The ultimate strength measured for the dowel when loaded in direct shear using a graphite socket was 5960 N (1340 lb); the total deflection was 1.04 mm (0.041 in.). At about 3780 N (850 lb), the deflection constant (load/deflection) changed from 7175 N/m (63,500 lb/in.) to 4960 N/m (43,900 lb/in.). The deflection at this point was 0.41 mm (0.016 in.). After the abrupt change in slope, the load continued until failure. Some flattening was noted near the ultimate load, but this is attributable to some load redistribution.

The dowel assembly was removed and inspected. Figure 5 shows the dowel and surrounding webs of the element. Failure occurred between the dowel and the adjacent coolant holes as the dowel appeared to rotate in the threaded socket holding it. The additional cracking radiating out to the fuel holes was the result of excessive deflection that was permitted after the failure load was reached.

TABLE 1
LOAD AND DEFLECTION AT FAILURE

Sample No.	Ultimate Strength [N (lb)]	Total Deflection [mm (in.)]
1	5960 (1340)	1.04 (0.041)
2	6120 (1375)	0.97 (0.038)
3	5780 (1300)	Not determined

TABLE 2
LOAD AND DEFLECTION AT FIRST INDICATION OF FAILURE

Sample No.	Load at First Failure [N (lb)]	Deflection [mm (in.)]
1	3780 (850)	0.41 (0.016)
2	3670 (825)	0.28 (0.011)
3	3220 (725)	0.28 (0.011)

75HT1216

Fig. 5. Sample No. 1 after failure

5.2. Metal Socket - Sample 2

The ultimate strength measured for a dowel and a metal socket was 6120 N (1375 lb) (in shear as for sample 1); the total deflection was 0.965 mm (0.038 in.). As in the test of sample 1, a change in the deflection constant was observed. This occurred at about 3670 N (825 lb) and 0.28 mm (0.011 in.) deflection and changed from about 15.9 MN/m (90,600 lb/in.) to about 5.08 MN/m (29,000 lb/in.). In terms of a system of a dowel and socket, the actual constant would be about half this amount.*

In order to establish averages of the deflection constants, several samples would have been required. Obtaining these data was not the purpose of this test. Therefore, the repeated tests were not conducted.

Loading was continued until failure was evident and then released. The failure mode was similar to that for sample 1, i.e., cracks propagating outward from the dowel socket to surrounding coolant holes (see Fig. 6). The dowel remained relatively undamaged and appeared to rotate in the threaded socket.

5.3. Metal Socket, Cycled Load - Sample 3

A dowel made the same as samples 1 and 2 was first loaded up to 4450 N (1000 lb) and released 100 times. As in the tests with the first two samples, during the first cycle an abrupt change in the load was observed. At ~3220 N (725 lb) load and 0.18 mm (0.007 in.) deflection, the load dropped to 2890 N (650 lb) and then continued to 4450 N (1000 lb) at a different deflection constant. The constant started at 12.7 MN/m (72,500 lb/in.)

* The dowel and socket can be compared to two compression springs working in series. The equivalent spring in this case is described as: $K_e = K_1 K_2 / (K_1 + K_2)$, where K_1 and K_2 are spring constants for the dowel and socket, respectively. A graphite dowel in a graphite socket would make $K_1 \approx K_2$ and, therefore, $K_e = K_1 / 2$. For a graphite dowel in a metal socket $K_e \gg K_1$, which gives $K_e \approx K_1$, the dowel constant.

75HT1219

Fig. 6. Sample No. 2 after failure

and changed to 8.06 MN/m (46,000 lb/in.). On the second and subsequent cycles, the constant remained approximately 11.6 MN/m (66,000 lb/in.).

After 50 cycles the sample was removed and inspected. The web on one side of the dowel was cracked (see Fig. 7). No overall displacement was evident, nor were any other webs cracked.

The sample was returned to the test fixture and loaded to 4450 N (1000 lb) for 50 more cycles. No abrupt changes in the load-deflection curves were noted. The deflection constant gradually decreased from 11.6 MN/m (66,000 lb/in.) to 9.6 MN/m (55,000 lb/in.) over the 99 cycles following the initial change. Some nonlinearity appeared to develop, which probably was due to deflection of the frame.

After the 100 cycles at 4450 N (1000 lb), the load was increased to 4890 N (1100 lb) and cycled 10 times. The deflection constant was 8.9 MN/m (51,000 lb/in.), which is nearly the same as at the end of the 100 cycles. No abrupt changes were observed in the load traces.

The load was increased to 5340 N (1200 lb) and cycled 10 more times. For the first cycle, the deflection constant was $\sim$ 8.6 MN/m (49,000 lb/in.). By the tenth cycle, the constant had decreased to 7.1 MN/m (44,000 lb/in.).

At 5780 N (1300 lb) load, one full cycle was made. Failure occurred on the second cycle. The deflection constant on this cycle was 7.0 MN/m (40,000 lb/in.), which showed a further reduction from the tenth cycle at 5340 N (1200 lb). The sample was removed and inspected. Failure was similar to that of samples 1 and 2, as can be seen from Fig. 8.

Fig. 7. Top view of dowel showing location of initial cracked web

75HT1217

Fig. 8. Sample No. 3 after complete failure

6. CONCLUSIONS

Although the test was limited to three samples and some allowances had to be made for the block having fuel holes, several conclusions can be drawn from the data:

1. The ultimate shear strength of a dowel in a reflector block is greater than 5780 N (1300 lb). This is somewhat higher than the strength of a dowel in a fuel block, perhaps by 900 N (200 lb) (Ref. 2). The additional support in the fuel holes, which was simulated with plugs, is probably the reason.
2. The material used for the socket (metal or graphite) affects the deflection constant somewhat but not the ultimate strength. This implies that the strength of the connection between a plenum and the top reflector is not significantly different than that between reflector elements.
3. The ultimate strength is not greatly diminished by load cycling. Up to 4450 N (1000 lb) or 75% of the ultimate, there appears to be little change in the load-deflection behavior. Above this amount, however, the dowel seems to become softer (lower deflection rate).
4. At a shear load of between 3110 N (700 lb) and 3780 N (850 lb), one of the webs cracks and the deflection rate changes. This occurs at about 0.18 mm (0.007 in.) to

0.25 mm (0.01 in.) deflection. The abrupt change in the load-deflection behavior has been observed in all previous dowel shear tests (Ref. 3).

The cracked web does not seem to pose a serious problem. It does not expose fuel or block coolant flow. However, if the load is to be limited to that at which the first crack develops, the capacity of the dowel/socket will have to be revised downward by nearly 40%.

REFERENCES

1. Final Safety Analysis Report, Fort St. Vrain Nuclear Generating Station, Section 4.4.
2. "Public Service Company of Colorado 330-MW(e) High-Temperature Gas-Cooled Reactor Research and Development Program Quarterly Report for Period Ending June 30, 1966," USAEC Report GA-7314, General Atomic, Division of General Dynamics, September 30, 1966, Table 3.1., page 29.
3. Stenger, D. C., "2000/3000 MW(t) Hexagonal Element Dowel/Socket Strength Test Report," General Atomic Company unpublished data.