US Army Corps of Engineers
Waterways Experiment Station

Technical Report SL-96-15
September 1996

Workability of Mass Concrete

Report 2
Supplemental Proportioning Parameters

by Billy D. Neeley, Michael K. Lloyd

WES

Prepared for Headquarters, U.S. Army Corps of Engineers

Technical Report SL-96-15
September 1996

Workability of Mass Concrete

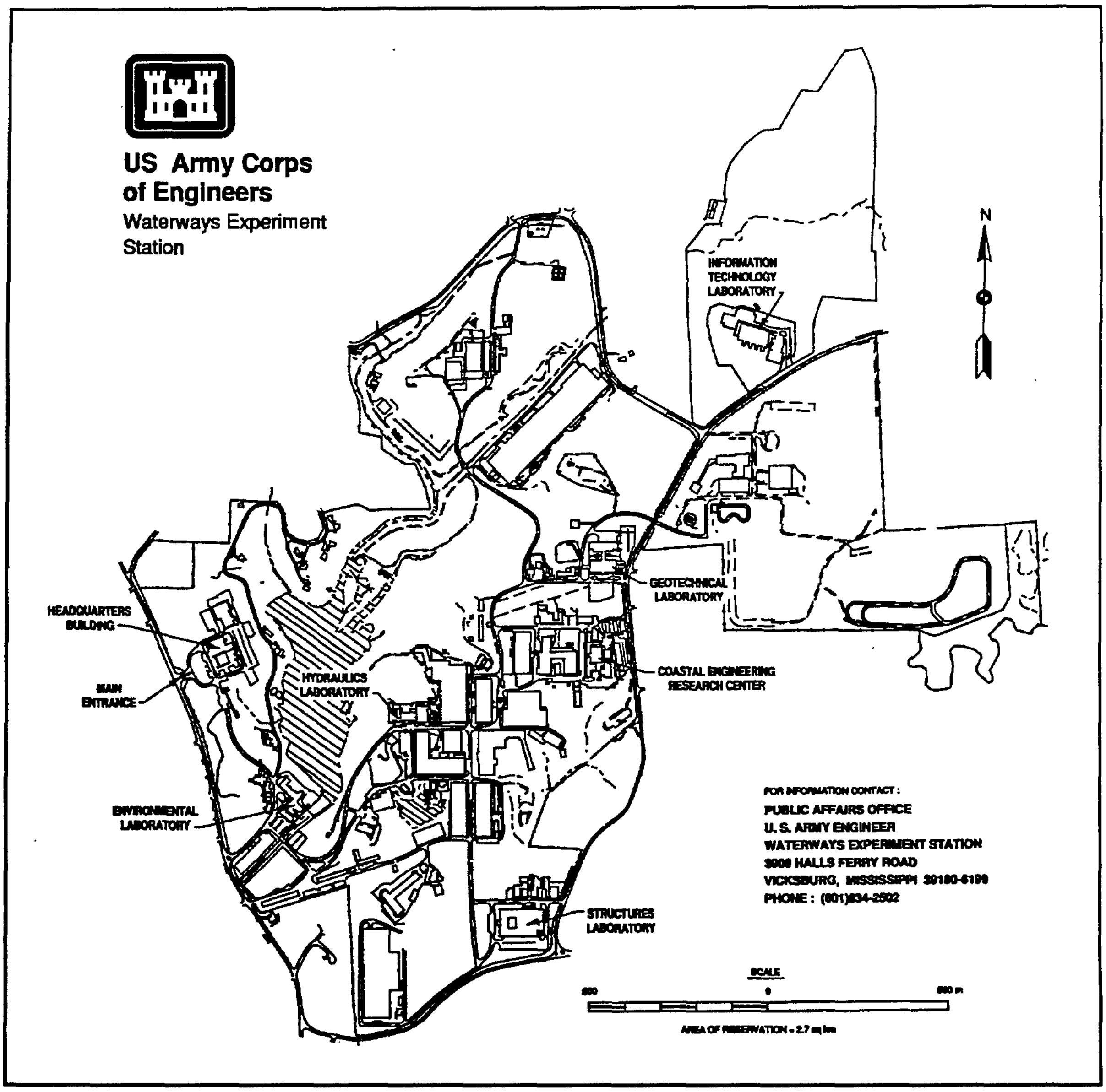
Report 2
Supplemental Proportioning Parameters

by Billy D. Neeley, Michael K. Lloyd

U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Report 2 of a Series

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000



Waterways Experiment Station Cataloging-in-Publication Data

Neeley, Billy D.
Workability of mass concrete. Report 2, Supplemental proportioning parameters / by Billy D. Neeley, Michael K. Lloyd ; prepared for U.S. Army Corps of Engineers.
60 p. : ill. ; 28 cm. — (Technical report ; SL-96-15 rept.2)
Includes bibliographic references.
Report 2 of a series.
1. Concrete — Evaluation. 2. Paste. 3. Mortar. 4. Concrete — Additives. I. Lloyd, Michael K. II. United States. Army. Corps of Engineers. III. U.S. Army Engineer Waterways Experiment Station. IV. Structures Laboratory (U.S. Army Engineer Waterways Experiment Station) V. Title. VI. Title: Supplemental proportioning parameters. VII. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; SL-96-15 rept.2.
TA7 W34 no.SL-96-15 rept.2

Contents

Preface

This report was prepared by the Structures Laboratory (SL), U.S. Army Engineer Waterways Experiment Station (WES), under the sponsorship of Headquarters, U.S. Army Corps of Engineers (HQUSACE), as a part of Civil Works Investigation Studies Work Unit 32768, "Workability of Mass Concrete."

The study was conducted under the general supervision of Messrs. Bryant Mather, Director, SL, and John Q. Ehrgott, Assistant Director, SL. Direct supervision was provided by Dr. Paul F. Mlakar, Chief, Concrete and Materials Division (CMD), and Mr. Edward F. O'Neil, Acting Chief, Engineering Mechanics Branch (EMB), CMD. Dr. Tony C. Liu, HQUSACE, was the Technical Monitor. Mr. Billy D. Neeley, EMB, was the Principal Investigator. Messrs. Neeley and Michael K. Lloyd, EMB, prepared this report. The authors acknowledge the assistance of Messrs. Percy L. Collins, Michael Hedrick, and Jimmy W. Hall III, EMB, in preparing and testing the concrete mixtures in this investigation.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

1 Introduction

Background

A large percentage of concrete used by the U.S. Army Corps of Engineers (CE) to construct Civil Works Structures is mass concrete the proportions of which are selected as a result of studies conducted by the division laboratories in accordance with the American Concrete Institute (ACI) Standard 211.1 (ACI 1993b) (CRD-C-99).[1] In recent years, a number of contractor complaints have been received at CE projects regarding poor workability of mass concrete. In some instances, these complaints have been followed by actual production delay claims. Although the problems associated with the workability of the concrete generally appear to be related more to the contractor's selection of materials, placing operations, or lack of adequate contractor quality control (CQC) than the Government's mixture proportions, it is often difficult for the Government to be certain that the mixture itself is not at fault. Civil Works Investigation Studies Work Unit No. 32768, "Workability of Mass Concrete," was initiated to address some of the problems related to the selection of proportions for mass concrete with assurance that the concrete will have adequate workability.

The initial phase of this study was to obtain information from CE division and district staff members having recent experience with mass concrete construction. Their input was solicited to describe workability complaints as well as the purported causes of the problems. A survey form was designed to identify potential problems in five areas that could lead to workability problems or the perception of workability problems. The five areas were (a) materials, (b) mixture proportions, (c) transporting and placing, (d) consolidation, and (e) overall considerations. The results of this survey (Neeley 1993) indicated (a) problems with aggregate grading, usually associated with improper handling at the job site, (b) improper handling and placement procedures for the fresh concrete, (c) improper consolidation procedures, and (d) frequent adjustments to mixture proportions when taken from the laboratory to the field.

---

[1] CRD-C equivalent in parentheses is from the *Handbook for Concrete and Cement*, U.S. Army Engineer Waterways Experiment Station (USAEWES), 1949, Vicksburg, MS.

Only one of these problem areas is under direct control of the government; i.e., the selection of mixture proportions and adjustments thereof. Aggregate gradings are prescribed in the specifications for the work. Handling procedures, transporting, placing, and consolidation are the direct responsibility of the contractor. Adequate guidance in each of these areas is available from the ACI, the Portland Cement Association (PCA), and the CE to assist the contractor in completing a successful placement:

Aggregate gradings -

"Mass Concrete," Civil Works Guide Specification 03305 (Headquarters, U.S. Army Corps of Engineers (HQUSACE) 1992).

"Standard Practice for Concrete for Civil Works Structures," Engineer Manual 1110-2-2000 (HQUSACE 1994).

Aggregate handling procedures -

"ACI Manual of Concrete Inspection," SP-2 (ACI 1992).

"Guide for Measuring, Mixing, Transporting, and Placing Concrete," ACI 304R (ACI 1993c).

"Design and Control of Concrete Mixtures," (Kosmatka and Panarese 1988).

Transporting and placing fresh concrete-

"Mass Concrete," Civil Works Guide Specification 03305 (HQUSACE 1992).

"Standard Practice for Concrete for Civil Works Structures," Engineer Manual 1110-2-2000 (HQUSACE 1994).

"ACI Manual of Concrete Inspection," SP-2 (ACI 1992).

"Guide for Measuring, Mixing, Transporting, and Placing Concrete," ACI 304R (ACI 1993c).

"Placing Concrete with Belt Conveyors," ACI 304.4R (ACI 1993d).

"Design and Control of Concrete Mixtures," (Kosmatka and Panarese 1988).

Consolidating fresh concrete-

"Mass Concrete," Civil Works Guide Specification 03305 (HQUSACE 1992).

"Standard Practice for Concrete for Civil Works Structures," Engineer Manual 1110-2-2000 (HQUSACE 1994).

"ACI Manual of Concrete Inspection," SP-2 (ACI 1992).

"Guide for Measuring, Mixing, Transporting, and Placing Concrete," ACI 304R (ACI 1993c).

"Guide for Consolidation of Concrete," ACI 309R (ACI 1993e).

"Design and Control of Concrete Mixtures," (Kosmatka and Panarese 1988).

Concrete mixture proportions should not be adjusted to avoid complaints if this involves accepting materials that are out of specification or improper transporting, placing, or consolidation procedures. Many complaints of inadequate workability could be eliminated by following proper aggregate handling and fresh concrete transporting, placing, and consolidating procedures. Neeley (1993) also concluded that:

> by their nature, mass concrete mixtures are lean and, if not properly proportioned, can be harsh. It should be recognized that laboratory conditions where mixtures are proportioned are often nearly ideal and always different from the actual field conditions. While CE field staff members are responsible for assuring that the contractor uses materials that meet specifications and proper procedures to mix, transport, place, and consolidate, the laboratory staff who proportion mass mixtures should do so realizing that field conditions are never ideal. Mixtures should be proportioned in such a way to accommodate a reasonable amount of field variations without causing excessively harsh mixtures. The solution may be to increase the mortar content by a small enough amount to provide additional workability without causing an excessive increase in temperature rise. This scenario may now be possible with increasing amounts of fly ash, or other pozzolan or ground slag constituting the cementitious material.

It was recommended that a laboratory investigation be initiated to examine the feasibility of suggesting a minimum mortar content in 37.5-mm (1-1/2-in.) nominal maximum size aggregate (NMSA) mass concrete similar to that for 75-mm (3-in.) NMSA mass concrete. It was also recommended that a laboratory investigation be initiated to examine the feasibility of suggesting a paste-mortar ratio in 37.5-mm (1-1/2-in.) and 75-mm (3-in.) NMSA mass concrete similar to that for roller-compacted concrete.

As a continuation of this program, this report documents the investigation into the potential benefits of minimum and maximum mortar contents for 37.5-mm (1-1/2-in.) NMSA mass concrete, and minimum and maximum paste-mortar ratios for 37.5-mm (1-1/2-in.) and 75-mm (3-in.) NMSA mass concrete.

Mortar Content

Historically, most mass concretes have contained either 75-mm (3-in.) or 150-mm (6-in.) NMSA, and appropriate guidance for proportioning these mixtures is available. ACI Standard 211, "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete," (ACI 1993b) recommends minimum and maximum mortar contents for mass concretes having 75-mm (3-in.) and 150-mm (6-in.) NMSA. The Committee 211 report states that "experience has demonstrated that large aggregate mixtures, 75-mm (3-in.) and 150-mm (6-in.) NMSA, require a minimum mortar content for suitable placing and workability properties." The minimum mortar content is that which will be necessary to provide adequate workability for placement and consolidation. The maximum mortar content is suggested to prevent unnecessarily high cementitious contents which would generate an undesirable amount of heat and increase the temperature rise of the mass of concrete.

The Committee 211 report also places emphasis upon the combined grading of the coarse aggregates. It states that the individual size groups should be combined to produce a grading that approaches maximum density. This minimizes void space allowing more of the mortar to be available for workability, placability, and finishability. The parabolic maximum density curve (Eq. 1) originally developed from work by Fuller and Thompson (1907) and later modified by others, including Plum (1950), is suggested as a guide for approaching maximum density with 75-mm (3-in.) and 150-mm (6-in.) NMSA. The exponents, 0.5 and 0.8, are suggested based upon the results of numerous dry-rodded weights obtained with various types of coarse aggregates (Tynes 1968).

$$P = \frac{d^x - 4.75^x}{D^x - 4.75^x} \tag{1}$$

where

P	=	cumulative percent passing the d-size sieve
d	=	sieve opening, mm
D	=	NMSA, mm
x	=	exponent (0.5 for rounded and 0.8 for crushed aggregate)
4.75	=	minimum size aggregate included, mm

It is not expected that the combined grading of the individual aggregate size groups match the parabolic maximum density curve perfectly. The grading of the individual aggregate size groups will be a limiting factor determining how closely the maximum density grading can be matched. The dry rodded unit weight method is suggested for combining individual size groups up to a maximum of 37.5-mm (1-1/2-in.) to approach maximum density.

In recent years, an increasing amount of mass concrete has been placed using smaller NMSA. The authors have proportioned mass concrete mixtures for construction of four hydraulic structures in the CE in the past 10 years which used

37.5-mm (1-1/2-in.) NMSA. The authors have also proportioned mass concrete mixtures for structural applications using 19.0-mm (¾-in.) and 9.5-mm (⅜-in.) NMSA. Proportioning mass concrete mixtures having adequate workability, placability, and finishability characteristics can sometimes be more difficult with the smaller NMSA. The smaller aggregate necessitates an increased mortar content (water, cementitious material, fine aggregate, air), yet the need to limit heat generated and temperature rise requires the cementitious material be held to a minimum. The practitioner must weigh each of these requirements when proportioning mass concrete mixtures. Unfortunately, there is little, if any, guidance for minimum mortar contents in concretes having NMSA less than 75-mm (3-in.). Therefore, the experience of the person proportioning the mass mixtures with smaller NMSA can have a significant impact upon the outcome of the mixtures; i.e., has the cementitious content been minimized as much as possible to reduce the generation of heat, and will the mixtures have adequate workability, placeability, and finishability when proper procedures are followed.

Another factor that must be considered is material variation in the field. Mixtures are proportioned in the laboratory using a small, presumably representative sample of materials that have been selected for use. Optimum mixtures will be proportioned using these materials. However, caution must be exercised to avoid proportioning the mixtures such as to have barely adequate workability in the laboratory mixtures. It must be recognized that some material variation in the field is normal, especially involving aggregates. If the laboratory mixtures are proportioned with aggregates with a favorable combined grading, and subsequent variations in the field produce a less favorable grading, then workability problems can result. The minimum mortar content guidance in ACI 211 (ACI 1993b) addresses this concern for mass concrete mixtures having 75-mm (3-in.) and 150-mm (6-in.) NMSA. One purpose of this investigation is to determine if similar principles can also apply to mass concrete mixtures having smaller NMSA.

Paste-Mortar Ratio

The ACI Committee 207 report "Roller Compacted Mass Concrete" (ACI 1993a) describes several different concepts and procedures for proportioning roller compacted mass concrete (RCC). One of the methods involves determining the minimum paste requirement for the proposed fine aggregate after the coarse aggregate grading has been selected. Normally, the void content of fine aggregate ranges from 34 to 42 percent. The goal of this method is to determine the minimum paste (water, cementitious material, and air) necessary to fill the voids between the fine aggregate particles and provide some additional paste which will be needed to ensure necessary workability to the mixture. For RCC, this extra paste is minimal. For slumpable concretes, a larger amount of extra paste will be necessary. The Committee 207 report states that air-free paste-mortar ratios (p/m), by volume, of 0.38 for interior mass concretes and 0.42 for bedding mixtures have generally been found acceptable. Another purpose of this investigation was to determine if similar principles can be applied to slumpable, mass concrete mixtures to improve their workability, placeability, and finishability.

Objectives

The objectives of this research were three-fold. The first objective was to examine the feasibility of requiring a minimum mortar content in 37.5-mm (1-1/2-in.) NMSA mass concrete similar to the requirement for 75-mm (3-in.) NMSA mass concrete. The second and third objectives were to examine the feasibility of requiring a p/m in 37.5-mm (1-1/2-in.) and 75-mm (3-in.) NMSA mass concretes similar to the requirement for RCC. Concretes having two different 37.5-mm (1-1/2-in.) coarse aggregates were evaluated for mortar content and p/m. One was a crushed material consisting primarily of blocky particles. The other was a crushed material having more flat and elongated particles.

Scope

A number of mass concrete mixtures that had been proportioned at the U.S. Army Engineer Waterways Experiment Station (WES), Concrete and Materials Division (CMD), in recent years were surveyed to determine typical mortar contents and p/m used. Using these typical values as a starting point, mass concrete mixtures having 37.5-mm (1-1/2-in.) and 75-mm (3-in.) NMSA were then proportioned having a range of mortar contents and p/m encompassing the historical values. The fresh properties of each mixture were evaluated using a variety of test methods. The results were evaluated with consideration given to actual mixtures used in construction which exhibited good workability and other mixtures which were more troublesome during actual field placements. Many of the measurements were made in non-SI units and converted to SI units using conversion values in American Society for Testing and Materials (ASTM) E 380 (ASTM 1993m).

2 Concrete Mixtures

Review of Recent Mass Concrete Mixtures

37.5-mm (1-1/2-in.) NMSA mixtures

A total of 91 mixtures that had been proportioned between the years 1974 and 1992 for eleven different projects were examined. Natural sand fine aggregate was used at 10 of the 11 projects. A manufactured limestone fine aggregate was used at the remaining project. Coarse aggregates included natural gravel, crushed limestone, and crushed granite. A complete listing of materials and other pertinent properties are given in Appendix A, Table A1.

The mortar content and p/m were calculated for each of the mixtures. All subsequent references to mortar content are based on a 1-m^3 batch. Corresponding mortar contents shown in parentheses are for a 1-yd^3 batch. The relationship between water-cement ratio (w/c) and both mortar content and p/m for all mixtures are shown in Figures A1 and A2, respectively. The relationship between the mortar content and p/m for all mixtures is shown in Figure A3. Averages for each type of coarse aggregate are shown in Figures 1, 2, and 3. A description of the acronyms used to identify each type of coarse aggregate in the figures is given in Appendix A. It can be seen from Figures 1 and 3 that mixtures containing all crushed coarse aggregates used a higher mortar content than mixtures which contained natural gravel coarse aggregates or a combination of crushed and natural gravel coarse aggregates. Mixtures containing crushed coarse aggregates generally used approximately 0.537 m^3 (14.5 ft^3) of mortar while mixtures containing natural gravel coarse aggregates used approximately 0.515 m^3 (13.9 ft^3) of mortar. The mortar content did not appear to be significantly affected by the w/c nor the p/m. Figures 2 and 3 indicate that the p/m remained relatively constant at 46 to 47 percent, regardless of the w/c and mortar content.

It is suggested from this examination of existing 37.5-mm (1-1/2-in.) NMSA mass concrete mixtures that the p/m remains relatively constant at approximately 46 to 47 percent when the slump is generally between 50 and 75 mm. It is also suggested that the mortar content ranges from approximately 0.515 m^3 (13.9 ft^3) for mixtures containing natural gravel coarse aggregates to

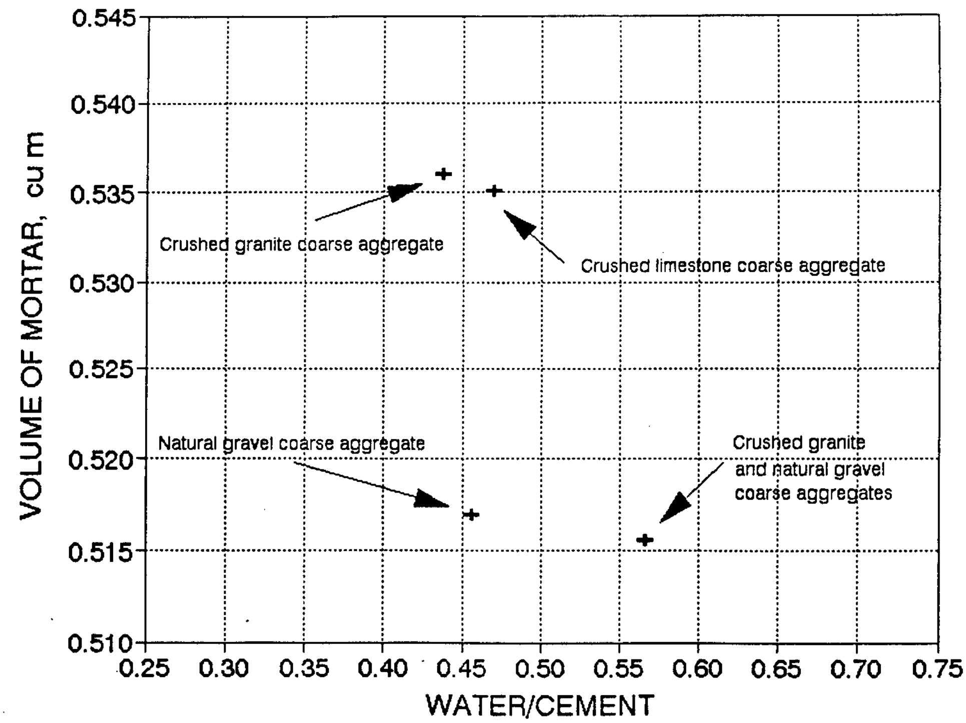


Figure 1. Average mortar content of 37.5-mm NMSA mass concrete mixtures reviewed for historical data

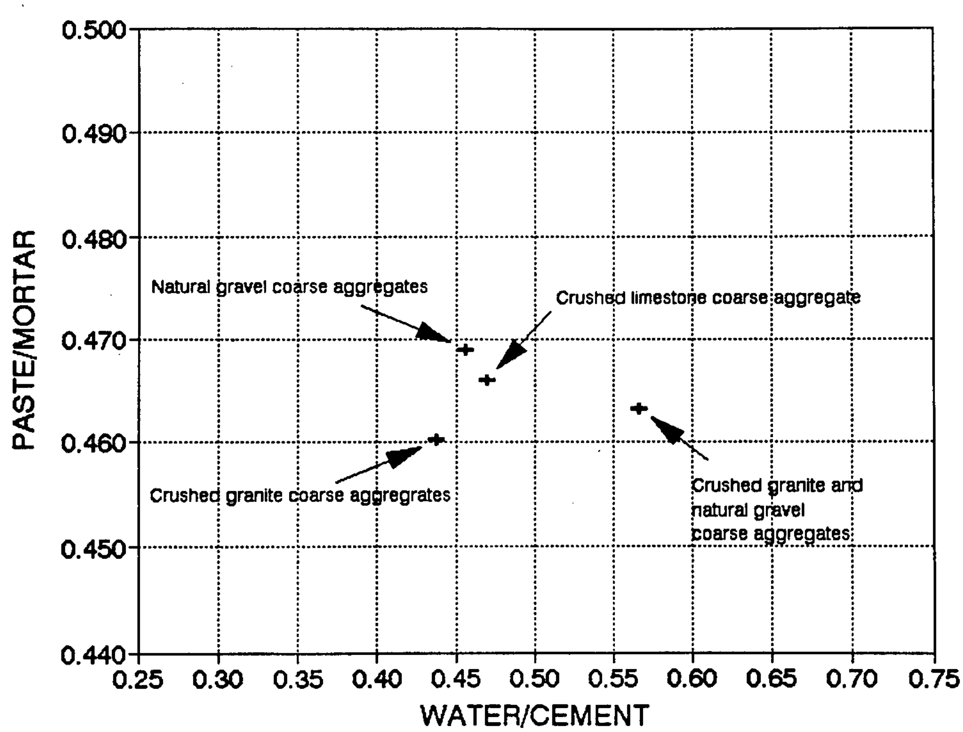


Figure 2. Average paste/mortar of 37.5-mm NMSA mass concrete mixtures reviewed for historical data

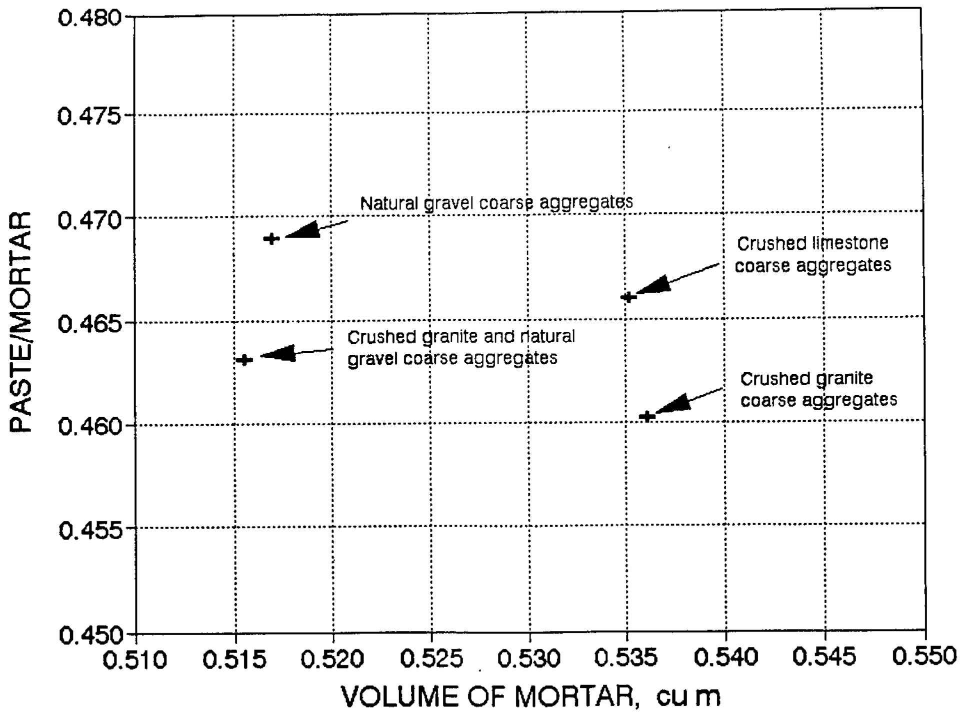


Figure 3. Relationship of average mortar content and paste/mortar of 37.5-mm NMSA mass concrete mixtures reviewed for historical data

approximately 0.537 m^3 (14.5 ft^3) for mixtures containing crushed coarse aggregates. Therefore, it is possible that these two parameters could be effective guides to assist in the proportioning of mass concrete mixtures using 37.5-mm (1-1/2-in.) NMSA.

75-mm (3-in.) NMSA mixtures

A total of 17 mixtures that had been proportioned between the years 1974 and 1992 for four different projects were examined. Natural sand fine aggregate was used at three of the four projects. A manufactured limestone fine aggregate was used at the remaining project. The coarse aggregate was crushed limestone in each project. A complete listing of materials and other pertinent properties are given in Appendix A, Table A2.

The mortar content and p/m were calculated for each of the mixtures. All subsequent references to mortar content are based on a 1-m^3 batch. Corresponding mortar contents shown in parentheses are for a 1-yd^3 batch. The relationship between w/c and both mortar content and p/m for all mixtures are shown in Figures A4 and A5, respectively. The relationship between the mortar content and p/m for all mixtures is shown in Figure A6. Averages are shown in Figures 4, 5, and 6. It can be seen from Figures 4 and 6 that mixtures containing the manufactured limestone fine aggregate used a higher mortar content than mixtures which contained natural fine aggregates. Mixtures containing

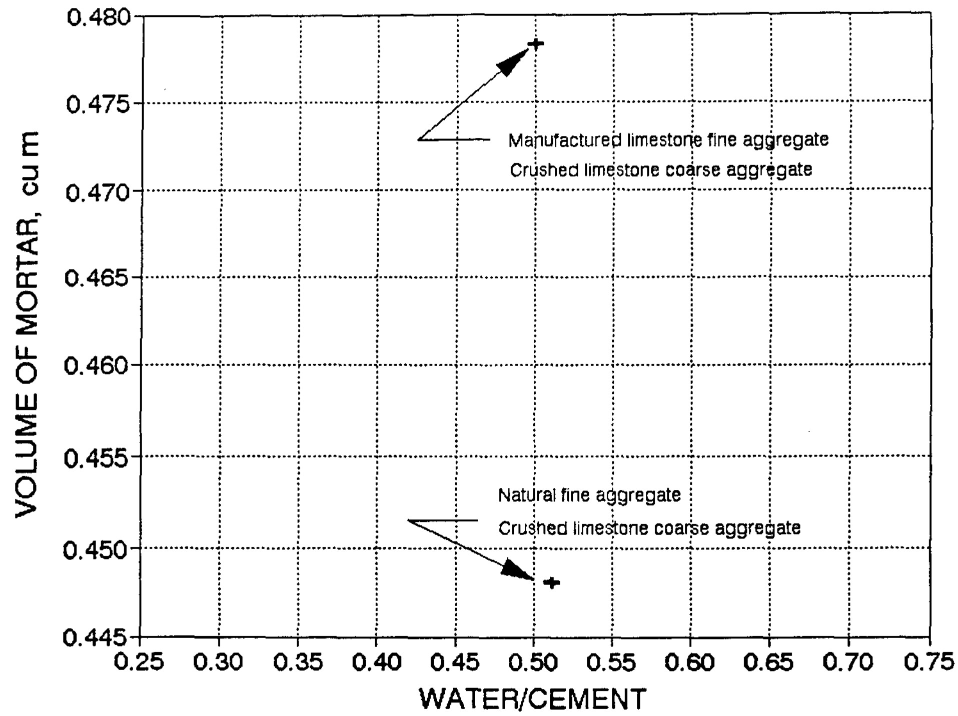


Figure 4. Average mortar content of 75-mm NMSA mass concrete mixtures reviewed for historical data

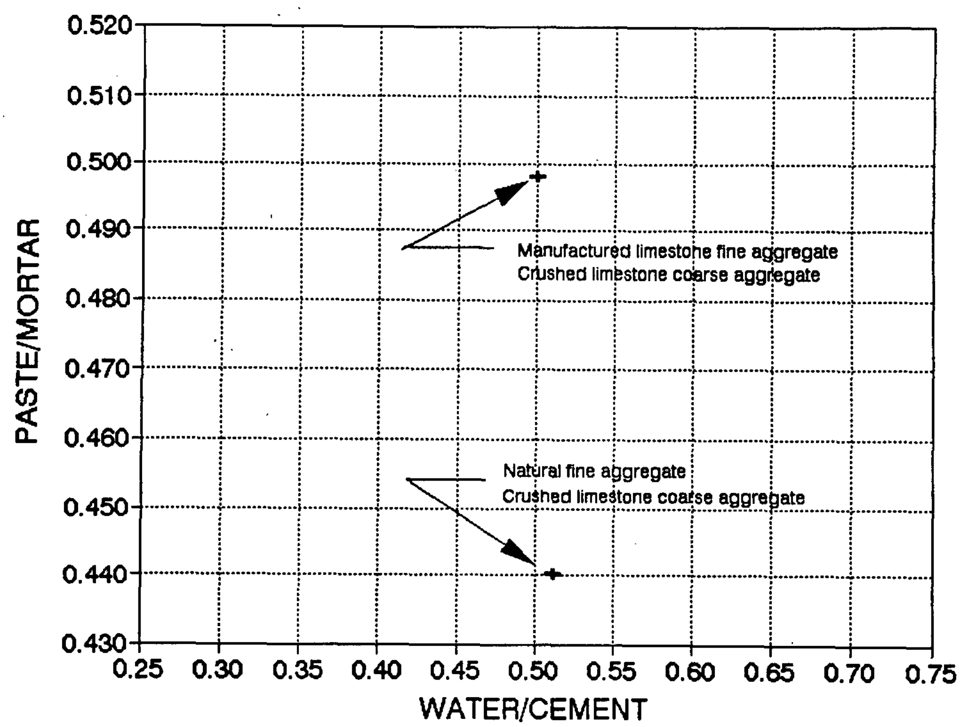


Figure 5. Average paste/mortar of 75-mm NMSA mass concrete mixtures reviewed for historical data

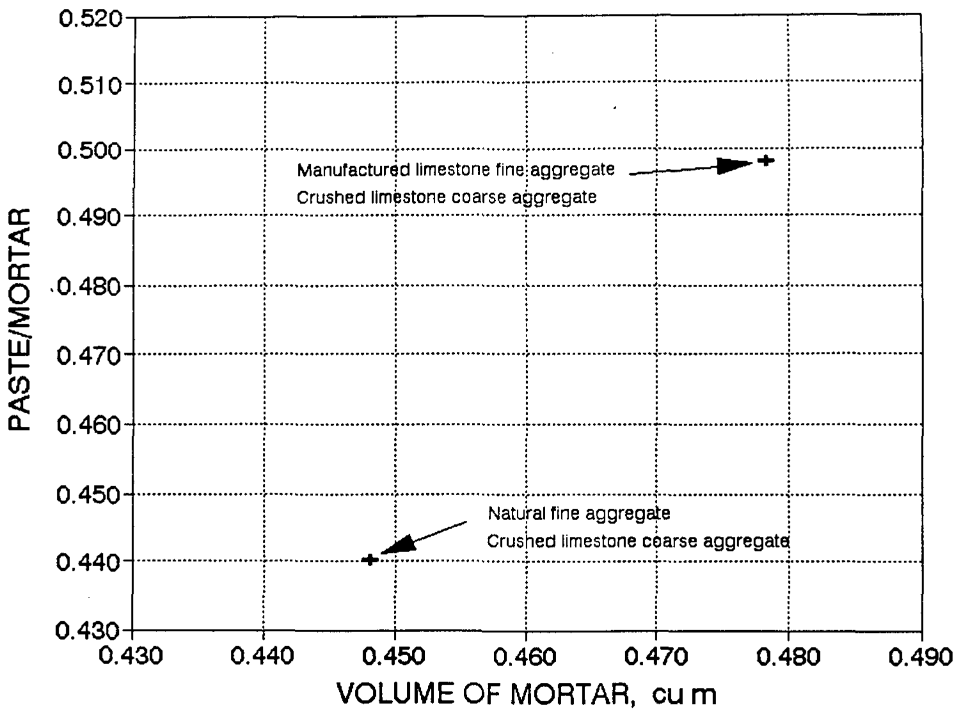


Figure 6. Relationship of average mortar content to paste/mortar of 75-mm NMSA mass concrete mixtures reviewed for historical data

manufactured limestone fine aggregate generally used approximately 0.478 m^3 (12.9 ft^3) of mortar while mixtures containing natural fine aggregates used approximately 0.447 m^3 (12.0 ft^3) of mortar. As shown in Figures 5 and 6, the paste/mortar of the mixtures containing manufactured limestone fine aggregate was also higher than that of the mixtures containing natural fine aggregate; approximately 50 percent versus 44 percent, respectively.

Materials Used In Current Investigation

A listing of the materials used to proportion the 37.5-mm (1-1/2-in.) and 75-mm (3-in.) NMSA mass concrete mixtures used in the current investigation is provided here. The numbers in parenthesis following each material are CTD identification numbers assigned to all materials used in research programs to ensure traceability.

Cement

Portland cement, Type II (940054)

Pozzolan

Fly ash, class C (LMK-4 AD-4)

Aggregates

Natural sand fine aggregate (920100)

9.5-mm (3/8-in.) nominal maximum size (NMS) crushed limestone coarse aggregate (920337)

19.0-mm (3/4-in.) NMS crushed limestone coarse aggregate (920048)

37.5-mm (1-1/2-in.) NMS crushed limestone coarse aggregate (CL-2 MG-2)

75-mm (3-in.) NMS crushed limestone coarse aggregate (920322)

19.0-mm (3/4-in.) NMS crushed granite coarse aggregate (940294)

37.5-mm (1-1/2-in.) NMS crushed granite coarse aggregate (940295)

Admixtures

Air-entraining admixture (AEA) (920090)

The sieve analysis (ASTM C 136 (ASTM 1993c)) of each aggregate and values of absorption and specific gravity (ASTM C 127 (coarse aggregate) and C 128 (fine aggregate)) (ASTM 1993a,b) are given in Table 1. The portland cement conformed to Type II requirements of ASTM C 150 (ASTM 1993f). The fly ash conformed to Class F requirements of ASTM C 618 (ASTM 1993k). Physical and chemical properties of the cement and fly ash are given in Tables 2 and 3, respectively.

The 19.0-mm (3/4-in.) and 37.5-mm (1-1/2-in.) NMS crushed limestone coarse aggregates were generally blocky and were judged to have a favorable particle shape for crushed coarse aggregates. The crushed granite and the 9.5-mm (3/8-in.) NMS crushed limestone coarse aggregate contained more flat and elongated particles and were judged to have a less favorable particle shape for crushed coarse aggregates. Particle shape classifications as described in ASTM D 4791 (ASTM 1993*l*) for each of the aggregates listed above are given in Table 4. Natural gravel coarse aggregates were not included in this investigation. However, it can be assumed that they would usually have a more favorable particle shape than either of the crushed materials. Principles shown to be applicable to the crushed coarse aggregates could be extended to the natural gravel coarse aggregates with additional research.

Table 1
Aggregate

Sieve Size	Cumulative Percent Passing						
	Coarse Aggregate						
	Crushed Limstone 920322	Crushed Limestone CL-2 MG-2	Crushed Limestone 900048	Crushed Limestone 920337	Crushed Granite 940295	Crushed Granite 940294	Fine Aggregate 920100
75 mm	96						
50 mm	40	100			100		
37.5 mm	14	96			91		
25.0 mm	10	29	100		32	99	
19.0 mm	6	7	97		7	84	
12.5 mm		3	67	100	1	38	
9.5 mm		3	39	97	1	15	
4.75 mm		2	6	42		1	100
2.36 mm			1	8			95
1.18 mm							81
600 μm							55
300 μm							18
150 μm							3
Specific Gravity	2.64	2.74	2.71	2.72	2.63	2.65	2.65
Absorption	2.90	0.3	0.2	0.4	1.0	0.8	0.3

Table 2
Report of Tests on Hydraulic Cement

TO:	FROM:
Billy Neeley Structures Laboratory	U. S. Army Corps of Engineers Waterways Experiment Station Engineering Materials Group 3909 Halls Ferry Road Vicksburg, Mississippi 39180-6199
Company: Lone Star Industries	Test Report No.: WES-7-94
Location: Cape Girardeau, Missouri	Program: Single Sample
Specification: ASTM C 150, II, HH*	CTD No.: 940054
Contract No.:	Job No.: ACSAZ081A1S3100
Project: Workability of Mass Concrete	Date Sampled: 21 Jan 94

_________Partial test result

2/3/94 Tests complete, material X does, ____does not meet specification

Chemical Analysis	Result	Retest	ASTM C 150 Spec Limits "Type II"
SiO_2, %	21.9		20.0 min
Al_2O_3, %	4.1		6.0 max
Fe_2O_3, %	3.1		6.0 max
CaO, %	62.9		-
MgO, %	3.3		6.0 max
SO_3, %	2.6		3.0 max
Loss on ignition, %	0.07		0.75 max
Na_2O, %	1.1		3.0 max
Insoluble residue,%	0.10		-
K_2O, %	0.7		-
Alkalies-total as Na_2O, %	0.57		0.60 max
TiO_2, %	0.26		-
P_2O_5, %	0.10		-
C_3A, %	7		8 max
C_3S, %	47		-
C_2S, %	27		-
C_4AF, %	9		-
Physical Tests			
Heat of hydration, 7-day, cal/g	72*		70 max
Surface area, m^2/kg (air permeability)	392		280 max
Autoclave expansion, %	0.07		0.80 max
Initial set, min. (Gillmore)	160		60 min
Final set, min. (Gillmore)	255		600 max
Air content, %	8		12 max
Compressive strength, 3-day, psi	3,020		1,500, 1,000[a] min
Compressive strength, 7-day, psi	4,320		2,500, 1,700[a] min
False set (final penetration), %	-		50 min

REMARKS: [a]Applies only to heat of hydration cement.

*Heat of hydration tested and reported for information only.

CF:

Melvin C. Sykes

Information given in the report shall not be used in advertising or sales promotion to indicate endorsement of this product by U.S. Government.

Table 3
Report of Tests on Pozzolan

TO: Billy Neeley Structures Laboratory	LMK-4 AD-4	FROM: Structures Laboratory USAE Waterways Experiment Station ATTN: Cement and Pozzolan Unit PO Box 631 Vicksburg, MISSISSIPPI 39180-631
COMPANY: Gifford-Hill		TEST REPORT NO.: 17 Mar 88
LOCATION: Boyce, LA		REPORT DATE:
SPECIFICATION: ASTM C 618, Class C		DATE SAMPLE:
CONTRACT NO.: Red River Waterway Thermal Study		PROGRAM: 3 Mar 88

TEST RESULTS OF THIS SAMPLE

[XX] COMPLY
[ ] DO NOT COMPLY
WITH SPECIFICATION LIMITS

$S_iO_2 + Al_2O_3 + Fe_2O_3$ %	MgO	SO_3	AVAILABLE ALKALIES % (a) (b)	POZZOLANIC STRENGTH % CONTROL (b)				AUTOCLAVE EXPANSION %
REQUIREMENTS								
MINIMUM		MAXIMUM	MAXIMUM	MINIMUM				MAXIMUM
TEST RESULTS								
61.3	5.0	2.2	•	•				0.0

SAMPLE	MOISTURE	LOSS OF	FINENESS	FINENESS	LIME	WATER	DENSITY	DENSITY
REQUIREMENTS								
____	MAXIMUM	MAXIMUM	MAXIMUM	MAXIMUM	MAXIMUM	MAXIMUM	____	MAXIMUM
TEST RESULTS								
1	0.0	0.7	19	0	--	92	2.53	3
AVERAGE	____	____	____	____	____			____

(a) OPTIONAL REQUIREMENT
(b) 28 DAY TEST

LABORATORY CEMENT USED:
LABORATORY LIME USED: CHEMSTONE

REMARKS:

SiO_2: 36.5; Fe_2O_3: 6.5: Al_2O_3: 18.2

CQSCL383A1SR300

Toy S. Poole
Chief, Cement and Pozzolan Unit

NOTE: THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U.S. GOVERNMENT.

FORM
WES 1195
R AUG 87

EDITION OF 1 SEP 84 IS OBSOLETE

Table 4
Coarse Aggregate Particle Shape

Aggregate	Not Flat or Elongated, %	Flat or Elongated, %
37.5-mm (1-1/2-in.) NMS crushed limestone	97	3
19.0-mm (¾-in.) NMS crushed limestone	95	5
9.5-mm (⅜-in.) NMS crushed limestone	41	59
37.5-mm(1-1/2-in.) NMS crushed granite	70	30
19.0-mm (¾-in.) NMS crushed granite	49	51

Mixture Proportions

37.5-mm (1-1/2-in.) NMSA mixtures

Mixtures having w/c of 0.50 and 0.60, by mass, were proportioned and tested. Thirty-five percent of the cementitious material, by volume, was fly ash. The coarse aggregates were separated into two groups, those with a favorable particle shape and those with a less favorable particle shape. The group having a favorable particle shape consisted of the 19.0-mm (¾-in.) and 37.5-mm (1-1/2-in.) NMS crushed limestone. The group having a less favorable particle shape consisted of the 9.5-mm (⅜-in.) NMS crushed limestone and the 19.0-mm (¾-in.) and 37.5-mm (1-1/2-in.) NMS crushed granite. A range of mortar contents and p/m were evaluated for each group of coarse aggregate and w/c. A test matrix is given in Table 5.

Favorable coarse aggregate particle shape. Mixtures containing coarse aggregates with a favorable particle shape were evaluated at mortar contents ranging from 0.504 to 0.548 m^3 for a w/c of 0.50, and at mortar contents ranging from 0.504 to 0.559 m^3 for a w/c of 0.60. Five different p/m's were used at each mortar content. The combination of coarse aggregates was 53 percent 37.5-mm (1-1/2-in.) NMS crushed limestone and 47 percent 19.0-mm (¾-in.) NMS crushed limestone. The combined grading is shown in Figure 7. A total of 55 mixtures were proportioned and tested.

Less favorable coarse aggregate particle shape. Mixtures containing coarse aggregates with a less favorable particle shape were evaluated at mortar contents ranging from 0.515 to 0.548 m^3 for a w/c of 0.50, and at mortar contents ranging from 0.526 to 0.548 m^3 for a w/c of 0.60. Either three or four different p/m's were used at each mortar content. The combination of coarse aggregates was

Table 5 Test Matrix			
Aggregate Shape	w/c, wt	Mortar Content, m^3	p/m
Favorable	0.50	0.504	0.4466 to 0.4966
Favorable	0.50	0.515	0.4453 to 0.4953
Favorable	0.50	0.526	0.4441 to 0.4941
Favorable	0.50	0.537	0.4430 to 0.4030
Favorable	0.50	0.548	0.4418 to 0.4918
Favorable	0.60	0.504	0.4228 to 0.4728
Favorable	0.60	0.515	0.4215 to 0.4715
Favorable	0.60	0.526	0.4202 to 0.4702
Favorable	0.60	0.537	0.4190 to 0.4690
Favorable	0.60	0.548	0.4178 to 0.4678
Favorable	0.60	0.559	0.4167 to 0.4467
Less Favorable	0.50	0.515	0.4591 to 0.4941
Less Favorable	0.50	0.526	0.4549 to 0.4949
Less Favorable	0.50	0.537	0.4526 to 0.4926
Less Favorable	0.50	0.548	0.4512 to 0.4912
Less Favorable	0.60	0.526	0.4315 to 0.4715
Less Favorable	0.60	0.537	0.4294 to 0.4694
Less Favorable	0.60	0.548	0.4306 to 0.4706

47 percent 37.5-mm (1-1/2-in.) NMS crushed granite, 43 percent 19.0-mm (¾-in.) NMS crushed granite, and 10 percent 9.5-mm (⅜-in.) NMS crushed limestone. The combined grading is also shown in Figure 7. A total of 23 mixtures were proportioned and tested.

75-mm (3-in.) NMSA mixtures

Mixtures having w/c of 0.50, by mass, were proportioned and tested. Thirty-five percent of the cementitious material, by volume, was fly ash. The coarse aggregates, consisting of the 19.0-mm (¾-in.), 37.5-mm (1-1/2-in.), and 75-mm (3-in.) NMS crushed limestone, were considered to have a favorable particle shape. The combination of coarse aggregates was 55 percent 75-mm (3-in.) NMS crushed limestone, 23 percent 37.5-mm (1-1/2-in.) NMS crushed limestone, and 22 percent 19.0-mm (¾-in.) NMS crushed limestone. The combined grading of the coarse aggregates is shown in Figure 8. The mortar content was 0.445 m^3 (12.0 ft^3), and p/m ranged from 44.6 to 46.6 percent. Three mixtures were proportioned and tested.

Tests

Tests performed on the fresh concrete included slump (ASTM C 143) (ASTM 1993e), air content (ASTM C 231) (ASTM 1993h), unit weight (ASTM C 138)

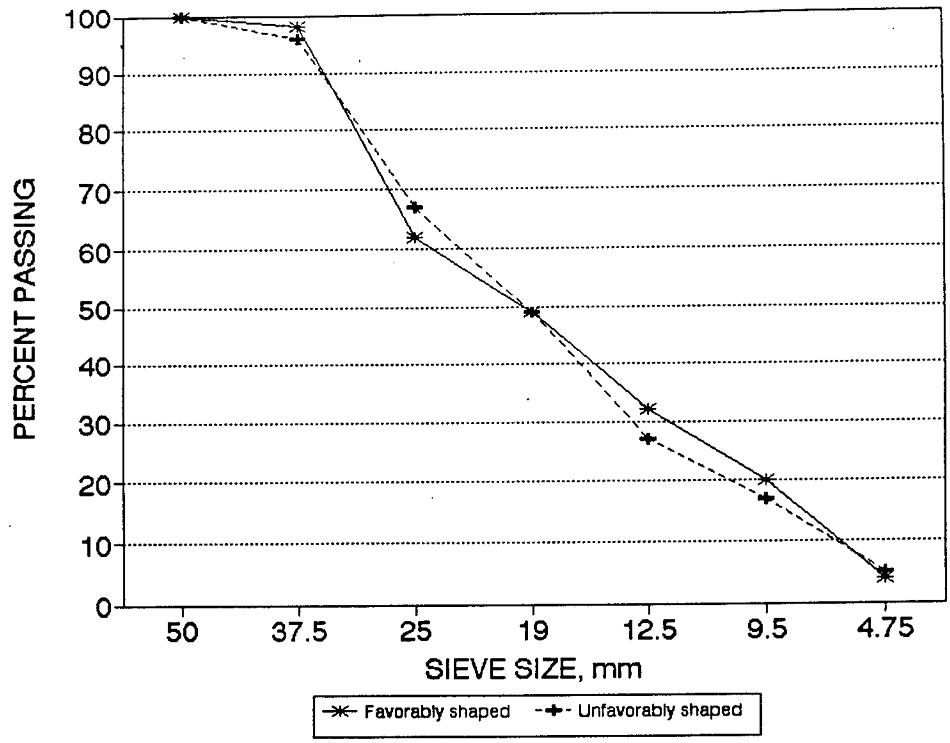


Figure 7. Combined grading of coarse aggregate used in 37.5-mm (1-1/2-in.) NMSA mixtures

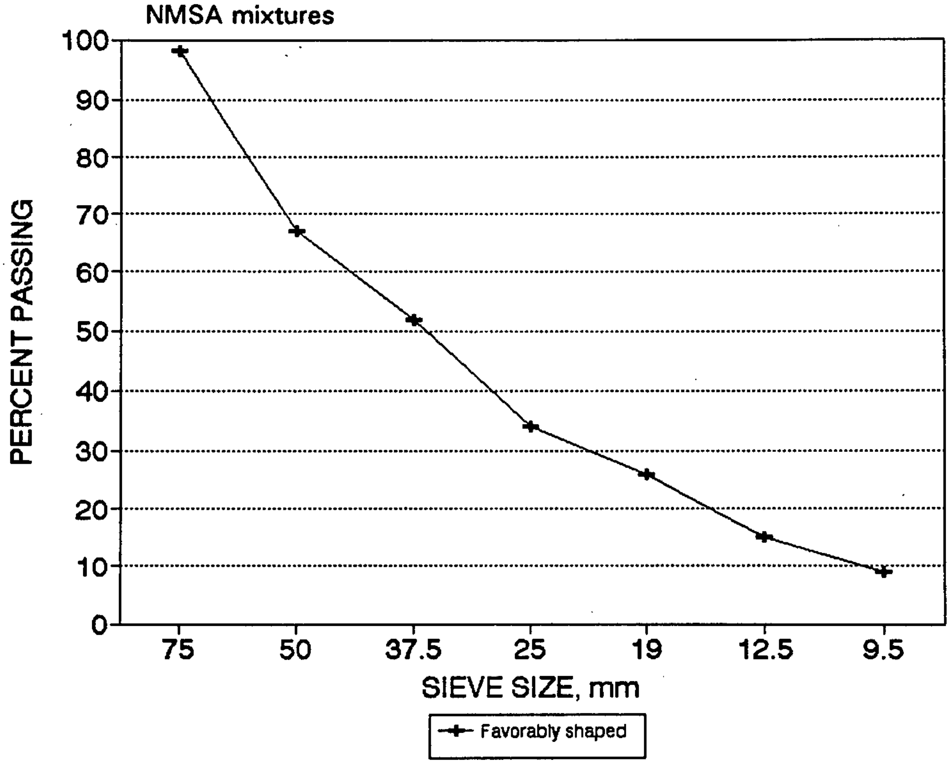


Figure 8. Combined grading of coarse aggregates used in 75-mm (3-in.) NMSA mixtures

(ASTM 1993d), bleed (ASTM C 232) (ASTM 1993i), and a modified Vebe test similar to British Standard Method for Determination of Vebe Time (BS 1881: Part 104) (British Standards Institute 1983). The British Vebe test procedure was modified to use a larger sample of concrete. Otherwise, the test procedure was essentially unchanged. The modified test procedure is given in Appendix B. The Vebe test was included in the investigation because it provides a measure of the mobility and compactability of concrete under vibration, while the slump test provides a measure of the consistency of the concrete under static conditions. The size of the Vebe apparatus was increased for two reasons: (a) the authors believed that a larger sample might provide a more representative measure of the mobility and compactability, and (b) the larger size was necessary to be able to test mixtures having 75-mm (3-in.) NMSA without wet sieving to remove the larger particles. Test results on wet-sieved material without the large aggregate particles may not adequately represent the workability and placability of the actual concrete.

Test results for mixtures containing a 37.5-mm (1-1/2-in.) NMS coarse aggregate of favorable particle shape are given in Table 6. Each result represents the average from at least two batches of concrete. Test results for mixtures containing a less favorable 37.5-mm (1-1/2-in.) NMS coarse aggregate particle shape are given in Table 7. Each result represents the average from at least two batches of concrete. Test results for mixtures containing 75-mm (3-in.) NMSA are given in Table 8.

Table 6
Test Results on 37.5-mm (1-1/2-in.) NMSA Mixtures with Favorably Shaped Coarse Aggregate

1 m³															
w/c = 0.50								w/c = 0.60							
Mixture No.	Mortar Content, m³	p/m, %	Water Content, kg/m³	Slump, mm	Air Content, %	Unit Weight, kg/m³	Vebe Time sec	Mixture No.	Mortar Content, m³	p/m, %	Water Content, kg/m³	Slump, mm	Air Content, %	Unit Weight, kg/m³	Vebe Time Sec
17L2	0.504	0.447	107	30	5.2	2,400	33	16L2	0.504	0.423	107	50	5.2	2,392	27
17L1	0.504	0.457	110	40	5.1	2,403	29	16L1	0.504	0.433	110	40	5.4	2,377	28
17	0.504	0.467	113	50	5.4	2,400	17	16	0.504	0.443	113	45	4.7	2,412	15
17H1	0.504	0.477	116	90	5.5	2,387	18	16H1	0.504	0.453	116	50	5.3	2,384	14
17H2	0.504	0.497	122	115	5.3	2,384	12	16H2	0.504	0.473	123	75	4.9	2,400	9
6L2	0.515	0.445	110	45	5.3	2,400	23	1L2	0.515	0.422	109	45	5.4	2,416	39
6L1	0.515	0.455	113	45	5.4	2,396	26	1L1	0.515	0.432	113	45	5.3	2,377	10
6	0.515	0.465	116	55	5.1	2,284	24	1	0.515	0.442	116	70	5.3	2,364	16
6H1	0.515	0.475	119	75	5.5	2,387	14	1H1	0.515	0.452	119	65	5.5	2,380	7
6H2	0.515	0.495	125	100	5.6	2,390	13	1H2	0.515	0.472	126	125	4.9	2,384	6
7L2	0.526	0.444	112	25	5.2	2,406	31	2L2	0.526	0.42	112	25	4.9	2,400	22
7L1	0.526	0.454	116	40	5.2	2,400	25	2L1	0.526	0.43	115	30	5.2	2,388	23
7	0.526	0.464	119	55	5.5	2,366	20	2	0.526	0.44	119	65	5.5	2,364	19
7H1	0.526	0.474	122	65	5.5	2,384	16	2H1	0.526	0.47	122	90	5.6	2,368	12
7H2	0.526	0.494	128	120	5.3	2,374	11	2H2	0.526	0.47	129	120	4.6	2,384	8
8L2	0.537	0.443	115	40	5.2	2,384	23	3L2	0.537	0.419	115	25	4.9	2,390	23
8L1	0.537	0.453	118	50	5.8	2,371	15	3L1	0.537	0.429	118	30	5.2	2,390	17
8	0.537	0.463	122	65	5	2,379	17	3	0.537	0.439	122	65	5.5	2,360	18
8H1	0.537	0.473	125	95	5.6	2,371	12	3H1	0.537	0.449	125	90	5.6	2,364	10
8H2	0.537	0.493	131	140	5	2,384	8	3H2	0.537	0.469	132	120	4.6	2,380	6
9L2	0.548	0.442	117	45	5.4	2,377	20	4L2	0.548	0.418	117	25	5.5	2,400	26
9L1	0.548	0.452	121	65	5.8	2,371	14	4L1	0.548	0.428	120	50	5.4	2,388	14
9	0.548	0.462	124	75	5.5	2,360	15	4	0.548	0.438	124	75	5.3	2,364	15
9H1	0.548	0.472	128	90	5.5	2,374	8	4H1	0.548	0.448	128	70	5.4	2,368	10
9H2	0.548	0.492	134	140	4.6	2,380	8	4H2	0.548	0.468	135	120	4.4	2,384	5
								5L2	0.559	0.417	120	25	5.4	2,380	20
								5L1	0.559	0.427	123	40	5.5	2,355	9
								5	0.559	0.437	127	70	5.4	2,352	12
								5H1	0.559	0.447	131	85	5	2,374	5

Table 7
Test Results on 37.5-mm (1-1/2-in.) NMSA Mixtures with Less Favorably Shaped Coarse Aggregate

1 m^3															
w/c = 0.50								w/c = 0.60							
Mixture No.	Mortar Content, m^3	p/m, %	Water Content, kg/m^3	Slump, mm	Air Content, %	Unit Weight, kg/m^3	Vebe Time sec	Mixture No.	Mortar Content, m^3	p/m, %	Water Content, kg/m^3	Slump, mm	Air Content, %	Unit Weight, kg/m^3	Vebe Time Sec
18L1	0.515	0.459	114	0	2.8	2,384	100								
18H1	0.515	0.479	119	15	3.7	2,347	58								
18H2	0.515	0.494	125	70	4.8	2,319	21								
19L1	0.526	0.455	116	30	4.6	2,335	62	22L1	0.526	0.432	116	20	4.2	2,307	44
19H1	0.526	0.475	122	45	4.7	2,310	34	22H2	0.526	0.452	123	30	3.9	2,323	70
19H2	0.526	0.495	129	70	5.1	2,287	15	22H2	0.526	0.472	129	50	4.2	2,307	27
20L1	0.537	0.453	119	25	5.2	2,307	48	23L1	0.537	0.429	118	15	4.9	2,320	33
20	0.537	0.463	121	70	5.2	2,303	18	23H1	0.537	0.449	125	40	4.8	2,300	22
20H1	0.537	0.473	125	45	4.6	2,313	16	23H2	0.537	0.469	132	85	5	2,287	15
20H2	0.537	0.493	131	90	5.3	2,284	21								
21L1	0.548	0.451	120	30	4.9	2,310	33	24L1	0.548	0.431	122	15	4.8	2,310	41
21	0.548	0.461	124	40	4.8	2,310	33	24H1	0.548	0.451	128	45	5.1	2,291	24
21H1	0.548	0.471	128	65	4.8	2,307	19	24H2	0.548	0.471	136	70	4.9	2,291	18
21H2	0.548	0.491	134	65	4.9	2,300	19								

Table 8
Test Results on 75-mm (3-in.) NMSA Mixture with Favorably Shaped Coarse Aggregate

Mixture No.	Mortar Content, m^3	p/m	Water Content, kg/m^3	Slump, mm	Air Content, %	Unit Weight, kg/m^3	Vebe time, sec
16	0.445	0.446	92	25	5.4	2,356	47
17	0.445	0.456	95	40	5.6	2,353	62
18	0.445	0.466	98	45	5.5	2,353	60

3 Discussion and Analysis

37.5-mm (1-1/2-in.) NMSA Mixtures

Criteria

Consideration was given to actual mixtures used in construction that exhibited good workability, and some which were more troublesome, to estimate what would be an appropriate Vebe time to describe a mixture easily consolidated. It was also noted that historically, 37.5-mm (1-1/2-in) NMSA mass concrete mixtures have been proportioned to have slumps ranging from 40 to 75 mm (1-1/2 to 3 in.). Using these criteria, it is suggested that a Vebe time of 12 to 20 seconds would indicate that a mixture has adequate workability to be easily placed and consolidated. The following discussion is based on these assumptions.

Favorable coarse aggregate particle shape

Fifty four mixtures were evaluated as shown in Tables 5 and 6. Plots of p/m versus Vebe time at each mortar content are shown in Figures 9 and 10 for w/c of 0.50 and 0.60, respectively. Slump values are indicated on each curve at the appropriate location. The data indicate that for a given p/m, the Vebe time necessary to consolidate the sample decreases as the mortar content increases. A corresponding increase in slump is also indicated as the mortar content increased in the mixtures having a 0.50 w/c. For a given mortar content, the Vebe time necessary to consolidate the sample decreases as the p/m increases; however, it does not appear to be a linear relationship. There appears to be a close relationship between the p/m and slump. Regardless of the mortar content, the slump increases as the p/m increases. Each of these relationships between the mortar content, p/m, slump, and Vebe time were expected. The data provide quantification of the relationships.

Mixtures with 0.50 w/c. The data indicate that mixtures having mortar contents of 0.526 m^3 (14.2 ft^3) and less could be judged difficult to consolidate when the slump is less than 50 mm (2 in.). Higher p/m were necessary to reduce the Vebe time. While the higher p/m did not necessarily increase the water

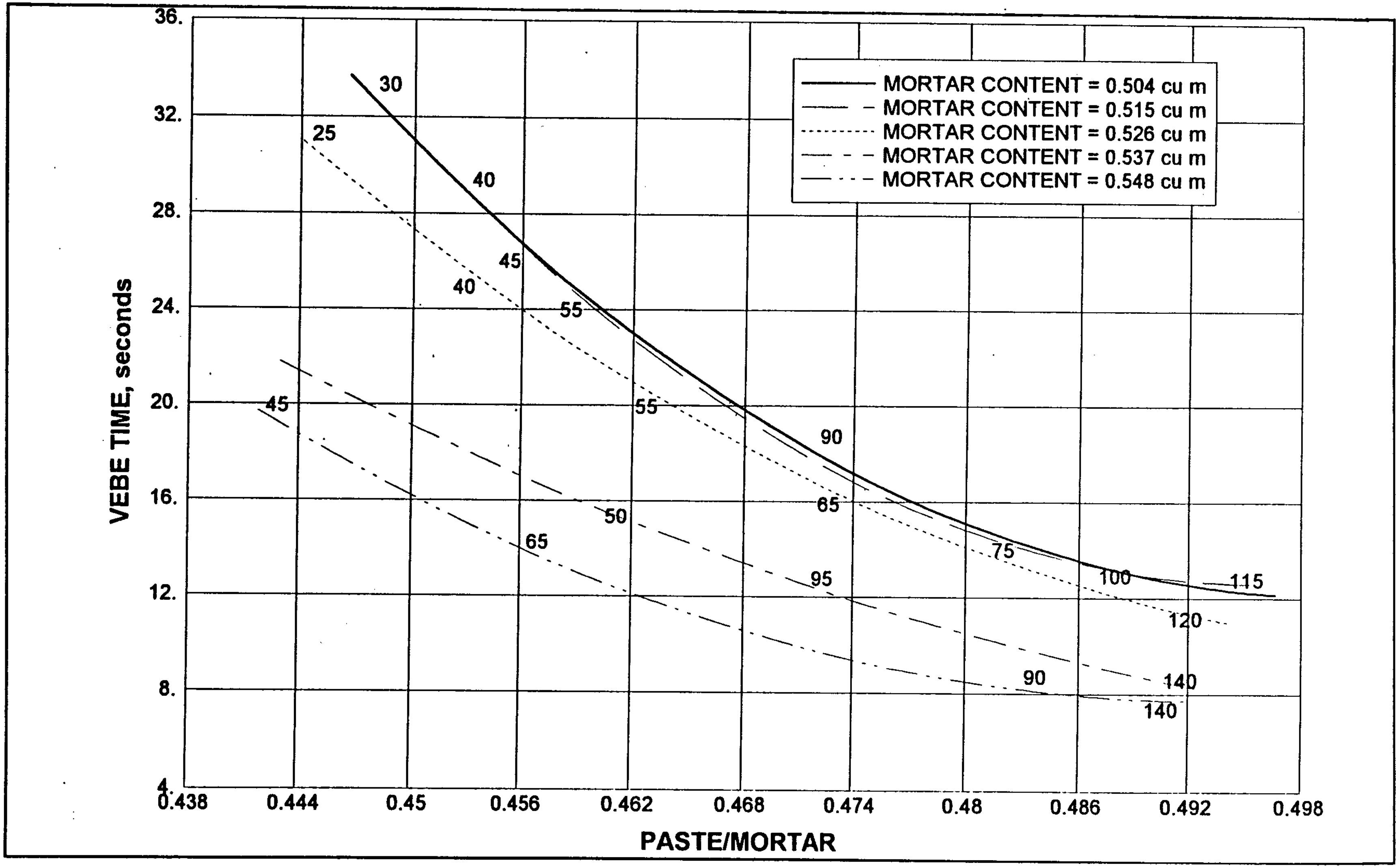


Figure 9. Vebe times for 37.5-mm (1-1/2-in.) NMSA mixture using favorably shaped coarse aggregate particles and having a 0.50 w/c

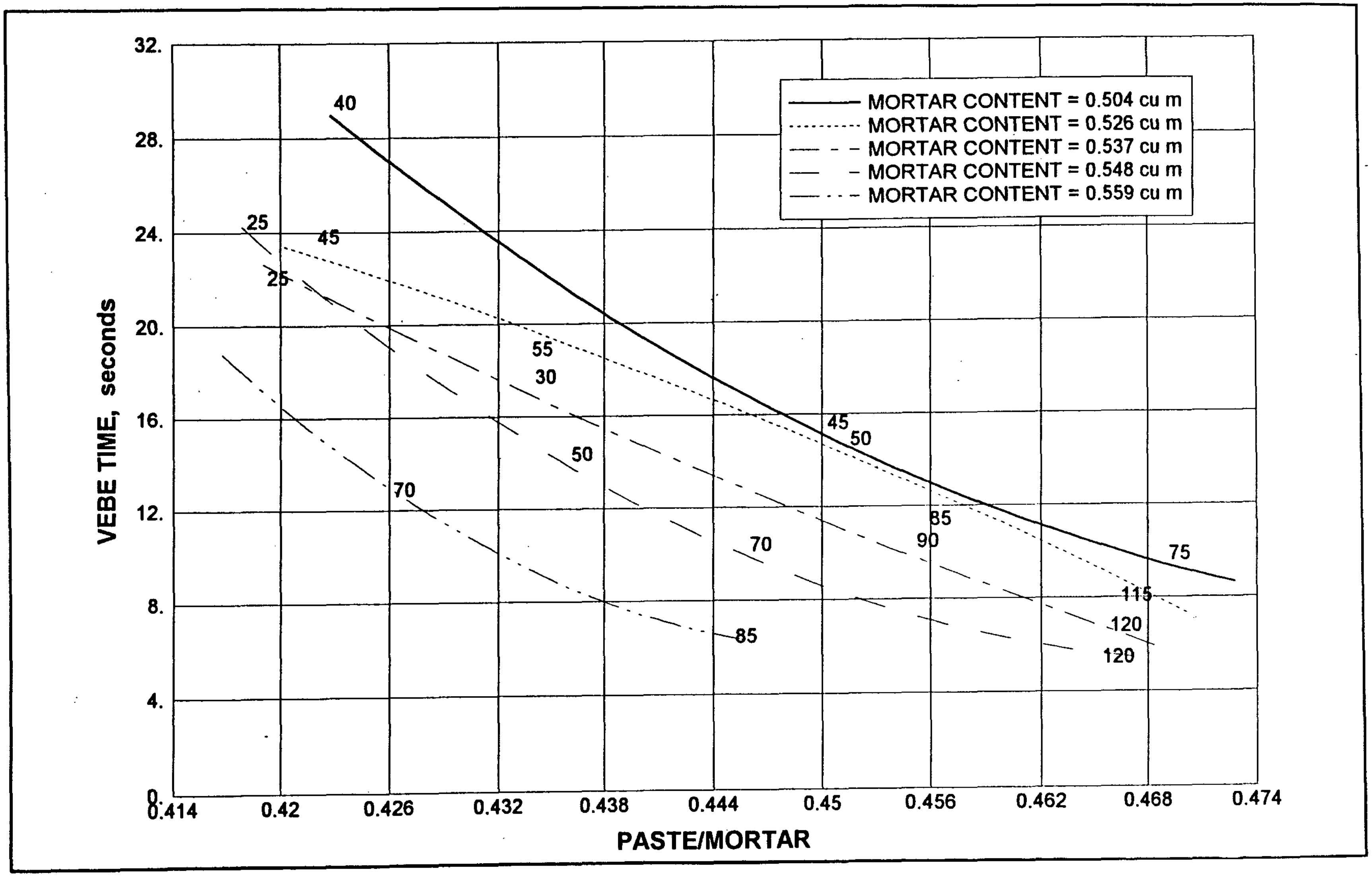


Figure 10. Vebe times for 37.5-mm (1-1/2-in.) NMSA mixture using favorably shaped coarse aggregate particles and having a 0.60 w/c

content above that of mixtures having higher mortar contents, the higher p/m did result in higher slumps. From a visual observation, the mixtures having a lower mortar content and higher p/m appeared to be "wet." Mortar coating the coarse aggregate particles had a noticeable water sheen. Yet these mixtures could be more difficult to consolidate than other mixtures having a lower p/m but higher mortar content. The data indicate that mixtures having mortar contents of 0.537 m^3 (14.5 ft^3) and higher required less vibratory effort to consolidate. Lower p/m could be used while maintaining adequate slumps of 40 to 75 mm (1-1/2 to 3 in.). Paste-mortar ratios of approximately 0.45 to 0.46 appeared to result in slumps between 40 and 75 mm (1-1/2 to 3 in.).

Mixtures with 0.60 w/c. The data indicate that mixtures having mortar contents of 0.515 m^3 (13.9 ft^3) and less could be judged difficult to consolidate when the slump is less than 50 mm (2 in.). Higher p/m were necessary to reduce the Vebe time. While the higher p/m did not necessarily increase the water content above that of mixtures having higher mortar contents, the higher p/m did result in higher slumps. From a visual observation, as was the case at a 0.50 w/c, the mixtures having a lower mortar content and higher p/m appeared to be "wet." Mortar coating the coarse aggregate particles had a noticeable water sheen. Yet these mixtures could be more difficult to consolidate than other mixtures having a lower p/m but higher mortar content. The data indicate that mixtures having mortar contents of 0.526 m^3 (14.2 ft^3) and higher required less vibratory effort to consolidate. Lower p/m could be used while maintaining adequate slumps of 40 to 75 mm (1-1/2 to 3 in.). Paste-mortar ratios of approximately 0.43 to 0.44 appeared to result in slumps between 40 and 75 mm (1-1/2 to 3 in.).

Overall. The data support the statement by ACI Committee 211 that a minimum mortar content is necessary for suitable workability and placeability. While Committee 211 was referring to 75-mm (3-in.) and 150-mm (6-in.) NMSA mass concrete mixtures, the above data suggest that the relationship is also applicable for mass concrete mixtures containing 37.5-mm (1-1/2-in.) NMSA. As would be expected, there appears to be a direct relationship between slump and p/m. The resulting increase in water content with an increase in the p/m provides for an increase in slump. However, the data point out that an increase in slump is not always the most effective way to make a concrete mixture easier to consolidate. Perhaps a more desirable approach would be to provide for an adequate proportion of mortar while holding the p/m to the minimum necessary to achieve the required slump at that mortar content. As shown in Figures 11 and 12, the Vebe time required to consolidate a mixture at a constant slump usually decreases as the mortar content increases. For w/c of 0.50 to 0.60, the data suggest that a mortar content of 0.537 ± 0.007 m^3 (14.5 ± 0.2 ft^3) might be an appropriate mortar content for suitable placing and workability properties in 37.5-mm (1-1/2-in.) NMSA mass concrete. Lower mortar contents appear to result in less workable concretes. Higher mortar contents can result in unnecessarily high cementitious contents. The p/m necessary to produce slumps between 40 and 75 mm (1-1/2 to 3 in.) increased as the w/c decreased due to the increased cementitious content.

Replacement page

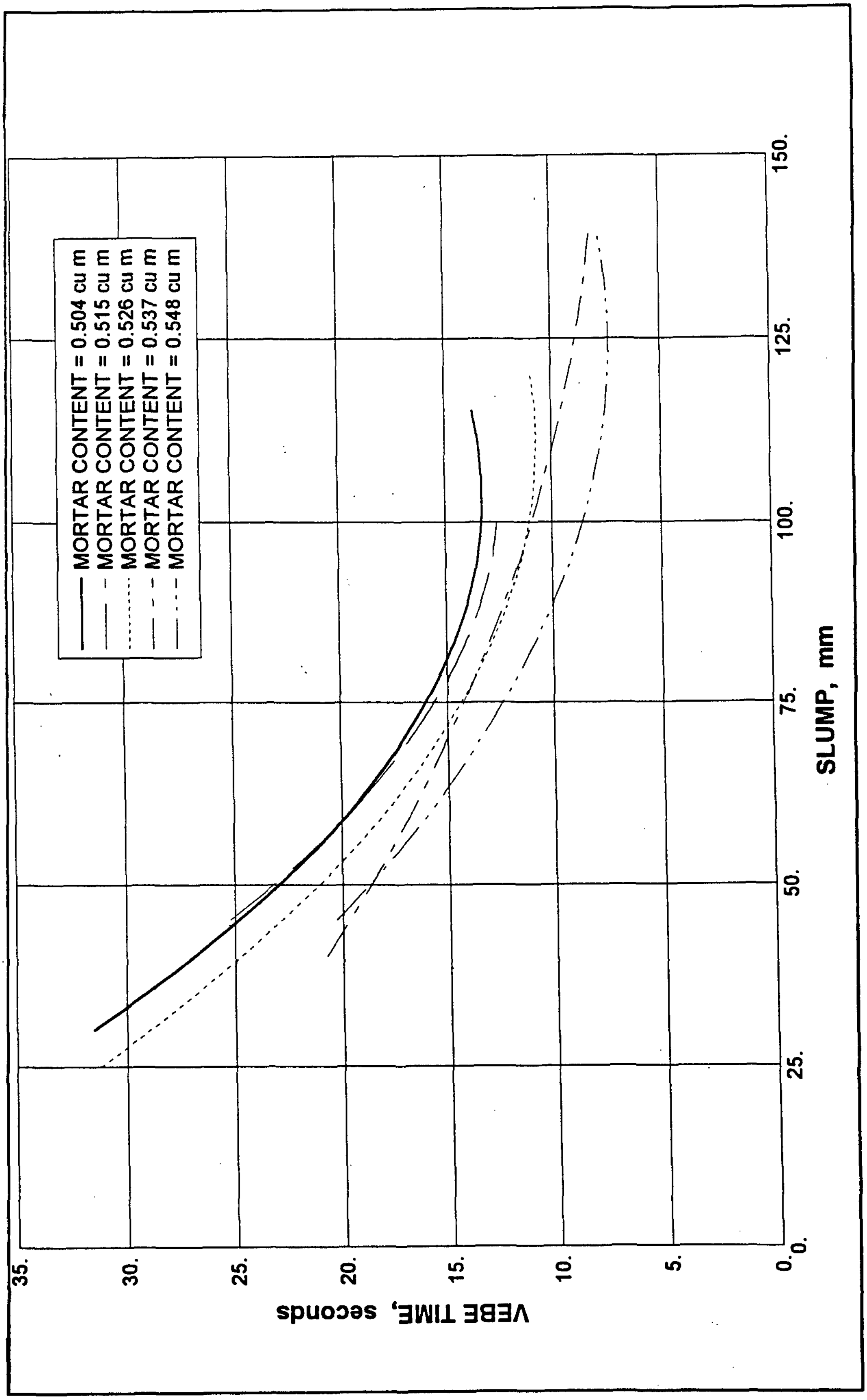


Figure 11. Relationship of Vebe time to slump for 37.5-mm (1-1/2-in.) NMSA mixtures using favorably shaped coarse aggregate particles and a 0.50 w/c

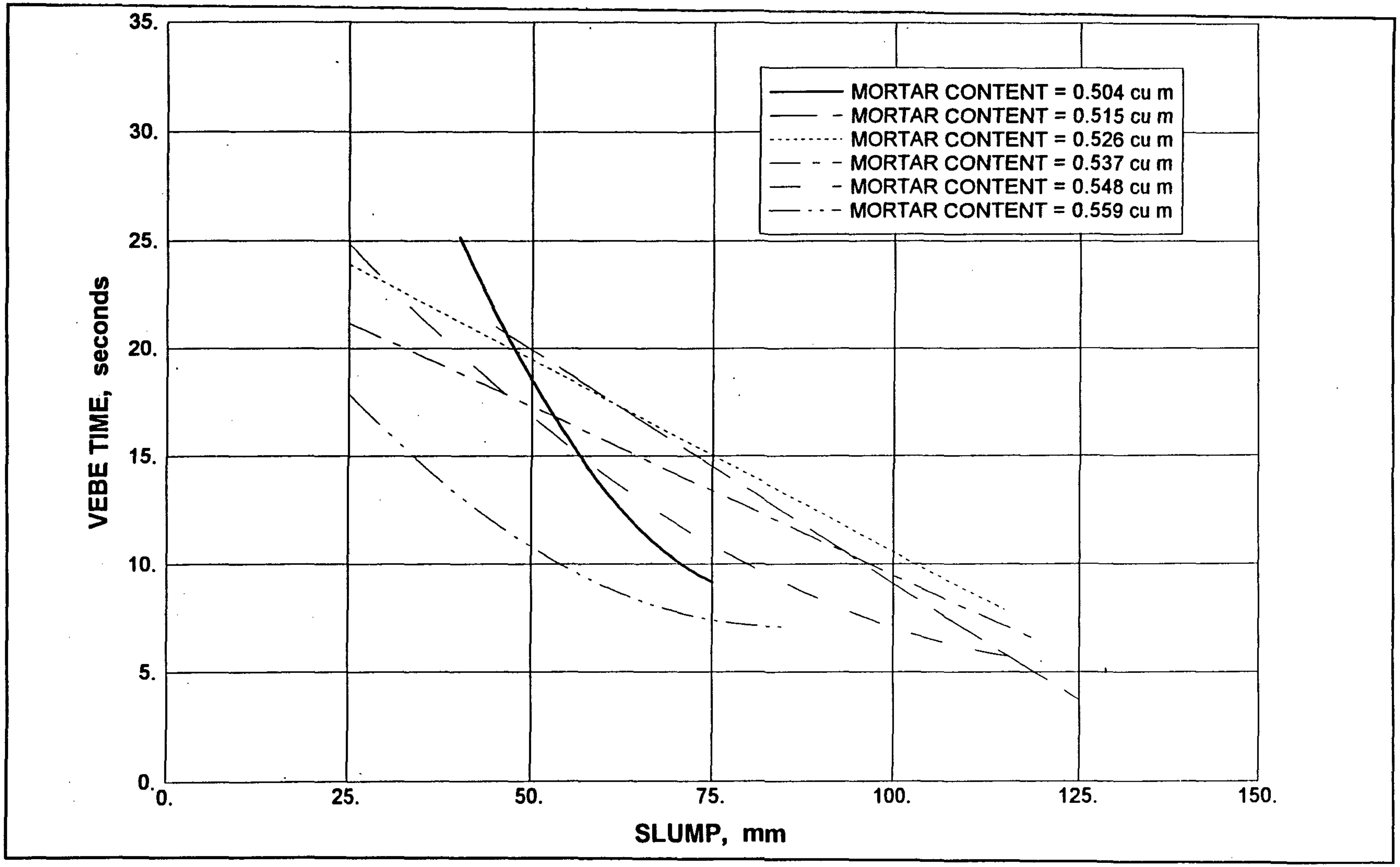


Figure 12. **Relationship of Vebe time to slump for 37.5-mm (1-1/2-in.) NMSA mixtures using favorably shaped coarse aggregate particles and a 0.60 w/c**

Less favorable coarse aggregate particle shape

A total of 23 mixtures were evaluated as shown in Tables 5 and 7. Plots of p/m versus Vebe time at each mortar content are shown in Figures 13 and 14 for w/c of 0.50 and 0.60, respectively. Slump values are superimposed on each curve at the appropriate location. As was the case with coarse aggregate having a favorable particle shape, the data indicate that for a given p/m, the Vebe time necessary to consolidate the sample decreases as the mortar content increases. A corresponding increase in slump is also indicated as the mortar content increased. For a given mortar content, the Vebe time necessary to consolidate the sample decreases as the p/m increases, however it does not appear to be a linear relationship. There appears to be a close relationship between the p/m and slump. Regardless of the mortar content, the slump increases as the p/m increases. Each of these relationships between the mortar content, p/m, slump, and Vebe time were expected. However, the data provide quantification the magnitude of the relationships.

Mixtures with 0.50 w/c. The data indicate that mixtures having mortar contents of 0.537 m^3 (14.5 ft^3) and less could be judged difficult to consolidate when the slump is less than 50 mm (2 in.). Higher p/m's were necessary to reduce the Vebe time. While the higher p/m did not necessarily increase the water content above that of mixtures having higher mortar contents, the higher p/m did result in higher slumps. From a visual observation, the mixtures having a lower mortar content and higher p/m appeared to be "wet." Mortar coating the coarse aggregate particles had a noticeable water sheen. Yet these mixtures could be more difficult to consolidate than other mixtures having a lower p/m but higher mortar content. The data indicate that mixtures having mortar contents of 0.548 m^3 (14.8 ft^3) required less vibratory effort to consolidate. Mortar contents higher than those examined in this investigation might have proved beneficial. Lower p/m could be used while maintaining adequate slumps of 40 to 75 mm (1-1/2 to 3 in.). Paste-mortar ratios of approximately 0.47 to 0.48 appeared to result in slumps between 40 and 75 mm (1-1/2 to 3 in.).

Mixtures with 0.60 w/c. The data indicate that mixtures having mortar contents of 0.526 m^3 (14.2 ft^3) and less could be judged difficult to consolidate when the slump is less than 50 mm (2 in.). Higher p/m's were necessary to reduce the Vebe time. While the higher p/m did not necessarily increase the water content above that of mixtures having higher mortar contents, the higher p/m did result in higher slumps. From a visual observation, the mixtures having a lower mortar content and higher p/m appeared to be "wet." Mortar coating the coarse aggregate particles had a noticeable water sheen. Yet these mixtures could be more difficult to consolidate than other mixtures having a lower p/m but higher mortar content. The data indicate that mixtures having mortar contents of 0.537 m^3 (14.5 ft^3) and higher required less vibratory effort to consolidate. Mortar contents higher than those examined in this investigation might have proved beneficial. Lower p/m's could be used while maintaining adequate slumps of 40 to 75 mm (1-1/2 to 3 in.). Paste-mortar ratios of approximately 0.46 to 0.47 appeared to result in slumps between 40 and 75 mm (1-1/2 to 3 in.).

Replacement page

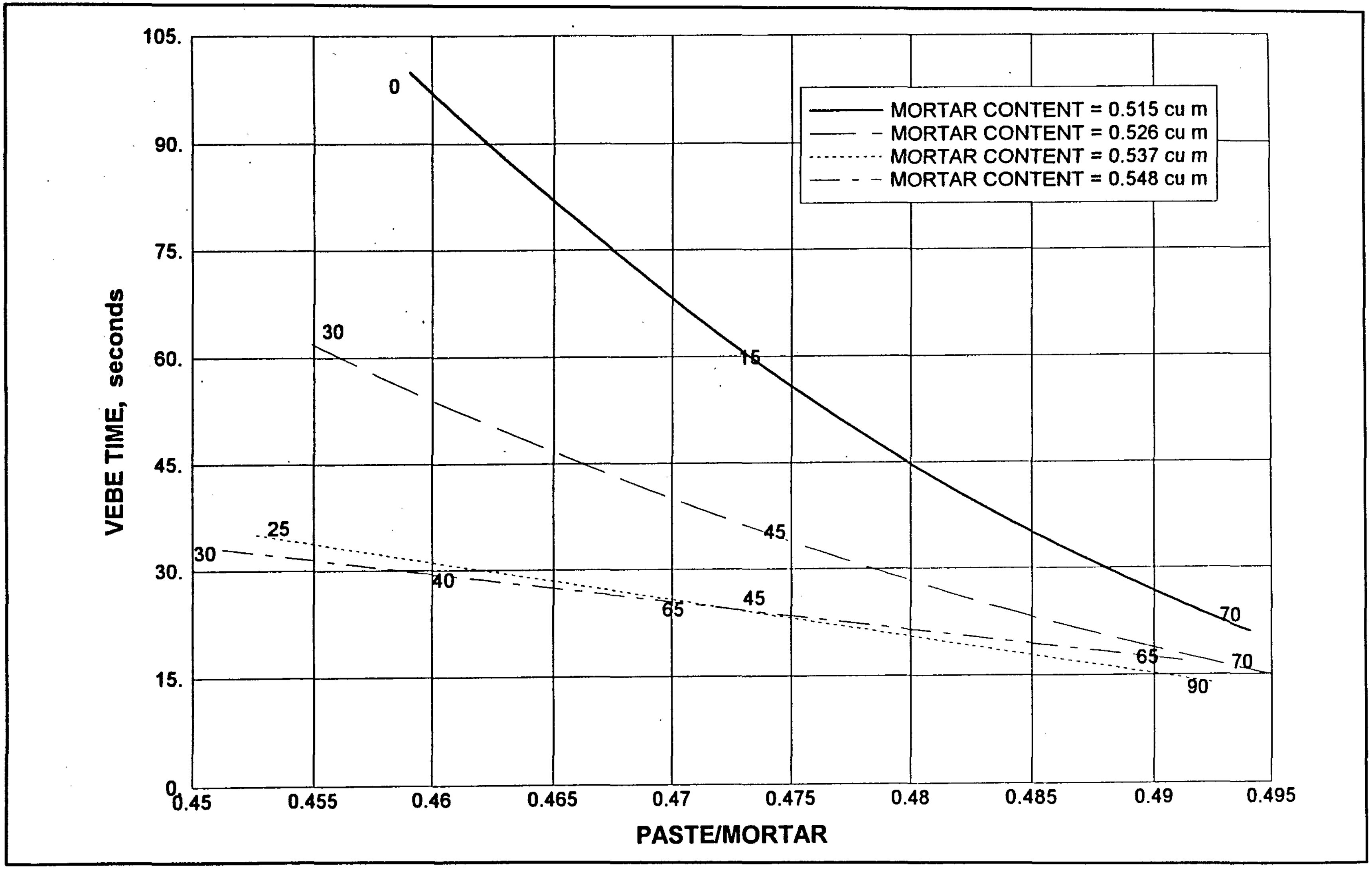


Figure 13. Vebe time for 37.5-mm (1-1/2-in.) NMSA mixtures using unfavorably shaped coarse aggregate particles and having a 0.50 w/c

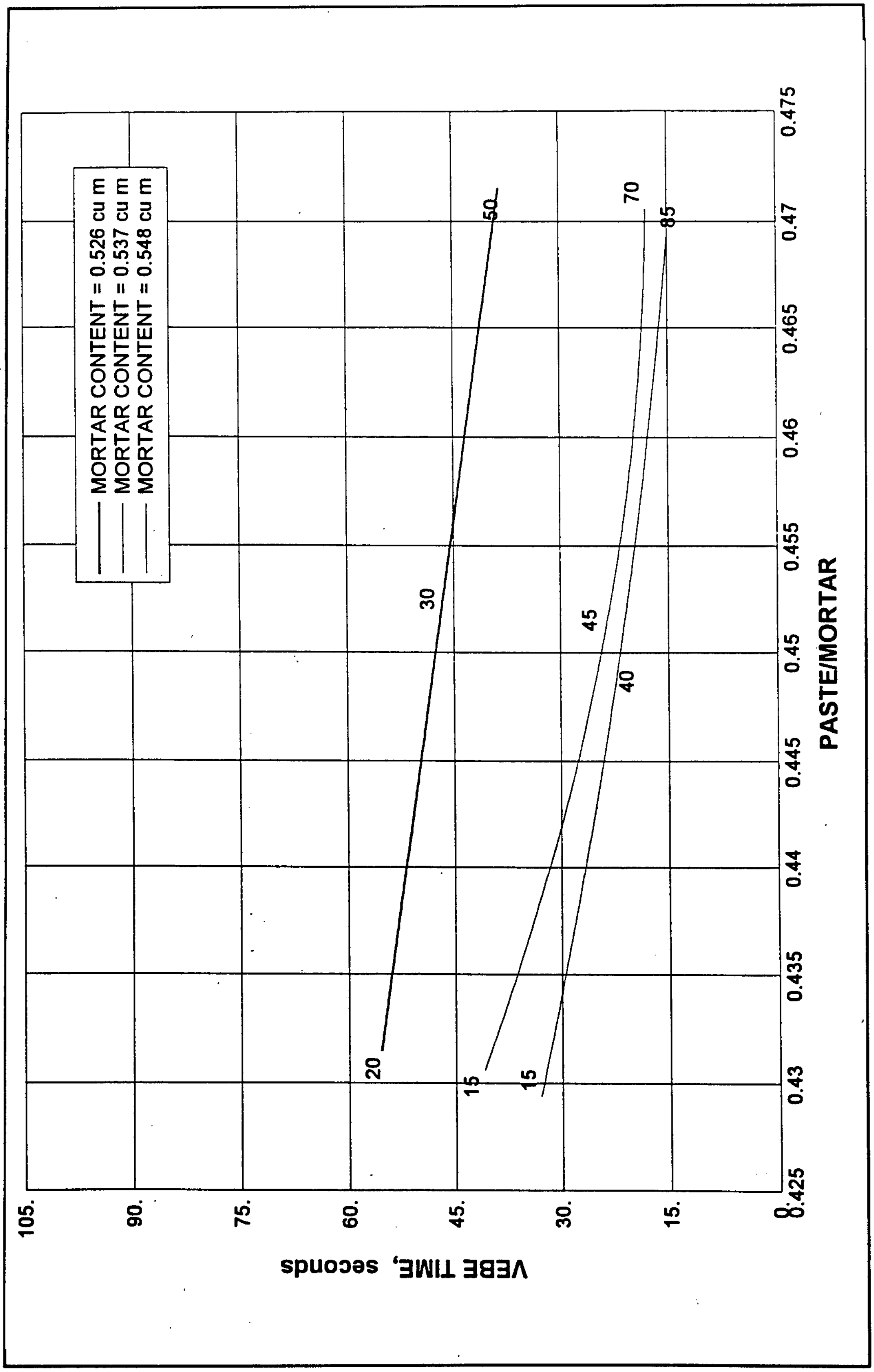


Figure 14. Vebe time for 37.5-mm (1-1/2-in.) NMSA mixtures using unfavorably shaped coarse aggregate particles and having a 0.60 w/c

Overall. The data describing mixtures having coarse aggregate with a less favorable particle shape support similar conclusions as those from mixtures having a favorable particle shape. There are a few significant differences: (a) a higher mortar content is indicated when the coarse aggregate particles have a less favorable shape, (b) an increase in mortar content or p/m does not have as dramatic an effect upon Vebe time or slump as is the case with the favorably shaped coarse aggregate particles, (c) it was difficult to entrain the proper amount of air in mixtures having mortar contents less than 0.537 m^3 (14.5 ft^3), and (d) a higher p/m was required to produce slumps between 40 and 75 mm (1-1/2 to 3 in.). As shown in Figures 15 and 16, the Vebe time required to consolidate a mixture at a constant slump usually decreases as the mortar content increases. For w/c of 0.50 to 0.60, the data suggest that a mortar content of 0.548 ± 0.007 m^3 (14.8 ± 0.2 ft^3) might be an appropriate mortar content for suitable placing and workability properties in 37.5-mm (1-1/2-in.) NMSA mass concrete. Lower mortar contents appear to result in less workable concretes and possible difficulty in entraining an appropriate amount of air. Higher mortar contents can result in unnecessarily high cementitious contents. The p/m necessary to produce slumps between 40 and 75 mm (1-1/2 to 3 in.) increased as the w/c decreased due to the increased cementitious content.

75-mm (3-in.) NMSA Mixtures

The modified vebe test procedure, which tested the concrete as mixed rather than wet-sieved portion, was unable to detect changes in the workablility of 75-mm (3-in.) NMSA mass concrete mixtures as successfully as had been the case with the 37.5-mm (1-1/2-in.) NMSA mass concrete mixtures. Changes in mixture proportions which should have affected the workability of the concrete mixtures did not result in a change measurable by the test procedure. It appears that the mold size was not large enough to adequately test a representative sample of the 75-mm (3-in.) NMSA mass concrete. Increasing the size further would have required two people to handle the mold. Therefore, it was decided not to pursue evaluation of the 75-mm (3-in.) NMSA mixtures. Test results for the three mixtures that were evaluated are given in Table 8.

Replacement page

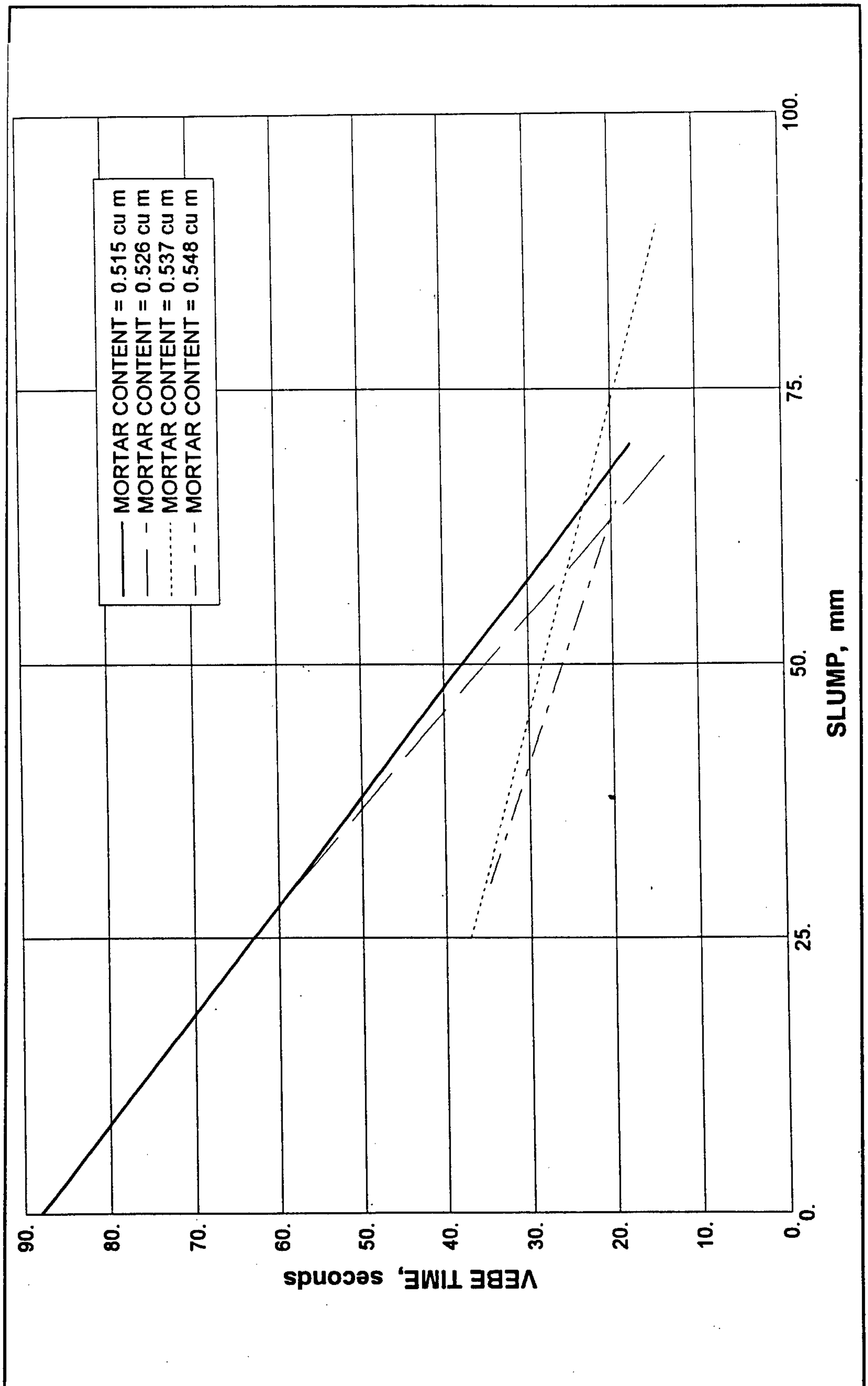


Figure 15. Relationship of Vebe time to slump for 37.5-mm (1-1/2-in.) NMSA mixtures using unfavorably shaped coarse aggregate particles and a 0.50 w/c

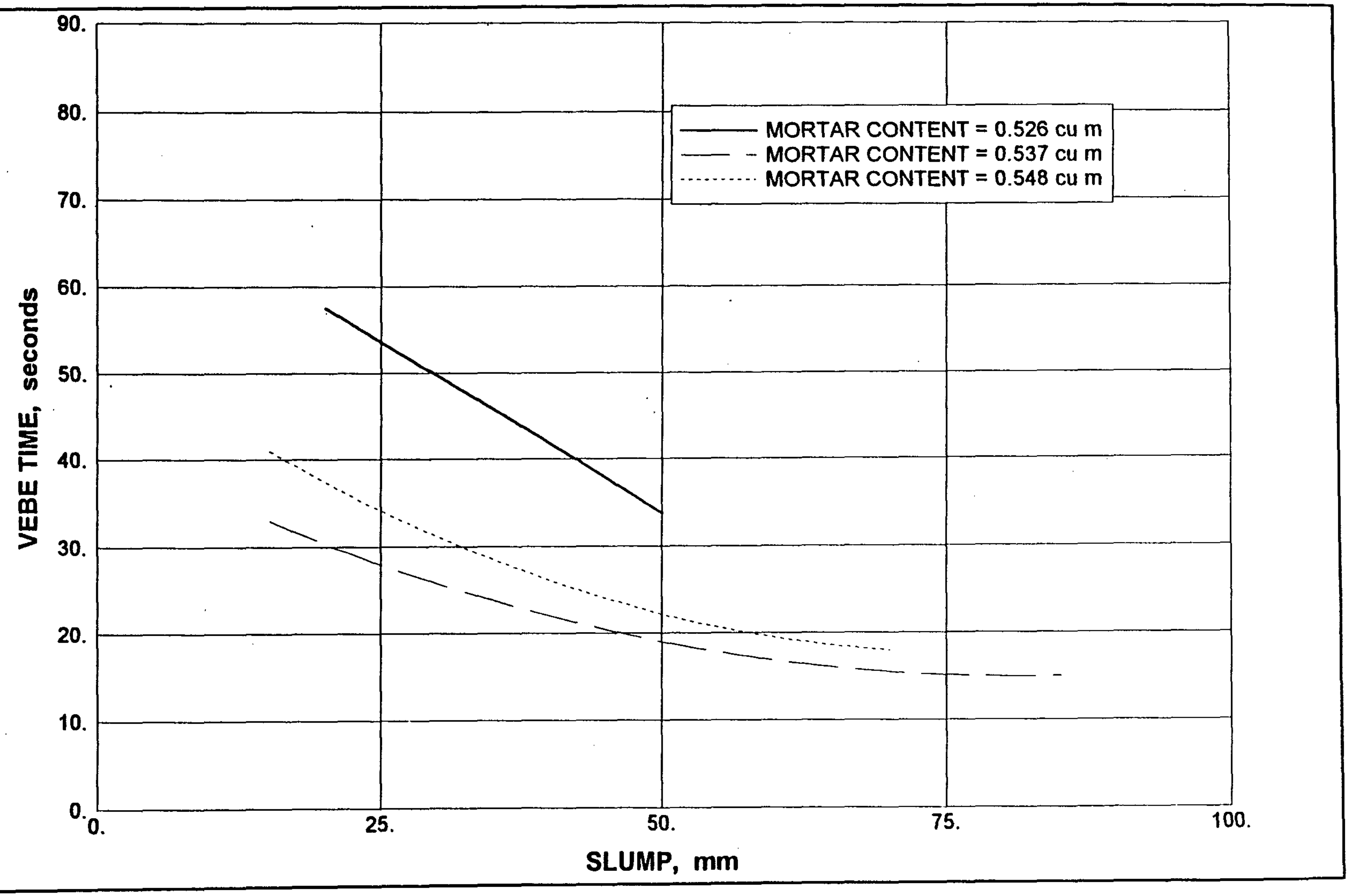


Figure 16. Relationship of Vebe time to slump for 37.5-mm (1-1/2-in.) NMSA mixtures using favorably shaped coarse aggregate particles and a 0.60 w/c

4 Conclusions and Recommendation

Conclusions

The data indicate that a recommended minimum and maximum mortar content could be a useful guide to aid in proportioning workable mass concrete mixtures containing 37.5-mm NMS coarse aggregate. An approximate minimum and maximum mortar content was identified for mixtures containing favorably shaped coarse aggregate particles (primarily blocky with minimal flat and elongated) and for mixtures containing less favorably shaped coarse aggregate particles (higher percentage of flat and elongated). All mixtures contained natural fine aggregate. The following mortar contents are suggested for the initial proportioning of mixtures having slumps of 55 ± 20 mm:

a. Favorably shaped crushed coarse aggregate: 0.537 ± 0.007 m^3 (14.5 ± 0.2 ft^3).

b. Less favorably shaped crushed coarse aggregate: increase the minimum mortar content by 0.011 m^3 (0.3 ft^3); i.e., 0.548 ± 0.007 m^3 (14.8 ± 0.2 ft^3).

These mortar contents appear to be appropriate for mixtures having w/c ranging from 0.50 to 0.60. Mixtures having w/c significantly higher or lower than these could require mortar contents outside the ranges suggested above. It is reasonable to expect that mortar contents similar to the minimum values suggested for favorably shaped crushed coarse aggregate, or perhaps somewhat lower, would be appropriate for rounded natural coarse aggregate. It is also reasonable to expect that higher mortar contents would be necessary if a manufactured fine aggregate were being used. However, additional research will be necessary to confirm this.

The p/m does not appear to be as useful as the mortar content as a guide to assist in proportioning workable mass concrete mixtures containing 37.5-mm NMS coarse aggregate. The p/m appears to have more impact upon the slump of the mixture than upon the amount of vibratory effort required to consolidate the concrete. The p/m appears to remain relatively constant for a given slump, w/c, and type of coarse aggregate, even when the mortar content changes. When the slump increases or the w/c increases, the p/m will necessarily increase also. It may, however, be significant that a higher p/m was necessary when the coarse aggregates were less favorably shaped; i.e., those including more flat and elongated particles.

It should also be pointed out that when the coarse aggregate contains a significant number of flat and elongated particles, it may not be possible to proportion a mixture whose workability will be as good as if the coarse aggregate particles were more blocky. Even when the mortar content and the p/m were increased in the mixtures containing the less favorably shaped aggregate, the slump did not increase nor did the Vebe time decrease as much as when similar changes were made to the mixtures containing favorably shaped coarse aggregate particles. EM 1110-2-2000, "Standard Practice for Concrete for Civil Works Structures," (Headquarters, Department of the Army 1994) states in paragraph 2.3, that

> "Excessive amounts of flat or elongated particles, or both, in aggregates will severely affect the water demand and finishability. In mass concrete structures, the amount of flat or elongated particles, or both, at a 3:1 length-to-width ratio or width-to-thickness ratio is limited to 25 percent in any size group of coarse aggregates."

In view of the data presented in this investigation, this appears to be prudent guidance.

Recommendation

EM 1110-2-2000, "Standard Practice for Concrete for Civil Works Structures," (Headquarters, Department of the Army 1994) states in paragraph 4.1, that "Proportions for mass concrete or structural concrete are to be selected in accordance with ACI 211.1 (ACI 1993b) (CRD-C 99) (USAEWES 1949) and other criteria as described in the following paragraphs of this chapter whether the work is done by the Government or the Contractor." It is recommended that consideration be given to revising current guidance by adding a subparagraph to paragraph 4.3, "Criteria for Mixture Proportioning," which states the following:

"For mass concretes containing 150-mm (6-in.) and 75-mm (3-in.) NMSA, mortar contents within the range recommended by ACI 211.1 (CRD-C 99) are suggested for initial mixture proportions. For mass concretes containing 37.5-mm (1½-in.) NMSA, the following mortar contents are suggested for initial mixture proportions.

a. Primarily blocky shaped crushed coarse aggregate: 0.537 ± 0.007 m^3 (14.5 ± 0.2 ft^3).

b. Crushed coarse aggregate with higher percentages of flat and elongated particles: 0.548 ± 0.007 m^3 (14.8 ± 0.2 ft^3).

These mortar contents appear to be appropriate for mixtures having w/c ranging from 0.50 to 0.60 and slumps of 55 ± 20 mm when natural fine aggregates are being used. Mixtures having w/c or slumps significantly higher or lower than these could require mortar contents outside the ranges suggested above. Use of a manufactured fine aggregate could require mortar contents above the ranges suggested above."

References

American Concrete Institute Committee 207. (1993a). "Roller compacted mass concrete." *ACI manual of concrete practice,* Part 1. ACI 207.5R-89, American Concrete Institute, Detroit, MI.

American Concrete Institute Committee 211. (1993b). "Standard practice for selecting proportions for normal, heavyweight, and mass concrete." *ACI manual of concrete practice,* Part 1. ACI 211.1-91, American Concrete Institute, Detroit, MI.

American Concrete Institute Committee 304. (1993c). "Guide for measuring, mixing, transporting, and placing concrete." *ACI manual of concrete practice,* Part 2. Report Number 304R-89, American Concrete Institute, Detroit, MI.

American Concrete Institute Committee 304. (1993d). Placing concrete with belt conveyors." *ACI manual of concrete practice,* Part 2. Report Number 304.4R-89, American Concrete Institute, Detroit, MI.

American Concrete Institute Committee 309. (1993e). "Guide for consolidation of concrete." *ACI manual of concrete practice,* Part 2. Report Number 309R-87, American Concrete Institute, Detroit, MI.

American Concrete Institute Committee 311. (1992). *ACI manual of concrete inspection.* Publication SP-2(92), 8th ed., American Concrete Institute, Detroit, MI.

American Society for Testing and Materials. (1993). *1993 Annual Book of ASTM Standards*. Philadelphia, PA.

a. Designation C 127-88. "Standard test method for specific gravity and absorption of coarse aggregate."

b. Designation C 128-88. "Standard test method for specific gravity and absorption of fine aggregate."

c. Designation C 136-84. "Standard method for sieve analysis of fine and coarse aggregate."

d. Designation C 138-81. "Standard test method for unit weight, yield, and air content (gravimetric) of concrete."

e. Designation C 143-90. "Standard test method for slump of portland cement concrete."

f. Designation C 150-92. "Standard specification for portland cement."

g. Designation C 172-90. "Standard practice for sampling freshly mixed concrete."

h. Designation C 231-89a. "Standard test method for air content of freshly mixed concrete by the pressure method."

i. Designation C 232-87. "Standard test methods for bleeding of concrete."

j. Designation C 311-92. "Standard test method for sampling and testing fly ash or natural pozzolans for use as a mineral admixture in portland cement concrete."

k. Designation C 618-92. "Standard specification for coal fly ash and raw or calcined natural pozzolan for use as a mineral admixture in portland cement concrete."

l. Designation D 4791-89. "Standard test method for flat or elongated particles in coarse aggregate."

m. Designation E 380-91. "Standard practice for the use of the international system of units."

British Standards Institute. (1983). "Standard method for determination of vebe time." *Testing Concrete*. BS 1881: Part 104, London, England.

Fuller, W. B., and Thompson, S. E. (1907). "The laws of proportioning concrete," *Transactions, American Society of Civil Engineers* 59, 76-143.

Headquarters, Department of the Army. (1992). "Mass concrete," Civil Works Construction Guide Specification CWGS-03305, Washington, D.C.

__________. (1994). "Standard practice for concrete for civil works structures," Engineer Manual 1110-2-2000, Washington, D.C.

Kosmatka, Steven H., and Panarese, William C. (1988). *Design and control of concrete mixtures*. 13th ed., Portland Cement Association, Skokie, IL.

Neeley, Billy D. (1993). "Assessing workability complaints in mass concrete construction," Miscellaneous Paper SL-93-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Plum, N. M. (1950). "The predetermination of water requirement and optimum grading of concrete," Building Research Studies No. 3, The Danish National Institute of Building Research, Copenhagen, Denmark.

Tynes, William O. (1968). "Effect of fineness of continuously graded coarse aggregate on properties of concrete," Technical Report No. 6-819, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

U.S. Army Engineer Waterways Experiment Station. (1949). *Handbook for concrete and cement* (with quarterly supplements), Vicksburg, MS.

Appendix A Recent Mass Concrete Mixture Information

Key

Calion L&D	Calion Lock and Dam, Ouachita River, Arkansas
Clarence Cannon	Clarence Cannon Dam, Salt River, Missouri
CRGNT	Crushed granite coarse aggregate
CRLS	Crushed limestone coarse aggregate
L&D 26 - 1st Stage	Lock and Dam No. 26, 1st Stage, Mississippi River, Missouri
L&D 26 - 2nd Stage	Lock and Dam No. 26, 2nd Stage, Mississippi River, Missouri
Melvin Price L&D	Melvin Price Lock and Dam, Mississippi River, Missouri
MLS	Manufactured limestone fine aggregate
Natural	Natural sand fine aggregate
NG	Natural gravel coarse aggregate
Overton L&D	Overton Lock and Dam, Red River, Louisiana
Red River #3	Lock and Dam No. 3, Red River, Louisiana
Red River #4	Lock and Dam No. 4, Red River, Louisiana
Red River #5	Lock and Dam No. 5, Red River, Louisiana
Red River TS	Thermal Study, Red River Locks and Dams, Louisiana
Tensas Cocodrie	Tensas Cocodrie Pumping Plant, Louisiana

Table A1
Mixture Information from Recent 37.5-mm NMSA Mass Concretes

Project	Mix #	w/c	s/a	1 m^3									
				Volume Air, m^3	Volume Cementitious, m^3	Volume Water, m^3	Volume Fine Aggregate, m^3	Volume Coarse Aggregate, m^3	Type Coarse	Type Fine	Slump	Volume Mortar, m^3	Paste/ Mortar
Red River #5	A1	0.5	39	0.0500	0.0731	0.1151	0.2971	0.4647	CRGNT	NATURAL	65	0.5353	0.4451
Red River #5	A2	0.45	38	0.0500	0.0800	0.1134	0.2875	0.4691	CRGNT	NATURAL	70	0.5309	0.4584
Red River #5	A3	0.4	37	0.0500	0.0914	0.1151	0.2751	0.4684	CRGNT	NATURAL	65	0.5316	0.4826
Red River #5	A5	0.45	38	0.0500	0.0839	0.1187	0.2840	0.4634	CRGNT	NATURAL	75	0.5366	0.4707
Red River #5	B1	0.5	39	0.0500	0.0765	0.1205	0.2937	0.4593	CRGNT	NATURAL	60	0.5407	0.4568
Red River #5	B2	0.45	38	0.0500	0.0850	0.1205	0.2829	0.4616	CRGNT	NATURAL	65	0.5384	0.4745
Red River #5	B3	0.4	37	0.0500	0.0980	0.1234	0.2696	0.4590	CRGNT	NATURAL	70	0.5410	0.5017
Red River #5	C3	0.35	36	0.0500	0.1056	0.1163	0.2621	0.4660	CRGNT	NATURAL	50	0.5340	0.5092
Red River TS	A1	0.65	38	0.0500	0.0580	0.1187	0.2939	0.4795	CRGNT/NG	NATURAL	85	0.5205	0.4355
Red River TS	A1R	0.65	38	0.0500	0.0562	0.1151	0.2959	0.4827	CRGNT/NG	NATURAL	65	0.5173	0.4280
Red River TS	A2	0.6	37	0.0500	0.0628	0.1187	0.2843	0.4841	CRGNT/NG	NATURAL	70	0.5159	0.4488
Red River TS	A2R	0.6	37	0.0500	0.0597	0.1128	0.2877	0.4899	CRGNT/NG	NATURAL	65	0.5101	0.4360
Red River TS	A3	0.55	37	0.0500	0.0620	0.1074	0.2888	0.4917	CRGNT/NG	NATURAL	70	0.5083	0.4318
Red River TS	A3R	0.55	37	0.0500	0.0613	0.1063	0.2895	0.4929	CRGNT/NG	NATURAL	70	0.5071	0.4291
Red River TS	A4	0.65	38	0.0500	0.0586	0.1199	0.2932	0.4784	CRGNT/NG	NATURAL	70	0.5216	0.4379
Red River TS	A4R	0.65	38	0.0500	0.0574	0.1175	0.2945	0.4806	CRGNT/NG	NATURAL	75	0.5194	0.4330
Red River TS	A5	0.6	37	0.0500	0.0619	0.1169	0.2854	0.4859	CRGNT/NG	NATURAL	70	0.5141	0.4450
Red River TS	A5R	0.6	37	0.0500	0.0612	0.1157	0.2860	0.4870	CRGNT/NG	NATURAL	90	0.5130	0.4424
Red River TS	A6	0.55	37	0.0500	0.0613	0.1063	0.2895	0.4929	CRGNT/NG	NATURAL	50	0.5071	0.4291
Red River TS	A7	0.65	39	0.0500	0.0600	0.1229	0.2992	0.4680	CRGNT/NG	NATURAL	70	0.5320	0.4377
Red River TS	A7R	0.65	39	0.0500	0.0580	0.1187	0.3016	0.4717	CRGNT/NG	NATURAL	55	0.5283	0.4291
Red River TS	A7R2	0.65	39	0.0500	0.0594	0.1217	0.2999	0.4690	CRGNT/NG	NATURAL	85	0.5310	0.4353

(Sheet 1 of 5)

Table A1 (Continued)

Project	Mix #	w/c	s/a	1 m^3									
				Volume Air, m^3	Volume Cementitious, m^3	Volume Water, m^3	Volume Fine Aggregate, m^3	Volume Coarse Aggregate, m^3	Type Coarse	Type Fine	Slump	Volume Mortar, m^3	Paste/ Mortar
Red River TS	A8	0.6	38	0.0500	0.0641	0.1211	0.2906	0.4742	CRGNT/NG	NATURAL	85	0.5258	0.4472
Red River TS	A84	0.6	38	0.500	0.0628	0.1187	0.2920	0.4764	CRGNT/NG	NATURAL	60	0.5236	0.4422
Red River TS	A9	0.55	38	0.0500	0.0637	0.1104	0.2948	0.4810	CRGNT/NG	NATURAL	65	0.5190	0.4319
Red River TS	A10	0.5	36	0.0500	0.0667	0.1051	0.2801	0.4981	CRGNT/NG	NATURAL	65	0.5019	0.4419
Red River TS	A11	0.45	35	0.0500	0.0729	0.1033	0.2709	0.5030	CRGNT/NG	NATURAL	70	0.4970	0.4550
Red River TS	A12	0.55	38	0.0500	0.0596	0.1033	0.2991	0.4880	CRGNT/NG	NATURAL	70	0.5120	0.4158
Red River TS	A13	0.5	37	0.0500	0.0644	0.1015	0.2901	0.4940	CRGNT/NG	NATURAL	95	0.5060	0.4267
Red River TS	A13R	0.5	37	0.0500	0.0626	0.0985	0.2919	0.4970	CRGNT/NG	NATURAL	40	0.5030	0.4197
Red River TS	A14	0.45	36	0.0500	0.0679	0.0961	0.2830	0.5030	CRGNT/NG	NATURAL	65	0.4970	0.4306
Red River TS	A15	0.45	37	0.0500	0.0649	0.0920	0.2934	0.4997	CRGNT/NG	NATURAL	95	0.5003	0.4135
Calion L&D	1	0.55	39	0.0500	0.0709	0.1171	0.2972	0.4649	CRGNT/NG	NATURAL	50	0.5351	0.4447
Calion L&D	2	0.51	38	0.0500	0.0753	0.1154	0.2886	0.4708	CRGNT/NG	NATURAL	55	0.5292	0.4547
Calion L&D	3	0.48	37	0.0500	0.0797	0.1150	0.2795	0.4759	CRGNT/NG	NATURAL	65	0.5241	0.4668
Clarence Cannon	8	0.45	37	0.0500	0.1018	0.1364	0.2634	0.4484	CRLS	MLS	40	0.5516	0.5225
Clarence Cannon	1	0.39	36	0.0500	0.1151	0.1350	0.2520	0.4480	CRLS	MLS	40	0.5520	0.5435
Red River #4	A1	0.5	37	0.0500	0.0701	0.1104	0.2847	0.4848	CRLS	NATURAL	75	0.5152	0.4474
Red River #4	A2	0.45	36	0.0500	0.0775	0.1104	0.2744	0.4877	CRLS	NATURAL	75	0.5123	0.4644
Red River #4	A3	0.4	35	0.0500	0.0876	0.1104	0.2632	0.4888	CRLS	NATURAL	65	0.5112	0.4852
Red River #4	A4	0.5	37	0.0500	0.0746	0.1175	0.2804	0.4775	CRLS	NATURAL	70	0.5225	0.4634
Red River #4	B1	0.5	37	0.0500	0.0739	0.1163	0.2811	0.4787	CRLS	NATURAL	65	0.5213	0.4607
Red River #4	B2	0.45	36	0.0500	0.0821	0.1163	0.2706	0.4810	CRLS	NATURAL	55	0.5190	0.4784
Red River #4	B3	0.4	34	0.0500	0.0923	0.1163	0.2520	0.4893	CRLS	NATURAL	65	0.5107	0.5065
Red River #4	B4	0.5	36	0.0500	0.0791	0.1246	0.2686	0.4776	CRLS	NATURAL	75	0.5224	0.4858
Red River #4	C3	0.35	33	0.0500	0.1023	0.1128	0.2426	0.4924	CRLS	NATURAL	75	0.5076	0.5221

(Sheet 2 of 5)

Table A1 (Continued)

Project	Mix #	w/c	s/a	1 m³									
				Volume Air, m^3	Volume Cementitious, m^3	Volume Water, m^3	Volume Fine Aggregate, m^3	Volume Coarse Aggregate, m^3	Type Coarse	Type Fine	Slump	Volume Mortar, m^3	Paste/ Mortar
Red River #3	A1-1	0.65	42	0.0500	0.0737	0.1294	0.3137	0.4332	CRLS	NATURAL	65	0.5668	0.4465
Red River #3	A1-2	0.6	41	0.0500	0.0774	0.1264	0.3060	0.4403	CRLS	NATURAL	55	0.5597	0.4434
Red River #3	A1-3	0.55	40	0.0500	0.0783	0.1175	0.3017	0.4525	CRLS	NATURAL	65	0.5475	0.4490
Red River #3	B1-1	0.5	39	0.0500	0.0836	0.1151	0.2910	0.4552	CRLS	NATURAL	70	0.5448	0.4658
Red River #3	B1-2	0.45	38	0.0500	0.0904	0.1134	0.2817	0.4595	CRLS	NATURAL	65	0.5405	0.4789
Red River #3	C1-1	0.45	38	0.0500	0.0942	0.1187	0.2801	0.4570	CRLS	NATURAL	70	0.5430	0.4842
Red River #3	C1-2	0.4	37	0.0500	0.1012	0.1157	0.2712	0.4618	CRLS	NATURAL	65	0.5382	0.4960
Red River #3	B1-1S1	0.5	41	0.0500	0.0791	0.1080	0.3107	0.4471	CRLS	NATURAL	50	0.5529	0.4379
Red River #3	A1-1S2	0.5	39	0.0500	0.0836	0.1151	0.2910	0.4552	CRLS	NATURAL	100	0.5448	0.4658
L&D 26-1st Stage	2A	0.36	37	0.0500	0.0942	0.1069	0.2771	0.4718	CRLS	NATURAL	90	0.5282	0.4754
L&D 26-1st Stage	2B	0.34	37	0.0500	0.1026	0.1099	0.2729	0.4646	CRLS	NATURAL	75	0.5354	0.4903
L&D 26-1st Stage	2C	0.34	37	0.0500	0.1067	0.1143	0.2697	0.4593	CRLS	NATURAL	95	0.5407	0.5011
L&D 26-1st Stage	5A	0.45	39	0.0500	0.0796	0.1128	0.2958	0.4619	CRLS	NATURAL	55	0.5381	0.4503
L&D 26-1st Stage	5B	0.42	38	0.0500	0.0853	0.1128	0.2857	0.4662	CRLS	NATURAL	50	0.5338	0.4647
L&D 26-1st Stage	5C	0.4	37	0.0500	0.0895	0.1128	0.2767	0.4710	CRLS	NATURAL	55	0.5290	0.4770
L&D 26-1st Stage	6A	0.45	39	0.0500	0.0741	0.1050	0.3007	0.4703	CRLS	NATURAL	40	0.5297	0.4324
L&D 26-1st Stage	6B	0.42	38	0.0500	0.0794	0.1050	0.2909	0.4747	CRLS	NATURAL	40	0.5253	0.4462
L&D 26-1st Stage	6C	0.4	37	0.0500	0.0833	0.1050	0.2818	0.4799	CRLS	NATURAL	40	0.5201	0.4582
L&D 26-2nd Stage	C2-1	0.65	37	0.0500	0.0609	0.1246	0.2829	0.4816	CRLS	NATURAL	30	0.5184	0.4543
L&D 26-2nd Stage	C2-2	0.6	36	0.0500	0.0660	0.1246	0.2734	0.4860	CRLS	NATURAL	45	0.5140	0.4681
L&D 26-2nd Stage	C2-3	0.55	35	0.0500	0.0713	0.1234	0.2644	0.4909	CRLS	NATURAL	45	0.5091	0.4807
L&D 26-2nd Stage	D2-1	0.5	35	0.0500	0.0780	0.1229	0.2622	0.4870	CRLS	NATURAL	45	0.5130	0.4890
L&D 26-2nd Stage	D2-2	0.45	34	0.0500	0.0854	0.1211	0.2528	0.4907	CRLS	NATURAL	45	0.5093	0.5036

(Sheet 3 of 5)

Table A1 (Continued)

Project	Mix #	w/c	s/a	1 m³									
				Volume Air, m^3	Volume Cementitious, m^3	Volume Water, m^3	Volume Fine Aggregate, m^3	Volume Coarse Aggregate, m^3	Type Coarse	Type Fine	Slump	Volume Mortar, m^3	Paste/ Mortar
L&D 26-2nd Stage	D2-3	0.4	33	0.0500	0.0951	0.1199	0.2426	0.4924	CRLS	NATURAL	40	0.5076	0.5221
L&D 26-2nd Stage	E2-1	0.5	44	0.0500	0.0829	0.1306	0.3240	0.4124	CRLS	NATURAL	95	0.5876	0.4485
L&D 26-2nd Stage	E2-2	0.45	42	0.0500	0.0963	0.1365	0.3012	0.4160	CRLS	NATURAL	75	0.5840	0.4842
L&D 26-2nd Stage	E2-3	0.4	41	0.0500	0.1083	0.1365	0.2891	0.4160	CRLS	NATURAL	75	0.5840	0.5049
Melvin Price L&D	C2-1	0.65	40	0.0500	0.0614	0.1258	0.3051	0.4576	CRLS	NATURAL	50	0.5424	0.4374
Melvin Price L&D	C2-2	0.6	40	0.0500	0.0653	0.1234	0.3045	0.4567	CRLS	NATURAL	50	0.5433	0.4395
Melvin Price L&D	C2-3	0.55	39	0.0500	0.0692	0.1199	0.2967	0.4641	CRLS	NATURAL	50	0.5359	0.4462
Melvin Price L&D	D2-1	0.5	39	0.0500	0.0754	0.1187	0.2947	0.4611	CRLS	NATURAL	50	0.5389	0.4529
Melvin Price L&D	D2-2	0.45	38	0.0500	0.0812	0.1151	0.2864	0.4673	CRLS	NATURAL	45	0.5327	0.4625
Melvin Price L&D	D2-3	0.4	38	0.0500	0.0914	0.1151	0.2825	0.4610	CRLS	NATURAL	40	0.5390	0.4759
Melvin Price L&D	E2-1	0.5	38	0.0500	0.0810	0.1276	0.2817	0.4596	CRLS	NATURAL	70	0.5404	0.4787
Melvin Price L&D	E2-2	0.45	37	0.0500	0.0921	0.1306	0.2691	0.4582	CRLS	NATURAL	75	0.5418	0.5033
Melvin Price L&D	E2-3	0.4	36	0.0500	0.1060	0.1336	0.2558	0.4547	CRLS	NATURAL	95	0.5453	0.5310
Melvin Price L&D	F2-1	0.45	39	0.0500	0.0745	0.1057	0.3002	0.4696	NG	NATURAL	55	0.5304	0.4340
Melvin Price L&D	F2-2	0.4	39	0.0500	0.0857	0.1080	0.2949	0.4613	NG	NATURAL	70	0.5387	0.4525
Melvin Price L&D	F2-3	0.35	38	0.0500	0.1012	0.1116	0.2801	0.4570	NG	NATURAL	55	0.5430	0.4840
Tensas Cocodrie	1A	0.53	35	0.0500	0.0764	0.1276	0.2611	0.4849	NG	NATURAL	45	0.5151	0.4932
Tensas Cocodrie	1B	0.5	35	0.0500	0.0810	0.1276	0.2595	0.4819	NG	NATURAL	45	0.5181	0.4992
Tensas Cocodrie	1C	0.47	35	0.0500	0.0862	0.1276	0.2577	0.4786	NG	NATURAL	50	0.5214	0.5059
Overton L&D	1A	0.5	37	0.0500	0.0711	0.1120	0.2837	0.4831	NG	NATURAL	45	0.5169	0.4510
Overton L&D	1B	0.55	37	0.0500	0.0647	0.1121	0.2861	0.4871	NG	NATURAL	45	0.5129	0.4421
Overton L&D	1C	0.6	38	0.0500	0.0593	0.1121	0.2959	0.4827	NG	NATURAL	45	0.5173	0.4280
L&D 26-1st Stage	8A	0.44	37	0.0500	0.0768	0.1434	0.2837	0.4461	NG	NATURAL	55	0.5539	0.4878

(Sheet 4 of 5)

Table A1 (Concluded)

Project	Mix #	w/c	s/a	1 m^3									
				Volume Air, m^3	Volume Cementitious, m^3	Volume Water, m^3	Volume Fine Aggregate, m^3	Volume Coarse Aggregate, m^3	Type Coarse	Type Fine	Slump	Volume Mortar, m^3	Paste/ Mortar
L&D 26-1st State	8B	0.42	36	0.0500	0.0781	0.1033	0.2767	0.4919	NG	NATURAL	40	0.5081	0.4555
L&D 26-1st Stage	8C	0.4	36	0.0500	0.0820	0.1033	0.2753	0.4894	NG	NATURAL	50	0.5106	0.4607
L&D 26-2nd Stage	F2-1	0.45	33	0.0500	0.0762	0.1080	0.2527	0.5130	NG	NATURAL	65	0.4870	0.4811
L&D 26-2nd Stage	F2-2	0.41	33	0.0500	0.0836	0.1080	0.2503	0.5081	NG	NATURAL	55	0.4819	0.4913
L&D 26-2nd Stage	F2-3	0.37	32	0.0500	0.0922	0.1074	0.2401	0.5103	NG	NATURAL	70	0.4897	0.5097

(Sheet 5 of 5)

Table A2
Mixture Information from Recent 75-mm NMSA Mass Concrete

				1 m^3 batch									
Project	Mix #	w/c	s/a	Volume Air, m^3	Volume Cementitious, m^3	Volume Water, m^3	Volume Fine Aggregate, m^3	Volume Coarse Aggregate, m^3	Type Coarse	Type Fine	Slump, mm	Volume Mortar, m^3	Paste/ Mortar
Clarence Cannon	3	0.54	32	0.395	0.0726	0.1176	0.2465	0.5238	CRLS	MLS	40	0.4762	0.4824
Clarence Cannon	7	0.45	31	0.396	0.0885	0.1187	0.2335	0.5197	CRLS	MLS	40	0.4803	0.5138
L&D 26-1st Stage	4A	0.5	33	0.371	0.0614	0.0967	0.2656	0.5391	CRLS	NATURAL	30	0.4609	0.4238
L&D 26-1st Stage	4B	0.45	33	0.371	0.0669	0.0948	0.2644	0.5368	CRLS	NATURAL	30	0.4632	0.4293
L&D 26-2nd Stage	4C	0.42	32	0.371	0.0708	0.0948	0.2551	0.5421	CRLS	NATURAL	45	0.4579	0.4429
L&D 26-2nd Stage	C3-1	0.65	31	0.370	0.0510	0.1045	0.2503	0.5571	CRLS	NATURAL	50	0.4429	0.4347
L&D 26-2nd Stage	C3-2	0..6	31	0.370	0.0550	0.1039	0.2493	0.5549	CRLS	NATURAL	50	0.4451	0.4399
L&D 26-2nd Stage	C3-3	0.55	31	0.370	0.0593	0.1027	0.2483	0.5527	CRLS	NATURAL	40	0.4473	0.4448
L&D 26-2nd Stage	D3-1	0.5	30	0.370	0.0660	0.1039	0.2380	0.5552	CRLS	NATURAL	50	0.4448	0.4650
L&D 26-2nd Stage	D3-2	0.45	30	0.370	0.0720	0.1021	0.2367	0.5522	CRLS	NATURAL	30	0.4478	0.4715
L&D 26-2nd Stage	D3-3	0.4	29	0.370	0.0810	0.1021	0.2262	0.5537	CRLS	NATURAL	40	0.4463	0.4932
Melvin Price L&D	C3-1	0.65	32	0.370	0.0504	0.1033	0.2549	0.5544	CRLS	NATURAL	45	0.4456	0.4279
Melvin Price L&D	C3-2	0.6	32	0.370	0.0521	0.0985	0.2559	0.5564	CRLS	NATURAL	50	0.4436	0.4231
Melvin Price L&D	C3-3	0.55	32	0.370	0.0541	0.0938	0.2608	0.5543	CRLS	NATURAL	30	0.4457	0.4149
Melvin Price L&D	D3-1	0.5	32	0.370	0.0577	0.0908	0.2566	0.5580	CRLS	NATURAL	40	0.4420	0.4196
Melvin Price L&D	D3-2	0.45	32	0.370	0.0628	0.0890	0.2555	0.5556	CRLS	NATURAL	30	0.4444	0.4250
Melvin Price L&D	D3-3	0.4	31	0.370	0.0721	0.0908	0.2440	0.5561	CRLS	NATURAL	40	0.4439	0.4503

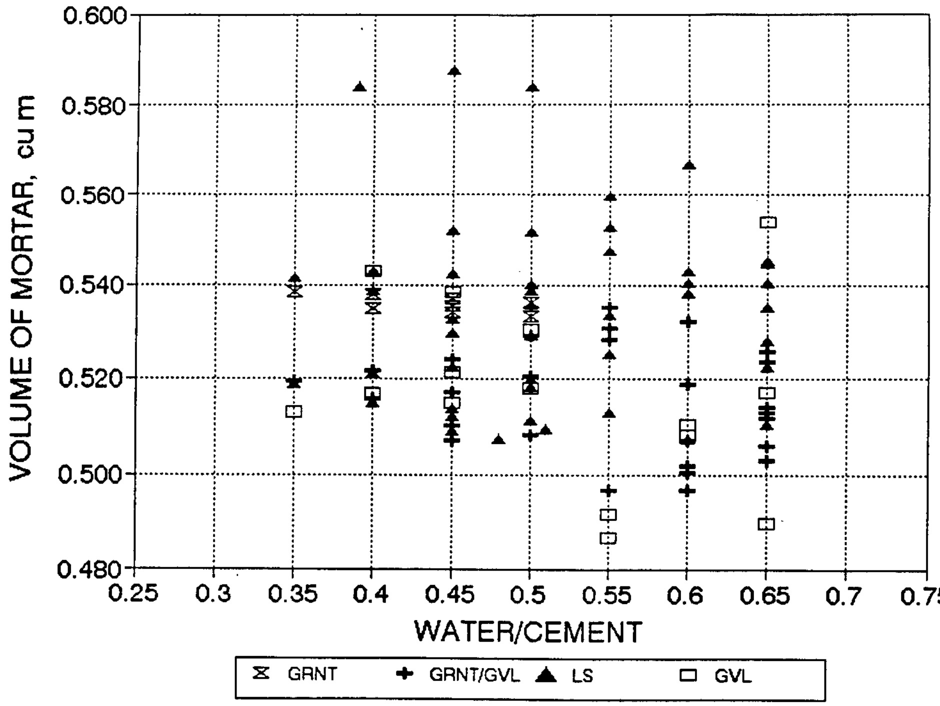


Figure A1. Mortar content of 37.5-mm NMSA mass concrete mixtures reviewed for historical data

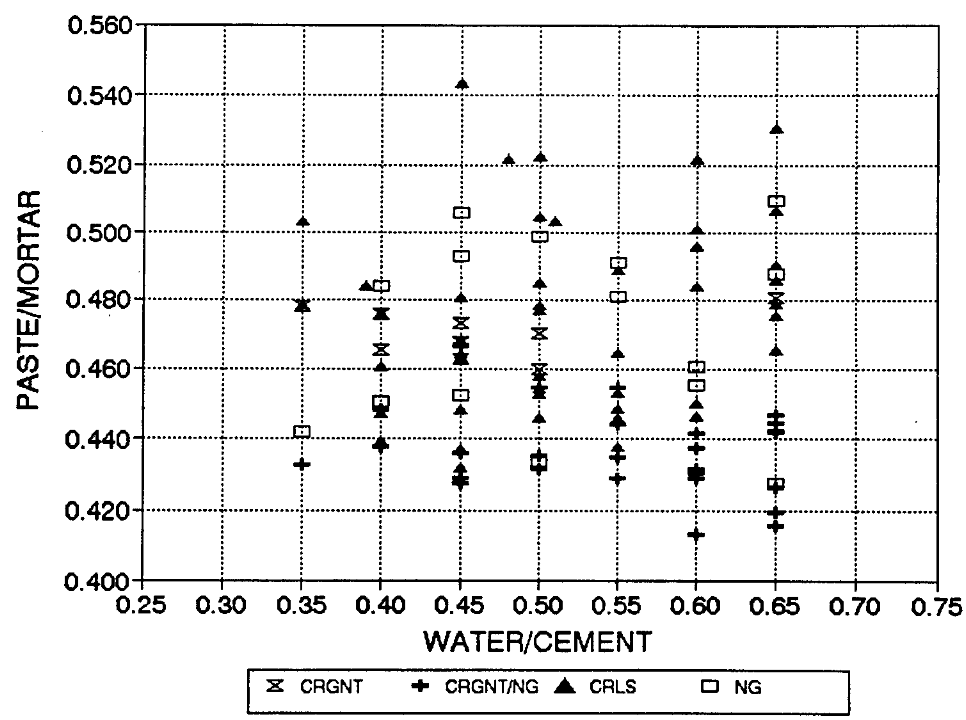


Figure A2. Paste/mortar of 37.5-mm NMSA mass concrete mixtures reviewed for historical data

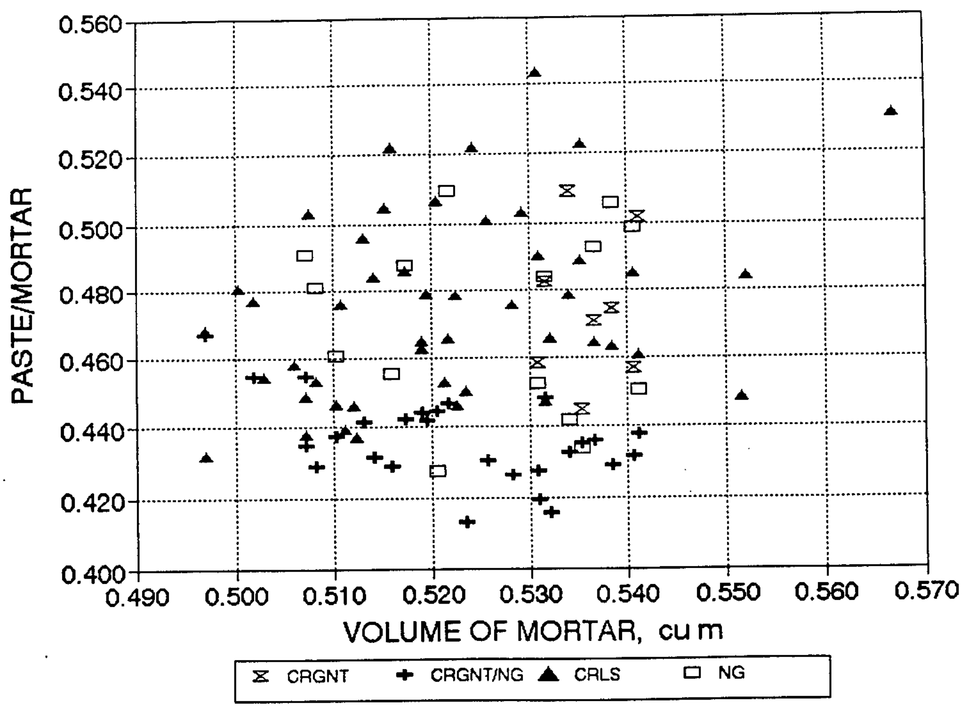


Figure A3. Relationship of mortar content to paste/mortar of 37.5-mm NMSA mass concrete mixtures reviewed for historical data

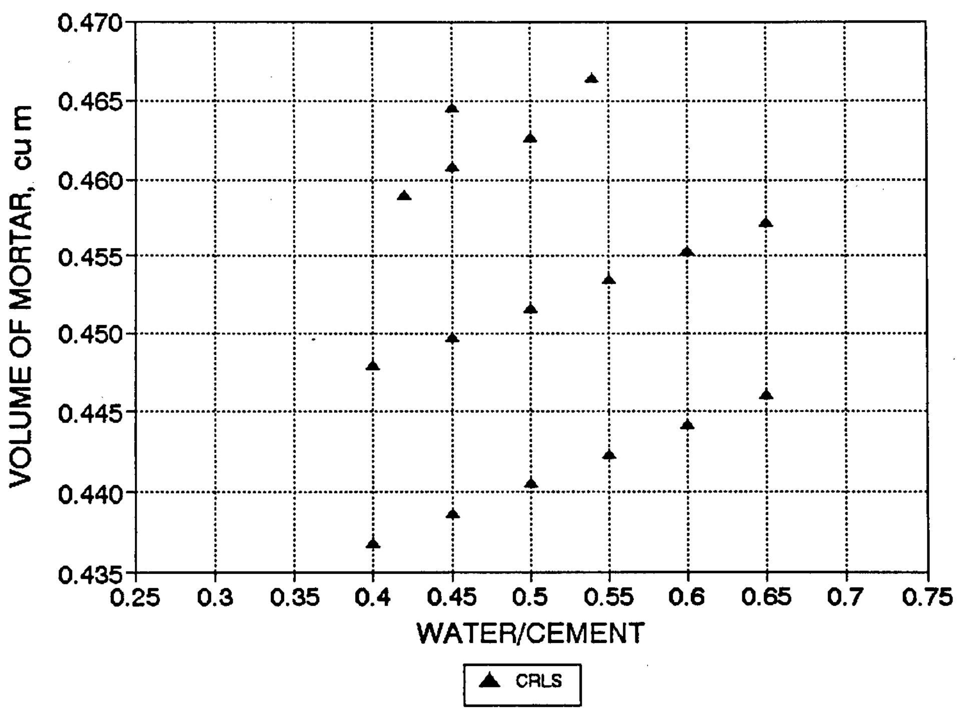


Figure A4. Mortar content of 75-mm NMSA mass concrete mixtures reviewed for historical data

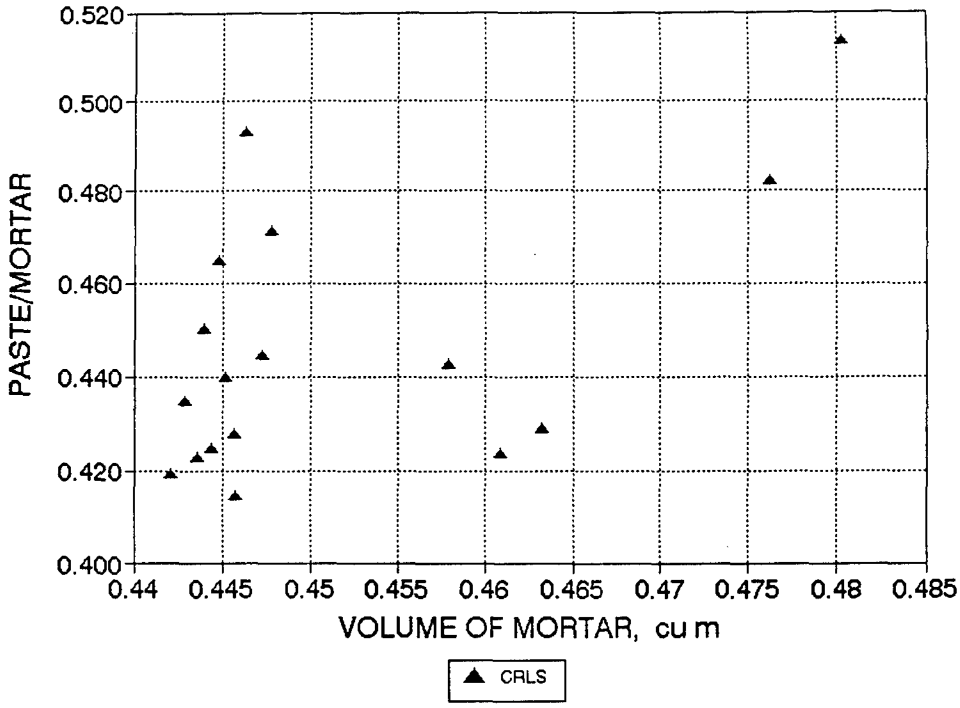


Figure A5. Paste/mortar of 75-mm NMSA mass concrete mixtures reviewed for historical data

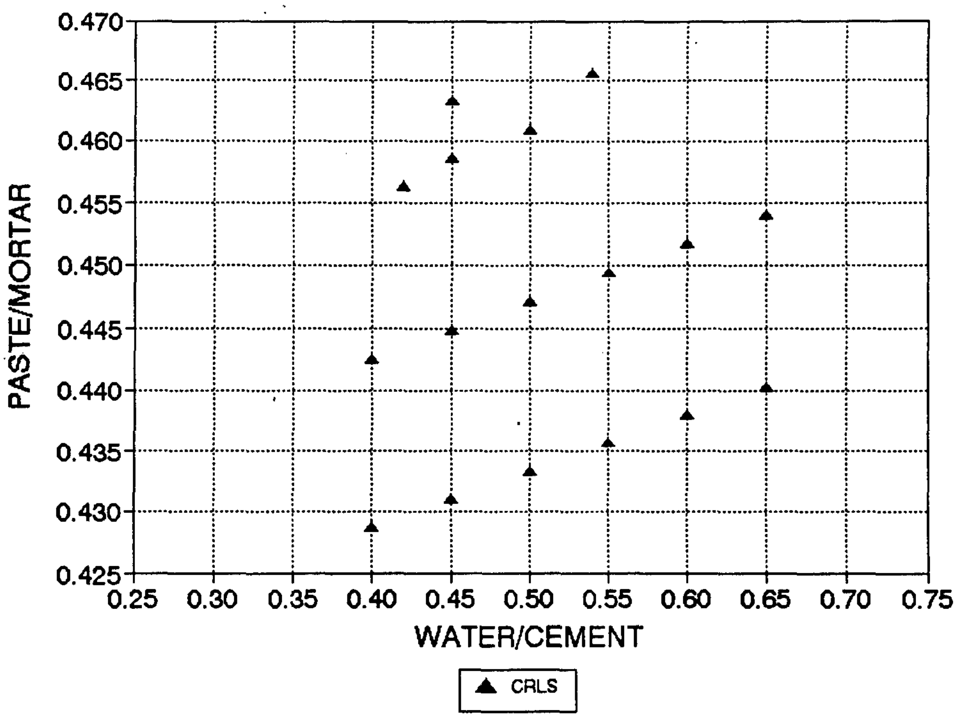


Figure A6. Relationship of mortar contents to paste/mortar of 75-mm NMSA mass concrete mixtures reviewed for historical data

Appendix B
Modified Vebe Test Procedure for Mass Concrete Mixtures

The modified list procedure presented below is patterned after the British Standard Method for Determination of Vebe Time (BS 1881: Part 104) British Standards Institute 1983).[1]

1. Scope

1.1 This method describes a procedure for determining the consistency of mass concrete mixtures and is applicable in both the laboratory and the field. It is intended to supplement the slump test.

1.2 This method is considered applicable to concrete containing 50-mm (2-in.) nominal maximum size aggregate or smaller.

2. Applicable Documents

2.1 ASTM Standards

C 143 (ASTM 1993e)[1] Method for Slump of Hydraulic Cement Concrete (CRD-C 5)[2]

C 172 (ASTM 1993g)[1] Method of Sampling Freshly Mixed Concrete (CRD-C 4)

C 231 (ASTM 1993h)[1] Method for Air Content of Freshly Mixed Concrete by the Pressure Method (CRD-C 41)

---

1 References are listed following main text.

2 CRD-C equivalents in parentheses are from the *Handbook for Concrete and Cement*, U.S. Army Engineer Waterways Experiment, 1949, Vicksburg, MS.

2.2 American Concrete Institute Standard

ACI 211 Standard Practice for selecting proportions for normal, heavyweight, and mass concrete (CRD-D 99)

2.3 British Standard

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

3. Summary of Method

3.1 This method provides a measure of the consistency of mass concrete mixtures. The consistency is measured as the time required to remold and consolidate a given volume of concrete in a cylindrical mold using external vibration.

3.2 This method tests a larger sample of concrete than does the British Standard 1881, "Method for Determination of Vebe Time."

4. Apparatus

4.1 Cylindrical Mold - The cylindrical mold shall have an inside diameter of 356 ± 3 mm and a height of 286 ± 3 mm. The volume of the sample container shall be approximately 0.028 cu m. The cylindrical mold shall be capable of being rigidly clamped to a vibrating table. The top rim of the mold shall be smooth, plane, and parallel to the bottom of the mold.

4.2 Conical Mold - The conical mold shall be 305 ± 3 mm at the base, 152 ± 3 mm at the top, and 457 ± 3 mm high. The base and top shall be open and parallel to each other and at right angles to the axis of the cone. The interior of the cone shall be relatively smooth and free from projections or dents. The conical mold shall have a clamp which is capable of holding the mold firmly in place while filling.

4.3 Tamping Rod - The tamping rod shall be a round, straight steel rod 16-mm in diameter and approximately 900-mm in length, having the tamping end rounded to a hemispherical tip the diameter of which is 16-mm.

4.4 Surcharge - The surcharge shall be a circular acrylic plate 330 ± 3 mm in diameter and 13 ± 1 mm thick.

4.5 Vibrating Table - A steel vibrating table shall be clamped to a level concrete floor or base slab having a mass of at least 50 kg to avoid movement during vibration. The vibrating table shall produce a sinusoidal vibratory motion with a frequency of 60 ± 1.7 Hz and an amplitude of 0.70 ± 0.08 mm.

4.6 Miscellaneous Equipment - Also required are a shovel, scoop, and stopwatch.

5. Sampling

5.1 Samples of freshly mixed concrete shall be taken in accordance with ASTM C 172.

6. Procedure

6.1 Obtain a representative sample of freshly mixed concrete in accordance with ASTM C 172, having a minimum mass of 100 kg.

6.2 Remix the sample carefully with a shovel to correct for any segregation that may exist.

6.3 Dampen the cylindrical and the conical mold. Clamp the cylindrical mold onto the vibrating table. Place the conical mold into the cylindrical mold and clamp into place. From the sample of concrete obtained in accordance with Section 6, immediately fill the conical mold in three layers, each approximately one third the volume of the mold.

6.4 Rod each layer with 50 strokes of the tamping rod. Uniformly distribute the strokes over the cross section of each layer. For the bottom layer this will necessitate incling the rod slightly and making approximately half of the strokes near the perimeter, and then progressing with vertical strokes spirally toward the center. Rod the bottom layer throughout its depth. Rod the second layer and the top layer each throughout its depth, so that the strokes just penetrate into the underlying layer.

6.5 In filling and rodding the top layer, heap the concrete above the mold before the rodding is started. If the rodding operation results in subsidence of the concrete below the top edge of the mold, add additional concrete to keep an excess of concrete above the top of the mold at all times. After the top layer has been rodded, strike off the surface of the concrete by means of a screeding and rolling motion of the tamping rod. Carefully remove any excess concrete that may have fallen from the top of the cone to the outside of its base inside the cylindrical mold.

6.6 Loosen the clamps holding the conical mold to the cylindrical mold and immediately remove the conical mold from the concrete by raising it carefully in a vertical direction with a steady upward lift with no lateral or torsional motion. The conical mold should be completely removed from the concrete in 5 $\pm$ 2 seconds.

6.7 Place the surcharge on the sample of concrete so that it is centered over the cylindrical mold.

6.8 Turn the vibrating table on and begin timing the test. Observe the concrete underneath the surcharge and around the edge of the surcharge. As the test progresses, mortar will cover the bottom of the surcharge and migrate between the surcharge and the wall of the mold. When the bottom of the surcharge has been completely covered with mortar and a ring of mortar has formed around the periphery of the surcharge, stop the test and determine the elapsed time to the nearest second. Record this as the Vebe Time.

7. Report

7.1 Report the Vebe Time to the nearest second.

8. Precision and Bias

8.1 Precision - The precision of this test method has not been determined.

8.2 Bias - This test method has no bias since Vebe Time is defined only in terms of this test method.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 1996

3. REPORT TYPE AND DATES COVERED
Report 2 of a Series

4. TITLE AND SUBTITLE
Workability of Mass Concrete
Report 2, Supplemental Proportioning Parameters

5. FUNDING NUMBERS

6. AUTHOR(S)
Billy D. Neeley, Michael K. Lloyd

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report SL-96-15

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Headquarters, U.S. Army Corps of Engineers
Washington, D.C. 20310-0000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report presents the results of a research program examining the potential benefits of requiring minimum and maximum mortar contents for 37.5-mm (1-1/2-in.) nominal maximum size aggregate (NMSA) mass concrete and minimum and maximum paste-mortar ratios for 37.5-mm (1-1/2-in.) NMSA mass concrete. The purpose of the research program was to supplement existing guidance on proportioning mass concrete mixtures.

Two 37.5-mm (1-1/2-in.) nominal maximum size (NMS) coarse aggregates were used. One was a crushed material consisting primarily of blocky particles. The other was a crushed material having more flat and elongated particles. All mixtures contained natural fine aggregate.

The results indicate that a recommended minimum and maximum mortar content could be a useful guide to aid in proportioning workable mass concrete mixtures containing 37.5-mm (1-1/2-in.) NMS coarse aggregate. An approximate minimum and maximum mortar content was identified for mixtures containing favorably shaped coarse aggregate particles (primarily blocky with minimal flat and elongated) and for mixtures containing less favorably shaped coarse aggregate particles (higher percentage of flat and elongated). The paste-mortar ratio appears to be less useful.

Recommendations are made to consider supplementing existing guidance on proportioning 37.5-mm (1-1/2-in.) NMSA mass concrete mixtures with minimum and maximum mortar contents.

14. SUBJECT TERMS

Concrete	Mass concrete
Concrete aggregates	Mortar content
Concrete workability	Paste-mortar ratio

15. NUMBER OF PAGES
60

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		