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Title

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Publication Date

1962-02-01

Structure and Materials Research Department of Civil Engineering

Series 100

Issue 17

Report er O

Department of Public Works Division of Architecture State of California

Under State of California Standard Agreement No. 2379

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EFFECT OF TYPE OF ACCRECATE ON

SHRINKAGE AND CRACKING CHARACTERISTICS

OF CONCRETE

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SHRINKAGE AND CRACKING CHARACTERISTICS OF CONCRETE

0 f Berkeley, Engineering Standard Agreement Number cretes type Reported herein was made on their State O H California during the period June 1961 to January 1962 aggregate Materials Laboratory of the University O Im California under the conditions of State of for the Division of Architecture, Department of Public shrinkage and 9 7 8 of continued mixing and retempering of the 2379. and cracking characteristics. results These o H studies an investigation on the Were of California, carried This California investi-) |coneffect C D @

breakdown, continued mixing and retempering increases shrinkage Ċι major Results factor influencing shrinkage and cracking of concrete, and that clearly air demonstrate entrainment that somewhat Lype and source reduces and aggregate shrinkage o f aggregate that

SCOPE OF PROGRAM

type content struction of 1/2-in. O Ha o H aggregate 0 m main maximum~size 5-3/4 reinforced concrete buildings. typical concrete mix that might be purpose of scy g and the magnitude aggregate a maximum slump of 4 these studies was to determine O Ph shrinkage The mix used had a cement inches, and and employed in the the the effect tendency contained contowards 0 m

Burxim usually require that study to Continued mixing times evaluate and cracking O th 3/4, 1. 1. 1. 1. 1. (h) }---å effects and retempering 1/2 concrete mix of concretes. and on degradation of w hours (B) Ó Data were obtained discharged from concrete Although specifications aggregates E (1) (2) included įΔi for continued truck mixer and in this

707 santhin 45 minutes, O O discharge. sometimes concretes CL CD agitated för longer periods

ffect Also included 17 (0) (0) (1) (1) (1) Ö Ph Surxing Ω3 j...l., |**} included entrainment and retempering in this only standard~mixed concretes not subjected investigation on shrinkage and Sas cracking a limited characteristics study of ct O

7700000 heavy-liquid aggregate was also employed gravel WILES FOUR Valley deposits. assresates and Watsonville concrete separation Were aggregates were included representative crushed The other in one mix granite. two aggregates included Fair Oaks O Ph after being ET 10 The Ľ, Livermore Valley and of Livermore beneficiated by study. Valley JWO TWO coarse 0 the

٠ ت ت CUMPA 50 percent relative humidity М О М 100 **17** ٤b period of seven days prior shrinkage and cracking study, to exposure ₽3 |---| |---| concretes to drying were at 70°F moist-

CONCRETE MATERIALS AND MIXES

Portland Cement

content investigation. Çx: Santa O O this Cruz Type II cement was 0.5 100 chemical cement was used in all concretes analysis percent بدر ازی and its C3A content given in Table نسۇ د () () only The 1 alkali percent

Asgregates

HOUR aceresates included in these tests were

- Cement e C L E Assresare gravel and Prattco sand, supplied by Company of 12 13 13 13 Francisco the Pacific
- Oakland amount godine. No. O Ph Livermore Felton sand, all <u>}~</u>} ;] (ĭ) Livermore Valley fine materials supplied and came coarse bу the Henry from aggregate 0 company's <u>C-4</u> Kaiser used with Radum Company of plant smal]

820 the Felton sand from their plant in Olympia near Felton.

- g Pacific the Alameda Creek Cement and Aggregate Company from their plant west Ni les Valley coarse accrecate and sand, supplied by O |*** Wiles
- D8 (** plant. granite is produced by the Granite Rock Company in their Watsonville their Granite Rock Company, Watsonville, The Olympia plant. Watsonville Olympia sand crushed is produced by the Central Supply Company granite and Olympia sand, California. The supplied by crushed

prepared coarse aggregate remove material (1) (1) (1) (1) Also submitted for test was a small sample of the Livermore by the Henry J. Kaiser Company, was employed in only one of conditions of specific gravity lower than 2.60. which was processed by heavy-liquid separation This material, Valley

をおけまる Livermore report (16) (16) above-described combinations as Fair Oaks, Livermore Valley, Niles Valley, and Watsonville. beneficiated Livermore Valley aggregate. Valley accrecate subjected to of aggregates heavy liquid separation is desare designated in

(1) (1) given Physical Properties. H Table 2 The physical properties O irh the aggregates

Livermore Valley substantially Valley sand. Pranteo fineness modulus sand used with the Fair Oaks gravel to rangin Both the Fair Oaks and Watsonville aggregates and Wiles sand equivalent and cleanness of the concrete Valley accrecates sands ranged from (بر) د دسخ دسخ دسخ values than did OK the Miles 2,85

acontensative o judged by the special ار 10 اما Oak to and Watsonville aggregates gravities and absorption capacities would be

considered and Niles Valley aggregates O Fh superior quality in comparison with the Livermore

liquid separation increasing its specific gravity and reducing its absorption capacity. The beneficiation of Livermore improved somewhat the quality of the material by Valley coarse accrecates by heavy-

randum No. 6-370, "Test Data Concrete Aggregates in Continental United aggregates tates", Petrographic are summarized as follows: (A) reported Analyses. S. Corps Petrographic analyses O Ph Engineers, Technical Memo-0 H concrete

schist sandstone (11%), quartzite (5%), slate (2%), wein quartz, chert, and igneous rocks (2%). Oaks (24%), basic gravel from the American River meta-igneous rocks (42%), andesite consists O Ith basic (14%),

amphibole Monterey Bay. meta-volcanic The sand used with this garnet, This sand is composed of and antigorite minerals. rock types eravel with quartz, granitics, sandstone, chert, Presented o fallspar, Ø8 dune sand biotite, magnetite, from the

Radum, California. and graywacke asic meta-igneous rocks (9%), and jasperoid type chert (10%). Livermore (61%), vein quartz (14%), basic igneous rocks (6%), Valley aggregate is a river sand The coarse accrecate judq Vi composed ŭ C O Hh gravel from sandstone

igneous rocks, sand julo (I) meta-basic igneous rocks composed O Fh graywacke and sandstone, and chert (jasperoid type). quartz, basic

(50%), with Its mineral sand addition to this sand, , ОО constituents consist largely trace quantities from (T Zayante O Fit Creek a small amount of Felton sand was used (18) (17) e r daz 10 O Hi quartz (50%) and Felton, California feldspar

vein quartz (8%), basic igneous rocks (4%), basic meta-igneous rocks Niles. jasperoid type chert (1%), and a trace of shale. The coarse aggregate consists of sandstone and graywacke (84%), Wiles Valley aggregate is from the Alameda Creek west of

igneous The sand consists of sandstone, graywacke, vein quartz, basic rocks, basic meta-igneous rocks, chert and shale

near which has Watsonville, California. Watsonville crushed coarse aggregate comes from a quarry an abundance of amphibole. It is composed of a dark-colored granite

magnetite of quartz sand from The concrete sand used with this crushed granite was Olympia (50%) and feldspar (50%), with a trace of biotite a deposit at Olympia on Zayante Creek. This sand is composed

Concrete Mixes

quite similar materials, the same basic mix design was employed for both the Livermore Valley and the Niles Valley coarse aggregates are reinforced concrete buildings. Mix proportions for the concretes mix is typical of that which could be used in the construction of content of 5-3/4 scy and a slump of 4 inches. Livermore concretes containing suggested by the Henry J. Kaiser Company to be used with their Concrete mixes employed in this investigation had a cement Valley aggregate containing these the aggregates investigated are given in Table two materials. The mix selected was the This type of concrete فيا • Since

produce the desired 4-inch slump. Table (u) except that the water contents were adjusted slightly mixes used were Actual water contents used are on the mix proportions shown in

given in Table 4.

Darex was added in sufficient quantity to produce an air content of about 4.5 percent. (S/A) of the air-entrained concretes was reduced by 0.03. also Three of the aggregates (Fair Oaks, Livermore Valley, and Watsonville) used in air-entrained concretes. As shown in Table 4, the sand-to-total aggregate ratio The air-entraining admixture

more Valley aggregate. HOH ratio ranged from 4.92 gal/sk for Fair Oaks aggregate to 5.22 gal/sk ranged from 5.53 gal/sk for Fair Oaks aggregate to 5.83 gal/sk for Liverthe Livermore Valley aggregate. As shown in Table 4, the water-cement ratios of the plain concretes For the air-entrained concretes the water-cement

the unprocessed material. aggregate was of similar proportions to those of the concrete containing 0.38), and its water-cement concrete mix containing beneficiated Livermore Its S/A ratio was slightly reduced (from 0.39 ratio was also slightly lower Valley coarse

MIXING PROCEDURES AND TEST SPECIMENS

Mixing of Concretes

together The aggregate and cement were placed in the mixer first, and were mixed minutes, after which the concrete was mixed for an additional 2 minutes. a mixing speed of 17 rpm for 2 minutes. Mixing was then stopped for concrete was then discharged into a wheelbarrow, slump and air All concretes were mixed in a tilting-type, 3-cubic-foot capacity were determined, and specimens were casts for half a minute. The mixer was equipped with an adjustable speed motor. Water was added, and mixing was continued

2000 initially mixed following the procedure just described. ត ត be subjected to continued mixing and retempering After

O Mh discharging of the concrete. bring the slump to 4 inches. of plastic continued mixing the opening of completion discharge. continued continued N **EC.** がない pours All concretes subjected to to prevent 0 continued mixing, retempering was done at mixing and just prior TOP CINE et E E the retempering water ()a C* initial mixing, at subjected to continued mixing were evaporation of water. 3-hour continued mixing periods of a mixer to discharge mixing period, retempering was done at 명 () (건 For the concretes subjected to 3/4 hours the drum mixer was sealed with a sheet speed of the concretes subjected to 1,1/2 hours a mixer speed only E B B B B I hour Tests were made on concretes Ú added just prior to e mora a Do 3/4, of 17 rpm, During this just 1-1/2, and retempered to TOLICE (A)

3 constructed 9 The entire procedure of mixing was carried out percent relative humidity. MOOM (wood frame and plastic cover) maintained at H. ()a specially 70°F

Aggregate Breakdown Tests

er Er analysis eir-dried the concrete was wet-screened through successively smaller Mixing entire Ö continued mixing accrecate. E. Ou batch before O Ph determine the degradation of 300 (2) (2) (4) made the aggregate prior to mixing. then fines on air-dry aggregates. Materials rescreened through the set and after mixing. and retempering, a sieve analysis was made on the passing the No. retained on the 100 sieve were aggregates in concretes subjected The sieve; analysis For the analysis after mixing, individual of sieves used for the washed sleve STRVES. ABMBA 81Zes prior Ente

Test Specimens

0 (1) (1) (2) (3) († (1) (1) (1) condition there were () () () () () two 4-7/8 by 6 βď 16-inch

shrinkage details of 0 by 12-inch compressive-strength cylinders. S 24 C c e two 4-7/8 by 6 two types of concrete bars employed by 40-inch crack-resistance In Fig. | | O PH are shown

in the concrete. diameter brass pecimens The nol ds Ö permit C e o plugs secured in the ends of These plugs projected 1/2 inch out of the concrete length measurements. FOR casting of shrinkage the molds specimens had er Or embedment 1/2 inch-

0° 0 permit length measurements, This length, longitudinally concrete steel rod was Q) anchorage, the bar 80 CT (F. C.) order Q# (*** rod of 1-1/2-inch diameter was secured to produce the restraining effect along each end E threaded at covered with 1/8-inch-thick To prevent bond along the remaining the centerline the steel bar projected 1/2 inch out each end of the mold. for a distance of 80£t for the crack-resistance i O in the mold rubber shown in 34-inch 3 inches tube, 00 1-4 1-4 1-4 0 O

board molds Compressive-strength specimens were cast in 6 ۸. ۵. 12-inch card-

Casting of Specimens

0 14 0 10 C S ro T remained stored successive layers, each consolidated by the use internal vibrator. in the molds Che curing for shrinkage curing room (70°F and 100 percent relative humidity) room. Immediately after casting, They and crack-resistance were stripped after bars specimens were O Ph 24 Ωn Were hours laboratoryfilled

FOCE compressive-strength specimens. tandard procedure E C C employed for the casting 0 m

measurements

measured at weekly intervals. resistance bars which did not crack within 30 days were thereafter e to every 24 hours for the first two weeks and then every 2 days until a S measurements were taken on both the shrinkage and the crack-resistance crack occurred in the crack-resistance bars. percent then continued, at weekly intervals, After completion of The bars were then transferred to the drying room (70°F and relative humidity), where length measurements were taken the 7-day moist-curing period, initial for three months. Shrinkage measurements Crack

O Th the effective length (15 inches) of the concrete bar. length, was computed by dividing the total change in length by Shrinkage -- The shrinkage, in millionths of an inch per inch

uated on the bases of (1) tensile observed length change of the steel bar, using the of crack and (2) the drying period (in days) required to produce a drying shrinkage (Fig. 1). Crack resistance of a concrete is evalthe tensile Crack Resistance e D stress developed in the concrete due to restrained tensile stress in the concrete was calculated from the -- The resistance of concrete to cracking is stress developed prior to formation following equation:

where

 S_c a Average tensile stress in concrete, psi $\triangle L$ a Measured deformation of steel rod, in.

L = Effective length of steel rod = 37 in

(ম) জ Modulus of elasticity of steel rod = 30 x 10⁶ d Ser.

As Area of steel rod = 1.77 sq. in.

Ac = Net area of concrete bar = 26.85 sq. in.

becomes SULTACE threaded portion of the steel bar, varies linearly assumption that the tensile stress subjected O H (34 + 1 - 1/2 + 1 - 1/2) = 37 inches. the threaded portion of the steel bar to its maximum at effective O the average tensile stress length 3 inches gavij i O Fh 37 inches was determined on the from the surface. in the concrete, and the effective length can be considered from 0 at the over the 3-inch Therefore 0110

Sar a taining crack during characteristics crack discontinued. Crack-resistance bars made with a concrete mix within the 90-day drying period, after which time the tests e D Fair Oaks and the Watsonville the drying period. and of high tensile strength might not develop a In this investigation concretes conaggregates O His did not low shrinkage develop

cylinders Specification C39. cylinders Compressive Strength, Çib 1775 00 00 00 00 0 M Hydrostone was used for capping the ends of the and 28 -- Compressive-strength days were made in accordance tests S S with **ር**ኮ څ. ۵, MISA 12-inch

TEST RESULTS

Properties of Concretes

ب. and Properties 28 days O M O o H given in Table 4. fresh concretes and compressive strengths at ages

ratio ₽ O Ph plain concrete Requirement. ĝ U containing P (5) shown Fair Oaks gravel بر تا Table \$ C C C C water-cement E OB OD ن ا ن ن gal/sk,

5.83 gal/sk for the concrete Livermore Valley for Watsonville Sanor-Cenent ratto and Wiles Valley Valley coarse crushed of the concrete containing aggregate was 5.68 gal/sk aggregates 5.83 and 5.71 gal/sk respectively. granite containing 5.65 gal/sk, and the unprocessed material. for the Livermore as compared the beneficiated rt O

n n entraining admixture concretes. LOWOL reduction of the sand content in mixes containing the airimproved workability produced by The water-cement ratios of the air-entrained concretes were by about ф О reduction in water-cement ratio gal/sk than those (Darex). the air-entrainment for the corresponding plain **E** oue out ii Or Dut also e Ino G

CT CT 00 (~) average of Compressive Strength. -- Compressive strengths On H shown in the last two columns of Table three cylinders n o (1) (1) (1) (1) condition. ţ (3) (*) ages of 7 and Data given are

Watsonville concretes of lower compressive strengths than did the Fair Oaks or concretes excess of The Livermore Valley and the Niles Valley aggregates plain concretes produced 28-day compressive だのでの 0004 accrecates. To I o somewhat lower The 28-day compressive strengths of than those of ር ርጉ ው corresponding strengths air-entrained produced nirid

Livermore those Compressive O Ph the concrete mix made with the unprocessed material Valley coarse aggregate were strengths of concrete about 10 containing the beneficiated percent higher than

Breakdown of Aggregates

mixing 60 Ö 0 <u></u> aggregates, 1-1/2 determine degradation of and namely Livermore Valley, Niles Valley, and 3 hours were made aggregates on concretes Caused containing Å. continued

0 Watsonville. ert O in. continued ŗ minutes **建加叶侧** miximo (A) peed recempered ÇT. o Cro 4-minute mixing Qg. О Н Сл condition described earlier, mixing speed , md. Ç bring the slump to 4 inches. represents Concretes subjected O Fh time ord bree the concrete was mixed mdī (18) concrete a ಗಿರ Surxim to this × E (18 (10) subjected only continued then The O-hour for continued Ç@ TOTAL

00 Hr. T O SEC t erms completion combined S C N O in adations 0 change () Hh aceraceate et O continued 0 judi, (193 (20) figure fineness modulus, aggregates .Suixim the degradation *66regate. were determined Also ب ca change m m shown in shown shown separately ۳. 5 before بسر (۵ grading t ne the M (8) Surxim degradation expressed diagrams TO K and after ă

O ITh continued mixing. O m change e De e C 0.17 Watsonville ing ing aggregate study or O fineness modulus of the sand ranged from 0.04 (Livermore 0.22 (Niles Valley) for 0 hours of continued mixing and O Ha these diagrams breakdown After aggregate changed its fineness modulus Valley) (,,) hours of continued mixing occurs to 0.50 (Fig, within Ŋ (Niles reveals the Valley) sand fraction, t bat after ር መ C D (Livermore major part sand fraction Å, (.e) hours only 0.15. O m

given change 0 have inconsistencies SCHEEN pode (wa) (wa) Ö breakdown fineness Ph O significance. would modulus observed produce three Ö in the change t ne periods coarse ***** the small Few pieces of continued mixing, aggregate in fineness was only 0.05 differences observed. 0 coarse S C C C sulubom j aggregate Ca F O Hh Cases the considered gaissing The maximum very COMPAG small.

О Рћ μ ()) (), Š diagrams Ö En studying breakdown 0 the 0.0 Tr. 0 17h degradation 2) aggregate occurred during E WILL 0 o O the observed that about combined aggregate rt De 4 4 င် minutes

0 O Hh mixine. assersate AFTER was approximately proportional The second initial large degradation, to mixing time further breakdown

Shrinkage and Crack Resistance

Livermore Valley, and 30 Crack rosistans (Livermore accrecates relative specimens \$ 12° OFMOXIMENDIATION Shrinkage jaraji jaraji humidity. moist-cured for $1/2_{5}$ Valley, investigated. 300 and 678 (10) (14) (14) (15) Wiles crack-resistance (4,) Fest csts Watsonville aggregates S B B B hours, O Ph evaluated Valley, and Watsonville) were shrinkage concretes were made ·~• Also included days Effect of prior to drying for subjected Ö tests concretes containing Fair concretes air entraiment for were made three G O continued mixing containing the at 70°F О Н on concrete the on shrinkage aggregates # | | | | | Š percent and

20g comparisons concretes Shrinkage pa H (O moist-cured for made --Shrinkage data H Figs. 7 days (1) ç for 00 (A) selected 81Ven 2000 2000 in Table 5, E († () 90 and various

asseresate containing taining aggregates mixing Sgregate 00 00 Effect Valley 6 Niles E Os Os hours). Fair Oaks aggregate was exhibited substantially lower The 420 millionths Data O Ph aggregate. even Valley or Livermore Valley et II° O type Livermore <u>></u> O Ph slightly lower days concrete Concretes 0.0 i.... i.xi of aggregate Q Fh Shrinkage ئيا Valley (0.0420 percent) On T drying containing containing for concretes aggregate on shrinkage than (Table of concrete containing Watsonville 220 millionths e E 21.7 5 and Fig. assregates. shrinkage Niles Valley material concrete for containing Oaks not ç c t e subjected to 90 (0.0220 percent) as or Watsonville than concretes 17.8G concrete ٣ よった 17) 131 141 for days Ç. somewhat the concrete o O Oaks Posts Offi containing continued COM e O

produce 0 1 X 3 3 線線 ಹಿಡ್ಡುತ್ತಿದ್ದ S C concretes should be pointed out for exceptionally low. n D Watsonville aggregate O Ph such low shrinkage e E E that the are e not many concretes shrinkages characteristics, aggregates () |* (1) observed Ö ው መ けばれ ror. considered the Fair ₩. 1-4 1-4

aggregate aggregates effect tor ng ng e T mixing 1 ()() ()() ()() somewhat Pag DB Pag Pag days shrinkase e O 1.3 1.3 1.4 for 4 Oaks SER TO THOO CT cement ି corresponding of drying Oaks e de la companya de l Data of hours). observed Livermore O H On the other enrinkase ratios characteristics reduction SEE BIRDSIDES M M M (20 (20 (Table for the concrete mix containing Ö H entrainment }---\$ 2**~**\$ 5**~**\$ air-entrained concrete mix. Valley, or Þ in shrinkage. C 17.0 characteristics are Ų, hand 020000 and Fig. 4) for air-entrained mixes 220 millionths tor. of concrete air-entrainment on shrinkage the Watsonville concretes (C) (D) For example, of the concretes. O H containing Watsonville 300 the plain concrete (A) air entrainment O Ph assresates compared had subjected to are concretes t ne litte Even primarily responsi-Livermore er O shrinkage after jui. W a greater effect containing 190 millionths E D e shown reduced continued Valley containreduced 9

LDAG concretes (T (D) concret (Watsonville glven rt O continued different en ac <u>ر</u>م Shrinkage in Table (D) (Niles Off subjected Were ct ii o Surxing assregate). periods Valley recempered J data up corresponding mixes and plotted in Fig. Ö (for aggregate), and O Ph continued mixing to 90 days continued mixing. 3/4 (T maintain 1-1/2, given are the 0 not subjected in the and 3 hours) Ç drying Ça (Livermore and retempering 4-inch slump, lower ,> () for concretes water-cement described hal f and recempering are e# O Valley continued c F Shrinkage S earlier, aggregate), Fig. 7 ratios subjected greater O Hh 70° ()8) J---4 g---4

Livermore concretes continued mixing produced Valley somewhat subjected shrinkase in shrinkage. 9 7/2 longer aggregate aceregate greater made ranged O assresate. O Ph قع) continued mixing ेक्ट्री () (न्ह hours of period (Right from 15 to Fig. (0 Ph Ph (0) (1) example, O Im ٥ 9 Ni les on shrinkage of continued mixing. continued mixing, a more severe than on concretes gs (n after 21 days of drying, 0 earlier discussed and accrecate percent for and. from then degradation of concretes 30 a D Continued mixing concretes containing 9 for 4 larger those containing percent (D) subjected the increase € (3) (3) containing shown Livermore aggregate TON () () er. Niles those increas r Or

° 0 permitted Tron of O or carly in water-cement continued ೦ ಬ justity truck mixer within 45 minutes to 0.3 gal/sk N gal/sk mixine ;----|**3** FACTOR: († 13 8 in O shrinkage and **(..**) for 3/4 hours of continued mixing retempering Bours This increase requirement observed in O Ph continued (# (*) and that no retempering be in water-cement ratio primarily garxim, concrete concretes due ω Ω, These Ö discharged and from increases results

beneficiated Although 00 52 54 relatively large containing the beneficiated Livermore Valley coarse aggregate er Er COAC Shrinkage beneficiated. 9 O Ph Lower accecate water-cement data up reduction concrete COarse € 69 50 O O Im 90 made ratio ()() ()() ()() in shrinkage must slightly aggregate days with the unprocessed O M œ O Th the concrete lower The drying was lower shrinkage (0.15)for also be due mix containing Å, rt D gal/sk), 0 about COarse concrete concrete rt Fr to the im-8 accrecate. percent EX. 3 contain che

material of minus provement in the quality 2,60 specific o m the STEVITY. coarse aggregate Ą removal

87010 (para) (No.) C concrete ll, and (effect shrinkage of shrinkage crack-resistance bars are plotted c C F Resistance, --75 00 air entrainment) (C) (C) (C) **~** 2 for concretes corresponding to observed The Tensile stresses developed in the in specimens lower halves are plotted in Fig. 4, of corresponding of Figs. 7 to 11 contain jedu Poj TO CO do 3 those haives of shown concretes restrainedin Fig. 13 10 00 8

tensile stress OMBOXING: cracking, periods of These and the shrinkage values 71 O 7 drying to crack data are summarized and shrinkage at concretes which did not crack within 90 days, formation, the tensile stress in Table 6, 90 days for the drying period are given, in which are given d T at time of to time values of O Th

They 0 20 1 S properties, and creep characteristics of the concrete mix. that evaluated, specimen influence the cracking tendency of include shrinkage characteristics, tensile strength, elastic several In evaluating these crack-resistance data it should comparisons should be made on a However , e n c jul. (f) factors degree of far. the cracking more influence the tendency significant than restraint tendency of a (size of restraining the drying shrinkage alone, relative rather a concrete mix concrete mix, cowards CTACK steel bar) will than an absolute (A) 9 OD. formation. Size of realized this herein

Watsonville aggregata: concretes. Valley longer cracking was Q H the elapsed shown Niles Valley obtained within 90 days on bars pol. 00 120 period 9 and Table 6, concretes containing Livermore aggregates of drying without cracked after It might be pointed out that the formation containing 13 days o H O Hh 다 (*) 90 drying. crack, Oaks

Creep COLUMN TOWN treasth increases inde Wi O O requires possibility with time: T P4 (7) (0) that O m tensile a crack Will stress development; form. This рт. (О 8180 drie drie tensile

rensile mixing and concretes نسو الدرة 10 14 concretes cays,) () (4 Concretes 0 (Table STYCSSOS those e mine con containing subjected TO DEST on. containing containing O M 0.6 In. In. Ö continued these concretes to continued mixing Watsonville 7) cracked Niles Valley aggregates in Fig. 11. Livermore Valley aggregates Surguer mixing within the 90-day granite and subjected to at 90 days were about and retempering from 190 (Table 6) to 265 psi. cracked drying S is shown in Fig. cracking continued within 8 300 psi. period. None All of these O H rendency O 5

() () () The corresponding 92∰ 140 600 6 entrainment containing development 0 have effect tensile because of drying, accinecate بر ال containing their improved 30 ertect о Н Livermore did not O Ph SEPTIS of the lower cracking non-air-entrained air entrainment E De On T O (**)**# (77) O Hh the cracking characteristics the Watsonville aggregate. Ŝ, 270 of the compared concretes. €til June June reduce Valley tendency would be improved in comparison to TSD In some entraimment Water air-entrained the 90-day tensile stress developed in conand that o O aggregate did not OB HS (T) 0 **3** 0 0 0 0 0 13 days for the corresponding For example, the air-entrained mixes contents E O on crack resistance is 9 Ö H conclusive the concrete S O H, these plain mix 0 Hn Although the results of のようのな and the **3** ۲. ۲۲ mix containing air-entrained conentrainment would be until 300 rensile , S after shown plain mix. expected concrete 5000000 appears 200 porte Las

Enl's Beneficiation of 0 reduced the cracking tendency of the gandi, Garge comparison with t D e Livermore Valley et Die Ct О М ## ## ## COarse m X containing the unprose concrete aggregate containing (E.T.8)

containing ののはのない。 96 (a) 作为(a) (a) 137 157 mererial () () () O Ph O Ph Thorone and a 220 pst. Concrete **9** containing SOUND OF CHARLE Ç10 TO THE SECOND in the second Designation Later () Ph ~ ~ 0 CO FAC 'S' is days 別語に会どしまし Q Ph STATE OF THE SAME Cracked

DISCUSSION

Results of this investigation indicate that:

- O Matsonville LYGINGTO percentage indiacacine the entire and orecaine containing Fair Oaks Or owner exceptionally low, Shrinkshe STITLINGSO 學學工具學學 O Ph crushed granite. sandatone and araywacker の記録が異のでの下があればいいの and Wiles () () () O Fn and Watsonville aggregates as very few aggragates would produce OF BOX 130 D SORTERSTO LO Valley However OTHER MOTOR TANGE WELL OF THE TOTAL STATE aggregates, which contain a the shrinkage of concretes THE RESERVE CHANGE TO CHANGE OF CONTRACTOR 0110 O M M M M M M M should 神神 Toler Oaks gravel D D considered comparable O Ng
- 001,4 exhibited continued Sm211 Concretes subjected to continued mixing Çω recompering, the greater was larger shrinkage than did corresponding control mixes MINIMA FOR increase in shrinkage 3/4 hours 3-13 100 100 was observed for concretes subjected longer the period 竹門市 一番の下の最後の 200 jude Si retempering etrinkage O M CORTINGE
- 数の部件の影響が示 **新花河中山田田田山** addictonal obtained TI KOOK COOK within the initial mixing period, Continued mixing **E** breakdown occurred within destadation MI TO CENT 1 Motes and toe major in continued mixing C C 80 accrecate. סטרוייסט סא resulted }*** (**} (**) in significant aggregate accreases CONTINUO Property of the second MY WORK ON O Gentragation of The major THE CANADAM mixing produced assresate

- ment O ith ሮት መ E 90 (0) concretes. primarily entrainment reduced responsible for the Reduction in water-cement ratio by use of air entrainsomewhat reduction in shrinkage the shrinkage characteristics
- concrete. 0 i gui a specific (O) separation improved the quality of 00000 Beneficiation of Livermore Valley coarse This beneficiation was accomplished by gravity od the less than 2.60 shrinkage and cracking characteristics e e assresate with respect removal acerecate of material Ą 0 Hh heavy-

0 certain limits otructure: specimens analyzed Results cannot 9 for various concrete **3**# duplicate Q Hb laboratory comparative basis. laboratory the properties of concretes (0 kg %) (1000 (1000 (1000) (1000) however, properties. H (D (A) (A) relatively small herein 00 14 00 essential reported, *** *** Ç Laboratory should Tull-scale Cotadian only

ACKNOWLEDGMENTS

Granite Rock obtained Oakland, arranging California The l Wj Trong investigation herein reported was sponsored by the Pacific 0 Meehan of the Division of Architecture Department Company of Watsonville: three et E E Cement and Aggregates (T) (D) (T) aggregate producers: of Public Works, Division program. Additional financial support was Company of Henry J. Kaiser was instrumental of Architecture, SAN Francisco, Company (A)) (1) C th

Ω¢ Ω, graduate C F various phases ŗ, crack-resistance studies (D) Ö casting of specimens and the student Chang g El-Erian; graduate in Civil of this 嫌 visiting Engineering, students project. acholar in Civil Engineering, Mr. Yuzo Akatsuka, collection E C C from responsible Egypt. () **h Messro. () () () () S S (A) (A) (A) carried WOY O Ct CT (D) supervised Ç shrinkase <u>ر</u> د

Kaculty Kaculty investigators were Professors David 100 PM MILO: Polivka:

TABLE 1 -- CHEMICAL ANALYSIS OF SANTA CRUE TYPE II CEMENT

C ₄ AF	CA	°28	GS	Compound Composition	Ignition loss	\$0 	Alkalies as Na20	MgO	CaO	Fe203	A1203	S10 ₂	Oxide Composition
gd gd	4	نين نيا	46		လ ဝ	2.0	0.5	1 ,	64.2	·**	ري پ	25.4	Percent

在自然公共的政治 manifestation of model for first height the					Wines-issuppines networkelink Chief	Cu	mulativ	e Percent	Passir	 1g		BITTE OF BUILDING BOOK OF THE PARTY OF THE P		The state of the s	ing and the second
Sieve	F	air Oak	3		Live	rmore Va	lley	Benefici Livermo	ated ore	N	iles Vall	ey'	We	tsonvil	
Size	Sand	No: 4 to 3/4 in	3/4 to 1 1/2 in.	Blend Send♥	Sand	No. 4 to 3/4 in	3/4 to 1 1/2 in.	No. 4 to 3/4 in	3/4 to 1 1/2 in.	Sand	No. 4 to 3/4 in	3/4 to 1 1/2 in.	Sand	No. 4 to 3/4 in	3/4 to 1 1/2 in.
$1 \frac{1}{2} in$	E281703-	424 (224)	93			*photox	9 5	Yard toon	97		eter cod	98	der Vije Beschingen beleichen der zeit	ener stad	100
1	e= unic	100	27	™	.cs e=	100	3 6	100	41	grad Est.	100	52.	wane	100	56
3/4		99	. 9		⇔ 	96	4.	93	9	يسوع	95	3	<i>⊏न पनि</i>	99	5
1/2	professi.	64	3	F equal	tus (22)s	69	0	44	0	poplets.	59	J.	***	77	2.
3/ 8	1.5 ma	41	1	= -	ent ente	30	rmigine.	17	>cohrēd.#∳-	100	21	. 0	100	40	0
No. 4	100	2	0	100	100	٥	2000 Paral	0	45/mm/ 2/2/20	96	1	size+	95	4.	edge takiji-
8	96	. 0	1771 GSN	99	85	\$60 CC.	ipaquan	ginte gants	Asot idus	77	0	with city	76	0	em rico.
16	63	time de la constante	100 BH	98	56	F	1340-1223	w464	رسيو مده	57	meli, ext/r	score carbit	67	enot extra-	Man's meta
30	33	न्थन् प्रज्ञे	ACHUS ABBANA	93	32	emety scool	44 EM			37	place ment	70 na 42 ná	45	ence-crash	States Editors
50	19	sid esta	738-Apri	33	14	New pile	7,100° Janua	one proteinty	म्बन जोर	17	soner aven.	took sign	20	Annu piter	met sex
100	4	چيوزيي		. 7	5	1239-1712	ens ethi	ango kent		5	******	क्षम् एवम	4	ಎಷ್ ಬರ್ಗಿ	9709°-022m
Fineness Modulus	2,85	6.58	7.9 7	1,72	3,08	6.74	8,01	6.90	7.94	3.11	6.83	7.99	2.93	6.57	7 ₀ 95
Specific Gravity	2 2 64	2,79	2,79	2,60	2.64	2.68	2.71	2.70	2.72	2.61	2,67	2,66	2.60	2,89	2.92
Absorption Capacity,%	0,8	0.9	0,8	0.9	1.9	1.3	12	lel	1,,0	1.0	1.7	1.5	0.9	1,0	0.8
Sand Equivalent	92	AND	COME STATE	69	74	месуломна остумент насельности регоди	ANIE PERSON	x-3854	178 A15h	63	enign zour	37 45-3-	89		ortespelljanske omenske
Cleanness Value	est out	97	97	ALK THE	AMES STORY	86	84	e Cambrio - mode de destruito de la Signy Cabrio espera Arquin proc Casar-pendr	acid 2005	son ilda	86	71	See Andr	94	90

a--Prattco sand b--Felton sand

c--Beneficiated by heavy-media separation to remove material of specific gravity lower than 2.60. d--Olympia sand,

TABLE 3 -- CONCRETE MIX PROPORTIONS

ly-in. maximum size aggregate
Shiring Type II cement
Nomisal slump 4 inches

NEW TOWNSHIP OF THE PROPERTY O	01.2.15	ities of Mat	Quantities of Materials, ib per cu. yd.	CIL. YO.
ų	Fair Oaks	Livermore Valley	Niles Valley	Watsonville
Can all t	Le Lor Jour	J	50 44 pm	US A
超级 行命件	265	% 0	280	270
S de Fa	5 20	jamil Special Special Special	bud NO Vd Just	244
Blend Sand	G D	5000	ñ B	9
No. 4 to 3/4-in.	1030	t. 60	4. 00	827
3/4 to 1 1/2-in.	1040	joné Pos South	اسر اند اند اند	1264
Characteristics of annual process to the control of	CTHAN THE CHARLES OF THE CHARLES WITH TH	- The second sec		

TABLE 4-- PROPERTIES OF CONCRETES

1½-in. maximum size aggregate
Cement content 5 3/4 scy: Santa Cruz Type II cement
Slump 4 inches

and reorganization of the contract of the cont		SAN THE SECOND CONTRACTOR OF THE PERSONS ASSESSED.	*			
Concrete	Aggregate	S	A C	P	Compressive Strength, psi	th,
	menter de la companya	Ratio, by weight	gal/sk	Content, percent	7 de	28 da
	Fair Oaks	0, 39	. S	pend tr pend	3090	4690
	Livermore	0, 39	От 800 Lu		2260	4070
in to to	Benefic ciated Livermore	0,38	Ф.		25540	4450
	Niles	0,39	5 ,1	Ö	21 50	4110
	Watsonville	0.37	Š		2740	4630
	Fair Oaks	O 36	4,92	<i>\$</i> .7	2660	4290
Air- Entrained b	Livermore	9	Š.	\$	2250	3780
	Watsonville	0 34 4	5.06	4.2	2550	4140

Average of three 6 by 12-in. cylinders; standard curing

b - Air-entraining admixture Darex

12-in. maximum size aggregate Cement content 5-3/4 scy; SantaCruz Type Slump 4 inches II cement

eterichent Chiese stern Control mittel seine Consequentie	And Cores, practice of the state of the stat		ļ-				And of the latest of the lates	and the second district of the second		older of the second
		Contin-			Sh	Shrinkage,	į	millionths	nths	
Concrete	Accepted at the	Mixing and Retem- pering,	W/C, gal/sk	Moj	Moist-curing drying at 50°	2.2	for 7	days	then 70°F,	
		hours		post.	w	7	21	42	60	90
	Fair Oaks	0	5 5 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	75	120	,, 55	220	290	325	385
	The second secon	0	5 °83	110	170	240	6	590	710	820
	will do	3/4	6.1 2	90	150	240	410	595	건 (5	825
	Fivermore	112	6,34	95	150	260	460	675	790	895
		· W	7 , 05	120	220	290	515	740	860	955
TO CO CO CO CO CO CO CO CO CO CO CO CO CO	Beneficiated Livermore	0	5 68	85	120	175	325	490	575	665
		0	5,7	95	150	250	420	640	760	890
	r o o	3/4	5,90	드	165	255	470	069	805	9 25 5
		1 1/2	6.17	110	5 95	275	490	205	835	960
		w	6°62	140	220	۵ 25	580	820	950	1090
		· 0	5,65	45	60	တ္	50	240	290	360
	Watsonville	1 1/2	∞ α ω ν	4 6	8 S	108	195 200	200 200 200 200 200 200 200 200 200 200	3 C C C	8 0 0 0
		(w	6,44	65	85	120	220	310	370	425
	Fair Oaks		4,92	Ĉ	90	120	190	265	310	350
Air- Entrained	Livermore	0	5.22	100	150	0.6	360	Ui Ui	0 0 0	000
	Watsonville		5,06	35	50	80	160	240	285	340
a - Average	of two 4	7/8-in by	6 by 16-	16-in, concrete	crete	o ars				

O, 00

Average of two 4.7/8-in by 6 by 16-in. concrete bars After initial mixing for 4 minutes at normal speed (17 rpm), mixing continued at slow speed (5rpm) for period indicated.

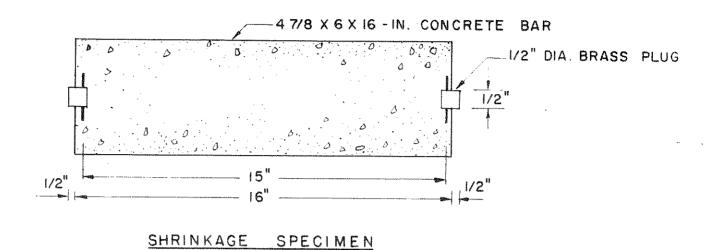
15-in. maximum : Cement content : Slump 4 inches size aggregate
5 3/4 scy; Sauta Was Type II cement

Control of the Contro	and the state of t		over an expensive different contraction of the cont	POTENTIAL PROPERTY OF THE PROP	pro-transferration of the forest contraction	istolik ilika (j. 1882) se
		E Contin-		Crack Formation	ii o	Shrinkage,
	0 0 0 0 0 0 0	and Retem- pering, hours	80 a c c c c c c c c c c c c c c c c c c	Days at 50% R.H.	Tensile stress, psi	(at time of crack formation, or at 90 da)
фаван наранного установан Сунтеван город	Fair Oaks	•	ري ابن دي	(90) [©]	(300) ^c	(385)°
		0	Ö Ö	ئىن زىئ	220	305
	Q	3/4	భ గ	N	240	305
	E TIVE		7.02	5 W	265 240	200 s
	Benefi-	der med semi – Combinder of Armados sistematiskense.			And the second s	emplend terent judoj eta esta esta desenda de mandere esta esta esta esta esta esta esta est
ro a I	Livermore	C	0000	6	710	3/0
		0	S S	w	230	320
	**************************************	3/4	2,90	ford Janua	225	310
	Z F G U	;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;	6.17	Ö	267	W W
		ثم	6.62	က	190	345
		0 0	5,65	(90) [©]	(265) ^C	(360)°
		3/4	5.83	(90)°	(295) ^c	(390)°
	SOLSONVILLE	£ 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	5.87	(90)°	(285)°	(390)°
THE COMPANY OF THE PROPERTY OF	TO AN OTHER PROPERTY AND AND AN OTHER PROPERTY AND	ယ	9°44	(90) ^c	(290) ^C	(425) ^c
	Fair Oaks	Ne-Enthrühenüben überühlüben Annuaren Distati	4.92	(90)°	(270)°	(350)°
	Livermore	0	5.22	28	u Us	
Entrained	Watsonville	Transform Committee Commit	5.08	(90)°	(300)°	(340) ^c
·) `	•		4	3

Ça

Average of two 4 7/8 by 6 by 40-in. restrained concrete bars, moist cured for 7 days
After initial mixing for 4 minutes at normal speed (17 rpm), mixing continued at slow speed (5 rpm) for period indicated.

⁰ No crack within 90 days of drying; values of tensile stress and shrinkage are for 90 days of drying.



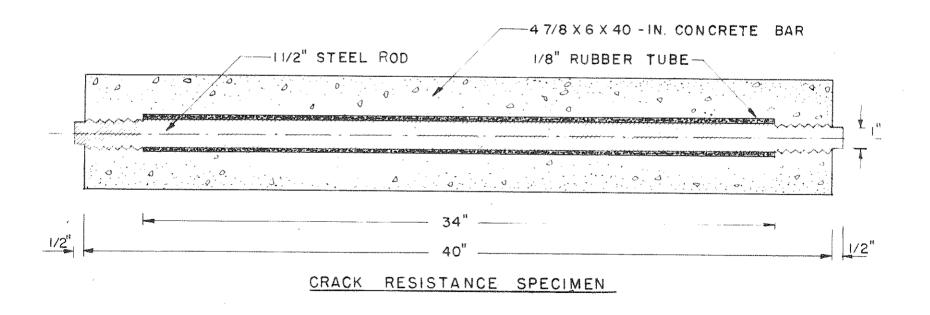


FIG. 1 - SHRINKAGE AND CRACK RESISTANCE SPECIMENS

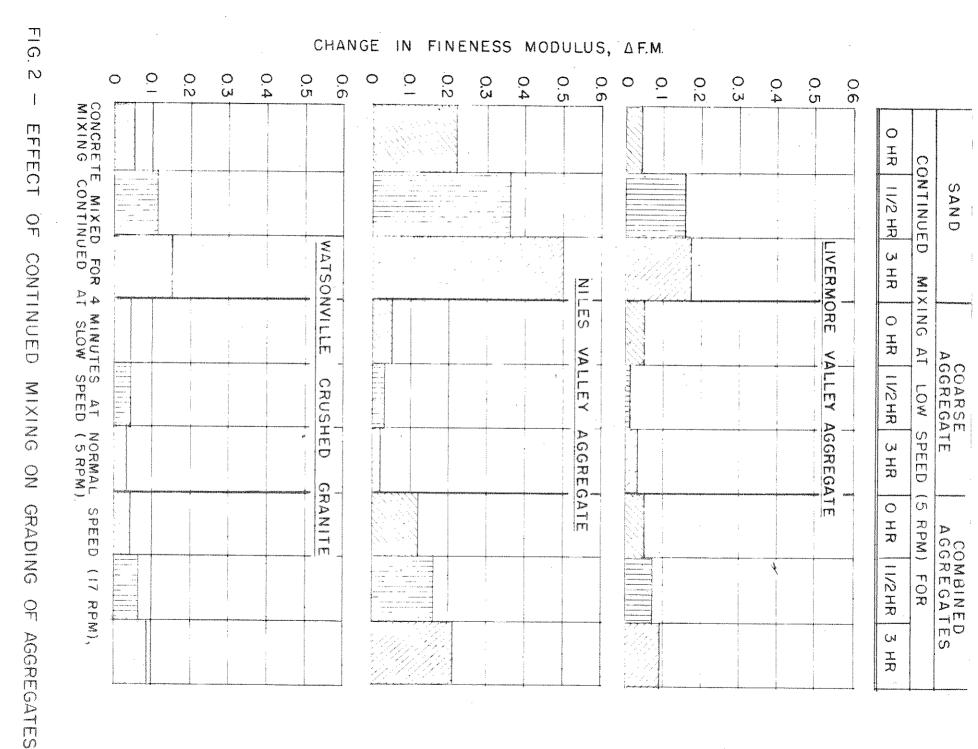


Fig. 2

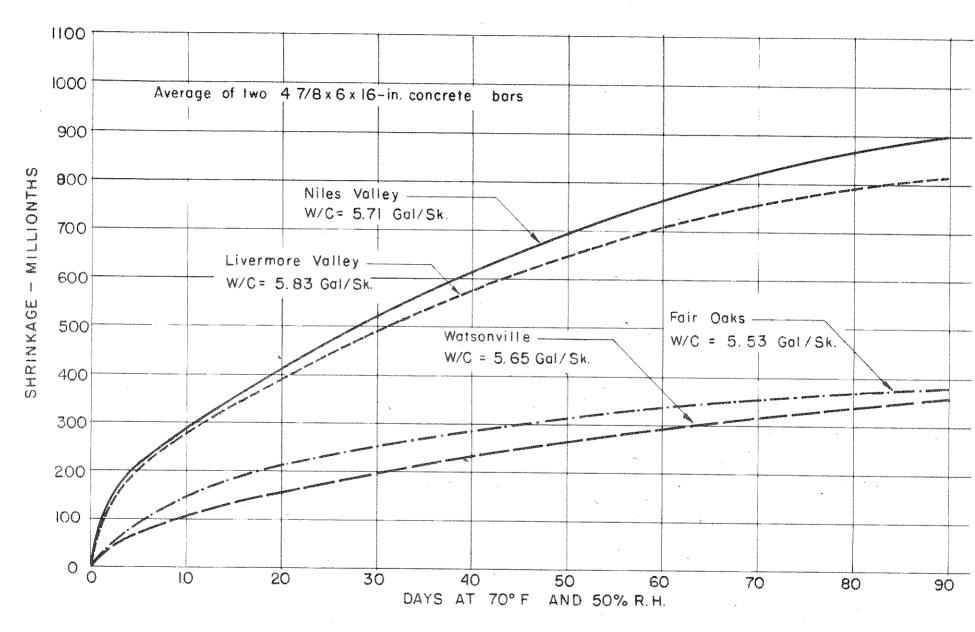


FIG. 3 — EFFECT OF TYPE OF AGGREGATE ON SHRINKAGE OF CONCRETE 53/4 Scy., Santa Cruz Type II Cement, 11/2-in. Maximum Size Aggregate, 4-in. Slump, Moist Cured for 7 Days

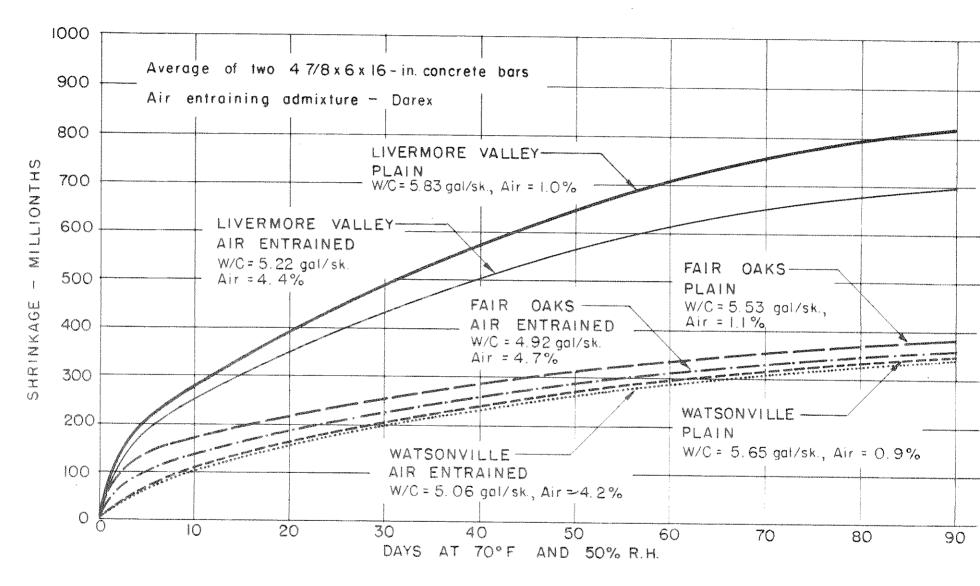
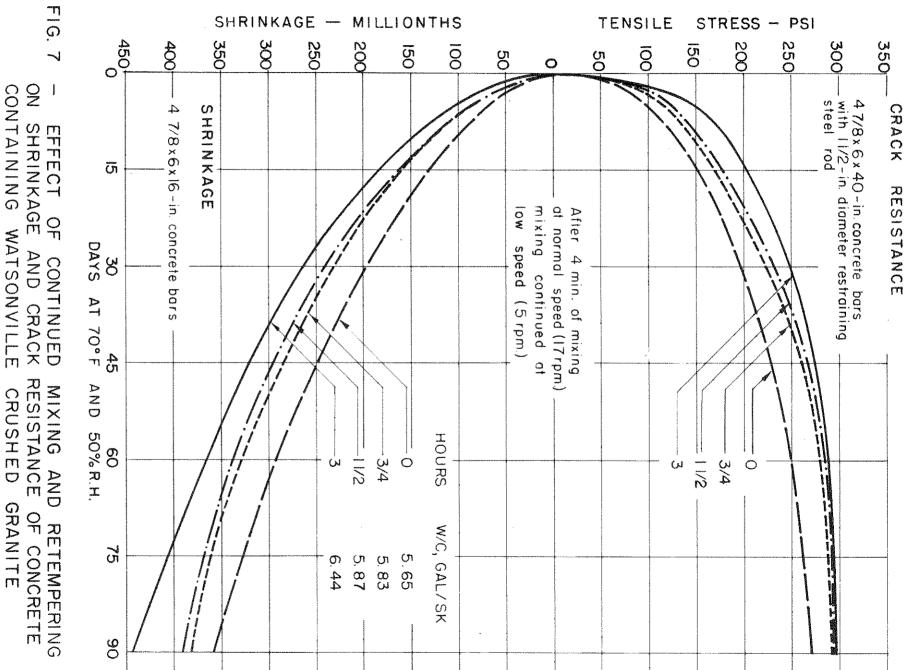


FIG. 4 - EFFECT OF AIR ENTRAINMENT ON SHRINKAGE OF CONCRETE
5 3/4 Scy., Santa Cruz Type II Cement, 11/2-in.Max.Size Aggregate,
4-in. Slump, Moist Cured for 7 Days

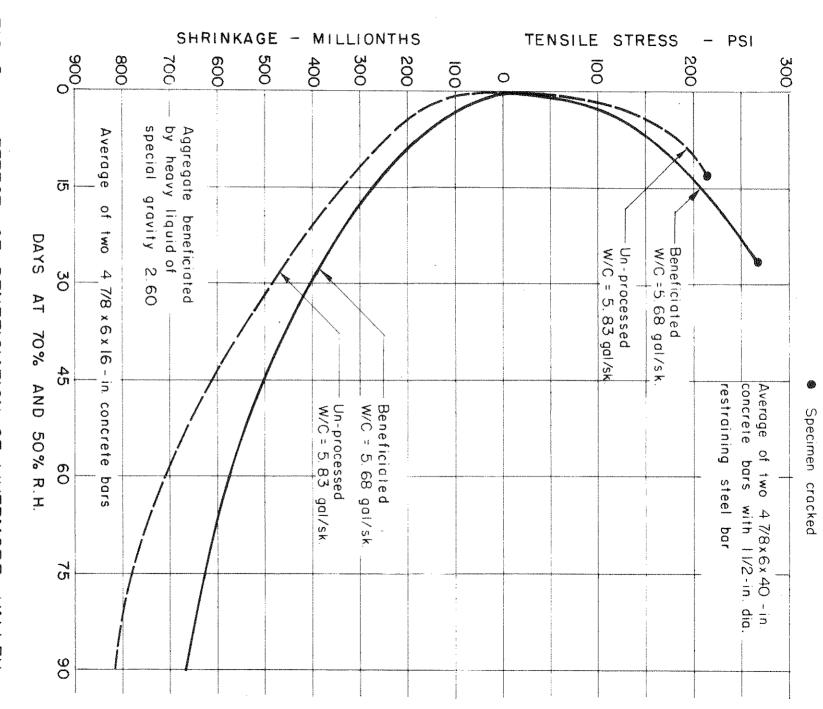
FIG. 5 — EFFECT OF CONTINUED MIXING AND RETEMPERING ON SHRINKAGE OF CONCRETE CONTAINING LIVERMORE VALLEY AGGREGATES 5 3/4 Scy., Santa Cruz Type II Cement, 11/2-in. Maximum Size Aggregate, 4-in. Stump, Moist Cured for 7 Days

FIG. 6 — EFFECT OF CONTINUED MIXING AND RETEMPERING ON SHRINKAGE OF CONCRETE CONTAINING NILES VALLEY AGGREGATES

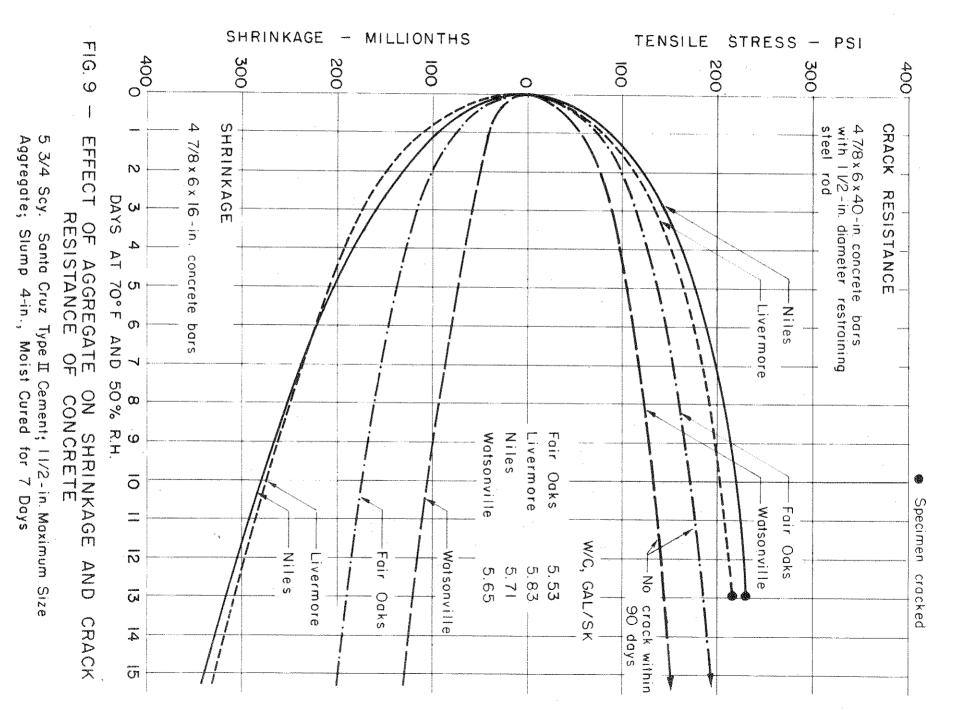
5 3/4 Scy., Santa Cruz Type II Cement, 11/2-in. Maximum Size Aggregate,

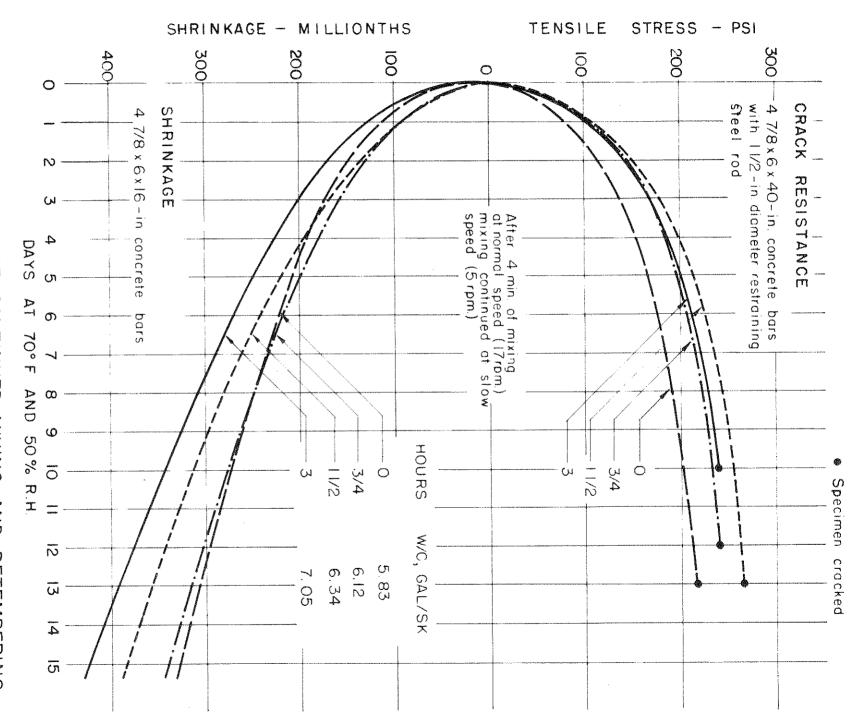


5 3/4 Scy., Santa Cruz Type II Cement, 1 1/2-in. Maximum Aggregate, 4-in. Slump, Moist Cured for 7 Days Size



<u>F</u>|6 ∞ 5 3/4 Scy., Aggregate, - EFFECT AGGREGATE Santa Cruz Type II Cement, 11/2-in. Maximum 4-in. Slump, Moist Cured for 7 Days BENEFICIATION OF LIVERMORE SHRINKAGE AND CRACK RESIST CONCRETE CRACK RESISTANCE VALLEY Size 9





 $\frac{1}{C}$ ō 9 5 3/4 Scy., Santa Cruz Type II Aggregate, 4-in Slump, Moist CONTAINING EFFECT OF SHRINKAGE LIVERMORE CONTINUED AND CRACK Cement, 11/2-in Maximum Cured for 7 Days VALLEY MIXING AND RESISTANCE AGGREGATE OF CONCRETE Size

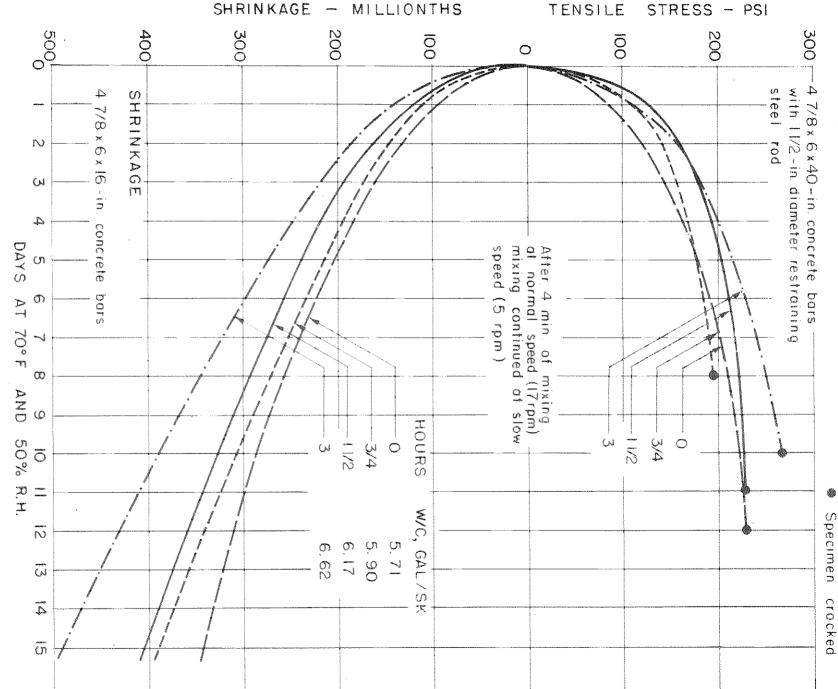


FIG. II O Scy, J.
-in. Slump, ON SHRINKAGE CONTAINING Santa Cruz Type II Cement, Slump, Moist Cured for 7 CONTINUED MIXING NILES AND CRACK VALLEY Days 11/2 - in. Max. Size RESISTANCE AGGREGATE PZO 20 M TEMPERING OF CONCRETE Aggregate,

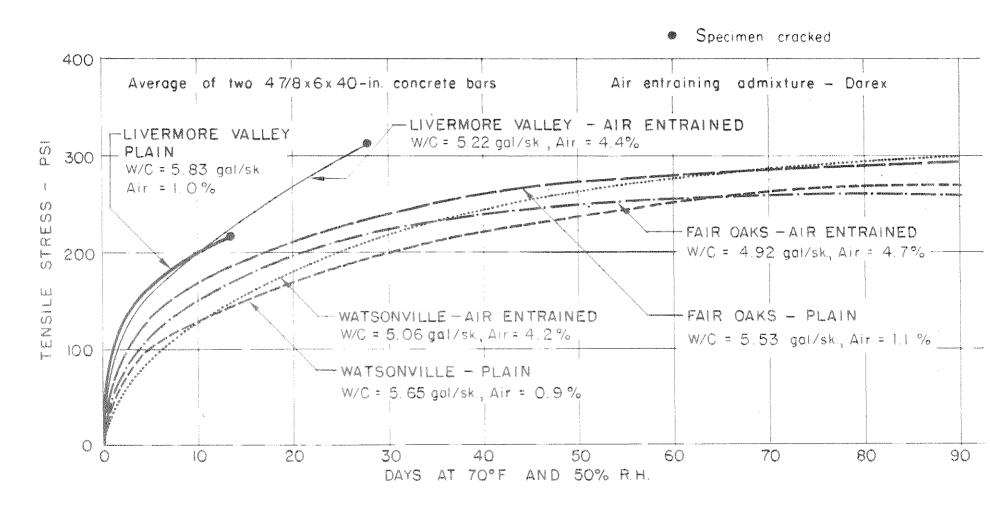


FIG. 12 — EFFECT OF AIR ENTRAINMENT ON CRACK RESISTANCE OF CONCRETE 53/4 Scy., Santa Cruz Type II Cement, 11/2 -in. Maximum Size Aggregate, 4-in. Slump, Moist Cured for 7 Days