# Manufacture and Placement of Ultra Heavyweight Concrete

## A case study on radiation shielding in a hospital

*by Jim Noller, Manjit Chopra, Kyle Hargreaves, and Brian H. Green*

When radiation shielding was needed for a new addition to the Lahey Hospital and Medical Center (LHMC) in Burlington, MA, heavyweight concrete—also known as high-density concrete—proved to be the obvious solution. But how does a contractor procure materials for such a concrete mixture? While some concrete producers and contractors may have experience in working with high-density aggregates, few can provide concrete with a unit weight of 325 lb/ft$^3$ (density of 5200 kg/m$^3$). That's more than double the density of normalweight portland cement concrete mixtures and about two-thirds the density of steel!

Liberty Construction Services, LLC (LCS) was faced with this challenge in April 2015, when Suffolk Construction retained the company to provide concrete forming and placement for the LHMC project. The contract called for LCS to place a series of concrete columns and a large concrete slab totaling about 400 yd$^3$ (305 m$^3$) of heavyweight concrete (Fig. 1) for a new emergency department located above a shell space that will eventually house a new radiation oncology department. The shell space will house equipment using radiation sources that will require shielding protection for the personnel and patients within the new emergency department. The heavyweight concrete slab had to be carefully designed to provide the necessary protection and fit within the space allotted. Once the requirement for a 325 lb/ft$^3$ (5200 kg/m$^3$) heavyweight concrete was confirmed, LCS went to work to identify the right company to assist them.

Nuclear Shielding Supplies & Service (NSS) in Tucson, AZ, turned out to have a product that was "just what the doctor ordered." Their extensive experience with heavyweight concrete (DenseCRETE®) spans over five decades of service to the nuclear, medical, and industrial radiation shielding industries, including projects at McMaster University, Hamilton, ON, Canada; Centre hospitalier de l'Université de Montréal, Montreal, QC, Canada; and McGill University, Montreal, QC, Canada. This history showed that NSS could meet the requirements for the LHMC project and provide assistance along the way to help LCS place the material without any glitches.

**Fig. 1: A heavyweight concrete floor slab was required to shield the hospital's emergency department from radiation produced in an oncology department located below the slab**

**Table 1:**
**Concrete mixture test results**

| Mixture purpose | Unit weight, lb/ft$^3$ | Slump, in. | Compressive strength, psi | | |
|---|---|---|---|---|---|
| | | | 7-day | 14-day | 28-day |
| Columns | 328 to 333.9 | 4.5 to 6.0 | 5180 to 5810 | 6370 to 7250 | 7273 to 8120 |
| Slab | 328 to 331.5 | 4.0 to 5.5 | 5410 to 5810 | 6130 to 7250 | 7800 to 9027 |

Note: 1 lb/ft$^3$ = 16 kg/m$^3$; 1 in. = 25 mm; 1 psi = 0.007 MPa

## Project Challenges

### Limited space

The plans for the future radiation oncology department include up to three treatment rooms, each with a linear accelerator. In addition to a base level of shielding on the walls and ceiling, each treatment room will require areas of increased shielding on two walls and in the ceiling directly above the accelerators. While a thicker section of standard concrete (sometimes as thick as 6 to 8 ft [1.8 to 2.4 m]) can be used to provide the necessary protection of adjacent spaces, the volume available for the three-story hospital addition required a much thinner ceiling section.

### Extra weight

The project design team had to carefully consider how to properly support the heavy slab within the space below. The design solution included four reinforced concrete columns constructed with the same heavyweight concrete as the supported slab.

### Project credits:

**Owner:** Lahey Hospital & Medical Center Burlington, MA
**General Contractor:** Suffolk Construction Company, Boston, MA
**Concrete Supplier:** Liberty Construction Services, Braintree, MA
**Concrete Producer:** Benevento Companies, Wilmington, MA
**Admixture Supplier:** BASF Corporation, Florham Park, NJ
**Mixture Designer and Supplier of Heavy Aggregates:** Universal Minerals International, Inc. (dba Nuclear Shielding Supplies & Service), Tucson, AZ
**Architects:** JACA Architects, Quincy, MA; and Freeman White, Charlotte, NC
**Structural Engineer:** O'Donnell & Naccarato Structural Engineers, Philadelphia, PA
**Physicist:** H. Halvorsen, Chief, Radiation Therapy Physics, Lahey Health – Radiation Oncology

### Mixture proportions

Although NSS had developed heavyweight concrete mixtures for previous projects, this was the first known North American application for such a large volume of the material. Prior to this placement, the general practice for tackling a project of this magnitude had been to use preplaced-aggregate concrete to avoid segregation of the larger and heavier aggregate particles within the lower-density paste.

NSS used a blend of proprietary materials to develop a 330 lb/ft$^3$ (5290 kg/m$^3$) mixture, and LCS hired Benevento Concrete to assist in the concrete placement. NSS shipped Benevento samples of the high-density aggregate to perform their own tests to confirm that the high density and workability of the concrete mixture could be achieved. NSS then sent a representative to meet with Benevento personnel and their preferred admixture supplier to conduct tests to confirm that the heavyweight concrete mixture would meet the specifications and perform as expected.

The owner's engineers and physicist determined that the concrete mixtures for the structure should have a dry density of 325 lb/ft$^3$ (5205 kg/m$^3$) and compressive strength of 6000 psi (41.4 MPa) for the columns and 5000 psi (34.5 MPa) for the roof slab. The specified slumps were 4 to 6 in. (100 to 150 mm) and 3 to 5 in. (75 to 125 mm) for the columns and roof slab, respectively. The heavyweight concrete mixture was proportioned using the absolute volume method in accordance with ACI 211.1-91(2009).[1] The delivered concrete properties are summarized in Table 1.

Heavyweight concrete must be carefully proportioned. It must achieve its high density without segregation of the aggregate particles, which would lead to radiation streaming, therefore defeating the purpose of the protective barrier. The specified dry density of 325 lb/ft$^3$ is rare and required steel particles be used as a portion of the aggregate.

The steel aggregate was initially designed as a blend of particles retained on sieve sizes ranging from the No. 8 to 1/2 in. (2.36 to 12.5 mm). The average specific gravity (SG) of the steel aggregate was 7.74. When steel aggregates are used, it is important that the mortar fraction of the concrete mixture is capable of keeping the steel particles in suspension. A volume of fine steel particles retained on the No. 100 to the No. 8 (150 µm to 2.36 mm) sieves was therefore included in the mixture to minimize the settling of the larger steel particles (particles that ranged in size from the No. 4 to the 1/2 in. sieves [4.75 to 12.5 mm]).

In addition to the steel particles, both coarse and fine crushed, high-density, mineral aggregates were used in the mixture. Both of these mineral aggregates met ASTM C33/C33M[2] gradation requirements and each had a specific gravity of 5.0 and very low absorption. The coarse aggregate was a blend of hematite and magnetite from nondomestic sources and met ASTM C33/C33M No. 57. The fine aggregate consisted of hematite from two nondomestic sources.

The particle surfaces of these mineral aggregates allowed strong bonding with the cementitious components of the mixture and gave higher than anticipated compressive strengths at all ages.

## Material delivery

LCS worked with Benevento to determine the most efficient way to produce the heavyweight concrete and deliver it to the jobsite. Benevento transit mixer loads were limited to 3 to 4 $yd^3$ (2.3 to 3.1 $m^3$) to comply with truck weight restrictions. In 1 week, from 100 to 130 loads would be required to deliver the 400 $yd^3$ (306 $m^3$) of material needed on the project. To complicate things further, placements were limited to evening hours only to avoid traffic issues and to control the concrete temperature.

To help with the batching of this concrete, Benevento worked closely with NSS to have the high-density aggregates delivered in bulk bags to their batch plant (Fig. 2). NSS carefully proportioned and blended the aggregates into the bulk bags to achieve the desired batch volumes requested by Benevento.

**Fig. 2: High-density aggregate was supplied in bulk bags**

**Fig. 3: A custom conveyor system for loading the high-density aggregates into the mixer allowed the producer to keep concrete deliveries on schedule**

Benevento developed a concrete batching sequence that allowed it to open the bulk bags and move the required material into transit mixers efficiently via a custom-designed hopper and conveyor system (Fig. 3). This allowed the material to be loaded quickly and made it easier for Benevento to predict how long it would take to load and deliver a truck to the site. Benevento, LCS, and Suffolk then worked to create a schedule to deliver the required volume of concrete to be placed each night.

## Concrete placement

Benevento and LCS carefully developed a plan to place the heavyweight concrete efficiently. Trucks were scheduled to arrive in intervals of approximately 30 minutes to allow for the heavyweight concrete to be placed prior to the arrival of subsequent trucks. The heavyweight concrete was unloaded from each transit mixer into a 1 $yd^3$ (0.8 $m^3$) concrete bucket, specially manufactured to carry heavy loads, positioned using a crane, and then discharged manually. To limit segregation of the high-density aggregate in the concrete, workers were careful not to excessively vibrate the concrete using heavy-duty vibrators per Section 4.4 of ACI 304.4R-95(2008)[3] recommendations.

Density and compressive strength were assessed by an independent testing agency. All results met or exceeded the requirements imposed by the architect and structural engineer. The heavyweight concrete was placed over a five-night period with excellent results. The combined efforts and professional execution of the contractors, suppliers, concrete producer, and designers have paved the way for Lahey Hospital & Medical Center to provide expanded emergency and radiation oncology services to patients within the region.

## References

1. ACI Committee 211, "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete (ACI 211.1-91) (Reapproved 2009)," American Concrete Institute, Farmington Hills, MI, 1991, 38 pp.

2. ASTM C33/C33M-11a, "Standard Specification for Concrete Aggregates," ASTM International, West Conshohocken, PA, 2011, 11 pp.

3. ACI Committee 304, "Placing Concrete with Belt Conveyors (ACI 304.4R-95) (Reapproved 2008)," American Concrete Institute, Farmington Hills, MI, 1995, 15 pp.

Selected for reader interest by the editors.

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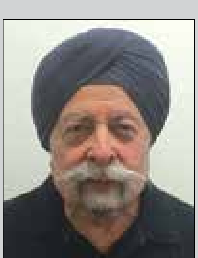

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