STEEL GRID BRIDGE FLOORING

NEW INNOVATIONS TO A PROVEN MODULAR DECKING SYSTEM

by Gene Gilmore

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INTRODUCTION

In the 1920's, engineers looking for a lightweight but high strength deck alternative butted flanges of tees together and filled the structure with concrete. These early grid reinforced concrete bridge decks spawned many variations in the years to come and were the birth of the most time-tested and most durable of all bridge decks.

Today four types of steel grid flooring are in everyday use. They are depicted in FIGURE 1. They are: (1) Full-Depth grid reinforced concrete decks (using 3" Tees or 4¼" I-sections as main reinforcement), (2) Half-Depth grid reinforced concrete decks (using 5 3/16" I-sections as main reinforcement), (3) "Exodermic" bridge grid decking (variable depth unfilled grid with a composite slab on top of the grid network) and (4) open steel grid bridge flooring (either welded or riveted construction).

The grid reinforced concrete decks have played and are playing an ever increasing role in bridge rehabilitation. Product design advantages such as reduced dead load, durability (many bridges have grid reinforced concrete decks with more than 50 years of service), composite action with supporting steel, coupled with construction advantages such as speed of deck replacement and ease of precasting have brought grid flooring to the forefront as the premier deck replacement material. All of these advantages blend with attractive "in-place" costs of $20-$25 psf <u>including</u> a wearing course <u>and</u> corrosion protection. This presentation will examine the products' history, the design differences among the various types, the latest precasting and connection details, case histories of recent projects, corrosion protection and finally, recent and future testing and the "lost report" on composite action with supporting steel.

PRODUCT HISTORY

As I indicated in my opening statement, the first grid reinforced concrete decks were made from structural tees. FIGURE 2 shows the 10th Street Bridge in Pittsburgh opened to traffic in 1932. This picture was taken prior to its 1981 rehabilitation. At that time the deck was still found to be in excellent condition. It has now been in service for 55 years enduring heavy truck traffic and de-icing chemicals for most of its life.

FIGURE 3 is certainly the mainstay of grid reinforced concrete bridge decks. The I-Beam Interlock floors were introduced in the 1930's. At one time, there was a family of the I-Beam sections; 2½", 3", 3½", 4¼" and 5". Only the 4¼" I-Beam section has survived the lean years of bridge rehabilitation and the mill closings of the 70's and 80's. However, as demand continues to rise, I feel this family will make a comeback.

FIGURE 4 shows the Half-Depth Grid reinforced concrete deck that was developed in the 1950's. Striving to decrease weight even further, an intermediate flange was added to the I-Section to allow placement of a form pan halfway down in the grid network. Including a 2" cover, the bridge industry now had a deck that weighed less than 70 lbs psf with span capabilities up to 13'.

It should be noted that the 3" and 4¼" grids also require a wearing course on top of the steel grid network. Riding on the armored surface will eventually "cup" the concrete and expose the grid bars. This can result in a bumpy ride and could be slippery. For these reasons, a wearing course is <u>always</u> recommended for Full-Depth or Half-Depth grid reinforced concrete decks.

However, the "Exodermic" deck shown in FIGURE 5 does not require a wearing course. Its 3" or 4" composite concrete overlay is a wearing course in itself and as a result this design yields the lightest concrete deck alternate. This innovation was developed in the 1980's and was extensively tested by the Fritz Laboratories of Lehigh University. Its unique structure is a miniature T-Beam composite cross section. The neutral axis of this variation is located near the top of the steel grid. In positive moment the concrete is in compression while the steel grid is in tension. Also, welds on the steel grid are located near the low stress area of the neutral axis. The slab is connected to the grid by shear studs and an elevated grid bar that penetrates about 1" into the slab. Because of all these positive design features the Lehigh University study stated "... that an infinite in-service fatigue life can be expected ..."* While Full-Depth and Half-Depth grids can be either precasted or poured in place, the "Exodermic" grid type is supplied only as a precast deck slab.

FIGURE 6 depicts the two types of open grids, welded and riveted construction. Riveted design evolved first in the 1920's. However, because of the riveted floors higher weight, welded floors eventually dominated this market. Recent testing, however, indicates that the riveted floor should not have been "shelved" so quickly. This will be discussed further in the section on testing.

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*Daniels and Slutter, "Behavior of Modular Unfilled Composite Steel Grid Bridge Deck Panels", Lehigh University, Jan. 1985, p. 21

IN-PLACE PRODUCT COSTS

Based on recent bids and discussions with the bridge community, FIGURE 7 was developed to present reasonable expected in-place costs including a protective wearing course for the various alternative.

DESIGN & PERFORMANCE

To assist in the understanding of the design and performance characteristics of these products, FIGURE 8 has been prepared. Based on design and performance criteria presented, the "exodermic" grid offers the best performance, although some of its comparison factors are based on laboratory results. The precast grid follows closely, but its performance factors have been field verified.

For the best blend of performance and value, the cast-in-place grid fulfills this objective. With in-place costs of $20.00 psf average, it is the prime candidate for value.

Open decks must be considered separately since they are not considered to be acceptable and are rarely used on primary highway structures. The riveted floor has the best performance characteristics, but is also generally heavier and more costly to manufacture and erect. However, it may be money well spent when you factor in the superior fatigue life that it offers over its welded counterpart.

CONNECTION METHODS & PRECASTING

The method of connection is an obviously important detail to be considered when using any form of grid deck. Furthermore, precasting the grid prior to placement requires additional considerations over and above the traditional cast-in-place connection details. Let us examine these important and various installation details.

FIGURE 9 displays the traditional method of deck connection: welding the grid to supporting steel. This method, although still used on many projects, is rapidly being replaced by the use of shear studs. Precasting of grids that are either welded or studded to supporting members require that "pockets" be left in the precast grid reinforced concrete panels. The following slides show the precast deck replacement (a Half-Depth Grid Reinforced Concrete Deck) on the McClugage Bridge in Peoria, Ill.

The connection "pockets", which permit the field welding of the main grid elements to the stringers, were grouted after all the deck panels had been placed. An asphalt overlay was then placed over the armored surface. All deck work was done at night and the bridge was fully opened to traffic during the day. The 133,000 sq. ft. of deck was replaced in 8 months.

The more current and preferred method of deck connection is by the use of shear studs. By using studs, many of the question marks associated with welding are eliminated. FIGURE 10 shows various details of deck connection using studs. When the deck units are precast, a leveling bolt can be used similar to attachment method #5. After proper elevation is achieved, the joint is grouted and the leveling bolt is removed. Since shear studs are used, the deck develops full composite action with the support system. The isometric drawing in FIGURE 11 depicts the exodermic deck attached by shear studs to the structural beams. The concrete overlay is composite with the grid which in turn is composite with the structural steel. This results in a very efficient combination of lightweight decking and composite design.

Threaded shear connectors were chosen for the replacement decks on the Queensboro Bridge ramps in New York City. As FIGURE 12 shows, the threaded studs permitted raising or lowering deck panels into desired position while also acting as the temporary support for the unfilled deck which was haunched at varying depths. The ramps had horizontal and vertical curves in combination with superelevations and varying roadway widths. The haunches were field formed and continuously poured with the grid and a 2-inch concrete wearing surface. Finally, the "double duty" threaded shear studs provided a positive connection for composite action with supporting steel after the cure.

It should be noted that welding of grid reinforced concrete decks to supports provides composite action also. This will be further discussed in the testing section of this report.

The use of shear studs with grout on top of the structural steel flange is also worthy of note. FIGURE 13 shows the final form of such an attachment method. An added benefit is that the concrete cover provides protection for the beam flanges which is sometimes an objection when an open grid deck is proposed. Again, any questions involved with field welding are minimized.

RECENT CASE HISTORIES AND IN-PLACE COSTS

Thousand Islands Bridge Over St. Lawrence Seaway, Upstate New York

Probably no other recent project so completely expresses the positive benefits of grid reinforced concrete decks like the Thousand Islands Bridge. Built in the 30's, this bridge (the American Crossing) and its twin (the Canadian Crossing) span the St. Lawrence Seaway in the picturesque area known as the 1000 Islands. Its long approach ramps were reinforced concrete decks which had badly deteriorated due to de-icing compounds and extreme freeze/thaw cycles over the years. However, the main span of the sturcture was a 4¼ inch grid filled flush with concrete and never overlaid. It had performed admirably in this severe environment and required no repairs although the roadway was widened during the rehabilitation.

The construction was limited to night time work only, but one lane had to be maintained during the night and the entire bridge was to be opened to traffic during the day. The contractor would precast the grids at the jobsite during the day time hours. He built his precasting hut under the bridge approaches. The panels, one half the roadway in width (13½ ft.) and up to 39 ft. in length, were delivered to the bridge. Since the deck was to be precast, form pans in the grid were not required.

The decks were then brought into the precast hut and filled with concrete including a 2 inch overfill for a wearing course. The finished precast decks were placed in the storage area for night time installation. Holes were drilled in the precast decks to permit field attachment. The eroded concrete slab was then removed at night and replaced with the precast grid system. The grid, precasting and installation was bid at $22.00 psf according to the contractor. This project displays all of the grid decks' advantages: ease of precasting and traffic maintenance, durability in severe environments and cost competitive replacement with a lighter weight superior product.

Allegheny River Bridge, Penna. Turnpike Commission

This slide is the Allegheny River Bridge on the Penna. Turnpike. This ongoing replacement, again, shows the many advantages of grid reinforced concrete decks. This 4-lane bridge was widened by 12 ft. under traffic with no summer deck work permitted. Also, 2 and 3 lanes of traffic had to be maintained during the deck replacement and all 4 lanes made available in summer and winter.

The grid was delivered to the jobsite and placed on the bridge stringers. Another benefit of grid usage is evident here. The grid acts as a working platform during reconstruction. This greatly improves installation time and permits increased traffic flow during reconstruciton.

FIGURE 14 is a summary of the bid prices for the replacement deck. The complete 4¼ inch grid system was bid at an attractive price of less than $20.00 psf including a 1½ inch latex modified concrete overlay. It should be noted that all expansion and relief joints, and all scuppers were factory installed, once again highlighting the product's flexibility and factory controlled quality benefits.

Missouri DOT 5-Year Average Prices

The Missouri DOT over the past dozen years has had an aggressive bridge rehabilitation program underway. They have extensively used the Half-Depth Grid Reinforced Concrete Deck System and have kept very detailed deck reconstruction costs.

The Half-Depth Grid Reinforced Concrete Deck met their needs because it reduced dead load by 30 to 50# psf and acted as a working platform for the contractor. The working platform benefit facilitates "assembly line" deck replacement and makes more deck area available for traffic maintenance. Naturally, the reduced dead load, as is the case for most grids, decreases the need for extensive structure repair and reinforcing or allows for increased live load capacity. Half-Depth Grids in their unfilled state can usually carry HIS loading without overstress.

FIGURE 15 displays the 5 year average costs for the in-place grid decks including waterproofing and wearing course. Once again, the total system cost is less than $20.00 psf. Recently, where dead load was not as critical, Missouri has gone to the 4¼ inch Full-Depth Grid in anticipation of even lower in-place costs.

CORROSION PROTECTION

Corrosion protection of steel grids, specifically concrete filled grids, has been a matter of much debate. Many theories, both positive and negative, have been put forth on this subject. It is difficult to draw conclusions on this matter, but let us examine the evidence.

FIGURE 16 summarizes a study done in 1976 on various Western Penna. bridges, some with grid decks and others with reinforced concrete slabs.* The comparison is dramatic. Chloride ion contents in the grids are high, but their average age is considerably older than the reinforced slabs, yet their surface condition is far better than the concrete slabs. These decks had no corrosion protection, neither protective overlay or coated steel. Certainly this is a positive statement for deck performance without corrosion protection. This study brought to light the fact that steel grids are grounded systems that limit stray corrosive currents that are present in reinforced concrete slabs. (Copies of this study are available direct from Greulich or can be picked up at the Bridge Grid Flooring Manufacturer's Booth).

Also, many grid floors are 50 years and older and have performed admirably under de-icing chemicals and severe environments such as the existing Thousand Islands grid deck. This combination of a grounded deck system and superior performance life would indicate that corrosion is not a significant problem.

Those are the positives, but what about the negatives? What about the "deck growth" phenomena? FIGURE 17 outlines this negative factor. At the bottom of FIGURE 17 are the positives for deck performance in corrosive environments. Ultimately, the owner must decide whether corrosion protection is desirable and at what cost.

Waterproofing overlays can cost anywhere from $2.00 psf up to $10.00 psf for thin exotic wearing surfaces. Galvanizing the grid after fabrication adds about $2.00 psf to the cost of the system and is a relatively low cost but proven method. Coatings such as zinc paints and epoxy coatings have been used also. These coatings add $2.00 to $6.00 psf to the price of the entire deck system.

*"An evaluation of the Comparative Effect of Chlorides on the Deterioration of Reinforced Concrete Slab and Concrete-Filled Grid Bridge Decks" Carl Angeloff, P.E., Penn DOT, District 11-0 M.S.C.E, U. of Pgh, 1976

Therefore, a value judgment must be made concerning the need and to the extent of corrosion protection. The use of a lower cost method for corrosion protection might be the best decision.

It's important to point out at this time that another feature of the exodermic grid decking is that it cannot exhibit the deck growth phenomena since the grid cells are not filled with concrete like the conventional grid floors

TESTING

The "Lost" Study on Composite Action

This slide shows a report done by USS in 1960. The report positively indicates that full composite action between concrete-filled grid decks and supporting steel is realized via full scale testing outlined in this report. Many times over the question of composite action has arisen, and many times over composite action has been assumed. That question can now be laid to bed since the "discovery" of this report which had been "lost" in the archives of USS for over 25 years. The report conclusively shows no slip between the deck and supporting system. Furthermore, a summary analysis done recently by the University of Pittsburgh supports the composite action conclusion of this study. Copies of the Test Report and Summary are available from the Bridge Grid Flooring Manufacturers Association.

Present Testing - West Virginia Univ. - Open Grids

Presently Dr. Hota Ganga Rao of West Virginia University is doing an in-depth study of the performance characteristics of various open welded grids and riveted bridge decks.

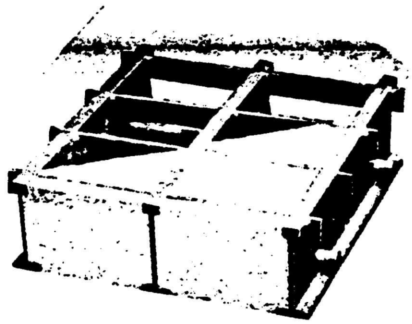
Early fatigue studies reveal that riveted decks have a significantly longer fatigue life than welded floors. This can be attributed to the fact that they are generally heavier and their riveted connection provides a method for the riveted design to relieve stresses under live loads. Conversely, welded open grids rely on stiffness, and if transverse stiffness is not adequate, welds will break and fatigue cracks will develop. Dr. Ganga Rao found high residual stresses in the welded panels. To lower these stresses, he is recommending heat treating or galvanizing. Galvanizing, he believes, will perform the same function as heat treating at lower cost and will also provide the benefit of corrosion protection. He will likely recommend a stiffer transverse bar also. Due to his study, we are likely to see a resurgance of the riveted design along with heavier open decks in general.

Future Testing

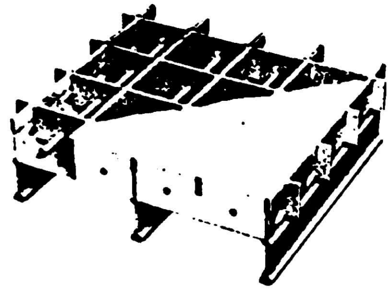
The Bridge Grid Flooring Manufacturers Association is considering tests on filled grids using shear stud connections to supporting steel to verify composite action. Along with this study, wheel distribution will be examined to see if the AASHTO distribution formula for reinforced concrete decks is too conservative when applied to a filled grid. The grid network should provide superior distribution.

SUMMARY

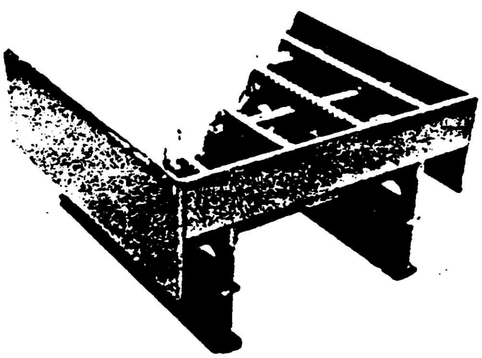
FIGURE 18 highlights the advantages and features of grid reinforced concrete decks. These benefits combined with new connection techniques and design features make these products the leading candidates for bridge deck construction.



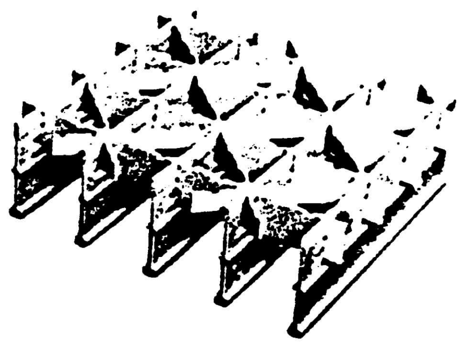
4¼ inch Interlock



5 inch Half filled



Exodermic

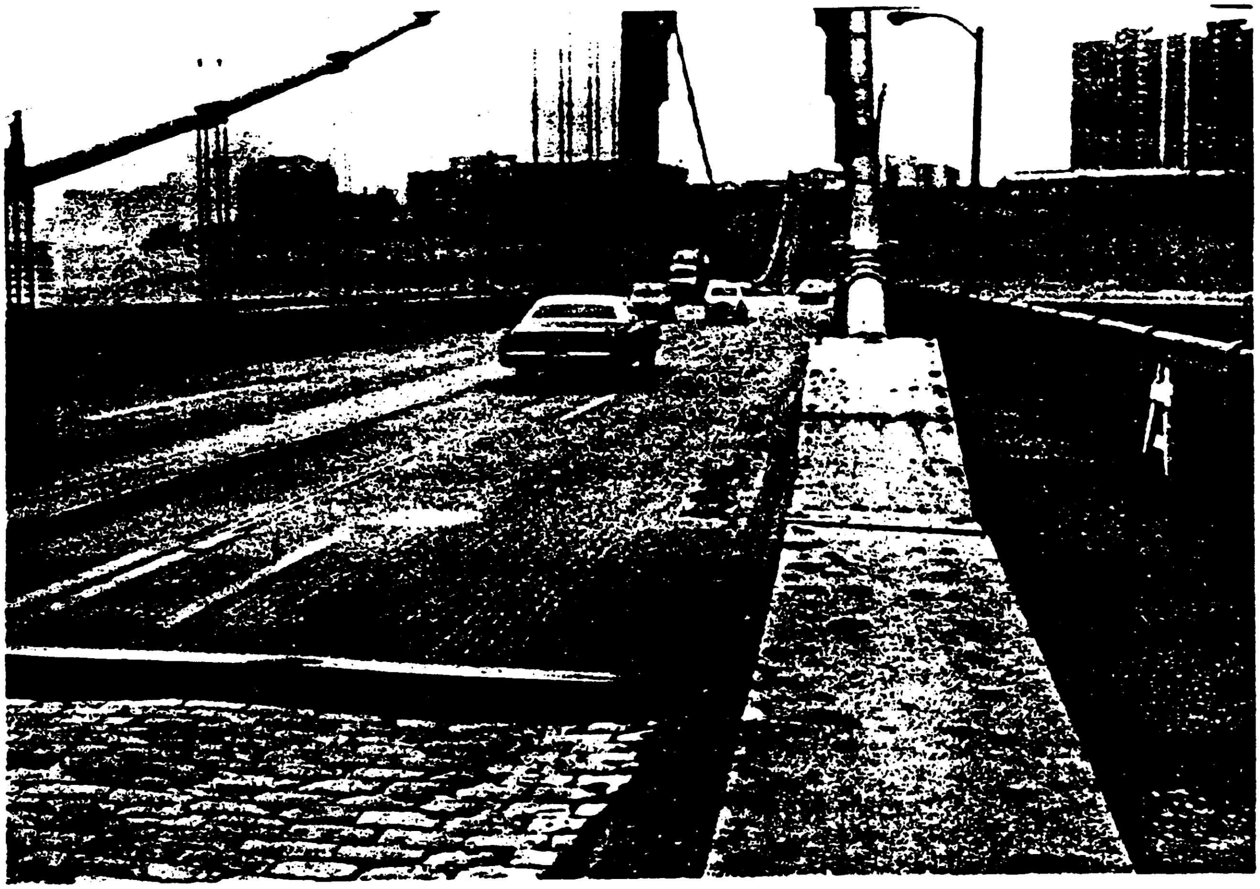


5 inch 4 way

Riveted

Open Grid

FIGURE 1



10TH ST. BRIDGE, PITTSBURGH, PA

DECK TYPE: 3"TEE

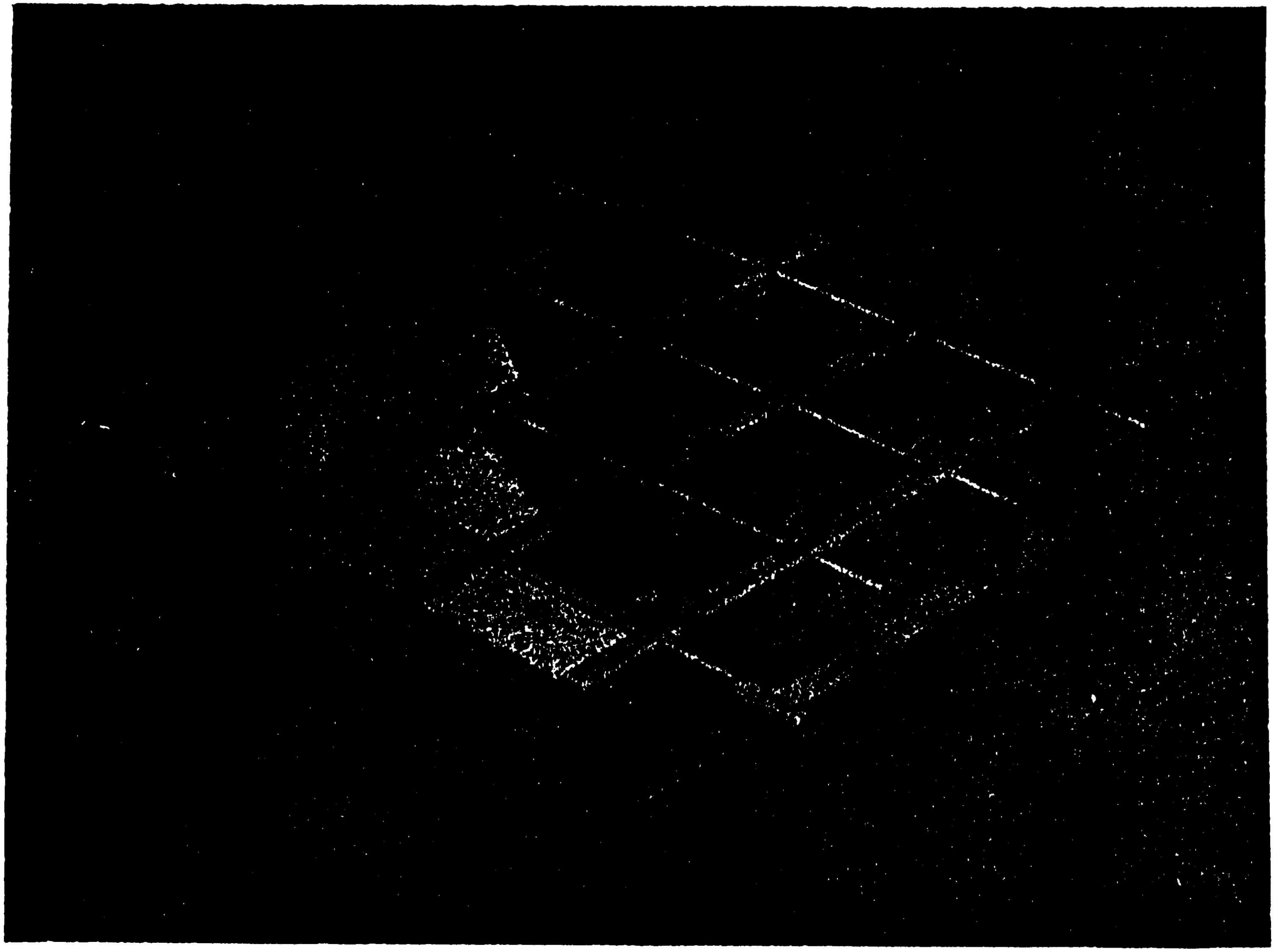
INSTALLED: 1932 (55 YRS. OLD)

MAJOR REHAB 1981 - DECK WAS IN EXCELLENT STRUCTURAL

STRUCTURAL CONDITION - WAS OVERLAID WITH

RUBBERIZED ASPHALT

FIGURE 2



<u>4 1/4" I-BEAM INTERLOCK</u>

MANY BRIDGES BUILT IN 30's & 40's WITH THIS DESIGN ARE STILL IN USE TODAY

MOST POPULAR OF FULL DEPTH FILLED GRIDS (& MOST ECONOMICAL)

FIGURE 3

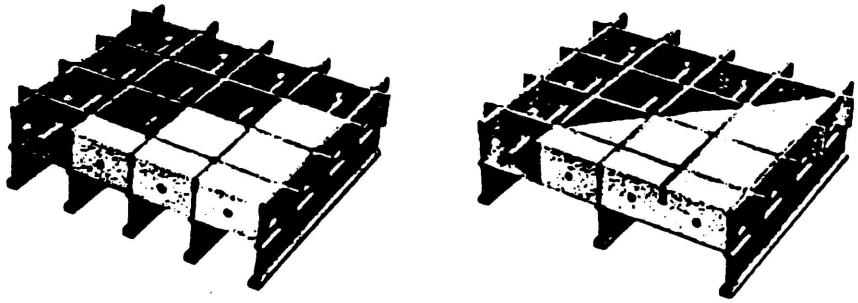
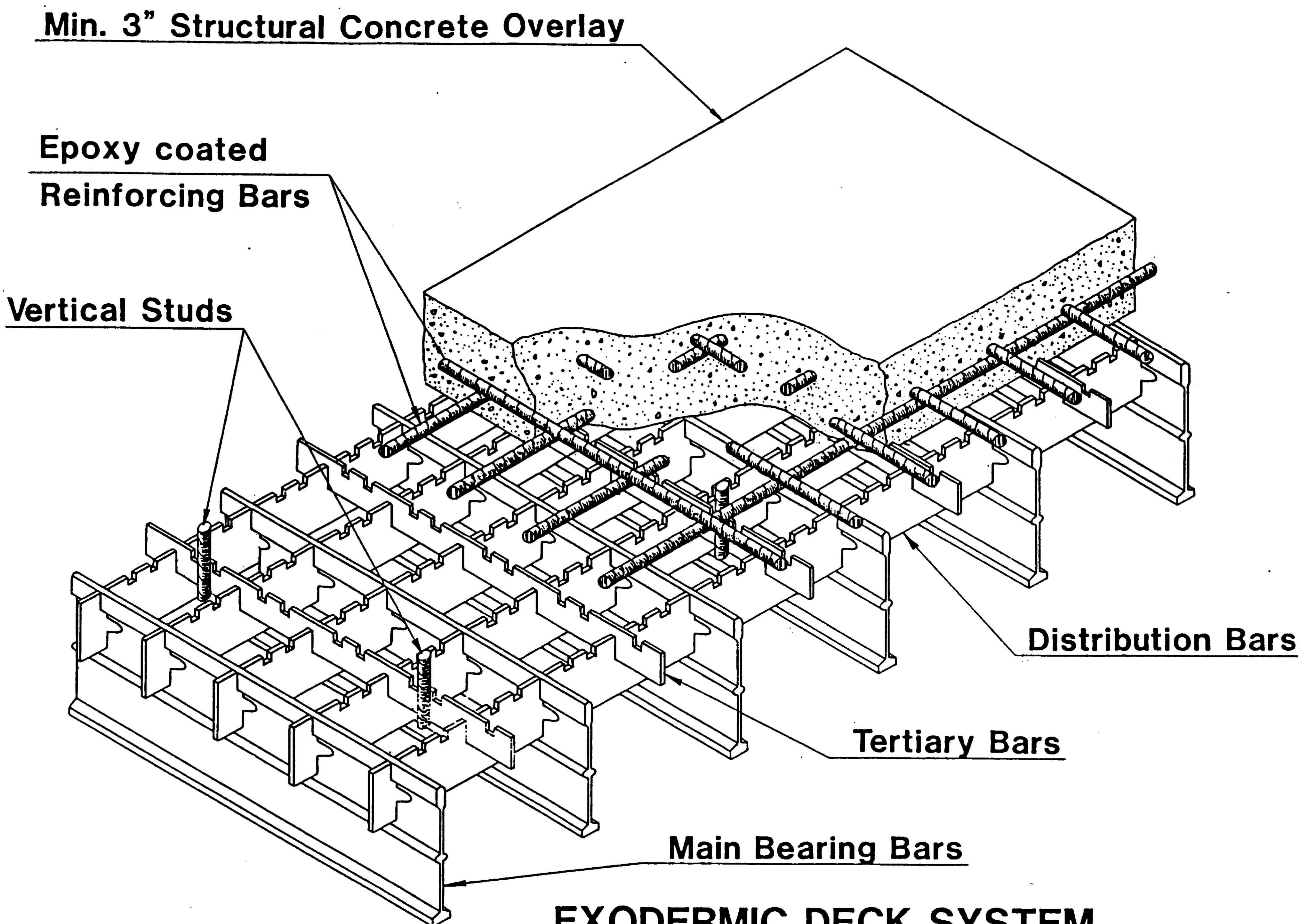


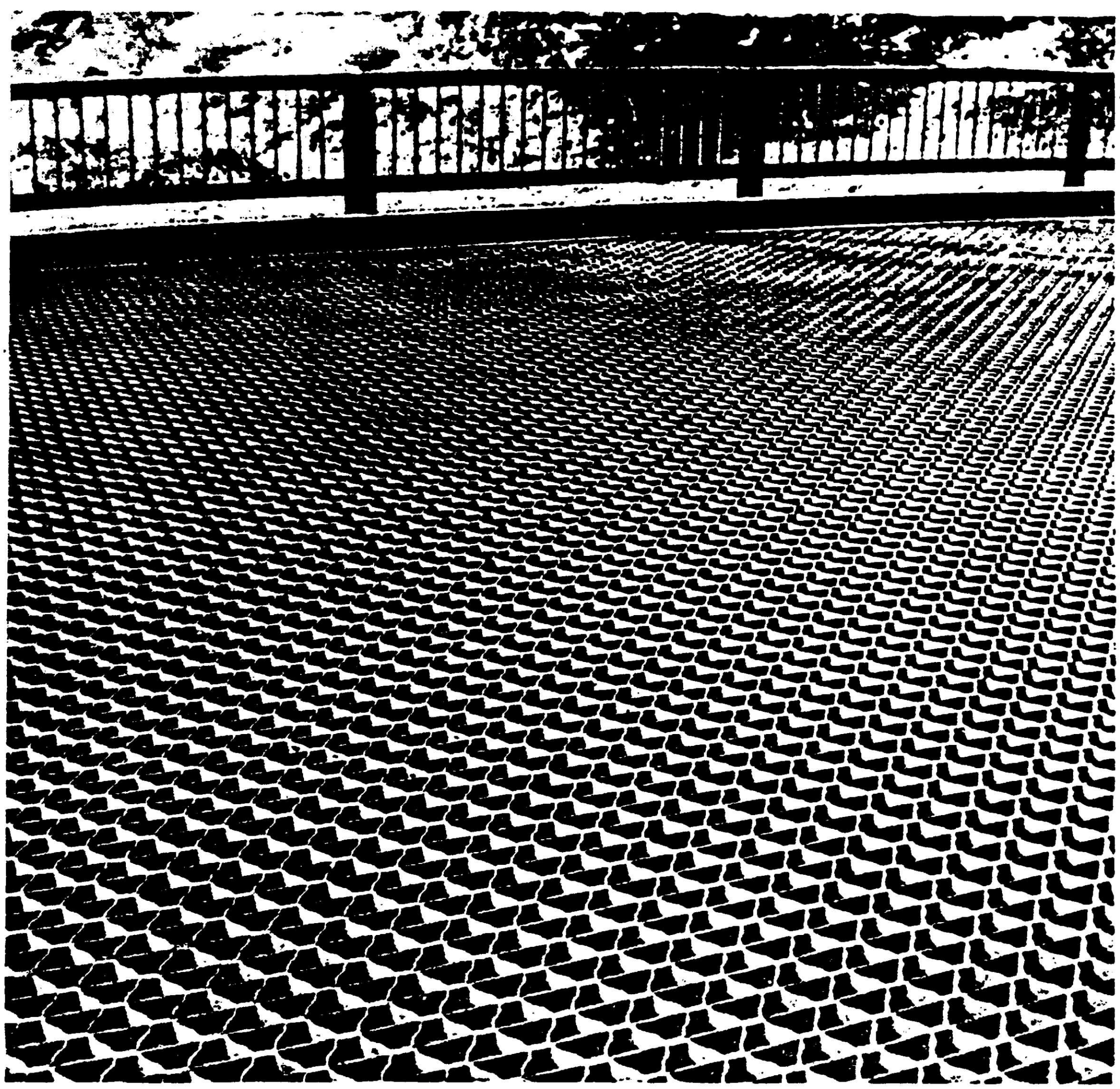
FIGURE 4



EXODERMIC DECK SYSTEM

FIGURE 5

5 Inch 4-Way Open Grid



Riveted Open Grid

FIGURE 6

IN-PLACE DECK COSTS IN $ PSF

TYPE OF DECK

	— Precast Decks —			— Cast-in-Place Decks —		— Open Decks —	
	Exodermic Grid	Precast Grid	Precast Concrete	Cast-in-Place Grid	Cast-in-Place Concrete	Riveted	Welde
Manufacturing Cost	$14	$9		$9		$14	$12
Concreting Cost	6	4		2		—	—
Erection Cost	6	6		6		12	6
Corrosion Protection*	2	2		2		2	2
(or) Protective** Overlay	(Not Req'd)	4		4		—	—
Totals	$28	$21 (or) $23	$20	$19 (or) $21	$15	$28	$20

*Assumed to be Galvanizing
**Assumed to be Latex Modified Concrete

FIGURE 7

RELATIVE VALUE
COMPARISON OF BRIDGE DECKS

TYPE OF DECK

	— Precast Decks —			— Cast-in-Place Decks —		— Open Decks —	
Comparison Factor	Exodermic Grid	Precast Grid	Precast Concrete	Cast-in-Place Grid	Poured-in-Place Concrete	Riveted	Weldec
Cost of Deck Installed	2	3	4	4	5	2	4
Cost of Traffic Maintenance	5	5	4	4	1	4	4
Weight	4	3	1	3	1	5	5
Future Replacement	5	4	4	3	1	4	4
Ease of Installation	5	4	4	3	1	4	5
Quality Control	5	4	5	3	2	4	3
AASHTO Standards	5	5	5	5	5	5	1*
Remaining Useful Life-Rehabilitation Project	5	4	1	4	1	5	5
Deck Service Life	5**	5	2	5	2	4	2
Totals	41	37	30	34	19	37	33

Key: 1 = Poor (or Lowest)
2 = Below Average
3 = Average
4 = Above Average
5 = Best (or Highest)

*Meets AASHTO STNDS, but there is an inadequacy ir method of wheel distribution
**According to lab tests

FIGURE 8

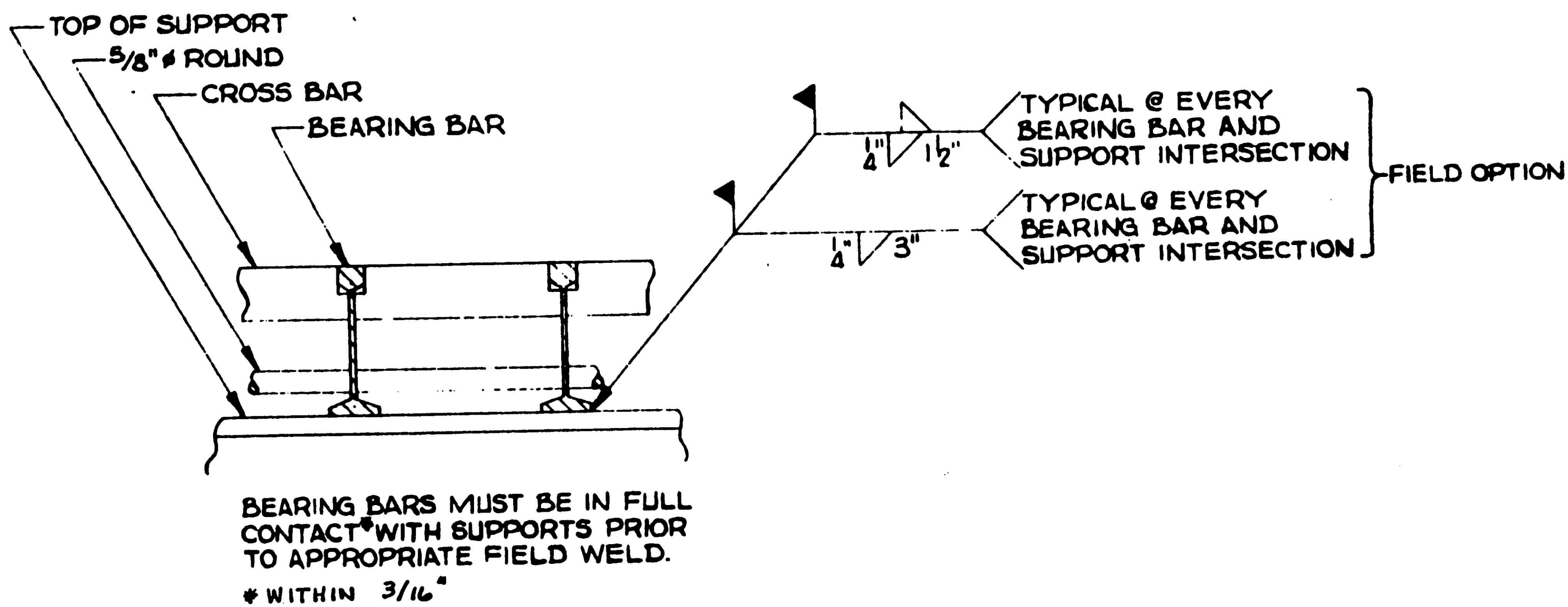
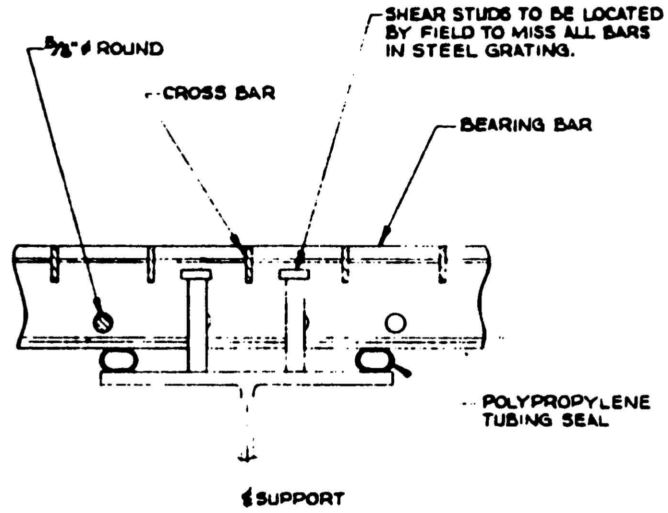

TOP OF SUPPORT
5/8" ø ROUND
CROSS BAR
BEARING BAR
1/4" 1 1/2"
TYPICAL @ EVERY BEARING BAR AND SUPPORT INTERSECTION
1/4" 3"
TYPICAL @ EVERY BEARING BAR AND SUPPORT INTERSECTION
FIELD OPTION
BEARING BARS MUST BE IN FULL CONTACT* WITH SUPPORTS PRIOR TO APPROPRIATE FIELD WELD.
* WITHIN 3/16"

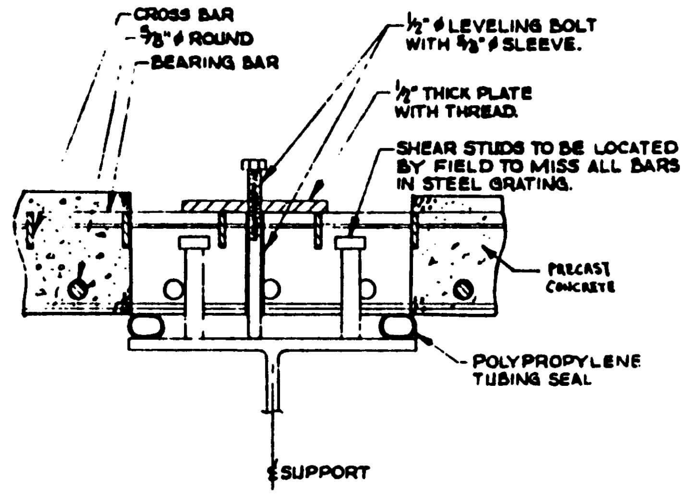
FIGURE 9



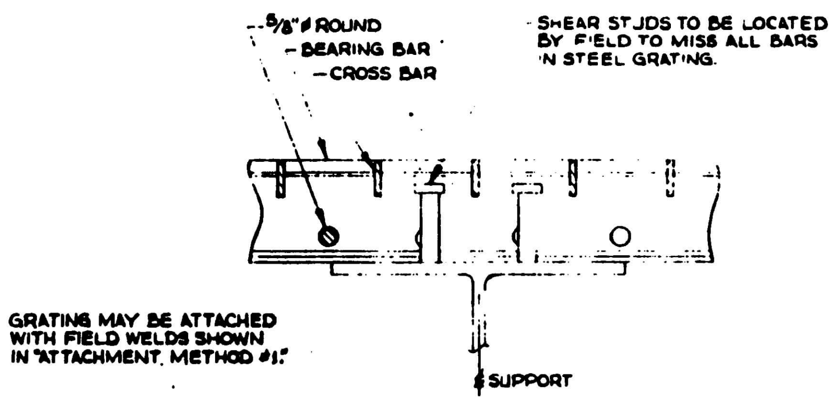
ATTACHMENT METHOD #2

ATTACHMENT METHOD #4

100%



ATTACHMENT METHOD #5



ATTACHMENT METHOD #3

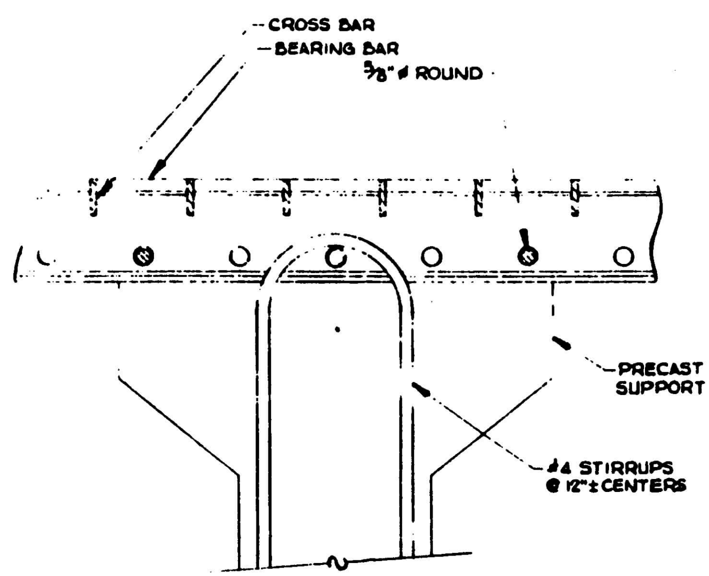
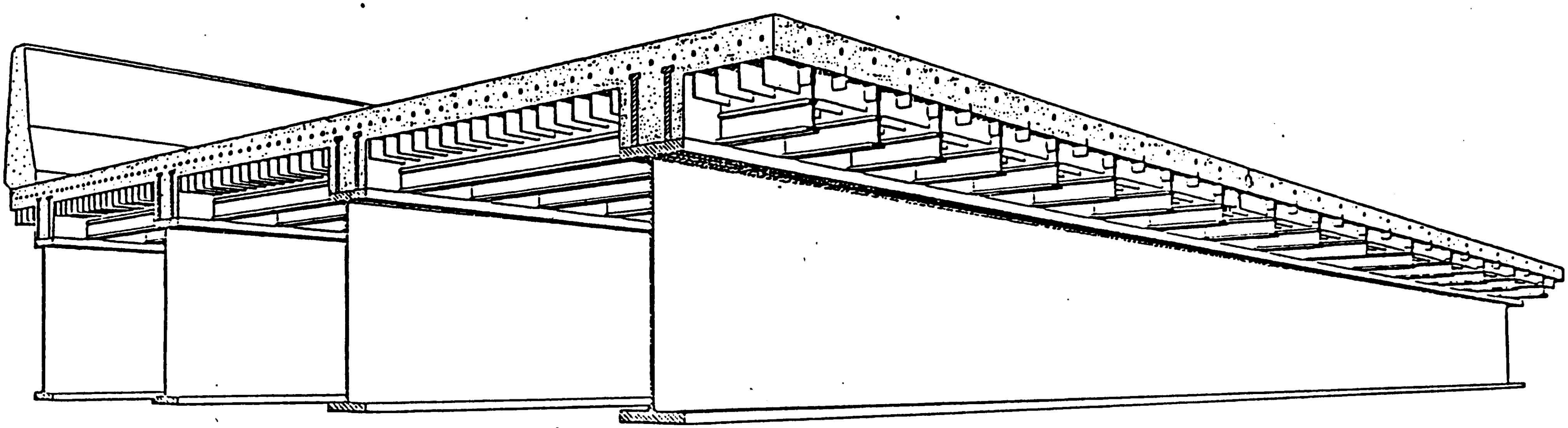


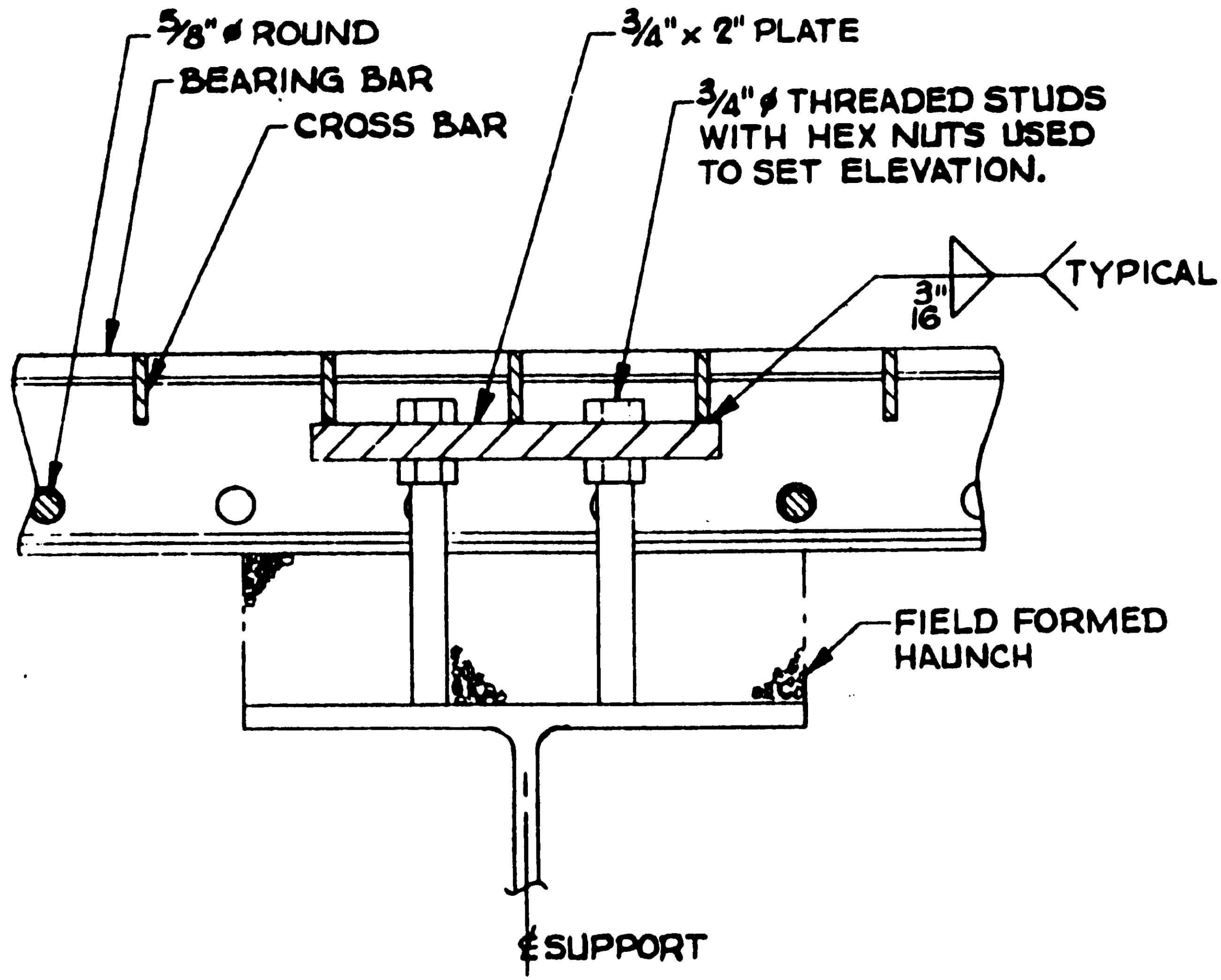
FIGURE 10

ATTACHMENT METHOD #6



Exodermic Composite Profile

FIGURE 11



5/8" ø ROUND
BEARING BAR
CROSS BAR
3/4" x 2" PLATE
3/4" ø THREADED STUDS WITH HEX NUTS USED TO SET ELEVATION.
3/16"
TYPICAL
FIELD FORMED HAUNCH
℄ SUPPORT

FIGURE 12

FIGURE 13

Allegheny River Bridge Bid Prices

4 1/4" Grid Installed	$13.45 psf
4 1/4" Concrete	2.50 psf
1 1/2" Latex Overlay	3.50 psf
Total In-Place Cost	$19.45 psf

FIGURE 14

Missouri DOT 5 Yr. Average Pricing

$5^{3}/_{16}$" Half-Depth Grid, Installed With Concrete	$15.48 psf
Waterproof Membrane & 2" Asphalt Wearing Course	4.17
Total In-Place Cost	$19.65 psf

FIGURE 15

CHART #3

GENERAL DAMAGE COMPARISON:
CONCRETE FILLED STEEL GRID DECKS vs. REINFORCED CONCRETE SLAB DECKS

Type	Date built:	Salt content/ cu. yd. concrete:	Deck area:	Deck area damaged:
CONCRETE FILLED STEEL GRID	1934	10.490 lbs.	468 sq. ft.	0.0%
	1940	4.412 lbs.	4,669 sq. ft.	0.0%
	1958	0.246 lbs.	2,596 sq. ft.	0.0%(asphalt)
	1932	2.902 lbs.	50,000 sq. ft.	0.0%
	1932	1.070 lbs.	13,770 sq. ft.	0.0%
	1937	1.900 lbs.	31,000 sq. ft.	0.0%(asphalt)
	1931	6.575 lbs.	35,430 sq. ft.	0.0%(asphalt)
	1940	3.496 lbs.	96,240 sq. ft.	0.0%(asphalt)
REINFORCED CONCRETE	1958	3.572 lbs.	49,704 sq. ft.	0.0%(asphalt
	1956	5.016 lbs.	1,332 sq. ft.	50.0%
	1952	5.510 lbs.	7,327 sq. ft.	32.0%
	1950	5.130 lbs.	11,616 sq. ft.	18.0%
	1962	2.710 lbs.	17,200 sq. ft.	7.0%
	1962	0.207 lbs.	11,000 sq. ft.	3.0%
	1965	1.290 lbs.	44,145 sq. ft.	0.5%
	1973	0.796 lbs.	8,325 sq. ft.	0.0%

Note: "0.0%(asphalt)" in damage column denotes normal wear of of wearing surface.
Reinforced concrete chart is composed of every fifth bridge listed in original study.*

FIGURE 16

* "An evaluation of the Comparative Effect of Chlorides on the Deterioration of Reinforced Concrete Slab and Concrete-Filled Grid Bridge Decks" Carl Angeloff, P.E., Penna DOT, District 11-0, M.S.C.E. Univ. of Pgh., 1976

DECK GROWTH PHENOMENA:

THEORY:	AFTER 40 YRS.± OF SERVICE, STEEL IN GRIDS EXPANDS DUE TO "EXPANSION" IN HIGHLY COMPRESSED CONCRETE CUBES.
LIMITATIONS:	95% OF CASES WHERE IN VERY OLD DECKS THAT WERE FINISHED FLUSH WITH CONCRETE AND NO OVERLAY, NOT EVEN ASPHALT.
OTHER THEORIES:	CONCRETE USED POOR QUALITY STEEL INSUFFICIENT EXPANSION ALLOWANCE
POSSIBLE ACTIONS:	PRIME STEEL INSIDE AND OUT WATER PROOF SYSTEMS CONCRETE ADDITIVES ALWAYS USE OVERLAY, AT LEAST ASPHALT - FROM RIDING QUALITY STANDPOINT ALSO!
EFFECTS OF SALT:	SUPERIOR PERFORMANCE (ANGLEOFF REPORT) GROUNDING ASPECTS OF GRIDS LACK OF STRAY CORROSIVE CURRENTS GRID BRIDGES IN STUDY, C1 - CONTENT/CU. YD. AND AGE OF DECK

10TH STREET	2.9 LBS.	54 YRS.
HIGHLAND PARK	3.5 LBS	47 YRS.
BOSTON BRIDGE	6.6 LBS.	49 YRS.

FIGURE 17

FILLED GRIDS:

1. HISTORY:	FIRST USE IN 1920's - TEE TYPE I-BEAM TYPE 1930's HALF-FILLED TYPE 1950's EXODERMIC TYPE 1980's
2. DESIGN:	SIMILAR TO REBAR SLAB-COMPOSITE TRANSFORMED AREA METHOD FOR SECTION PROPERTIES DISTRIBUTION OF LOAD BY AASHTO 3.24.3.1 & 3.24.3.2
3. CONSTRUCTION FLEXIBILITY:	PRECAST OPTION SHOP ATTACHMENT OF STRUCTURAL STEEL ACTS AS WORKING PLATFORM DURING CONSTRUCTION
4. PRODUCT ADVANTAGES:	DEAD LOAD REDUCTION SPEED OF DECK REPLACEMENT SIMPLIFIES MAINTENANCE OF TRAFFIC DURABILITY FACTORY CONTROLLED QUALITY PRICE - YES, PRICE

FIGURE 18