A STUDY OF THE EFFECTS OF CONSTRUCTION PRACTICES ON BRIDGE DECK CONSTRUCTION

Philip D. Cady and John C. Theisen, Pennsylvania State University

During the period of 1964 through 1966 seven concrete bridge decks were observed under construction in Pennsylvania. Slumps and air contents were recorded for every truckload of concrete that went into the decks. Also, the precise location of placement of every truckload of concrete was recorded, and note was taken of construction practices that might adversely affect the performance of the concrete.

The 7 bridge decks were subsequently inspected during the period of 1967 through 1969, and the various forms of deterioration were observed and recorded. In this way it has been possible to determine rates of deterioration and to relate concrete properties and construction practices to observed deterioration.

In this paper, details of bridge construction pertinent to durability and observations made during subsequent inspections are covered for each deck. Finally, the construction difficulties that lead to durability problems, based on the observations made in this study, are summarized.

BRIDGE 1

This structure is a 4-span, prestressed box-beam bridge. The span lengths are 34 ft, 76 ft, and 36 ft, simply supported. The roadway widens from 34 ft at the south end of the deck to 49 ft at the north end because of an exit ramp. The average daily traffic (ADT) is 800. The deck was constructed in 1965.

Construction Techniques

The deck slab and the diaphragms were placed as a monolith using ½-cu yd bottom dump buckets and a crane. Transit mix concrete was used, and the mix water was added at the job site. Hand vibrators were used to compact the concrete. Screeding was done with a longitudinal screed with an attached vibrator system. The screed traveled on rails set in the parapet areas. The screed could be telescoped and thus adjusted to the varying width of the deck. Final finishing was performed from a work platform traveling behind the screed; a burlap drag was suspended from this platform. The deck was covered with wet burlap and a water spray was employed for curing.

Field Observations

Each truck was observed during mixing, and the batched concrete was tested for slump and air content. Mixing times ranged from 7 to 13 min. The maximum wait time

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after mixing to start of placement was 17 min. Slumps ranged from 1 to 5¼ in. on span 1, from ½ to 3½ in. on span 2, from 1¼ to 3 in. on span 3, and from ½ to 3 in. on span 4. Air contents, as determined by the pressure meter, varied from 2.7 to 7.1 percent. The specification requirements with respect to slump and air content were 2 in. ± 1 in. and 6.5 percent ± 1.5 percent respectively.

In spans 1 and 2, the concrete stiffened rapidly, and normal screeding left the surface uneven requiring considerable reworking to obtain a smooth finish. Air temperatures ranged from 70 to 80 F during the placement, and the winds were periodically high. These conditions were undoubtedly a factor in the difficulties encountered in finishing.

Adjustment of the mix proportions to permit a higher water-cement ratio and omission of the set retarding admixture appeared to improve the workability of the concrete on spans 3 and 4. However, periodic high winds still caused some areas to set up rapidly on span 3, and sprinkling had to be used to aid finishing.

The top reinforcing steel in this bridge deck was not adequately supported (Fig. 1). The weight of the construction crew caused the reinforcing mat to sag. In some areas the mats almost touched the lower reinforcing steel.

On each span, the placing progressed well from section to section until the last sections of the span were reached. Then, in each case, there was a delay in the arrival of the transit mix trucks, and the placement time doubled. This delay increased the finishing time, and as a result the deck surface required considerable reworking. On each span the start of cure on the sections first completed was delayed. On some of the sections placed early in the day, there was as much as a 2-hour time lapse between the completion of finishing and the start of curing.

1967 Survey

The first survey of this deck revealed a great number of transverse cracks, almost 130 in all, over the 230-ft deck (Fig. 2). It was hypothesized that the cracking was due to the high winds and temperatures during placement. The bridge was 2 years old at the time of the first survey and had experienced 2 winter seasons.

1968 Survey

In 1968 the total number of cracks increased to almost 180. Two areas with extensive cracking were found by a pachometer survey (Fig. 3) to have very shallow top steel with average covers of 1.10 and 1.20 in. respectively. A third area, with slight cracking, had an average cover of

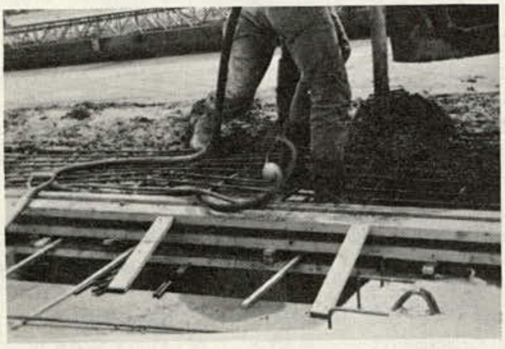

Figure 1. Inadequately supported reinforcing steel.

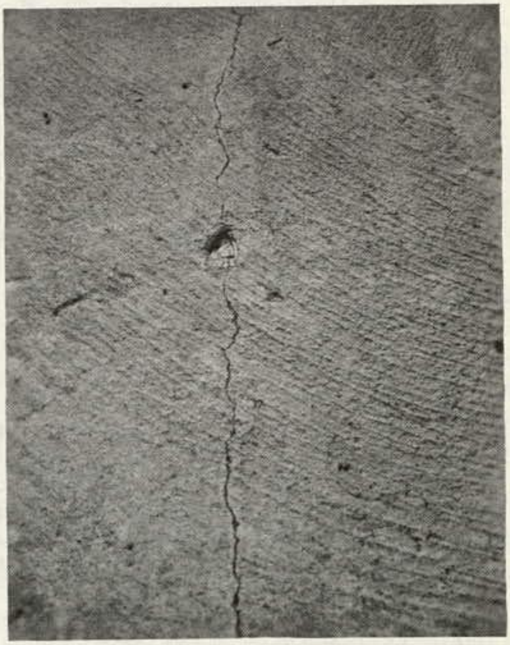

Figure 2. Transverse crack over steel (note pop-out).

1.20 in. but had a wide range of 0.90 to 1.55 in. This indication of bowed reinforcing steel is supported by the original observations during construction. A fourth area, with no cracking, had an average cover of 1.60 in. There was a definite correlation between depth of steel and location of cracks.

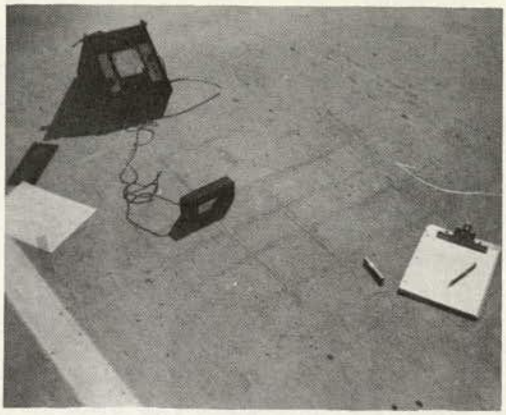

Figure 3. Pachometer and reinforcing steel layout.

1969 Survey

The 1969 survey showed that the total number of cracks had increased to 225, or an average of 1 crack per foot of deck. Surface mortar deterioration (SMD) also increased sharply. In the previous 2 years, only 1 small area had been affected by SMD and that only slightly. In 1969, three-fourths of the deck displayed slight to moderate SMD. In addition, 1 fracture plane and 1 small pothole had appeared in the same spot on the deck.

BRIDGE 2

This structure is a simple 5-span, prestressed box-beam bridge. The span lengths are 48 ft, 55 ft, 53 ft, 63 ft, and 63 ft. The roadway width is 32 ft and the ADT is 300. The deck was placed on July 20 and 21, 1966.

Construction Techniques

The deck slab was placed by using a truck crane and two 1-cu yd buckets. Transit mix concrete was brought to the job site in 7-cu yd trucks, and the mix water was added at the site. A hand vibrator was used to compact the concrete, and the screeding was done with a longitudinal screed. The final finishing was performed with bull floats and hand floats from a work platform following the screed. A burlap drag was suspended from the platform to provide the final surface texture. The deck was covered with a double thickness of burlap, and water sprays were used for curing. The deck was built with steel stay-in-place (SIP) forms.

Field Observations

The rate at which the concrete was delivered to the job was such that there were usually one or more trucks waiting to discharge. The mixing times ranged from 8 to 17 min. The maximum wait time was 28 min, but this delay was due to locating the crane in a more favorable position. The slumps ranged from 2 to $5\frac{1}{2}$ in. on span 1 (average $3\frac{1}{2}$), $1\frac{1}{2}$ to $8\frac{1}{4}$ in. on span 2 (average $4\frac{1}{2}$), $1\frac{1}{4}$ to 6 in. on span 3 (average $3\frac{1}{4}$), $2\frac{1}{4}$ to 4 in. on span 4 (average 3), and 2 to 5 in. on span 5 (average 3). The lowest air content determined by the pressure meter was 4.2 percent, and many went off the scale, which had a maximum reading of 7.5 percent.

The temperature was in the 90's during the first day of construction and in the 80's the second day. The highest concrete temperature recorded was 84 F. As the air temperature rose during the first day, the concrete required more water. As the water requirements rose, so did the air contents.

Placement during the second day was completed in the morning when the temperature was in the 80's. The water requirements were generally constant as were the slumps. The air contents were generally constant but rather high.

During placement of the deck and as the men were walking and working on the reinforcing steel, it appeared to be adequately supported and tied. In all the cases where the depth of steel below the concrete surface was measured, it was at least 2 in.

Although the concrete had a high slump immediately after discharge from the mixing trucks, it had stiffened considerably by the time it was placed on the deck. The high air contents also probably hampered finishing by reducing bleeding. As a result, normal screeding left the surface open, and sprinkling and reworking were required to obtain a smooth surface. High air temperatures were a major factor in the difficulties encountered in finishing. One section in span 1 was observed to have developed an initial set before curing procedures were initiated.

1967 Survey

The 1967 survey showed slight SMD developing over about 20 percent of the deck. The affected areas seemed to correlate with recorded locations of high slump loads. One crack was found. The bridge was 1 year old at the time of this survey, and it had experienced 1 winter season.

1968 Survey

This survey revealed an increase in SMD to about 35 percent of the deck. The lone crack in the deck remained the same. The depth of the top reinforcing steel was studied with a pachometer and found to be adequate and uniform. This is supported by the field observations in 1966. Two areas were surveyed, and the average depths were 1.90 and 1.76 in. respectively. Furthermore, all the values in each area were ±0.10 in. from the average. The steel under the crack, however, was found to be less than 1.5 in. deep and was probably a factor in the formation of the crack.

1969 Survey

The SMD had greatly increased to the extent that it extended over the entire deck. Pitting was widespread over the deck but was light on the whole. This pitting was for the most part of very small diameter (1 to 2 mm), but some rather large pop-outs were also found. A second transverse crack was found a few feet away from the one first observed in 1967. SMD is by far the worst problem on this deck. This is apparently a result of the high-slump concrete and the finishing practices used in the construction of the deck.

BRIDGE 3

This structure is a prestressed I-beam bridge. The roadway is 40 ft. This bridge was constructed in 1964 and opened to traffic in the middle of August 1967. The ADT is 2,700.

Construction Techniques

The deck slab and the diaphragms were poured as a monolith by using concrete buggies and a system of portable platforms. Transit mix concrete was used, and mix water was added at the job site. Compaction and screeding were accomplished with hand vibrators and hand screeds with attached vibrators. The hand screeds traveled on rails set in the roadway area at finished grade. Bull floats and hand floats were also used in finishing. Final finishing was performed from a work platform that traveled on rails set in the parapet area. A burlap drag was suspended from this platform. Curing consisted of a wet burlap cover and a water spray.

Field Observations

Mixing times ranged from 6 to 18 min. The maximum wait time after mixing to start of placement was 44 min. Slumps ranged from 1 to 4 in. Air contents as determined by the pressure meter varied from 3.5 to 7.5 percent.

The concrete set up rapidly. This may have been due in part to the 80 F temperatures and high winds present during placement. The individual rail sections used as guides for the screeds were too long, with the result that the first concrete placed in a section developed initial set before the screeding reached the end of a rail section.

These rail grooves were then patched and finished (Fig. 4). The delay caused by the screed rails resulted in more than half of the deck surface being sprinkled to aid finishing. During the early stages of the placement there was a considerable time lapse between completion of finishing and start of curing. Also, the type of initial cure, a single thickness of wet burlap, did not appear to be adequate.

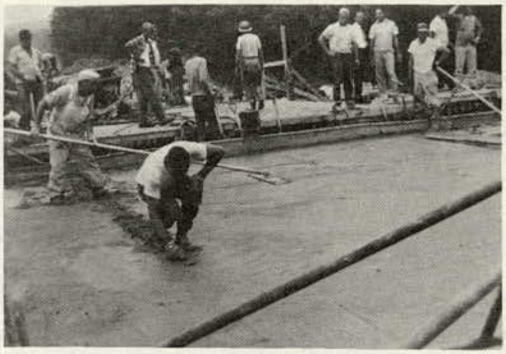

Figure 4. Finishing of void remaining on removal of screed rail (note that concrete has gained initial set).

1967 Survey

In 1967, even though it had not been opened to road traffic yet, the bridge had slight SMD over 20 percent of its surface. Four minor cracks were found. The bridge was 3 years old at the time of this survey, and it had experienced 3 winter seasons.

1968 Survey

In 1968, the SMD remained constant even though the bridge had been opened to traffic. However, the number of cracks increased from 4 to 18. The depth of the top steel was checked in 3 areas. The first 2 areas had average depths of 1.95 and 2.00 in., but the third had an average depth of only 1.65 in. Evidence of minor bowing was found.

1969 Survey

The SMD had increased in depth over about 10 percent of the deck. This area of the deck contained concrete that had a high slump and was excessively vibrated according to notes taken during construction. Most SMD was found in low areas of the deck, where excess water would be likely to collect. The number of cracks increased from 18 to 28. These were concentrated in the water tables at either end of the deck, but a few were found in the roadway and in the middle of the deck.

BRIDGE 4

This structure has 4 simple spans, 2 of 27 ft and 2 of 54 ft. The deck is supported by prestressed box beams. This bridge deck was placed on August 25 and 26, 1966, and the ADT is 6,000.

Construction Techniques

A truck crane and two 1-cu yd buckets were used to place the concrete on the deck. The transit mix trucks were used to deliver centrally mixed concrete. On the first day, 9-cu yd capacity trucks were used, and those on the second day had a capacity of 11 cu yd. The screeding was done with a mechanical screed that traveled on rails set in the parapet area. A burlap drag was used to attain the final surface texture. Burlap and water soaking were used for curing. Steel SIP forms were used.

Field Observations

On the first day placement was begun at the center of the bridge (the end of span 2) and proceeded to span 1; the second day, spans 3 and 4 were placed. In general, the air contents were high with an average of 7.1 percent. Five of the 28 truckloads tested had air contents over 8 percent. Slumps ranged from $1\frac{3}{4}$ to $5\frac{1}{2}$ in. The finishing of the deck on both days of placement required sprinkling. On the first day the temperatures were in the low 80's, and there were periodic high winds. Some drying was observed on the surface of the first section placed. Because of the delivery delays on the second day, the screed could not close the surface and more sprinkling was required.

1967 Survey

The 1967 survey showed no SMD, cracks, potholes, or fracture planes. The main defect was extensive pitting, which was evident over most of the deck. This pitting appeared to be caused by air bubbles that had been exposed near the surface; the pits were very small in diameter, averaging perhaps 2 mm. This bridge was 1 year old at the time of this survey.

1968 Survey

The 1968 survey showed a great deal of change after 2 years under traffic. The entire deck suffered from slight SMD. The pitting increased slightly, probably due to the SMD. In addition, 1 minor crack appeared. Three areas were checked with a pachometer for depth of steel. One had a range of 1.75 to 2.25 in. with an average of 2.0 in., which was the design value. The other two, however, had ranges of 2.55 to 2.80 in. and 2.50 and 2.70 in. respectively. The averages of 2.70 and 2.60 in. were considerably over the design value. Furthermore, the readings indicated that the steel mat had been bowed during construction.

1969 Survey

The SMD remained widespread and uniform, but did not appear to increase in depth. The pitting first noticed in 1967 had become severe over the entire deck (Fig. 5). No additional cracks were found. The SMD was concentrated in the wheel tracks; the coarse aggregate, a limestone, appeared to be wearing down as quickly as the cement paste.

BRIDGE 5

This structure is a 3-span, prestressed I-beam bridge with span lengths of 61, 99, and 68 ft. The width of the roadway is 28 ft. This bridge was observed under construction in 1965. The ADT is 4,500.

Construction Techniques

The deck slab and the diaphragms were placed as a monolith by using concrete buggies and a system of portable platforms. Transit mix concrete was used, and mix water was added at the job site. Both 6- and 9-cu yd trucks were used. The skewed portion of span 1, the most southerly, was compacted with hand vibrators and hand finished. Rails were set in the roadway at finished grade as a guide to the finishers. The remainder of the deck, through the end of span 3, was compacted by hand vibrators, mechanically screeded, and then hand finished. A vibrating screed was used. This screed traveled on elevated rails set in the parapet and median areas. Bull floats and hand floats were used for finishing. A burlap drag was used to give the final surface texture. Curing consisted of a wet burlap cover (double thickness) and a water spray.

Field Observations

Mixing times for the 6-cu yd mixers ranged from 7 to 33 min, and for the 9-cu yd mixers, from 11 to 22 min. The maximum wait time from completion of mixing to start of placement was 42 min. Slumps ranged from 1 to 3⅝ in. on span 1, from 2 to 6¾ in. on span 2, and from 1 to 6¼ in. on span 3. Twenty of the 32 slumps taken during placement exceeded 3 in.

The tests indicated that an adequate amount of air was entrained in the concrete.

Figure 5. Pitting and surface mortar deterioration.

The average air content, as determined by the pressure meter, was 5.07 percent. The air contents ranged from 3.00 to 7.50 percent.

The placement of the first span suffered numerous delays. The platform runners used for the concrete buggies were not properly positioned, and as a result there were holdups in moving the concrete onto the deck. These delays in turn caused finishing problems. Prior to the placement of spans 2 and 3, the platform runners were rearranged. This greatly reduced the delay time and finishing problems.

The curing was begun late on each span. The sections completed early in the day were exposed, following finishing, for periods of from 2 to 3 hours.

Difficulties were encountered with the 9-cu yd transit mix trucks. The uniformity of the concrete varied within the individual mixes and periodic remixing was required. Two of these 9-cu yd loads were rejected during the placement of span 2; one because it was overtime and the other because it was too full to mix properly.

1967 Survey

This deck was surveyed for the first time in 1967 after 2 years of exposure. It was in very good condition, showing only 3 slight diagonal cracks, 2 slight transverse cracks, and some pattern checking.

1968 Survey

The bridge had just been opened to traffic but no SMD had appeared yet. One slight crack became moderate. The deck was studied with a pachometer, and it was found that the top steel was from 2.30 to 2.60 in. deep with an average of 2.55 in. This was considerably above the design value of 2 in. Furthermore, the study showed that the mat had been bowed during construction.

1969 Survey

In 1969, slight SMD was found over about half the deck and severe SMD at one location. The latter occurred at the exact spot where, during construction, it had been noted that "water ran onto the deck and drained into scupper." The cracking, both diagonal and transverse, had not progressed.

BRIDGE 6

This is a 3-span, continuous, prestressed box-beam structure. It has one 40-ft span and two 20-ft spans. The width of the deck is 40 ft, and the ADT is 6,500. The deck was observed under construction on August 15, 1966.

Construction Techniques

The deck slab and diaphragms were placed by using a truck crane and two 1-cu yd bottom dump buckets. Two 7-cu yd and one 6-cu yd transit mix trucks were used. Two hand vibrators and a mechanical screed were used to compact the concrete. The screed traveled on rails that were set in the deck. A double thickness of burlap and a sprinkling system were used for curing. The deck was built with steel SIP forms.

Field Observations

Mixing times ranged from 4 to 15 min. The maximum wait time was 15 min on span 2. The slumps ranged from $\frac{3}{4}$ to $4\frac{3}{4}$ in. Eight of the 23 slumps were recorded as greater than 3 in., but the overall average was $2\frac{3}{4}$ in. The lowest air content by the pressure meter was 3.3 percent, and several could not be determined because they were higher than the scale reading of 7.5. The third span had the highest slumps and the highest air contents.

Three trucks were used to carry the concrete to the job site, and there were delays in their arrival throughout most of the day, particularly during placement of the last span. As a result, the mixing times of the trucks used on that span were generally lower than on the other 2 spans. The trucks were seldom in a level position during mixing.

The highest air temperatures recorded at the job site were approximately 90 F. The concrete temperatures increased as the air temperature rose and reached a maximum of 92 F. There was no significant increase in the amount of mixing water added during the placement as a result of changes in the air temperature. There were delays in placement, and the finishing of the deck required sprinkling with water in 1 section.

Placement of the first section was begun at 8:53 a.m., and curing was begun at 1:53 p.m. Before the curing, several dry spots were observed in that section.

1967 Survey

The 1967 survey revealed 15 moderate cracks in the deck even though the bridge had not been opened to road traffic yet. The cracks were concentrated in the middle of the deck, an area of negative moment, and it was therefore theorized that the cracking might be a structural problem rather than one of deterioration. In addition to the cracking, SMD was found over approximately half of the deck. There was a full-depth replacement of an 11- by 35-ft section of the deck for unknown reasons. Unfortunately, this concrete was not of very good quality as evidenced by heavy popping-out and scaling. This bridge was 1 year old at the time of the initial survey.

1968 Survey

In 1968 the cracking increased slightly in severity, with 3 cracks going from slight to moderate. However, with the bridge open to traffic, SMD was extended to all sections of the deck. The patched area was scaling extensively. The cover over the top reinforcing steel was checked in 3 areas. The cover seemed adequate, ranging from 1.75 to 2.05 in. with an average of 1.90 in. One area gave indications of having bowed steel mats. In that area the cracks were found to be located directly above the transverse bars.

1969 Survey

The SMD increased in depth over about three-fourths of the deck. There appeared to be a good correlation between slump and severity of SMD. Four additional slight cracks had appeared.

BRIDGE 7

This bridge is a welded-plate girder structure having 7 spans, two of 151 ft and five of 184 ft. The ADT is 1,700. The placement of a portion of this deck was observed on September 29 and 30, 1966.

Construction Techniques

The concrete was carried to the job site and mixed in 9-cu yd trucks and transported to the placement location by a conveyor system. A hand vibrator was used for compaction, and a longitudinal screed was used for the screeding. Burlap covered with a plastic blanket was used for curing.

Field Observations

Bay 18 on span 4 was placed on September 29, and bays 19 and 20 on spans 3 and 4 were placed on September 30, 1966. On the first day, the slumps averaged 3¼ in., and the air contents by the pressure-meter method ranged from 5.7 to 6.9 percent. On the second day the slumps ranged from 2 to 5¼ in. and the air from 4.4 to 8.6 percent.

1967 Survey

In 1967, the bridge had not been opened to traffic yet and was in nearly perfect condition except for a few surface imperfections due to finishing. The bridge was 1 year old at the time of the initial survey.

1968 Survey

The 1968 survey showed light SMD in 3 areas and 8 cracks, mainly at the edges of drains. Two areas were checked with the pachometer. The first had a uniform cover of 1.45 in., but the other varied from 1.45 to 1.80 in. with an average of 1.65 in., indicating bowing of the steel mat. All readings were below the design value of 2 in. No traffic had been on the bridge yet.

1969 Survey

In 1969, the number of transverse cracks remained at eight, and some map cracking appeared in the water tables. However, slight SMD extended to 28 of the 38 survey sections observed on this deck. Because of the conveyor-belt method of placement, it was not possible to locate the concrete from each truckload on the deck. Therefore, no conclusions can be drawn. However, the SMD was fairly evenly distributed, so it is doubtful that there is any correlation between slump and SMD.

SUMMARY

The main practices and adversities observed in conjunction with bridge deck construction that were considered to be detrimental to durability included sprinkling and reworking or overworking deck surfaces, high winds and high ambient temperatures, high slumps, low air contents, shallow placement or inadequate support of reinforcing steel, and improper or late application of curing procedures.

Obviously, the first 4 factors are interrelated to various degrees. The observed construction practices and materials and weather factors are given in Table 1; the deterioration ratings for the bridge decks after 3 years of exposure are also given. These data tend to indicate that high slump concrete and sprinkling or overworking the surface lead to surface mortar deterioration. Also, it is shown that cracking seems to be associated with conditions that produce premature set, such as high winds and temperatures and delays in applying curing procedures. Such cracks almost invariably occur over the top reinforcing steel, and their frequency of occurrence is inversely proportional to the depth of cover of the steel.

Of the 3 bridges that continue to show very low incidence of cracking (bridges 2, 4, and 5), only one was not subjected to the conditions that appear to enhance cracking (bridge 5). The other two, interestingly, were built with steel SIP forms. This apparent relationship between reduced transverse cracking and use of SIP forms has been

TABLE 1

SUMMARY OF CONSTRUCTION OBSERVATIONS AND DETERIORATION AFTER 3 YEARS

Factors and Observations	Bridge Number						
	1	2	3	4	5	6	7
Materials							
Percentage slumps > specification	5	53	14	39	43	35	68
Percentage air < specification	66	5	48	0	46	39	11
Construction							
Minimum mixing time, hr	0.12	0.13	0.10	–	0.12	–	–
Maximum waiting time, hr	0.30	0.47	0.73	–	0.70	0.25	–
Maximum finishing time, hr	3.0	2.5	2.25	2.0	2.0	2.5	–
Maximum time to start of curing, hr	2.25	2.0	3.75	3.0	3.0	2.5	–
Minimum rebar cover, in.	0.90	1.76	1.65	1.75	2.30	1.75	1.45
Sprinkling to aid finishing	X	X	X	X		X	
Reworking of surface	X	X		X			
Inadequate rebar support	X			X	X		
Weather							
High ambient temperatures	X	X	X	X		X	
High winds	X		X	X			
Observed deterioration (at age 3 yr)							
Weighted SMD per section	0.02	1.24	0.79	0.97	0.00	2.70	0.74
Transverse cracks per 100 ft	75	1	3	0	2	27	3

observed previously in studies of bridge deck performance in Pennsylvania. Plots of SMD and transverse cracking versus age are given in Figures 6 and 7. To permit valid comparison, these data have been weighted for severity of SMD and expressed on a unit basis.

The major construction requirement, from the standpoint of placing and finishing a suitably durable deck surface, is a concrete mixture that is inherently durable and can be manipulated without the necessity for sprinkling or overworking to produce desired surface characteristics. Unfortunately, the aforementioned attributes are not wholly compatible. For example, an inherently durable mixture (assuming that the aggregates are suitably frost resistant and nonreactive) requires a relatively low slump and an air content of perhaps 5 to 8 percent. However, adverse environmental conditions (high temperatures, low relative humidities, high winds) will result in slump losses between delivery and finishing. In other words, under adverse conditions it is often necessary either to give up a little inherent durability (increase the slump) or to permit sprinkling in order that the surface may be finished to the proper grade and smoothness.

Although the problem can be alleviated to varying degrees by using sunshades and windbreakers, cooling the concrete ingredients, and using set retarders, the slump loss generally cannot be totally countermanded. The difficulty involved in attempting to consistently obtain an inherently durable concrete mixture is illustrated in the slump and air content data given in Table 1. An interesting fact about these data is the apparent correlation between the frequency of high slumps and high air contents. Although the correlation for the particular data given in Table 1 is significant at the 95 percent confidence level, the danger of suggesting a cause and effect relationship between the

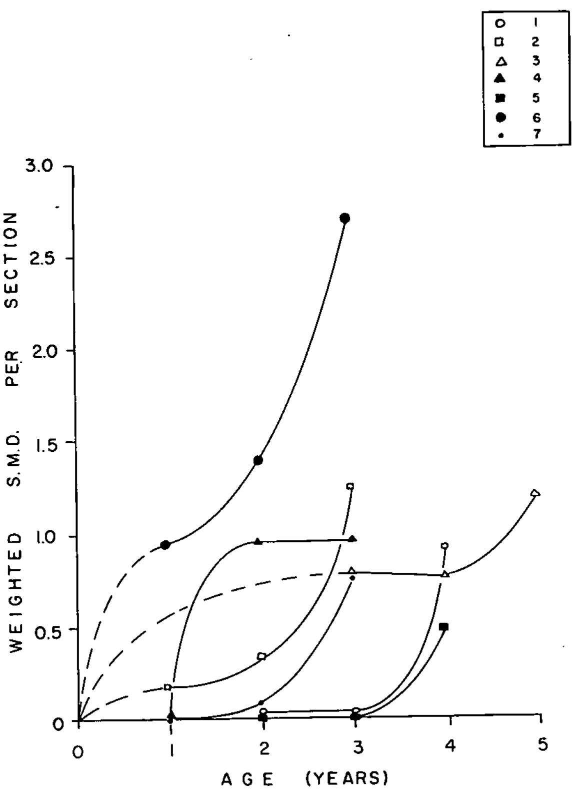

Figure 6. Surface mortar deterioration versus age.

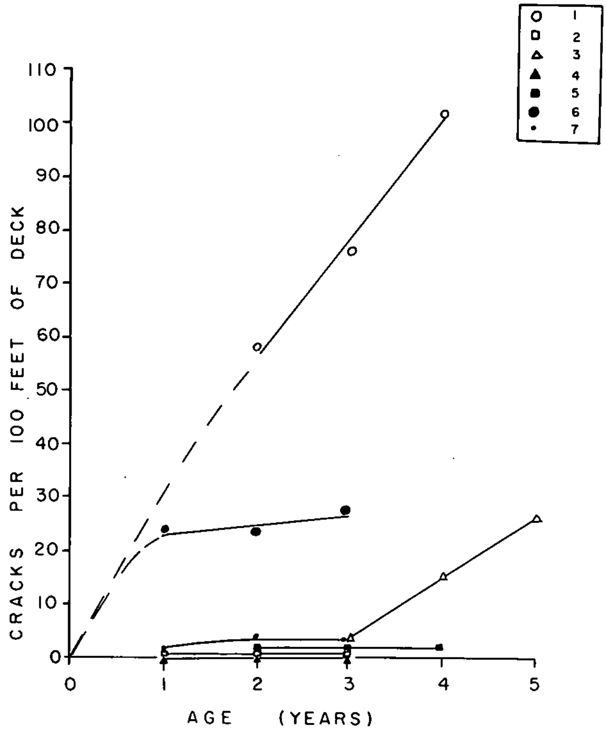

Figure 7. Cracking versus age.

2 variables is obvious. However, this rather interesting comparison does suggest that perhaps we are too optimistic to expect that we can simultaneously control the 2 factors that influence inherent durability (slump and air content) in the field, under adverse environmental conditions, while at the same time providing the contractor with a material that will remain workable through the finishing operation.

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