AN EVALUATION OF THE COMPARATIVE EFFECT OF CHLORIDES ON THE DETERIORATION OF REINFORCED CONCRETE SLAB AND CONCRETE-FILLED GRID BRIDGE DECKS

by

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ABSTRACT

An Evaluation of the Comparative Effect of Chlorides on the Deterioration of Reinforced Concrete Slab and Concrete-Filled Grid Bridge Decks

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An assessment of the effects of deicing salts on the deterioration of two types of bridge decks was undertaken in this investigation. Forty-two reinforced concrete slab bridge decks on the Penn-Lincoln Parkway and Interstate 79 were sampled and analyzed for chloride concentrations as well as evaluated for physical distress in their riding surfaces. Eight concrete-filled bridge decks were similarly tested.

The results indicated that, although concrete-filled grid decks experienced high chloride concentrations, no physical deterioration was evident due to the corrosive effects of deicing salts. Reinforced concrete slab decks, however, exhibited a large percentage of surface spalling due to excessive chloride concentrations.

STATEMENT OF THE PROBLEM

The major bridge deck deterioration problem is delamination of the concrete near the level of the top mat of reinforcing steel and the subsequent spalling of surface concrete. Research has shown that the most prevalent cause of this distress is corrosion of the reinforcing steel due to the intrusion of chlorides into the concrete from repeated deicer applications for snow and ice removal.

This research has led to the development of methods (waterproofing membranes, polymer-impregnated concrete, cathodic protection, galvanized and epoxy-coated reinforcing steel, etc.) for obtaining improved durability of existing and future bridge decks. Currently the FHWA and the various transportation agencies are researching these methods for acceptance in construction and reconstruction of bridges.

Although the initial test results of some of these new procedures are encouraging, they do not provide the cure-all presently being sought.

In the meantime, millions of dollars of tax monies are being wasted on bridge decks that may not last five years, not to mention the hardship caused motorists and the economic effect on those communities served by a bridge that must be closed to traffic in order to replace a deteriorated deck. A good example is the current reconstruction of the Penn-Lincoln Parkway in Pittsburgh, Pennsylvania.

Most research to date has been conducted on reinforced concrete slabs, which are the most common type of bridge deck construction. And this research has been generally directed at stopping or abating the intrusion of chlorides into bridge deck concrete.

Surprisingly little or no research has been conducted on different designs that chlorides will not affect, especially since concrete-filled grid bridge decks have been in existence over forty years and do not seem to be suffering from the deteriorating effects of deicing salts.

Concrete-filled grid bridge decks have seen very limited use by highway departments throughout the United States. One reason may be that they were generally more expensive than the conventional reinforced concrete slab. Also, a few of the earlier grid decks did not perform satisfactorily due to inadequate welding of grids to supporting steel, splicing details, and provision of transverse steel. This gave them a bad reputation and discouraged their use.

However, with the additional design features required to protect conventional slabs from salt and the improved design details of grid decks, concrete-filled grid bridge decks are an economical solution to deterioration caused by deicing chemicals.

Therefore, the purpose of this research is two-fold. First, this study will evaluate the chloride concentration at the depth of reinforcing steel of reinforced concrete slab and concrete-filled grid bridge decks. The laboratory analysis of concrete samples will determine whether chlorides are present in sufficient quantities to cause deterioration of both bridge deck types. The chloride concentration will indicate the potential for corrosion and will be correlated to the physical survey of each deck to determine whether deterioration has occurred.

Secondly, this study will develop an awareness among responsible highway officials and researchers that there exists a bridge-deck type that has performed well under the debilitating effects of chlorides for over forty years. Also, it will show that concrete-filled grid decks may offer the fastest and most economical solution to the bridge deck deterioration problem.

The Corrosion Process

The chloride ion does not attack reinforcing steel in concrete. It does, however, provide the environment for the natural conversion of iron to iron (ferrous) oxide, the predominant form in which it occurs in nature.

Reinforcing steel does not corrode in an uncontaminated (no chloride) concrete because of the high pH (twelve to thirteen) afforded by the soluble calcium hydroxide (lime) originally present in the cement. This high pH initially forces the formation of ferric oxide (mill scale) on the surface of the steel. This oxide of iron is not detrimental because the reaction ceases after a surface film is formed and no further degradation occurs. And, in fact, rebars have been observed with original mill scale after twenty-five years in place.

However, when soluble chlorides are introduced into the concrete, this protective high pH environment begins to be neutralized. When sufficient chloride is present to destroy the necessary alkalinity and the normal passivity of the iron, the natural transformation of iron to rust occurs along with its associated increase in volume. The affected steel oxidizes and expands two and one-half to fifteen times in volume. This expansion causes tensile stresses to be exerted against the surrounding concrete. When these stresses exceed the tensile strength of the concrete, delamination and subsequent surface spalling occur.

The entire process of oxidation has been duplicated under laboratory conditions at the Fairbanks Research Station, McLean, Virginia, a facility of the Office of Research, Federal Highway Administration.

The Fairbanks Station, after running time-percolation tests, determined a corrosion profile based on the amount of chloride ion recoverable at the top level of reinforcing steel for existing structures requiring reconstruction. It indicates the following:

(a) A concrete deck containing less than one pound of salt per cubic yard of concrete can almost surely be restored. (The qualification is necessary because other sources of deterioration may be causing damage simultaneously.)

(b) With between one and two pounds of salt per cubic yard of concrete, the deck may be salvageable. Federal funds are allowed for rehabilitation work, if practical.

(c) Decks containing more than two pounds of salt per cubic yard of concrete should be scheduled for replacement at an early date.[1]

According to FHWA policy, test results have generally established that the corrosion threshold (not necessarily destructive corrosion) is approximately 1.0 to 1.3 pounds of free chloride per cubic yard at the level of the rebars for typical bridge deck concrete. However, 2.0 pounds is considered an adequate level for bridge deck replacement.[2]

Sampling Procedure

A systematic procedure for investigating the quality of reinforced concrete slab and concrete-filled grid bridge decks was based on two parameters:

(a) chloride content;

(b) percentage of traffic lane area spalled.

Forty-one reinforced concrete slab bridge decks were sampled on the Penn-Lincoln Parkway and Interstate 79 (I-79). Also, one bridge deck on the Fort Duquesne Bridge was included because its reinforced concrete slab was designed with a waterproof membrane. Waterproofing membranes are a product of some of the research completed to date on methods to prevent intrusion of chlorides into the deck. Test results will provide some insight into their effectiveness.

The Parkway bridges were chosen because of the comparative variables associated with their service life. All the bridges tested were constructed similarly and experienced the same traffic conditions; most importantly, it is reasonable to assume that relatively similar quantities of salt were applied to all decks.

The I-79 structures were sampled for the same reasons as the Parkway bridges. However, they have experienced a shorter salting period due to their newer construction. Also, quality control during construction was vastly improved during that period.

Therefore, it is hoped that their selection will provide knowledge as to the effects of chlorides during an early period in the service life of a bridge deck. Also, their selection should show whether or not their concrete, resulting from better quality control, has improved the ability of bridge decks to retard chloride intrusion.

All eight concrete-filled grid decks in PennDOT's engineering district 11-0, with a service life greater than one year, were sampled.

The chloride content at the depth of reinforcing steel is the most important parameter being evaluated in this study. The chloride content represents a potential for the corrosion of reinforcing steel even without further salt additions. It is important to understand that once the chloride content corrosion threshold has been reached, this does not mean that active corrosion is occurring. It does mean that the potential for corrosion is there and that once the threshold has been reached, it is an irreversible process.

The second parameter will indicate, by documenting actual physical distress, that the corrosion threshold has been reached and that active corrosion is occurring. Physical distress is termed surface spalling. Surface spalling is defined as the separation and removal of relatively large concrete segments from the deck surface that impedes riding quality.

The top layer of deck reinforcement is often exposed and examination of the spalled area often indicates that the reinforcement is an integral factor in the occurrence of the spall.

Surface spalling is determined as a percentage of the total traffic lane area by the following formula:

$$\% \text{ spalled} = \frac{\text{area of spalls}}{\text{area of traffic lanes}} \qquad (1)$$

Generally, a deck with greater than five per cent of its traffic lane area spalled will be overlaid with an asphalt wearing surface to improve its riding quality. Decks with overlays will be designated as such in the per cent spalled column of the test results tables. Decks with five per cent or greater of the deck visibly spalled are considered to be undergoing extensive active corrosion.

Most of the concrete-filled grid decks have asphalt overlays. This is due to the slipperiness of the grid itself, because of the cupping action of the concrete within each grid resulting from vehicle wear. The asphalt wearing surface is not indicative of surface spalling. In fact, none of the tested grid decks exhibited spalls, which was substantiated by reviewing the past maintenance history of each bridge.

Sample Acquisition

Collection of test samples consists of recovering pulverized concrete dust particles in a zone one-half inch above the top mat of reinforcing steel.

First, a reinforcing bar is located and its depth is determined by using a Pachometer (metal detection device). A rotary percussion drill with a three-quarter inch carbide steel-tipped bit is used to drill within one-half inch of the reinforcing bar. A vacuum syringe is then used to blow all the concrete dust from the hole.

A plastic aerosol can cap, approximately two and one-quarter inches in diameter and with a hole large enough for the drill bit to pass through, is placed over the drill hole.

The drill is then operated until the remaining one-half inch of concrete is pulverized. The spiral action of the drill bit lifts the concrete powder from the bottom of the test hole into the plastic cap. A sample can is placed over the cap and the sample is collected.

Care must be taken to insure that the sample does not get wet to prevent the loss of free chloride ion.

Testing Procedure

The procedure developed by H. A. Berman was used for performing the chloride analysis of the test samples.[3]

The dilute nitric acid extraction procedure has proven to be both accurate and rapid. In this method, the total chloride ion content is determined by dissolving the sample in 1 + 16 nitric acid (one volume of reagent-grade nitric acid plus sixteen volumes of distilled water), filtering and titrating with the aid of a chloride-selective electrode. The accuracy of the method is within 0.5 per cent of the chloride present and the estimated sensitivity is 0.02 mg. chloride.

General Bridge Deck Construction Information

Reinforced Concrete Slab

In general, the thickness of concrete covering over the top mat of reinforcing has been specified to be a minimum of one and one-half to two inches, depending on the date the bridge was constructed.

As an indication of inadequate quality control during construction of the fifty-three bridges investigated (especially the Parkway bridges), actual thickness of the concrete cover ranged from zero to a maximum of three and one-quarter inches.

Normally, the decks have been constructed of concrete having six to seven sacks (ninety-four pounds each) of cement per cubic yard, and a water-cement ratio of five to six gallons per sack of cement. The concrete is designed to provide a slump of two and three-quarter inches plus or minus three-quarters of an inch.

Cement concrete is designed with an air content of five and one-half per cent plus or minus one and one-half per cent in the plastic state.

Concrete-Filled Grid

Grid flooring is made in a wide range of depths and grid spacings. The cement concrete criteria are similar to that for the reinforced concrete slab design.

This deck type has not seen widespread usage in the past. Research done by Hasija indicates that nine hundred and sixty-seven bridges, utilizing over six million square feet of concrete-filled grid decking, are currently in service in the United States.[4]

Grid flooring's limited use is further substantiated by the fact that approximately four million square feet of this is accounted for by only eighteen bridges.

DISCUSSION OF RESULTS

The analysis of the data obtained for this study will proceed with two objectives in mind. The first one will concern itself with the actual chloride content of the two types of decks tested and whether these values are sufficient to cause corrosion. The second will deal with the actual physical effect of high chloride concentrations on each deck type.

Also, as a result of this research, some insight will be provided in the effectiveness of waterproofing membranes in preventing chloride intrusion.

The test results for the concrete-filled grid decks, Parkway decks, and I-79 bridge decks are located in Tables 1, 2, and 3, respectively.

The average chloride concentration for all the Parkway bridges is 4.977 pounds of chloride per cubic yard of concrete. The average coefficient of variation is sixty-three per cent. The high coefficient of variation reflects the large deviation in the depth of concrete cover over the reinforcing steel of all the decks.

Research indicates that for each additional inch of depth, the chloride content would be reduced by approximately one-half.[5]

Therefore, with the depth of cover ranging from zero to three and one-quarter inches in some decks, the chloride concentration would also vary greatly.

The Parkway decks on L. R. 765, L. R. 766 (with the exception of bridge Numbers 5, 6, and 7) and L. R. 764 were all constructed during the beginning of the "bare pavement policy" and registered the highest mean chloride concentration of 5.880 pounds of chloride per cubic yard of concrete. Their mean coefficient of variation is sixty-one per cent.

Only three of the eighteen bridge decks in this group had concentrations of less than two pounds. Bridge Number 1, after twenty-three years in service, contained only 0.570 pounds of chloride and no surface spalling.

No explanation can be offered for this since areas of high steel were present.

The bridge decks on L.R. 187 PAR and L. R. 766, Numbers 5, 6, and 7, were constructed in the early sixties and contained a mean chloride concentration of 4.00 pounds of chloride. The surface spalls varied from three to forty-five per cent of the traffic lanes. In general, all decks were in poor condition. The mean coefficient of variation of this group is sixty-four per cent.

The bridge decks on L. R. 1016 were constructed between 1965 and 1973. These decks represent a more advanced period in highway construction techniques.

The mean chloride concentration of these decks is 1.680 pounds of chloride per cubic yard of concrete, with a coefficient of variation of thirty-six per cent. The coefficient of variation closely approximates that found by other researchers and reflects the more uniform depth of concrete cover resulting from better quality control during construction.

Twenty-seven per cent of the twenty-two decks tested show chloride concentrations greater than two pounds of chloride. Two of these decks are only five years old.

In general, the decks are in good condition. The largest amount of surface spalling is on bridge Number 32, with one per cent of its area spalled, which corresponds to the largest chloride concentration of 8.110 pounds of chloride per cubic yard of concrete.

The mean chloride concentration of the concrete-filled grid decks was 3.880 pounds of chloride with a coefficient of variation of thirty-six per cent. This value is the same as for the structures on L. R. 1016. Concrete-filled grids do not contain reinforcing steel, and since the grid is exposed at the surface, all samples were collected at a one and one-half inch depth. This resulted in more consistent values than the Parkway bridges.

Note that of the three decks with less than two pounds of chloride, two were in service less than three years. Therefore, disregarding these two decks, a more representative mean chloride concentration is 4.960 pounds of chloride. This is equivalent to the average chloride concentrations of 4.977 pounds of chloride for all the Parkway bridges. Even though the average chloride concentrations of the Parkway and concrete-filled grid decks are equal, the surface spalling problem experienced by them differs widely.

None of the grid decks exhibited any signs of physical distress in their deck surface. On the contrary, all Parkway decks, with the exception of bridge Number 1, exhibited from moderate to severe surface spalling. The problems experienced by the Parkway decks are further substantiated by the $130 million Parkway Safety Update project that will eventually replace ninety-five per cent of the reinforced concrete slab decks of the mainline bridges.

The good durability of concrete-filled grid decks in a chloride environment is dramatically illustrated by bridge Number 43 shown in Figure 1. This deck has been in service for forty-two years and contained a mean chloride concentration of 10.490 pounds of chloride per cubic yard of concrete. This was the second highest concentration determined. Figure 2 is a close-up view of the grid deck of bridge Number 43 and shows the remarkably good condition of the deck even though rust staining is evident on the concrete.

Figure 3 shows a deck view of bridge Number 46. After forty-four years in service and containing a mean chloride concentration of 2.902 pounds of chloride, the deck is in generally very good condition.

There is not a reinforced concrete slab bridge deck in existence with a similar service life and located in a chloride environment that can boast such accomplishments.

This study did not attempt to investigate the reasons why concrete-filled grid bridge decks are able to resist the corrosive effects of chlorides. However, this researcher believes there are three probable explanations for their effectiveness. First, the reason that surface spalls do not develop is that, upon corrosion of the steel grid, each concrete cube within that grid experiences compressive forces. Unlike the tensile forces that cause the concrete covering of reinforced concrete slabs to break out, the compressive forces acting within a grid keep them in place.

Secondly, since a grid deck is welded to the stringers and floorbeams at every bar, a continuous system is developed. Unlike reinforced concrete slabs that have discontinuous top and bottom mats of reinforcing steel, grid decks are grounded to the bridge floor system throughout the entire length of the structure. Thus, stray currents are less likely to develop and the problem of differences in potential between top and bottom mats of reinforcing steel does not exist. Differences in potential cause currents to flow.

Thirdly, grid flooring is grounded due to its connection to the floor system, which is in contact with the superstructure and subsequently connected with the ground by the substructure.

Bridge Number 31 was tested to evaluate the effectiveness of a waterproofing membrane in preventing the intrusion of chlorides into bridge deck concrete. The mean chloride concentration is 0.244 pounds of chloride per cubic yard of concrete with a coefficient of variation of 152.0 per cent. The high coefficient of variation is probably due to localized breaks in the membrane that allowed chlorides to penetrate these locations. It should be noted that fifty per cent of the samples indicated zero chloride and the largest concentration determined was 1.333 pounds of chloride per cubic yard of concrete. No signs of physical distress were evident on the asphalt wearing surface.

It is realized that one bridge deck installation cannot be used to judge the effectiveness of waterproofing membranes. However, since the development of membranes is relatively new and this was the only installation with more than a few winters of deicing salts placed on it, it will provide some insight into their usefulness.

Conclusions

The following conclusions can be drawn from the work carried out in this research:

(a) The chloride concentrations found in concrete-filled grid bridge decks are sufficient to initiate corrosion of the steel grid. However, none of the grid decks tested exhibited any surface spalling.

(b) The chloride concentrations found in the reinforced concrete slab decks of the Parkway bridges are sufficient to initiate corrosion of the reinforcing steel. As indicated by the physical condition of the majority of these bridge decks, surface spalling is a serious problem.

(c) The chloride concentrations in the reinforced concrete slab decks of the bridges located on L. R. 1016 indicated that twenty-seven per cent of the decks sampled contained chlorides in amounts sufficient to initiate reinforcing steel corrosion. However, since the oldest deck is only eleven years old and all decks are in generally good condition, it is concluded that these bridge decks are merely undergoing the preliminary phases of steel corrosion and surface spalls have not had sufficient time to develop.

(d) The waterproofing membrane installed on one reinforced concrete slab deck did not prevent the intrusion of chlorides into bridge deck concrete.

The single most important conclusion that can be made from this study is the fact that concrete-filled grid bridge decks are effective in providing long serviceability in chloride environments. This is accomplished without the help of waterproofing membranes, galvanization, or any of the other by-products of research designed to prolong bridge deck life.

A review of two bridge biddings in October, 1975 indicates that concrete-filled grid decks are economically competitive with reinforced concrete slabs.

The bid price received for the reinforced concrete slab decks of the Parkway West Safety Update Project (which includes bridge Numbers 1 through 4) was $11.63 per square foot. This includes galvanized bars and a waterproofing membrane.

The low bid received for the replacement of bridge Number 44 was $12.00 per square foot for a concrete-filled grid deck. Considering the proven advantages of grid decks in chloride environment, the extra thirty-seven cents per square foot is a good investment.

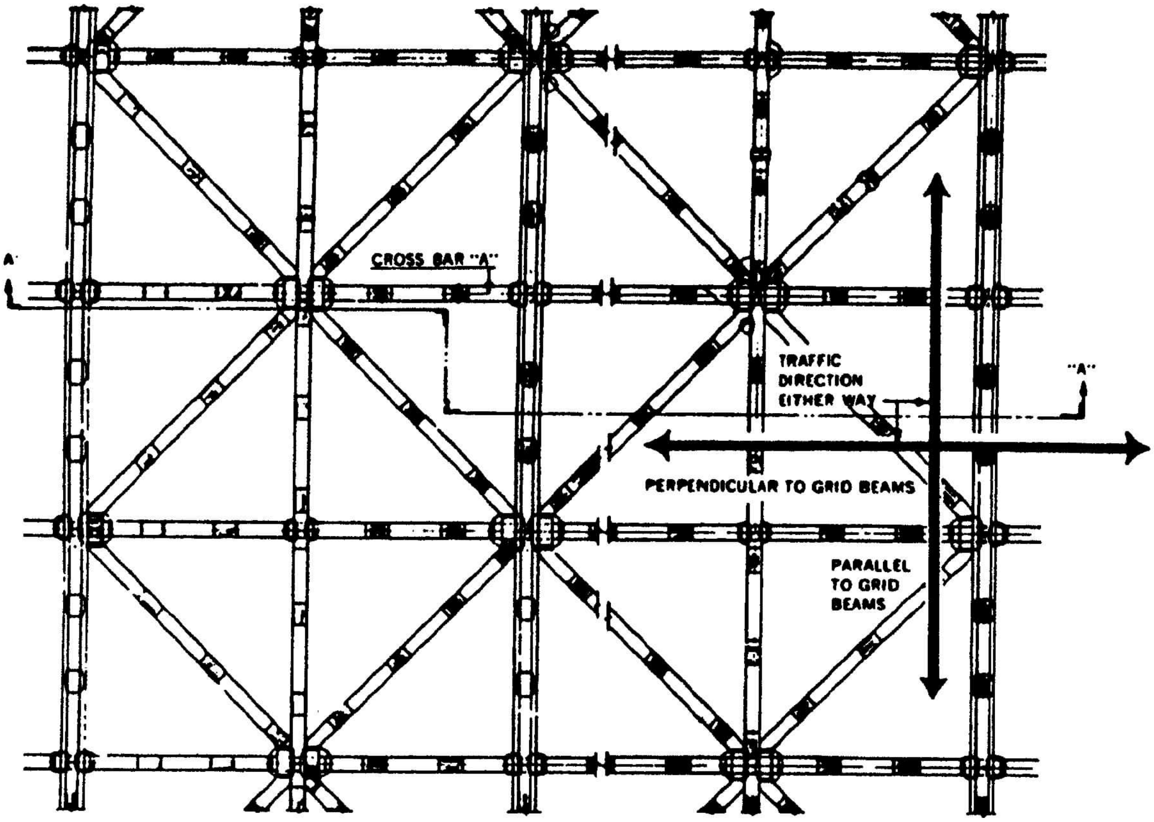
Recommendations for Further Research

Based on the results of this thesis, the following recommendations for additional research are made:

(a) Studies should be conducted to determine why concrete-filled grid bridge decks are not affected by chlorides, even though the top surface of the steel grid is exposed to direct salt applications.

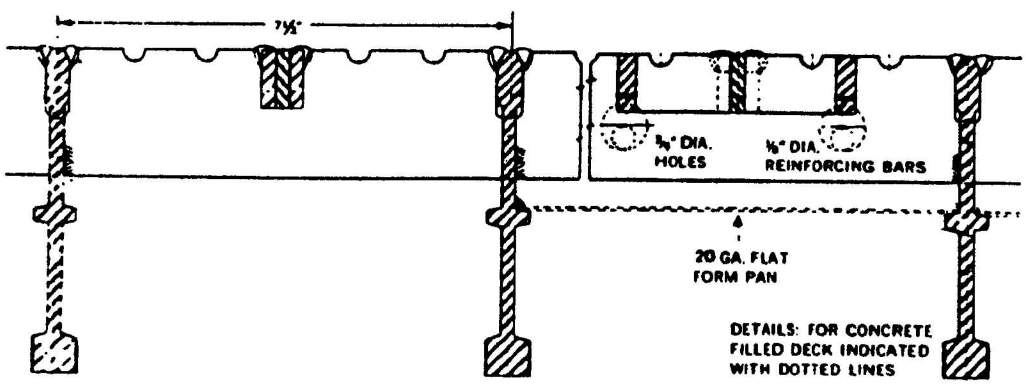
(b) An experimental bridge deck project should be undertaken to construct a reinforced concrete slab deck with continuity of reinforcing steel between top and bottom mats and also between spans. Furthermore, grounding of the reinforcing steel to the floor system can be accomplished by connecting both mats to the stringer and floorbeam shear connectors used in composite design. This would reduce the differences in potential between the top and bottom mats of reinforcing steel and also would provide a good ground with the bridge.

(c) Potential measurements of grid decks should be made to determine what voltages are present from the ongoing corrosion, if any, of steel grids. If corrosion voltages are greater than 0.350 volts, then corrosion is well under way and should be reflected by surface spalling.



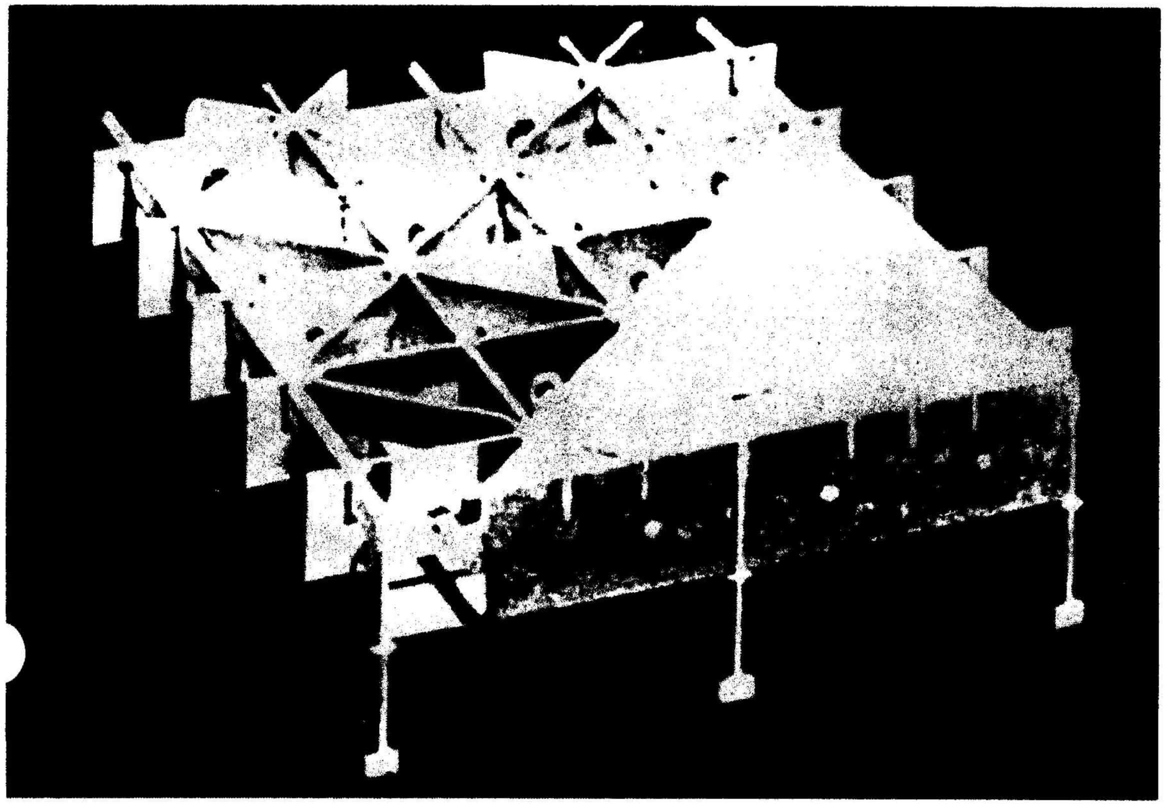
PART PLAN

STANDARD PANEL WIDTH 7'-8"



SECTION "A-A" CROSS BARS "A"

Part plan of a standard 5-inch 4-way steel-grid bridge-decking system. Plan and cross-sectional details of a heavy-duty diagonal grid design system suitable for deck rehabilitation or new bridge construction. Fabricated of either ASTM A-36 or ASTM A-588 high-strength corrosion-resistant steel, a concrete-filled steel-grid deck provides a smooth riding surface, corrosion resistance and less dead weight than a comparable reinforced concrete slab deck.



Grid cross-section concrete filled. Steel-grid bridge decking is made in a wide range of depths and spacings, and different configurations can be designed for complete or partial fill in specialized applications. (Shown is partially filled grid.) Cut-away of a heavy duty grid shows positions of grid members and reinforcing bar sections in relation to concrete fill volume. Concrete used with steel grid systems meets criteria similar to those for reinforced concrete slab decks.

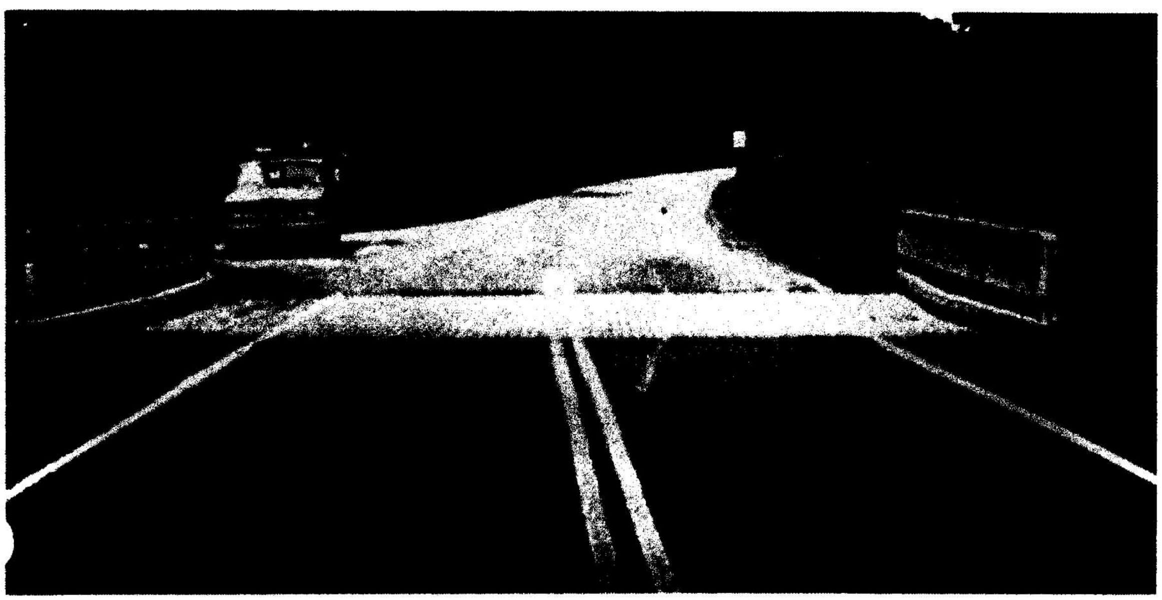


FIGURE 1. L. R. 04026, Station 422 + 72

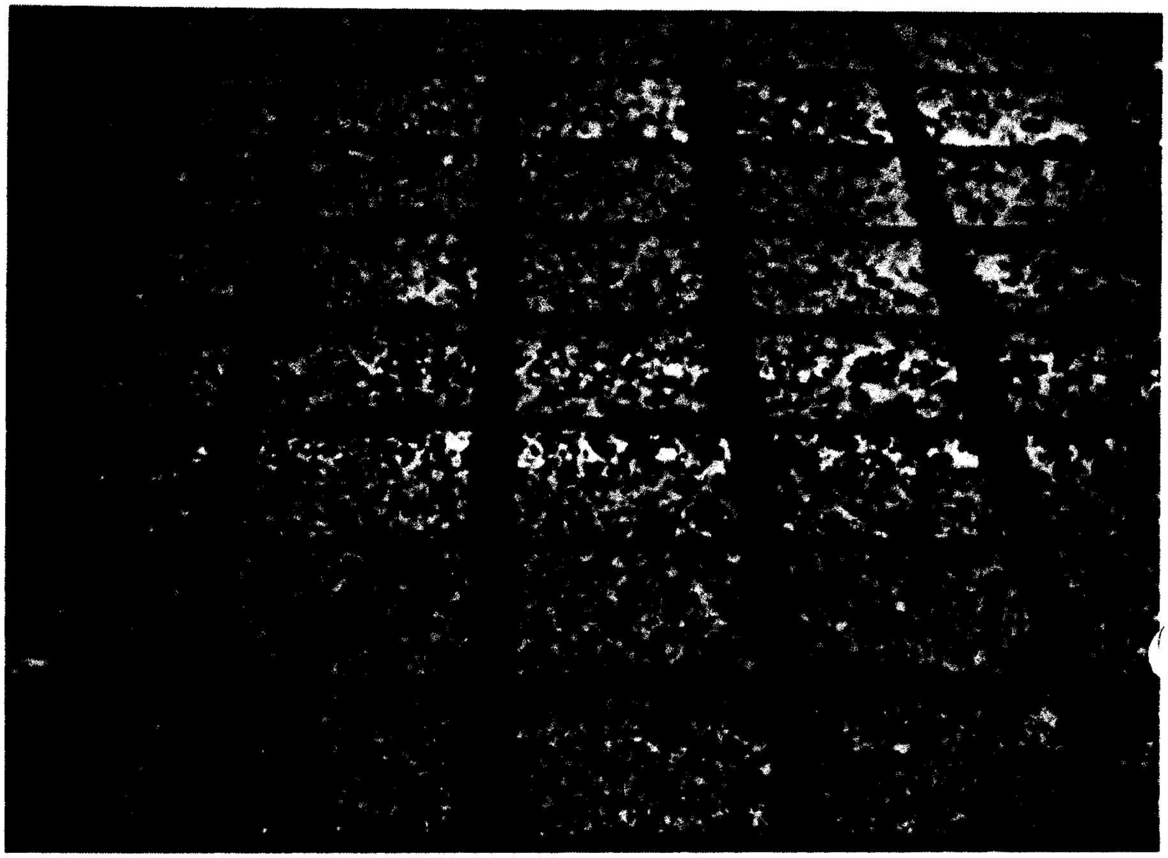


FIGURE 2. L. R. 04026, Station 422 + 72 Close-up View

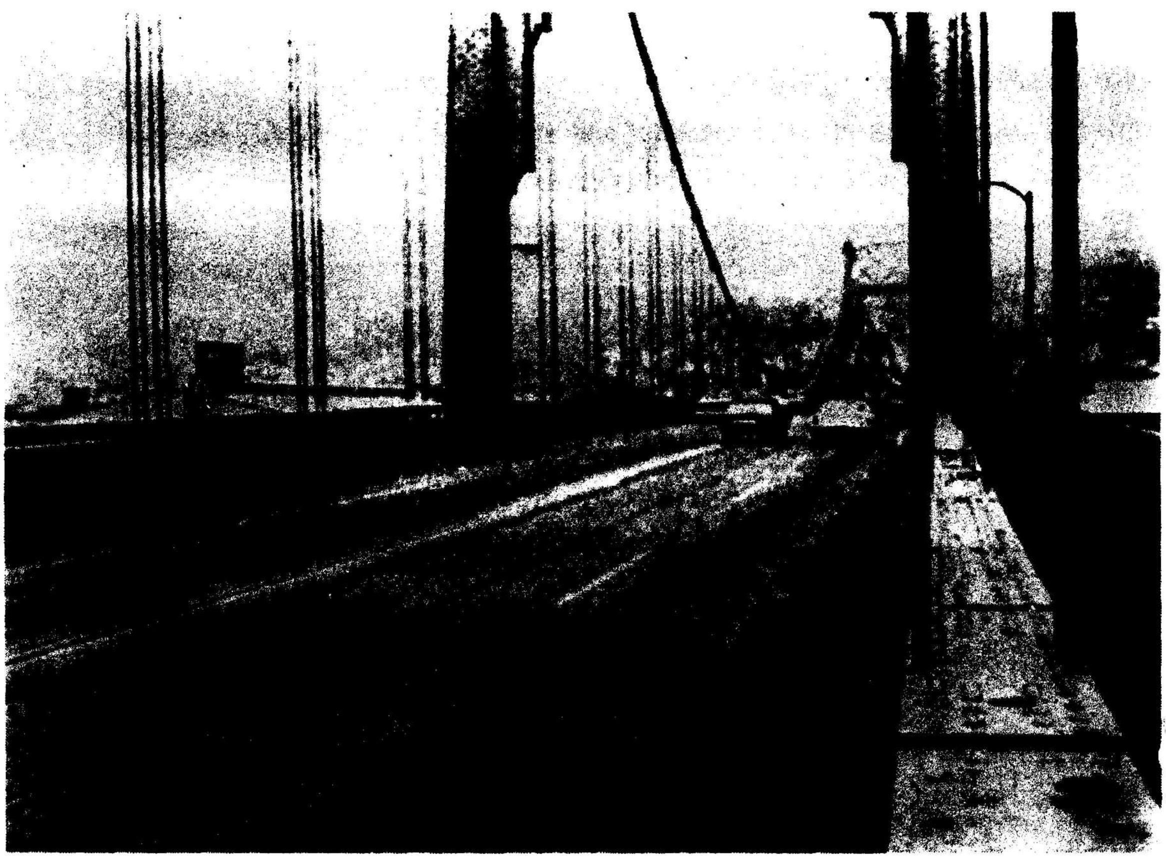


FIGURE 3. Tenth Street Bridge

No.	Date Built	Descriptor	Deck Area (sq. ft.)	% Spalled	Lbs. Cl^-/cu. yd. of concrete	Coefficient of Variation (%)
43	1934	LR 04026, Sta. 422+72	468	0.0	mean 10.490 std. dev. 2.211	21.1
44	1940	LR 482, Sta. 435+92	4,669	0.0	mean 4.412 std. dev. 2.070	46.9
45	1958	LR 04027, Sta. 26+80 Fombel Bridge	2,596	asphalt	mean 0.246 std. dev. 0.103	41.8
46	1932	10th Street Bridge	50,000	0.0	mean 2.902 std. dev. 1.090	37.5
47	1932	LR 254 SPUR E. Rochester-Monaca Br.	13,770	0.0	mean 1.070 std. dev. 0.465	43.4
48	1937	LR 392 Jerome Street Bridge	31,000	asphalt	mean 1.900 std. dev. 1.146	60.3
49	1931	LR 288, Sta. 483+07 Boston Bridge	35,430	asphalt	mean 6.575 std. dev. 1.720	26.1
50	1940	LR 02260, SPUR 3 Highland Park Bridge	96,240	asphalt	mean 3.496 std. dev. 1.154	33.0

TABLE 1 – Test Results of Concrete-Filled Grid Decks

No.	Date Built	Descriptor	Deck Area (sq. ft.)	% Spalled	Lbs. Cl^-/cu. yd. of concrete		Coefficient of Variation (%)
1	1953	LR 765, Sta. 264+72 over Bell Avenue	32,960	0.0	mean	0.570	56.3
					std. dev.	0.321	
2	1953	LR 765, Sta. 279+92 over Chartiers Creek	52,224	2.0	mean	0.760	68.8
					std. dev.	0.523	
3	1953	LR 765, Sta. 296+02 over Whiskey Run	42,772	asphalt	mean	1.444	71.0
					std. dev.	1.026	
4	1953	LR 766, Sta. 440+17 over Banksville Road	15,604	2.0	mean	5.510	130.3
					std. dev.	7.182	
5	1958	LR 766, Sta. 518+30 Fort Pitt Bridge (lower)	49,704	asphalt	mean	3.572	42.1
					std. dev.	1.482	
6	1958	LR 766, Sta. 518+30 Fort Pitt Bridge (upper)	49,704	asphalt	mean	3.078	64.2
					std. dev.	1.976	
7	1958	LR 764, Sta. 542+99 over Mon Wharf	42,336	asphalt	mean	7.105	24.0
					std. dev.	1.710	
8	1958	LR 764, Sta. 582+06 over B&O R.R.	71,463	45.0	mean	5.985	20.9
					std. dev.	1.254	
9	1953	LR 764, Sta. 605+41 over Second Avenue	27,288	asphalt	mean	10.906	29.2
					std. dev.	3.154	
10	1956	LR 764, Sta. 632+65 WB over Brady Street	1,332	50.0	mean	5.016	27.9
					std. dev.	1.406	
11	1956	LR 764, Sta. 638+81 EB over Brady Street	27,720	25.0	mean	9.356	45.2
					std. dev.	4.256	
12	1952	LR 763, Sta. 675+48 over Bates Street	16,896	5.0	mean	5.244	57.9
					std. dev.	3.040	
13	1951	LR 763, Sta. 729+23 over Frazier Street	86,240	12.0	mean	7.866	88.8
					std. dev.	6.992	
14	1951	LR 763, Sta. 729+23 over Saline Street	33,352	70.0	mean	4.370	51.0
					std. dev.	2.204	

TABLE 2 – Test Results for Parkway Bridges

No.	Date Built	Descriptor	Deck Area (sq. ft.)	% Spalled	Lbs. Cl^-/cu. yd. of concrete		Coefficient of Variation (%)
15	1952	LR 763, Sta. 774+23 over Forward Avenue	7,327	32.0	mean	5.510	48.6
					std. dev.	2.660	
16	1951	LR 763, Sta. 870+83 over Ramp B	8,008	asphalt	mean	5.358	108.5
					std. dev.	5.814	
17	1951	LR 763, Sta. 875+75 over Braddock Avenue	12,648	asphalt	mean	9.500	37.7
					std. dev.	3.572	
18	1948	LR 763, Sta. 948+17 over Ardmore Boulevard	22,720	asphalt	mean	9.158	51.7
					std. dev.	4.750	
19	1951	LR 763, Sta. 959+12 over Ramp G	4,724	5.0	mean	6.460	100.5
					std. dev.	6.498	
	1971	Widened right lane	1,180	0.0	mean	0.000	0.0
					std. dev.	0.000	
20	1950	LR 763, Sta. 1018+72 over Beulah Road	11,616	18.0	mean	5.130	72.5
					std. dev.	3.725	
21	1950	LR 763, Sta. 1023+46 over LR 187	5,160	2.0	mean	7.790	33.4
					std. dev.	2.584	
22	1961	LR 187 PAR, Sta. 9+47 over Ramp A	6,000	45.0	mean	7.790	33.4
					std. dev.	2.584	
23	1961	LR 187 PAR, Sta. 25+92 over Rodi Road	34,578	5.0	mean	5.510	47.5
					std. dev.	2.620	
24	1961	LR 187 PAR, Sta. 50+54 over Wm. Penn Highway	48,488	asphalt	mean	8.580	29.4
					std. dev.	2.520	
25	1962	LR 187 PAR, Sta. 112+25 over Thompson Run	17,200	7.0	mean	2.710	105.0
					std. dev.	2.845	
26	1962	LR 187 PAR, Sta. 166+54 over Wm. Penn Highway	21,504	37.0	mean	0.304	87.5
					std. dev.	0.266	
27	1962	LR 187 PAR, Sta. 195+60 over Wm. Penn Highway	21,216	22.0	mean	7.500	57.9
					std. dev.	4.350	

TABLE 2 – Continued

No.	Date Built	Descriptor	Deck Area (sq. ft.)	% Spalled	Lbs. Cl^-/cu. yd. of concrete		Coefficient of Variation (%)
28	1962	LR 187 PAR, Sta. 220+06 WB over Haymaker Rd.	6,496	5.0	mean	0.461	119.2
					std. dev.	0.549	
29	1962	LR 187 PAR, Sta. 220+54 EB over Haymaker Rd.	6,496	4.0	mean	1.300	121.2
					std. dev.	1.580	
30	1962	LR 187 PAR, Sta. 227+84 EB over LR 187	11,000	3.0	mean	0.207	103.0
					std. dev.	0.214	
31	1969	Fort Duquesne Bridge (Lower)	39,600	asphalt	mean	0.244	152.0
					std. dev.	0.371	

TABLE 2 – Continued

No.	Date Built	Descriptor	Deck Area (sq. ft.)	% Spalled	Lbs. Cl^-/cu. yd. of concrete		Coefficient of Variation (%)
32	1965	Station 157+22 NB over LR 545	18,630	1.0	mean	8.110	32.4
					std. dev.	2.630	
	1965	Station 157+22 SB over LR 545	18,630	0.5	mean	3.910	40.1
					std. dev.	1.570	
33	1965	Station 165+65 NB over Chartiers Creek	43,560	0.5	mean	1.950	30.9
					std. dev.	0.604	
	1965	Station 165+65 SB over Chartiers Creek	43,560	0.5	mean	2.250	40.8
					std. dev.	0.920	
34	1965	Station 239+00 NB over Chartiers Creek	15,390	0.5	mean	1.260	17.6
					std. dev.	0.223	
	1965	Station 239+00 SB over Chartiers Creek	15,390	0.5	mean	3.525	61.8
					std. dev.	2.180	
35	1965	Station 285+39 NB over Oakdale Road	44,145	0.5	mean	1.290	105.4
					std. dev.	1.360	
	1965	Station 285+39 SB over Oakdale Road	44,145	0.5	mean	0.467	135.9
					std. dev.	0.635	
36	1972	Station 357+04 NB over Noblestown Road	16,515	0.0	mean	0.515	27.1
					std. dev.	0.140	
	1972	Station 357+04 SB over Noblestown Road	16,515	0.0	mean	0.533	10.1
					std. dev.	0.054	
37	1972	Station 362+63 NB over Robinson Run	60,570	0.0	mean	0.618	18.4
					std. dev.	0.114	
	1972	Station 362+63 SB over Robinson Run	60,570	0.0	mean	0.470	33.1
					std. dev.	0.156	
38	1973	Station 442+69 NB over Ramp B	23,265	0.0	mean	0.760	25.7
					std. dev.	0.196	
	1973	Station 442+69 SB over Ramp B	23,265	0.0	mean	1.030	29.5
					std. dev.	0.304	

TABLE 3 – Test Results of I-79 Decks

No.	Date Built	Descriptor	Deck Area (sq. ft.)	% Spalled	Lbs. Cl^-/cu. yd. of concrete		Coefficient of Variation (%)
39	1973	Station 452+77 NB over LR 279	20,925	0.0	mean std. dev.	0.830 0.232	27.9
	1973	Station 452+77 SB over LR 279	20,925	0.0	mean std. dev.	0.683 0.089	13.0
40	1973	Station 460+08 NB over Campbells Run	8,325	0.0	mean std. dev.	0.796 0.102	12.8
	1973	Station 460+08 SB over Campbells Run	8,325	0.0	mean std. dev.	1.010 0.242	23.9
41	1971	Station 554+40 NB over LR 257	19,620	0.0	mean std. dev.	0.836 0.116	13.8
	1971	Station 554+40 SB over LR 257	19,620	0.0	mean std. dev.	1.260 0.400	31.7
42	1971	Station 608+97 NB over Clever Road	22,230	0.5	mean std. dev.	2.860 1.336	46.7
	1971	Station 608+97 SB over Clever Road	22,230	0.0	mean std. dev.	2.036 0.469	23.0

TABLE 3 – Continued

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