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RICHLAND, WASHINGTON HANFORD ATOMIC PRODUCTS OPERATION
May 5, 1955

To File:

USE OF HIGH-DENSITY PREPACKED CONCRETE
IN REACTOR CONSTRUCTION

The attached unclassified article was prepared for publication in Civil Engineering. It describes construction techniques and equipment used in processing, prepacking, and grouting heavy aggregates used in the construction of the K-reactors. This material supplements technical data presented in the following documents:

- HW-32968 - "Analysis of Control Data For High Density Concrete Placed at 105-K"
- HW-33951 - "An Evaluation of Costs For Constructing High Density Concrete Shields at 105-K"
- HW-35881 - "The Development and Construction of Concrete Biological Shields For the New Production Reactors at Hanford".

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App 4-3-57

By L. McCarmick-4-23-57

USE OF HIGH-DENSITY PREPACKED CONCRETE IN REACTOR CONSTRUCTION

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Introduction

The erection of a concrete biological shield at Hanford, Washington presented several unique construction problems. This shield encloses the radioactive core of a reactor and is designed to protect operating personnel from the harmful effects of pile neutrons and associated gamma radiations. Permanent steel forms were erected to close tolerances around the reactor and filled with high density concrete by means of the prepacked method. Prefabricated sections of the steel forms, or crates, were five to eight feet deep and weighed up to 18 tons each. During erection, the process holes through successive crates were kept within 0.012 in. of their nominal distances. The left side, top shield, and right side of this biological shield were constructed integrally to form a rigid frame. The front and rear crates, which contain numerous process holes, were keyed into the side and top shields so as to permit relative expansions of shield components and to provide for their lateral support. These massive steel and concrete walls provide considerable resistance to blast and earthquake forces, support numerous process facilities, contain pile gas, as well as protect personnel from nuclear radiations.

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High Density Concrete

Three types of high density concrete were developed especially for this job: two prepacked concretes and one conventional concrete. They contain an optimum amount of retained water in order to improve their shielding ability for attenuating pile neutrons. Limonite-goethite ore, a hydrous iron ore, was used both as coarse and fine aggregate because of its high content of crystallized water and its high density. In critical sections of the biological shield, coarse aggregate consisting of steel punchings and limonite-goethite ore were placed in the forms and compacted to the specified unit weight. Magnetite ore, an iron oxide of high density, was used instead of expensive steel aggregate in certain sections of the shield where high density was not required. A special heavy grout was then pumped into the bottom of the forms under a two-foot head of water until the void spaces between pieces of heavy aggregate were filled with grout.

The prepacked method was selected for placing high density concrete in order to minimize segregation of coarse aggregates and to maintain close control of density and composition. Due to the inherent difficulties of placing concrete containing steel punchings around embedded tubes and in restricted areas, the prepacked method offered greater assurance of obtaining the desired uniformity and density than any other construction method. However, care in selecting and processing heavy aggregates, close control of aggregate blending and compaction, and proper supervision of grout mixing and pumping all contributed to the successful completion of the work.

Problems of special interest and procedures used on this job are described briefly below. Construction of the shields was performed by

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Kaiser Engineers, a division of Henry J. Kaiser Company, under contract with the Atomic Energy Commission. High density concrete was placed under the supervision of the Prepakt Concrete Company, a sub-contractor of Kaiser Engineers. The General Electric Company was responsible for design and the technical direction of reactor construction. The Hanford Atomic Products Operation is operated by the General Electric Company for the Atomic Energy Commission.

Procurement of Heavy Aggregates

Descriptive data on heavy aggregates are summarized in Table 1. The steel, limonite, and magnetite aggregates procured for this job were some of the best obtainable. Limonite-goethite ore, due to its high water and iron content, is an excellent material for slowing down and thermalizing neutrons. Magnetite (Fe_3O_4) was used because it was the heaviest and cheapest type of aggregate available at Hanford. Care was taken in selecting sources of heavy aggregates in order to obtain sound aggregates suitable for use in concrete. It is noted that the limonite-goethite ore used on this job is referred to below as limonite. Actually, the goethite ore ($\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$) produced better concrete aggregate than did limonite ($2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$). Limonite is essentially an amorphous form of goethite and often contains a higher amount of fine, weak, or porous material.

No difficulty was experienced in obtaining approximately 3800 tons of graded coarse magnetite; however, certain problems arose during the procurement of dense limonite due to its limited availability. Western limonites usually occur in small sporadic deposits and are lower in density than ore from Michigan. However, some of these western limonites contain 20 percent more fixed water of crystallization than does the Michi-

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gan ore. Fifty-seven hundred tons of limonite ore were obtained from a western vendor before his deposit was depleted. This mine-run ore contained substantial amounts of fines and porous material as well as dense limonite, and required careful processing at Hanford in order to produce suitable 3/8 to 1-inch coarse aggregate for use in prepacked concrete. The grout sand processed from this limonite produced excellent grout having a density of 147 lb per cu ft.

When it was apparent that sufficient tonnage of coarse aggregate could not be obtained from the above limonite source, 2000 tons of limonite were obtained from a mine in Michigan. The ore was screened at the source, and only the plus 3/4, minus 8-inch material shipped to Hanford. This limonite was then crushed down to produce 1/2 to 1-1/2 inch coarse aggregate. By not shipping the unwanted fine ore to Hanford, an estimated \$60,000 were saved in freight and limonite charges.

Steel aggregate was shipped to Hanford from around Denver and San Francisco at a cost of about \$20 per ton, making the total cost of steel aggregate at \$140 per ton, FOB Hanford. It consisted primarily of sheared bar stock and some punchings, 1/2 to 1 inch and 1/2 to 1-1/2 inches in size. When blended with 1-inch maximum limonite, the smaller size of steel aggregate was used for prepacking restricted areas of the shield. In general, pieces of steel aggregate were cubical in shape, clean, and relatively free of thin or elongated pieces of steel. Steel aggregate, as well as limonite and magnetite, was obtained on a competitive bid basis.

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Aggregate Processing Plant

Limonite aggregates were crushed and processed in the plant shown in Figure 1 by the Lake City Gravel and Materials Company, a subcontractor of Kaiser Engineers. In the background are shown the feeder bin, primary jaw crusher and roll crusher. In the foreground are a three deck screening plant, cone crusher and conveyor systems. Mine-run limonite ore was transported from the rear stockpile pile and dumped into the feeder bin by means of a front-end loader. After passing through the roll crusher, material finer than the No. 6 screen was removed and used at a later date for producing a reserve supply of grout sand. Crushed limonite, $3/8$ to 1-inch in size, was stockpiled at the right of the plant. The long conveyor belt and scaffolding were erected to permit hand removal of undesirable pieces of coarse aggregate. The magnet, supported over the top of the conveyor belt, was being used when Figure 1 was taken to remove extraneous pieces of steel punchings which had been inadvertently mixed with the limonite.

Limonite chips, which passed the $3/8$ inch screen after going through the cone crusher, were processed into grout sand in the plant shown in Figure 2. Grout sand made from these chips had a bulk specific gravity of 3.71 as compared to 3.52 for the reserve sand made later using fines from the primary crusher. Lake City used both a hammer mill and a ball mill to process sand. These pieces of equipment are not visible in Figure 2; however, the loader, double compartment bin and conveyor are shown in action. Limonite grout sand was weighed and sacked in 60 pound bags and transported on pallets. Processed coarse aggregates were stockpiled on concrete slabs, while the bagged

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sand was stored in sheds until used in order to prevent their contamination by foreign materials.

Aggregate Blending

Specifications required that coarse aggregates consisting of steel aggregate and limonite (or magnetite and limonite) be blended together, mixed uniformly and placed in the forms without appreciable amounts of segregation and aggregate breakage. The plant developed by Kaiser Engineers for washing and blending these aggregates is shown in Figure 3. A clamshell bucket was used to transport heavy aggregate to washing bins located at the left of this picture. Puddling of limonite and magnetite with water was sufficient to remove fine material and surface dust. Steel aggregate was not washed prior to batching.

Aggregates were stored and weighed separately in the three-bin batcher shown in Figure 3. A half cubic yard of steel and limonite, or a full cubic yard of magnetite and limonite, were batched at a time and then mixed together in the portable concrete mixer shown at the right. The mixer was filled partly with water to minimize aggregate breakage and turned over a few times before its load was discharged into the skip hoist bucket. Water was removed through holes in the discharge top of the mixer and through holes in the skip hoist bucket. The wet aggregates were then elevated and passed over a 3/8-inch vibrating screen before being dumped into concrete buckets and hauled to the reactor site. A close up of the batcher and mixing equipment is shown in Figure 4.

Although batching and handling of wet aggregates presented certain

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control problems, the above blending method proved satisfactory for mixing aggregates, removing fines from the blended aggregate, and for eliminating dust during handling and prepacking. Segregation of steel punchings was also minimized by installing baffles in all buckets in such a manner as to deflect the steel punchings to the sides of the bucket rather than letting it pile up in the center. Unit weights of representative samples of blended aggregates from each bucket were determined just prior to prepacking them in the forms. About one bucket out of ten containing steel aggregate and limonite was rejected for being over or under weight. The rejection rate of magnetite-limonite aggregates was almost nil. Rejected material was not wasted but used in less critical sections of the shields.

Aggregate Placement

Heavy aggregates were placed in the forms in uniform layers up to six inches deep and then compacted to a void content of 40 to 44 percent. Aggregates were dropped through an "elephant trunk" as near as possible to the desired location in order to minimize aggregate segregation. As required to fill restricted areas and corners, they were then moved and compacted with the aid of pneumatic tampers. This operation is shown in Figure 5. Also shown are the 3/4-inch insert pipes used later to pump grout into the aggregate mass. Compaction of aggregates in a corner of the side shield is illustrated in Figure 6. A close up view of aggregate placement between girders in the top shield is shown in Figure 7.

Since it was desired to reduce compressive stresses on the inside

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faces of the left and right side shields, the top girders were supported near the outside edges of the side shields and the center section of the top shield filled with heavy aggregates prior to welding of the ends of the girders to the side crates. Two of the last end sections to be filled with coarse aggregate are shown in Figure 8. Heavy aggregates were placed in the crates and top shield at an average rate of 3 cubic yards per hour. The rate of aggregate placement varied from about 2 cubic yards per hour for the front and rear crates to over 4 cubic yards per hour for less restricted areas of the side crates and top shield. The location and alignment of embedded items, such as the step casing shown in Figure 8, were checked prior to solidifying aggregates with heavy grout.

It is noted that the limonite and magnetite aggregates are rather brittle and that excessive amounts of compaction tended to crush the weaker pieces. Thus, the type and amount of compaction had to be controlled carefully in order to minimize aggregate breakage or segregation, and still compact the aggregate to the desired density. In order to determine the void content of the prepacked aggregates, water was metered while being pumped into the crates prior to, and after the placement of aggregates. These void content values were found to check closely computed values based upon the number of buckets and weight of aggregates placed in the respective crates.

Construction Techniques

From a grouting standpoint, it would have been more desirable to solidify aggregates in a complete side shield during one pumping operation.

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However, due primarily to alignment problems, it was necessary to pump only one crate at a time. The normal sequence of erection consisted of aligning a rear crate, placing grout insert pipes and reinforcing steel, filling the crate with heavy aggregate, and then pumping it with limonite grout. Just as soon as the rear crate was positioned, the next front crate was aligned, followed by corresponding crates on the left and right sides. Thus, work progressed around the shield, one tier at a time. Working three shifts per day, a tier of four crates could be erected and filled with concrete in one week.

Construction joints between successive lifts of prepacked concrete presented a difficult problem. An uneven joint was desired with uniform concrete density throughout. The geometry of the crates and large number of embedded items prevented the use of top forms. To maintain structural continuity of the concrete between successive crates, vertical bars of reinforcing steel were placed as shown in Figure 5 and 6. Heavy aggregates were then placed to within 19 inches of the top of each crate. Since surface flooding of grout was undesirable, the grout at a construction joint was kept about eight inches below the top aggregate surface. As an aid in controlling this grout elevation, short sections of two inch pipe were placed in the top layer of prepacked aggregates so that they extended about twelve inches down into the aggregates.

Just prior to grouting a crate, water was pumped into the bottom of the aggregate mass through several insert pipes. This provided a means of checking water-tightness, promoting a uniform grout rise, and filling all the void spaces between aggregate particles with heavy grout. About two feet of water was carried above the grout surface to start with.

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When this water appeared at the top aggregate surface, it was removed by means of a pneumatic sludge pump. The presence of grout near the top aggregate surface was noted by observing the immediate rise of water in the two-inch sump pipes. It was inevitable that grout should occasionally boil up through the layer of aggregates in localized areas; however, procedures were developed to minimize this difficulty. Any grout or laitance which covered the aggregate surface was allowed to dry and then was removed prior to placing aggregates in successive lifts of the next crate.

The grout insert pipes were removed during the grouting operation. At the conclusion of grouting, the top aggregate surface was covered with water; this water being removed just prior to the erection of the next higher crate. Thermocouples placed in the concrete indicated that a maximum temperature rise of about 12°F occurred in around 30 hours in the front and rear crates, and 18°F at 50 hours in the side crates. During this period, the two-inch sump pipes were turned occasionally and then removed, leaving a hole through the top layer of aggregates down to the hardened grout. Grout insert pipes were then placed in these holes for the next lift. Operations during grouting of a side crate are shown in Figure 9, while those for the top shield are shown in Figure 10.

Grout Data and Methods

A heavy grout made with limonite sand was developed especially for this job. It had good pumping qualities and weighed about 147 lb per cu ft. Due to the use of limonite sand having a high content of

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natural fines, separation of grout ingredients was nil. A special admixture called Intrusion Aid* was also used to impart expansive and colloidal properties to the grout. Equipment for mixing and pumping grout is shown in Figure 11. This plant was set up about 200 feet from the shield and produced up to six cubic yards of grout per hour. Each mixer could handle a batch of grout every five minutes. A batch consisted of four bags of Type II portland cement, 480 pounds of limonite sand, 6.5 pounds of Intrusion Aid, and about 210 pounds of water.

In solidifying the top shield, two mixers and four pumps were used to pump grout into the prepacked aggregates while only half the plant was required for supplying grout to the side crates. During grouting operations, the grout inserts along the center line of each side crate were pumped consecutively for four minutes each until grout appeared in the two-inch sump pipes. Side inserts in these crates were then pumped until all sumps showed evidence of grout approaching the aggregate surface. A slightly different procedure was used on the top shield where it was divided into four quadrants. Inserts in each quadrant were pumped in a predetermined pattern designed to bring up the grout evenly through the aggregate mass and not flood the surface. After grout was within about eight inches of the top, all sump pipes and grout inserts were removed. The upper layer of aggregate in the top shield was then penetrated with grout by forcing a special insert down into the aggregate with the aid of a pneumatic hammer. Excess surface grout was then removed

*Manufactured by the Concrete Chemicals Company of Cleveland, Ohio.

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and the top shield covered with ten inches of magnetite-limonite concrete. This concrete cap layer was placed conventionally and then covered with a steel membrane; thus, completing the construction of the biological shield.

Conclusions

1. The quality and uniformity of heavy aggregates were exceptionally good. The steel, limonite and magnetite aggregates, and the grout used on this job produced sound concrete having a compressive strength of over 5000 psi at 60 days.
2. Workmanship and control during construction were adequate for obtaining concrete having the specified density and composition. Reasonable assurance was obtained to show that (a) coarse aggregates were prepacked to the required densities, (b) segregation and breakage of pieces of coarse aggregates were minimized, (c) all void spaces in the aggregate mass were filled with limonite grout, and (d) the concrete hardened in full contact with pipe, casings and other embedded items.
3. The prepacked method is a suitable method for constructing concrete shields made with heavy aggregates. This especially is true when steel punchings are used as coarse aggregate or when high density concrete is to be placed in restricted areas and around numerous embedded items.

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TABLE 1
PHYSICAL PROPERTIES OF HEAVY AGGREGATES

<u>Source</u>	<u>Limonite</u>		<u>Magnetite</u>
	<u>Utah</u>	<u>Michigan</u>	<u>Nevada</u>
<u>Natural Ore</u>			
Percent Iron (Fe)	54.5	58.3	63.5
Percent Silica (SiO ₂)	5.9	3.2	3.7
Fixed Water at 100°C	11.0	9.0	1.5
<u>Coarse Aggregate</u>			
Specific Gravity (SSD)	3.46	3.75	4.62
Unit Weight (Dry and Rodded)	118	134	167
Absorption (Percent)	3.30	2.9	0.5
Percent Retained on Stnd. Sq. Screens:			
1-1/2 inch	0	1	2
1-1/4 inch	0	12	10
1 inch	0	43	37
3/4 inch	45	76	61
1/2 inch	87	96	90
3/8 inch	98	99	95
Coef. of Expansion in/in/°C (10 ⁻⁶)	6.1	5.4	--
Specific Heat BTU/(lb °F)	0.19	0.19	-- ©
Chemical Reactivity With Sodium Hydroxide	Innocuous	Innocuous	Innocuous
<u>Fine Aggregate</u>			
Specific Gravity (SSD)	3.71	3.75	4.50
Fineness Modulus	1.19	2.05	1.15
Percent Retained:			
No. 16 screen	0	25	0
No. 100 screen	64	79	67
<u>Procurement Data</u>			
Cost F.O.B. Hanford	\$19.75	\$25.58	\$16.18
Condition	Mine Run	Screened	Crushed
Size	0-16 in.	3/4 to 8 in.	1/4 to 1-1/2 in.

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PHOTOGRAPHS

- Figure 1 Crushing Heavy Aggregate
- Figure 2 Processing and Bagging Limonite Grout Sand
- Figure 3 Plant for Washing, Batching and Blending Coarse Aggregates
- Figure 4 Closeup View of Aggregate Blending Plant
- Figure 5 Placing and Compacting Coarse Aggregates In A Side Crate
- Figure 6 Compacting Coarse Aggregates In A Corner Section
- Figure 7 Placing Coarse Aggregates In The Top Shield
- Figure 8 End Sections Between Girders Prior to Placing Final Layer
Of Coarse Aggregates In Top Shield
- Figure 9 Solidifying Aggregates In A Side Crate
- Figure 10 Solidifying Aggregates In The Top Shield
- Figure 11 Plant For Mixing and Pumping Heavy Grout

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FIGURE 1

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FIGURE 11

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