Factors Affecting the Durability of Concrete Bridge Decks

Phase I: Construction Practices

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Construction history was recorded on 28 concrete bridge deck placements incorporating planned variations in concrete slump, strike-off machine, finishing, texturing and curing.

The effect of these variations on deck durability is evaluated by comparing recorded construction data with cracking, surface defects, and abrasion and skid-resistance properties of the finished deck. A deck cracking index, a key factor in the evaluation, has been developed.

Comparison of initial and pre-traffic crack surveys show concrete age to have a significant effect on cracking. Also, the pre-traffic cracking pattern is significantly unlike that found on similar structures after normal traffic usage. Hence, conclusions on the study's objectives are deferred pending a post-traffic survey.

Normal construction problems hampered control of variations and data collection. These problems will probably reduce the study's overall effectiveness.

•THE effect of construction practices on concrete deck durability is the objective of a study on 7 grade separations, constructed by Peter Kiewit Company, on I-210 near Los Angeles. These structures were selected for the construction practices phase of an extensive study of deck durability due to the close proximity of the batching plant and the fact that each deck pour would be approximately the same size and shape. This would provide an opportunity to virtually eliminate the effects of common variables such as mixing time, aggregates, structure configuration, and duration of placement.

Figure 1. Typical structure.

Each structure is a single-span concrete box girder supported on abutment walls of 4-deg maximum skew. Thus, negative moment and skew variables are not present. Most significant, however, is that the absence of approach fills kept vehicular traffic off the decks for a considerable time after they were constructed,

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MACHINES

a. Bidwell (control)
b. Borges
c. Trueline
d. Clarey
e. Clarey overworked

FINISHING

a. Float once, approximately 45 min after strike-off, with a wooden 16-ft longitudinal plow handle float (control)
b. Float once as early as possible with wooden float
c. Float once as late as possible with wooden float
d. Float twice—early and late
e. Float once at standard time with two 6-in. diameter aluminum pipes placed parallel at 1-ft centers.

TEXTURING

a. Stiff bristle broom (control)
b. Burlap drag
c. Wooden finishing float

CURING

a. Fog as needed during finishing followed with wet rugs when set (control)
b. Delayed placement of wet rugs
c. Monomolecular evaporation retarder placed during strike-off and finishing operations followed with wet rugs when set
d. Membrane curing compound placed after texturing followed with wet rugs the next day.

SLUMP

a. 4-in. (control)
b. 2½-in.
c. 6-in.
d. pozzolith 8

Figure 2. Planned placement variables.

thus affording an excellent opportunity to separate shrinkage and traffic influence on deck cracking.

The structures vary in length from 60 to 91 ft (Fig. 1) and in width from 146 to 170 ft. The excessive width necessitated each deck being placed in 4 separate units. This resulted in 28 placements available for study.

VARIABLES

Seven of the placements, one on each structure, were selected as controls to which the others could be compared. Variations were made in one or more of the construction techniques in the remaining 21 placements. These included concrete slump, type of strike-off machine, type and application timing of finishing floats, method of texturing, and method and time of applying the cure. The control and variable techniques are shown in Figure 2.

A 4-in. slump was the control with 2½ and 6-in. slumps as variables. (California currently equates 1 in. of Kelly ball penetration to 2 in. of slump, but plans to change over to penetration limits in the near future.)

The Bidwell strike-off machine (Fig. 3) was adopted as a control machine. Others included: Trueline (Fig. 4), Borges (Fig. 5), and Clarey (Fig. 6).

The control finishing float was a wooden 16-ft longitudinal plow handle float (Fig. 7) applied approximately 45 min behind the strike-off machine. Variables included one floating as close behind the strike-off machine as possible, one floating as late as the workability of the concrete would permit, and a combination of both an early and late floating, all with the wooden float; floating at the standard time with two 6-in. diameter, 10-ft long aluminum pipes in tandem (Fig. 8); and floating at the standard time with a single 4-in. diameter 10-ft long aluminum pipe equipped with a handle for full floating control (Fig. 9). All floating was transversely applied.

The standard texturing was achieved with a stiff bristle broom (Fig. 10). The texturing variables were burlap drag (Fig. 11) and natural texturing by the longitudinal wooden float (Fig. 12). All texturing was transversely applied.

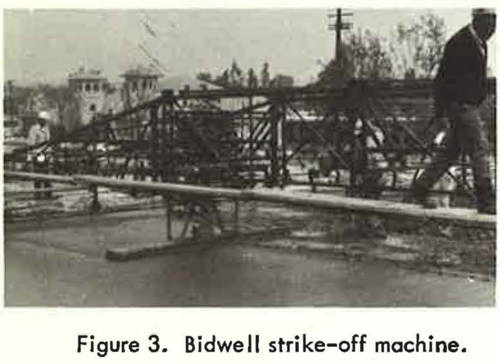


Figure 3. Bidwell strike-off machine.

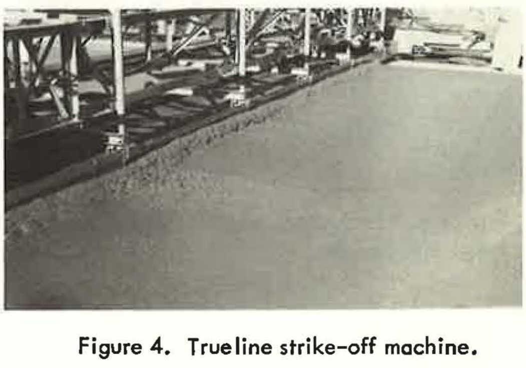


Figure 4. Trueline strike-off machine.

Figure 5. Borges strike-off machine.

Figure 6. Clarey strike-off machine.

Figure 7. Sixteen-foot longitudinal plow handle float.

Figure 8. Aluminum pipes (6-in. diameter, 10 ft long) float in tandem.

Figure 9. Aluminum float (4-in. diameter, 10 ft long) with handle.

Figure 10. Surface texturing with stiff bristle broom.

Figure 11. Surface texturing with burlap drag.

Figure 12. Natural texturing by longitudinal wooden float.

Figure 13. Placing rugs for a wet rug cure.

Figure 14. Applying liquid membrane-type curing compound.

The standard 7-day cure was provided by wet rugs (Fig. 13) with variations of delayed cures and liquid membrane-type curing compounds (Fig. 14). The membrane cures were supplemented with the wet rugs the day after the cure began. A monomolecular film evaporation retarder was used on 4 placements before the standard cure.

DATA COLLECTION

Previous experience has shown that normal construction records do not contain enough detail to correlate final results with placement conditions. The records reflect average construction conditions, whereas the final results are most often affected by conditions which vary from the average. To furnish a more complete picture of placement conditions, an unprecedented quantity of data were collected during these placements.

During each placement, a minimum of 7 men were engaged in either collecting data or assisting in maintaining construction control. Two men at the batch plant checked the batch proportions, obtained cement and aggregate samples, and recorded the quantity of water added to the mix from cleaning operations. One man at the job site controlled the water added to produce the desired slump, recorded slump (Fig. 15) and concrete temperature measurements, made unit weight tests (Fig. 16), and fabricated test specimens (Fig. 17). Two men conducted normal inspection duties, coordinated control of operational timing variables, and placed grid reference points in the finished concrete (Fig. 18).

A majority of the construction data was collected by a 2-man observation team. A typical packet used by this team to record events during each placement is included as an Appendix. The collected data include:

1. Condition of forms, support and tying of reinforcing steel, and depth of cover over the steel.

2. The in-place location of each batch of concrete (Fig. 19).

3. A time history on each batch of concrete: total batch time, and the time when each batch was placed in the deck, vibrated, struck-off, finished, textured, and cured; also, the number of passes made by the strike-off machine and finish float was recorded.

4. Irregularities, such as over or under vibration, excessive bleed water areas (Fig. 20), premature drying areas, and areas where excessive walking in the fresh concrete occurred (Fig. 21).

5. Weather history of temperature, humidity, wind direction and velocity, and rate of evaporation (Fig. 22).

Figure 15. Measuring concrete slump with a Kelly ball.

Figure 16. Making unit weight test.

Figure 17. Fabricating concrete cylinder test samples.

Figure 18. Placing grid reference points.

Figure 19. Recording concrete placement.

Figure 20. Excessive bleed water.

Figure 21. Excessive walking in the fresh concrete.

Figure 22. Recording climatological data.

6. Concrete temperature at various time intervals after placement.

Time placement plots of each operation furnished a visible history of the respective placement (Fig. 23).

To reference events during construction with final results, the decks were laid out in a grid pattern at 10-ft intervals along girder lines. For easy reference, most data were recorded on duplicate grid sheets (Appendix).

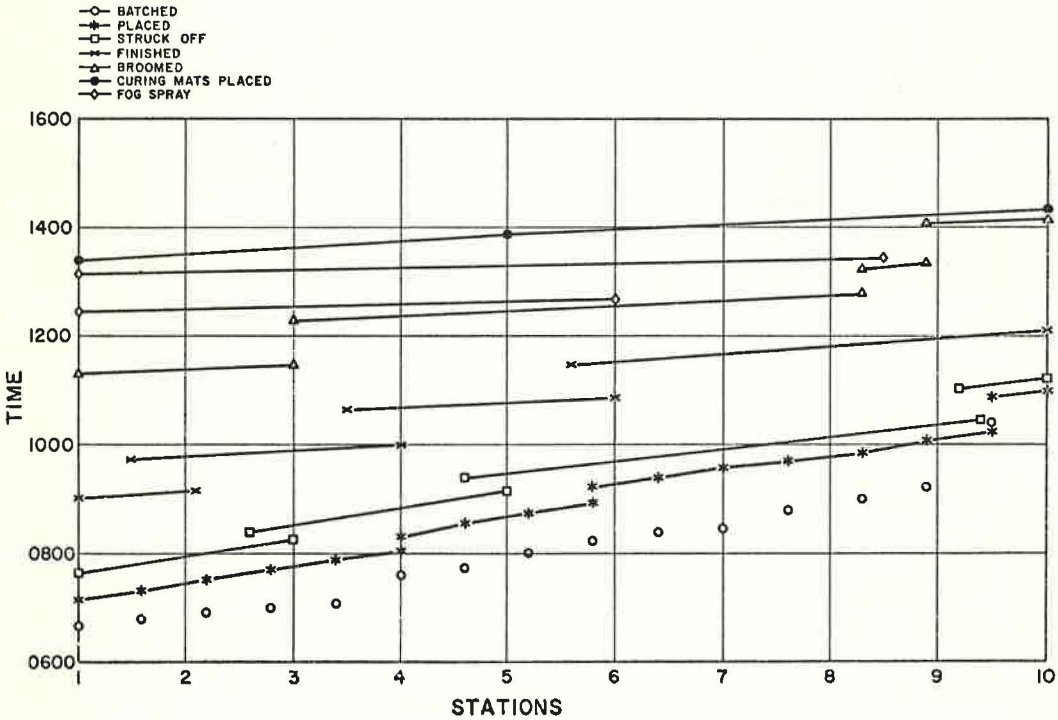


Figure 23. Time placement plots; time study, observation No. 4.

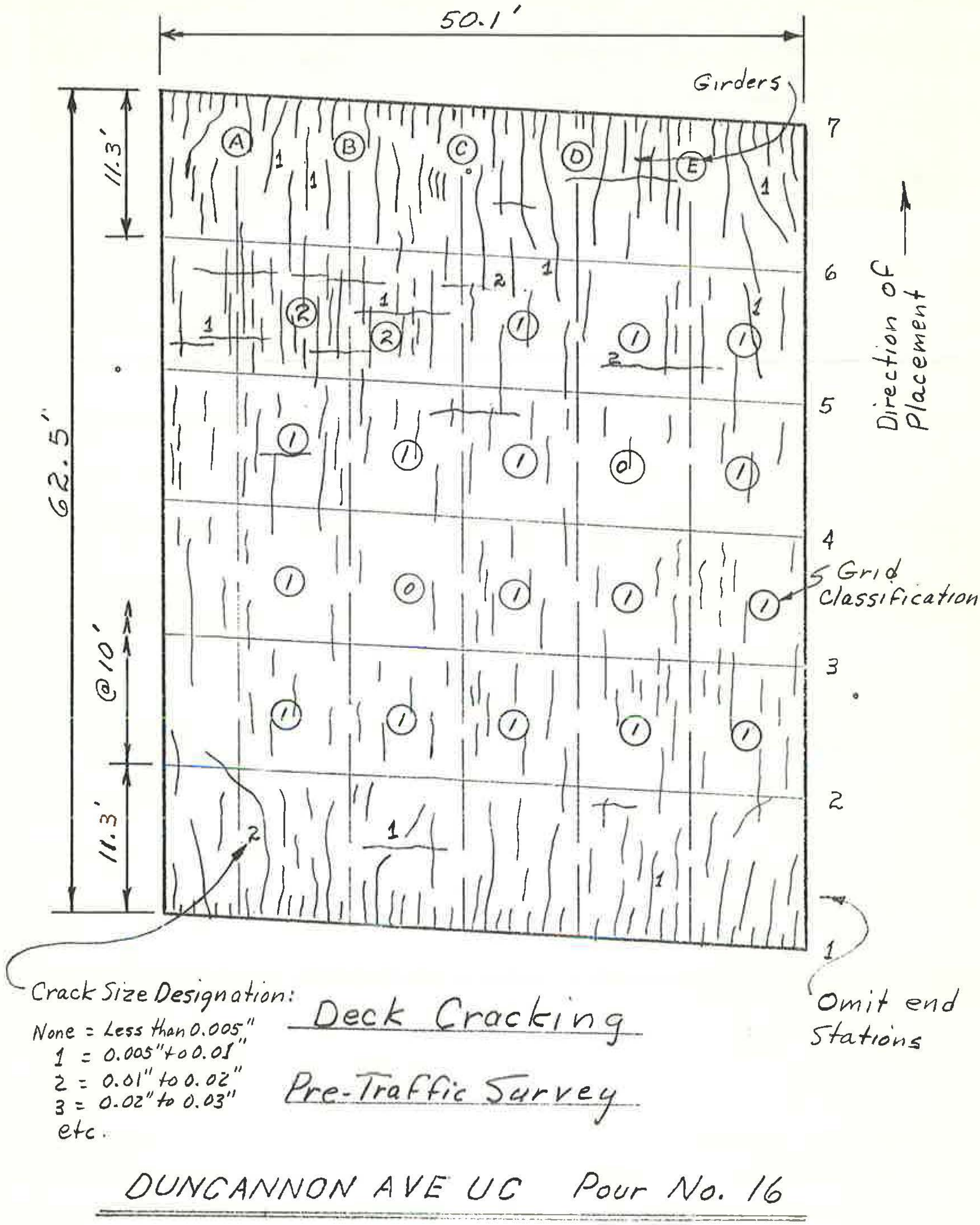


Figure 24. Crack severity rating.

Observation No. 16

Crack Width 0.005 In. or Less

Classification	No. of Grids Appearing	Classification Times Number of Grids
0	2	0
1	16	16
2	2	4
		Sum 20

$$\frac{\text{Sum}}{\text{Total grids}} = \frac{20}{20} = 1.0$$

Crack Width Greater Than 0.005 In. but Less Than 0.02 In.

$$\frac{\text{Sum}}{\text{Total grids}} = \frac{4}{20} = 0.2$$

Crack Width 0.02 In. or Greater

$$\frac{\text{Sum (1.5)}}{\text{Total grids}} = \frac{2(1.5)}{20} = 0.2$$

CRACK SEVERITY RATING: 1.4

Figure 25. Deck crack severity rating.

EVALUATION

The variables in this study are to be evaluated by comparing the collected construction data with properties of the finished deck. These properties will include cracking and other defects, and abrasion and skid resistance.

A number of cores will be taken both before and after traffic is allowed on the decks. Of primary interest are those taken through the same cracked areas at different times. These cores will be examined visually and microscopically in the anticipation that some measure of progression can be determined of both the macrocracks and the microcracks. In addition, some cores will be tested for abrasion resistance to see if any correlation can be found between this property and deck durability.

The most practical way to compare the influence of controlled study variables on deck durability appears to be in reducing the various durability parameters (cracking, abrasion resistance, etc.) into a single quantitative value. Before the single value can be obtained, however, each of the parameters must be evaluated quantitatively. Developing a system whereby this can be done is one objective of the study. So far, all efforts in this direction have been concentrated on a deck-cracking rating system, and one has been developed which appears to be a useful tool in comparing overall cracking severity in concrete decks.

CRACK RATING

Rating the crack severity of concrete decks is highly subjective. There is not always agreement on which should be given the greatest weight, in respect to detrimental effect on a deck, crack size or total number. Generally, crack size is considered to be more harmful, and the rating system developed reflects this. However, a large number of small cracks could eventually cause deterioration, hence the system promotes the assigned weight of this condition.

Observations are referenced to a grid system; the girder lines and 10-ft longitudinal stations, for instance. The cracks are then located, marked and sized, and the information recorded on a grid sheet (Fig. 24).

In making the rating from the plotted information, the cracks are grouped, or counted, according to their width: < 0.005 in., > 0.005 but < 0.02 in., and 0.02 in. or greater. The groups are then treated as follows:

<u>Widths 0.005 In. or Less</u>

1. Classify each grid according to the number of < 0.005 in. cracks that appear in it: "0" for 0 to 3 cracks, "1" for 4 to 10 cracks and "2" for 11 or more.
2. Multiply each classification number by the number of grids in which it appears.
3. Divide the sum of the products in Step 2 by the total number of grids. This is the small crack numerical rating.

Figure 26. Conducting a deck crack survey.

Widths Greater Than 0.005 In., but Less Than 0.02 In.

The middle size cracks are rated by dividing the total number appearing in all of the grids by the total number of grids.

Widths 0.02 In. or Greater

Before rating the larger cracks, their weight is promoted by multiplying the total number appearing in all the grids by 1.5. They are then rated by dividing this product by the total number of grids. The sum of the three ratings gives a crack severity rating for the deck. A sample is shown in Figure 25.

Concrete construction practices at the beginning and ending areas of deck placements generally differ from the central area, both in placing and finishing. Furthermore, the underlying support (usually rigid end diaphragms) is different. These local factors appear to create different cracking patterns at the bridge ends from those manifested in the central deck area. Therefore, end areas are excluded in the rating determination.

CRACK SURVEY

Two crack surveys have been made: initial and pre-traffic. Age of the concrete varied from 21 to 202 days for the initial and from 295 to 492 for the pre-traffic. For each survey, the deck was thoroughly washed (Fig. 26), and a 4-man team systematically examined the deck for cracks. As cracks were found, a keel mark was placed alongside them. The larger ones were measured and coded according to their width. The location and width of each was later indicated on the respective grid sheet.

DEFERMENT

From the wealth of data collected, there is ample reason to believe that considerable knowledge will be gained regarding the effect of certain construction practices on

Figure 27. Comparison of initial and pre-traffic crack surveys.

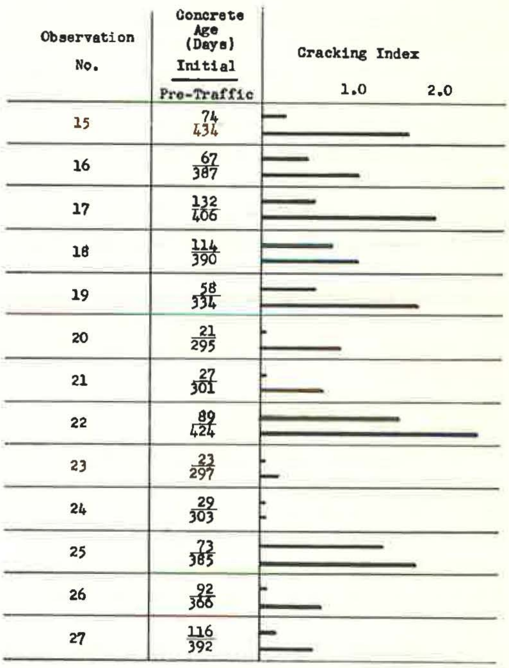


Figure 28. Comparison of initial and pre-traffic crack surveys.

concrete deck durability. However, the only yardsticks available for comparing the practices at this time are the pre-traffic crack surveys. These surveys show concrete age to have a significant effect on deck cracking for several months after construction. The older pre-traffic cracking generally increased substantially above the initial cracking level (Figs. 27 and 28). The greatest change occurred in the number of cracks and the widening of smaller cracks; the width of larger cracks changed little. The surveys also show the pre-traffic cracking pattern to be unlike that found on structures after they have been under traffic a few years. (Pre-traffic cracking has a longitudinal orientation, whereas, post-traffic cracking usually has a transverse orientation.)

Because the cracking pattern and cracking intensity are expected to be markedly different after traffic uses the decks, it appears that conclusions based on the pre-traffic surveys would be premature. Consequently, conclusions will be deferred until after the post-traffic crack survey.

RESEARCH PROBLEMS

Instead of giving conclusions, this report will discuss some of the problems encountered during the project. These problems may be of interest to those concerned with bridge deck construction, particularly to those contemplating a similar research project.

From the beginning, it was considered important that an accurate accounting be maintained on the amount of water in each batch of concrete. Unfortunately, the accuracy of some of the accumulated data is not as good as desired. The water introduced at the plant or added at the site was metered, and the indicated amounts are probably reliable. But, water used to wash the mixing drum after discharging concrete was not entirely removed prior to charging the subsequent batch, and the amount present could be only roughly estimated. Also, variations in moisture content of the sand probably were not always accurately measured by the moisture meter. Another source of error was the practice of hosing off all cement dust and sand from the trucks after charging. The water entering the drums from hosing had to be estimated. Thus, the data accumulated to show total water and water-cement ratio in each batch of concrete have some margin of error.

Close observation of water is also needed in curing. It is well known that improperly cured concrete leads to cracking. Consequently, if uniformity in curing is not maintained during a research project with an objective of determining effect of other variables on cracking, the results could be greatly altered by the curing variable, thereby defeating the objective. Control of curing was delegated to regular construction personnel, but it was found that at times the curing did not receive the attention it deserved for research purposes. In future studies, an inspection form will be provided that is to be filled in periodically in order to act as a reminder to the inspector, draw attention to the importance of curing uniformity, and provide a record of curing irregularities that might occur.

Visual evaluation of the properties and behavior of the fresh concrete did not always agree with the consistency as determined by Kelly ball "slump." Certain batches of concrete appeared extremely fluid when discharged from the placing bucket onto the deck forms. Other batches exhibited a large amount of free water at the front of the placing and finishing operation. In spite of this, slump recorded for these batches is about 4 in. No explanation for this anomaly is apparent; however, it is believed that variation in aggregate gradation or caliber of slump measurements could be factors.

The biggest problem during the construction phase was controlling, or scheduling, the planned variables and avoiding unplanned variables. Planned variables were often disrupted by either equipment breakdown, the weather (remaining mild when variables to combat hot or windy conditions were being used), unavailable machinery, or insufficient finishing personnel. In most cases, it was possible to work around the disruptions by changing a variable during placement or by reclassifying the variable after studying the placement data. There was one occasion, however, when it was impossible to do either and the placement was declared unsuitable for any of the variable classifications. Unfortunately, most of the events that disrupted the scheduling were common problems in construction, and as such were unavoidable. Scheduling several repetitions of single variable groups will mitigate this problem.

An anticipated problem is how to isolate the numerous variables introduced. The variables are grouped into so many combinations that isolation will be very difficult. For some, about all that can be expected is an indication of their effect on deck durability. In retrospect, the number of variables should have been decreased and the number of placements of selected combinations increased.

The problems encountered will no doubt reduce the overall effectiveness of the study. Nevertheless, considerable knowledge is expected to be gained, not only on the study's objectives, but also in more clearly defined directions for further research.

SUMMARY

1. Execution of planned variables that relate to weather conditions or coordinating variable timing with contractor's operations are difficult problems.
2. Numerous repetitions are needed of each planned variable combination to minimize conflict with weather and normal construction variables.
3. Accurate accounting of total water in a transit mix delivery is very difficult, but essential to a research project.
4. Concrete age is a significant factor in the cracking pattern during the first months after placement.

ACKNOWLEDGMENTS

It took many people to plan and execute the construction phase of this research project. Each served a vital part and deserves recognition. However, it is not practical to list all those who took part. The authors, therefore, wish to thank as a group all who contributed to the project, and give special recognition to a few: W. Ames, J. Woodstrom, and C. Sundquist of the Materials and Research Department; A. Rossing, the Bridge Resident Engineer, and his assistant H. Wolfe; and W. Egloff, of the Special Studies Section of the Bridge Department.

Appendix

FACTORS AFFECTING THE
DURABILITY OF CONCRETE BRIDGE DECKS
Construction Observations

PROJECT INFORMATION

Construction Variable Late Finish

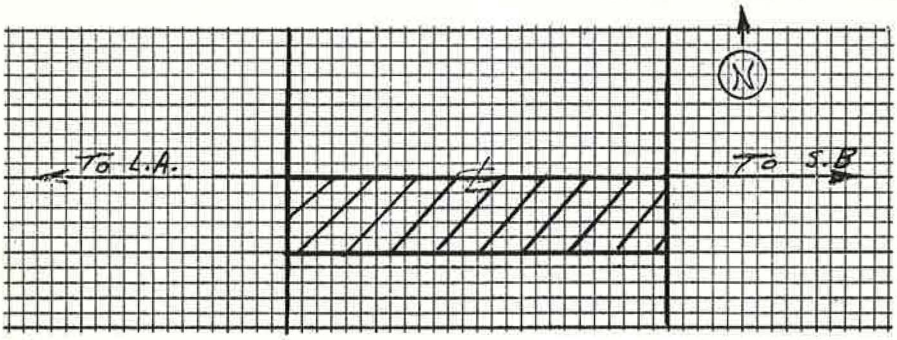
Date of Placement 2-2-66 Bridge No. 53-1824

Contract No. 14-042134 Bridge Name Highland Ave. OC

Road 07-LA-210 - R33.7/R35.9 Bridge Type Box Girder ~ S.S.

Limits Magnolia Ave. to Highland Ave.

Section Placed First ½ of S. Half



Contractor Peter Kiewit

Contractor (Structures) Same

Resident Engineer Al Rossing

Bridge Dept. Repr. Same

Bridge Inspector H. Wolf & F. Bartley

Research Investigators: W. Egloff B. Neal
C Sundquist

Comments

14030 - 951128
19503 - 762500 - 35145

Observation No. Sample

MATERIALS

Concrete Supplier Consolidated Rock ~ Irwindale

Aggregate Source San Gabriel Wash ~ Irwindale

Cement (Brand, Source and Type) SW Portland Cement ~ Majave ~ Type II

Mixing Water (Source) City of Irwindale

Admixture None

Type of Mixing (Plant and Truck) 2 1/6 Yd Batch Plant - 3 batches per transit mix truck

Mix Design

Wts.		Sp.Gr.	Abs.	SE/CV	LART 500 rev.	NaSO4	Mortar Strength
Sand	1312 (SSD)	262	1.2	82/	-	1.0	1.25
3/4x#4	970 (SSD)	265	1.2	/88	29%	1.0	-
$1\frac{1}{2}$ x#4	1050 (SSD)	266	1.0	/86	31%	1.0	-

Cement 564

Water 282

Admixture None

Notes:

FALSEWORK AND FORMS DESCRIPTION

(Pictures/sketches) Generally there is a 1/8" gap between the lost deck forms and girder stems. Lost deck forms appear to be solid enough.

Date falsework removed 2-23-66.

REINFORCING STEEL

(Ties, supports, etc.) Top mat tied every other lap. Is supported by plastic chairs setting on concrete blocks which are spaced @ 5'± C-C, longitudinally between girders. 1 3/4" Cover. Bottom mat tied every 1 in 5 laps. Is supported by plastic chairs spaced at 12"± along & between girders.

Observation No. Sample

SUMMARY SHEET

Concrete Delivery Data
and Test Results

Length of Haul 6.2 Miles, 15-20 Minutes

Type of Haul Roads AC & PCC Pavement

(Batch Data (Obtain all pertinent batch data from Resident Engineer)

Load No.	Ticket Number	Truck Number	Depart. Time	Arrival Time	Begin Disch.	End Disch.	No. of Revs.	W/C* (#/C.Y.)	Slump Inches	Temp. Degrees	Unit Weight	Air Content	Cement Factor
1	996-38	4501	0646	0708	0717	0728	177	286					
2	39	4518	0651	0710	0732	0742	200	283	3-4-3½	64°	153.2		6.10
3	40	4506	0702	0728	0745	0800	250	302					
4	41	4509	0715	0734	0800	0812	195	283					
5	42	08	0725		0816	0825	-	312					
6	43	01	0758		0847	0854	-	302	4-5-4½	63°	151.9		6.02
7	44	18	0802		0856	0904	-	295					
8	45	06	0813		0909	0916	-	287					
9	46	08	0830		0917	0927	-	292					
10	47	01	0848		0937	0945	-	283					
11	48	06	0908		1002	1009	-	283					
12	49	05	0938	0958	1010	1018	-	283	3-2½-3½	67°	152.6		6.07
13	50	04	0950	1008	1019	1025	-	277					
14													
15													
16													
17													
18													
19													
20													

*Obtain all necessary data to determine W/C per batch.
Obtain 9 cylinders on 2nd load, 3 for 7, 14, and 28-day strengths.
Obtain 3 cylinders near center of pour and near end of pour for 28-day strengths.

Observation No. Sample

METHODS AND EQUIPMENT

Placement Crane & Bucket

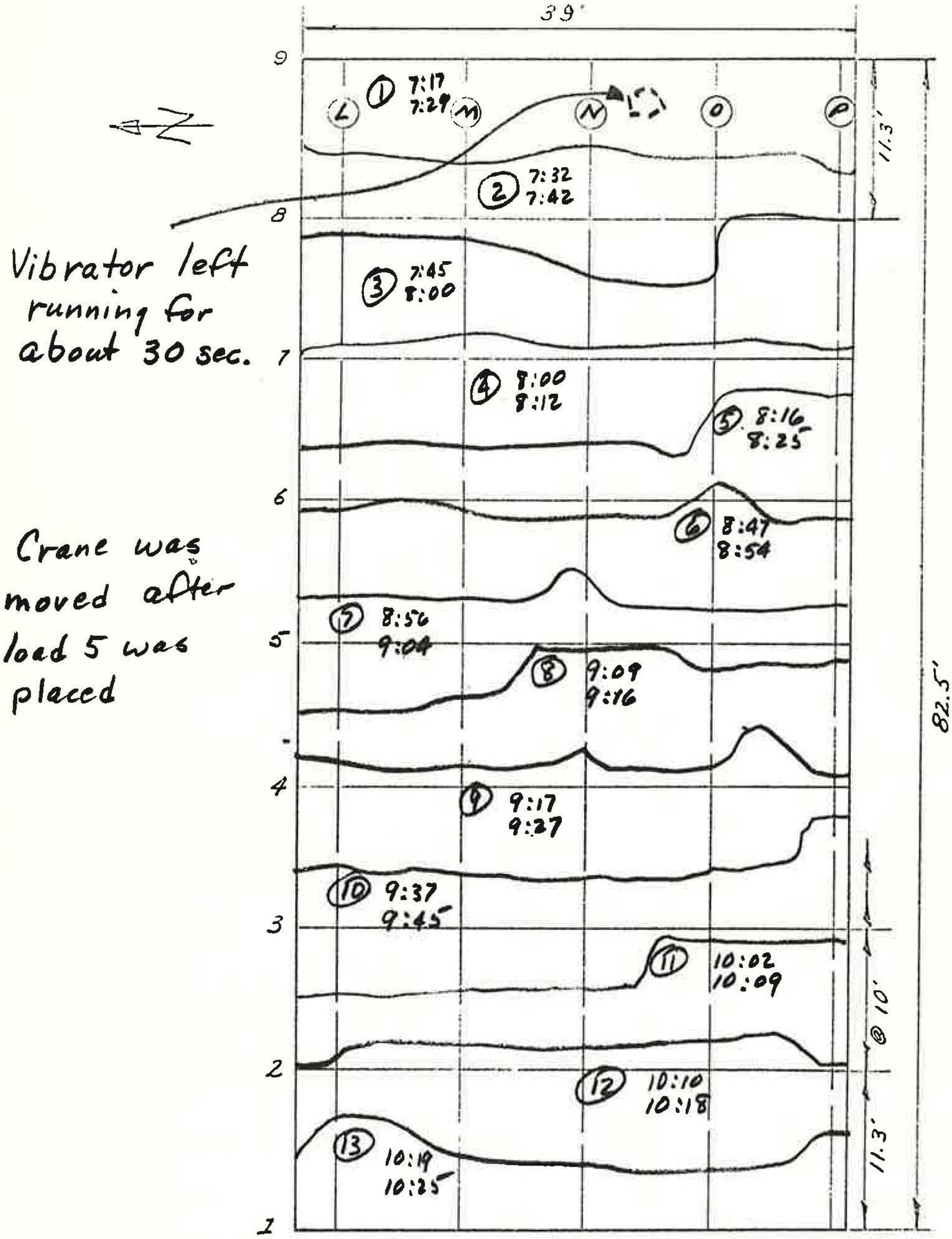
Vibration 2 1/2" McGinnis ~ 10,000 cycles/min

Strike-off Bidwell

Finishing 16' Longitudinal Wooden Plow Handle Float

Curing Wet Rugs

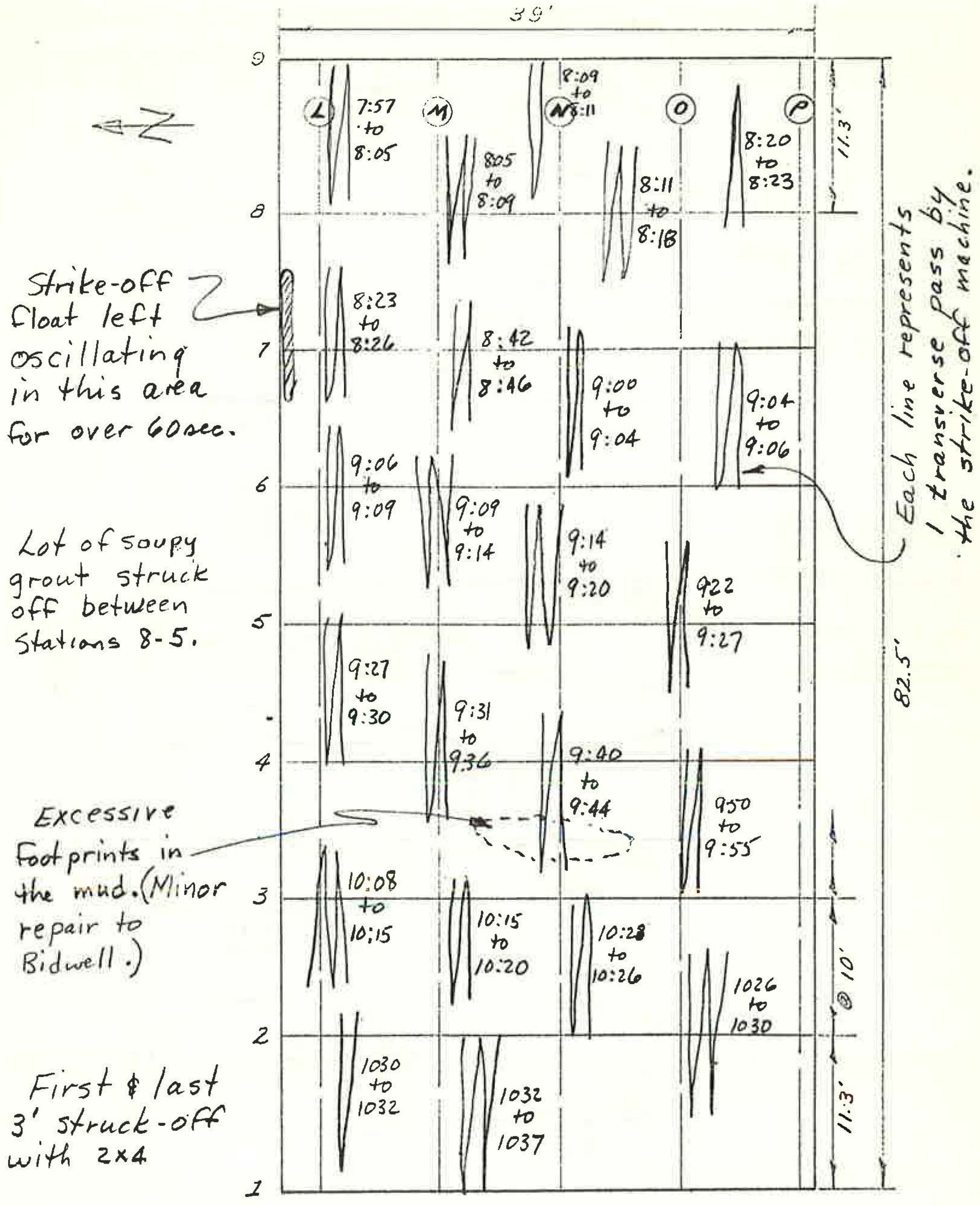
Observation No. Sample



Placing

Scale 1"=10'

HIGHLAND AVE U.C. Pour No. Sample

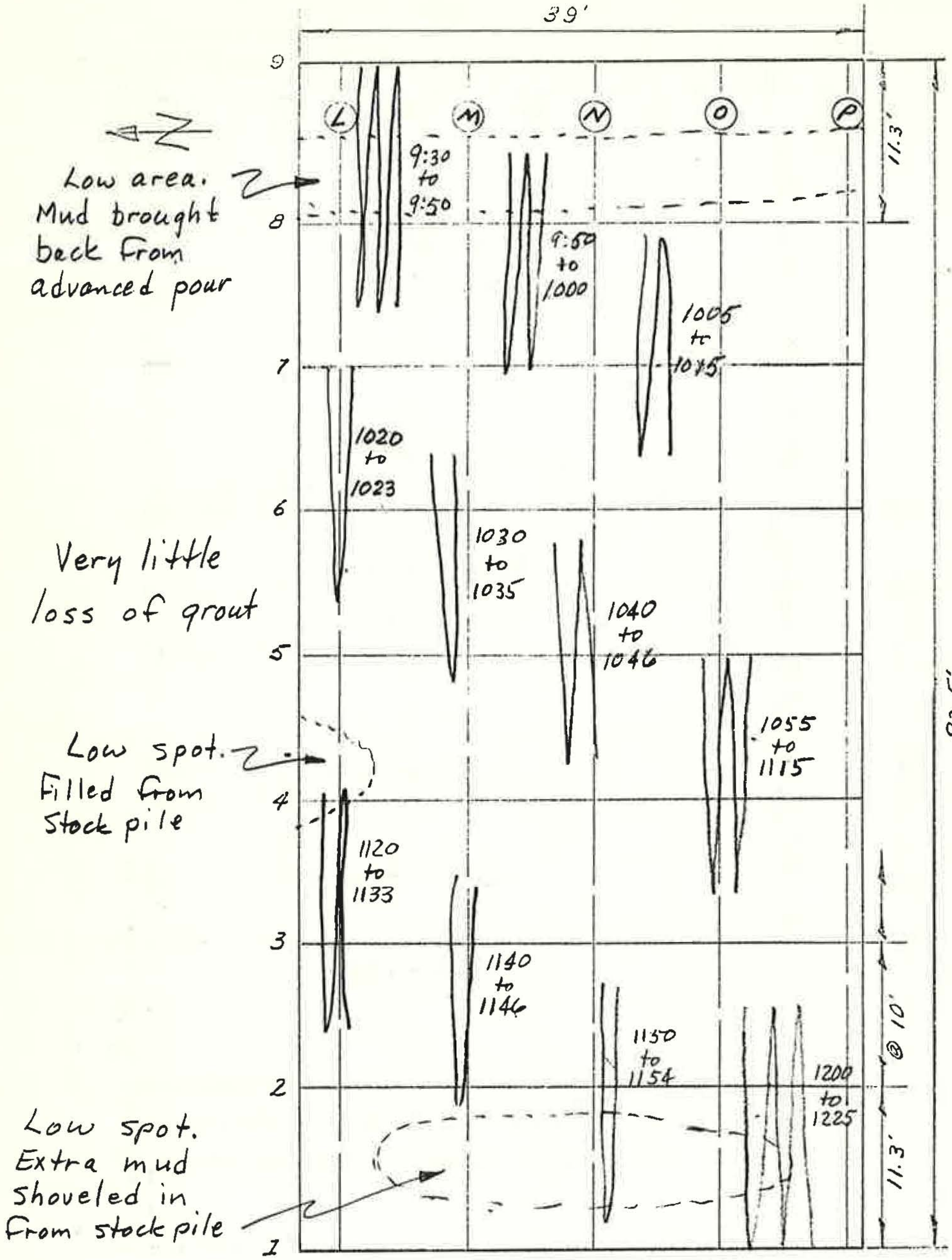


Strike-Off

Bidwell

Scale 1"=10'

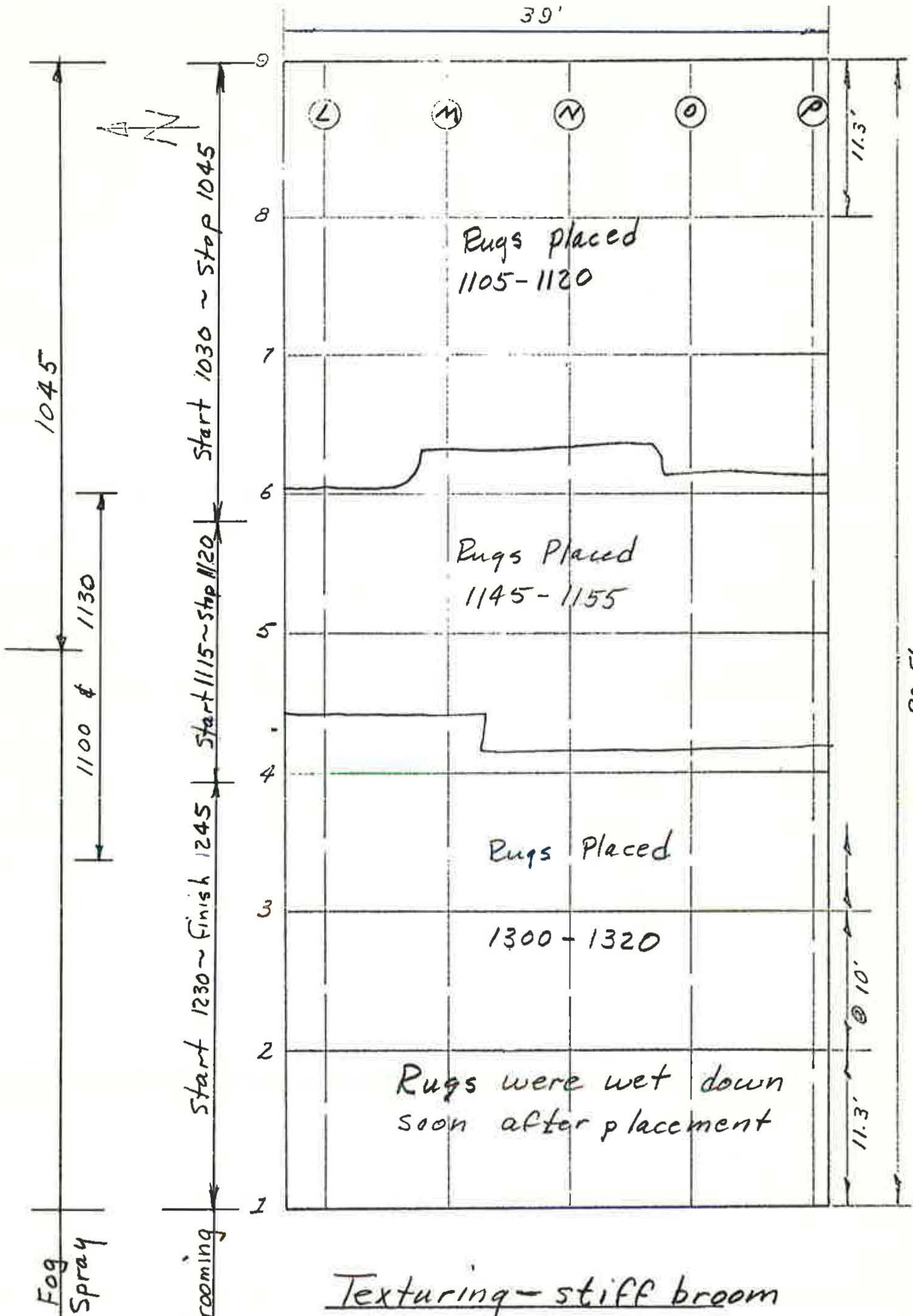
HIGHLAND AVE U.C. Pour No. Sample



Finishing (Late)

16' Longitudinal-Wooden Scale 1"=10'

HIGHLAND AVE U.C. Pour No. Sample



Texturing – stiff broom

Curing – wet rugs   Scale 1"=10'

HIGHLAND AVE U.C.   Pour No. Sample