ATL TESTING LABORATORIES

ROLLER COMPACTED CONCRETE QUALITY REVIEW EAST PAPAGO LOOP RAM-600-5-517

ROLLER COMPACTED CONCRETE
QUALITY REVIEW
EAST PAPAGO LOOP
RAM-600-5-517

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INTRODUCTION

This Handout is provided as a supplement to an oral presentation by Pulice Construction, ATL, Inc. and Paul Mueller to the Arizona Department of Transportation, Maricopa County Flood Control District and other involved parties. The purpose of the presentation is to:

1. Provide an Overview of Roller Compacted Concrete; what is it, how does it compare to other materials and what is current state of the art knowledge on how to evaluate it.

2. Review project test data and evaluate its relevance to the material in-place.

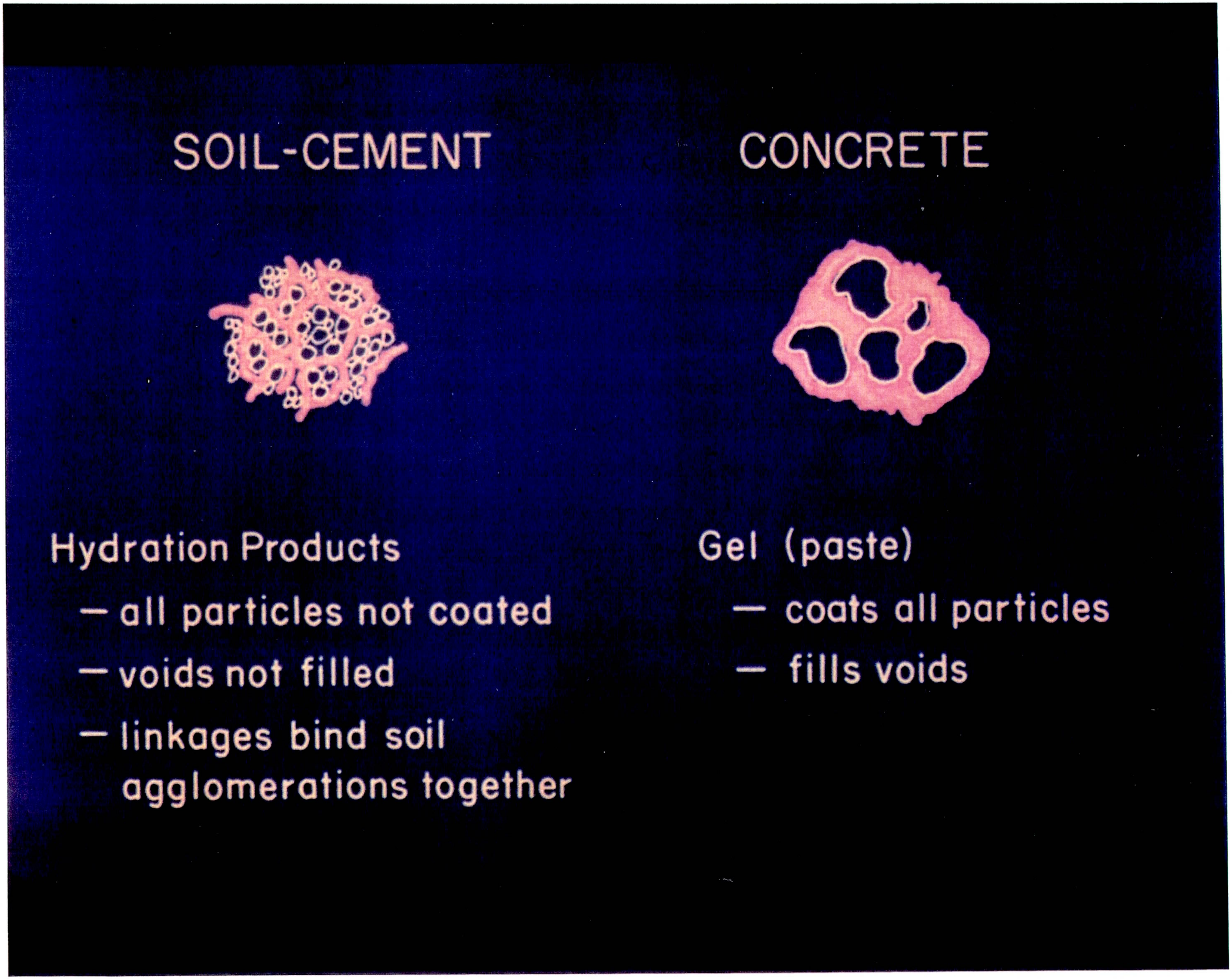
3. Discuss the need for additional information.

4. Assess the ability of the structure to perform as intended by the original design.

REFERENCE SHEETS

FOR

ROLLER COMPACTED CONCRETE
PORTLAND CEMENT CONCRETE
SOIL CEMENT


SOIL-CEMENT
CONCRETE
Hydration Products
— all particles not coated
— voids not filled
— linkages bind soil agglomerations together
Gel (paste)
— coats all particles
— fills voids

ROLLER-COMPACTED CONCRETE (RCC) SHORT COURSE/TOUR DECEMBER 2-3, 1993

The Portland Cement Association held a short course and tour on roller-compacted concrete (RCC) at Palmdale, California on December 2 and 3, 1993. PCA had originally expected 60 to 70 people, but 128 attended. Gene Wirkus and Darrell Pieper represented the California Cement Promotion Council. It could be billed as an international audience, as there were 21 attendees from Greece, Mexico, and Canada, as well as 77 from California and 30 from other states. The course started with a history and description of RCC and ended with a tour of the rehabilitation of the Littlerock Dam, which is being done using RCC.

WHAT IS RCC ?

Roller-compacted concrete is a method of placing concrete. The mixture of cement, sand, aggregates, and water is very dry, sometimes known as no slump concrete. When released from the batch plant, it appears as if it were a well graded aggregate base. This mixture is placed like an aggregate base using conveyors, loaders, graders, and other equipment, and is then compacted with a vibratory roller. The finished product cannot be distinguished from regular concrete, except it may have a few more air voids than regular concrete. The one year compressive strength ranges from 2000 to 4000 p.s.i., depending on the design requirements.

The RCC acts like a soil compaction project. In designing the mix, sand, aggregate, cement and water are mixed and compacted. As water is introduced, the mix increases in compressive strength, until it reaches an optimum moisture content, and then with the addition of more water, the strength diminishes. This is similar to the curves developed to determine the optimum moisture for compacted soils.

RCC HISTORY

The first RCC dam in the United States was constructed in 1982. Since then, 25 dams over 50 feet high have been constructed or rehabilitated using RCC. Because the technology is relatively new, the standards for specifications are still evolving and improving with each new project. The important things learned are that RCC dams are going to increase in number. The major reason for this is cost. RCC costs between $20 and $45 per cubic yard. Conventionally produced and placed concrete costs between $45 and $80 per cubic yard. If a new dam is being considered that can be either an earth fill dam or an RCC dam, the RCC dam will generally cost less because it requires much less material and can therefore be constructed in much less time.

LITTLEROCK DAM

Littlerock Dam is a multiple-arch dam located near Palmdale in Southern California. It has a maximum height of 175 feet and a crest length of 720 feet and consists of 28 arches. When it was completed in 1924, it was the highest multiple-arch dam in the U.S. In 1924, there were no considerations for earthquakes, even though the dam is only 1.5 miles south of the San Andreas fault. Over the years, the dam was criticized for lack of lateral stability. The owner eventually decided to rehabilitate the dam. The major part of the rehabilitation is to place a concrete gravity section between and around the downstream portions of the existing buttresses. This is to remedy the lack of lateral stability of a multiple-arch dam by providing a continuous support system in the form of a RCC gravity section tied into the existing buttresses. The designers calculated that RCC construction would cost about $12.5 million, while a mass concrete design would cost approximately $22.5

million. The RCC saved the owners $10 million.

The specifications called for the RCC to achieve a compressive strength of 2300 psi at 365 days. The mix that was settled on after several trials calls for a well graded aggregate with a 1-1/2-inch maximum size, 37% to 45% passing the No. 4 sieve, and between 2% and 7% passing the No. 200 sieve. Per cubic yard of RCC, 110 pounds of cement and 165 pounds of flyash are used. A test section was constructed to help train the construction crew and test the design mix before starting the actual RCC placement. This test section resulted in modifying the design mix to achieve a higher strength, as well as eliminating some of the problems in working in a restricted site.

The RCC is being placed in 12-inch thick lifts and compacted with vibratory rollers. The number of passes with the vibratory rollers was determined during the test fill. The specified compaction is to achieve a running average wet density of 99% of the density of laboratory test cylinders. The minimum acceptable density is 97% of the laboratory density. To provide bond at lift surfaces, bedding mortar is placed on the compacted RCC surfaces. Test cores indicate that the contractors surface preparation between lifts is very good and shear strength at the lift surface is at least as good as the interior of the RCC.

The course concluded with a tour of the rehabilitation of the Littlerock Dam site. The site is very small, requiring careful planning to set the location of the dual drum mixers, conveyor belts from the mixers, delivery chutes, cranes, loaders, vibratory compactors, aggregate stockpiles, and all the miscellaneous equipment. Aggregate, sand and cement are brought in from local suppliers, and the longest haul distance if 42 miles. This means that the contractor can schedule his material requirements such that he does not need a large reserve of materials on site. The contractor is working two shifts per day. At the time of the tour, the contractor had completed all foundation work and had started his RCC layers up to approximately 20 feet above the foundations. A Christmas card three weeks later contained a photo showing that the RCC had been placed to about 75 feet, or about half the total height. This indicates how fast RCC can be placed given the right conditions, materials, and planning.

Reprinted from *Hydro Review* magazine, Volume 12, Number 2, April 1993

Using Roller-Compacted Concrete for Cost-Effective Dam Modification

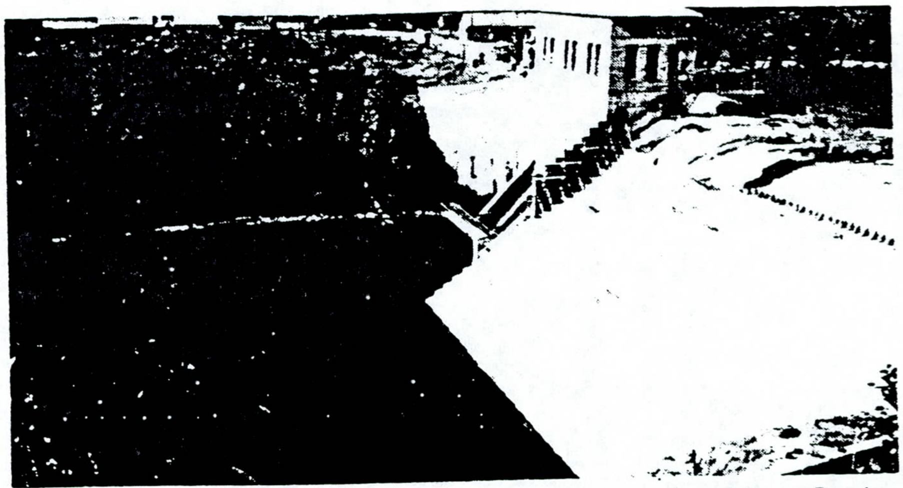
Roller-compacted concrete, or RCC, has become one of the most widely used materials for upgrading or replacing aging embankment dams in the U.S. Examples of modifications show that low cost and rapid application are the main advantages of RCC.

By Kenneth D. Hansen

Roller-compacted concrete (RCC) is one of the most popular materials for upgrading embankment dams in the U.S. Dam owners and engineering consulting firms who are users of RCC point to its low cost, proven performance, and rapid construction methods as benefits of the material.

To date, RCC has been used on 48 dam modification projects in the U.S. More than 60 percent of these projects were completed in the past three years. Of these 48, 38 were rehabilitations of existing dams (mostly for providing protection of the downstream slope when the dam is overtopped during a flood). The remaining ten were dam replacements, four of which were part of hydroelectric developments. In this article, I briefly describe a few of these modifications—both rehabilitation and replacement—focusing primarily on dams at hydroelectric developments.

RCC consists of a dry mixture of aggregate, water, a relatively small amount of cement, and, at times, fly ash. RCC provides the strength of conventional concrete at lower cost by using placing methods ordinarily associated with embankment dam construction.



Placing roller-compacted concrete on the downstream embankment slope of Ashton Dam in Idaho not only provided increased spillway capacity for the structure, but also increased the structural stability of the section. Black & Veatch, the project engineer, chose to place the RCC in stair steps to minimize flow acceleration and velocity, and thus improve the hydraulic efficiency of the spillway. The dam is part of the 8.2-MW Ashton-St. Anthony hydro project owned by PacifiCorp.

Using RCC for Dam Rehabilitation

Like much of the U.S. infrastructure, many dams were built 50 or more years ago. The safety of these dams has become an important issue in the past decade, and many dam owners are finding that their structures need to be modified to meet present-day hydraulic and seismic criteria. To modify an embankment dam to meet current dam safety criteria, a dam owner or engineer has several choices:

—Raise the dam and spillway crest to store a greater percentage of the design flood;

—Construct new spillways or modify existing spillways to increase capacity; or

—Increase spillway capacity by reinforcing the downstream slope and toe of the dam for erosion protection and then allow the dam to be overtopped in the event of a flood.

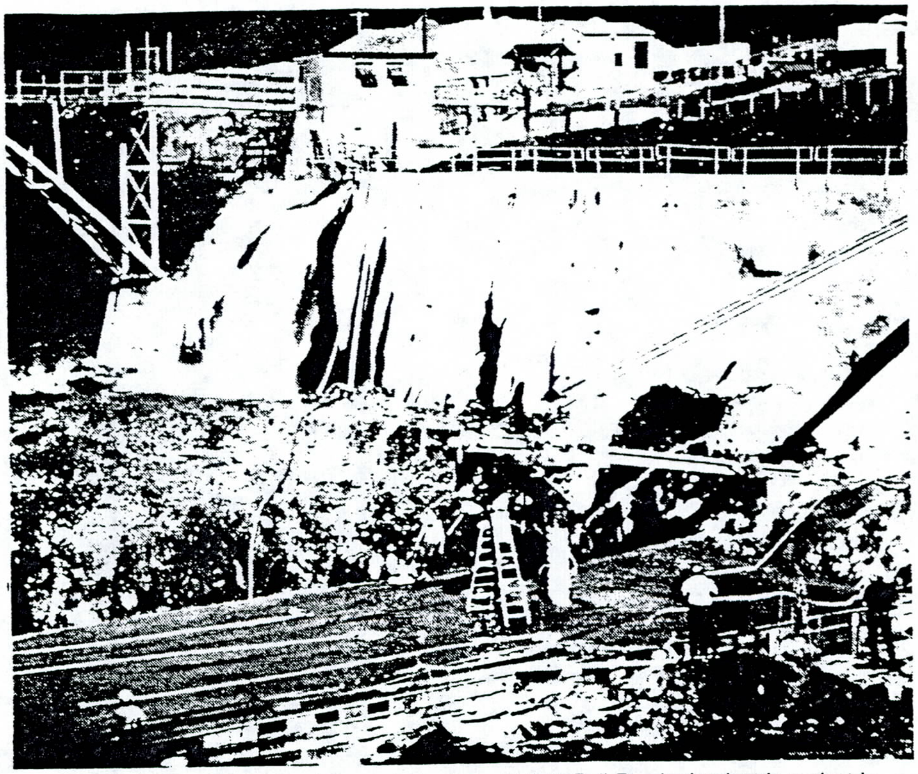
RCC has been used as a cost-effective solution for increasing spillway capacity and for providing overtopping protection. Table 1, on page 3, provides detailed information about all of the RCC overtopping protection projects in the U.S. to date. This section gives highlights about some of the projects listed in the table.

Brownwood Country Club Dam

The Brownwood Country Club Dam in West Texas is the site of the first real overtopping of an embankment with RCC to accommodate 100 percent of the probable maximum flood (PMF).

The 19-foot-high Brownwood Country Club Dam in Brownwood, Texas,

Ken Hansen, P.E., is senior water resources engineer for two affiliates of the Portland Cement Association.



Marmot Dam is part of Portland General Electric's 21-MW Bull Run hydroelectric project in Sandy, Oregon. The dam had partially failed in late 1988. In 1989, Ebasco Services, the project engineer, recommended replacing the dam with RCC. RCC was mixed at the site and conveyed over the intake channel to the site of the new dam (shown in the forefront of the photo). The flow in the center of the photograph is excess flow that is being diverted away from the construction area.

was constructed in 1938 with a 65-foot-wide spillway at its right abutment. Capacity of the spillway was 2,600 cubic feet per second (cfs). The dam forms a reservoir in the middle of the Brownwood Country Club's golf course. In the early 1980s, an updated PMF calculation indicated that the spillway needed to be capable of passing 11,600 cfs. The state dam safety engineer declared the dam unsafe and required that the country club draw down the level of the reservoir, which caused aesthetic problems on the golf course. Consequently, Brownwood Country Club contracted with Freese and Nichols engineering consultants to study modification options.

Each of the initial spillway modification alternatives considered by Freese and Nichols were estimated to cost at least $225,000. In searching for a less expensive option, the engineers devised a scheme to widen the spillway by 300 feet by lowering the embankment 5 feet and placing RCC in stair steps on the downstream slope. This solution cost $72,000, and created a spillway that could be overtopped without danger of eroding and subsequent dam failure during a flood.

Central Plains Contracting Company placed the RCC in 9-inch-thick layers over 300 feet adjacent to the existing spillway. The width of each layer was 8 feet, to accommodate earthmoving equipment such as dump trucks that hauled the RCC from the on-site mixing plant to the placement area. The contractor placed approximately 1,400 cubic yards of concrete in two days.

Several dam owners in the U.S. have used RCC for increasing spillway capacities. Project examples include Boney Falls Dam in Michigan, the Ashton Dam in Idaho, and the Tellico and Nickajack dams in Tennessee.

Boney Falls

Boney Falls Dam in the Upper Peninsula of Michigan was completed in 1921. Mead Paper Company generates electricity at the hydropower plant at the dam. In 1986, the company determined that the original spillway at the dam was not adequate to pass the PMF under present-day dam safety criteria, and would need to be modified. (The spillway had been designed to pass about 33,000 cfs of water without breeching. The PMF study estimated the peak discharge during the design flood at 147,000 cfs. However, further analysis indicated that floods greater than 100,000 cfs peak discharge would produce minimal incremental damage downstream if the dam were to fail. Therefore, additional spillway capacity was required to pass approximately 67,000 cfs.)

After studying several alternatives, Harza Engineering Company, the consulting engineer for the project, determined that RCC overtopping protection for 1,000 feet of the dam's left abutment would be the least costly plan for increasing spillway capacity. By using the left abutment as a spillway, Mead Paper could save $147,000 on modifications.

Harza eventually modified the design so that a concrete gravity section made of RCC would be placed directly behind an existing concrete core wall in the embankment. This change reduced the length of the new concrete gravity spillway section from the original 1,000 feet to 500 feet. An earth berm containing a "fuse plug" (a controlled failure mechanism) was placed over the RCC section. The plug, comprised of earth and rockfill embankment, would erode in a predictable and controlled manner when the flood capacity exceeds the capacity of the spillway and the outlet works. Bacco Construction Company placed about 4,800 cubic yards of RCC in the new gravity spillway section in eight days.

Ashton Dam

Ashton Dam, on Henry's Fork of the Snake River near Ashton, Idaho, was constructed between 1910 and 1913. The dam, along with the 6.7-MW Ashton-St. Anthony hydroelectric plant, is owned by PacifiCorp. The 60-foot-high earth and rockfill embankment dam sets in the center of the river between the powerhouse and an 82-foot-wide reinforced concrete spillway. In its efforts to relicense the Ashton project in the mid-1980s, PacifiCorp estimated the PMF for the site using present-day criteria. The PMF at the dam was determined to be 46,100 cfs; the existing spillway capacity was only 12,100 cfs. Therefore, the Federal Energy Regulatory Commission (FERC) required the utility to increase the dam's spillway capacity.

Black & Veatch, the consulting engineer for the project, evaluated several alternatives for passing the PMF flow. Six options were studied that would maintain the reservoir level at

Table 1: U.S. Dams Using Roller-Compacted Concrete for Overtopping Protection

Name of Dam Year Constructed	City State	Owner Engineer	Maximum Height (in feet)	RCC Volume (in cubic yards)	RCC Cost ($ per cubic yard)
Addicks (1988)	Houston, TX	U.S. Army Corps of Engineers, Galveston District	48.5	56,700 (both Addicks and Barker)	$79
Ashton (1991)	Ashton, ID	PacifiCorp Black & Veatch	60	7,700	Not Available
Barker (1988)	Houston, TX	U.S. Army Corps of Engineers, Galveston District	36.5	56,700 (both Addicks and Barker)	$79
Bishop Creek No. 2 (1989) New Emergency Spillway	Bishop, CA	Southern California Edison SCE & J.M. Montgomery	41	4,000	$88
Boney Falls (1989)	Escanaba, MI	Mead Paper Company/ Harza Engineering Company	25	4,850	$60
Brownwood Country Club (1984)	Brownwood, TX	Brownwood Country Club Freese and Nichols	19	1,400	$42
Butler Reservoir (1992)	Camp Gordon, GA	U.S. Army Corps of Engineers, Savannah District	43	9,150	Not Available
Comanche (1990) New Spillway	Estes Park, CO	City of Greeley/ Morrison-Knudsen Engineers	46	3,500	$67
Comanche Trail (1988)	Big Spring, TX	City of Big Spring/ Freese and Nichols	20	6,500	$39
Goose Lake (1989)	Nederland, CO	City of Boulder/ Harza Engineering Company	35	4,200	$51
Goose Pasture (1991)	Breckenridge, CO	Town of Breckenridge/ Tipton & Kalmbach	65	4,230	$48
Harris Park No. 1 (1986)	Bailey, CO	Harris Park Water & Sanitation District/ Edward Shaw	18	2,300	$47
Holmes Lake Dam (1991)	Marshall, TX	T&P Lake, Inc./ East Texas Engineering	31	2,800	Not Available
Horsethief (1992)	Rapid City, SD	Black Hills National Forest U.S. Forest Service, Denver Office	65	6,250	$50
Kemmerer City (1990)	Kemmerer, WY	City of Kemmerer/ Woodward-Clyde	31	4,100	$75
Lake Diversion (1992) New Emergency Spillway	Wichita Falls, TX	City of Wichita Falls/ Briggs & Mathews	85	46,500	$30
Lake Lenape (1991)	Mays Landing, NJ	Atlantic County/ O'Brien & Gere	17	3,050	$70
Lima (1993)	Dell, MT	Beaverhead County Red Rock River W&S District/HKM Associates	54	14,800	$52
Meadowlark Lake (1992)	Ten Sleep, WY	Bighorn National Forest U.S. Forest Service, Denver Office	28	2,550	$66
North Fork Toutle River (1980) Replacement Service Spillway	Castle Dale, WA	U.S. Army Corps of Engineers, Portland District	38	18,000	$37
North Potato Diversion (1992) New Spillway	Copperhill, TN	Federal Bankruptcy Court Dames & Moore	35	4,500	$66
Phillipsburg Dam No. 3 (1992)	Phillipsburg, PA	PA-American Water Co. O'Brien & Gere	20	1,400	Not Available
Ringtown No. 5 (1991) Combined Principal and Emergency Spillway	Ringtown, PA	Borough of Shenandoah Gannett-Fleming	60	6,300	$46
Rosebud (1993)	Rosebud, SD	Rosebud Sioux Tribe/ Harza Engineering Company	33	5,200	$78
Saltlick (1991) Two Emergency Spillways	Johnstown, PA	Johnstown Water Authority Gannett-Fleming	110	11,100	$79
Spring Creek (1986)	Gunnison, CO	Colorado Division of Wildlife Morrison-Knudsen Engineers	53	4,840	$37
Thompson Park No. 3 (1990)	Amarillo, TX	City of Amarillo/ HDR Engineering	30	2,730	$52
Umbarger (1993)	Canyon, TX	U.S. Fish & Wildlife Service GEI Consultants	40	28,500	$47
White Cloud (1990)	White Cloud, MI	City of White Cloud/ OMM Engineering	15	1,000	$83
White Meadow Lake (1991)	Rockaway, NJ	White Meadow Lake Association/ O'Brien & Gere	20	1,000	Not Available

Simplified Version of the Recommended Practice for Evaluation of Strength Test Results of Concrete

Reported by ACI Committee 214

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The purpose of this report is to introduce the use of a simplified version of the statistical concepts as outlined in ACI 214 for the specification, control, and evaluation of the production of concrete. For a more elaborate discussion of the concepts, see the "Recommended Practice for the Evaluation of Strength Test Results of Concrete" (ACI 214).

Keywords: coefficient of variation; **compression tests**; compressive strength; concrete construction; **concretes**; cylinders; **evaluation**; **quality control**; sampling; standard deviation; **statistical analysis**; variations.

CONTENTS

INTRODUCTION

The strength test is widely used in specifying, controlling, and evaluating concrete quality. Quality concrete must be able to: 1) carry loads imposed upon it; 2) resist deterioration; and 3) be dimensionally stable.

There are several tests that can be made with plastic and hardened concrete, but the strength test is generally accepted as a measure of the quality of concrete being placed on a project.

Although the strength test is not a direct measure of concrete durability or dimensional stability, it provides an indication of the water-cement ratio of the concrete. The water-cement ratio, in turn, directly influences the strength; durability; wear resistance; dimensional stability; and other desirable properties of concrete. The strength test is also used to measure the variability of concrete. By using statistical methods based on the strength test, realistic specifications can also be prepared.

VARIABILITY OF CONCRETE

Portland cement concrete is subject to numerous factors that affect its strength and other properties. These may include variations in the manufacture of portland cement; preparation of aggregates; batching, mixing, and curing of concrete; and finally in the preparation, handling, and testing of the cylinders. The major variables are listed in Table 1.

These variables must be considered when specifying, producing, or controlling the strength of concrete.

NORMAL DISTRIBUTION

Test data from large concrete projects with many tests show a grouping around the average strength. A

*Principal author of this report.

Designation: C 192 – 90a

Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory[1]

This standard is issued under the fixed designation C 192; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This practice has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This practice covers procedures for making and curing test specimens of concrete in the laboratory under accurate control of materials and test conditions using concrete that can be consolidated by rodding or vibration as described herein.

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information purposes only.

1.3 *This standard does not purport to address the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 31 Practice for Making and Curing Concrete Test Specimens in the Field[2]
C 33 Specification for Concrete Aggregates[2]
C 70 Test Method for Surface Moisture in Fine Aggregate[2]
C 125 Terminology Relating to Concrete and Concrete Aggregates[2]
C 127 Test Method for Specific Gravity and Absorption of Coarse Aggregate[2]
C 128 Test Method for Specific Gravity and Absorption of Fine Aggregate[2]
C 138 Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete[2]
C 143 Test Method for Slump of Hydraulic Cement Concrete[2]
C 172 Method of Sampling Freshly Mixed Concrete[2]
C 173 Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method[2]
C 231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method[2]
C 330 Specification for Lightweight Aggregates for Structural Concrete[2]
C 470 Specification for Molds for Forming Concrete Test Cylinders Vertically[2]
C 511 Specification for Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes[2]
C 566 Test Method for Total Moisture Content of Aggregate by Drying[2]
C 567 Test Method for Unit Weight of Structural Lightweight Concrete[2]
C 617 Practice for Capping Cylindrical Concrete Specimens[2]
C 1064 Test Method for Temperature of Freshly Mixed Portland-Cement Concrete[2]
D 448 Classification for Sizes of Aggregate for Road and Bridge Construction[2]
E 171 Specification for Standard Atmospheres for Conditioning and Testing Materials[3]

2.2 *NIST Standard:*

Handbook 44 Specifications, Tolerances, and other Technical Requirements for Commercial Weighing and Measuring Devices[4]

3. Apparatus

3.1 *Molds, General*—Molds for specimens or fastenings thereto in contact with the concrete shall be made of steel, cast iron, or other nonabsorbent material, nonreactive with concrete containing portland or other hydraulic cements. Molds shall conform to the dimensions and tolerances specified in the method for which the specimens are required. Molds shall hold their dimensions and shape under conditions of severe use. Molds shall be watertight during use as judged by their ability to hold water poured into them. A suitable sealant, such as heavy grease, modeling clay, or microcrystalline wax, shall be used where necessary to prevent leakage through the joints. Positive means shall be provided to hold base plates firmly to the molds. Reusable molds shall be lightly coated with mineral oil or a suitable nonreactive release material before use.

3.2 *Cylinder Molds:*

3.2.1 *Molds for Casting Specimens Vertically* shall conform to the requirements of 3.1 and Specification C 470.

3.2.2 *Horizontal Molds for Creep Test Cylinders* shall conform to the requirements of 3.1 and to the requirements for symmetry and dimensional tolerance in 3.1.2 of Specification C 470. The use of horizontal molds is intended only

[1] This practice is under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.61 on Testing Concrete for Strength.

Current edition approved April 27, 1990. Published June 1990. Originally published as C 192 – 44 T. Last previous edition C 192 – 90.

[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 15.09.

[4] Available from the National Institute of Standards and Technology, Gaithersburg, MD 20899.

Standard Test Methods for Moisture-Density Relations of Soil-Cement Mixtures[1]

This standard is issued under the fixed designation D 558; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

$^{\epsilon 1}$ NOTE—Sections 10 and 11 were added editorially in September 1990.

1. Scope

1.1 These methods cover the determination of the relationship between the moisture content and the density of soil-cement mixtures when compacted before cement hydration as prescribed.

1.2 A 1/30-ft^3 (944-cm^3) mold and a 5.5-lb (2.49-kg) rammer dropped from a height of 12 in. (304.8 kg) are used and two methods, depending on soil gradation, are covered, as follows:

	Sections
Method A, using soil material passing a No. 4 (4.75-mm) sieve. This method shall be used when 100 % of the soil sample passes the No. 4 (4.75-mm) sieve	5
Method B, using soil material passing a 3/4-in. (19.0-mm) sieve. This method shall be used when part of the soil sample is retained on the No. 4 (4.75-mm) sieve	6

2. Referenced Documents

2.1 *ASTM Standards:*

C 150 Specification for Portland Cement[2]

C 595 Specification for Blended Hydraulic Cements[2]

D 559 Test Methods for Wetting-and-Drying Tests of Compacted Soil-Cement Mixtures[3]

D 560 Test Methods for Freezing-and-Thawing Tests of Compacted Soil-Cement Mixtures[3]

D 698 Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 5.5-lb (2.49-kg) Rammer and 12-in. (305-mm) Drop[3]

D 2168 Test Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors[3]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[4]

3. Significance and Use

3.1 These tests determine the optimum moisture content and maximum density to be used for molding soil-cement specimens in accordance with Methods D 559 and D 560.

NOTE 1—Since these tests are used in conjunction with Methods D 559 and D 560 and the criteria referenced therein, the test differs in several aspects from Test Methods D 698.

4. Apparatus

4.1 *Mold*—A cylindrical metal mold having a capacity of 1/30 ± 0.0004 ft^3 (944 ± 11 cm^3) with an internal diameter of 4.0 ± 0.016 in. (101.60 ± 0.41 mm) and conforming to Fig. 1 to permit preparing compacted specimens of soil-cement mixtures of this size. The mold shall be provided with a detachable collar assembly approximately 2½ in. (63.5 mm) in height. The mold may be of the split type consisting of two half-round sections or section of pipe with one side split perpendicular to the pipe circumference and that can be securely locked in place to form a closed cylinder having the dimensions described above. The mold and collar assembly shall be so constructed that it can be fastened firmly to a detachable base (Fig. 1).

4.2 *Rammer:*

4.2.1 *Manual Rammer*—A manually operated metal rammer having a 2.0 ± 0.005-in. (50.80 ± 0.13-mm) diameter circular face and weighing 5.5 ± 0.02 lb (2.49 ± 0.01 kg). The rammer shall be equipped with a suitable guidesleeve to control the height of drop to a free fall of 12.0 ± 1/16 in. (304.8 ± 1.6 mm) above the elevation of the soil-cement. The guidesleeve shall have at least four vent holes not smaller than 3/8 in. (9.5 mm) spaced 90° apart and located with centers 3/4 ± 1/16 in. (19.0 ± 1.6 mm) from each end and shall provide sufficient clearance that free-falls of the rammer shaft and head will not be restricted.

4.2.2 *Mechanical Rammer*—A mechanically operated metal rammer having a 2.0 ± 0.005-in. (50.80 ± 0.13-mm) diameter face and a manufactured mass of 5.5 ± 0.02 lb (2.49 ± 0.01 kg). The operating mass of the rammer shall be determined from a calibration in accordance with Methods D 2168. The rammer shall be equipped with a suitable arrangement to control the height of drop to a free-fall of 12.0 ± 1/16 in. (304.8 ± 1.6 mm) above the elevation of the soil-cement.

4.2.3 *Rammer Face*—A sector face may be substituted with mechanical rammers provided the report shows that a sector face rammer was used. The sector face shall be a sector of a 4.0 ± 0.016-in. (101.60 ± 0.41-mm) diameter circle and shall have an area equal to that of the circular face rammer.

NOTE 2—The sector face rammer shall not be used to compact test specimens in accordance with Methods D 559 and D 560, unless previous tests on like soils show strength and resistance to wetting-and-drying and freezing-and-thawing of specimens compacted with this

[1] These methods are under the jurisdiction of ASTM Committee D-18 on Soil and Rock and are the direct responsibility of Subcommittee D18.15 on Stabilization of Additives.

Current edition approved Oct. 1, 1982. Published December 1982. Originally published as D 558 – 38. Last previous edition D 558 – 57 (1976).

[2] *Annual Book of ASTM Standards*, Vols 04.01 and 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.08.

[4] *Annual Book of ASTM Standards*, Vols 04.01, 04.06, and 14.02.

Standard Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures[1]

This standard is issued under the fixed designation D 559; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 These test methods cover procedures for determining the soil-cement losses, moisture changes, and volume changes (swell and shrinkage) produced by repeated wetting and drying of hardened soil-cement specimens. The specimens are compacted in a mold, before cement hydration, to maximum density at optimum moisture content using the compaction procedure described in Test Methods D 558.

1.2 Two test methods, depending on soil gradation, are covered for preparation of material for molding specimens and for molding specimens as follows:

	Sections
Test Method A, using soil material passing a No. 4 (4.75-mm) sieve. This method shall be used when 100 % of the soil sample passes the No. 4 (4.75-mm) sieve ...	5
Test Method B, using soil material passing a ¾-in. (19.0-mm) sieve. This method shall be used when part of the soil sample is retained on the No. 4 (4.75-mm) sieve ..	6

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 150 Specification for Portland Cement[2]
C 595 Specification for Blended Hydraulic Cements[2]
D 558 Test Methods for Moisture-Density Relations of Soil-Cement Mixtures[3]
D 560 Test Methods for Freezing-and-Thawing Tests of Compacted Soil-Cement Mixtures[3]
D 2168 Test Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors[3]
E 11 Specification for Wire-Cloth Sieves for Testing Purposes[4]

3. Significance and Use

3.1 These test methods are used to determine the resistance of compacted soil-cement specimens to repeated wetting and drying. These test methods were developed to be used in conjunction with Test Methods D 560 and criteria given in the *Soil-Cement Laboratory Handbook*[5] to determine the minimum amount of cement required in soil-cement to achieve a degree of hardness adequate to resist field weathering.

4. Apparatus

4.1 *Mold*—A cylindrical metal mold having a capacity of $1/30 \pm 0.0004$ ft³ (944 ± 11 cm³) with an internal diameter of 4.0 ± 0.016 in. (101.60 ± 0.41 mm) and conforming to Fig. 1 to permit preparing compacted specimens of soil-cement mixtures of this size. The mold shall be provided with a detachable collar assembly approximately 2½ in. (63.5 mm) in height. The mold may be of the split type consisting of two half-round sections or a section of pipe with one side split perpendicular to the pipe circumference and that can be securely locked in place to form a closed cylinder having the dimensions described above. The mold and collar assembly shall be so constructed that it can be fastened firmly to a detachable base.

4.2 *Rammer:*

4.2.1 *Manual Rammer*—A manually operated metal rammer having a 2.0 ± 0.005-in. (50.80 ± 0.13-mm) diameter circular face and weighing 5.5 ± 0.02 lb (2.49 ± 0.01 kg). The rammer shall be equipped with a suitable guidesleeve to control the height of drop to a free fall of 12 ± 1/16 in. (304.8 ± 1.6 mm) above the elevation of the soil-cement. The guidesleeve shall have at least four vent holes not smaller than ⅜ in. (9.5 mm) spaced 90° apart and located with centers ¾ ± 1/16 in. (19.0 ± 1.6 mm) from each end and shall provide sufficient clearance that freefalls of the rammer shaft and head will not be restricted.

4.2.2 *Mechanical Rammer*—A mechanically operated metal rammer having a 2.0 ± 0.005-in. (50.80 ± 0.13-mm) diameter face and a manufactured weight of 5.5 ± 0.02 lb (2.49 ± 0.01 kg). The operating weight of the rammer shall be determined from a calibration in accordance with Methods D 2168. The rammer shall be equipped with a suitable arrangement to control the height of drop to a free-fall of 12.0 ± 1/16 in. (304.8 ± 1.6 mm) above the elevation of the soil-cement.

4.2.3 *Rammer Face*—Strength and resistance to wetting-and-drying of specimens compacted with the sector face rammer may differ from that of specimens compacted with the circular face rammer. Therefore, the sector face rammer

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[1] These test methods are under the jurisdiction of the ASTM Committee D-18 on Soil and Rock and are the direct responsibility of Subcommittee D18.15 on Stabilization of Additives.

Current edition approved July 28, 1989. Published September 1989. Originally published as D 559 – 39. Last previous edition D 559 – 82.

[2] *Annual Book of ASTM Standards*, Vols 04.01 and 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.08.

[4] *Annual Book of ASTM Standards*, Vols 04.01, 04.06, and 14.02.

[5] *Soil-Cement Laboratory Handbook*, Portland Cement Assn., 1971.

Standard Test Methods for Freezing and Thawing Compacted Soil-Cement Mixtures[1]

This standard is issued under the fixed designation D 560; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 These test methods cover procedures for determining the soil-cement losses, moisture changes, and volume changes (swell and shrinkage) produced by repeated freezing and thawing of hardened soil-cement specimens. The specimens are compacted in a mold, before cement hydration, to maximum density at optimum moisture content using the compaction procedure described in Test Methods D 558.

1.2 Two test methods, depending on soil gradation, are covered for preparation of material for molding specimens and for molding specimens as follows:

	Sections
Test Method A, using soil material passing a No. 4 (4.75-mm) sieve. This method shall be used when 100 % of the soil sample passes the No. 4 (4.75-mm) sieve	5
Test Method B, using soil material passing a ¾-in. (19.0-mm) sieve. This method shall be used when part of the soil sample is retained on the No. 4 (4.75-mm) sieve	6

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 150 Specification for Portland Cement[2]

C 595 Specification for Blended Hydraulic Cements[2]

D 558 Test Methods for Moisture-Density Relations of Soil-Cement Mixtures[3]

D 559 Test Methods for Wetting-and-Drying Tests of Compacted Soil-Cement Mixtures[3]

D 2168 Test Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors[3]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[4]

3. Significance and Use

3.1 These test methods are used to determine the resistance of compacted soil-cement specimens to repeated freezing and thawing. These test methods were developed to be used in conjunction with Test Methods D 559 and criteria given in the *Soil-Cement Laboratory Handbook*[5] to determine the minimum amount of cement required in soil-cement to achieve a degree of hardness adequate to resist field weathering.

4. Apparatus

4.1 *Mold*—A cylindrical metal mold having a capacity of 1/30 ± 0.0004 ft³ (944 ± 11 cm³) with an internal diameter of 4.0 ± 0.016 in. (101.60 ± 0.41 mm) and conforming to Fig. 1 to permit preparing compacted specimens of soil-cement mixtures of this size. The mold shall be provided with a detachable collar assembly approximately 2½ in. (63.5 mm) in height. The mold may be of the split type consisting of two half-round sections or a section of pipe with one side split perpendicular to the pipe circumference and that can be securely locked in place to form a closed cylinder having the dimensions described above. The mold and collar assembly shall be so constructed that it can be fastened firmly to a detachable base.

4.2 *Rammer:*

4.2.1 *Manual Rammer*—A manually operated metal rammer having a 2.0 ± 0.005-in. (50.80 ± 0.13-mm) diameter circular face and weighing 5.5 ± 0.02 lb (2.49 ± 0.01 kg). The rammer shall be equipped with a suitable guidesleeve to control the height of drop to a free fall of 12 ± 1/16 in. (304.8 ± 1.6 mm) above the elevation of the soil-cement. The guidesleeve shall have at least four vent holes not smaller than ⅜ in. (9.5 mm) spaced 90° apart and located with centers ¾ ± 1/16 in. (19.0 ± 1.6 mm) from each end and shall provide sufficient clearance that free-fails of the rammer shaft and head will not be restricted.

4.2.2 *Mechanical Rammer*—A mechanically operated metal rammer having a 2.0 ± 0.005-in. (50.80 ± 0.13-mm) diameter face and a manufactured weight of 5.5 ± 0.02 lb (2.49 ± 0.01 kg). The operating weight of the rammer shall be determined from a calibration in accordance with Methods D 2168. The rammer shall be equipped with a suitable arrangement to control the height of drop to a free-fall of 12.0 ± 1/16 in. (304.8 ± 1.6 mm) above the elevation of the soil-cement.

4.2.3 *Rammer Face*—Strength and resistance to freezing and thawing of specimens compacted with the sector face rammer may differ from that of specimens compacted with the circular face rammer. Therefore, the sector face rammer

[1] These test methods are under the jurisdiction of ASTM Committee D-18 on Soil and Rock and are the direct responsibility of Subcommittee D18.15 on Stabilization of Additives.

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[2] *Annual Book of ASTM Standards*, Vols 04.01 and 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.08.

[4] *Annual Book of ASTM Standards*, Vols 04.01, 04.06, and 14.02.

[5] *Soil-Cement Laboratory Handbook*, Portland Cement Assn., 1971.

Standard Test Methods for Determining Consistency and Density of Roller-Compacted Concrete Using a Vibrating Table[1]

This standard is issued under the fixed designation C 1170; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 These test methods are used to determine the consistency of concrete by the Vebe[2] consistometer apparatus and the density of the consolidated concrete specimen. These test methods are applicable to freshly mixed concrete, prepared in both the laboratory and the field, having a nominal maximum size aggregate of 50 mm (2 in.) or less. If the nominal maximum size of aggregate is larger than 50 mm (2 in.), the methods are applicable only when performed on the fraction passing the 50-mm (2-in.) sieve with the larger aggregate being removed in accordance with Practice C 172.

1.2 These test methods, intended for use in testing roller-compacted concrete, may be applicable to testing other types of concrete such as cement-treated aggregate and mixtures similar to soil-cement.

1.3 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information purposes only.

1.4 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 29/C 29M Test Method for Unit Weight and Voids in Aggregates[3]

C 143 Test Method for Slump of Hydraulic Cement Concrete[3]

C 172 Practice for Sampling Freshly Mixed Concrete[3]

E 1 Specification for ASTM Thermometers[4]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[5]

2.2 *ACI Reports and Standards:*

207.5R-88 Report on Roller-Compacted Concrete[6]

211.3-75 (R 1988) Standard Practice for Selecting Proportions for No-Slump Concrete[6]

2.3 *Bureau of Reclamation Test Procedure:*

USBR 4905-86 Consistency and Density of No-Slump Concrete by Vibrating Table[7]

2.4 *British Standard:*

BS 1881: Part 104: 1983 Method for Determination of Vebe Time[8]

3. Summary of Test Methods

3.1 The Vebe vibrating table is used to measure the consistency of stiff to extremely dry concrete mixtures (Note 1). Consistency is measured as the time required for a given mass of concrete to be consolidated by vibrating in a cylindrically shaped mold. Density of the compacted specimen is measured by determining the mass of the consolidated specimen and dividing by its volume, which is determined using water-displacement methods.

NOTE 1—Further description of concrete of this consistency is given in ACI 207.5R-88 and ACI 211.3-75 (R 1988).

3.2 Two procedures are provided:

3.2.1. *Test Method A* [using a 50-lb (22.7-kg) surcharge mass placed on top of the test specimen]—Test Method A shall be used for testing concrete of very stiff to extremely dry consistency in accordance with ACI 211.3-75 (R 1988).

3.2.2 *Test Method B* (no surcharge)—Test Method B shall be used for concrete of stiff to very stiff consistency or when the Vebe time by Test Method A is less than 5 s.

4. Significance and Use

4.1 These test methods are intended to be used for determining the consistency and density of stiff to extremely dry concrete mixtures common when using roller-compacted concrete construction.

4.1.1 Because of the stiff to extremely dry consistency of some roller-compacted concrete mixtures, the standard Vebe test method[7] of rodding the specimen in a slump cone is substituted by Test Methods A and B. For Test Method A, the surcharge mass is increased from 6 lb (2.72 kg) to 50 lb (22.7 kg); and for Test Method B, the surcharge mass is eliminated.

4.2 Test Method A uses a 50-lb (22.7-kg) surcharge and is used for concrete consolidated by roller-compaction methods. The consistency and density of concrete suitable

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[1] These test methods are under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregates and are the direct responsibility of Subcommittee C09.45 on Roller-Compacted Concrete.

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[2] The Vebe vibrating table, including cylindrical mold and guide sleeves, is manufactured by SoilTest, 86 Albrecht Drive, P.O. Box 8004, Lake Bluff, IL 60044-9902.

[3] *Annual Book of ASTM Standards*, Vol 04.02.

[4] *Annual Book of ASTM Standards*, Vols 14.03 and 05.03.

[5] *Annual Book of ASTM Standards*, Vols 04.02 and 14.02.

[6] *ACI Manual of Concrete Practice, Part 1, Materials and General Properties of Concrete*, American Concrete Institute, P.O. Box 19150, Detroit, MI 48219, 1988.

[7] "Guidelines for Designing and Constructing Roller-Compacted Concrete Dams," *ACER Technical Memorandum No. 8*, Bureau of Reclamation, Denver, CO, Appendix A, 1987.

[8] *Testing Concrete*, British Standards Institute, 2 Park Street, London, England W1A 2BS.

Standard Practice for Making Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Table[1]

This standard is issued under the fixed designation C 1176; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers procedures for making cylindrical test specimens from concrete when the standard procedures of rodding and internal vibration, as described in Practice C 31, are not practicable. This practice is applicable to freshly mixed concrete, prepared in the laboratory and the field, having a nominal maximum size aggregate of 50 mm (2 in.) or less. If the nominal maximum size aggregate is larger than 2 in., the practice is applicable only when performed on the fraction passing the 50-mm (2-in.) sieve with the larger aggregate being removed in accordance with Practice C 172. This practice, intended for use in testing roller-compacted concrete, may be applicable to testing other types of concrete such as cement-treated aggregate and mixtures similar to soil-cement.

1.2 Two methods are provided for making concrete cylinders using a vibrating table:

1.2.1 Method A is a procedure for making test specimens in steel reusable molds attached to a vibrating table.

1.2.2 Method B is a procedure for making test specimens in single-use plastic molds that have been inserted into a metal sleeve attached to a vibrating table.

1.3 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information purposes only.

1.4 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 31 Practice for Making and Curing Concrete Test Specimens in the Field[2]

C 39 Test Method for Compressive Strength of Cylindrical Concrete Specimens[2]

C 143 Test Method for Slump of Hydraulic Cement Concrete[2]

C 172 Practice for Sampling Freshly Mixed Concrete[2]

C 192 Practice for Making and Curing Concrete Test Specimens in the Laboratory[2]

C 470 Specification for Molds for Forming Concrete Test Cylinders Vertically[2]

C 496 Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens[2]

C 1170 Test Methods for Consistency and Density of Roller-Compacted Concrete Using a Vibrating Table[2]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[3]

2.2 *ACI Reports and Standards:*

207.5R-88 Report on Roller-Compacted Concrete[4]

211.3-75 (R 1988) Practice for Selecting Proportions for No-Slump Concrete[4]

2.3 *Bureau of Reclamation Test Procedure:*

USBR 4906-86 Casting No-Slump Concrete in Cylinder Molds Using Vibratory Table[5]

3. Summary of Practice

3.1 This practice describes methods for making cylindrical concrete test specimens using a vibrating table. Test specimens are made in cylindrical molds that are attached to the vibrating table under a 20-lb (9.1-kg) surcharge to facilitate consolidation.

4. Significance and Use

4.1 This practice is intended to be used for stiff to extremely dry concrete mixtures commonly used in roller-compacted concrete construction. This practice is used instead of rodding or internal vibration, which cannot properly consolidate concrete of this consistency (Note 1).

NOTE 1—Further description of this concrete consistency is given in ACI 207.5R-88 and 211.3-75 (R 1988). The consistency of concrete may be determined in accordance with Test Method C 1170.

5. Apparatus

5.1 *Molds:*

5.1.1 *Type A Mold*—A cylindrical mold conforming to the requirements of Specification C 470 for 6-in. (152-mm) diameter by 12-in. (305-mm) high reusable molds. Molds shall be made of steel or other hard metal not readily attacked by the cement paste. Aluminum molds shall not be used. Molds shall be equipped with permanently affixed metal slotted brackets on the baseplate so the molds can be rigidly clamped to a vibrating table. The top rim of the mold

[1] This practice is under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.45 on Roller-Compacted Concrete.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vols 04.02 and 14.02.

[4] *ACI Manual of Concrete Practice, Part 1, Materials and General Properties of Concrete*, 1988, American Concrete Institute, P.O. Box 19150, Detroit, MI 48219.

[5] "Guidelines for Designing and Constructing Roller-Compacted Concrete Dams," *ACER Technical Memorandum No. 8*, Bureau of Reclamation, Denver, CO, Appendix A, 1987.

Mass Concrete

Reported by ACI Committee 207

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This report presents a discussion of materials and practices employed in proportioning, mixing, placing, and curing mass concrete, and of the properties and behavior of the hardened mass concrete. Particular emphasis is placed on the differences between mass concrete and other concrete. It is designed to serve as a reference for those engaged in the design and construction of massive concrete elements and structures.

Keywords: admixtures; aggregate gradation; aggregate size; aggregates; air entrainment; arch dams; batching; bridge piers; cements; compacting; compressive strength; concrete construction; concrete dams; concrete durability; cooling; cracking (fracturing); creep properties; **curing;** diffusivity; formwork (construction); heat of hydration; history; instruments; **mass concrete;** measuring instruments; **mix proportioning;** mixing; modulus of elasticity; permeability; **placing;** Poisson's ratio; pozzolans; roller compacted concrete; shear properties; shrinkage; strains; stresses; temperature control; temperature rise (in concrete); thermal expansion; thermal gradient; thermal properties; vibration; volume change.

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Roller Compacted Mass Concrete

Reported by ACI Committee 207

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Roller compacted concrete (RCC) is a concrete of no-slump consistency in its unhardened state that is transported, placed, and compacted using earth and rockfill construction equipment. Properties of hardened RCC are similar to those of conventionally placed concrete. This report applies to the use of RCC in structures that require measures be taken to cope with the generation of heat from hydration of the cementitious materials and attendant volume change to minimize cracking. Mixture proportioning, physical properties, mixing, transporting, placing, consolidating, curing, protection, testing, inspection, design, and construction are covered.

Keywords: admixtures; aggregate gradation; **aggregates**; aggregate size; air entrainment; cement pastes; cements; coarse aggregates; **compacting; compressive strength; concrete construction**; concrete dams; **concretes; consolidation**; construction joints; conveying; creep properties; curing; dams; **density (mass/volume)**; durability; elastic properties; fine aggregates; fly ash; formwork (construction); gap-graded aggregates; gravity dams; joints (junctions); mass concrete; mixers; **mixing; mixture proportioning**; modulus of elasticity; **no-slump concrete; permeability; placing**; pozzolans; shear properties; stability; structural design; temperature; thermal properties; **vibration**; voids; volume change; water-cement ratio; water content; workability.

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*Task Group member.
Committee 207 acknowledges with thanks the contribution of Lewis H. Tuthill, consulting member of the committee.
This report supersedes ACI 207.5R-80.

containers for maximum aggregate sizes equal to or less than 1½ inches and for sizes greater than 1½ inches. The larger sizes use greater input vibration to offset the size effect of the larger containers. The proper vibration time for the smaller sizes appears to be approximately 20 sec, whereas it appears to be about 60 sec for the larger sizes.

Consolidation is the reduction of entrapped air voids within the mass by rearrangement of aggregate particles. Compaction reduces the volume of entrapped air by forcing the aggregate particles into a smaller volume. The degree to which this is accomplished is dependent on the lubrication of the aggregate particles by the surrounding paste (water, cement, and pozzolan) and the combined effects of vibration and compactive effort. If the paste volume is inadequate or the paste is too fluid, there will be inadequate lubrication of particles for lateral movement and consolidation will be more difficult.

There will be little, if any, discernible change in the compacted surface of the RCC to indicate that full compaction has been accomplished. When the paste content is adequate to provide a measurable consistency, paste will rise to the surface and fill the voids between aggregates. The time required for this to be accomplished is an indication of the mixture's workability.

6.7—Compressive strength

Compressive test specimens of mixtures having a consistency measurable by vibration time will fully consolidate under extended externally applied vibration. Full consolidation is achieved when paste rises to the surface. Overvibration is not a problem because of the very low entrainment of air in mixtures of this stiffness. Cylinders will require longer periods of vibration than the consistency measurements because of the difference in shape of the containers. A surcharge weight may be needed for mixtures that require more than 30 sec of vibration for consolidation by the standard Vebe. Test specimens molded in this fashion correlate extremely well with cores when tested at the same age.

Test specimens of mixtures of unmeasurable consistency will not fully consolidate under external vibration and must be molded by some other means.[29] At Willow Creek, the tamped specimens of the leaner mixtures were consistently higher in strength than the vibrated specimens. With the exception of the upstream concrete, the cores at one year correlated reasonably well with the 9 x 18 in. test specimens. The cores of richer mixtures also correlated with the 6 x 12 in. Vebe molded specimens. The key to preparing test specimens of unmeasurable consistency RCC appears to be that of correlating the compactive effort in tamping the cylinders with the compactive effort of the field placement.

6.8—Density

Due to limitations in some laboratory techniques and equipment, density and compressive strength cylinders made in the laboratory may not be representative of the quality achievable in the field. If these limitations are not recognized, they can result in the unwarranted use of extra cement or fly ash, a more restrictive aggregate specification than is required, or overdesign. During construction, comparisons should be made to see how closely laboratory procedures simulated field compaction and achieved similar qualities.

Low densities can be the result of various deficiencies, including high or low moisture, insufficient rolling, a vibratory amplitude or frequency inappropriate for the material, time delay before rolling, poor gradation or segregation, and nonrepresentative testing. The deficiency should be promptly identified and corrected.

Two approaches to quality control of RCC density are by method and by performance. For routine control during construction, specifying a method of spreading and a minimum number of passes with required rolling equipment has been successful. Specifying performance with a minimum density and an average required density regardless of the number of passes is an alternate approach requiring more testing but providing tighter control of placement. Density tests should be performed to verify that the specified method is routinely providing the required density and should be taken on a random basis to provide the necessary coverage of each lift.

As with moisture, a chart should be kept showing the number of tests performed each day, the standard deviations, the average density for the day, and the moving average of the last 50 tests. Fig. 6.1 shows a density control chart from Willow Creek Dam.

6.9—Placing and joint bonding

An important element of quality control in RCC is visual monitoring of the delivery, dumping, and spreading operation. Segregation, contamination, and timeliness should be carefully monitored and procedures should be immediately corrected when seen to be deficient. This includes preventing contamination of lift surfaces by hauling equipment, preventing the freshly spread compacted surfaces from drying, avoiding segregation and monitoring joint maturity in degree-hours (see Section 4.5.1).

To assure proper bonding, the joint or lift upon which fresh RCC is to be placed must be clean and damp. When a dry or damaged surface develops, or if its specified maturity limit is exceeded, joint treatment is necessary prior to placing the next layer. This may include cleaning the surface with air jets and providing a bedding mixture.

6.10—Frequency of testing during construction

Table 6.2 chart shows a recommended range relative to field testing frequency.

6.11—Grade and alignment control

The compactive equipment used in RCC construction is typically insensitive to minor and gradual variations in lift thickness. A tolerance of about ±15 per-

Table 1 — Principal sources of variations in strength test results

Variations in properties of concrete	Discrepancies in testing methods
Changes in water-cement ratio Poor control of water Excessive variation of moisture in aggregate Retempering	Improper sampling procedures
Variations in water requirement Aggregate grading, absorption, particle shape Cement and admixture properties Air content Delivery time and temperature	Variations due to fabrication techniques Cylinder molding Poor quality molds Handling and curing of newly made cylinders
Variations in characteristics and proportions of ingredients Aggregates Cement Pozzolans Admixtures	Changes in curing Temperature variation Variable moisture Delays in bringing cylinders to the laboratory
Variations in batching, mixing, transporting, placing, and compaction Variations in temperature and curing	Poor testing procedures Care of cylinders, transportation and capping Improper placement in testing machine Testing machine platens out of specifications Incorrect speed of testing

CONSTRUCTION CONTROL OF RCC AND SOIL-CEMENT USING THE HEAT OF NEUTRALIZATION TEST, NUCLEAR MOISTURE DENSITY GAUGE, VIBRATING COMPACTION HAMMER, AND VEBE[a]

By E. Kunzer[1] and A. Benavidez[2]

Abstract: Soil-cement and roller-compacted concrete (RCC) require a combination of soil and concrete construction control methods. These methods need to be simple and quick because of field conditions, rapid placing rates, and need for fast feedback to the inspectors and the contractor. The Bureau of Reclamation (Reclamation) uses a modified heat of neutralization test to monitor cement content, vibrating table (Vebe) tests to check consistency and wet density of RCC, and a combination of sand cone density tests and nuclear moisture-density gauge measurements to monitor compaction. A vibrating compaction hammer is being evaluated to determine maximum dry unit weight and to prepare compressive strength test cylinders. Data are presented on the advantages and disadvantages of the various methods and their applicability to soil-cement and RCC.

INTRODUCTION

As construction materials, soil-cement and roller-compacted concrete (RCC) are a transition between soil and concrete. They combine the workability of soil when freshly placed with the increasing strength of conventional concrete as they cure. Soil-cement and RCC are used for such things as road subbases, backfill, pipe bedding, channel and reservoir linings, protective blankets, and slope protection. Also, RCC has been used for gravity concrete dam construction. Mixture proportions differ between soil-cement and RCC primarily in aggregate grading, consistency, and cement plus pozzolan content. The mixture proportions range from a stabilized soil mix with no plus 4.75-mm (No. 4) sieve material to a lean concrete mix with up to 55 percent plus 4.75 mm (No. 4) size material that may include water-reducing admixtures and pozzolan. Conventional soil and concrete placing methods and construction control must be adapted to deal with the special characteristics resulting from this range of materials and mixture proportions.

Soil-cement and RCC can contain 0-30 percent fine, nonplastic soil; enough water to wet the mixture to within ± 1 percent of optimum water content; 3-16 percent portland cement; and may contain up to 55 percent minus 51 mm (2 inch) to plus 4.75 mm (No. 4) aggregate. All proportions are based on dry mass of soil and/or aggregate. RCC tends to have less fines and more coarse aggregate than soil-cement. After placing, the mixture is usually compacted to 98-100 percent of maximum dry unit weight (soil-cement) or air-free wet density (RCC) using modified earth fill placement techniques. Soil-cement is moist-cured for 7 days. When used, soil-cement and RCC are chosen because of workability, adaptability to a wide range of applications, rapid construction capability, and generally lower cost than alternatives. The Bureau of Reclamation (Reclamation) uses soil-cement and RCC for slope protection when a source of high quality riprap is not economically available, or for overtopping protection. RCC is also used as mass concrete in dams and other large placements.

Soil-cement and RCC placement is very rapid, field conditions can be demanding, and trained personnel are usually scarce. Because of these circumstances, inspectors and contractors need quick and accurate construction control tests requiring a minimum number of personnel using equipment that remains accurate under field conditions. To meet these testing needs, Reclamation uses a modified heat of neutralization test to monitor cement content of freshly mixed soil-cement, a vibrating table (Vebe) test to check consistency and wet density of RCC, and sand cone density tests and/or nuclear moisture-density gauge measurements to monitor compaction of both soil-cement and RCC. Reclamation is also evaluating the use of a vibrating compaction hammer to replace compaction machines presently used to determine maximum dry unit weight of soil-cement, and to prepare compressive strength test cylinders for soil-cement and RCC. This paper discusses the use of these tests (table 1) and presents some preliminary data from the vibrating hammer evaluations.

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The Vebe is also used to make strength test specimens. These specimens are made using a 150- by 300-mm (6- by 12-inch) metal or plastic mold which is attached to the Vebe apparatus. Place RCC in three separate lifts by vibrating each lift under a 9.1 ± 0.25 kg (20 ± 0.5 lbm) surcharge until a mortar ring forms around the perimeter of the surcharge.

The Vebe must be securely anchored and should be calibrated regularly to ensure proper frequency and amplitude of the platform. When this is done, the Vebe allows rapid determination of RCC consistency and density and can fully consolidate RCC specimens for compressive strength testing. Testing and preparation time is similar to that of construction control for conventional concrete. The Vebe is not used for testing soil-cement mixtures with a high pit-run fines content because of incomplete consolidation and problems with formation of the mortar ring.

VIBRATING HAMMER

The vibratory hammer is a rugged, simple field instrument which has possibilities for determining the maximum dry density of cohesionless materials and preparing test specimens for RCC and soil-cement. The core of this apparatus is of the same type currently used for drilling and/or chipping concrete and other structural material.

Reclamation constantly evaluates new testing equipment and procedures to obtain optimum efficiency for field and laboratory operations. A possible replacement method for vibratory tables used to determine maximum dry density of cohesionless materials (relative density test) is needed because of problems with premature failure of table parts and sensitivity to line voltage and amperage fluctuations (Selig and Ladd 1973). The British Standards Institute (BSI) has adopted vibrating hammers for densification testing of cohesionless soils and graded aggregates (BS 1924, BS 5835, and BS 1377).

Reclamation is currently investigating the use of vibrating hammers for determining the maximum dry unit weight of cohesionless soils, preparing soil-cement and RCC test specimens, and determining wet density of soil-cement and RCC. Two sizes of Kango™ vibrating hammer are being studied. One is model 638 rated at 750 watts and delivering 2800 blows per minute, and the other is model 950X rated at 1020 watts and delivering 2000 blows per minute. The hammers are mounted in a compaction rig attached to a concrete block (figure 7). The original design was adapted by addition of an electric winch to aid in raising and lowering the compaction hammer and an automatic timer to increase accuracy.

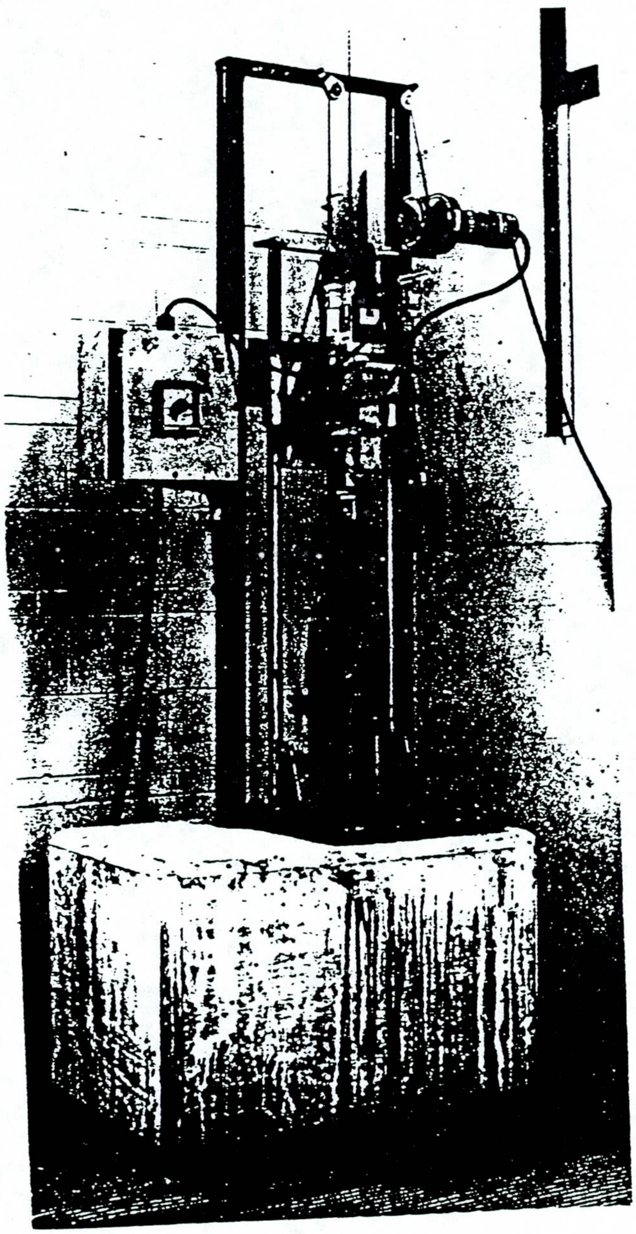

Figure 7. Vibrating Hammer Compaction Apparatus

Initial results using the Kango™ hammer model 638 for maximum density determinations (table 6), indicate good correlation with results using an accepted standard (USBR 5330). The complete test results are forthcoming (Benavidez and Young in publication).

Roller Compacted Concrete for Embankment Overtopping Protection

by

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ABSTRACT

In the first National Dam Safety Inventory and inspection performed by the Corps of Engineers, the majority of deficiencies found were related to the inability of the project to retain or safely pass the Probable Maximum Flood, i.e., a hydraulic deficiency. The ability to economically modify a project to remedy this type of deficiency is particularly important for small dams.

A method which has proven both effective and economical is the use of roller compacted concrete (RCC) to provide additional spillway capacity or protection for safe overtopping of embankment dams. At this time, thirty projects in the USA have been modified using RCC, and several have been tested by experiencing spillway or overtopping flows.

This paper presents a summary of projects where RCC has been used; a review of design considerations involved in this type of remedial construction; and a review of the "soils" approach to RCC mix design and construction procedures. Comments on successes, performance, and lessons learned, or suggestions for improvements are presented.

INTRODUCTION

The overtopping of embankments may result in serious erosion and ultimate failure, depending on the height of overtopping, duration of flow, slope of the downstream flow surface, the nature of the materials in the embankment, and the degree of protection provided. The impacts of dam failure resulting in total or partial loss of the reservoir may include loss of life, or may be purely economic. There has been a rapidly changing state

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operation, and the overall production rate can usually be increased due to more efficient construction methods and greater working space.

Included in Table 2 are the low bid, unit costs for overtopping protection projects. Generally, the cost of aggregate and processing has been considerably greater than the cost of cement or cement plus fly ash. Therefore, in order to reduce costs on these small volume projects, greater consideration should be given to simplifying the aggregate requirements and construction operations than to reducing the amount of cementitious materials. Formed steps generally increase costs and reduce placement rates.

RCC MIX PROPORTIONING CRITERIA AND MATERIALS

General

The basic objective in determining RCC mix proportions is to produce a concrete that satisfies performance requirements using the most economical combination of materials that can be placed by roller-compaction methods. In the selection of design criteria and materials for RCC overtopping protection projects, the designer must consider that the RCC is exposed to the weather and infrequent spillway flows.

Because adequate air-entrainment is usually not obtainable in the drier RCC mixtures associated with the "soils" approach to RCC mixture proportioning (Reeves and Yates, 1985; Hansen, 1991), the durability of RCC is correlated with its compressive strength, which is directly proportional to its dry density for a constant mixture. In areas where the RCC is exposed to few, if any, freeze-thaw cycles per year, a minimum 28-day compressive strength of 14.5 MPa (2100 lb/in^2) is suggested. For freeze-thaw areas, a 20.7 MPa (3000 lb/in^2) 28-day compressive strength is considered a minimum. With a well-graded, high quality aggregate, a minimum cementitious content of 148 and 193 k/m^3 (250 and 325 lb/yd^3), respectively, will generally produce the required durability. If the aggregate is of lesser quality, or is not well-graded, higher cementitious contents will be required to produce the desired strength.

The suggested RCC mix proportion criteria assume infrequent flows of water containing little abrasive material. Also, designs generally assume that some minor surface weathering or erosion is acceptable, as more RCC thickness than necessary to meet design requirements usually results from the minimum width of stair-stepped RCC layers (usually 8 feet minimum) needed for ease and safety of construction using traditional earth-moving equipment. If abrasive flow is anticipated, the strength requirements should be increased and a competent aggregate used in the mixture.

RCC Mix Proportioning Concepts

In the development of RCC technology for dams, two concepts or approaches to RCC mix proportioning emerged. They have been termed the "soils," or geotechnical, approach and the "concrete" approach. Although both approaches can produce a concrete that is termed "zero" slump, mixes produced using "concrete" proportioning methods have a more fluid consistency than those developed using the "soils" approach.

The basic difference is that for "concrete" mixes there is enough paste available to fill all voids in the aggregate following some vibration. For "soils" mixes, all voids are generally not filled following compaction. In the "soils" approach to RCC mix proportions, the goal is to determine an optimum moisture content in the laboratory which corresponds to the compactive effort and density obtained by vibratory rolling in the field. A modified Proctor test (ASTM D-1557) has generally been used. The "concrete" approach to RCC mix design assumes a fully consolidated concrete whose strength and other properties follow the traditional water-cement ratio law (i.e., a lower water-cement ratio produces higher strength).

PROJECT DATA

AND

DISCUSSION

CEMENT CONTENT TESTS

Titration tests to determine cement content of the RCC mix were performed daily, in the morning. The design required a content of 10.7% by volume. The attached data sheets and graph summarize the daily titration results and the corresponding 28-compressive strength values from tests performed by ATL.

The graph dramatically shows the "shotgun" results, with compressive strength values above and below the 3000 psi target, regardless of cement content. More than 80% of the cement content values met or exceeded 10.7%.

ATL Testing Laboratories

PULICE CONSTRUCTION – EAST PAPAGO LOOP

RCC DESIGN
DESIGN STRENGTH: 3000 psi @ 28 DAYS

DATE TESTED	COMPRES. STRENGTH	CEMENT CONTENT
10-21-93	3430	10.7
10-21-93	2160	10.7
10-22-93	3700	10.7
10-22-93	2740	10.7
10-22-93	1750	10.7
10-25-93	2020	9.8
10-25-93	2420	9.8
10-25-93	3710	9.8
10-25-93	4160	9.8
10-26-93	3520	11.4
10-26-93	3940	11.4
10-26-93	3540	11.4
10-26-93	2830	11.4
10-27-93	3170	10.5
10-27-93	2880	10.5
10-27-93	3590	10.5
10-27-93	3930	10.5
10-28-93	2830	11.7
10-28-93	2740	11.7
10-28-93	3340	11.7
10-28-93	2480	11.7
10-29-93	3170	11.0
10-29-93	2740	11.0
10-29-93	2650	11.0
10-29-93	3260	11.0
10-30-93	1150	11.2
10-30-93	3340	11.2
10-30-93	1690	11.2
11-02-93	2730	11.0
11-02-93	2910	11.0
11-02-93	3000	11.0
11-02-93	4190	11.0
11-03-93	3090	10.7
11-03-93	3270	10.7
11-03-93	2640	10.7
11-03-93	3010	10.7
11-04-93	3170	10.7
11-04-93	3610	10.7
11-04-93	3960	10.7
11-04-93	2120	10.7
11-05-93	2260	11.2
11-05-93	3660	11.2
11-05-93	2760	11.2
11-05-93	2830	11.2
11-08-93	2180	10.8
11-08-93	1720	10.8
11-08-93	2030	10.8
11-08-93	1630	10.8
11-09-93	2200	10.4
11-09-93	1450	10.4
11-09-93	1690	10.4
11-09-93	2620	10.4

no Flyash on 10/30

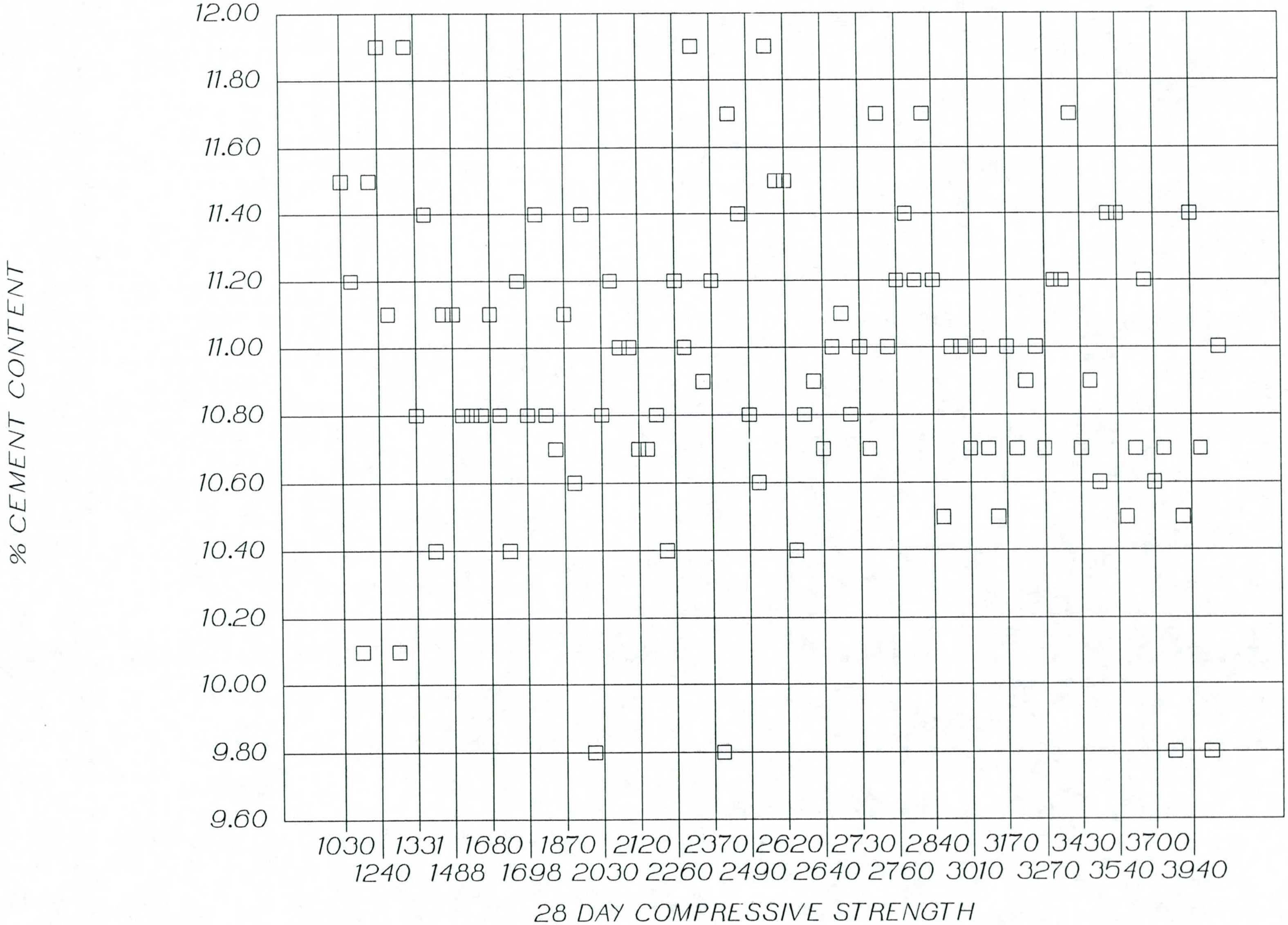
PULICE CONSTRUCTION – EAST PAPAGO LOOP

RCC DESIGN
DESIGN STRENGTH: 3000 psi @ 28 DAYS

DATE TESTED	COMPRES. STRENGTH	CEMENT CONTENT
11-10-93	3080	11.0
11-10-93	2100	11.0
11-10-93	2120	11.0
11-10-93	2300	11.0
11-12-93	1870	11.1
11-12-93	1680	11.1
11-19-93	2560	11.5
11-19-93	2620	11.5
11-19-93	1030	11.5
11-19-93	1180	11.5
11-20-93	1330	11.9
11-20-93	1240	11.9
11-20-93	2300	11.9
11-20-93	2550	11.9
11-22-93	1410	11.4
11-22-93	1700	11.4
11-22-93	2000	11.4
11-22-93	2490	11.4
11-23-93	2840	11.2
11-23-93	3280	11.2
11-23-93	2080	11.2
11-23-93	2370	11.2
11-24-93	3700	10.6
11-24-93	3490	10.6
11-24-93	1950	10.6
11-24-93	2540	10.6
11-29-93	1160	10.1
11-29-93	1320	10.1
12-03-93	1488	11.1
12-03-93	2666	11.1
12-03-93	1297	11.1
12-03-93	1480	11.1
12-06-93	1698	10.8
12-06-93	1601	10.8
12-06-93	1495	10.8
12-06-93	1331	10.8
12-07-93	2310	10.9
12-07-93	2639	10.9
12-07-93	3230	10.9
12-07-93	3460	10.9
12-08-93	2490	10.8
12-08-93	2690	10.8
12-08-93	2630	10.8
12-08-93	1680	10.8

PULICE CONSTRUCTION - EAST PAPAGO LOOP

28 DAY COMPRESSIVE STRENGTH vs % CEMENT



ATL and ADOT Strength Results

The following sheets summarize 28-day compressive strength data obtained from both ATL and ADOT's laboratories. Note that both laboratories assisted in fabricating the cylinders in the field and then transported the specimens to their laboratories for curing and crushing.

The wide, within test variation of 24% indicates that the procedure is not precise. The fact that many specimens exceeded the 3000 psi requirement indicates that the mix design has been followed. The ONLY significant variable being the variability due to cylinder fabrication.

ATL Testing Laboratories

PULICE CONSTRUCTION – EAST PAPAGO LOOP

ATL vs. ADOT BREAKS
RCC DESIGN – BREAK DATA

TEST NO.	LAB NO.	DATE CAST	ATL'S 28 DAY (psi)	ATL'S 28 DAY AVG. (psi)	ADOT'S 28 DAY (psi)
1	1500	10–21–93	3430		
2	1500	10–21–93	2160	2795	
3	1522	10–22–93	3700	3700	3686
4	1523	10–22–93	2740		
5	1523	10–22–93	1750	2245	4461
6	1542	10–25–93	3710		
7	1542	10–25–93	4160	3935	3377
8	1543	10–25–93	2020		
9	1543	10–25–93	2420	2220	3398
10	1560	10–26–93	3940		
11	1560	10–26–93	2830	3385	3191
12	1561	10–26–93	3520		
13	1561	10–26–93	3540	3530	3747
14	1567	10–27–93	3930		
15	1567	10–27–93	3590	3760	3822
16	1568	10–27–93	2880		
17	1568	10–27–93	3170	3025	2660
18	1609	10–28–93	2480		
19	1609	10–28–93	2830	2655	3350
20	1610	10–28–93	2740		
21	1610	10–28–93	3340	3040	4386
22	1611	10–29–93	2740		
23	1611	10–29–93	2650	2695	3627
24	1612	10–29–93	3170		
25	1612	10–29–93	3260	3215	2024
26	1613	10–30–93	1690	1690	2513
27	1619	10–30–93	1150		
28	1619	10–30–93	3340	2245	4240
29	1621	11–01–93	2920	2920	3278
30	1622	11–01–93	3015	3015	3467
31	1630	11–02–93	4190		
32	1630	11–02–93	2730	3460	2873
33	1631	11–02–93	3000		
34	1631	11–02–93	2910	2955	1631
35	1658	11–03–93	2640		
36	1658	11–03–93	3010	2825	1850
37	1659	11–03–93	3090		
38	1659	11–03–93	3270	3180	1954
39	1664	11–04–93	3170		
40	1664	11–04–93	3610	3390	3124
41	1671	11–04–93	3960		
42	1671	11–04–93	2120	3040	1583
43	1689	11–05–93	2760		
44	1689	11–05–93	3660	3210	2088
45	1690	11–05–93	2260		
46	1690	11–05–93	2830	2545	3463
47	1697	11–08–93	2180		
48	1697	11–08–93	2030	2105	3223
49	1699	11–08–93	1630		
50	1699	11–08–93	1720	1675	3172

ATL Testing Laboratories

PULICE CONSTRUCTION – EAST PAPAGO LOOP

ATL vs. ADOT BREAKS
RCC DESIGN – BREAK DATA

TEST NO.	LAB NO.	DATE CAST	ATL'S 28 DAY (psi)	ATL'S 28 DAY AVG. (psi)	ADOT'S 28 DAY (psi)
51	1708	11-09-93	2200		
52	1708	11-09-93	2620	2410	2373
53	1709	11-09-93	1690		
54	1709	11-09-93	1450	1570	3116
55	1713	11-10-93	2100		
56	1713	11-10-93	3080	2590	2592
57	1714	11-10-93	2120		
58	1714	11-10-93	2300	2210	2921
59	1741	11-12-93	1870		
60	1741	11-12-93	1680	1775	3412
61	1802	11-19-93	2560		
62	1802	11-19-93	2620	2590	3259
63	1803	11-19-93	1030		
64	1803	11-19-93	1180	1105	2091
65	1808	11-20-93	1330		
66	1808	11-20-93	1240	1285	1912
67	1809	11-20-93	2300		
68	1809	11-20-93	2550	2425	3573
69	1820	11-22-93	1410		
70	1820	11-22-93	1700	1555	
71	1821	11-22-93	2000		
72	1821	11-22-93	2490	2245	2304
73	1832	11-23-93	2840		
74	1832	11-23-93	3280	3060	2426
75	1833	11-23-93	2080		
76	1833	11-23-93	2370	2225	2950
77	1846	11-24-93	3700		
78	1846	11-24-93	3490	3595	4426
79	1847	11-24-93	1950		
80	1847	11-24-93	2540	2245	2121
81	1859	11-29-93	1160		
82	1859	11-29-93	1320	1240	1622
83	1911	12-03-93	1488		
84	1911	12-03-93	2666	2077	
85	1912	12-03-93	1297		
86	1912	12-03-93	1480	1389	
87	1924	12-06-93	1698		
88	1924	12-06-93	1601	1650	2108
89	1925	12-06-93	1495		
90	1925	12-06-93	1331	1413	1695
91	1945	12-07-93	2310		
92	1945	12-07-93	2639	2475	3223
93	1946	12-07-93	3230		
94	1946	12-07-93	3460	3345	3626
95	1984	12-08-93	2490		
96	1984	12-08-93	2690	2590	3726
97	1985	12-08-93	2630		
98	1985	12-08-93	1680	2155	3539
99					
100					

ATL COMPRESSIVE STRENGTH AND DENSITY

This data is a more detailed summary of ATL's test results, including 7 and 56 day compressive strength tests. In addition, hardened concrete densities of cylinders have been randomly provided along with observations by the laboratory technician of the condition of the cylinder prior to crushing.

Their appears to be a general trend of low hardened density equals low strength. The 56-day strength results indicate a continued strength gain, as would be expected due to the fly ash in the mix. This trend should continue up to 365 days from the date of fabrication.

ATL Testing Laboratories

PULICE CONSTRUCTION – EAST PAPAGO LOOP

RCC DESIGN – MIX SUMMARY
DESIGN STRENGTH: 3000 psi @ 28 DAYS

TEST NO.	LAB NO.	DATE CAST	SAMPLE SOURCE	7 DAY (psi)	7 DAY UNIT WT. (lbs/cu.ft.)	28 DAY (psi)	28 DAY UNIT WT. (lbs/cu.ft.)	56 DAY (psi)	56 DAY UNIT WT. (lbs/cu.ft.)
1	1500	10–21–93	RCC BASIN #1	1330		3430–L			
2	1500	10–21–93	RCC BASIN #1			2160			
3	1522	10–22–93	RCC #1, SOL #1	2420		3700			
4	1523	10–22–93	RCC, SOL #2	2920		2740			
5	1523	10–22–93	RCC, SOL #2			1750–L			
6	1542	10–25–93	1ST LVL, STA. 301+50, 50'RT OF CL	2650	144.30	3710			
7	1542	10–25–93	1ST LVL, STA. 301+50, 50'RT OF CL			4160			
8	1543	10–25–93	SET 2	2030		2020		2480–L	
9	1543	10–25–93	SET 2			2420			
10	1560	10–26–93	1ST LEVEL, STA. 302+00, 250'RT OF CL	3710		3940			
11	1560	10–26–93	1ST LEVEL, STA. 302+00, 250'RT OF CL			2830			
12	1561	10–26–93	1ST LVL, STA. 302+10, 225'LT OF CL	2250–L		3520			
13	1561	10–26–93	1ST LVL, STA. 302+10, 225'LT OF CL			3540			
14	1567	10–27–93	LEVEL 1, 301+74, 25'LT OF CL	4000–L	148.42	3930			
15	1567	10–27–93	LEVEL 1, 301+74, 25'LT OF CL			3590			
16	1568	10–27–93	LEVEL 1, 302+15, 230'RT OF CL	2600–L	143.82	2880			
17	1568	10–27–93	LEVEL 1, 302+15, 230'RT OF CL			3170			
18	1609	10–28–93	STILL BASIN 2, 301+00, 100'LT OF CL	2260–L	148.19	2480–L	151.08		
19	1609	10–28–93	STILL BASIN 2, 301+00, 100'LT OF CL			2830–L	148.91		
20	1610	10–28–93	LEVEL II, 301+45, 215'RT OF CL	2120–L		2740–L	146.02		
21	1610	10–28–93	LEVEL II, 301+45, 215'RT OF CL			3340–L	147.53		
22	1611	10–29–93	301+15, 60'LT OF CL	2300–L		2740		3470	
23	1611	10–29–93	301+15, 60'LT OF CL			2650			
24	1612	10–29–93	300+95, 105'LT OF CL, STILL BASIN II	970–L		3170			
25	1612	10–29–93	300+95, 105'LT OF CL, STILL BASIN II			3260			
26	1613	10–30–93	300+30, LEVEL III, 50'RT OF CL	1800		1690			
27	1619	10–30–93	300+30, LEVEL III, 200'LT OF CL	3430		1150–L			
28	1619	10–30–93	300+30, LEVEL III, 200'LT OF CL			3340			
29	1621	11–01–93	301+00, STILL BASIN III	1590		2920		3630	148.67
30	1622	11–01–93	301+10, 10'RT OF CL	1640		3015		1595	141.17
31	1630	11–02–93	300+05, 50'LT OF CL	4140		4190			
32	1630	11–02–93	300+05, 50'LT OF CL			2730			
33	1631	11–02–93	302+50, 150'RT OF CL	2340		3000			
34	1631	11–02–93	302+50, 150'RT OF CL			2910			
35	1658	11–03–93	300+50, 265'LT OF CL	2070		2640		2492–L	146.45
36	1658	11–03–93	300+50, 265'LT OF CL			3010			
37	1659	11–03–93	300+05, 275'RT OF CL	2860		3090			
38	1659	11–03–93	300+05, 275'RT OF CL			3270			
39	1664	11–04–93	300+25, 250'LT OF CL	2920		3170			
40	1664	11–04–93	300+25, 250'LT OF CL			3610			
41	1671	11–04–93	300+05, 265'RT OF CL	2420–S		3960		4315	146.92
42	1671	11–04–93	300+05, 265'RT OF CL			2120			
43	1689	11–05–93	300+10, 25'RT OF CL	2860		2760			
44	1689	11–05–93	300+10, 25'RT OF CL			3660			
45	1690	11–05–93	STILL BASIN 3, LIFT 7, 300+80, 10'RT	2560		2260			
46	1690	11–05–93	STILL BASIN 3, LIFT 7, 300+80, 10'RT			2830			
47	1697	11–08–93	STILL BASIN 3, 300+30, 225' RT	1540–L		2180		1149–L	144.99
48	1697	11–08–93	STILL BASIN 3, 300+30, 225' RT			2030			
49	1699	11–08–93	300+55, 15' LEFT OF CL	1060		1630–L		909–L	141.33
50	1699	11–08–93	300+55, 15' LEFT OF CL			1720–L			

L = LARGE AIR VOIDS   S = SMALL AIR VOIDS

ATL Testing Laboratories

PULICE CONSTRUCTION – EAST PAPAGO LOOP

RCC DESIGN – MIX SUMMARY
DESIGN STRENGTH: 3000 psi @ 28 DAYS

TEST NO.	LAB NO.	DATE CAST	SAMPLE SOURCE	7 DAY (psi)	7 DAY UNIT WT. (lbs/cu.ft.)	28 DAY (psi)	28 DAY UNIT WT. (lbs/cu.ft.)	56 DAY (psi)	56 DAY UNIT WT. (lbs/cu.ft.)
51	1708	11–09–93	300+70, 200'RT OF CL	880–L		2200		1240	
52	1708	11–09–93	300+70, 200'RT OF CL			2620			
53	1709	11–09–93	301+40, 50'RT OF CL	1330		1690–F		820–L,F	141.30
54	1709	11–09–93	301+40, 50'RT OF CL			1450–F			
55	1713	11–10–93	300+48, 145'LT OF CL	1960		2100		2340	145.97
56	1713	11–10–93	300+48, 145'LT OF CL			3080			
57	1714	11–10–93	300+93, 120'RT OF CL	1680		2120		2491	145.12
58	1714	11–10–93	300+93, 120'RT OF CL			2300			
59	1741	11–12–93	301+20, 50'RT OF CL	2180		1870		2349	147.40
60	1741	11–12–93	301+20, 50'RT OF CL			1680			
61	1802	11–19–93	300+95, BASIN 2, RIGHT OF CL	2300	149.81	2560	144.18	2555	148.52
62	1802	11–19–93	300+95, BASIN 2, RIGHT OF CL			2620	144.52		
63	1803	11–19–93	300+85, BASIN #2, LT OF CL	2030		1030–L		1540	143.10
64	1803	11–19–93	300+85, BASIN #2, LT OF CL			1180–L			
65	1808	11–20–93	301+55, 150'RT OF CL	1330		1330	144.01	2069	144.29
66	1808	11–20–93	301+55, 150'RT OF CL			1240	141.46		
67	1809	11–20–93	301+90, 200'LT OF CL	3220		2300	146.37	2172	152.89
68	1809	11–20–93	301+90, 200'LT OF CL			2550	145.87		
69	1820	11–22–93	301+64, 100'LT OF CL	900–L		1410–L		690	141.60
70	1820	11–22–93	301+64, 100'LT OF CL			1700–L			
71	1821	11–22–93	302+36, 150'RT OF CL	1430–L		2000		2167	145.98
72	1821	11–22–93	302+36, 150'RT OF CL			2490			
73	1832	11–23–93	301+64, 75'RT OF CL	2120		2840			
74	1832	11–23–93	301+64, 75'RT OF CL			3280			
75	1833	11–23–93	301+64, 250'RT OF CL	2060		2080		SCHD. 1/18	
76	1833	11–23–93	301+64, 250'RT OF CL			2370			
77	1846	11–24–93	300+04, 200'LT OF CL	3400–L		3700–L			
78	1846	11–24–93	300+04, 200'LT OF CL			3490–L			
79	1847	11–24–93	300+04, 150'RT OF CL	1640		1950	147.23	SCHD. 1/19	
80	1847	11–24–93	300+04, 150'RT OF CL			2540	144.11		
81	1859	11–29–93	300+80, 255' LEFT OF CL	1470–L		1160–L	143.06	SCHD. 1/24	
82	1859	11–29–93	300+80, 255' LEFT OF CL			1320–L	144.38		
83	1911	12–03–93	301+50, 150' LEFT OF CL	1110		1488	142.90	SCHD. 1/28	
84	1911	12–03–93	301+50, 150' LEFT OF CL			2666	148.45		
85	1912	12–03–93	SET #2	780		1297	142.05	SCHD. 1/28	
86	1912	12–03–93	SET #2			1480	139.82		
87	1924	12–06–93	302+00, 310' LEFT OF CL	1500		1698	141.91	SCHD. 1/31	
88	1924	12–06–93	302+00, 310' LEFT OF CL			1601	143.39		
89	1925	12–06–93	300+42, 300' RIGHT OF CL	970		1495	143.44	SCHD. 1/31	
90	1925	12–06–93	300+42, 300' RIGHT OF CL			1331	140.91		
91	1945	12–07–93	301+50, 310' RIGHT OF CL	1500	144.08	2310	145.61		
92	1945	12–07–93	301+50, 310' RIGHT OF CL			2639	147.69		
93	1946	12–07–93	300+75, 310' LEFT OF CL	2390	144.33	3230	149.07		
94	1946	12–07–93	300+75, 310' LEFT OF CL			3460	142.47		
95	1984	12–08–93	301+00, EAST LEVEE	2050	144.70	2490	145.04		
96	1984	12–08–93	301+00, EAST LEVEE			2690	145.24		
97	1985	12–08–93	APPROX. STA. 302+00, NORTH LEVEE	1400	142.65	2630	144.90		
98	1985	12–08–93	APPROX. STA. 302+00, NORTH LEVEE			1680	143.38		
99									
100									

L = LARGE AIR VOIDS   S = SMALL AIR VOIDS   F = FLAKEY

CEMENT STABILIZED ALLUVIUM - SOIL CEMENT

The following sheets provide data on Cement Stabilized Alluvium (CSA) used on this project. Several points of information need to be noted:

1. The aggregate grading used was identical to the RCC grading.
2. The cementatious material content was 10% by volume. The RCC was 10.7%.
3. The **within-test** variations were much smaller than RCC.
4. The test method used to fabricate the specimens has been proven over the past 40 years.

ATL Testing Laboratories

EAST PAPAGO LOOP – PULICE CONSTRUCTION

CSA BREAKS – DATA SUMMARY

DESIGN STRENGTH: 750 psi @ 7 DAYS

TEST	DATE CAST	LAB NO.	SAMPLE SOURCE	3	7	14	28
1	11-30-93	1857	91+50 NORTH LEVEE		2707		
2	12-01-93	1866	91+00 NORTH LEVEE		4042		
3	12-01-93	1867	91+50 NORTH LEVEE		4271		
4	12-02-93	1906	209+50 NORTH LEVEE		2616		
5	12-02-93	1907	215+00 NORTH LEVEE		3007		
6	12-06-93	1926	NOT NOTED		3155		4420
7	12-09-93	2013	214+00, NORTH LEVEE		3360		3364
8	12-09-93	2014	214+00, NORTH LEVEE		3861		2863
9	12-10-93	2015	208+00, NORTH LEVEE		2831		4197
10	12-10-93	2016	215+00, NORTH LEVEE		2870		4116
11	12-13-93	2030	214+00, NORTH LEVEE		3130		3320
12	12-13-93	2031	205+00, NORTH LEVEE		2984		
13	12-16-93	2054	208+50, NORTH LEVEE		2697		3004
14	12-15-93	2057	205+00, NORTH LEVEE		2465		2200
15	12-15-93	2058	205+00, NORTH LEVEE		2154		3890
16	12-15-93	2059	EAST LEVEE		2379		4080
17	12-14-93	2060	90+00, NORTH LEVEE		2741		3312
18	12-12-93	2117	208+00, NORTH LEVEE		3185		
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37							
38							
39							
AVG					3025		3524

RCC COMPRESSIVE STRENGTHS AND CORE DATA

The following data provides RCC strength data from identical batches, using the CSA procedure of screening material over a 3/4" screen before fabrication in a proctor mold. Companion cylinders were fabricated from the same batch using the RCC procedure. Cores were obtained from the surface course of RCC when fence post holes were drilled and these cores were crushed at 28 days along with the RCC cylinders.

The data indicates that the **method of specimen fabrication** greatly effected the compressive strength. The **core strength were signficantly higher** than the cylinder results. If the 85% allowance is applied, the core strengths averaged 3360 psi. Unit weight data was also complied and shows that the cores were compacted to over 98% of the laboratory value.

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PULICE CONSTRUCTION – EAST PAPAGO LOOP

RCC –3/4" PROCTOR MOLD PLUGS
RCC DESIGN – PLUG vs. 6X12 BREAK DATA
DESIGN STRENGTH: 3000 psi @ 28 DAYS (6X12)
DESIGH STRENGTH: 750 psi @ 7 DAY (RCC PLUG)

DATE CAST	7 DAY RCC PLUG	7 DAY 6X12 CYL.	28 DAY RCC PLUG	28 DAY 6X12 CYL.	28 DAY 6X12 CYLINDER UNIT WT. LBS/CU.FT.	RCC CORE BREAKS	RCC CORE UNIT WT. LBS/CU.FT.
12–07–93	2920	1500	4167	1698	141.91		
				1601	143.99		
12–07–93	3212	2390	3517	3230	149.07		
				3460	142.47		
12–08–93	3710	2050	3517	2490	145.04	** 2349	150.83
				2690	145.24	** 3185	146.50
12–08–93	2911	1400	4929	2630	144.90	** 2992	146.70
				1680	143.38		
12–08–93	* 3349		3846				
12–08–93	* 3051		4850				

* EXTRA SET OF RCC PLUGS CAST.
** CORES TAKEN FROM RCC PLACEMENT ON 12–08–93 at surface

FIELD DENSITY TESTS

The following sheets are represented of the more than 380 field density tests obtained on the RCC in-place. They indicate **no value below 98%** of the laboratory value, which corresponds to densities exceeding 146.7 pcf. Based on the cylinder and core densities, it can be concluded that the RCC material in-place is highly consolidated and moderately or better consolidated cylinders yield 28-day compressive strengths in excess of 3000 psi.

PHOTOGRAPHS

Photo 1. Core: 2992 psi
Cylinder: 2690 psi (Before Preparation)

Photo 2. Core: 1854 psi (Before Preparation)
Cylinder: 2490 psi

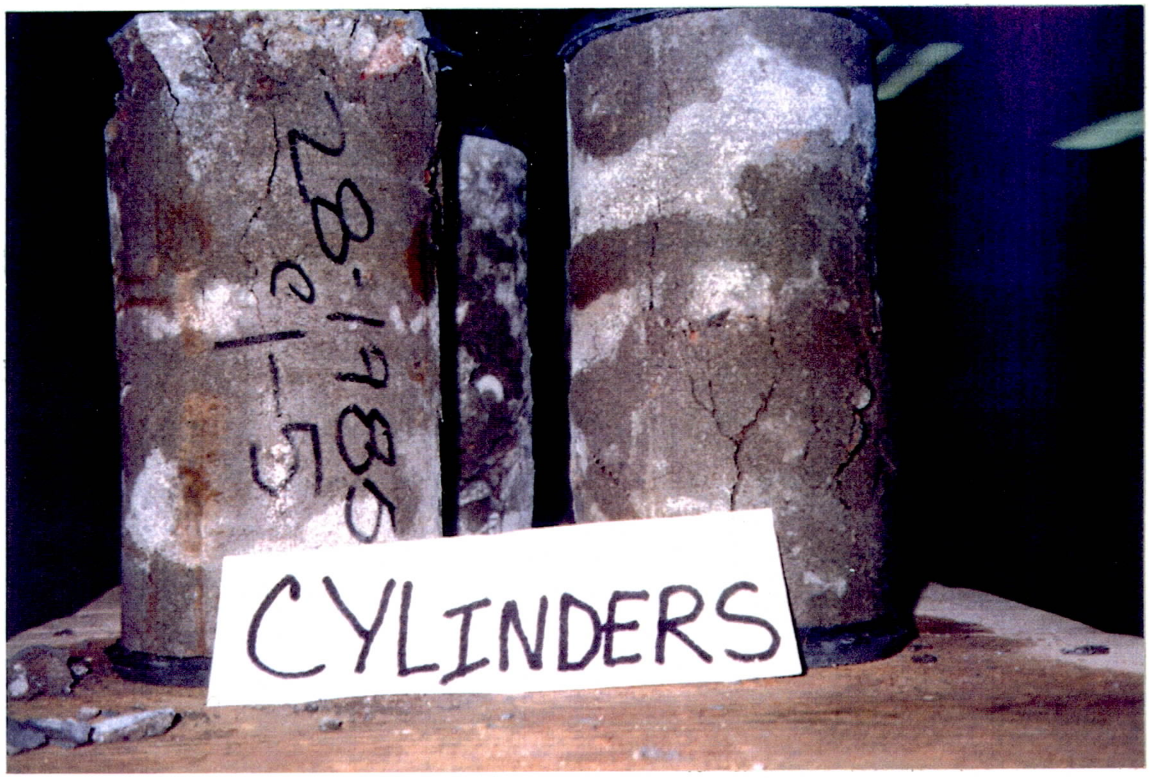

Photo 3. Crushed RCC Cylinders (12/8/93 Placement)

Photo 4. Crushed Cores (12/8/93 Placement)

Photo 5. Crushed RCC Cylinders (12/8/93 Placement)

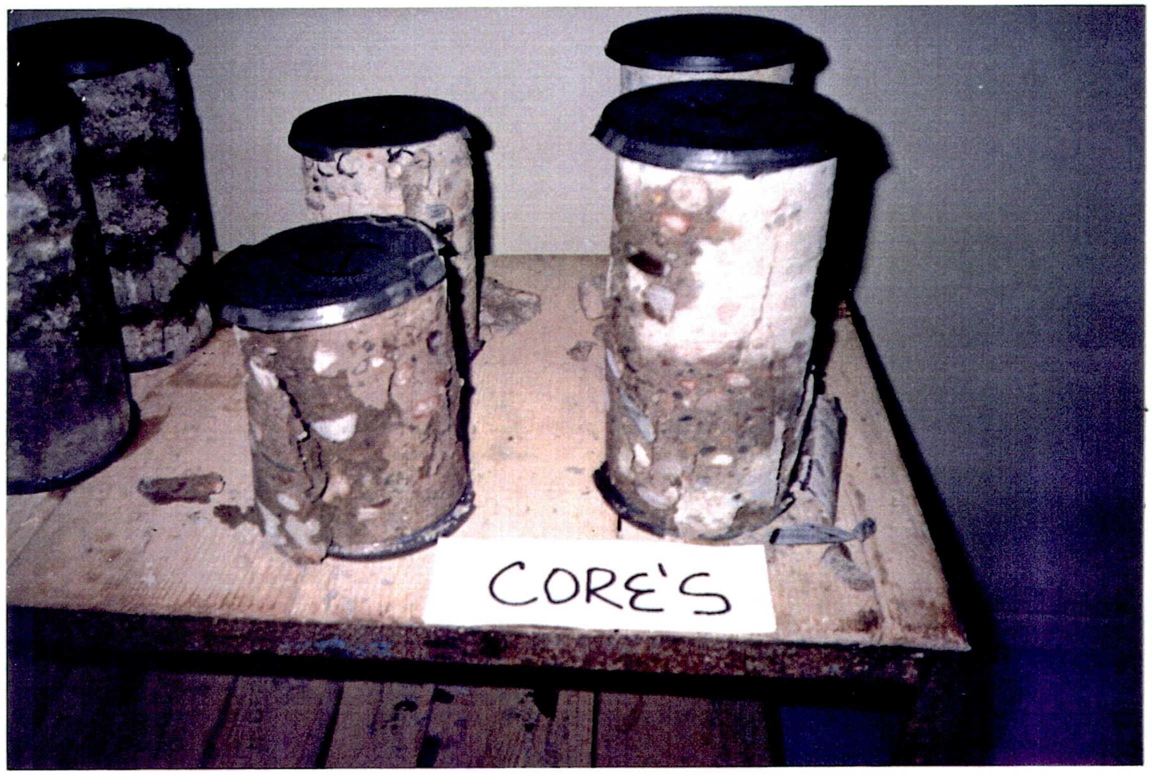

Photo 6. Crushed RCC Cores (12/8/93 Placement)

Photo 7. Cores before Sawing and Corresponding RCC Cylinders

Photo 8. RCC Cores before Sawing & Capping

Photo 9. Core: 2349 psi (Photo before Preparation)
Cylinder: 1680 psi

Photo 10. ***Core: 3185 psi (Before Preparation)***
Cylinder: 2630 psi