

AN EXPERIENCE SURVEY ON THE USE OF
PERMANENT STEEL BRIDGE DECK FORMS

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia
Department of Highways & Transportation and the University of Virginia)

Charlottesville, Virginia

October 1975
VHTRC 76-R15

SUMMARY

Permanent forms for bridge decks have become increasingly more attractive to the construction industry in recent years. Many highway officials, however, have reservations concerning the use of permanent steel forms. These reservations are related to the effect the forms might have on the durability of the concrete decks and to the possibility of future form corrosion problems. To evaluate the potential for the occurrence of each of these two possibilities, an experience survey and review of prior research were conducted.

A survey of 38 states revealed that approximately half of them either disallowed or minimized the use of steel forms because of a fear of future maintenance problems related to their use. A number of disadvantages related to the use of steel forms were cited by the responding states. A composite evaluation of the state survey and the prior research, however, indicated that permanent steel forms do not singularly affect the durability of concrete bridge decks. In addition, permanently formed decks generally have less transverse cracking and increased composite action between the deck and the girders. As compared to conventionally formed decks corrosion of steel forms can be a problem if moisture and salt solutions are allowed to gain access to the forms through joints or drainage features, or by other means. Data obtained from atmospheric corrosion tests indicate that galvanized steel forming should have a life expectancy equal to that of the bridge deck if adequately protected from moisture and salt solutions. (Corrosion resulting from the penetration of chlorides through sound concrete to the depth of the forms is unlikely.) The main access channels to the forms would appear to be through cracks or deteriorated concrete.

It was concluded that steel forms do not have a detrimental effect on initially good quality concrete decks and, with forming installations designed to minimize possible contact with moisture and salts, corrosion should not be a significant problem during the normal life expectancy of a bridge deck.

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Currently three general methods are used to form for the construction of concrete bridge decks in the United States. The most widely used method is that of constructing the forms in place on the structure using lumber and plywood. Once the deck has been placed and the concrete has gained adequate strength, these forms must be removed. A more recent approach has been the use of precast, prestressed panel subdecks that serve as the forming for the upper portion of the deck thickness while becoming an integral part of the completed total deck thickness. The subdeck technique has been used successfully in several states as indicated in an earlier state of the art review.⁽¹⁾ The third approach involves the use of permanent galvanized steel forms (Figure 1) which are left in place after the bridge deck is completed. This technique is widely used in several northeastern states and has been used to varying degrees in a number of other states.

Permanent type forms, whether steel or concrete, have become increasingly more attractive to the construction industry in recent years for several reasons. First, during periods of high national and international demand for lumber products, wood and plywood prices increase and occasionally these materials are in limited supply. Secondly, more stringent federal safety requirements for the protection of workmen have made form stripping more undesirable due to the potential injury hazards involved in the operation. In addition, the elimination of the form stripping operation can result in savings of both labor costs and construction time. The time and labor normally required to form a bridge deck during construction can also be reduced when permanent forming is used.

While prestressed panel subdecks have been used by a number of states, permanent steel forms have probably been used on a larger number of bridges throughout the country. Many states, however, do not allow the use of these type forms at all, whereas others allow contractors to use them on an optional basis. Still others allow the use of permanent steel forms only on special request or in special situations where their use is deemed to be advantageous.

Whether representing a state that allows or disallows use of the steel forms, most highway engineers and administrators appear to have reservations concerning their use. These reservations primarily revolve around the long-term durability of the bridge deck concrete as it might be affected by the permanent forms and the long-term corrosion resistance of the forms themselves. In the former case, it is feared that entrapment of moisture and/or deicing salts between the forms and the deck might cause or accelerate deterioration of the reinforced concrete deck. In the latter case, it is feared that corrosion of the forms themselves may lead to future maintenance problems and/or the necessity of ultimate form removal. Either of these possibilities would require expensive corrective operations and are just cause for concern.

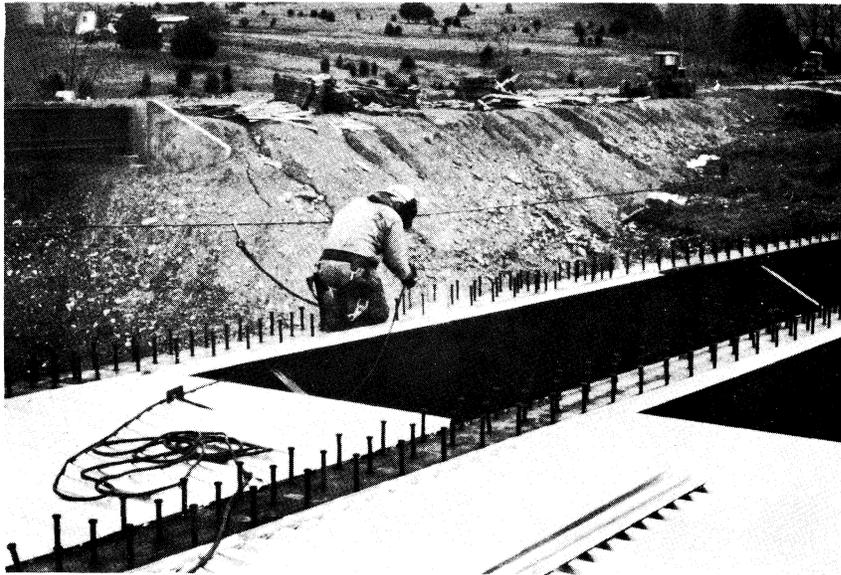


Figure 1. Permanent steel forms being installed on a steel girder bridge.

From a construction viewpoint, however, the use of permanent forms is a logical step and the pressure for their use is likely to increase. Undoubtedly, there are potential risks involved in using permanent steel forms as well as a number of disadvantages which sometimes may tend to offset initial construction advantages. This state of the art review is an attempt to assemble much of the available information regarding the experience that many of the states have had as well as to examine certain research results that may be relevant to the use of permanent steel forms on bridge decks.

PURPOSE AND SCOPE

Because of the general uncertainties regarding the use of permanent steel forms on bridge decks, a study was undertaken for the following purposes:

1. To summarize the advantages and disadvantages that have been noted from the experiences many of the states have had with the use of permanent steel forms;
2. to review and summarize the pertinent research results that are available in the literature;
3. to evaluate the potential long-term detrimental effects of the forms as related to concrete deterioration and steel corrosion; and

4. to draw conclusions and make recommendations regarding precautions that can be taken to minimize the disadvantages that are related to the use of permanent steel forms.

The scope of the material contained in this report is limited to a review of the use of permanent steel forming on bridge decks. Consideration is given to both the use of permanent forms as a construction material and to an analysis of the potential long-term effects the forms might have on the future integrity of a structure.

EXPERIENCE SURVEY

Permanent steel forms have been used for the construction of bridge decks for a number of years. Although not extensively used during the early years of their availability, permanent steel forms have been installed on a considerable number of bridges in the last 10 to 15 years. At the outset of the survey it was suspected that a few states in the northern regions might have installations on the order of 20 years old. It was known, however, that several of the northeastern states had made the most extensive use of steel forms. Accordingly, all of the northeastern and a large sample of the remaining states were queried with regard to their experiences in the use of permanent steel forms on bridge decks. A letter of inquiry was mailed to the construction engineers in 36 states and direct communication was made with the bridge engineers of 2 additional states. Specifically, these engineers were requested to supply general information regarding the problems that their state might have had with the use of steel forming. In addition, each state was asked whether they had observed concrete deck deterioration that could be associated with the use of steel forms, or if they had observed any corrosion of the forms on their older installations.

The majority of those states that were not surveyed are located in the western and southwestern regions of the country. Only a random sampling of these states was taken since preliminary information had indicated that they had built few structures using steel forms. The results from those western states surveyed tend to support that observation.

Replies were received from all but 3 of the total of 38 states contacted. Of the 35 responding states, only 8 have generally permitted the contractor the use of permanent steel forms as an alternate (Table 1). One of these would not allow their use over salt water. As also shown in Table 1, however, 13 additional states have allowed the use of permanent forms on some projects or on projects under contract upon special request by the contractor. An additional 6 states have a general policy of not permitting the use of permanent forms except in special situations. Some typical special situations were generally deemed to be high bridges over stream and rail crossings or in instances where the use of permanent forms might save time on contracts having tight completion schedules.

TABLE 1
STATE POLICIES CONCERNING USE OF PERMANENT STEEL FORMS
(AS OF 1974)

Total states surveyed	States responding	States permitting as an alternate	States that have permitted on some contracts	States permitting only in special situations	States that have not permitted
38	35	8	13	6	8

Twenty-one of the 35 responding states have allowed the use of permanent forms on an alternate basis or they appear to have no definite policy of avoiding their use. At the time of the survey, however, 9 of the 21 states had used the forms on fewer than 5 bridges. Eight states have not permitted permanent steel forms at all, and half of these states cited the fear of future maintenance problems as the reason for avoiding their use. The 4 remaining states simply had not used the forms.

Advantages and Disadvantages of Permanent Steel Forms

The advantages of permanent forms are well recognized and generally are related to the savings of construction time and labor and to the reduced safety hazards that their use affords. Bid prices for bridge deck concrete have sometimes been reduced by several percentages when steel forms are used. A number of the disadvantages associated with the use of permanent forms, however, were pointed out by the respondents to the survey. Some of the disadvantages, or problems, related to the use of the forms have been actual observed situations whereas others are potential problems that construction and maintenance engineers are concerned about. Nonetheless, all these problem areas are logical concerns which should be recognized by all those who have the responsibility of approving the use of steel forming for certain bridge construction projects. Therefore, a summary of those actual or potential problem areas mentioned by the respondents to the survey follows.

1. Future bridge widening and/or reconstruction can be more difficult and costly when permanent steel forms have to be removed prior to construction. As a result, some of the initial advantages of the use of steel forms can be lost in cases where widening and reconstruction are required.
2. When permanent forms are removed for bridge widening the concrete in the fluted area of the form's surface has sheared off in some instances and exposed portions of the lower reinforcing steel in the deck.
3. Safety hazards are increased when permanent forms have to be removed prior to widening an existing bridge deck.

4. The forms are usually attached to the bridge girders by angles welded to the girder flanges. Consequently, the need for field welding is sometimes considered a disadvantage and, once set to fixed elevations, vertical adjustments of the forms prior to concrete placement is difficult.
5. It was reported by one state that, in some instances, the upstanding vertical leg of the form support angles can "preform" continuous longitudinal cracks in the underside of the deck slab. (It should be noted, however, that this problem can be handled by not allowing the legs of angles to protrude into the deck slab.)
6. As opposed to wooden forms, the use of reinforcing steel tie downs on steel forms is more difficult.
7. The use of insulation on the underside of steel forms for cold weather concreting is a difficult problem since the insulation cannot be tacked to the forms as it can to the wood forming.
8. One state reported that some rusting of the steel forms occurred during storage on the job site. Insufficient zinc coating on the steel was cited as the cause of the problem.
9. Where permanent steel forms are used near longitudinal joints and drainage scuppers, some form rusting has been reported after only two to three years' service. The rusting in these areas has been attributed to water and salt solutions filtering through the longitudinal joints and drainage openings to make contact with the metal forms.
10. In locations where moisture does seep through cracks in the concrete deck, it can be directed to the supporting structural steel members and cause corrosion of the top flanges. Slight steel corrosion resulting from this cause was suspected by one state.
11. Permanent steel forms are believed to cause excess moisture content in concrete bridge decks by preventing or slowing moisture evaporation. Excess moisture content in the concrete has caused bonding problems with the application of water-proof membrane overlays on some bridge decks in one of the responding states.
12. The possibility of form corrosion causes some concern that future painting of the underside of the forms might be required. In a related manner, the possibility of rust staining could have an effect on the overall appearance of a structure. (It should be noted that neither of these two possibilities was reported as having occurred as yet.)
13. The size of structural members usually has to be increased to carry the additional weight of the forms and the concrete that occupies the flutes in the forms.
14. Welding of form support angles to the flanges of steel girders is considered to be undesirable -- particularly welding in zones where tensile stresses will occur.

15. Forms of too thin a gage may have been used on some earlier installations and resulted in greater than desirable deflections under the weight of the concrete deck.
16. The underside of concrete decks cannot be visually inspected after initial construction or at later dates for maintenance purposes.
17. Inspection of the concrete deck by "sounding" on the underside of the steel forms by random tapping with a hammer or other object has not always been found to be a reliable indication of soundness. One state reported that more than 30% of the steel panel emitted a hollow sound when tapped but the concrete was sound when the forms were removed for visual inspection. This observation indicates that the forms do not always bond to the concrete as expected.
18. In one unusual case, it was reported that a vehicular fire beneath an overpass structure damaged the permanent steel forms, caused considerable distortion and loss of galvanizing, and generally created a visibly undesirable situation.

A number of these disadvantages and potential problem areas are discussed in more detail later.

Concrete Deck Durability

As stated earlier, one of the primary concerns among potential users of permanent steel forms is the possibility of the forms contributing to the deterioration of concrete bridge decks. Referring to Table 2, 21 of the 24 states that commented on the effect of permanent form installations could not associate concrete deck deterioration with the presence of steel forming. Since bridge deck deterioration problems have been a national concern for a number of years, it is not surprising that visual inspections would not indicate a noticeable difference between bridge decks with or without permanent steel forming. The underside of the decks is the area of concern, however, since moisture and delicing salts could be entrapped at the interface between the concrete and the forms. With the intent of permanent forms being to leave them in place, removal for inspection purposes is a difficult operation. Accordingly, there have been few attempts to remove the forms. Only 3 states indicated that some of the forms had been removed -- 2 of these for the purpose of widening the bridges involved. One state, which widened three 10 to 13 year old structures, removed the forms from the fascia bays of the superstructure and reported no material difference between the appearance of the concrete on these structures as opposed to others without the forms. A second state (which removed some damaged forms from a bridge after a vehicular fire underneath) found no deterioration of the deck. A third state widened 2 bridges (approximately 15 years old) and found shallow surface deterioration on 1 structure and unsound concrete in the curb zone of the other. The unsound concrete was found to extend approximately 2 feet from the curb. Beyond this zone only minor surface deterioration was noted. It was not clear whether the deterioration could be directly attributed to the presence of the steel forming. Nevertheless, these conflicting observations tend to suggest that factors such as the relative location of permanent forms with respect to joints, drainage scuppers, etc., may have a significant bearing on the potential for entrapment of moisture and salts between the forms and the deck.

Adequate drainage of the deck as well as the initial quality of the concrete would also appear to have a significant bearing on the durability of decks having permanent forms. These last named factors, of course, are important for any bridge deck concrete but could be even more critical when permanent forms are in place.

TABLE 2

EFFECT OF PERMANENT STEEL FORMS ON DECK DURABILITY

States commenting on deck durability	States indicating no unusual deck deterioration	States indicating deck problems related to the forms	States routinely employing deck overlays	States that have removed some forms from older decks
24	21	1	2	3

The experience of 1 state (Table 2) indicated that the presence of permanent steel forms prevented the concrete from drying out and resulted in excess moisture in the decks. The excess moisture was noted as causing some problems when placing bituminous waterproofing overlays on the decks.

Two states routinely use waterproof membranes on the bridge deck surface and, as a result, cannot inspect either side of their decks when permanent forms are used.

In general, the response to the inquiry did not clearly indicate that permanent steel forms would or would not reduce the long-term durability of bridge decks. Obviously complicating the problem of evaluating the effect of the forms are several factors. First, durability has been a problem on many bridge decks both with and without permanent steel forms, so it has been virtually impossible to detect significant differences in deck performance to date. Secondly, the difficulty involved in removing the panels has tended to discourage inspection of the underside of the decks. In cases where moisture has been found under the forms during removal it has been difficult to determine whether it resulted from, caused, or has contributed to a concrete durability problem.

Permanent Form Durability

In addition to the concern about possible concrete durability problems, the possibility of corrosion of the forms themselves is an area of concern. Many of the states that were surveyed had only a few relatively new permanent steel form installations and, consequently, could not evaluate form durability. Only 16 of the 35 responding states commented on form corrosion, with half of these reporting that no corrosion had been observed (Table 3). Three states reported that corrosion had been

observed in areas where the forms were adjacent to longitudinal joints, deck drains, and expansion joints. One of the 3 states reported that some corrosion had been observed in the vicinity of scuppers and longitudinal joints after the forms had been in service for only 2 or 3 years. Corrosion at some of the welds which join the form support angles to the bridge girders was observed by 3 states, and 1 state reported some minor rusting at the juncture area between the forms and the girders.

TABLE 3

CORROSION OF PERMANENT STEEL FORMS

States commenting on form corrosion	States reporting no corrosion	States reporting corrosion at deck joints, drains, etc.	States noting corrosion at welds attaching form supports	States noting corrosion at juncture of forms and girders	States noting corrosion on forms removed
16	8	3	3	1	2

Two states reported rusting on some panels which were removed from several bridge decks. One of the installations was from a 10 year old bridge; the other was removed from two 15 year old bridges which were being widened. In the former instance, 2 panels of the forming were removed for inspection. One panel had some rusting whereas the other did not. In the latter case, the corrosion was observed on the forming in areas adjacent to openings provided for deck drains.

Although the information obtained on form corrosion is limited, it is apparent that permanent steel forms will corrode if exposed to water and detrimental quantities of deicing salts. The greatest potential for corrosion, however, appears to be strongly related to the location of the forms with respect to joints, drainage scuppers or other points where water can gain access to the forms. Judicious use of the forming or bridge design modifications to avoid the placement of the forms adjacent to joints and drains could reduce the possibility of corrosive conditions.

Interpretation

The results of the experience survey tend to suggest that the quality of a concrete bridge deck could have significantly more influence on the durability of the permanent forms than the permanent forms will have on the durability of the concrete. Thus, when permanent forms are used on construction, it is apparent that the importance of obtaining quality concrete in the deck takes on an added dimension — that of protecting the forms from the infiltration of water and salt solutions.

RESULTS OF PRIOR STUDIES

General Steel Form Surveys

One of the earliest surveys of permanent steel formed bridge decks was reported by Benjamin and Walsh, ⁽²⁾ who inspected 21 steel formed and 10 wood formed bridges in Illinois. The bridges were from 6 months to 5 years old at the time and were located in 3 geographical areas of the state. Three of the bridges had both metal and wood formed areas.

The quality of the concrete in the deck was determined by use of a Swiss hammer and the data were statistically analyzed. By use of this technique the investigators concluded that the quality of the concrete was independent of the method of forming. Additional sounding tests indicated that, in general, the forming had good bond to the deck. Corrosion of the forms was reported on only 1 bridge in an area adjacent to a floor drain. The general condition of the forms was described as good.

Deuterman, et al. ⁽³⁾ reported on some of the earlier use of steel for the forming of bridge decks and cited several structures that were built approximately 60 years ago and were still in good condition. The steel used on these very early installations was not designed specifically for use as forming but was an adaptation of material designed for other uses. One such case cited by the authors involved the use of corrugated barn siding on a structure in Texas. Over the years some of these panels have broken loose from the underside of the deck since adequate permanent attachments to the structure were not used.

A number of the early (prior to 1966) installations of permanent forms that had had failures were jointly investigated by the Bureau of Public Roads and the American Iron and Steel Institute. ⁽³⁾ Most of the problems found were of the type that could be avoided by proper deck placement techniques and by certain modifications in the design of the structure, the forms, and in the specifications. Rusting of the forms was found beneath longitudinal construction joints and longitudinal median joints. Calcium chloride, used as a retarder in the concrete, was suspected as contributing to the rusting of the forms on 1 bridge deck. Bending and distortion in the forms on one structure were attributed to dropping the concrete from excessive height during construction and to installing certain steel panels upside down. Other problems were found to be related to poor consolidation of the concrete, a too large aggregate and poor attachment of the forms to the girders. The results of the investigation led to the development of specifications for the use of steel forms. ⁽³⁾ Many of these provisions appear to be incorporated in the specifications now employed by many state highway and transportation departments.

Composite Action With Concrete Decks

The amount of composite action that can be expected from the use of permanent corrugated steel forms was investigated by Barnoff et al. in a study of 2 parallel continuous girder bridges located in Pennsylvania. ⁽⁴⁾ One of the twin structures was constructed using permanent steel forms and the other utilized conventional wood forms that were removed after construction. The bridge without the permanent forms

had significantly more transverse cracking than the one with the permanent forms. Other tests and analyses indicated that the steel forms tend to act as shear connectors and develop considerable composite action between the concrete deck and steel girders. Composite action was found to be greater when the slab and beam were subjected to positive moment than to negative moment stresses.

In further studies for composite action, Barnoff and Jones⁽⁵⁾ conducted push-out tests on specimens having steel forms supported by several types of beams to form connections. The general type connection most widely used by contractors (Figure 2) for attaching the steel forms to bridge beams was found to produce a high percentage of composite action. Although full-scale tests were not conducted, the tests results indicated that the number of shear connectors used on a girder theoretically could be substantially reduced when using steel forms. It should be noted that this finding was only meant to indicate the degree of composite action obtained from the corrugated forms. It was not recommended that the number of shear connectors be reduced for design purposes without full-scale study.

Deck Durability With Permanent Steel Forms

In a study of 249 4-year old bridge decks in Pennsylvania, Cady et al.^(6,7) related the extent and severity of bridge deck deterioration to those factors or combinations of factors which could cause deterioration. The lengths of cracks, areas of spalls, fracture planes, and mortar deterioration were measured on each deck and the data analyzed using a computerized statistical technique which related the interaction of causes with the deterioration noted on the bridge decks. It was generally found that variations in construction practices was a major cause of the differences in deck deterioration observed. In addition, the analysis indicated that the use of permanent steel forms was related to reduced deck cracking and could also be associated with slight increases in surface mortar deterioration on the decks. Many decks with steel forming and high traffic counts, however, had little surface mortar deterioration, which suggested that construction practices and concrete quality are, as always, important factors and may assume added significance when permanent forms are used.

Spalling of the concrete decks was not found to be related to permanent forming. Fifty-three of 55 decks having spalling were found to have insufficient cover over the reinforcing steel.

The deterioration of 7 concrete bridge decks was observed by Cady et al.⁽⁶⁾ over a 5-year period subsequent to construction. Three of these decks were built with conventional removable forming, whereas 4 were built with permanent steel forms. The decks built with removable forms exhibited higher rates of cracking but lower rates of surface mortar deterioration than the decks built with permanent steel forms. The average rate of cracking on the bridge decks is shown in Figure 3, which indicates that after 5 or 6 years of service, the conventionally formed decks exhibited roughly 3 times more cracking than did the permanently formed decks. The authors suggested that the reduced cracking on the latter decks could be attributed to two factors. First, as indicated earlier in the work conducted by Barnoff et al.⁽⁴⁾

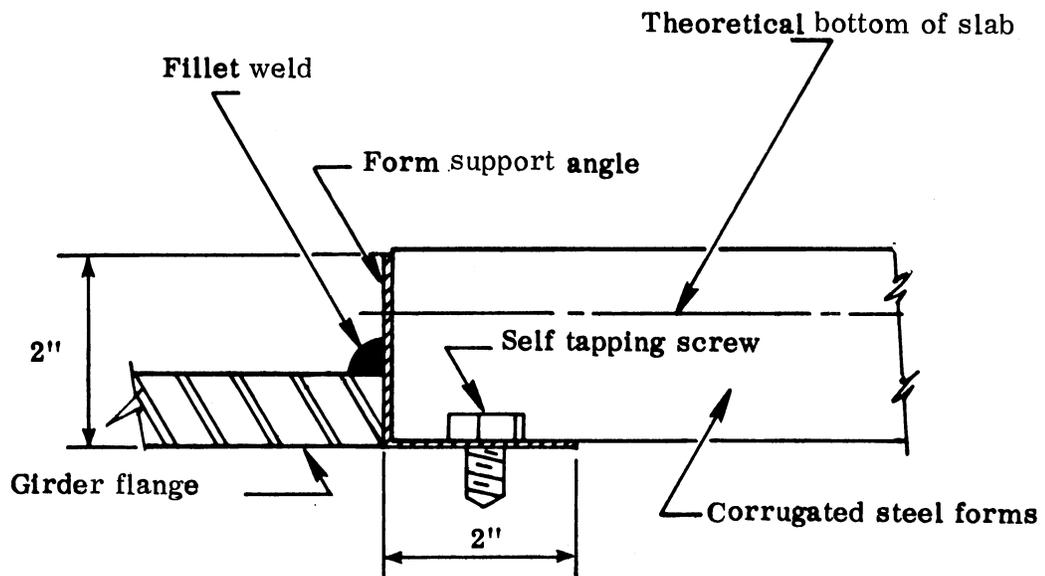


Figure 2. Typical form support and sheet metal screw connection used in push-out tests conducted by Barnoff and Jones. (5)

permanent forms produce decks that are stiffer than conventionally formed decks and thus their use might reduce cracking precipitated by dynamic loads. Secondly, the steel forms would aid moisture retention for longer periods of time and thus reduce shrinkage cracking resulting from early moisture loss in the newly placed concrete.

Figure 4 shows the relationship between the form type used and the mean rates of surface mortar deterioration (SMD) found on the bridge decks. As indicated in Figure 4, the SMD on the permanently formed decks after 1 year was roughly equal to that developed after 3 years on the conventionally formed decks. The trend of the conventional form curve, however, suggests that the SMD may only be lagging by several years the deterioration noted on the permanently formed decks.

In a later report, ⁽¹²⁾ Cady cautions that permanent forms cannot be assumed to be the primary cause of SMD, but in combination with the contractor involved and calcium chloride usage they were found to have influence on the problem. It was suggested that the cause of the greater SMD on the permanently formed decks was due to longer moisture retention, which caused the decks to be more susceptible to frost action and perhaps to traffic wear. Further studies by Cady and Carrier ⁽⁸⁾ involved the measurement of the moisture content and distribution in the concrete of 2 bridge decks in Pennsylvania. One was constructed with removable forms and the other with permanent forms. Measurements were averaged over an 11-month period and the moisture distribution compared with that of a concrete pavement. As shown in Figure 5, the permanent steel formed deck and the concrete pavement had similar moisture distribution characteristics, with the higher moisture content at the center and bottom of the sample cores. The exposed surfaces (top and bottom) of the conventionally formed bridge deck sample were drier than those for the pavement and permanently formed deck. Thus, it was concluded that bridge decks built with permanent metal forms have generally higher moisture contents than decks built with removable forms. It should be noted, however, that this result might have varying significance in different geographic regions having climatic conditions different from those of Pennsylvania.

The results of studies conducted by Chamberlin, et al. ⁽⁹⁾ involving 716 bridges in New York State were generally similar to those from the work conducted in Pennsylvania. Scaling and spalling were found to be roughly equivalent on bridges formed by either procedure in New York, whereas spalling was less extensive on steel formed decks in Pennsylvania. ⁽¹²⁾ Transverse cracking, however, was found to be considerably less on permanently formed decks in both states. The deck cracking results of the New York and Pennsylvania studies were compared by Chamberlin, et al. ⁽¹⁰⁾ and found to be quite similar, as shown in Table 4. The relationship between surface mortar deterioration and permanent steel forms was not found in the New York study.

Additional work in New York, reported by Allison, ⁽¹¹⁾ involved removing several permanent form panels from some 10 to 12 year old bridge decks. All of these decks were covered with an asphalt wearing surface and were believed to represent the worst permanently formed decks available. In a few instances some deteriorated concrete was found on the underside of the deck but no determination of the basic cause or severity of the distress was made. In all cases the concrete was found to be damp when the panels were removed but no rusting of the steel was noted.

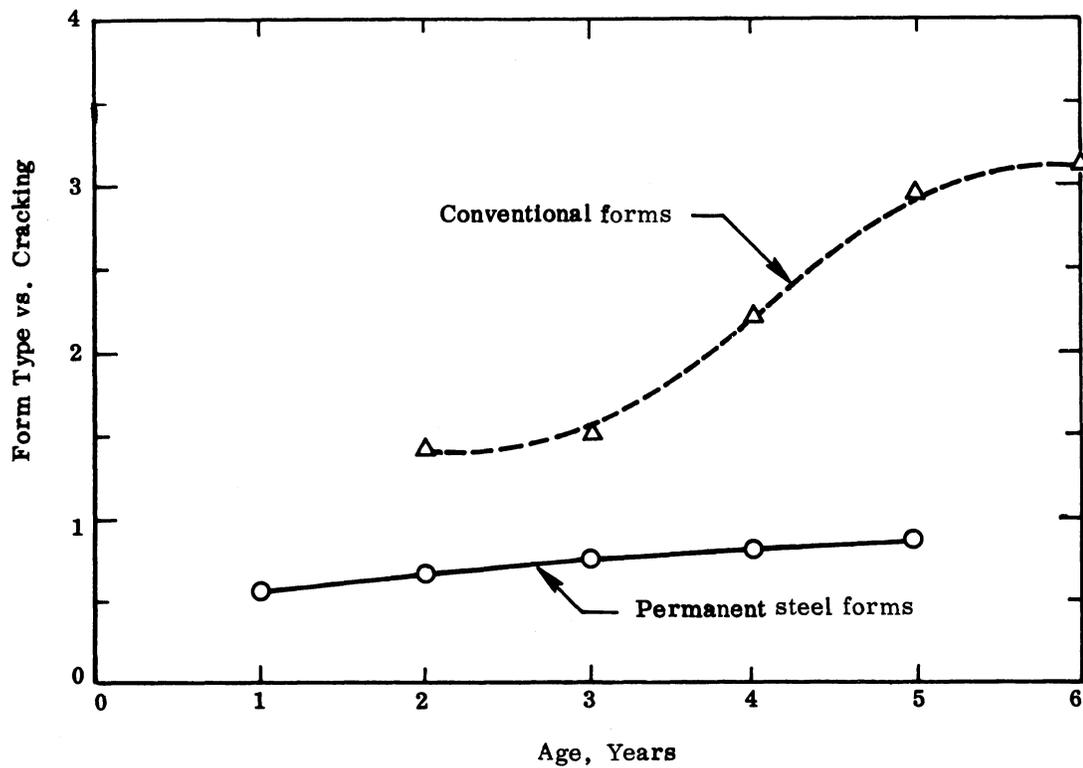


Figure 3. Relationship of rate of deck cracking to type of deck forming used. From Cady et al. (6)

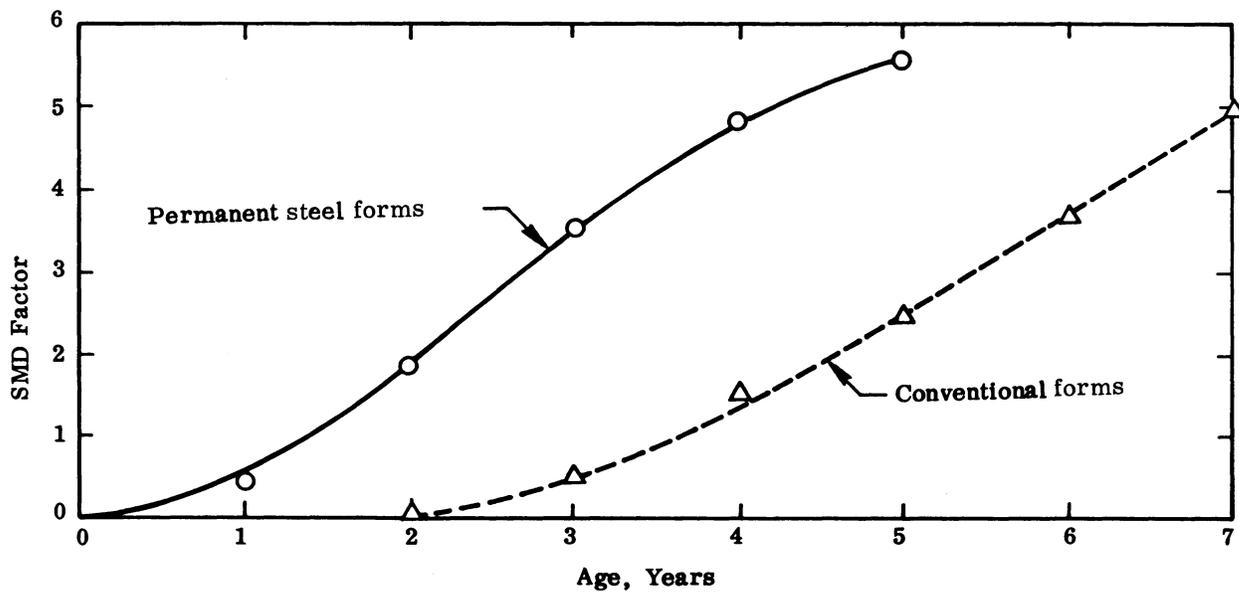


Figure 4. Relationship of rate of deck SMD to type of deck forming used. From Cady et al. (6)

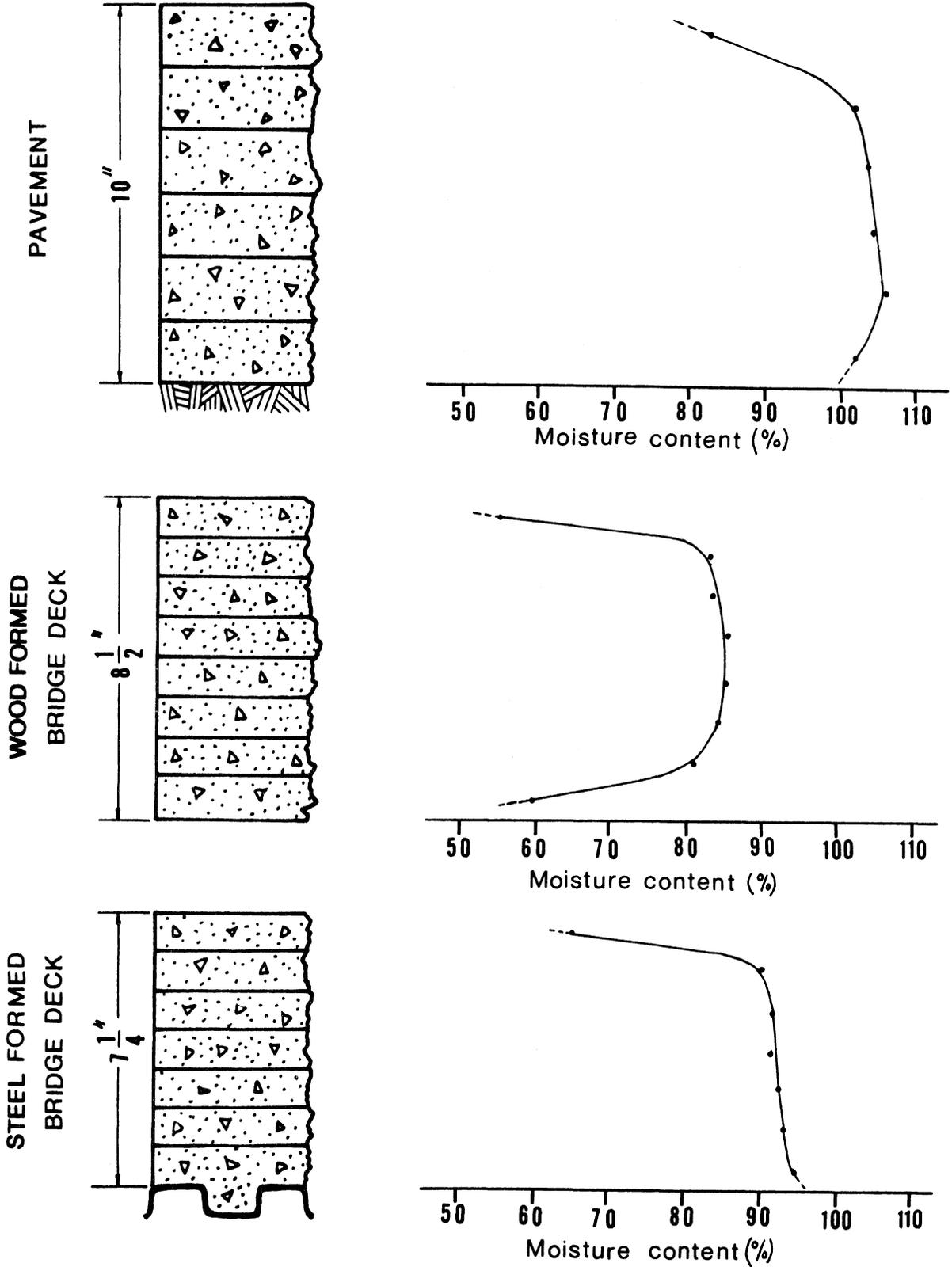


Figure 5: Moisture distribution in a pavement and in bridge decks.
From Cady and Carrier Ref. (8).

TABLE 4
 LINEAR FEET OF TRANSVERSE CRACKS PER 100 SQ. FT. OF BRIDGE DECK
 (From Chamberlin, et al. Ref. 10)

Source of Data	Forming Method	
	SIP	Conventional
Pennsylvania	0.46	1.50
New York	0.55	1.27

Freeze-Thaw Durability

Since permanently formed decks were generally found to have higher moisture contents than conventionally formed ones, Cady investigated the possibility that these decks would be more susceptible to freeze-thaw damage.⁽¹²⁾ Both laboratory and field exposure tests were conducted on test slabs with and without permanent forms and with and without several types of surface overlay treatments. In the laboratory, the slabs were maintained in a saturated condition and subjected to 75 freeze-thaw cycles. Subsequently, the slabs were exposed to one winter of natural conditions. Pulse velocity tests indicated no evidence of freeze-thaw damage.

Additional inspections and tests were conducted on 26 bridges—13 each in New York State and on the New Jersey Turnpike. One of the New York bridges did not have permanent forms, but all were 12 to 13 years old at the time of the survey. The New Jersey structures ranged in age from 1 to 11 years old. With the one exception noted, all the decks had permanent forms and all were sealed with some type of waterproofing material. These decks were chosen to investigate the possibility of increased freeze-thaw susceptibility when the concrete is sealed on the top and bottom. Pulse velocity tests revealed that 2 of the New York decks probably contained deteriorated concrete. One of these was the deck without permanent forms. Tests on the remaining bridges did not indicate freeze-thaw damage.

Form panels were removed from 12 bridges and the concrete on the underside of the decks was found to be in sound condition. The results of these inspections are summarized in Table 5.

Thus, the results suggest that the freeze-thaw durability of covered concrete decks with permanent forms is not different from those without the forms.

TABLE 5
 CONDITION OF CONCRETE WHERE FORMS WERE REMOVED
 (From Cady et al., Ref. 12)

Bridge	Excellent	Incomplete Consolidation	Deteriorated	Foreign Materials Found Under Forms
NYDOT-2	X			Sawdust Wood Chips
NYDOT-5	X			
NYDOT-7	X			
NYDOT-10	X			
NYDOT-13	X			Sand
NJTP-2	X			
NJTP-3	X			
NJTP-5	X			
NJTP-6	X	X		
NJTP-7	X			
NJTP-8	X			
NJTP-10*	X			
TOTALS	12	1	0	

*Removed by Others

Testing for Incomplete Consolidation

In support of the state survey discussed earlier, Cady et al. (12) found that hammer soundings on the underside of steel formed decks did not necessarily relate to incomplete consolidation of the concrete. In addition to locating areas of incomplete consolidation, hollow soundings were found to indicate separation of the forms from the decks. The extent of hollow soundings was also found to be related to deck age and thus to progressive separation of the forms from the concrete. The authors concluded, however, that separation of the forms from the concrete has no effect on either the durability of the deck or of the forms.

Interpretation

An interpretation of the studies and field inspections that have been reported to date do not implicate permanent steel forms as singularly causing deck durability problems. The preponderance of the evidence suggests that given deck design details which will minimize the possibility of deck drainage gaining contact with the forms, plus the construction of an initially durable concrete, the forms should not have a detrimental effect on deck durability. In some respects—such as the case with cracking and spalling—the forms appear to aid deck durability. While surface mortar deterioration was found to correlate with the use of permanent forms in 1 state, the correlation was only valid when the use of the forms was taken in combination with several other variables.

Corrosion Resistance of Permanent Steel Forms

General visual inspections of the in-place forms during the New York study⁽⁹⁾ and the earlier Pennsylvania studies⁽⁷⁾ revealed little or no evidence of form corrosion. Removing some panels from what was described as the worst permanently formed decks available in New York, however, Allison found some corrosion. On several panels, approximately 5% of the total area was described as completely rusted through. These forms had been installed for 10 to 12 years prior to their removal but no indication of the possible causes of the distress was given.

In the latest study by Cady et al.,⁽¹²⁾ form panels were removed from 5 bridges in New York State and 7 on the New Jersey Turnpike. The New York bridges were of the same age group as those involved in Allison's work, and all the decks, including those in New Jersey, were covered with some type of waterproof membrane and/or asphalt. In general, corrosion on the inside of the removed panels was described as virtually nonexistent. Two panels had a few spots of light rusting and 1 some slight corrosion where wood and sawdust (see Table 5) had been left on the form prior to concrete placement.

General visual inspection of the forms indicated that they were in good condition. Most of the corrosion that was observed was located along the fascia girders and at the ends of spans and could be traced to the drainage of salts from the deck surface. Drop inlets on bridge decks were particularly related to adjacent form corrosion. Therefore, deck design features which permitted water to come in contact with the forms were related to the majority of the form corrosion. A summary of the observations on form corrosion is given in Table 6. As indicated, extensive corrosion was concentrated at span ends and along the fascia girders with very little being found in other areas of the decks. The authors concluded from their inspections that corrosion is generally not a problem where deck design provides for drainage which will not make contact with the forms.

TABLE 6
SUMMARY OF OBSERVATION ON FORM CORROSION
(From Cady et al., Ref. 12)

Bridge	Age Yrs	Form Corrosion												
		Along Fascia Girders			Span Ends (Expan. Joints)			Random						
		Extensive	Slight	Negligible	Extensive	Slight	Negligible	Extensive	Slight	Negligible				
NYDOT	-1	X			X									X
	-2	X			X				X					X
	-3	X			X									X
	-4	X			X									X
	-5			X	X									X
	-6			X	X									X
	-7			X	X									X
	-8			X	X									X
	-10			X	X									X
	-11			X	X									X
	-12			X	X									X
	-13			X	X									X
	NJTP	-1												
-2														X
-3														X
-4														X
-5														X
-6														X
-7														X
-8														X
-9														X
-10														X
-11														X
-12														X
-13														X
TOTALS		4	1	17	8	4	12	1	4	12	1	4	20	

*Sections of the deck having steel forms were not adjacent to fascia girders and/or abutments.

Time To Corrosion

Field studies have indicated that galvanized steel forming will corrode under adverse conditions. Under exposure to water and salt solutions, for example, form rusting has been observed after roughly 8 to 12 years of service. On the other hand, most (or all) of the forming is protected from some of the normal atmospheric weathering conditions such as precipitation and direct sunlight. Thus, it is difficult to predict how long the forming might survive corrosion at any given location. Data are available, ^(13, 14) however, concerning the time to various stages of corrosion of galvanized test sheets exposed to atmospheric conditions at a rural setting in Pennsylvania. These particular samples, representing various manufacturers, have been continuously exposed since 1926, and data are still being collected. Although the test samples are exposed to the weather whereas permanent forms normally are not, these data do afford a basis for judgement. Some of the corrosion data, showing the years to first rusting, 100% rusting, and first perforation for selected weights of zinc coating, are given in Figure 6. All of the data shown are for No. 22 gage material, which is usually the lightest gage sheeting used for forming. The curve showing first rusting represents the average of the data for 18 samples. The 100% rusting curve is an average of all data available up to the 1.5 oz./ft.² coating. The remainder of the curve is projected from the established trend. The time to perforation curve was conservatively estimated by adding to the former curve the lower of the time to perforation data for the 22 gage uncoated metal samples.

For a zinc coating weight of 2.0 oz./ft.², which is usually used for forming, the average first rusting, 100% rusting, and first perforation would be, respectively, 22.5, 55, and 80 years. Therefore, if a 22 gage forming were to corrode at a rate comparable to that experienced under atmospheric conditions at a rural setting in Pennsylvania, it would survive an average of 80 years before a perforation would occur. Assuming protection from water and deicing salts, the life of galvanized forming would generally appear to be as long as that normally experienced with bridge decks. One might expect, however, that a deteriorating bridge deck could precipitate deterioration of the forming.

The geographic location of a forming installation could also have a bearing on the corrosion factor, as indicated by data developed from other tests. ⁽¹⁴⁾ Samples exposed in 1960 to atmospheric corrosion at 5 sites demonstrate that heavy industrial and salt water environments can be severe. As shown in Figure 7, all test samples exposed at an industrial site at Newark, N. J., showed 100% rust after 12.6 years. It is likely that the presence of SO₂ and SO₃ in the air in some industrial regions increase the corrosion rate due to the acidity of condensed moisture. ⁽¹⁵⁾ It is interesting to note that the rusting of forming reported at joints and drainage areas on some bridges appears to be on a time scale similar to that of the corrosion observed on the industrial area test samples.

The next most severe of the 5 sites was a marine environment located 800 ft. from the surf. At 2 other marine sites located, respectively, at 1,930 ft. and 3,900 ft. from the surf, zinc corrosion products were noted but no bare metal rusting was found. Although it has been suggested that protective films of zinc carbonate are sometimes formed in marine locations, and help retard corrosion, ⁽¹⁵⁾ the data suggest avoiding areas close to salt water.

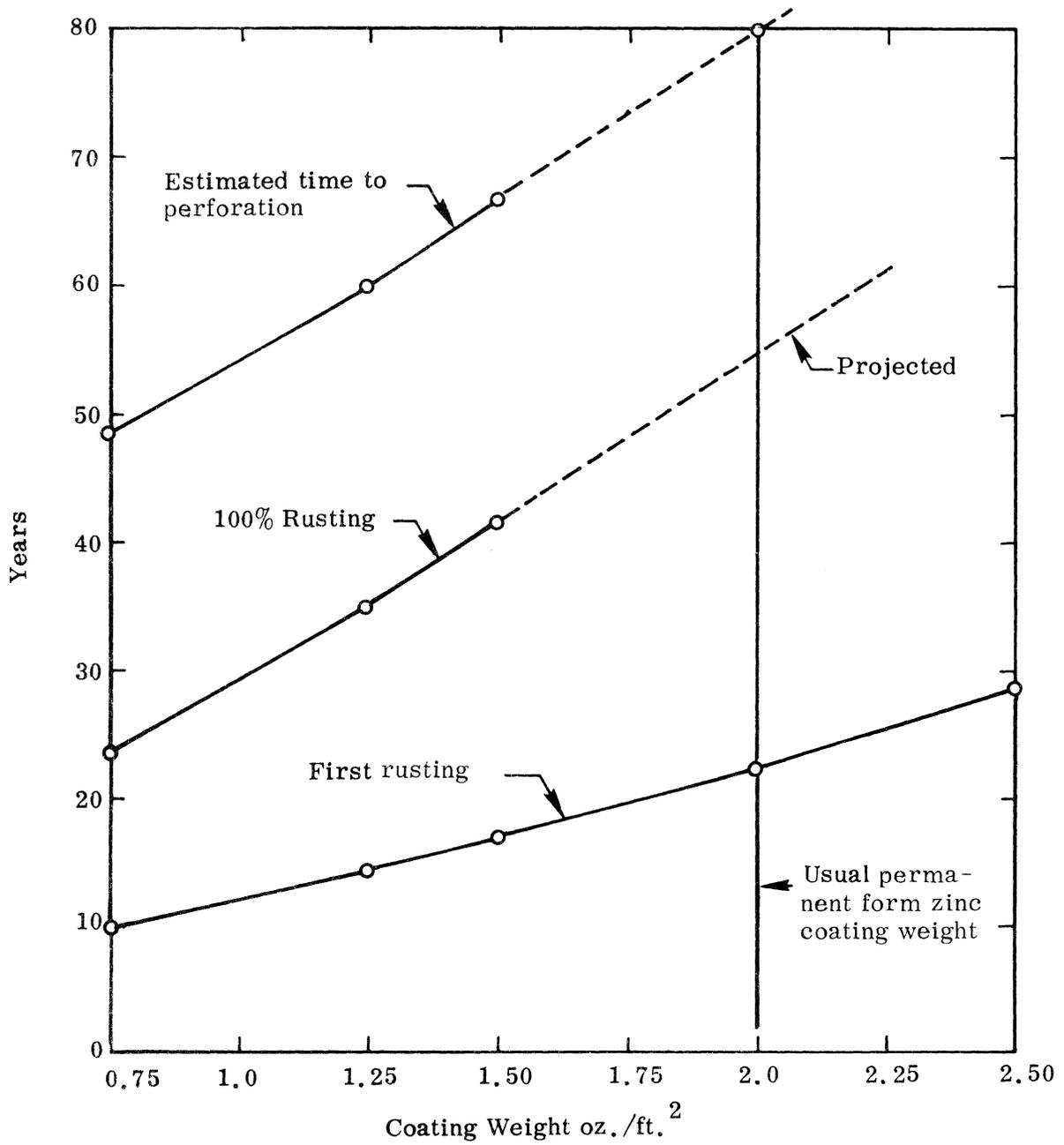


Figure 6. Average time to corrosion of 26" x 30" No. 22 gage corrugated galvanized sheets exposed to atmospheric corrosion at State College, Pa. in 1926. (Data developed from References 13 and 14.)

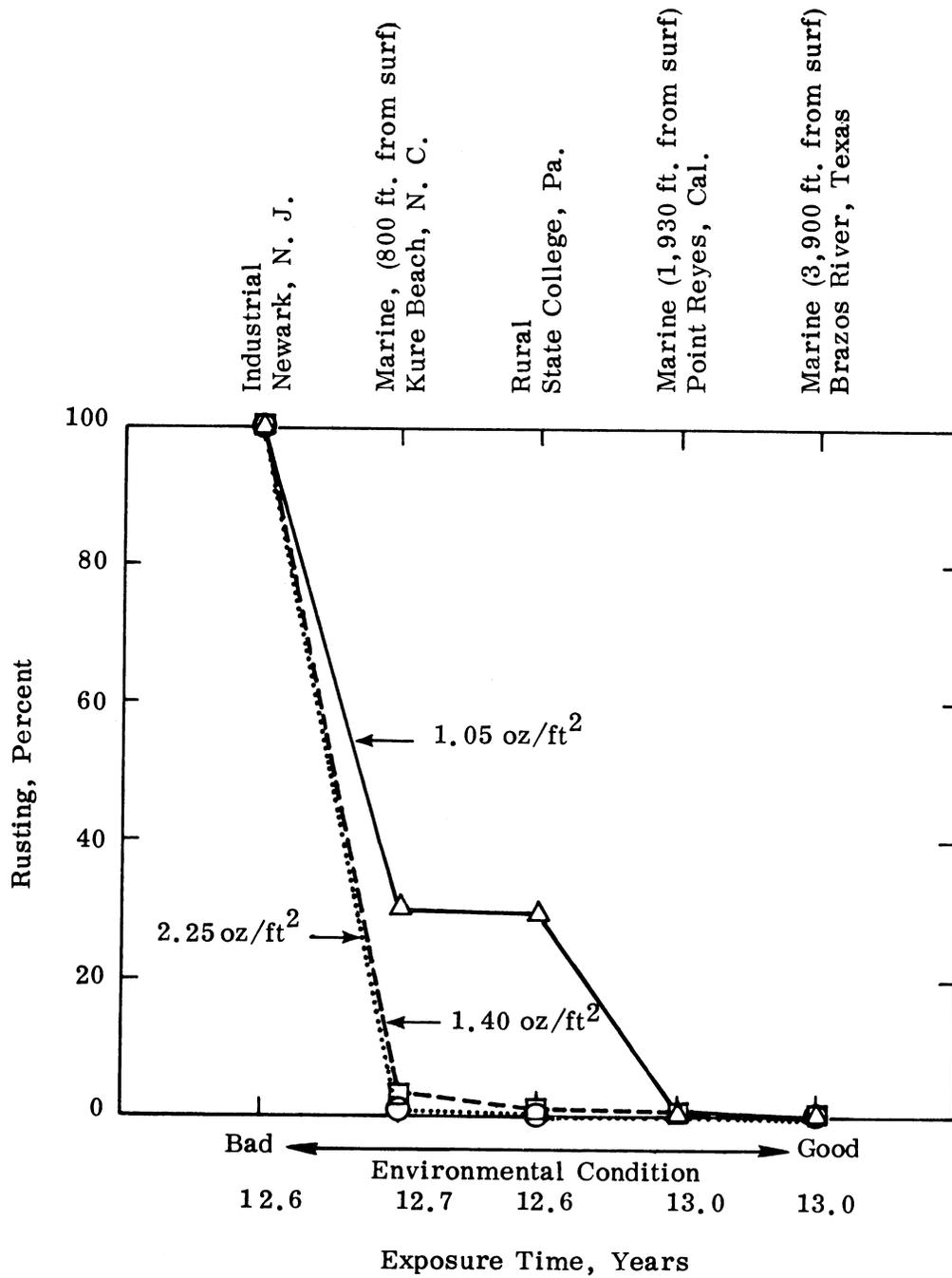


Figure 7. Effect of environmental conditions on the atmospheric corrosion of 28'' x 36'' corrugated galvanized sheets exposed at different locations. (Data developed from references 13 and 14.)

One might conclude from the data that even on the underside of bridge decks, galvanized forming might corrode faster in industrial and at, or near, salt water areas. In rural areas the principal corroding agent appears to be water, so galvanized panels should corrode slowly in areas with dry climates. Regardless of the location, the corrosion rate of galvanized sheeting will vary from the averages given in Figures 6 and 7. This is due mainly to the fact that zinc coatings are never uniformly distributed, and base steel at the edges of some panels could accelerate corrosion. (15)

Chloride Penetration

Chloride penetration to the depth of the forming has also been a matter of concern in some quarters. Studies on 3 bridges, (12) however, indicated that after 7 years' service the chloride content was negligible below 1.5 in. from the deck surface. Data developed by Clear (16) indicates that chloride contents at 3 in. depth are usually below the corrosion threshold for concrete having water-cement ratios of 0.5. Since chlorides would have to travel through on the order of 6 in. of concrete to reach the lower reinforcing steel and usually 8 in. or more to reach the forming, corrosion of the lower steel and the forming as a result of chloride penetration appears unlikely. Joints, drainage areas, and deep cracks or deteriorated areas of concrete would appear to be the most likely channels for penetration.

Interpretation

There is little doubt that permanent forming will corrode in only a few years if exposed to water and, particularly, salt solutions. With the use of adequate joint and drainage designs and forming installations designed to minimize possible contact with corrosive agents, however, permanent form durability should equal that of the bridge deck.

SUMMARY OF CONCLUSIONS

1. The state survey revealed a wide difference of opinion concerning the use of permanent forms. Some states do not allow the use of the forms, fearing future maintenance problems, whereas others feel their advantages outweigh their disadvantages.
2. A composite view of the state survey and the prior research studies indicates that permanent steel forms do not singularly affect the durability of concrete bridge decks. Removal of a number of forming panels on a recent study suggests very few instances where moisture has been entrapped between the deck and the forming, except in instances where the moisture could be traced back to joints and drainage areas on the deck.

3. The evidence suggests that the durability of the concrete deck may have a more significant effect on the durability of the forms than the forms will have on the durability of the deck.
4. Permanent steel formed decks generally have less transverse cracking and less spalling, and improve the composite action between the deck and the girders.
5. Permanent formed concrete decks have higher moisture contents and, in combination with other factors, have been found in one state to have generally more surface mortar deterioration than conventionally formed decks.
6. Hammer soundings taken on the forming to check for incomplete consolidation of the concrete are not reliable. "Hollow" sounds often reveal a lack of bond between the deck and the forming rather than poor consolidation of the concrete.
7. Corrosion of the permanent forms can be a significant problem if bridge and forming installation designs allow ready access to the forms through joints or drainage features. Therefore, permanent forms should not be used on those areas on the underside of bridge decks that are readily accessible to drainage moisture.
8. Data on the atmospheric corrosion of galvanized sheeting suggest that given adequate protection as described above, the forming should have a life expectancy equal to or greater than that normally experienced with bridge decks.
9. Data on the atmospheric corrosion of galvanized sheeting exposed close to salt water (marine) environments and in heavy industrial areas indicates the possibility of a higher than normal rate of corrosion.
10. Studies indicate that penetration of chlorides through the concrete deck to gain contact with permanent forming is unlikely. The most likely access channels for chlorides to gain contact with the forming would be through joints, drainage features such as drop inlets, deep cracking, or deteriorated deck concrete.

RECOMMENDATION

Based on information collected prior to the preparation of this report it was recommended earlier that the Department proceed with the use of permanent steel forms where their use appeared to be advantageous. While there are some disadvantages associated with the use of permanent steel forms as noted in the report, most of these will apply only infrequently. Some isolated instances of form corrosion will develop in the future; but the experience to date indicates that by using the forming only on the interior bays of the deck and by keeping the forming away from joint and drainage areas, corrosion problems can be held to a minimum.* It is therefore recommended that the Department continue to use the forming where it is felt to be advantageous. It is not recommended, however, that permanent steel forming be used over or within 1,000 ft. of salt water locations or adjacent to heavy industrial areas known to contribute significantly to atmospheric pollution.

* It should be noted that the results of the survey were based on past experience with steel forming having galvanized coating weights generally on the order of 2.0 oz/ft². For other coating weights the field experience may differ.

ACKNOWLEDGMENT

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This project was financed by state research funds and was under the general supervision of Mr. J. H. Dillard, Head, Virginia Highway & Transportation Research Council.

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