



## REMR Technical Note CO-RR-1.7

# Concrete Armor Unit Fabrication

### Purpose

The purpose of this technical note is to discuss the importance of quality control/quality assurance in the construction of concrete armor units with particular emphasis on concrete mixture design.

### Introduction

The Corps of Engineers has an extensive history of building concrete-armored rubble-mound structures and currently maintains 19 of these within the continental United States, Alaska, and Hawaii. In general, these structures have performed well, but many have required armor layer rehabilitation (Melby and Turk 1994). A major goal of the concrete armor unit research effort is to incorporate lessons learned from existing structure surveys with experiences gained in the laboratory and to provide District engineers with the latest concrete armor unit design guidance. One area that can improve concrete armor unit performance is attention to quality control and quality assurance, especially in the composition, casting, and handling of units.

### Concrete Considerations

Major advances have been made in concrete technology, and use of concrete with compressive strengths greater than 70 MPa is not uncommon. A concrete mixture must be proportioned to produce concrete that is capable of withstanding harsh marine environments. Ideally, concrete should be impervious to seawater attack, be abrasion resistant, and possess high strength. Quality assurance requires concrete to have a consistent homogeneity, free of defects and flaws. Concrete quality is a function of proportions and type of cement, aggregate, water, and admixtures. Mixing, casting, and curing are all integral to the fabrication process.

The following information on a recommended concrete mixture serves only as a starting point for mixture proportioning studies. Many factors affect the integrity of the final product. Variability in the chemical and physical interaction of the individual constituents requires rigorous testing of the final mixture proportions. Therefore, it is imperative that the mixture design be "fine-tuned" and tested in a certified concrete testing laboratory. It is recommended that axial compression and splitting tensile tests be used to evaluate mixture proportions and for quality control of the final product. While specific structural design guidance for concrete armor is available from the Coastal Engineering Research Center (CERC), Waterways Experiment Station, a minimum standard should be met regardless of armor unit

size. Information and guidance for the investigation and selection of concrete materials for civil works concrete structures are provided in Engineer Manual 1110-2-2000 (Headquarters, U.S. Army Corps of Engineers 1994).

Concrete used for concrete armor units should possess the following qualities:

- 28-day compressive strength - 35 MPa (minimum)
- 28-day splitting tensile strength - 3.5 MPa (minimum)
- Slump - 50 to 100 mm
- Air entrainment - 5 percent  $\pm$  1 percent

A typical baseline specification for trial mixture proportions is as follows:

*a. Cement.*

- (1) Type II or III with the optional 8-percent limit of  $C_3A$  invoked.
- (2) Water/cement ratio 0.35 to 0.40.

*b. Aggregate.*

- (1) Nonalkali-silica reactive.
- (2) Maximum size - 38 to 76 mm (dependent on armor unit size).
- (3) Gradation conforms to American Society for Testing and Materials (ASTM) C 33-84.
- (4) Fineness modulus for fine aggregate 2.4 to 3.0.

*c. Admixtures.*

- (1) Appropriate air entrainment.
- (2) Superplastizers, increases workability and reduces water content.
- (3) If steel reinforcement is used, avoid chloride-based accelerating agents.

In order to attain successful casting of concrete armor, the following guidelines are recommended:

- a.* Concrete should be placed in formworks in lifts no more than 18 in.
- b.* Each lift should be vibrated to remove voids.
- c.* Armor units with cold joints should always be rejected.
- d.* In general, forms should be stripped no sooner than 24 hr unless sufficient high early strengths are attained.
- e.* Curing agent should be applied as soon as forms are stripped.
- f.* Steam curing should be avoided unless the contractor can prove an acceptable level for the heat of hydration.
- g.* Heat of hydration should never be allowed to exceed 75 °C.

- h.* Quality-control test cylinders should be made for each concrete batch and cured at the same internal temperatures found at the core of the concrete armor units.

Once the units are cast, the following items warrant consideration:

- a.* Units must be handled carefully. Most armor unit types and sizes cannot withstand impact stresses generated from even moderate drop heights (<0.5 m).
- b.* If a unit is dropped, it must be carefully inspected. If cracked, it should be rejected.
- c.* Once onsite, if a unit is found to be cracked, it should not be placed on the armor layer.
- d.* During shipping, units should be secured (shimmed if necessary to avoid rocking) to prevent unit-to-unit impacts during transport.

## **Steel Reinforcement**

The question of whether concrete armor units need reinforcement is often asked. Several steel reinforcement schemes for dolosse, in particular, have been used worldwide. South Africans (Zwamborn 1988) proposed and tested the use of railroad rail steel reinforcing with moderate success, although by current U.S. construction practices, this is an unconventional approach. In the United States, the Corps of Engineers has placed steel reinforcement in dolosse ( $\approx 47$  kg of steel per cubic metre of concrete) on the Humboldt, CA, jetties; Manesquan Inlet, NJ, jetties; and several Hawaiian breakwaters (Markle and Davidson 1984).

Conventional steel reinforcement makes use of deformed steel bars placed within the cross section of the armor unit. As a unit is loaded, tensile stresses within the concrete are transferred to the steel dowels along their development length. This transfer of stress occurs only after the concrete cracks. Depending on the nature and severity of the loading condition, these cracks often extend through the concrete cover layer to the steel dowels. In the marine environment, degree and rate of corrosion are dependent on bar diameter, thickness of the cover layer, and concrete quality (Rasheeduzzafar 1992). Cracks provide a conduit for seawater intrusion resulting in corrosion and expansion of the steel. This causes spalling of the overlying concrete cover, which in turn exposes more steel and can ultimately lead to unit failure.

Steel fiber-reinforced concrete dolosse have been used on the Crescent City, CA, breakwater. With approximately 50 kg of steel added per cubic metre of concrete, a 7-percent tensile-strength increase was reported from tests conducted during trial mixture designs (Gutschow 1985). One of the initial problems encountered during

prototype casting was the tendency for steel fibers to congregate or "ball up" during concrete mixing. To prevent these "lumps" of steel fibers in the mixture, extra care was taken to evenly distribute the fibers during mixing. The added material and labor costs of steel fibers may not justify their marginal strength-increasing benefit.

## Future Developments

The development of concrete armor unit design is an evolving process. It is often difficult to obtain information on past projects. CERC researchers are always looking for information on past concrete armor unit projects for inclusion in a developing database. Any information pertaining to field experience and construction of concrete armor is of great value to the Point of Contacts and can be sent to the addresses listed at the end of this note.

## References

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