R-170

MICHIGAN
STATE HIGHWAY DEPARTMENT
Charles M. Ziegler
State Highway Commissioner

WALLACE STONE INVESTIGATION

PART I

SCALING ON MAIN STREET BRIDGES, LANSING
UB-1 AND UB-2 OF 33-6-4

Highway Research Project 51 A-12(1)
Progress Report

Research Laboratory
Testing and Research Division
Report No. 170
January 29, 1952

WALLACE STONE INVESTIGATION

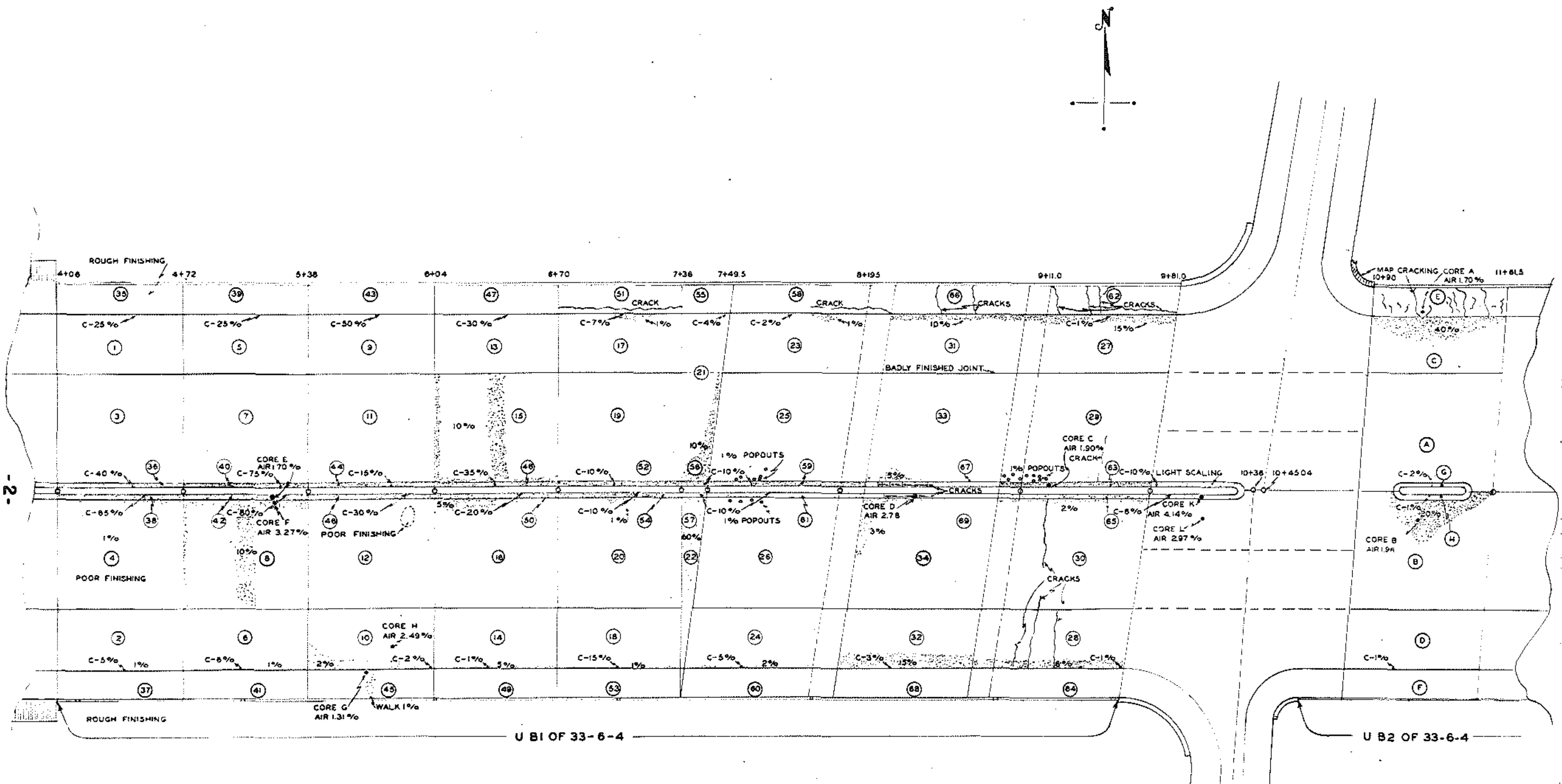
Part I. Scaling of Concrete, Main Street Bridge, Lansing, UB-1 and UB-2 of 33-6-4

Two highway bridges, UB-1 and UB-2 of 33-6-4, located on Main Street, Lansing, and completed in October, 1949, developed excessive scaling, especially along sidewalk-curb faces and divider strips within one year after construction. An investigation was authorized to study the matter to determine the cause of scaling and to check the suitability of Wallace stone for future construction, since Wallace stone was used in these bridges.

This is the first of three progress reports to be issued which will cover three phases respectively of the general investigation of Wallace stone. The second will deal with the evaluation of Wallace stone in existing structures, and the third will give the results of a cooperative laboratory investigation of Wallace stone carried out by the National Crushed Stone Association and the Research Laboratory of the Michigan State Highway Department. The present report on the Main Street Bridge covers the results of the condition survey, core study, construction review, and miscellaneous laboratory studies performed in connection with the investigation.

Condition Survey

The condition survey was made in May, 1951, by C. C. Rhodes, Myron Brown, and E. A. Finney. The character, extent, and amount of scaling encountered in the survey have been presented graphically and pictorially in Figures 1 and 2, respectively. Figure 1 gives the percent and location of scaling in relation to concrete pours and position in the structure. The location of subsequent test cores are also shown in Figure 1. Photographs A to M in Figure 2 illustrate the condition of the concrete surface at core locations. The letter under each photograph coincides with the core designation taken at that particular location. The condition survey has brought to light the following facts.

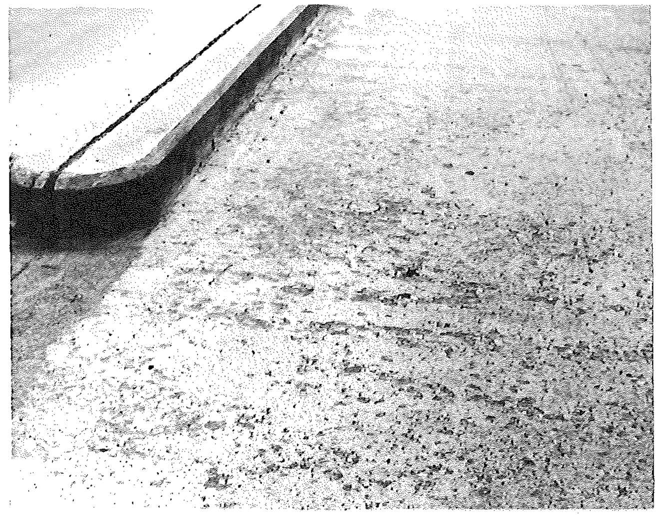


NOTE
C=CURB
④=POUR NUMBER
▒=SCALING
%=AMOUNT OF DETERIORATION

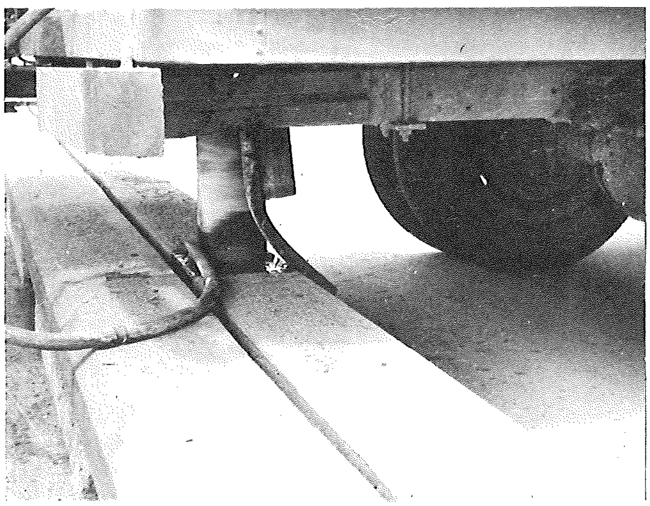
FIGURE I

CONDITION SURVEY OF THE MAIN STREET BRIDGES

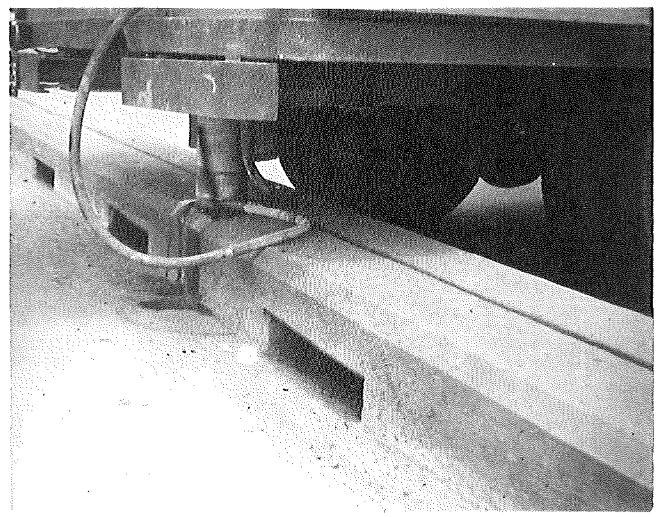
A MAP CRACKING, NORTH SIDEWALK, POUR E, CORE A, 1.70 % AIR. STATION 11+ 28.



B SCALED SLAB, POUR B, CORE B, 1.96 % AIR. STATION 11+ 20 - 5 FT. RT. OF CENTER.

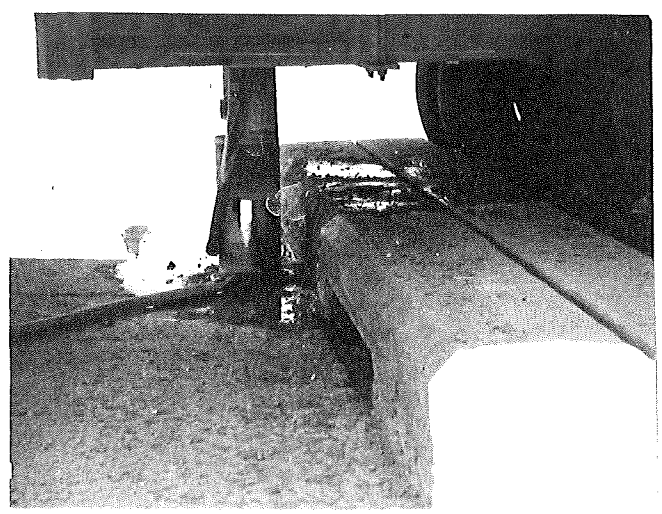


C SCALED CURB, POUR 63, CORE C, 1.90 % AIR, STATION 9 + 31, NORTH MEDIAN CURB.



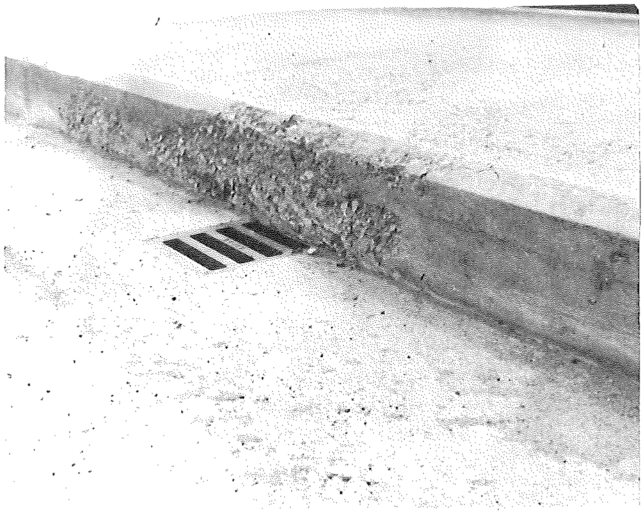
D UNSCALED SECTION OF CURB, POUR 69, CORE D, 2.78 % AIR. STATION 8 + 72, SOUTH MEDIAN CURB.

E SCALED CURB, POUR 42, CORE E, 1.70 % AIR, STATION 5 + 20, SOUTH MEDIAN CURB.



F SCALED CURB, POUR 8, CORE F, 3.27 % AIR, STATION 5 + 20, SOUTH LANE.

FIGURE 2. CONDITION OF CONCRETE SURFACE AT CORE LOCATIONS

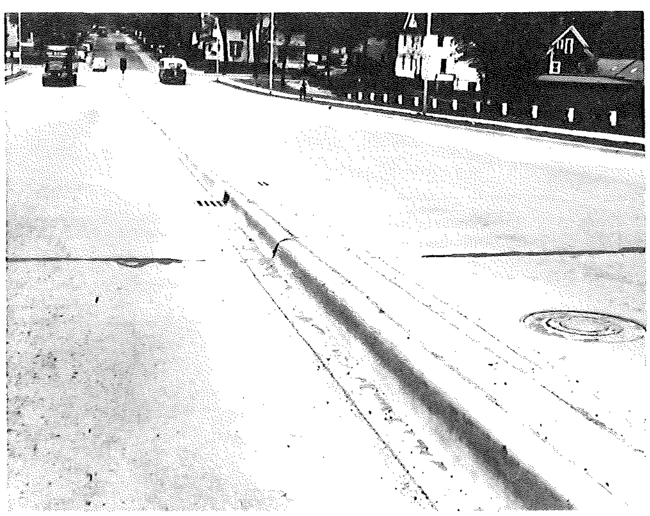


G BADLY SCALED AREA, SOUTH WALK, POUR 45, CORE G, 1.31 % AIR, STATION 5 + 64.

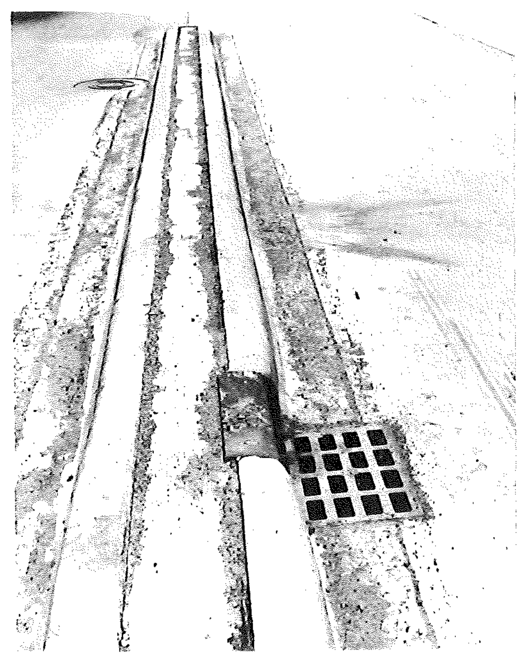
H UNSCALED SECTION OF SLAB, POUR 10, CORE H, 2.49 % AIR, STATION 5 + 73.

K SCALED GUTTER SURFACE, ROAD SECTION, CORE K, 4.14 % AIR, STATION 10 + 8. SOUTH MEDIAN CURB, GRAVEL AGGREGATE.

FIGURE 2.
CONDITION OF CONCRETE SURFACE AT CORE LOCATIONS



M UNSCALED WEST APPROACH TO BRIDGE, GRAVEL AGGREGATE.



L SCALED GUTTER OF PICTURE I AND ADJACENT UNSCALED SLAB, GRAVEL AGGREGATE, ROAD SECTION, CORE L, 2.97 % AIR.

1. Most of the excessive scaling has developed on the sidewalk-curb face and top and sides of the dividing strips, with lesser amounts on the deck surfaces. Further, the scale pattern along each element is sporadic, rather than continuous, which would indicate a variance in concrete quality and thus durability. This pattern has been developed in an accelerated manner by the salt applied during de-icing operations in 1949-50.

2. In general, scaling and concrete disintegration followed this pattern:

   a. Large and small aggregate pop-outs widely distributed over large areas.

   b. In localized areas, pitting highly concentrated, resulting in an advanced stage of disintegration, as shown in Figures 2B and 2F. This phenomenon has been observed on other air-entrained concrete surfaces and is a different form of failure from that encountered in non-air-entrained concrete.

   c. General disintegration of the mortar around the coarse aggregate, as shown in Figure 2G.

   d. Flaking off of thin mortar film used in final conditioning and repair of irregular or honey-combed surfaces. See Figures 2C and 2E.

3. Structural and hair cracks were found in certain deck and sidewalk pours. Extensive map cracking has developed in sidewalk pour E. See Figures 1 and 2A. Longitudinal cracks also appear in pours 51, 58, 66, and 62 on north walk; see Figure 1. It is believed that this type of cracking is due to the hollow tile construction in the walk sections. The transverse cracks in pours 28, 29, and 30 are obviously structural cracks.

4. With but one exception, no scaling has occurred to date on the approach and road sections which were constructed entirely with gravel aggregates and the same air-entraining cement. The exception is shown in Figures 2K and 2L. In this case, the gutter surface has scaled, exposing coarse aggregates, but the balance of the curb has not scaled. The air content of a core taken from the curb apron section (Core K) was found to be 4.14 percent.

Core Study

In all, ten cores were taken from different locations in the deck, divider strips, and sidewalks. They were selected from scaled and unscaled sections of concrete. Their location is shown in Figure 1. The air content of the concrete was determined from the cores by the Camera Lucida method, after which the core segments were subjected to 65 cycles of freezing and thawing in water. Data from the studies are presented in Table I. Pictures of the cores after removal from the freezing and thawing test are shown in Figure 3. Please note that the smooth solid portion at the bottom of the cores is the original capping mortar, which was not removed at the beginning of the tests.

TABLE I

SUMMARY OF DATA FROM CORE STUDY

Core Letter	Core Location	Condition of Concrete	Percent Entrained Air in cores by Camera Lucida (Ave. 4 Readings)	Weight Change, Grams at 65 Cycles Freeze and Thaw	Percent Loss
SCALED CONCRETE					
B	11+20 5' R	Badly scaled pavement 5' south of center curb	1.96	92	5.08
C	9+16	North side of center curb scaled on top and side	1.90	248	6.86
E		South side of center curb scaled on top and side	1.70	112	3.60
G	5+74	Badly scaled area of south sidewalk	1.31	404	13.00
K	10+23	Scaled area of curb apron	4.14	41	1.32
UNSCALED CONCRETE					
A	11+40 in north sidewalk of B_2	Map-cracking over north sidewalk. No scale	1.70	81	1.54
D	8+63	South side of center curb - unscaled section	2.78	23	0.66
F	5+13	Unscaled section of pavement	3.27	26	0.91
H	5+88	Unscaled pavement 6' north of south sidewalk	2.49	39	1.54
L	10+23	Unscaled section of pavement 6' south of center curb	2.97	8	0.27

The core study has also brought out several interesting facts. They are:

1. The air determination values shown in Table I indicate a lack of uniformity in air content of the concrete throughout the superstructure.

2. With one exception, the air content in the unscaled cores was on the low side of specification requirements, even though we take into account the fact that such air determinations may be as much as $1\frac{1}{2}$ percent less than that of the fresh concrete.* This fact alone may account for a large part of the scaling in the presence of border-line aggregate and excessive use of salt for de-icing purposes.

3. With but one exception, scaling in the cored areas was related to the low air content found in the respective cores. This exception is Core K, which was taken from gutter surface composed of natural aggregates from Cheney pit. Upon further examination it was found that the core surface was composed of a highly porous slurry, which evidently had no resistance to salt attack.

4. Cores from unscaled concrete sections with air contents within specification requirements showed, with the exception of Core A, to have high resistance to freezing and thawing.

5. With reference to Figure 3, it may be seen that Cores B, C, E, and G, with low air content, show failure due to mortar weakness, whereas those cores with higher air content (D, F, H, and L) show aggregate failure with mortar intact. Core L was taken from the road section with natural aggregates and air-entraining cement.

6. In connection with Cores A, D, F, and H, and to a certain extent in Cores B, C, E, and G, it was observed that the pieces of aggregate which showed distress in freezing and thawing were those consisting primarily of an argillacious shale with a laminated structure.

Construction Information

The concrete work on the above-mentioned segments of the structures was completed on October 29, 1949. The contractor was L. A. Davidson. Coarse aggregate was obtained from the Wallace Stone Company, of Bay Port. The fine aggregate came from Cheney Gravel Company, near Holt. Both regular and air-entraining Peninsular portland cement were used in the structures.

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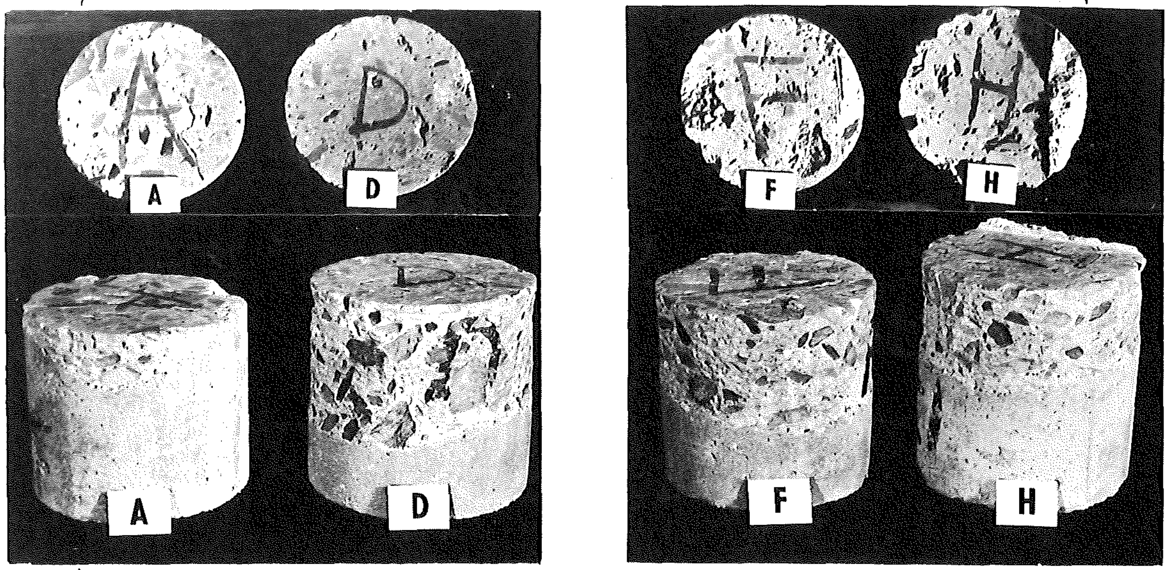
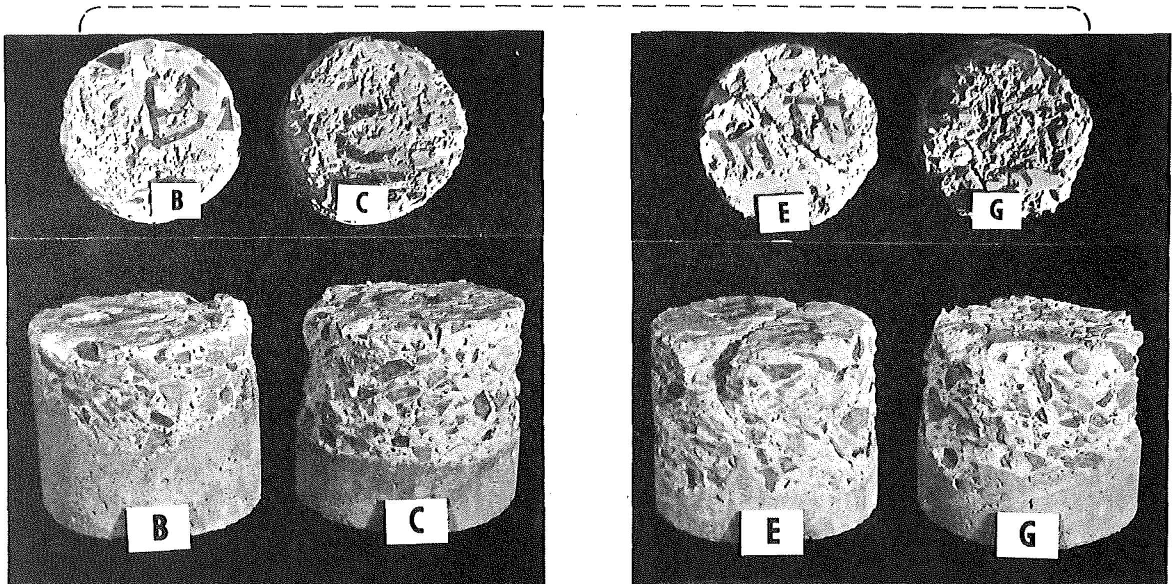
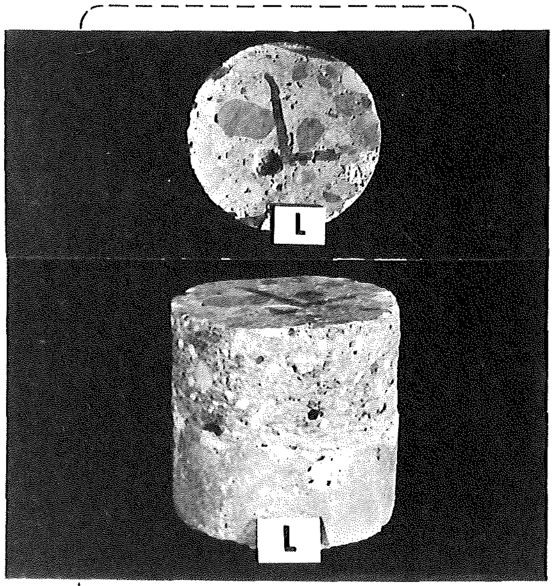
* A. Klein, D. Pirtz, M. Polivka, "New Methods of Determining Air Content of Hardened Concrete," Proceedings, ASTM. V. 50, p. 1283.



DISINTEGRATION OF COARSE AGGREGATE
WALLACE STONE CONCRETE



DISINTEGRATION OF MORTAR
WALLACE STONE CONCRETE



NO DISINTEGRATION
NATURAL AGGREGATES

CORE SPECIMENS AFTER 65 CYCLES
OF FREEZING AND THAWING IN WATER

FIGURE 3

Concrete Mixture: When regular cement was used, Darex was added to the concrete mixture at the mixer to produce the desired air content. In all cases a 6B vibrated concrete mix was specified with medium consistency, in accordance with Design Chart 49 MV-40. Cement content: 5.9 sacks per cubic yard.

Pour Data: A summary of concrete pour information and related construction data will be found in Table II. This material will be studied in relation to scaling of individual pours.

Weather Conditions: We have been informed by bridge personnel that bad finishing on certain deck pours was due to rain which made finishing difficult. The records show that rain occurred during pours listed below in Table III.

TABLE III

SUMMARY OF WEATHER CONDITIONS

Date	Pour	Location	Weather AM	Weather PM	Condition
8-11-49	8	Deck	Fair	Cloudy - Rain	10% Scale
9-23-49	28	Deck	Cloudy - Rain	Cloudy - Rain	6% Scale
10-4-49	50	Divider Strip	Partly cloudy	Rain	20% Scale
10-4-49	44	Divider Strip	Partly cloudy	Rain	15% Scale
10-4-49	52	Divider Strip	Partly cloudy	Rain	10% Scale
10-4-49	46	Divider Strip	Partly cloudy	Rain	30% Scale
10-4-49	22	Deck	Partly cloudy	Rain	60% Scale
10-21-49	B	Deck	Cloudy - Rain	Cloudy	20% Scale

Concrete Flexural Strengths: A summary of modulus of rupture strength data is presented in Table IV. The data exemplified two unsatisfactory conditions; first, the irregularity in making and breaking beam specimens, and second, low beam breaks for periods in excess of seven days. This latter condition could indicate poor concrete or lack of proper curing of beam specimens, or perhaps both.

Air-Control Checks: A search of the records shows that for the entire structure 13 air content checks were made, as shown in Table V.

TABLE II

SUMMARY OF CONCRETE POURS AND ASSOCIATE DATA
MAIN STREET BRIDGES UB-1 OF 33-6-4, C1 AND UB-2 OF 33-6-4, C2

Date	Bridge Pour No.	Bridge Span No.	Location	Air Temp. °F.	Cement Data Type	Cement Data Darex Additive	Slump Inches	Physical Condition Percent Scaling	Physical Condition Other Condition	Core No. % Air
8- 3-49	3	1	Deck		R	7 oz.	2½	None	- -	- - -
* 8- 4-49	4	1	"	75	R	7 oz.	2	1	P.F.	- - -
8- 9-49	2	1	"	93	R	7 oz.	3½	None	- -	- - -
8-10-49	1	1	"	78	R	7 oz.	3	"	- -	- - -
8-10-49	7	2	"	96	R	7 oz.	2½	"	- -	- - -
8-11-49	8	2	"	82	R	7 oz.	2½	10	- -	F 3.27
8-15-49	5	2	"	84	R	7 oz.	2½	None	- -	- - -
8-15-49	6	2	"	84	R	7 oz.	2½	1	- -	- - -
8-22-49	11	3	"	80	R	7 oz.	2½	None	- -	- - -
8-22-49	15	4	"	80	R	7 oz.	2½	10	- -	- - -
8-23-49	9	3	"	82	R	7 oz.	2½	None	- -	- - -
** 8-24-49	13	4	"	78	R	7 oz.	2½	"	- -	4.9
9- 2-49	12	3	"	76	R	7 oz.	2½	None	P.F.	- - -
9- 2-49	16	4	"	76	R	7 oz.	2½	5	- -	- - -
9- 2-49	19	5	"	76	R	7 oz.	2½	None	- -	- - -
9- 6-49	14	4	"	62	R	7 oz.	2½	5	- -	- - -
9- 6-49	10	3	"	62	R	7 oz.	2½	2	- -	H 2.49
9- 8-49	17	5	"	53	R	7 oz.	2	1	- -	- - -
9-17-49	29	8	"	60	R	7 oz.	2½	1	P	- - -
9-20-49	30	8	"	72	R	7 oz.	1½-2	2	C	- - -
9-21-49	27	8	"	70	R	7 oz.	2-2½	15	- -	- - -
9-23-49	28	8	"	56	R	8 oz.	2½	6	C	- - -
9-24-49	21	5A	"	-	R	8 oz.	2½	10	- -	- - -
9-24-49	25	6	"	-	R	8 oz.	2½	7	P	- - -
9-26-49	23	6	"	80	R	8 oz.	2	1	- -	- - -
9-27-49	20	5	"	68	R	8 oz.	1½-2	1	- -	- - -
9-28-49	33	7	"	-	R	8 oz.	2½	5	- -	- - -
9-29-49	31	7	"	62	R	8 oz.	2	2	C	- - -
9-30-49	26	6	"	76	R	8 oz.	2	1	P	- - -
9-30-49	18	5	"	70	R	8 oz.	2	1	- -	- - -
10- 1-49	34	7	"	68	R	8 oz.	2	3	- -	- - -
10- 4-49	22	5A	"	70	R	8 oz.	2½	60	- -	- - -
10- 4-49	44	3	Div. Strip	62	R	8 oz.	2½	42	- -	- - -
10- 4-49	46	3	"	62	R	8 oz.	2½	30	- -	- - -
10- 5-49	50	5	"	78	R	8 oz.	2½	20	- -	- - -
10- 5-49	52	5	"	78	R	8 oz.	2½	10	- -	- - -
10- 5-49	48	4	"	78	R	8 oz.	2½	35	- -	- - -
10- 5-49	54	5	"	78	R	8 oz.	2½	10	- -	- - -
10- 7-49	56	5A	"	80	R	8 oz.	2	10	- -	- - -
10- 7-49	57	5A	"	80	R	6 oz.	2	10	- -	- - -
10- 7-49	59	6	"	80	R	8 oz.	2	10	- -	- - -
10- 7-49	61	6	"	80	R	8 oz.	2	10	- -	- - -
10- 7-49	67	7	"	80	R	8 oz.	2	None	C	- - -
10- 7-49	69	7	"	80	R	8 oz.	2	"	C	D 2.78
10- 7-49	24	6	Deck	74	R	8 oz.	1½-2½	2	- -	- - -
10- 8-49	32	7	Deck	72	R	8 oz.	2	15	- -	- - -
10- 8-49	63	8	Div. Strip	—	R	8 oz.	2	10	- -	C 1.90
10- 8-49	65	8	"	—	R	8 oz.	2	8	- -	- - -
10-12-49	38	1	"	72	R	8 oz.	2	65	- -	- - -
10-12-49	36	1	"	72	R	8 oz.	2	40	- -	- - -
10-12-49	40	2	"	78	R	8 oz.	2	75	- -	- - -
10-12-49	42	2	"	78	R	8 oz.	2	80	- -	E 1.70
10-13-49	51	5	Walk	60	R	8 oz.	2	7-on curb	C	- - -
10-13-49	43	3	Walk	60	R	8 oz.	2	50-on curb	- -	- - -
10-13-49	47	4	Walk	60	R	8 oz.	2	30-on curb	- -	- - -
10-14-49	55	5A	Walk	68	R	8 oz.	2	4-on curb	- -	- - -
10-14-49	58	6	"	68	R	8 oz.	2	2-on curb	C	- - -
10-15-49	39	2	"	—	R	8 oz.	2	25-on curb	C	- - -
10-15-49	35	1	"	—	R	8 oz.	2	25-on curb	- -	- - -
10-18-49	62	8	"	—	A	- - -	1½-2	1-on curb	C	- - -
10-18-49	66	7	"	—	A	- - -	1½-2	None	C	- - -
10-19-49	37	1	"	72	A	- - -	2	"	P.F.	- - -
10-19-49	41	2	"	72	A	- - -	2	6-on curb	- -	- - -
10-20-49	45	3	"	—	A	- - -	1½-2½	3-on curb and walk	- -	G 1.31
10-20-49	49	4	"	—	A	- - -	1½-2½	1-on curb	- -	- - -
10-20-49	53	5	"	—	A	- - -	1½-2½	15-on curb	- -	- - -
10-22-49	60	6	"	46	A	- - -	1½-2	5	- -	- - -
10-22-49	64	8	"	46	A	- - -	1½-2	1	- -	- - -
10-22-49	68	7	"	46	A	- - -	1½-2	3	- -	- - -
			UB-1 of 33-6-4, C1 above							
			UB-2 of 33-6-4, C2 below							
10-14-49	A		Deck	78	R	8 oz.	2	None	- -	- - -
10-17-49	C		"	74	R	8 oz.	1½-2	40	- -	- - -
10-21-49	B		"	—	A	- - -	1½-2	20	- -	B 1.96
10-26-49	D		"	42	A	- - -	1½-2	3	- -	- - -
10-26-49	E		Walk	42	A	- - -	1½-2	None	- -	A 1.70
10-26-49	G		Div. Strip	42	A	- - -	1½-2	2	- -	- - -
10-26-49	H		"	42	A	- - -	1½-2	1	- -	- - -
10-29-49	F		Walk	—	A	- - -	2	1-on curb	- -	- - -
11-29-49	Bet. Bridges		Curb Apron	- -	A	- - -	- -	8	- -	K 4.14
11-22-49	Bet. Bridges		Pavement	- -	A	- - -	- -	None	- -	L 2.97

LEGEND:

P.F. = Poor finishing - rain
C = Cracks
P = Mainly popouts
Fine aggregate - Cheney Sand throughout
Coarse aggregate - Wallace Stone throughout

R = Peninsular Regular Cement
A = Peninsular Air-entraining Cement
* = Beams
** = Field Air Check

TABLE IV

SUMMARY OF MODULUS OF RUPTURE DATA

SUBSTRUCTURE UB1 of 33-6-4 C1

Peninsular Cement, Cheney 2NS Sand, Cheney 6A C. A.

Series No.	Date Molded	Cement Factor Sacks	Pour Location	*7 Day Mod. psi.	*28 Day Mod. psi.	*Other Curing Periods Age Days	Mod. psi.	Age Days	Mod. psi.
1	2- 9-49	5.9 + 10%	Pier 6 Tremie	----	----	9	554	12	682
2	2-10-49	5.5	Pier 1 Footing	----	588	8	604	---	---
3	2-16-49	5.5	Abut. A, Footing	709	590	----	---	---	---
4	2-23-49	5.5	Pier 6, Footing B,C,D	---	592	5	692	---	---
5	3- 4-49	5.5	Pier 6, Base G	599	---	---	---	---	---
6	Broken accidentally								
7	4- 4-49	5.9 + 10%	Pier 5, 5A, Tremie	762	900	---	---	---	---
8	4-12-49	5.5	Pier 5, 5A, Footing	450	583	---	---	---	---
9	4-15-49	5.5	Pier 5, Base Wall	---	659	9	536	---	---
12	5-14-49	5.9 + 10%	Pier 4, Tremie	---	---	5	430	6	458
13	5-18-59	5.9 + 10%	Pier 7, Tremie	497	---	---	---	---	---
15	5-24-49	5.5	Pier 4, Footing	---	715	16	616	---	---
16	6- 9-49	5.5	Pier 7, Basewall G	629	656	---	---	---	---
17A	6-10-49	5.5	Abut. B, Footing B, F	591	655	---	---	---	---
				Ave. 605	660				

SUBSTRUCTURE UB2 of 33-6-4 C1

Series No.	Date Molded	Cement Factor Sacks	Pour Location	*7 Day Mod. psi.	*28 Day Mod. psi.	Age Days	Mod. psi.	Age Days	Mod. psi.
23A	9-15-49	5.5	Abut. A, Footing	---	---	8	497	35	536

SUBSTRUCTURE UB1 of 33-6-4 C1

Peninsular Cement, Cheney 2 NS Sand and Wallace Stone 6B C. A.

Series No.	Date Molded	Cement Factor Sacks	Pour Location	*7 Day Mod. psi.	*28 Day Mod. psi.	Age Days	Mod. psi.	Age Days	Mod. psi.
10	4-25-49	5.5	Pier 2, Col. and Girder	591	---	---	---	---	---
11	5- 5-49	5.5	Abut. A, Wall	475	746	---	---	---	---
14	5-20-49	5.5	Pier 5, Col. & Girder	---	---	20	684	28	700
18	6-18-49	5.5	Pier 4, Col. & Girder	---	---	9	601	33	745
19	7-27-49	5.5	Abut. B, Wingwall	555	---	35	766	---	---
				Ave. 540	746				

SUBSTRUCTURE UB2 of 33-6-4 C1

Series No.	Date Molded	Cement Factor Sacks	Pour Location	*7 Day Mod. psi.	*28 Day Mod. psi.	Age Days	Mod. psi.	Age Days	Mod. psi.
22	9- 1-49	5.5	Abut. B, Wall	---	---	15	450	31	691

DECK - B1 of 33-6-4 C1

Peninsular Cement, Cheney 2NS Sand, Wallace Stone C. A.

Series No.	Date Molded	Cement Factor Sacks	Pour Location	*7 Day Mod. psi.	*28 Day Mod. psi.	Age Days	Mod. psi.	Age Days	Mod. psi.
20 A	8- 4-49	5.9	Span 1, Pour 4	---	804	13	610	---	---
21 A	8-24-49	5.9	Span 4, Pour 13	508	---	30	672	---	---
24 A	9-17-49	5.9	Span 8, Pour 29	---	---	16	640	----	---
24 B	9-17-49	5.9	Span 8, Pour 29	---	---	33	475	---	---
25 A	9-26-49	5.9	Span 6, Pour 23	---	---	8	511	---	---
25 B	9-26-49	5.9	Span 6, Pour 23	---	---	24	477	---	---
26 A	9-30-49	5.9	Span 6, Pour 26	---	---	20	496	---	---
26 B	9-30-49	5.9	Span 6, Pour 26	---	---	33	609	---	---
				Ave. 508	804				

*Average 2 breaks on a single beam.

TABLE V

SUMMARY OF AIR CHECKS
BRIDGES AND APPROACHES
For 1949

Date	Location	*Air Content
Feb. 7, 1949	Substructure	**1.3 R.S.F. Tremie
Feb. 8, 1949	Substructure	4.1 R.S.F.
Feb. 9, 1949	Substructure	***1.6 R.S.F. Tremie
Feb. 16, 1949	Substructure	4.4 R.S.F.
Feb. 25, 1949	Substructure	5.1 R.S.F.
Mar. 2, 1949	Substructure	3.8 R.S.F.
Mar. 14, 1949	Substructure	5.5 R.S.F.
Apr. 7, 1949	Substructure	2.7 - 5.3 R.S.F.
Apr. 25, 1949	Substructure	4.3 R.S.F.
May 13, 1949	Substructure	4.3 R.S.F.
July 25, 1949	Substructure	4.0 R.S.F.
Aug. 24, 1949	Deck	4.9 R.S.F.
Sep. 22, 1949	Substructure	2.9 - 3.6 R.F.D.
Oct. 17, 1949	Pavement under B_2, sta. 23+60	3.9 R.F.D.
Oct. 19, 1949	Pavement under B_2, sta. 33+00	4.1 R.F.D.
Nov. 16, 1949	West approach ramp, sta. 2+75	6.5 R.F.D.

* Average of several determinations
** Seal Coat Pier #1- Regular cement
*** Tremie - Pier #6 - Regular cement

The substructure required 66 pouring days to complete and, during this work, 12 air checks were made. In the case of the superstructure, the 77 listed pours were completed in 39 pouring days with one air check. Records show that one air check was made on approaches and curbs in 1949, and that was on the Main Street west approach ramp.

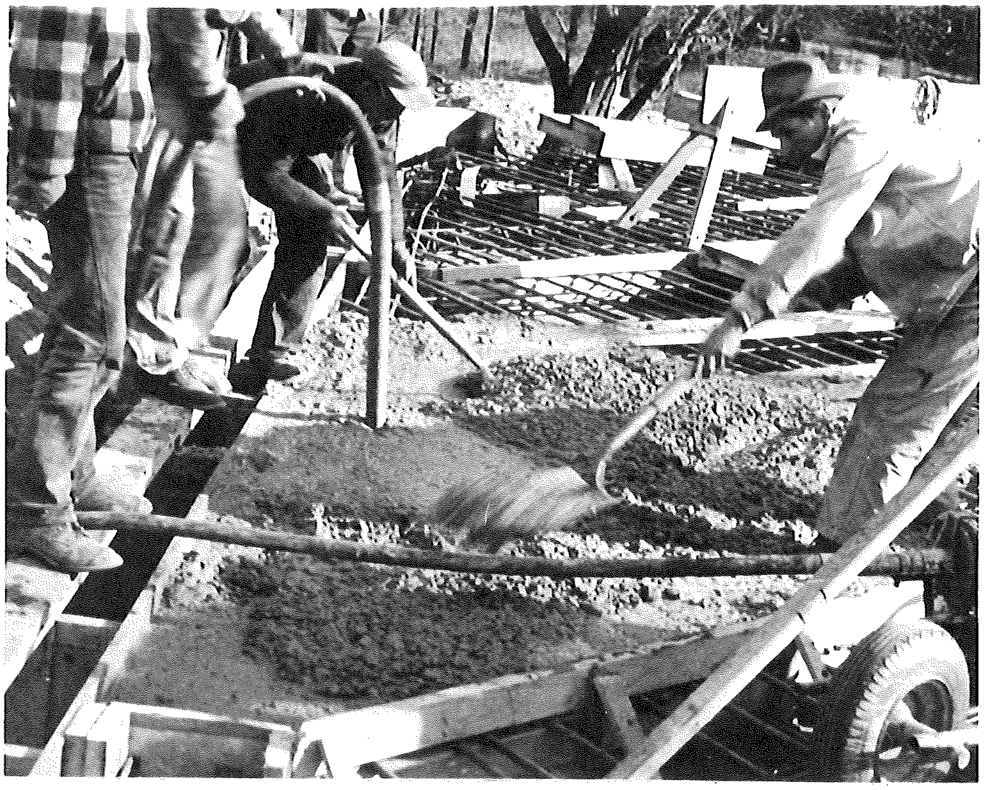
Clearly, this number of air checks in either case is not adequate to assure uniformity of air content. For example, the air content on April 7 and September 22 was below specification limits when checked. Since the previous checks were from three to four weeks prior to this time, there is no telling just how long this value 2.9 air content prevailed.

Addition of Air-Entraining Agents to Concrete Mixture: Darex was added to the sand in the weigh hopper through a semi-automatic dispenser in which the liquid was automatically weighed but manually discharged. The practice of adding air-entraining agent to the sand is not in keeping with specification requirements.

On this project it was observed by our inspectors that a sediment collected in the discharge spout of the Darex dispenser and partially clogged the opening. Furthermore, the discharge from this particular dispenser was reported to be slow and it is a matter of record that, in some instances, complete emptying did not take place for each batch.

Evidently such factors as these could materially influence the air content of the respective pours.

Vibration of Concrete in Superstructure: Although we have discussed this point with the project engineer, we were unable to unearth any factual information as to the character of the vibration technique employed on the structure and what possible influence it might have had on the subsequent scaling of the concrete. However, we are fully aware from observing vibration operations on other bridge structures that improper vibration technique results in segregation of the aggregates. Examples of vibrated concrete in bridge deck are shown in Figure 4.



VIBRATION OF CONCRETE IN FORMS PARTIALLY FILLED. NOTE SOUPY CONCRETE APPEARING AROUND VIBRATOR. SS B1 OF 33-7-9, 4

SAME LOCATION BUT FORMS COMPLETELY FILLED AND VIBRATION OF CONCRETE COMPLETE.

FIGURE 4. VIBRATION OF CONCRETE IN A BRIDGE DECK

Summary of Construction Factors: The most significant facts brought out by the study of construction practices are:

1. Less scaling has occurred on the pours made with air-entraining cement than on those containing regular cement with Darex added.

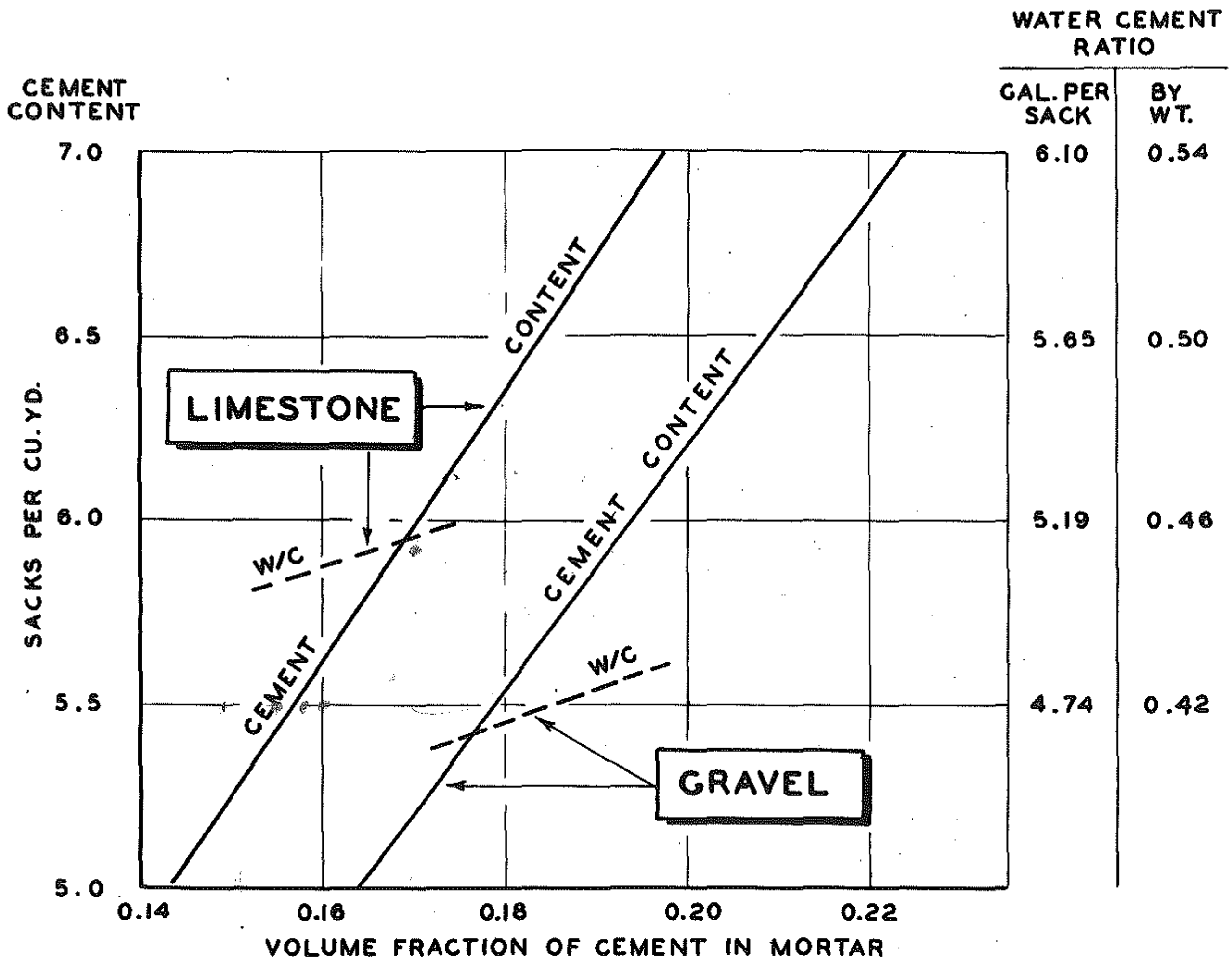
2. Lack of sufficient air checks to insure uniform control.

3. Possible construction factors contributing to non-uniform durability are: a) rain before completion of finishing operations; b) uncertainty of uniform quantities of air-entraining agent added to the batch; and c) vibration technique.

Miscellaneous Laboratory Studies

Several laboratory studies were made in order to discover further clues if possible. Some of these studies, although relatively limited in scope, have given significant indications of possible causes for the premature scaling observed on portions of the two bridges.

The Cement Content of Limestone Concrete: It can be seen from Figure 5 that the mortar in a natural gravel concrete is much richer in cement than a corresponding mortar in limestone mix. The two sets of curves in the figure were plotted from the two mortar voids charts actually used on the Main Street bridges. The cement content of the grade A medium consistency concrete, using Bay Port limestone 6B for the bridge decks, was 5.9 sacks per cubic yard, but this compares with a mix of only 5.1 sacks per cubic yard in a Cheney 6A concrete to produce the same cement-mortar ratio. This difference in mortar richness is true with all 100-percent crushed coarse aggregates, although not necessarily to the same extent. The difference in mortar richness is due to the lower unit weight for crushed coarse aggregates and the fact that more mortar is needed for workability. The water-cement ratio is also higher for the limestone concretes. The Wallace stone concrete should have about an extra 3/4 sack of cement per cubic yard to bring the mortar up to a richness equal to that of the Cheney gravel concrete.



BAYPORT 6B LIMESTONE - CHART 49 MV-40
CHENEY 6A GRAVEL - CHART 49 MV-14

FIGURE 5. CEMENT CONTENT AND WATER CEMENT RATIO, LIMESTONE VS GRAVEL CONCRETE

Soundness Tests on Wallace Stone: Table VI represents a complete listing of all sulfate soundness tests run on samples of crushed limestone from the Wallace stone quarry. The average of all tests run since June 22, 1950, when the bridge spans were completed, is 12.5 percent, which exceeds the specification maximum of 12 percent. No soundness tests were run on the Wallace aggregate just prior to the beginning of construction on the Main Street spans. Tests run in 1939 and before indicate the doubtful status of Wallace stone. Records show, however, that Wallace Bay Port was approved for use by the Bureau of Public Roads, even though soundness loss ran between 10 and 19 percent.

Use of De-Icing Salts on Bridge: By a directive from Mr. B. R. Downey, Maintenance Engineer, the city of Lansing was instructed to use only calcium chloride and sand on the Main Street bridges. According to Mr. Glenn Manz, City Engineer, chloriding for 1949 started November 15, but none was used on the Main Street Bridge before it was opened to traffic.

Main Street was opened to traffic on December 7, 1949, and the first application of chloride and sand was about one week later and in considerable amounts. With reference to Table II, it may be noted that the concrete in the divider strips, walks, and some deck sections were two months or less in age when the chloride treatments were applied.

Effect of Limestone Aggregates on Air Content: Special laboratory tests were made to determine whether or not limestone aggregates tended to act as a depressant, and thus lower the air content of concrete mixtures in which they were included, especially if the air content was low to start with. To this end, four limestone materials were selected to compare with a natural aggregate. All factors were kept constant except for the source and type of coarse aggregate. The study revealed that the four limestones used had no depressing action. In fact, they seemed to

TABLE VI

SUMMARY OF SOUNDNESS TESTS ON WALLACE AGGREGATE

Date	No. Samples	Soundness	Remarks
4-6-29	6 Ledge Rock	4 failed - 2 passed	MSHD
3-8-30	22 Ledge Rock	-----	No soundness reported
7-12-34	11 Ledge Rock	Sound	MSHD
3-22-35	7 Ledge Rock	3 failed - 4 passed	MSHD
8-15-38	4A - 10A	18.7	Bureau of Public Roads
8-9-38	Stock pile 4A	Passes test	R. W. Hunt Co.
8-27-38	14 Ledge Rock	8 failed-4 passed-2 questionable	MSHD
12-1-38	15 Ledge Rock	10 failed-1 passed-4 questionable	MSHD
6-14-38	4A	1.67	Considered failed by MSHD due
6-14-38	4A	2.01	to split, cracked and flaked particles
8-30-39	4A - 10A	9.8	Bureau of Public Roads
8-30-39	4A - 10A	9.8	Bureau of Public Roads
12-9-39	4A - 10A	17.2	Bureau of Public Roads
6-19-46	20 samples	I-V(2.24	(
6-28-46	Ledge Rock	1-5(6.36	(Meets specification
8-16-46		V-Z(5.15	(
1-8-47		7.33	Meets specification soundness
6-22-50	6B	13.19	MSHD
5-10-51	6B	16.09	MSHD
6-12-51	4A	11.30	MSHD
6-20-51	10A	12.78	MSHD
7-2-51	10A	11.64	MSHD
9-18-51	4A-6A-10A	15.98	North stripped face MSHD
9-18-51	10A	10.64	South face MSHD
9-18-51	10A	12.38	West face MSHD
9-22-51	10A	11.13	West face MSHD
10-1-51	4A and 10A	8.36	West face MSHD
10-4-51	10A	12.21	West face MSHD
10-5-51	10A	11.91	West face MSHD
10-10-51	10A-6A	14.50	Research Laboratory

cause a slight increase in air content over that of the natural aggregate. The results of the study are given in Table VII. Monon stone gave the greatest increase in air content, apparently due to petroleum in and on the stone particles.

Approaches to Main Street Bridge

In regard to the question as to why the better durability of the concrete in the approaches as compared to that in the bridge structure, the following construction difference must be taken into consideration:

1. The approaches were constructed as a concrete pavement slab with all associated controls and construction procedure which allow for better concrete such as lower slump, vibration only at edges and joints, less handling of mixture, better control of mixing process and finishing.

2. Natural aggregates well within the soundness requirements were used in the approaches.

3. The cement-mortar ratio of the concrete used in the approaches was considerably higher than that in the bridge structure.

Concluding Statement

On the basis of this study, it is believed that the premature scaling on the Main Street Bridge is the result of several factors acting singly and together, namely:

1. Variable air content of the concrete.

2. The presence of a high percentage of non-durable coarse aggregate pieces.

3. The failure of thin mortar films and pointing mixtures to withstand salt action.

4. The early application of de-icing salts to the surface in the fall and winter of 1949.

5. Concrete of variable quality resulting from construction irregularities.

6. Leaner mortars of limestone mixtures, compared to those for natural aggregates.

TABLE VII

Source of Aggregate	Slump inches	Air Content percent
American Aggregate, Green Oak	1½	4.1
American Aggregate, Green Oak	2½	4.0
Wallace Stone, Bay Port	3¼	4.95
Inland Lime and Stone, Port Inland	2	5.5
Monon, Indiana	2½	6.25
E. P. Brady, Millersburg (Big Cut Pit)	2½	5.0

Mix Design

Coarse aggregate made to average 6A grading

5.5 sacks cement, Peerless Regular Cement

.01 percent NVX for air-entrainment

$b/b_o = 0.76$

RWC = 1.15 for 2-3 inch slump

F.A. - Boichot 2NS, sp. gr. 2.68, absorption 0.81