Corps of Engineers, USAE Waterways Experiment Station	Petrographic Report	Structures Laboratory P. O. Box 631 Vicksburg, Mississippi
Project Examination of Concrete Samples from Wolf Creek Reactor Containment Building Base Mat, Kansas		Date 2 July 1979 ADB

Background

1. The design strength at 90-days age of the concrete in the base mat portion of the Wolf Creek Plant is 5000 psi. When it became apparent that this requirement was not met an investigation was started to determine the cause. The low strength cylinders were tested late in 1977. The Construction Technology Laboratories of the Portland Cement Association (PCA) examined fragments from some of these cylinders during 1978 and the early part of 1979 and issued several reports. Those dated 27 February and 25 April 1979 were studied as part of the present investigation.[1, 2] In general, their conclusion was that they could find no significant differences between the concrete from the low and normal strength cylinders and that the low strengths were probably due to factors other than the quality of the concrete.

2. By Interagency Agreement No. NRC-03-79-266 received 20 June 1979 the U. S. Nuclear Regulatory Commission (NRC) requested the U. S. Army Engineer Waterways Experiment Station (WES) to make a petrographic examination of concrete thin sections prepared by the PCA and to report the results. Fragments of cylinders were also examined.

Samples

3. On 19 June 1979 Messrs. D. H. Campbell of the PCA and C. R. Oberg of the NRC delivered 41 thin sections to WES for examination. A list of those sections as identified by the PCA is shown below:

PCA Slide No.	Cylinder No.	Age, days	Compressive Strength, psi
1	6503	90	— 4190
2	6350	90	6640
3	6444	90	4640
4	6784	90	4780
5	6596	90	4280
6	6546	90	3270
7	6606	90	4340
8	6767	90	5850
9	6538	90	5380
10	6599	90	?
11	6540	90	4329
12	6659	90	5390
13	6785	90	4830
14	6671	90	4370
15	6551	90	4290
16	6444-II	90	4640

(Continued)

PCA Slide No.	Cylinder No.	Age, days	Compressive Strength, psi
17	6794	28	4860
18	6771	28	5410
19	6752	28	4460
20	6561	28	5680
21	6700	28	4790
22	6735	28	4190
23	6718	28	4320
24	6717	28	4990
25	6651	28	5130
26	6640	28	4530
27	6586	28	5200
28	6583	7	4000
29	6543	28	5570
30	6531	28	5020
31	6490	28	4190
32	6424	28	4270
33	6509	?	?
34	6534	90	4660
35	6557	90	4180
36	6563	90	4620
37	6587	90	4670
38	6672	90	5230
39	6713	90	4630
40	6737	90	4520
41	6714	90	4370

In addition, on 27 June 1979 fragments of four broken 90-day cylinders were received at WES for examination. These cylinder fragments are identified below:

Cylinder No.	Compressive Strength at 90-day Age	No. of Corresponding PCA Thin Section or Slide
6546	3270	6
6557	4180	35
6659	5390	12
6767	5850	8

Test procedure

4. Dr. D. H. Campbell of the Construction Technology Laboratories of the PCA is the petrographer who made the petrographic examination at the PCA.[1, 2] He spent 19 June and part of 20 June 1979 at WES as an official observer and to discuss his thin sections. Part of this time was used to verify that there was accord on recognition of the various phases one would encounter in thin sections of concrete.

5. It is always desirable to make a petrographic examination of good or normal concrete in comparison with concrete of questionable quality.[3] In this case cylinders of low and of normal strengths were available as both thin sections and concrete fragments; both were used to make comparative examinations. The pairs of thin sections that were examined are shown below:

PCA Thin Section No.	Cylinder No.	Age of Breaking, days	Compressive Strength, psi
28	6583	7	4000
18	6771	28	5410
19	6752	28	4460
20	6561	28	5680
6	6546	90	3270
2	6350	90	6640
7	6606	90	4340
12	6659	90	5390
1	6508	90	4190
38	6672	90	5230

6. All of the 41 thin sections were examined with a polarizing microscope.

7. Portions of the four concrete cylinders were examined visually and with a stereomicroscope. The bulk of this examination was made by examining fresh fracture surfaces at 20X. The intent was to look for evidence of alkali-silica reaction or any other abnormal features. Fragments of microscopic white material believed to be alkali-silica gel were removed from pieces of cylinders 6659 and 6546 with a dissecting needle and examined with a polarizing microscope as powder immersion mounts in a liquid with a refractive index of 1.544.

8. A sawed surface of low strength cylinder 6546 and of normal strength cylinder 6767 was ground smooth and examined with the stereomicroscope.

9. Another sawed surface of the same two cylinders was etched for 30 seconds in dilute hydrochloric acid and then examined visually and with the stereomicroscope for possible rims on the carbonate coarse aggregate particles.

10. Representative portions of mortar from low-strength cylinder 6546 and normal-strength cylinder 6659 were used to prepare cement paste concentrates which were then examined with an X-ray diffractometer using nickel-filtered copper radiation. The cement paste was prepared by slight crushing of mortar followed by passing over a 150-μm (No. 100) sieve to concentrate paste in the smaller size material. This material was then ground to pass a 45-μm (No. 325) sieve before it was X-rayed.

Results

11. The appearance of the concrete in the fragments of the four cylinders (6546, 6557, 6659, 6767) was similar. The paste was gray with a slight glimmering vitreous luster rather than chalky or dull, which is often indicative of concrete in poor condition.[4]

12. There was no evidence of abnormal features such as detrimental alkali-silica or alkali-carbonate rock reaction in the concrete fragments. Microscopic amounts of white, porcellanous gel-like material were observed in one void in cylinder 6546, in two voids in cylinder 6557, and in two voids in cylinder 6659. This material was so small that it usually was not detectable by the unaided eye. Examination of some of this material from cylinders 6546 and 6659 in powder immersion mounts with a polarizing microscope showed it to be largely amorphous with a refractive index below 1.544. This material is alkali-silica gel. Its presence indicates that there was a small amount of alkali-silica reaction in both the low and normal strength concrete. The likelihood of detrimental alkali-silica or alkali-carbonate rock reaction occurring is considered negligible since low-alkali portland cement was used in this concrete.* This level of indication of alkali-silica reaction is regarded as normal for any concrete made using aggregates containing silica stored in water for ages of as long as 90 days.

13. Neither the smoothed nor the acid-etched surfaces of concrete from cylinders 6546 and 6767 indicated any abnormality with either sample.

14. Thin section examinations. The examination of the 5 pairs of thin sections representing low- and normal-strength concrete did not reveal significant differences nor did the examination of the other 31 sections of concrete reveal any significant features that would explain the low strengths of some cylinders.

15. The typical thin section indicated a dense, well consolidated concrete made with a carbonate coarse aggregate, a natural sand, and portland cement. No admixtures such as fly ash were recognized. The paste was a mixture of calcium silicate hydrate, calcium hydroxide, and unhydrated cement grains that seemed to be appropriate in amount. The calcium silicate hydrate is not specifically recognizable by examination of thin sections of concrete although its presence is readily inferred. The comparative examinations did not suggest different amounts of cement or of water between the different samples. Some of the thin sections were carbonated, or small areas were missing, or the epoxy resin was contaminated with small crystals that crystallized from the resin. These defects are common, are not

---

* Information furnished by Mr. C. Oberg of the NRC.

considered significant, and did not occur preferentially with the lower strength concrete. No reacted sand grains or opal-bearing sand grains were recognized in these thin sections.

16. The comparison of the X-ray diffraction patterns of concentrated cement paste from low strength cylinder 6546 and normal strength cylinder 6659 indicated general similarity.

Discussion

17. K. Mather[3] has described a similar situation involving low strength concrete cylinders. She pointed out that the pertinent questions in such a case are:

a. What processes could cause the observed results, in this case low strength?

b. What evidence would these processes leave in the concrete? These problems include excessive air content, too little cement, too much water, and early freezing.

18. While there could be other processes these illustrate the logic to follow. In the present case freezing is not an applicable consideration since the cylinders should all have been protected before testing. In addition, early freezing would leave ice crystal imprints which were not found by the present examination. Excessive air content, too little cement, or excessive water have been ruled out by the PCA data.[1, 2] However, the present examination would have found such conditions if they were present.

19. Thus, the comparative examination of the five pairs of thin sections representing low- and normal-strength concrete and also the examination of concrete fragments of low- and normal-strength concrete by eye and with a stereomicroscope was specifically designed to detect such differences as described or other differences. When this type of comparative examination of what should be the same concrete separated by strengths of 3270 psi (cylinder 6546) and 6640 psi (cylinder 6650) at the same age does not reveal a significant difference this strongly suggests there is no real difference between the concretes and that the problem is not with the concrete per se.

Conclusions

20. Since comparative examination of concrete thin sections and of concrete fragments representing low- and normal-strength concrete did not reveal significant differences and since the texture and structure is typical of relatively high-strength concrete, it is concluded that the indicated low strengths are invalid and that all of this concrete is of comparable quality approximately as indicated by the higher strength examples. This suggests that the indicated low strengths were probably due to one or more failures to follow current standards of good practice in testing.

21. Since the concrete quality appears to be as intended the concrete should provide the intended service.

22. These findings are in agreement with those reported by the PCA Construction Technology Laboratories.[1, 2]

REFERENCES

1. PCA Construction Technology Laboratories petrographic report dated 27 February 1979, project CT-0407.

2. Ibid, 25 April 1979.

3. Mather, K., "Petrographic Examination," in Significance of Tests and Properties of Concrete and Concrete-Making Materials, ASTM STP No. 169-B, pp 132-145, 1978.

4. ASTM C 856-77, "Standard Recommended Practice for Petrographic Examination of Hardened Concrete," Note to Table 2, Part 14.