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INVESTIGATION OF EXPANDING GROUT AND CONCRETE. REPORT 2. SUMMARY OF FIELD MIXTURE TEST RESULTS, JULY 1970 THROUGH JUNE 1971

George C. Hoff

Army Engineer Waterways Experiment Station

Prepared for:

Atomic Energy Commission Sandia Laboratories Defense Nuclear Agency

January 1973

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INVESTIGATION OF EXPANDING GROUT AND CONCRETE

Report 2 ·

SUMMARY OF FIELD MIXTURE TEST RESULTS JULY 1970 THROUGH JUNE 1971

by

G. C. Hoff



January 1973 Spannored by U. S. Atomic Energy Commission - Sandia Laboratories end Test Command, Defense Nuclear Agency Conducted by U. S. Army Engineer Waterways Experiment Station Concrete Laboratory Vicksburg, Mississippi

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Report 2

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ABSTRACT

Evaluations were made of 12 grout mixtures, six groutcrete mixtures, and 11 concrete mixtures, all of which contained type K expansive cement wholly or in part. The mixtures were developed for field use on a number of different projects. The mixtures varied widely in ingredients, proportions, coring, and the type of evaluations made. Very few direct comparisons of behavior could be made.

Three self-stressing type K expansive cements were used. Two of the cements were formulated to be moderately expansive while the other was to be highly expansive. The highly expansive cement was used as a portion of the total cement in a mixture. The moderately expansive cements were used as either the only cement in the mixture or as a portion of the total cement. Each mixture was evaluated for some, but not all, of the following physical characteristics: expansion, strength, modulus of elasticity, compressional wave velocity, temperature development, slump loss, and efflux time. Evaluations were made on both laboratory and field-cast specimens. Comparisons were made as appropriate. Temperature rise values as high as 172 F were observed in large field-cast sections. The various mixtures developed 28-day compressive strengths ranging from less than 300 psi to more than 8400 psi. Static modulus of elasticity values of 2.8 to 3.5 million psi were obtained. The greatest unrestrained expansion observed was 1.7 percent. Most expansions were considerably less, however. Restrained expansions were generally an order

of magnitude less than unrestrained expansions. Compressional wave velocities at 28 days age varied from 7400 to more than 12,000 ft/sec. Slump loss evaluations indicated that the amount of loss was a function of the mixture ingredients and proportions as well as time.

Petrographic analyses of the principal sand used with most mixtures and of a field-cast test specimen are included as Appendixes A and B, respectively.

PREFACE

The investigation reported herein was authorized jointly by the Test Command, Defense Nuclear Agency, and U. S. Atomic Energy Commission -Sandia Laboratories.

The work was conducted during fiscal year 1971 by personnel of the Concrete Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) under the supervision of Messrs. Bryant Mather, J. M. Polatty, R. V. Tye, Jr., B. R. Sullivan, and R. A. Bendinelli. This report was prepared by Mr. George C. Hoff. The investigation was coordinated with Mr. C. W. Gulick, Jr., of Sandia Laboratories and Mr. J. LaComb, Major M. J. Jones, Jr., CE, and LT A. J. Stuart, USN, of Test Command, Defense Nuclesr Agency. Subsequent reports will be issued in this series.

COL Ernest D. Peixottc, CE, was Director of WES during the conduct of this investigation and the preparation and publication of this report. Technical Director was Mr. F. R. Brown.

QUICK REFERENCE KEY

The following table is designed to give the user an indication of some of the physical characteristics of the expansive cement mixtures studied for use in the field for the period from July 1969 to June 1971. Some of these mixtures have been used on various programs at the Neveda Test Site (NTS). All of the data and the details associated with their origin, collection, and interpretation are contained in two USAE Waterways Experiment Station (WES) reports (Column 1). Report 1 is Miscellaneous Paper C-71-5, Investigation of Expanding Grout and Concrete; Summary of Field Mixture Test Results, July 1969 through June 1970, and was published in June 1971. Report 2 is contained herein. The various mixture designations are shown in Column 2. Three grades of type K expansive cement were used (Column 3): slightly expansive (CC); moderately expansive (CS-I); and highly expansive (CS-II). These cements were used as all or part of the total cement in the mixture, and the amount of the cement contained in a cubic foot of the grout, groutcrete, or concrete is shown in Column 4. The theoretical design density of each mixture is shown in Column 5.

Summaries of the physical characteristics of each mixture are contained in Columns 6-11. In many instances, data on particular properties are not available. The expansion levels in Column 6 are described as low, moderate, or high. These correspond to restrained expansions of 0-0.04, 0.04-0.12, and greater than 0.12 percent, respectively. Ranges of compressive strength and pulse velocity are shown in Columns 7 and 8,

respectively. Columns 9, 10, and 11 indicate whether data on modulus of elasticity, temperatures, and slump loss or flow are contained in the report listed in Column 1. Other data on tensile strength, shear, bond, and constrained stress are also reported in Reports 1 and 2 for a few mixtures but the amount of data is not sufficient for inclusion in the reference key.

Mixture Destonation	<u>Expansit</u>	ve Cement Amount 15/cm ft	Design Density 11/cm ff	Expansion Level	Coup Stry Range	Comp Wave Vei Range Fra v 103	Modulus of Electicity	Temp Rige	Slump Loss of Flow
HOTTERIX		11 11/01		4 8 1 2 1					
1	8	31.64	117.3	ł	1-2	ł	ı	×	t
-	CS-I	0.32	127.2	low	すしの	t 1	×	•	t
	CS-11	2.50	127.2	low	346	9-10	×	ŧ	1
41-	CS-I	0.31	126.8	TOW	2-3	;	×	×	×
બં	CS-I	0.53	123.1	low	4-5	1	×		1
ų	CS-I	0.68	128.0	low	¢-5	1	X	8	•
	CS-I	0.34	127.3	. low	1	ł	8	£	*
	CS-II	1,39	127.3	low	1-2	7-8	ſ	b	×
	CS-II	2.50	127.3	low	1-2	7-8	•	t	2
(Rev 1)	CS-II	16.53	118.8	h1gh	4-5	11-12	1	ł	×
	CS-II	27.52	118.4	high	۶۹ ۸	;	ł	ľ	ŧ
	CS-II	2.12	128.3	in low	6 .5	ļ	•	1	•
	CS-II	2.13	130.6	AF 10W	!	•	1	•	•
Ŕ	CS-II	3.54	123.6	low	3-4	!	J	ł	×
ų	CS-II	3.47	126.2	ł	;	ł	1	t	×
-B(Rev 1)	CS-II	3.47	126.5	Iow	3-4	11-12	•	×	•
•	CS-II	3.32	137.3	t I	:	ł	1	•	×
	II-80	7.02	122,8	. zoderate	2-3	9-10	ł	•	ı
	•								
II-d	CS-I	0 *99	131.9	Iow	4-5	11-12	M	×	ł
P-IIA	CS-I	1,00	132,3	:	3-4	11-12	×	×	١
P-11B	CS-I	2.00	141.3	ł	. 4-5	>12	×	×	×
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QUICK REFERENCE (EN) GROUT, GROUTCRETE, AND CONCRETE FIELD MIXIURE DATA

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lable Slump Loss or Flow	I I X X I K X I	н і мйкимині
a Avai Temp Rise	М I I И И Й И И	8 -1 - 1, 54 -5 54 8 - 1 - 2 - 54
Other Dat Modulus of Elasticity	м	.0 0 0 10 0 5 0 0 8 5 4
28-Day Comp Wave Vel Range fps X 10		
28-Day Comp Strg Range ksi	w X 2 w w w w w w 4	9 2 4 4 4 1 1 1 N 6 2 3 4 4 1 1 1 1 N
Expansion Level	low low moderate moderate moderate moderate	noderate moderate tight
Design Denisity <u>1b/cu.ft</u>	132,3 136,3 136,3 138,1 138,1 140,1 140,1 140,1 137,1	143.7 145.2 145.2 145.2 127.0 127.0 123.5 1123.5 1123.5 117.1
ve Cenent Amount Ib/cu ft	1,00 0,29 0,33 8,70 8,70 8,70 8,70 8,70 8,70 8,70 11,99 9,99 8,70 8,70 8,70 8,70 8,70 8,70 8,70 8,70	11,20 5,48 3,49 13,91 3,49 10,55 10,
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CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

Multiply	By	To Obt a in
inches	2.54	centimetres
feet	0.3048	metres
cubic feet	0.0283168	cubic metres
cubic yards	0.764555	cubic metres
cubic feet per second	0.0283168	cubic metres per second
ounces	28.3495	grams
pounds	0.45359237	kilograms
pounds per square inch	0.00689476	megapascals
Fahrenheit degrees	5/9	Celsius or Kelvin degrees ^a

British units of measurement used in this report can be converted to metric units as follows.

^a To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9)(F - 32). To obtain Kelvin (K) readings, use: K = (5/9)(F - 32) + 273.15.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The "Investigation of Expanding Grouts and Concrete" was authorized jointly by the Test Command, Defense Nuclear Agency, and U. S. Atomic Energy Commission - Sandia Laboratories to study the behavior of expansive cements when used in grout, groutcrete, and concrete and also to provide expansive cement mixture design support for field tests conducted at the Nevada Test Site (NTS) and other testing areas. The term "groutcrete" is local terminology commonly applied to grouts containing NTS concrete sand. The first report of this study (Reference 1) developed information as to the basic behavioral trends that expansive cement grouts and concretes might follow when adapted and modified to the job requirements of actual field tests. The second report (Reference 2) summarized field mixture test results for the period of July 1969 through June 1970.

This report describes the results of laboratory and field evaluations of grout, groutcrete, and concrete mixtures used at the NTS during Projects DIAMOND MINE, DIAGONAL LINE, MISTY NORTH, and CAMPHOR, plus the results of some laboratory evaluations of expansive cement concrete. Appendices A and B describe petrographic analyses of NTS concrete sand and a groutcrete used in DIAMOND MINE, respectively. All of the work was done between 1 July 1970 and 30 June 1971.

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Because of the differences in performance requirements for each project, the grouts, groutcretes, and concretes described in this report vary widely in type and proportion of ingredients, curing environment, specimen size, age of test, and type of evaluation made. Because of the many differences between each mixture, very few direct comparisons of behavior can be made. The data are presented solely for informational purposes and to supplement the very limited amount of information that is available on expansive cement grouts and concretes.

1.2 SCOPE

Twelve grout mixtuxes, six groutcrete mixtures, and 11 concrete mixtures were studied. Each mixture was evaluated for some but not all of the following physical properties and characteristics in either laboratory studies or from field-cast specimens or both:

1. Expansion.

a. Restrained.

b. Barestrained.

2. Stiength.

a. Comprassive.

5. Boad.

3. Modulus of elasticity.

4. Ultrasonic pulse velocity.

5. Temperatura rise.

6. Slump loss.

7. Flow determination.

A schedule of the physical test program is shown in Table 1.1.

Each mixture contained some self-stressing type K expansive cement. The expansive cement used represented three different productions of clinker burning and grinding. Each production resulted in a cement which produced slightly different levels of expansion when similarly proportioned in a mixture. The self-stressing cement was used in combination with either type II or class G portland cements. The type and proportion of other ingredients varied widely between mixtures so as to meet job criteria. このいろうろうろうろうろうろう

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The mixture designations under the projects that they were originally developed for, their revisions, and some general supporting information regarding the use of each mixture are as follows.

Mixture	Type of <u>Mixture</u>	Expansive Cement Content pcf of Mixture*	Remarks
		DIAMOND MINE	
DMC-II	Groutcrete	11.99	Laboratory development only
DMC-IIA	Groutcrete	11.99	Used in experimental plug - 16 tunnel
DMC-III (CS-I)	Groutcrete	17.40	Laboratory development only
DMC-III (CS-II)	Groutcrete	8.70	Used in experimental O6 and tail drifts

(Continued)

<u>Mixture</u>	Type of 	Expansive Cement Content pcf of Mixture*	Remarks
	DIAM	OND MINE (Continue	d)
DMC-IIIA	Groutcre te	8.70	Used in manway O6 drift and around instrument boxes
DTC S- 1	Grout	2,50	Used in instrument holes
DDCPP-IIB (Rev 1)	Grouterete	5.00	Used in overburden plug
DF-5	Grout	1.39	Used in O5 drift and instru- ment holes
D F - 5A	Grout	2.50	Used in instrument holes. Also in CAMPHOR
NCS-2 (Rev 1)	Grout	16.53	Used in instrument holes. Also in MISTY NORTH
		DIAGONAL LINE	
DL-2	Grout	2.12	Labelatory development only
ԻԼ-4	Grout	2.13	Used as stage 4 topout on satellite hole No. 1
		MISTY NORTH	
NCS-2 (Rev 1)	Grout	16.53	Used in instrument holes. Also used in DIAMOND MINE
		CAMPHOR	
NCS-5	Grout	27.52	Used for pressure grouting around gas seal plug and over- burden plug
DF-5A	Grout	2.50	Used for a close-in tunnel plug. Also used in DIAMOND MINE
HD-1	Grout	3.32	Used around a tunnel plug at Plimpton's Palace

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(Continued)

Mixture	Type of <u>Mixture</u>	Expansive Cement Content pcf of Mixture*	Remarks
	CA	MPHOR (Continued)	
GSVK-A	Grout	3.54	Laboratory development only
GSVK-B	Grout	3.47	Laboratory development only
GSVK-B (Rev 1)	Grout	3.47	Used at the fast gate gas seal plug and ES-1 drift
LTSG	Grout	7.02	Used at ES-1 cross drift plug
CAM4	Concrete	3.48	Used in the overburden plug
CAM4A	Concrete	3.48	Laboratory development only
CAM5	Concrete	3.49	Used in the gas seal plug
CAM5A	Concrete	3.47	Laboratory development only
CAM5A (Rev 1)	Concrete	13.91	Laboratory development only
CAM 5B	Concrete	3,55	Laboratory development only
CAM6	Concrete	10.44	Used in the overburden plug
	exp	ANSIVE CONCRETE M	IXTURES
EC-10	Concrete	9.77	Laboratory development only
EC-15	Concrete	14.39	Laboratory development only
EC-15 (Rev l)	Concrete	14.99	Laboratory development only
EC-15 (Rev 2)	Conc rete	14.99	Laboratory development only
EC-22	Concrete	22.00	Laboratory development only

and the second of the

* Amount of total batch cement that was a self-stressing expansive cement.

TABLE 1.1

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PHYSICAL TESTING PROGRAM

			Į		Madulus of	Ultrasonic	Tennerstiite		
Designation	Restrained	Unrestrained	Strg	Strg	Electicity	Velocity	D. 'opment	100	Determination
Groute									
prcs-1	ł	м	×	٠	•	м	•	•	·
B5	•	M	×	•	•	×	•		×
N2-54	•	×	×	•	•	×	•	•	•
MCS-2(Rev 1)	н	M	×	•	•	×	•	•	×
MCS-5	×	M	×	•	•	•	•	•	ı
DL-2	н	•	H		•	•	•	•	•
5-4 21-4	н	M	H	•	•	•	•	•	•
GSVK-A	н	•	н	•	ł	•	•	١	×
CSVK-B	٠	•	•	•	•	•	•	•	×
CSVK-B(Bev 1)	н	,	M	•		M	M	•	•
	•	•	•	•	•	•	•	•	н
LTSC	м	м	н	•	ŀ	×	١	•	•
Groutcretes									
11-040	м	м	M		•	•	, H	н	•
DHC-IIA	н	×	×	•	•	×	×	•	•
DHC-III(CSI)	×	н	×	•	•	•	×	H	•
DHC-III(CSII)	н	м	×	Ħ	H	×	×	M	•
DIC-111A	•	•	×	•	×	×	×	•	•
DDCPP-IIB(Rev 1)	٠	м	H	•	•	M	•	H	•
Concretas									
CANG	ĸ	×	` ×	•	•	•	H	×	ı
CANGA	×		×	•	•	•	•	×	•
CAMS	×	м	м	•	•	•	м	×	1
CAMSA	•	•	1	•	•	•	•	×	ł
CAM5A (Rev 1)	ŧ	•	•	•	•	•	•	×	•
CAM5B	•	•	•	•	•	•	•	×	•
CAM6	×	×	м	•	×	×	M	•	•
EC-10	×	•	ŧ	•	•	•	•	•	•
BC-15	×	•	•	•	•	•	M		•
EC-15 (Rev 1)	×	×	×	•	•	•	•	× :	•
BC-15 (Rev 2)	×	×	•	•	•	×	ŀ	H 1	•
BC-22	•	•	1	•	•	•	•	×	•

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CHAPTER 2

MATERIALS AND MIXTURE PROPORTIONS

The specific materials used in the formulation of the grouts, groutcretes, and concretes described in this report were dictated by the particular job requirements for which the grouts and concretes were used. This resulted in a large variety of different materials and considerable latitude in mixture proportioning, both of which make direct comparison of the physical properties obtained from different mixtures quite difficult.

Summaries of the mixture ingredients and proportioning for the grouts, groutcretes, and concretes are shown in Tables 2.1, 2.2, and 2.3, respectively. Descriptions, where available, of the various materials are contained in the following paragraphs.

2.1 CEMENTITIOUS MATERIAL

2.1.1 Portland Cements. A type G oil-well cement and a number of different brands of type II cement were used during the 12-month period covered in this report. Although the type G cement was obtained from a single source, the cement used represented numerous clinker productions by that mill. No chemical or physical testing was done for any of these cements.

<u>2.1.2 Expansive Compute</u>. The use of self-stressing type K expansive cements in some earlier concrete and grouting operations at NTS was reported in Reference 2. The continued use of these cements for the period July 1970 through June 1971 is discussed in this report. It is anticipated that their use will continue in the future. Many of concrete and grout mixtures used on particular projects are often used again on other projects and utilize essentially the same ingredients. Although these ingredients may be generally the same over the entire period of use, each new production run may be slightly different and may vary somewhat in composition and performance as a result of either deliberate planning or by standard production variations. This is particularly true for the expansive cement used. Three different production runs of a type K self-stressing expansive cement were used and have been given the following designations.

Production Run	WES Designation	Field Designation
1	RC-610(2)	ChemStiess I (68)
2	RC-645	ChemStress I (70)
3	RC-644(3)	ChemStress II (70)

The field designation of ChemStress I and ChemStress II refers to cements which were manufactured to be moderately and highly expansive, respectively. The numbers in parentheses indicate the year in which the cement clinker was burned and ground. This field designation de. ~iption will be used on all future production runs of the self-stressing type K cement used at NTS.

All three cements consist of portland cement compounds, anhydrous calcium aluminate sulfate ($C_4A_3\overline{S}$), calcium sulfate ($CaSO_4$), and lime (CaO). The $C_4A_3\overline{S}$ is a component of a separately burned clinker that is interground with portland clinker or blended with portland cement, or it may be formed simultaneously with the portland clinker compounds during the burning

process. The results of a chemical analysis and some limited physical testing for these cements are included in Table 2.4.

To obtain some indication of the expansive potential of each expansive cement, a mortar mixture using a blend of the expansive cement and a type II cement was adopted as a standard for comparison. The mortar mixture was designed to have a water-cement ratio (by weight) of 0.50, a sand-cement ratio (by weight) of 2.75, and an expansive-cement content of 25 percent of the total cement volume in the mixture. The remainder of the cement volume was comprised of type II cement. The highly expansive nature of the type K cement necessitated the use of a blend of cements as an all-type-K bar would expand to the point of self-destruction. The sand was 20-40 silica sand. Two 2-in, unrestrained and two 2-in. restrained bars (Section 3.2.1) were made for cement blends using ChemStress I (70) and ChemStress II (70). These cements will be referred to as CS-I (70) and CS-II (70), respectively, for the remainder of the report. No blend was made for ChemStress I (68), hereafter referred to as CS-I (68). The expansions were measured using a length comparator with the initial length determination being made 90 minutes after the mortar mixture had reached its final set as determined from CRD-C 86 "Standard Method of Test for Time of Setting of Concrete Mixtures by Fenetration Resistance" (Reference 3). After obtaining the initial length measurement, all bars ware stored in limewater at 72 F for the desired pariod of observation. The expansive potential of the two cement blends is shown in Fig. 2.1 with CS-II (70) being approximately two-and-one-half times as expansive (restrained) as CS-I (70). WHEN MAKING CEMENT SUBSTITUTIONS IN A MIXTURE, APPROXIMATELY TWICE AS MUCH CHEMSTRESS I CEMENT WILL BE REQUIRED TO PRODUCE THE SAME EXPANSIONS ACHIEVED WITH CHEMSTRESS II CEMENT.

2.1.3 Fly Ash. Fly ash (AD-387) is a pozzolanic material that is added to grouts and concretes, usually on a partial cement replacement basis, as a means for reducing the amount of heat developed during hydration and also to reduce the cost of the grout and concrete. It contributes to cementing behavior over extended time periods. The fly ash used had a specific gravity of 2.45.

2.2 SAND

Three different sands were used. The detail in which each sand was examined was dictated by the requirements of its ultimate use in the field; hence some sand descriptions are more detailed than others.

2.2.1 NTS Concrete Sand (NTS-53 S-1). This was a naturally occurring angular sand that had a specific gravity of 2.59 and an absorption of 2.4 percent. The grading was as follows.

Sieve	Cumulative
Number	Percent Passing
4	99.8
8	80.6
16	55.9
30	38.8
50	21.5
10 0	17.4
200	5.5

A detailed petrographic report of this sand can be found in Appendix A. <u>2.2.2 Monterey Sand</u>. This sand had a specific gravity of 2.65 and an absorption of 0.8 percent. The grading showed 97.8 percent passing a No. 20 sieve, with 95 percent being retained on a No. 40 sieve.

2.2.3 Rocklite Sand. This was a lightweight sand with a specific gravity of 2.05 and an absorption of 13.6 percent. The grading was as follows.

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Sieve	Cumulative
Number	Percent Passing
16	99
30	67
50	35
100	16
200	6

2.3 COARSE AGGREGATE

2.3.1 NTS Concrete Aggregate. This aggregate had a specific gravity of 2.63 and an absorption of 2.1 percent. The grading was as follows.

Sieve	Cumulative
<u>Size</u>	Percent Passing
1 in.	100
3/4 in.	67
1/2 in.	14
3/8 in.	2
No. 4	0

2.3.2 Naturalite Aggregate. This aggregate had a specific gravity

of 1.88 and an absorption of 6.1 percent. The grading was as follows.

Sieve	Cumulative
Size	Percent Passing
1 in.	100
3/4 in.	70
1/2 in.	51
3/8 in.	15
No. 4	3

2.3.3 Utelite Aggregate. This aggregate had a specific gravity of 1.16 and an absorption of 9.0 percent using laboratory test procedures. Pressures (300 psi) resulted in an absorption of approximately 13 percent. 2.4 BARITE

Barite (AD-426) is a barium sulfate and is an inert material added to grout mixtures to increase density, reduce strength, and reduce temperatures. The barite (AD-426) used in preparing laboratory mixtures had a specific gravity of 4.25 and was very fine with most of the material passing a No. 200 sieve. This fineness results in a higher water demand, which, in turn, reduces the strength of the grout containing the material. The barite used in the field was from a different source but had similar properties.

2.5 GEL

The term gel usually refers to sodium bentonites belonging to the general class of montmorillonite clays. Gel is used as a suspending medium for sands, cements, and fly ash, and also for its ability to retain water. Both of these characteristics aid in the pumping of grouts. The specific gravity of the gel (AD-369) used was 2.39.

2.6 TERRA ALBA

Terra Alba (AD-403) is a finely divided gypsum with 99.1 percent passing the No. 325 sieve. The material had a specific gravity of 2.50 and an SO₃ content of 46.5 percent. It was used to aid the expansive component in the cement by supplying some SO₃ to combine with the CaO in the formation of calcium sulfate.

2.7 ADMIXTURES

2.7.1 Pozzilith 8 (Pozz 8). Pozz 8 (AD-247) is a lignin-based, type A* water-reducing admixture which reduces the quantity of mixing water required to produce grouts or concretes of a given consistency.

* CRD-C 87, "Standard Specification for Chemical Admixtures for Concrete" (Reference 3). 2.7.2 CFR-2. CFR-2 (AD-420) is a sodium salt of polymerized alkylnaphthalene-sulfonic acids which is used as a friction-reducing admixture to aid in the pumpability of grouts.

2.7.3 Plastiment. Plastiment (AD-380) is a type D* chemical admixture that both reduces the quantity of mixing water required to produce concrete of a given consistency and retards the setting of the concrete.

^{*} CRD-C 87, "Standard Specification for Chemical Admixtures for Concrete" (Reference 3).

TABLE 2,1 Grouts - Materials and Mixture Proportions

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				Mixture	Propertie	ne for a	One-Cubic	-Foot Bate	4, 1b			
Mixture Designation	1-5320	2-10	27-24	NCS-2 (Rev 1)	NCS-5	57	7-70	CSVK-A5	CSVK-B5	GSVK-B30	- 보	17805
Cement,												
Type II	:	:	:	:	55.04	;	:	31.52	2R.42	27 26		33 16
Type G Type K	31.15	26.85	25.74	66.11	:	10.10	67*6	:			8	
ChemStress I(68) (AC-610(2))	1	;	:	:	;	:	:	:	1			
ChemStrass I(70) (RC-645)	;	;	;	:	;	;	;			; ;	:	:
ChemStress II(70)(RC-644(3))	2.50	1.39	2.50	16.53	27.52	2.12	2.13	2.6	3.47	1 47		
Fly ach	12.75	:	;	:	:	14.27	14.33	11.09	15.26	16.05	44 66	
Monterey sand	39.48	24.06	24.06	:	:	26.06	26.17	47.82	51.35	51.35	62.15	46.74
Barite	13.23	37.59	37.59	:	;	40.73	44.16	:	:		20.72	
13	0.95	67.7	3.39	:	:	3.19	3.21	1. 2	1.96	2.34	16.0	1.94
Nacar Boos B	27.63	33.84	33.88	35.90	35,89	00.10	51.15	27.72	25.47	25.32	21.13	27.50
		:	•	:	ţ	:	:	:	:	:	:	:
biartaart	0.23	0.055	0.055	; ;	; ;	0.05	0.05	:	0.30	00	0.13	;
fleetingen. Missenstant		:	:	4.95	3.51	:	;	X	:	:	:	0.157
Insuration unit weight, per Theo cament factor. ² 1b/cu we	127.2	127.3	127.J	116.8	116.4	128.3	130.6	123.6	126.2	126.5	137.3	122.8
Water-comencitious ratio ³	0.60	1.20	1.20	0.43	3 .0	1.20	1.20	9.6	5. S	0°54	408 0.65	785 0.62

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Units are in fluid ounces. This is the amount of all caments in the mixture. The camenitious fraction includes all caments plus the fly ash. Same as mixture GGC-8, CMVFDR. Mixture contained mylom fibers (TUP) added at a rate of 0.53 lb/100 lb of coment. Same as mixture MSSG.

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Groutcretes - Materials and Mixture Proportions TABLE 2.2

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			Mixture Prop	ortions for	a One-Cubic	-Foot Batch.	1b
	Mixture Designation	II-040	DHC-IIA ³	DMC-III ⁴ (CS-I)	DMC-III (CS-II)	DMC-IIIA4	DDCPP-IIB (Rev 1)
	Cement, Type II Type G Type K,	10.49	10.49 	: :	8 50 	17.39	27.57
31	ChemStress I(68) (RC-610(2)) ChemStress II(70) (RC-644(3)) Fly ash NTS concrete sand Barite Gel Water Pozz 8 CFR-2 Theorectical unit weight, pcf Theorectical unit weight, pcf Theorectical unit weight, pcf Theorectical unit weight, pcf	11.99 16.77 60.94 16.03 1.57 20.21 0.110 0.110 0.52 0.52	11.99 16.77 65.18 16.03 19.23 0.110 0.110 0.49	17.40 16.64 73.34 14.80 14.80 0.144 0.144 0.53 0.53	8.70 8.70 16.84 73.34 14.80 14.80 14.04 0.144 140.4 464 0.53	8.70 16.84 62.78 11.10 0.180 0.180 137.1 704 0.47	5.00 5.00 9.19 9.25 9.25 9.25 0.11 138.0 879 9.55

This is the amount of all cements in the mixture.

The commentations fraction includes all comments plus the fly ash. ChemStress I (68) was used in the laboratory study but ChemStress I (70) was used in the field with the exception that ChemStress II was used in the field placement of the DIAMOND MENE tunnel plug

ChemStress I (68) was used in the laboratory study but ChemStress I (70) was used in the field. 4.

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TABLE 2.3 Concretes - Materials and Mixture Proportions

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					-		- Philippine	FOOL BAL	:h. 19			
				Mixture	Proportio	101 01				20-15	EC-15	;
•					CASK!		3745	PC-10	EC-15	(Rev 1)	(Rev 2)	EC-22
	CANGS	CANGA ⁵	CAYS	<u>ار</u>	(Rev L)	12122						
Mixture Designation				ļ					50.00	7 65	7.65	:
			16 50	16.49	5.57	16.87	10.44	C2°1Z	77.12			
Cament, type II (NC-626)	10.34	\$0.05	~~~~					1			14 00	22.00
	•	1		1	10 11	:	:	9.97	14.39	14.37	14.77	
The start is the start of the s	3.4.8	3,48	:	:	17.11		10.44	;	:	:	:	:
Chemburgs 1 (co) (no Chh (3)		:	3.49	3.47			1	7.10	7.03	2.56	2.56	2.29
ChemStress 1 (10)/m-0-101	5 51	5.51	8.03	7.89	15.40	8,17	2.0					
Fly ash	;;								14 81	46.93	24.78	46.25
Sand.		57 53	45 18	16-22	41.29	45.95	53.70	37.15	10.00	1 4 7	10.61	18.50
when any and	52.33	2.2			: ;	:	:	:	:	10.01		
	:	:	;	:	}							
Rockiite sand								11 21	11.97	:	25.64	;
Coarse aggregate	5. 7.3	10 21	13.05	12.97	:	12.01	;			19.70	17.70	20,25
MTS constets aggregate	c).cc		21.02	26.95	29.49	27.57	:	:	•			;
Naturality Peristants	:	:			;	;	21.51	:	:	•	2	;
	;	:	:		;	;	:	:	:	:		16 31
	:	:	:	:			13 80	16.82	16.97	16.12	15.20	17.01
Terra (')' (Au-403)	11 (2)	14.79	14.06	15.97	17.79	10.01			92	0.96	0.96	0.95
		80	1.20	4.0	0.92	1.20	0.84			126.5	129.2	125.9
Flagt' Int	1.00			178.7	123.6	130.3	117.1	C.121				765
the set unit weight, pol	145.2	0.127			526	551	ž	859	926	110	110	0 66
Theo ar at factor 1b/cu yd	55 56		3	12.0	15.0	0.52	0.45	0.43	9		8.5	
Hiter-Lomentitious ratio ⁴	65.0	8."	\$									

All coarse aggregate is 3/4-in. maximum size.
Units are in fluid ounces.
This is the amount of all coments in the mixture.
The commutitions fraction includes all communy fly ash, and Terrs Alba.
ChemBtress I (58) was used in the laboratory while CherStress I (70) was used in the field.

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	Chemical Anal	ysis					
Cement Designation Constituents	RC-610(2) ¹	RC-(44 (3) ² Percent	RC-645 ³	Phys.	cal Properties RC-610(2)	RC-644 (3)	RC-645
sto ₂ .	18.5	14.6	17.6	Setting time, Gillmore			
A1203	6.2	8.4	6.3	hours:minutes			
rez03	1.8	1.6	1.7	Inttial	;	0:25	0:35
H go	2.8	2.7	2.4	Finel	:	1:00	1:35
ີ່ຮ	6.7	12.4	7.7				
C BO	61.9	57.6	61.5	Air content of morter, pct	;	6.9	7.6
Nazo	0.25	0.15	0.21	•			
K , O	0.43	67.0	0.42	Comp strg of mortar, pain-			
Loss on ignition	1.3	1.9	1.3	1 dev		475	:
Alkalies total as Na20	0.53	0.47	0.49	3 days	:	45	675
Insoluble residue	0.55	1.09	0.34	7 days	;	See note ⁵	1570
C ₃ A	13.5	19.5	13.9	•			
•				Surface area, Blaine finenesa, cm ² /E	:	4240	3745
				•			
				Heat of hydration, cal/g			
				1 day	;	51	z
				2 days	:	:	63
				3 days	:	70	67
				7 days	:	79	83
				28 days	:	76	16
				Specific gravity	3,06	3.04	3.08

ChemsGrress I (68). ChemsGrress II (70). ChemsGrress I (70). All compressive strength cubes had their steel molds removed at 24 hr age. Excessive expansion c-used disintegration of the cubes.





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CHAPTER 3

TEST PROCEDURES

3.1 TEMPERATURE DEVELOPMENT TESTS AND OBSERVATIONS

Seven hardened laboratory specimens of the 14 grout mixtures and two of the eight concrete mixtures were cured at temperatures other than the normal laboratory curing temperature of 73 F. Field-cast specimens of grout mixture DF-5A and of concrete mixtures CAM5 and CAM6 were also cured at temperatures other than 73 F. For these different curing conditions, the curing temperature history for each mixture was determined using measurements made in the field in connection with large mass placements of similar grouts or concretes or was agreed to by the sponsoring agencies and WES personnel. In a few instances, more than one curing temperature history was utilized for a given mixture. The moisture condition of the test specimens also varied and is described along with the temperature history for each test later in the report.

Most of the elevated temperature curing was done in a circulating air electric oven. The temperature in the oven was programmed to fit the desired curing history. In a few instances, where a constant elevated temperature was required, the specimens were placed in constant elevated temperature rooms for the duration of curing.

3.1.1 Grouts and Groutcretes

Laboratory Mixtures. One grout mixture (GSVK-B(Rev 1)) and four groutcrete mixtures (DMC-II, DMC-III(CS-I), DMC-III(CS-II), and DMC-IIIA) were evaluated to determine their temperature development behavior. This was done by placing a thermocouple in the center of a specimen made with the grout and then monitoring the temperatures as the grout cured. For each of the four DMC mixtures, the test specimen was a 2-ft cube. The cube was allowed to remain in the formwork for the entire period of observation. Ambient curing temperature was 73 F. An insulation mater al was placed on the exposed top surface of the cube to minimize heat loss through that surface. The output from the thermocouples was continuously plotted on strip chart recorders.

The test specimen for grout mixture GSVK-B(Rev 1) was a 6- by 14-in. unrestrained expansion cylinder (see Section 3.2.1). It was not insulated in any manner and was evaluated at an ambient temperature of 73 F. The thermocouple output was also continuously recorded.

<u>Field Observations</u>. Observations of the temperature development of groutcrete mixtures DMC-IIA, DMC-III(CS-II), and DMC-IIIA when placed in large sections were also made. All of the test sections were a part of Project DIAMOND MINE. Mixture DMC-IIA was placed in the experimental plug. It was instrumented with one internal thermocouple and had two dial thermometers inserted into but protruding from the grout. The dial thermometers were read visually while periodic measurements of the thermocouple output were made using a portable single measurement recorder. The temperatures were observed for only 3 days.

Mixtures DMC-III(CS-II) and DMC-IIIA were placed in the O6 drift plug at station 1+95 - 2+88 and station 2+88 - 3+59, respectively. DMC-III(CS-II) was instrumented with three thermocouples while DMC-IIIA

contained only two. Their approximate locations can be seen in Fig. 4.4 and 4.5, respectively. The thermocouple output was continuously monitored using a strip chart recorder. The two mixtures were observed for 5 and 6 days, respectively.

3.1.2 Concretes

Laboratory Mixtures. The only concrete mixture evaluated in the laboratory for temperature development was mixture EC-15. The test specimen was a 1-ft cube that contained a single thermocouple at its center. The cube was kept in a barrel of insulating material in order to minimize temperature losses. The thermocouple output was continuously monitored for approximately 5 days using a strip chart recorder.

<u>Field Observations</u>. Observations of the temperature development of concrete mixtures CAM4, CAM5, and CAM6 when placed in large sections were also made. All of the test sections were a part of Project CAMPHDR. Mixture CAM4 was placed in the overburden plugs. The work drift overburden plug was instrumented with five thermocouples whose approximate locations are shown in Fig. 4.6.

Mixture CAM5 was placed in the fast gate section and gas seal valve plug and was instrumented with four thermocouples (Fig. 4.7). Mixture CAM6 was placed in the 07 drift experimental gas seal plug and was instrumented with five thermocouples (Fig. 4.8). The output from the thermocouples in all three sections was continuously monitored on a strip chart recorder for time periods of approximately 13, 8, and 7 days for CAM4, CAM5, and CAM6, respectively.

3.2 EXPANSION TESTS

<u>3.2.1 Equipment and Procedures</u>. The expansions of the grouts and concretes were determined from the length changes of both unrestrained and restrained bars and unrestrained cylinders.

Length-change bar specimens, both for unrestrained and restrained tests, were made in molds conforming to those described in ASTM C 490. "Standard Specification for Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar, and Concrete," with the exception that for restrained bars the molds were blocked on the ends to provide a 10-in, gage length between end plates. Two- by two-in, bars and 3- by 3-in. bars, each with a 10-in. gage length, were used for both the restrained and unrestrained expansion determinations. The restrained bars had 3/8-in. plates on each end which were connected by a centrally located 1/4-in. and 3/16-in. diameter, continuously threaded mild steel rod for the 2-in. and 3-in. bars, respectively. Length changes were measured using a length comparator. The ends of the threaded rod which extended through the end plates of the restrained bar specimens were rounded on a grinding wheel so they could be used in the comparator. The demolding times of the bars varied depending on the hardening characteristics of the mixture and the work schedule. Unless otherwise noted, all bar measurements were made while the bars were at the temperature at which they were being cured.

The unrestrained cylinder expansion test used a 6-in,-diameter by 14-in,-high cylinder which is contained in a flexible neoprene sleeve. It has 6-in,-diameter by 1/2-in,-thick glass plates on both the top and bottom. The sleeve is clamped to the glass plates to form a scaled unit.

The test frame is composed of steel plates and Invar rods. A linear variable differential transformer (LVDT) is screwed into the top plate with its movable displacement rod extending through the plate and touching the surface of the top glass plate. Two LVDT's are also horizontally positioned at midheight of the specimen to measure lateral expansions.

The test specimen is prepared by filling the rubber sleeve with the desired mixture immediately after mixing. The filling is accomplianed by rodding and light tamping of the material. The top glass plate is then put in place. The LVDT's are then placed and the movements of the specimen monitored electronically. Length change or expansion is expressed as the percent change with regard to the 14-in. specimen height for the vertical LVDT and to the 3-in. radius for the horizontal LVDT's. Length changes are measured while the specimen is in both an unhardened and hardened state. All unrestrained cylinder expansions shown in this report are only for the hardened state, however. Unless otherwise stated, all unrestrained expansion cylinder tests were conducted at 73 ± 2 F.

<u>3.2.2 Grouts and Groutcretes</u>. Unrestrained expansion was measured on laboratory bar specimens for groutcrete mixtures DMC-III(CS-I) and DDCPP-IIF(Rev 1), and for grout mixtures DTCS-1 and DF-5A and on laboratory cylinder specimens for groutcrete mixtures DMC-II, DMC-IIA, and DMC-III(CS-II) and grout mixtures DTCS-1, DF-5, and DL-2, and GSVK-B(Rev 1). Restrained expansion of laboratory bar specimens was measured for groutcrete mixtures DMC-II, DMC-IIA, and DMC-III(CS-I), and grout mixtures NCS-2(Rev 1), DL-2, GSVK-A, GSVK-B(Rev 1), and LTSG.

Field-cast bar specimens were also evaluated for the following projects:

	Mixture	Expansion				
<u>Project</u>	Designation	Unrestrained	Restrained			
DIAMOND MINE	DMC-IIA	X	x			
	DMC-III(CS-II)	X	X			
	DF-5	X	-			
	DF-5A	X	•			
MISTY NORTH	NCS-2(Rev 1)	X .	x			
CAMPHOR	NC S- 5	X	X .			
DIAGONAL LINE	DL-4	x	x			

<u>3.2.3 Concretes</u>. Unrestrained expansion was measured on laboratory bar specimens for concrete mixtures EC-15(Rev 1) and EC-15(Rev 2). Restrained expansions of laboratory bars were determined for mixtures CAM4, CAM4A, EC-10, EC-15, EC-15(Rev 1), and EC-15(Rev 2). Both unrestrained and restrained expansions were determined from field-cast bar specimens of mixtures CAM4, CAM5, and CAM6 from Project CAMPHDR.

<u>3.2.4 Curing</u>. The curing history, with regard to state of moisture and temperature, of the various test specimens varied widely both within and between mixtures. The curing history of each set of specimens from a particular mixture is included in the figures (Fig. 4.9 to 4.42) which depict the expansion behavior for that mixture.

3.3 COMPRESSIVE STRENGTH TESTS

Compressive strength determinations were made on a number of different sized cylinders, cores, and cubes. The age of the materials at test varied from 1 to 226 days. The moisture condition and curing temperature histories of the test specimens also varied. The curing history information for each mixture is contained in Table 4.1. Unless otherwise stated, all cores and cylinders were capped immediately upon their removal from their curing environment, stored for 1-2 hours at 73 F, and then tested. All tests were conducted in accordance with one of the following test methods (Reference 3): CRD-C 14, "Standard Method of Test for Compressive Strength of Molded Cylinders"; CRD-C 27, "Standard Method of Obtaining and Testing Drilled Cores and Sawed Beams of Concrete"; and CRD-C 227, "Compressive Strength, Two-Inch Cubes."

3.3.1 Grouts and Groutcretes. Compressive strength tests were made on laboratory specimens from groutcrete mixtures DMC-II, DMC-III(CS-I), DMC-III(CS-II), DMC-IIIA, and DDCPP-IIB(Rev 1), and grout mixtures DTCS-1, DF-5, NCS-2(Rev 1), DL-2, GSVK-A, GSVK-B(Rev 1), and LTSG. Field-cast specimens were also evaluated for the following projects:

Project	Mixture Designation
DIAMOND MINE	DMC-IIA
	DMC-III(CS-II)
	DMC-IIIA
	DTCS-1
	DDCPP-IIB(Rev 1)
	DF-5
	D F-5 A
	NCS-2(Rev 1)
MISTY NORTH	NCS-2(Rev 1)
DIAGONAL LINE	DL-4
CAMPHOR	DF-5A
	NC S-5
	GSVK-B(Rev 1)
	LTSG

<u>3.3.2 Concretes</u>. Compressive strength tests were made on laboratory specimens from concrete mixtures CAM4, CAM4A, CAM5, and EC-15. Fieldcast specimens from mixtures CAM5 and CAM6 of Project CAMPHOR were also evaluated.

3.4 ULTRASONIC PULSE VELOCITY TESTS

Ultrasonic pulse velocity tests were made on laboratory specimens from grout mixture DF-5 and concrete mixture EC-15(Rev 2). Field-cast specimens were also evaluated for the following projects:

Project	Mixture Designation
DIAMOND MINE	DMC-IIA
	DMC-III(CS-II)
	DMC-IIIA
	DTCS-1
	DDCPP-IIB(Rev 1)
	DF-5
	DF-5A
	NCS-2(Rev 1)
MISTY NORTH	NCS-2(Rev 1)
CAMPHOR	DF-5A
	GSVK-B(Rev 1)
	LTSG
,	CAM6

The tests were conducted in accordance with CRD-C 51, "Tentative Method of Test for Pulse Velocity Through Concrete" (Reference 3).

3.5 MODULUS OF ELASTICITY

Static modulus of elasticity determinations were made on fieldcast specimens from groutcrete mixtures DMC-III (CS-I) and DMC-IIIA and also from concrete mixture CAM6. The tests were conducted using a compressometer and were in accordance with CRD-C 19, "Standard Method of Test for Static Young's Modulus of Elasticity and Poisson's Ratio in Compression of Cylindrical Concrete Specimens" (Reference 3). Ages at test varied for each mixture and ranged from 30 to 49 days.

3.6 BOND STRENGTH TEST

The bond strength of groutcrete mixture DMC-III(CS-II) to tuff rock was determined. Three pieces of irregularly shaped tuff were sawed into 4-1/2-in. slabs having two parallel sides. An NX size hole was then drilled through each slab in a direction perpendicular to the parallel sides. Each hole was filled with mixture DMC-III(CS-II) which was allowed to harden and bond to the tuff. For curing purposes, the exposed top surface of the grout and tuff was covered with plastic until tested. Tests were conducted by loading the end of the grout plug with a steel piston and gradually increasing the load until some slippage of the grout plug occurred. The load at which this slippage occurred was divided by the peripheral area of the plug to establish the average bond strength of the grout to the tuff. Two specimens were tested at 3 days age with the remaining specimen being tested at 10 days age. 日本のないないないであることのないないのである

3.7 SLUMP LOSS TESTS

Slump loss observations were made for groutcrete mixtures DMC-II, DMC-III(CS-I), DMC-III(CS-II), and DDCPP-IIB, and concrete mixtures CAM4, CAM4A, CAM5, CAM5A(Rev 1), CAM5B, EC-15(Rev 1), EC-15(Rev 2), and EC-22. Initial slumps were also measured for groutcrete mixture DMC-IIIA and concrete mixture CAM5A although no slump loss with time determinations were made for these two mixtures. Slumps were measured in accordance with CRD-C 5, "Standard Method of Test for Slump of Portland-Cement Concrete" (Reference 3). All tests were conducted at 73 F. With the exception of concrete mixture CAM4, a rest:mix cycle of 12:3 minutes was used for all mixtures. The duration of this cycling for each mixture was influenced by the anticipated handling it would receive when used in the field.

3.8 FLOW DETERMINATION TESTS

Measurements of the efflux time of grout mixtures DF-5, NCS-2(Rev 1), GSVK-A, and GSVK-B were made in accordance with CPD-C 79, "Method of Test for Flow of Grout Mixtures (Flow-Cone Method)" (Reference 3). All tests were conducted at 73 F. Mixture NCS-2(Rev 1) was also evaluated for the effects of prolonged agitation on flow. The pumping characteristics of grout mixture HD-1 were evaluated by pumping the mixture through 150 ft of 1-in,-diameter plastic hose. The pumping was done using a positive displacement type pump (Moyno).

CHAPTER 4

TEST RESULTS

4.1 TEMPERATURE DEVELOPMENT TESTS

The results of the laboratory studies of temperature development in the 2-ft cubes of the DIAMOND MINE groutcrete mixtures, the expansion cylinder of grout mixture GSVK-B(Rev 1), and the 1-ft cube from concrete mixture EC-15 are shown in Fig. 4.1, 4.32, and 4.2, respectively. The temperature development observations made in field-placed sections of groutcrete mixtures DMC-IIA, DMC-III(CS-II), and DMC-IIIA, and concrete mixtures CAM4, CAM5, and CAM6 are shown in Fig. 4.3 through 4.8, respectively. Total temperature rise, peak temperatures, and their times of occurrence after batching are as follows:

Mixture Designation	Cement Content 1b/cu vd	W/C Ratio by Wt	Total Temp Rise, F	Peak Temp F	Time of Occurrence hr
Laboratory		<u>21</u>			
DMC-II	607	0.52	64	141	32
DMC-III(CS-I)	470	0.53	45	115	45
DMC-III(CS-II)	464	0.53	64	124	52
DMC-IIIA	704	0.47	82	140	30
GSVK-B(Rev 1)	832	0.54	22	80	60
BC-15	956	0.40	67	143	16
<u>Field</u>					
DMC-IIA	607	0.49	104*	152*	80*
DMC-III(CS-II)	464	0.53	76	134	60
DMC-IIIA	704	0.47	70	130	38
CAM4	540	0.53	81	142	120
CAM5	542	0.50	63	123	120
CAM6	564	0.45	114	172	130

*Estimated. Test recorded ended at 150 F at 70 hr.

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The varying mixture proportions (Table 2.1 and 2.2) and ingredients make comparisons of the temperature data difficult. Mixtures DMC-III(CS-I) and DMC-III(CS-II) are comparable mixtures with only the cements varying. DMC-III(CS-I) used only ChemStress I (68) cement while DMC-III(CS-II) used a 50 percent blend of ChemStress II (70) and type II cement. For the laboratory study, the ChemStress II (70) cement blend appeared to produce more heat with a resulting 9 F increase in peak temperature. Concrete mixtures CAM4 and CAM5 are also somewhat comparable based on cement and water content. Major differences in composition between CAM4 and CAM5 include 68 1b more of fly ash per cubic yard of concrete in CAM 5 and the use of some lightweight coarse aggregate in CAM5. The peak temperatures of the field-placed sections of these two mixtures indicated that CAM4 was 19 F warmer than CAM5. Whether this difference was due solely or in part to the aforementioned composition differences is not known. Other factors such as initial temperature of the concrete, location of the thermocouples, and section configuration may also have influenced the final temperature.

Peak temperatures of laboratory specimens and field placements of groutcrete mixtures DMC-III(CS- $_{1}I$) and DMC-IIIA were compared. The field sections reached a peak temperature approximately 10 F higher and 8 hr later than the laboratory specimens. Mixtures DMC-III (laboratory) and DMC-IIA (field) are also comparable; they too reflect the 10 F difference although the peak temperature was reached much later in the field placement.

The peak temperature of 80 F for grout mixture GSVK-B(Rev 1) is obviously very low and this is due principally to the fact that the

small, uninsulated test specimen allowed much of the heat generated during hydration of the cement to be dissipated to room air. The 143 F peak temperature for concrete mixture EC-15 also appears to be low in view of the 956-1b/cu-yd cement content. Reasons for this reduced temperature are not known.

4.2 EXPANSION TEST RESULTS

The expansive behavior of the various grout, groutcrete, and concrete mixtures used in the laboratory or in the field, or both, was determined by measuring length changes occurring in small bars, or cylinders, or both, made from these mixtures. The length change observed in test bars of expansive cement grouts, groutcretes, and concretes depends, in general, on the thermal effects, internal chemistry of the materials, and the degree of restraint imposed on the specimens. The numerical description of the length change is also a function of the initial length determination which, in turn, is determined by the thermal state and chemistry effects at the time of initial measurement.

All grout and groutcrete mixtures except DMC-IIIA, GSVK-B, and HD-1 and all concrete mixtures except CAM5A, CAM5A(Rev 1), CAM5B, and EC-22 had some determinations made as to their expansive behavior. Groutcrete mixtures DMC-IIA and DDCPP-IIB(Rev 1), and grout mixtures GSVK-A, GSVK-B (Rev 1), and LTSG, and concrete mixtures CAM4 and CAM4A had some or all of their expansion bars cured at temperatures other than 73 F which is considered to be a control temperature for laboratory measurements. For the mixtures which had expansion determinations made, expansion bars were

used in all cases. The bar size (2 or 3 in.) varied both between mixtures and within mixtures. Unrestrained cylinders were also used with groutcrete mixtures DMC-II, DMC-IIA, and DMC-III(CS-II), and grout mixtures DTCS-1, DF-5, DL-2, and GSVK-B(Rev 1). The actual test data are shown in Fig. 4.9 to 4.42.

4.2.1 Expansion Determinations. The formation of the expansionproducing compounds in the cement begins immediately upon the addition of the mixing water. Until the mixture has stiffened sufficiently to produce a structure upon which the additional formation of ettringite can push and cause expansion, the mixture will not expand and will decrease in volume, particularly if it is a bleeding mixture. From practical considerations, a length-change bar specimen cannol we removed from its casting mold until the material has hardened sufficiently to avoid damaging the bar. At this point in the volume change history of a specimen containing enough expansive cement to cause positive expansions, the bar should be indicating some length increase (expansion). After removing the specimen from its casting mold, an initial length measurement is made using a comparator. The specimen is then subjected to a specified curing with subsequent length measurements being made. Length change is then expressed as a percent of the initial gage length.

The magnitude of the value for length change is dependent on a number of factors. In the case of expansive cement mixtures, the most significant of these factors is the time at which the test specimens are initially measured. Each mixture has a certain expansive potential that starts from the point of initial hardening and ends with the utilization

of all of the expansive components in the mixture. When selecting the time for making the initial length determination of a bar specimen, the more time that has elapsed after the mixture achieved its initial hardening, the smaller will be the total observed expansion. For the expansion bar data contained in Fig. 4.9 to 4.42, 12 different demolding times after casting were used and ranged from 8 to 30 hr. The actual setting times of the mixtures were, of course, always different from the casting times so it is possible that more than 12 different time intervals between hardening and initial bar length determinations existed. These differences were due for the most part to the constraints resulting from a normal 8-hr working day. It is simpler and more economical to demold and measure bars the next working day than the same evening or following early morning which is not considered the normal workday. aruna artikular artik

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The expansive behavior of the unrestrained cylinder is determined from a point in time of approximately 30 minutes after the mixture is batched. All of the mixtures studied showed some initial decrease in volume of the specimen before hardening. Once hardening occurred, positive expansions also occurred. The amount of initial decrease in volume is caused, in part, by the formation of smaller volume hydration products while the cement paste is in the unhardened (plastic) state. The final volume of these products is less than the sum of the individual volumes of the constituents involved in the reaction. The decrease is also a result of an absorption of the bleed water back into the specimen.

The decrease due to this absorption may be significantly more than the decrease due to hydration product formation. This initial volume decrease is a real phenomena. Its measurement often produces some erratic results, however. For comparison purposes in this report all expansions of unrestrained cylinders are referenced to the time and volume (length) when measurable positive expansions began. This time corresponds roughly to the final setting time of the mixture.

<u>4.2.2 Thermal Effects</u>. The test specimens for the grouts, groutcretes, and concretes have small mass to area ratios. The initial chemical reactions occurring in the mass are such that no large initial exotherms result. From these conditions, it is reasonable to assume that internal heat development is provably dissipated shortly after its occurrence and that the effect on length change due to internal heat is negligible. This may not be the case when mass to area ratios are large.

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The effects of external heat are somewhat different, however. External heat affects the length change of the bars both thermally and by causing the chemical reactions in the bars to proceed at different rates than they normally do. The effects of initial curing at elevated temperatures as great as 150 F can be seen in Fig. 4.10 and 4.39 to 4.35. When the ambient temperature decreases, the lengths of the bars also decrease. The expansion (or shrinkage) caused by external temperature changes depends both on the composition of the mixture and on its moisture condition at the time of temperature change. The thermal expansion of concrete or great varies only a little with the proportion of aggregate present, but varies considerably with the type of aggregate used. The chemical composition and fineness of the cement affect the thermal expansion only

insofar as they influence the properties of the cement gel at early ages. The moisture condition of the grout or concrete influences thermal expansion by producing the least amount of length change per degree $c\bar{x}$ temperature change for a goven mixture when the moisture content of the grout or concrete is at zero or 100 percent. At all humidities between these values, the length change tends to be greater with a maximum occurring between 50 and 70 percent humidity. The presence of normal amounts of air voids is not a factor. For large structures, where considerable restraint in movement exists, the total expansion per degree temperature increase will be reduced.

4.2.3 Restraint. The effect of either internal or external restraint is to reduce expansion of materials undergoing that phenomenon. This can be seen for the length-change bars of groutcrete mixtures DMC-IIA (Fig. 4.11 and 4.12), DMC-III(CS-I) (Fig. 4.16), and DMC-III(CS-II) (Fig. 4.18); grout mixtures NCS-2(Rev 1) (Fig. 4.25), NCS-5 (Fig. 4.26), and DL-4 (Fig. 4.29); and concrete mixtures CAM4, CAM5, and CAM6 (Fig. 4.35, 4.37, and 4.38, respectively), and EC-15(Rev 1) and EC-15(Rev 2) (Fig. 4.41 and 4.42, respectively). The expansion of the 3-in. restrained bar (3/16-in.diameter (No. 10) restraining rod) should be greater than a 2-in. restrained bar (1/4-in.-diameter restraining rod). This can be seen in Fig. 4.10, 4.11, 4.18, 4.26, 4.29, and 4.36 to 4.38. Expansions observed for the unrestrained test specimens of this report should be considered as limiting values. The actual expansions in large-section prototypes made with the same mixtures may not experience the same expansions, but instead expand less because of internal restraints and the restraints and constraints imposed by adjoining surfaces.

<u>4.2.4 Curing Conditions</u>. The effects of curing temperature were discussed in Sections 4.1 and 4.2.2.

The moisture condition during curing of grout, groutcrete, or concrete made with any type of cement directly affects the volume stability of the material. It is especially critical when expansive cements are used. Ideally, specimens containing expansive cement should be cured where a continual supply of free water is available for the process of forming expansion products. However, with the exception of DMC-IIA (Fig. 4.11 and 4.12) only those specimens which received elevated temperature curing were stored in water (Fig. 4.10, 4.21, 4.30, 4.31, 4.33, 4.34, and 4.36). All other bar specimens were bag cured in polyethylene plastic bags. The unrestrained cylinders were cured only with their as cast moisture. The bag curing was an attempt to duplicate the curing conditions of the prototype sections. No external free water is available to any of the prototype sections. In many instances the bars were coated with a sealing material prior to storage in the bags. In a few instances, a small amount of water was added to the bag to keep the relative humidity in the bag near 100 percent without removing any moisture from the specimen. The plastic bags containing the expansion bars were kept at relative humidities between 90 and 95 percent in an attempt to prevent any appreciable amount of moisture from escaping from the bags. The exact humidity inside the bags was not known. After reaching peak expansions, most of the expansion bars showed a gradual decrease in expansion with proloaged storage as can be seen in Fig. 4.10 through 4.12, 4.19, 4.22, 4.24 through 4.26, 4.29 through 4.31, 4.33, 4.34, and 4.36 through 4.38.

This occurred whether the bars were coated or uncoated or whether water had been added to bags or not. This phenomenon is most likely the result of internal self-desiccation of the cement as it uses up its free water during hydration with no direct moisture replacements. It is not known if the effects of the availability of water as witnessed for the small expansion bar specimens will produce similar behavior in large mass sections where the time of moisture transfer to the inner regions of the mass may be quite long. The advantages of using lightweight aggregates to retain moisture for continued hydration are discussed briefly in Section 4.2.6, Mixture EC-15(Rev 1). 4.2.5 Grout and Groutcrete Mixture Expansions. The following comments pertain specifically to the 14 grout and groutcrete mixtures for which expansion measurements were taken.

Mixtures DMC-II and DMC-IIA. DMC-II and DMC-IIA are similar enough in proportioning and constituents so that expected expansive behavior should be comparable for similar curing conditions. The expansive behavior of restrained laboratory bars for DMC-II and DMC-IIA is shown in Fig. 4.9 and 4.10, respectively. The data in Fig. 4.10 were obtained from specimens made from a DMC-IIA mixture that had ChemStress II (70) cement substituted for the ChemStress I (68) cement. Restrained and unrestrained (bars) expansive behavior of field-cast specimens from Project DIAMOND MINE is shown in Fig. 4.11 and 4.12, respectively. A comparison of the expansive behavior of unrestrained cylinders (Section 32.1) from both DMC-II and DMC-IIA is shown in Fig. 4.13. One unrestrained cylinder from DMC-IIA was made with ChemStress II (70) instead of ChemStress I (68) and was also

oven cured. It contained a thermocouple at its center which was continuously monitored during the oven curing. The oven temperature-time curve and the temperature history of the specimen are shown in Fig. 4.14. A comparison of the expansive behavior of a field-cast unrestrained cylinder of mixture DMC-IIA from P:oject DIAMOND MINE and the laboratory specimen of the same mixture is shown in Fig. 4.15.

The observed expansion of comparably cured 3-in. restrained bars for DMC-IIA was considerably more than that of DMC-II even though DMC-II was demolded 14 hr sooner. The major difference in curing was that the DMC-II bars were coated and bag cured while the DMC-IIA bars were uncoated and cured in a bag that contained some free water. The DMC-IIA might be expected to expand slightly more under these conditions but not 3-1/2 times more. The major variations in mixture composition between the two mixtures was the inclusion of gel in DMC-II and the substitution of ChemStress II (70) cement for ChemStress I (68) in the DMC-IIA mixture. The substitution of the cement probably had a significant impact on the expansion. From Fig. 2.1 it can be seen that the expansive potential of ChemStress II (70) is approximately 2.3 times that of ChemStress I (70). Although the expansive potential of ChemStress I (68) was not checked, it is believed to have been comparable to ChemStress I (70). In that light, the expansions of DMC-IIA appear to be reasonable.

The field-cast bar specimens of DMC-IIA (Fig. 4.11 and 4.12) indicate that the mixture was highly expansive, For the 3-in, restrained

bars, the smount of expansion observed results in extremely high stresses being developed in the 3/16-in.-dismeter restraining rod. These stresses are approaching the yield strength of the rod and may possibly have exceeded them. Of interesting note is the effect of curing on the expansion of the field specimens. All of the bag-cured, coated, restrained bar specimens appear to have greater expansions than those specimens that were uncoated and immersed in water (Fig. 4.11). This behavior is not understood. The expected behavior is shown in Fig. 4.12 for the unrestrained bars. In this instance the immersed bars indicated greater expansion.

The unrestrained cylinder expansion data in Fig. 4.13 suggest that DMC-IIA is somewhat more expansive than DMC-II at later ages. The effect on expansion of the ChemStress II (70) cement substitution is masked by the thermal influences derived from the oven curing (Fig. 4.14). The comparison of the field cast and laboratory specimens of DMC-IIA (Fig. 4.15) suggests that the field mixture was slightly more expansive than the laboratory mixture. <u>Mixtures DMC-III(CS-I) and DMC-III(CS-II).</u> DMC-III(CS-I) and DMC-III (CS-II) are identical in proportioning except that all of the cement in DMC-III(CS-I) is Chema'tress I (68) and the cement in DMC-III(CS-II) is a 50-50 blend of ChemStress II (70) and type II cement. The expansive behavior of both unrestrained and restrained laboratory bar specimens of DMC-III(CS-I) is shown in Fig. 4.16. The expansive behavior of an unrestrained laboratory cylinder for DMC-III(CS-II) is shown in Fig. 4.17.

A summary of some field-cast expansion bar data for DMC-III (CS-II) from Project DIAMOND MINE is shown in Fig. 4.18.

The limited emount of data available for the laboratory specimens of both DMC-III(CS-I) (Fig. 4.16) and DMC-III (CS-II) (Fig. 4.17) does not lend itself to any useful comparisons. The data from the field-cast specimens of DMC-III (CS-II) (Fig. 4.18) represent three different placements of the same mixture over a 2-1/2-month period. The results are erratic. Due to lack of first-hand knowledge as to the origin, fabrication, and handling of the specimens representing each placement, any discussion of the results would be highly speculative.

<u>Mixture DTCS-1</u>. The expansive behavior of both unrestrained laboratory bars and unrestrained laboratory cylinders for DTCS-1 is shown in Fig. 4.19 and 4.20, respectively. This mixture appears to be slightly expansive.

<u>Mixture DDCPP-IIB(Rev 1)</u>. The unrestrained expansive behavior of laboratory bars for DDCPP-IIB(Rev 1) is shown in Fig. 4.21. This mixture can be considered as being slightly expansive.

Mixtures DF-5 and DF-5A. DF-5 and DF-5A are comparable mixtures having the same ingredients and proportioning except that the amount of ChemStress II (70) used in the cement blend of type K and class G cement (Table 2.1) is approximately 5 and 9 percent (by volume) for DF-5 and DF-5A, respectively. This suggests that DF-5A is more expansive than DF-5. The unrestrained expansive behavior of field-cast bars of DF-5 from Project DIAMOND MINE is shown in Fig. 4.22. The unrestrained

expansive behavior of a laboratory cylinder of DF-5A is shown in Fig. 4.23. A comparison of both laboratory and field-cast unrestrained expansion bar data for DF-5A is shown in Fig. 4.24. The field-cast specimens came from Project DIAMOND MINE.

The data in Fig. 4.22 to 4.24 suggest that both DF-5 and DF-5A are slightly expansive mixtures. The average peak expansions of the fieldcast bars for both DF-5 and DF-5A are comparable; however, normally the unrestrained expansion of a 2-in. bar is somewhat greater than that of a 3-in. bar (Fig. 4.24). The increase in expansion of the laboratory specimens of DF-5A over those of the field is due in large part to the earlier demolding and initial measurement time associated with the laboratory specimens.

Mixtures NCS-2(Rev 1) and NCS-5. NCS-2(Rev 1) and NCS-5 are comparable mixtures in proportioning except that the percentage of the blended cement (Table 2.1) that is ChemStress II (70) is approximately 20 and 34 percent, respectively. NCS-5 would then be expected to be more expansive than NCS-2(Rev 1). A summary of both laboratory and fieldcast expansion bar data for NCS-2(Rev 1) is shown in Fig. 4.25. The field specimens came from Project MISTY NORTH. A summary of the expansive behavior of field-cast bars of NCS-5 from Project CAMPHOR is shown in Fig. 4.26. Comparing the unrestrained expansions of the 2-in, bars from both MISTY NORTH (Fig. 4.25) and CAMPHOR (Fig. 4.26) where both had a 21-hr

initial measurement time, NCS-5 appears to have an expansive potential of approximately 1.7 times that of NCS-2(Rev 1). This is consistent with the difference in the amount of ChemStress II (70) in the two mixtures. The major factor in the difference in expansion levels of the two placements of NCS-2(Rev 1) (Fig. 4.25) is the 9-hr difference in the initial measurement time of the bars. Both NCS-2(Rev 1) and NCS-5 can be considered as highly expansive mixtures. In all probability, the restraining rods in the 3-in. laboratory bars of NCS-2(Rev 1) and also those in the field-cast 3-in. bars of NCS-5 yielded due to the high level of expansions involved.

<u>Mixtures DL-2 and DL-4</u>. DL-2 and DL-4 are very similar in composition with DL-2 having a slightly greater cement content (increase of 16 lb/cu yd) and slightly reduced barite content (decrease of 93 lb/ cu yd). With identical ChemStress II (70) contents, their expansions for identical curing conditions should be similar. The expansive behavior of laboratory specimens in the form of restrained expansion bars and unrestrained expansion cylinders for DL-2 is shown in Fig. 4.27 and 4.28, respectively. The expansive behavior of field-cast bars of DL-4 from Project DIAGONAL LINE is shown in Fig. 4.29.

The expansions of the 3-in. restrained bars of DL-2 (Fig. 4.27) and DL-4 (Fig. 4.29) can be considered as comparable with the difference being attributed to the 6-hr difference in demolding times. The expansions of the 2-in, unrestrained bars of DL-4 (Fig. 4.29) appear to be somewhat low. Previous experience has indicated that, in general, the expansions of unrestrained bars are an order of magnitude greater than

the restrained bar expansions. Unrestrained bar expansions have also been comparable to the expansions of the unrestrained cylinders. Although no unrestrained cylinder data exist for DL-4, the unrestrained cylinder expansion of UL-2 (Fig. 4.28) suggests that perhaps the DL-4 2-in. unrestrained bar data are suspect. Both DL-2 and DL-4 can be considered as being slightly expansive mixtures. Mixtures GSVK-A and GSVK-B(Rev 1). GSVK-A and GSVK-B(Rev 1) have the same cementitious content (cement and fly ash) but GSVK-A has a higher cement content. Both mixtures contain similar amounts of Chem-Stress II (70). GSVK-A has a higher water content than GSVK-B(Rev 1). Enough other differences in composition also exist such that direct comparisons of expansive behavior between mixtures will not be attempted. The expansive behavior of laboratory restrained bars for GSVK-A and GSVK-B(Rev 1) is shown in Fig. 4.30 and 4.31, respectively. The expansive behavior of unrestrained cylinders made from GSVK-B(Rev 1) is shown in Fig. 4.32.

The expansions of 3-in. restrained bars cast from both mixtures appear to be comparable. The mixtures can be considered slightly expansive.

<u>Mixture LTSG</u>. The expansive behavior of 2-in. restrained bars cast in the laboratory from LTSG is shown in Fig. 4.33. No comparisons are possible for this mixture. LTSG can be considered slightly to moderately expansive.

<u>4.2.6 Concrete Mixture Expansions</u>. The following comments pertain specifically to the eight concrete mixtures for which expansion measurements were made.

<u>Mixtures CAM4 and CAM4A</u>. CAM4 and CAM4A are very similar in composition with the exception that CAM4 has approximately 50 percent more coarse aggregate than CAM4A. From the manner in which the specimens were cured and the difference in demolding times the effect on expansion from this coarse aggregate content difference is not readily discernible. The expansive behavior of laboratory-cast restrained expansion bars of CAM4 and CAM4A is shown in Fig. 4.34 and 4.36, respectively. The expansive behavior of field-cast bars of CAM4 from Project AMPHDR is shown in Fig. 4.35.

The expansive behavior of the field-cast specimens of CAM4 (Fig. 4.36) suggests that the mixture is moderately expansive.

<u>Mixture CAM5</u>. The expansive behavior of field-cast expansion bars of CAM5 used in Project CAMPHOR is shown in Fig. 4.37. The data represent two different placements. The differences in expansion of the two placements can be in part attributed to the difference in the initial measurement time. CAM5 can be considered a moderately expansive mixture.

<u>Mixture CAM6</u>. The expansive behavior of field-cast expansion bars of CAM6 used in Project CAMPHOR is shown in Fig. 4.38. This mixture can be considered highly expansive.

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<u>Mixture EC-10.</u> The expansive behavior of laboratory expansion bars of EC-10 is shown in Fig. 4.39. This mixture can be considered moderately expansive. <u>Mixtures EC-15, EC-15(Rev 1), and EC-15(Rev 2).</u> EC-15, EC-15(Rev 1), and EC-15(Rev 2) all contain comparable amounts of ChemStress I (68) cement but vary widely in the remainder of their compositions thus making any direct comparison of expansive behavior of the three very difficult. The expansive behavior of laboratory restrained bars of EC-15 is shown in Fig. 4.40. The expansive behavior of laboratory expansion bars of EC-15(Rev 1) and EC-15(Rev 2) is shown in Fig. 4.41 and 4.42, respectively.

Based on expansive cement content only, both EC-15(Rev 1) and EC-15 (Rev 2) should be expected to have comparable levels of expansion; however, as can be seen from Fig. 4.41 and 4.42, the EC-15(Rev 2) mixture has more than twice the expansion of EC-15(Rev 1). This is attributable generally to composition differences, and more specifically to the addition of Terra Alba to the EC-15(Rev 2) mixture. The Terra Alba aids the expansive component in the cement by supplying some SO₃ to combine with the CaO in the formation of calcium sulfate.

The expansion of EC-15(Rev 1) appears to continue at a substantial rate at ages up to 14 days and perhaps even longer. This behavior is different from that normally observed for most bag-cured grouts and concretes where the expansion rate is very small after the first few days and may be due to the inclusion of an absorbent lightweight sand and

coarse aggregate in the mixture. This aggregate will absorb water during mixing and hardening and will retain this water until the hydrating cement has a demand for it in order for hydration to continue. The water is then drawn out of the aggregate and used to sustain the hydration process. At this point, if the formation of the expansion products has not yet been completed, the additional water will also be utilized to continue the formation of these products. Similar behavior might be expected for EC-15(Rev 2) but is not readily discernible because of the brevity of the test records (Fig. 4.42).

EC-15 can be considered moderately expansive while EC-15(Rev 1) can be considered slightly to moderately expansive. EC-15(Rev 2) is moderately to highly expansive.

4.3 COMPRESSIVE STRENGTH TEST RESULTS

Because of the variability in mixture ingredients and proportions, curing conditions, age of test, and specimen size of all of the grout, groutcrete, and concrete mixtures, no comparisons of strength data were made. The exact curing temperature of many field-cast and stored specimens was not recorded, and the curing temperature of these specimens is recorded as "Ambient" in Table 4.1. In a capsulated form, the 73 F bagcured compressive strength at or near 28 days age can be estimated as follows:

		Con	pressive Strength	, ksi	
Less Than 0.5	1-2	2-3	3-4	4-5	Greater Than <u>5</u>
DL-2	DF-5 DF-5A	LTSG	DMC-II DMC-IIA DMC-III(CS-I) DMC-III(CS-II) DMC-IIIA DTCS-1 GSVK-A GSVK-B(Rev 1) CAM5	NCS-2(Rev 1) CAM4 CAM4A EC-15 DDCPP-IIB(Rev 1)	NCS-5 CAM6

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As can be seen in Table 4.1, when elevated curing temperatures are used (as in the prototype sections) the compressive strengths are greater than those for similar specimens cured at 73 F.

4.4 ULTRASONIC PULSE VELOCITY TEST RESULTS

A summary of ultrasonic pulse velocity data is given in Table 4.2. Because of the variability in mixture ingredients and proportions, curing conditions, age of test, and specimen size of all of the grout, groutcrete, and concrete mixtures, no comparisons of pulse velocity were made. A capsulated estimate and summary of the 28-day, 73 F, bag-cured ultrasonic pulse velocities for the mixtures of Table 4.2 is as follows:

	Oltrasonic	Fulse velocity, 10	/ SEC X 1000
7-8	9-10	11-12	Greater Than 12
DF-5 DF-5A	DTCS-1 LTSG	DMC-III(CS-II) DMC-IIIA GSVK-B(Rev 1) DMC-IIA NCS-2(Rev 1) CAM6	DPCPP-IIB(Rev 1) EC-15(Rev 2)

4.5 MODULUS OF ELASTICITY TEST RESULTS

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Three 3- by 6-in. cylinders of groutcrete mixture DMC-IIIA were obtained from each of two placements in Project DIAMOND MINE. The first three came from a placement at station 2+88 - 3+59, 06 drift and were tested at 39 days age with a resulting modulus of $E_{avg} = 2.80 \times 10^6$ psi. The second group came from a manway placement, 06 drift and were tested at 49 days age with a resulting modulus of $E_{avg} = 2.81 \times 10^6$ psi. All these specimens were bag cured at ambient temperatures from the time of casting.

Two 3- by 6-in. cylinders of groutcrete mixture DMC-III(CS-II) were obtained from a station 1+95 - 2+88, experimental drift placement in Project DIAMOND MINE. The specimens were bag cured for 10 days at ambient temperatures, then immersed in water at 135 F for 2 weeks, and then returned to bag curing at 73 ± 2 F until tested at 30 days age. The resulting modulus was $E_{avg} = 3.64 \times 10^6$ psi.

Two 3- by 6-in. cylinders of concrete mixture CAM6 were obtained trom the gas seal plug in Project CAMPHDR. The specimens were bag cured for 26 days at ambient temperatures, then immersed in water at 135 F for 2 weeks, and then returned to bag curing at 73 ± 2 F until tested at 46 days age. The resulting modulus was $E_{avg} = 3.06 \times 10^6$ psi.

4.6 BOND STRENGTH TEST RESULTS

The results of the bonding strength of groutcrete mixture DMC-III (CS-II) to tuff rock are as follows:

Age, Davs	No. of Specimens	Bond Strength, psi
3	2	60
10	1	130

14.7 SLUMP LOSS TEST RESULTS

A summary of the slump loss test results is shown in Table 4.3. After initial mixing all mixtures except CAM4 underwent a 12-min rest, 3-min mix cycle. CAM4 underwent a 4-min rest, 1-min mix cycle. Groutcrete mixture DMC-II, which contained a water-reducing admixture (WRA) but no retarder, experienced a 3/4-in. slump loss at 45 min and a 1-3/4in. slump loss at 75 min. DMC-III(CS-I) also contained a WRA and had slump losses of 1 and 3-1/2 in. at 1 and 2 hr, respectively. Although the total cement content of DMC-III(CS-I) was 137 lb/cu yd less than DMC-II, DMC-III(CS-I) contained 146 lb/cu yd more ChemStress I (68) than DMC-II. The greater water demand of the expansive cement was probably a contributing factor to the increased slump loss of DMC-III(CS-I). DMC-III(CS-II) is almost identical with DMC-III(CS-I) in proportioning but contains only half the amount of expansive cement that DMC-III(CS-I) does. DMC-III(CS-II) had a slump loss of 1-1/4 in. at 2 hr. DDCPP-IIB (Rev 1) did not contain a WRA but did contain a friction reducer admixture. It experienced slump losses of 1/2 and 1-3/4 in. at 1 and 2 hr, respectively.

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All of the concrete mixtures contained a water-reducing and retarding admixture. CAM4 and CAM4A both experienced 1-hr slump losses of 1-1/4 in. CAM5 had a 2-hr loss of 2-1/4 in. CAM5A(Rev 1) experienced a 1-hr loss of 1 in.; however, because of its relatively high expansive cement content (376 lb/cu yd) it might be expected to have a greater loss at 2 hr than the other CAM mixtures which had an average expansive cement content of only 94 lb/cu yd. CAM5B experienced a 2-1/4-in. slump loss at 2 hr. EC-15(Rev 1) and EC-22 are heavily sanded mixtures containing both natural and lightweight sands and also lightweight coarse aggregate. They have expansive cement contents of 405 and 594 lb/cu yd, respectively, which can be considered high when compared with the other concretes. EC-15 (Rev 1) had 2- and 3-in. slump losses at 1 and 2 hr, respectively, while EC-22 had 1-3/4- and 4-1/2-in. slump losses at 1 and 2 hr, respectively. EC-15(Rev 2) was similar in composition to EC-15(Rev 1) but it was not as heavily sanded and did contain some natural coarse aggregate. It experienced slump losses of 1 and 1-3/4 in. at 1 and 2 hr, respectively.

Mixtures DMC-IIIA and CAM5A are included in Table 4.3 even though no study was made of their slump loss characteristics. Initial slumps were measured for these mixtures, however, and are included for informational purposes.

4.8 FLOW DETERMINATION TEST RESULTS

The efflux times for grout mixtures DF-5 and GSVK-A were 16.0 and 19.0 sec, respectively. Attempts to measure the flow time of mixture GSVK-B were unsuccessful due to balling up of the nylon fibers. The fibers plugged the orifice on the flow cone and after 13 sec of initial flow additional flow was impossible.

The effect of continual agitation was observed for grout mixture NCS-2(Rev 1). Using a tub-type mixer, the mixture was continuously agitated for 4 hr with the efflux time being checked periodically. The results were as follows:

Elapsed Time	Efflux Time, sec
Initial flow	10.2
30 min	10.7
l hr	11.0
2 hr	14.5
3 hr	17.7
4 hr	21.9

With an efflux time of approximately 22 sec after 4-hr agitation, the mixture can still be considered a good pumpable mixture.

The pumping test of grout mixture HD-1 indicated that it pumped very easily for the 150-ft distance and no segregation of the constituents was observed. No. of the second s

		Learies	bag- cured .	Experimental plug, DIAMOND MINE. Cores represent depths sions longitudinal axis of tunnel plug of 2-6, 14-19, and 19-23 in., respectively.	Experiments plug, DIAMOND MINE.	Bag-cured. Cured at 73 F for the first 24 hr, then at 140 F for 36 hr, and then decreasing to 73 F	when rescu. Cored from 2-ft cube temperature development specimen.	Mot cured in water. Cored from 2-ft cube temperature development specimen.	Cured underwater.	Cast in steel mold. Cured at amount veryon- ture from 0 to 24 hr; from 24 to 70 hr; tem- perature uniformaly increased to 135 F. Cooled	and terves at refer year watery water and Same as above. Cast in cardboard mold, tall drift, DIANORD KING.	Page 1 of 6
	RESULTS	Average Compressive Strength, psi	1770) 2260 2100) 3160)	1240 12600 12600 12600	2255 2020 2020	560 1340	1320) 3220}	3100 2400) 2660]	3470) 4880)	0161	1720	
	TN TEST	Ac. 470	4-33	~~~~	\$% % X	~~	~ R	nr3	22	•	~	
TABLE 4.1	RESSIVE STRENC	No. of Specimens	****	8	4 M M M	~ ~	nn	~~~	n m	1	r1	(Continued)
	SURPARY OF CONT	Laboratory (L) or Field (F) Cast	د.	b a b a	٩	44	ч	فر فر	4	•		
		Epectaen Size	3- by 6-in. cylindere	3- by 6-in. cylindere 3- by 6-in. cores	2-in. cube	3- by 6-in. cylindere 3- by 6-in. cylinder	4- by 8-in. core	6- hy 12-in. cylinders 4- hy 8-in. core	3- by 6-in. cylinders	3- by 6-in. cylinder		
		Curing Temperature Biatory	73 ± 2 F	73 <u>+</u> 2 F See Fig. 4.3		73 ± 2 7 See remarks	See Fig. 4.1	150 7	1 051	See remarks		
		Mixture Designation	CIOUTCHETES	DIC-IIA		DHC-111 (CS-1)		DNC-111 (C6-11)				

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Remarko	Cast in steel wold. Station 1495 - Gured underwater.	Cast in steel wold. 2488,	Cast in cardboard molds.) ULANUNU FINE	Cast in cardboard mold, tail drift floor, DIAMOND MINE.	Cast in steel mold, station 1+95 - 2+88, DiAMOND MINE.	Cast in cardboard moid, station 1495 - 2488, DIAMOND MINE.	Station 2+88 - 3+59, DIAMOND MINE.	Station 1+95 - 2+68, DIAMOND MINZ.	Teil drift floor, DIAMOND MINE.	Tail drift floor, DIAMOND MINE.	Cut from unrestrained expansion bar, Ul6a.06	Cut from unrestrained expansion bar, DIAMOND	Station 1+95 - 2+88, DIAMOND MINE.	Tail drift, styge 2, DIAMOND MINE.	Teil drift, scage 2, DIAMOND MINE.		Arnot for setting	Curea in water.		Cored from the 2-ft cube temperature develop-	Cured in water. Station 2+88 - 3+59, DIANOND	MINE.	Manway, Station 1495 - 2488, 06 drift, DIAMOND MINE.
Average Compressive Strength, psi	1770	1400	950	2050	3180	3600	2830	2705	2250	2260	2760	3190	4230	3440	4210	1530)	2800	2825(3040)	3145	1840		2750
Age. daye	m	m	m	16	21	21	26	27	28	28	*	67	ŝ	12	121	1	m	m	m	•	'n		¢
No. of Spectment	1	г	2	-1	1	-	e	7	-	-	1	ч	2	~	\$	n	m	m	ę	8	-		7
Laboratory (L) or Field (F) Cast	6.	••	F	•	84	3 -1	ja,	b •	•	þ.	•	8 4	ţa.	F -	A .	L.		ц	Ļ	ц	.		b.
Specimen Size	3- by 6-in. cylinder	3- by 6-in. cylinder	3- by 6-in. cylinders	3- by 6-in. cylinder	3- by 6-in. cylinder	3- by 6-in. cylinder	3- by 6-in. cylinders	3- by 6-in. cylinders	6- by 12-in. cylinder	3- by 6-in. cylinder	3-in. cube	2-in. cube	3- by 6-in. cylindere	3- by 6-in. cylinders	3- by 6-in. cylinders	3- by 6-in. cylinders		3- by 6-in. cylinders	3- by 6-in. cylinders	4- ty 8-in. cylinders	3- by 6-in. cylinder		3- by 6-in. cylindere
Curing Temperature History	135 F	Ambient	Ambient	Amblent .	135 F	135 F	Ambient	Amblent	Ambient	Amblent	Ambient	Amblent	Ambient	Ambient	Amblent	See Fig. 4.1	I	110 F	120 P	See resurve	140 F		Amblent
Mixture Designation	DHC-III)	(Contd)														DHC-IIIA					,		

TALLE 4.1 (CONTINUED)

Page 2 of 6

(Continued)

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		- 3+59, DIAMOND MINE.	16 drift; instrument ft, Diamond Ming, Mandond Ming,	3459, DIANDND NIME,	a / hr, then in water	r, us drift overburden	ug, DIARDRD HIRZ,				Instrument holes, Diamond ming				-						•	betweet holes.	LANDAD KINK		18 3 of 6
	1	Manuay, station 2+88 -	scetton 2480 - 3459, U boxee in 06 end 04 dri Station 2488 - 3459, D	Cured at 73 % from 0 458 -	at 150 F until tested.	plug, DIMOND MING.			Bag-curad.	Companion specimens.)	Companion mentance	leanance manufactor			Instrument holes.		Stars 1. When of 2	Stee 2.	Stage 1.))			water tog abactment.		(- emerade manual -	9°2
	Average Compressive Strength, pei	3040		3640	1500	3080		2790)	0616	20802	2940	(crow	1490	1500/	1060	1660	1540	0661	2230	(155)		2120	1360	R 17	
(GENNI.	 •		- 23	; "	~ ~	~	i	2	4	911	8		21	9 9 7 7	9 ¥	16	41	157	161	21	12	122	8	12	
RUD) 1.4 LIE	No. of Breciment	44		• •	••	•		. n	n,	n n	•••	4	•	m e	• •	5	•	~	6	m		n (4	(Continued)
គ	Leboratory (L) or Field (F) Cast	Pu Pu	Bu Bu .	ب	•	••		ы	•	v			-1		•					•					
	Specimen Size	3- by 6-in, cylindere 3- by 6-in, cylindere	3- by 6-in. cylindere 3- by 6-in. cylindere	3- by 6-in. cylindere	3- by 6-in. cylindere	3- by 6-im, cylindere		3- by 6-in. cylindere	3- by 6-in. cylindara				J- by 6-in. cylindere	3- by 6-in. cylinders						3- by 6-in. cylinders					
	Curing Temperature History	Ambient Ambient	Ambient [.] Ambient	See , remarks	See remarks	Amb Seat		73 ± 2 F	Amblent				73 ± 2 ₽	Amblent						And int					
	Mixture Pesisnation	DHC-IIIA (Conté)		DCP-113			CINUTS	1-5210					D 7~ 5							3-B					

Remarks	ation 14.5 - 60.0, CAMPHOR; cured in water.	ch age is a different placement. Instrument ies, DIAMOND MINE.	fach age is a different placement. Instrument noies, DIAMOND MINE. Bag-cured.		<pre>mpanion Two placements, pressure grouting ecimens. work drift and experiment drift, CANTHOR.</pre>	red in water.)	Ast-room cured.	tellite hole 1, stage 4, DIAGONAL LINE	g-cured.	red in steel molds. Temperature raised to 0 F from ambient over 2-day period, then intained at 150 F for 3 days, lowered, and	intained at 40 tor 5 mays and then recreased I per day to 60 F and maintained at that vel until tested. Page 4 of 6
	St	ង ផ្	å	្រភ្ន	S 🕯	3	ох Х	S.	Ba	9 J 🖁	19.4
Average Compressive Strength, pa	1550) 1600)	6530) 5660 5360	3360 33600 4600	4510 5490 5820	4530) 4600) 8415	440)	290	590	2690	4600 4600 4600	
Age, daye	82	368	- n r a	36.58	28 ~ 5	~ v	28.7	42	~ 41	3232	
No. of Specimena	90	~~~		ገ ጦ ጦ ጦ.	0 N N	~ ~	I N M N	7	m m r		(Continued)
Laboratory (L) or Field (F) Cast	6 .	ja.		•	•	ч	ч	•	-1	L	
Specimen Size	3- by 6-in. cylinders	3- by 6-in. cylinders	3- by 6-in. cylinders	3- by 6-in. cylinders	3- by 6-in. cylindere	3- by 6-in. cylinders	3- by 6-in. cylinders	3- by 6-in. cylinders	3- by 6-in. cylinders	3- by 6-in. cylinders	
Curing Temperature History	140 F	. Ambient :	73 <u>+</u> 2 F	Ambient	Ambient	150 7	73 <u>+</u> 2 F	Ambient	73 <u>+</u> 2 F	See remarks	
Mixture Designation	DF-5A (Contel)	MCS-2 (Rev 1)			KCS-S	DL-2		1 -10	CSVR-A		
					71						

TABLE 4.1 (CONTINUED)

(Continued)

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Resarko	Bag-cured.	Same elevated curing in steel molds as for GSVK-A.	Fast gate gas seal plug, stage 2, CAUTHOR. Fast gate gas seal plug, stage i, CAUTHOR.	Bag-cured.	Cured in water (urmitionu) at the owner of the history as 055X-A.	ES-I Cross drift, stage 1, CAPHOR.		Moist-room cured.	Jag-cured.	Cured in water at the following temperatures: 0-2 days,150 F; 2-3 days, 125 F; 3-5 days, 110 F; 5-7 days, 100 F; and 7-56 days, 73 F.	Moist-room cured.	Bag-cured. Aread to unter at the same alevated tempera-	tures as CAN-4.
Average Compressive Strength, psi	2800) 3200 3505	0045	4040	1360	22700	1740 2140	13766	4540 6009	3390	2350 5350 2350	3150	0264	3620)
Age. days	222	1738	122	28	78 - 1	33	ľ	. 2 3	8-8:	****	~ #2	~ 7	~ 9 2
No. of Specimens	•••	• • • •	n w m	•	~ ~	4 4	•	N N 0		~~~~	n 11	M M	n n
Laboratory (L) or Field (F) Cast	-		•	ب	Ч	ba		-	ы	ы	در	7	4
Specimen Size	3- by 6-in. cylindere	3- by 6-im. cylinders	3- by 6-in. cylinders	3- by 6-in. cylindere	3- by 6-in. cylinders	3- by 6-in. cylinders		3- by 6-in. cylindere	3- by 6-in. cylinders	3- by 6-in. cylinders	3- by 6-in. cylinders	3- by 6-in. cylinders	3- by 6-in. cylindere
Curing Temperature History	73 ± 2 7	See remarks	Ambient	73 ± 2 F	See remarks	Ambient		73 ± 2 7	13 ± 2 F	See remarks	73 <u>+</u> 2 F	73±27	See remrks
Mixture Designation	CSVK-1	Ì		1116			CONCRETES	CLEFL			CUR-4A		
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TALLE 4.1 (CONTINUED)

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Remarka	Bag-cured for 24 hr, then cured in water at 150 F for 6 days; after 6 days, cured at 73 F. One each core from our incore	seal valve plug, carried and the gas approximately 12 in. from plug face. All 14-day specimens cured in service.	73 F. All other specimens cured in water at 135 F for 14 days, then at 73 F until tested. 07 drift gas seal plug, CAMPHOR. Beg-cured.	
Average Cumpressive Strength, psi	3220 4190 3960 3770	(0522	23200 23200 23200 23200 23200	
Age. daya	58 3 *	4	122 -3	
No. of Spectmens	* ~ ~ ~ ~		1 N m · m m	
Laboratory (L) or Field (F) Cast L	يحو الس	84	د .	
Specimen Size 3- by 6-in. cylinders	6- by 12-in. cylindera 3- by 6-in. corea	3- by 6-in. cylindere	3- by 6-in. cylinders	
Curing Temperature History See remarks	Sea 718. 4.8	See remarks	73 <u>+</u> 2 F	
Mixture Dest <u>ension</u> CAN-5		cut 6	EC-15 (Rev 1)	

TABLE 4.1 (CONCLUDED)

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arka					ataga 1. 1	final stage		~		06 dr.t.t., DI			NIN GNONAIG						DIAMOND IN		
		Experimental ning	Variation Of Auf a	06 drift plug. Dr	Sta 2+86 - 3+59.	Ste 1-95 - 2+88,	Sta 1+95 - 2+88	Tail drift. stage	Tail drift, stage	Overburden plug, (MINE			Instrument holes,				Instrument holes/	Ul6a.05. stage 3	Ul6a.05, stage 2)	Ul6a.05, stage 1	05 drift
Nilee Epe Average		12,040	11,610	10,660J 10,555	11,460	11,890	12.135	10,925	11,960	11,490		• 010	9,135	11,0407	7,315	99	7.555	7,895	7,745	7,740	8,475
Ultrasonic 1 Velocity, Lange		•	•	10,535-10,785 10,355-10,755	11,165-11,775	12.075-17 075	12,075-12,195	•	11,640-12,160	11,450-11,530		8.710- 9.410	9,960-9,450	AC1111_ACC1A	• •	•	7,425- 7,690	7,855- 7,935	7,575-7,855	7,500- 7,905	8,195-8,760
No. of Specimene		1		~ ~	m.	-4 67	. ••	 4 (m	2		~	~ ~)	14 pr	, 4	8	~	m (71 (N
Specimen Size		2- by 2- by 9+1/2-in. ber	3- by 20-in. cylinder	3- by 20-in. cylinder	3- by 6-in. cylinder To be 20-in. cylinder	3- by 6-in, cylinder	3- by 20-in. cylinder	3- by 20-in. cylinder	3- by co-14. cylinder	3- by 20-ia. cyliader		3- by 6-im. cylinder	<pre>3- by 6-in. cylinder 3- by 20-in. cylinder</pre>		3- by 6-in. cylinder 3- by 6-in. cylinder	3- by 6-in. cylimder	J- by 6-in. cylinder	J- by b-is. cylinder	Ju bu fute cylinder		
Age. daye		226	10 P	5	*:	2	2:	74	1	Ś		10	1 2	14	ភេ	ន	8 2	\$ \$	13	5	Ì
Laboratory (L) or Field (F) Cast		84	8 .		•					•		•		لر	I	J	•				
Mixture <u>Designation</u>	COUTCHETES	DHC-IIV	DHC-II'M		111-31 (CS-11)					DOCPP-IIB (Nev 1)	GRUTH	1-9014		2-2 2							

Page 1 of 2

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TABLE 4.2 (CONCLUDED)

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Renarke	Instrument holes, DIAMOND MINE.	Station 14.5 - 60.0, CANPHOR.	Instrument holes, DIAMOND WINE.	Instrument holes, DIAMOND MINE. Exp hole No. 1, MISIT MORTH. Instrument holes, DIAMOND MINE.	Fast gate gas seal door, stage 2. Fast gate gas seal door, stage 1.	ES-1 crous drift, stage 2, CANPHOR. ES-1 cross drift, stage 1, CANPHOR.		Cas soal plug, of drift, CAUBOK.	
ular Eps Average	7,630) 7,635) 7,635)	8,030) 7,675 8,415	8, 355 7, 395	11,680 11,340 , ⁷ 95	11, 390 11, 525 10, 810	9,220 9,695		11,305	11,605 12,010
Ultrasonic P Velocity, Range	7,500-7,730 7,560-7,685 7,590-7,680	7,950- 8,105 7,650- 7,700 -	8,050- 8,700 -		11,380-11,400 11,365-11,700 -	9,090- 9,355 9,570- 9,820		ı	11,550-11,640 12,000-12,015
No. of Specimens	m m N	~~~		- M M M	200	~~~		-	n n
Specimen Size	 3- by 6-in. cylinders 3- by 6-in. cylinders 3- by 6-in. cylinders 	3- by 20-in. cylinders 3- by 6-in. cylinders 3- by 20-in. cylinder	3- by 20-in. cylinder 3- by 20-in. cylinders 3- by 20-in. cylinder	3- by 20-in. cylinder 3- by 6-in. cylinders 3- by 20-in. cylinders	3- by 20-in. cylinders 3- by 6-in. cylinders 3- by 20-in. cylinder	3- by 20-fn. cylinders 3- by 20-in. cylindere		3- by 6-in. cylinder	3- by 18-in. cylinders 3- by 18-in. cylinders
Age. deye	3827	ននន	122	42 42 89	222	12		2	r 41
Laboratory (L) or Field (F) Cast	۰.			•	£n,	•		•	ч
Mixture Designation	DF-5A			NCS-2 (Rev 1)	CSVR-B (Rev 1)	LTSG	CONCRETES	CUN-6	EC-15 (Rev 2)

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Page 2 of 2

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	DETERMINA
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	SUMMARY

		120-min slump			8	9	œ	:	œ			:	I	:	7/7-0	;	1	6-1/2	5-1/2	8-1/4	5-1/2
		90-min Slump			t 7	1	1	; (6			ł	1		1	1	:	1	:	:	*
		75-min Slump			7-1/2	•	•	:	;			1	•	i		8	1	;	1	:	;
TINATIONS	D. inches	60-min Slump				2-1/2	1		7-1/4			7-1/2	6-3/4		1	 r	•	1	6-1/2	6	8-1/4
LOSS DETERN	Slum	45-min Slump		6/10	7/1_0		1					;	;	ł	8	1	•	1)	;	1,7	1
AND SLUMP]		30-min Slump		1	:	;	4					œ	1	i	:	1	1	8	1	;	•
OF SLUMPS		Initial Slump		4 -1/4	9-1/2	9-1/4	10-1 /2	9-3/4				8-3/4	×	8-3/4	10	~	8-21/	0-0/1	-7/1-0	10	1
SUMMARY	Rest:Mix Cycle After	Initial Mixing min:min		12:3	12:3	12:3	8	12:3			6 - 7		14 J	12:3	1	12:3	12:3	12.3	5.01	12.3	> •
		Designation	Groutcretes	DMC-II	DMC-III(CS-I)	DMC-III(CS-II)	DMC-IIIV	DDCPP-IIB (Rev 1)		Concretes	CAM4	CAM4.6				CAMDA (Rev I)	CAM5B	EC-15 (Rev 1)	EC-15 (Rev 2)	EC-22	

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Figure 4.5. Temperature Development in the 06 Drift Plug, STA 2+88 - 3+59, Project DIAMOND MINE - Groutcrete Mixture DMC-IIIA





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Figure 4.8. Temperature Development in the 07 Drift Gas Seal Plug, Project CAMPHOR - Concrete Mixture CAM6

3 NOTE: BARS COATED AND BAG -CURED AT 73 F. 20 -INITIAL MEASUREMENT MADE IO HOURS AFTER CASTING 9 ELAPSED TIME, DAYS RESTRAINED EXPANSION BÂRS (LABORATORY) 12 BASE LINE MIXTURE DMC-II OF 3 BARS) 0 3-IN. BARS (LVG 4 -0.04 0.121 0.08 0.04 0 EXPANSION, PERCENT



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Figure 4.16. Mixture MiC-III (CS-I): Expansion Versus Time Relations for Laboratory Specimens

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Figure 4.19. Mixture DTCS-1: Unrestrained Expansion (Bars) Versus Time Relation for Laboratory Specimens





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Ň CURING TEMPERATURES WERE AS FOLLOWS: 0-7 HOURS, 73 F; 7-72 HOURS, 150 F; 3-7 DAYS, GRAGUALLY DECREASED FROM 150 F TO 73 F. BARS CURED IN MOLDS FOR 24 HOURS; THEN IN WATER THROUGH 7 DAYS AGE. iNITIAL MEASUREMENT TAKEN 24 HOURS AFTER CASTING 2 2-IN. BARS (AVG OF 2 BARS) Ø ELAPSEU TIME, HOURS UNRESTRAINED EXPANSION BARS MIXTURE DDCPP-IIB (REVI) (LABORATORY) NOTE: 4 BASE LINE 2 0 0.05 0.03 0.02 0 0.06 0.08 0.07 0.04 0.01 -0.01 EXPANSION, PERCENT

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Restrained Expansion Vergus Time Relations for Laboratory Specimens Mixture GSVK-A: Figure 4.30.

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EXPANSION, PERCENT

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Mixture GSVK-B(Rev 1): Figure 4.31.



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Figure 4.42. Mixture EC-15(Rev 2): Expansion Versus Time Relations For Laboratory Specimens

APPENDIX A

PETROGRAPHIC ANALYSIS OF NTS CONCRETE SAND

A.1 MATERIALS

A sand sample from the NTS Gravel Gertie Pit in Area 5 was received for testing on 22 March 1971 and assigned CL Serial No. NTS-53 5-1. The specific gravity, absorption, and gradation of the sample are shown in Section 2.2.1.

A.2 TEST PROCEDURES

Representative samples from each sieve fraction were examined according to CRD-C 127 to determine the composition of the sand and to determine if any reactive components were present. The sand fractions coarser than the No. 30 sieve were examined and classified wet and dry under a stereoscopic microscope and also in hydrochloric acid. The fractions passing the No. 30 sieve were examined and classified as grain immersion mounts, in an index oil with a refractive index of 1.544 using a polarizing microscope. Selected samples were ground to pass a No. 325 sieve and examined using an XRD-5 diffractometer with nickel-filtered copper radiation.

A.3 DESCRIPTION OF CONSTITUENTS

The compositions of the sieve fractions and the weighted composition of each sieve fraction and the sample are given in table A.l. The constituents are described below.

<u>A.3.1 Light Carbonate</u>. About 25 percent of the material coarser than the No. 30 sieve ranged from very pale orange (10 YR 8/2) to light olive gray (5 Y 6/1) (Reference 4) and was sandy dolomitic limestone. The grains ranged from blocky to tabular and rounded to angular in shape. This constituent was recognized in the fraction coarser than the No. 30 sieve but was not differentiated from the other varieties of carbonate rock in the fraction finer than the No. 30 sieve. The calcite-dolomite ratio was approximately 1:1 as indicated by X-ray diffraction. Quartz was present in an amount equal to the calcite with each comprising approximately 30 percent of the sample examined by XRD.

<u>A.3.2 Dark Dolomitic Limestone</u>. The dark carbonate grains were medium gray to black (N 5 to N 1) (Reference 4) dolomitic limestone. The grains usually were more angular than the light carbonate grains. These grains also had a 1:1 calcite-dolomite ratio but did not contain as much quartz as did the light-colored grains. The dark dolomitic limestone grains were approximately 80 percent carbonate and 20 percent quartz and feldspar.

<u>A.3.3 Carbonate Coatings.</u> In the fractions coarser than the No. 30 sieve, over half of the carbonate grains were partially coated with a pale carbonate coating. The coating material was approximately 50 percent calcite, 25 percent dolomite, 15 percent quartz, and 10 percent feldspar, formed as a secondary carbonate deposit on the sand grains. Both rounded and angular grains were coated, and angular fragments of coating from coarser particles existed as grains in the coarse sand.

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<u>A.3.4 Carbonate Grains</u>. In the fraction finer than the No. 30 sieve, the three varieties of carbonate could not be differentiated and so are considered together. Most of these grains were rounded and had very few inclusions. XRD results indicated that the calcite:dolomite ratio of these grains was approximately 1:1.

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A.3.5 Quartz. Clear angular quartz was present in all the sieve fractions. Quartz was a minor constituent of the coarser fractions but was a major constituent of the finer fractions. The grains were subangular to angular in all size fractions.

<u>A.3.6 Sandstone</u>. Sandstones were a major constituent in the coarser fractions and were present in minor amounts in the finer fractions. These grains included quartzites, graywackes, and arkoses. Silica-cemented quartzite was the most common type and was found in all but the fraction passing the No. 200 sieve. No opal-bonded sandstone was found in any fraction; only a small percentage of the grains were cemented with carbonate.

<u>A.3.7 Acid Igneous Rocks</u>. Light-colored igneous rocks are the predominant kinds in this group. The grains were principally granite, rhyolite, and volcanic tuff. Most of the grains were angular. Some of the grains of tuff contained a small amount of glass but the amounts were too small to be considered deleterious.

A.3.8 Feldspar. Angular feldspar grains were present in the finer fractions. The grains were plagioclase, orthoclase, and microcline.

<u>A.3.9 Chert</u>. Minor amounts of chert were present in the finer fractions. The grains all had a refractive index greater than 1.544, indicating that they were not chalcedonic.

<u>A.3.10 Miscellaneous</u>. Included in this group were dark basaltic grains and a few grains that were not identified.

<u>A.3.11</u> Clays. A small amount of clay was present in the fraction passing the No. 200 sieve. XRD results indicated that the clays present were kaolinite, illite, chlorite, and montmorillonite.

A.4 SUMMARY OF RESULTS

The sand sample from NTS Gravel Gertie Pit, Area 5, contained approximately 56 percent dolomitic limestone, 20 percent quartz, 14 percent sandstone, and minor amounts of acid igneous rocks, chert, feldspar, and clays. The 1:1 ratio of calcite-dolomite in the carbonate grains indicates that the sand is potentially reactive. No other potentially reactive constituents were detected in the sand. Since the carbonate is potentially reactive, low alkali cement should be specified if the sand is to be used as fine aggregate.

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Composition of Sand From Gravel Gertie Pit, Area No. 5, NTS

	Numb	ber of Par	rticles as	Bercent	in Sieve l	ractions l	3el ow	
							Passing	Weighted
Constituents	<u>No. 8</u>	<u>No. 16</u>	No. 30	<u>No. 50</u>	No. 100	No. 200	No. 200	Average*
Light dolomitic limestone	26	38	20)					
Dark dolomitic limestone	38	18	12	77	77	41	40	56
Carbonate costings	11	12	16)					
Sandstone	13	20	19	13	13	-1	tr	13
Quartz	'n	'n	24	34	34	43	40	20
Acid igneous rocks	4	7	ŝ	1	1	;	8	4
Chert	:	3	1	Ś	ę	4	tr	•*
Feldspar	!	1	1.	4	4	Ś	20	Ś
Miscellaneous	5	7	m	-2	2	9	:	5
Total	100	100	100	100	100	100	100	100

* Based on the compositions of the fractions, at the left above, and on the grading of the whole sample.

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APPENDIX B

PETROGRAPHIC ANALYSIS OF FIELD-CAST GROUTCRETE MIXTURE DMC-IIA, DIAMOND MINE

B.1 MATERIALS

Two sawed slices from a 3- by 6-in. test cylinder cast from the DMC-IIA groutcrete mixture placed around the 16 tunnel experimental plug on 17 November 1970 were studied. The mixture proportions used for DMC-IIA are shown in Table 2.2. The grout was 60 days old when studied.

B.2 TEST PROCEDURES

Part of one slice was broken up, and the coarser sand was removed by handpicking. The material passing No. 100 sieve from the broken mortar was ground to pass No. 325 sieve and backpacked in a 3-in. aluminum holder. The holder was mounted on an XRD-5 diffractometer. A gastight hood with a mylar window was fitted over the sample holder and flushed with nitrogen; the hood contained a sponge soaked in $Ba(OH)_2$ solution to absorb CO_2 . The sample was scanned from 6 to 20 deg 20 using a 1-deg beam slit, a 3-deg beam slit as a Soller, and a 0.2 detector slit at 27 KVCP and 29 ma, and from 20 to 66 20 with a 3-deg beam slit, other slits as shown above, at 50 KVCP and 21 ma, using copper radiation.

B.3 TEST RESULTS

The proportions of materials in the groutcrete are shown in Table B.1 and the constituents identified by diffraction are shown in Table B.2. Table B.2 also contains the absorption coefficients for copper radiation

calculated for the constituents identified. They are included because the presence of barite, with an absorption coefficient much greater than any other constituent and a diffraction pattern containing many lines, has a conspicuous effect on the apparent quantitative relations in the groutcrete. のないのであるので、

Ettringite is present in substantial amount, probably amounting to more than 50 percent of the $Ca(OH)_2$ present, which has presumably been reduced from the amount that would be present if the fly ash had not begun to react with it. No calcium sulfate is detectable; most of the positions in which residual calcium silicates from the cements might appear are masked by barite and calcite; the most intense lime of $Ca_4Al_6O_{13} \cdot SO_3$ (C_4A_3S) at 3.76A is masked by barite.

B.4 CONCLUSIONS

It is apparent that the relative abundance of ettringite (the component resulting from hydration of the expansive constituents) is considerably more than the amount produced in normal cement hydration and thus is indicative of the presence of the ChemStress II (70) cement. More quantitative statements would require the preparation of a fairly complex series of calibration mixtures which may not be warranted for the amount of information that might be obtained.

TABLE	Β.	1
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Groutcrete Constituents as Percent by Weight

Sand Barite Cementitious materials, admixture, water*	46.62 11.47 <u>41.91</u> 100.00
* These were:	
Type II cement ChemStress Fly ash Water, Pozzolith 8	7.50 8.58 11.99 <u>13.84</u> 41.91

TABLE B.2

Constituents Identified by X-ray Diffraction

Source	Compound	Linear Absorption Coefficient for <u>Cu Radiation, cm⁻¹</u>
Concrete sand	Quartz	93
	Calcite	205
	Dolomite	143
	Feldspar (as albite)	87
Barite	Barite	1023
Cement hydrates	Ca(OH) ₂	219
	$(C_3A \cdot 3CaSO_4 \cdot 32H_2O)$	88

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