Metal Bridge Deck Form Specification Developed Cooperatively by Industry and Government

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Investigations of bridge deck slabs formed with steel forms to remain in place, made in connection with the cooperative preparation of a specification by industry and government, are reported. Research and questionnaire survey results that were reviewed are also reported. It was found that so-called failures of steel forms were caused by the application of other steel sheet products as a forming material, design details that permit salt-laden moisture to attack the metal, specification error, construction abuse, and lack of proper placement and consolidation of the concrete. The resulting specification is included.

•WITH THE EXCEPTION of dwellings, the bridge is probably the oldest and most fundamental structure affecting the welfare of man. Throughout the world bridges of every size, shape, and character exist; some still in use are centuries old, and some are as modern and unique as tomorrow. Bridge engineers are continually producing modern designs for aesthetic and utilitarian purposes. Research is projecting this ageless, fundamental structure into the space age alongside the space vehicle, miniature circuitry, and nuclear engineering.

This paper is a review of one facet of this continuing research, namely, the forming of the bridge deck, on which considerable effort has been spent over at least the past 15 years.

HISTORY OF USE OF STEEL IN BRIDGES

One of the accomplishments during these years has been the introduction of steel remain-in-place bridge forms. Few products affecting the highway construction market have been the subject of so much controversy. Because this controversy creates a barrier to acceptance of the product and because specifications for the product and its use became so divergent in character, the U. S. Bureau of Public Roads and the industry began conversations aimed at resolving the objections and preparing a nationally acceptable specification. We are pleased to report that an acceptable specification for steel remain-in-place bridge forms has been developed cooperatively by the Bureau of Public Roads and the industry.

Removable timber forms have been the standard or conventional method of forming bridge deck slabs, but a review of the historical development since the early years of this century reveals that various types of steel sheeting have also been used to form bridge deck slabs. In fact, shortly after sophisticated methods of concrete placement

Paper sponsored by Committee on Construction Practices—Structures and presented at the 49th Annual Meeting.

Figure 1.

were developed, and with concrete and steel structures beginning to appear across the country around the turn of the century, contractors and bridge builders began seeking ways and means of economically using steel. Corrugated sheets of various thicknesses and with varying amounts of galvanizing, originally designed for use as siding, roofing, and other purposes, have been both applied and misapplied as bridge deck forms.

One of the earliest steel forms consisted of corrugated grave vault sections employed as a jack arch form spanning between the bottom flanges of the stringers. Figure 1 shows the construction of a bridge using the grave vault sections. It is undated, but a spokesman for the Baltimore and Ohio Railroad dates a car pictured in the same literature as existing before 1910. This construction is a remote ancestor in the chain of evolutionary development, but it is not a remain-in-place steel bridge form per se.

Figure 2, a photograph taken in 1969, shows one of these installations that we are told is rather typical. We are told this was installed in 1913, about 57 years ago. It is still serviceable and amazingly intact despite its age. The next step in the long process of product evolution was the use of corrugated barn siding to form the slab. The most talked-about installation of this type is a bridge over the Pecos River on Highway 90 near Del Rio, Texas—one that is frequently cited in the criticism of steel bridge forms.

The need facing the contractor for a new and safer means of forming bridge decks is graphically shown in Figure 3. The distance from bridge deck to canyon floor is 275 ft. This great height prompted the contractor to use barn siding as forming, supported by wood cross members that were removed when the concrete was set. Initially, the barn siding was chemically bonded to the slab quite adequately. However, over the years, the bond between the deck and the coating deteriorated under flexing caused by continuous traffic and aided by severe temperature changes.

As can be seen in Figure 4, the result has been the falling away of some of the unsupported middle sheets and the precarious hanging of others, virtually by a thread. Again, this is not a steel remain-in-place bridge form installation. And it is reports of these so-called failures resulting from such applications that continue to circulate and that are today often wrongly associated with the deep-corrugated galvanized steel forms specifically engineered for forming bridge decks. Understandably, many bridge engineers have confused this application with the present system and denied approval on the premise that steel bridge forms as presently designed have fallen out of the structure.

Other elementary, unorthodox applications have been found in numerous structures around the country. Although indicative of misapplication of steel sheeting, they are

Figure 2.

Figure 3.

still illustrative of contractors' efforts to use steel as a forming material. In these instances there was no effort made to design a steel forming system specifically for the bridge decks. The attempt was merely to substitute existing steel products, which were designed for other purposes, as a forming material without consideration of suitable permanent attachments between the steel sheet and the supporting stringers and a slab.

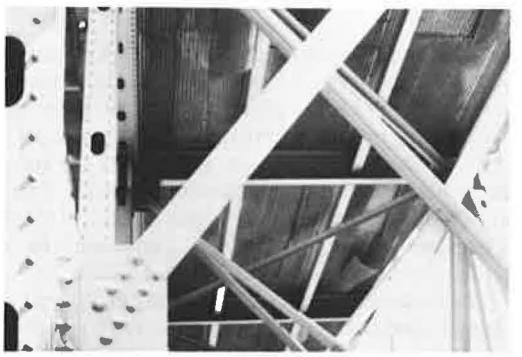

Figure 4.

In the middle 1950's, industry entered into an active research program and developed a steel forming system for bridge decks. This forming system has been used in a majority of the states. This steel forming system has been developed to meet design requirements of the various states, and to maintain the structural integrity of the slab required by bridge design departments. Design of the system has evolved to accommodate haunched slabs, lateral support, composite design, nonwelding in tension flange areas, changing of slab elevations, converging or diverging stringers, and other structural and aesthetic requirements set forth by bridge designers.

RESEARCH AND DEVELOPMENT OF THE SYSTEM

Design of the steel forming system for bridge decks has been engineered to allow the design strength of the deck slab to remain essentially unchanged from those designed to be formed by conventional methods. Actually, the basic element in the system is the deep-corrugated galvanized steel form. The custom-fabricated form has variable-width corrugations that can be provided in widths to accommodate spacing of the bottom main reinforcement when required. Of course, this remain-in-place sheet replaces the removable form. The gage of the base metal varies with load span, keeping deflection to a specified minimum.

A comparison of steel forms and removable forms is shown in Figure 5. The steel system becomes an integral part of the bridge slab where the support angles are securely fastened to the stringers and the deck panels rest on and are mechanically fastened to the supports. Design of the support allows vertical adjustment for camber and variable slab elevations. Recent development of the closed end or tapered form has eliminated the need for special end closures while increasing the efficiency of installation.

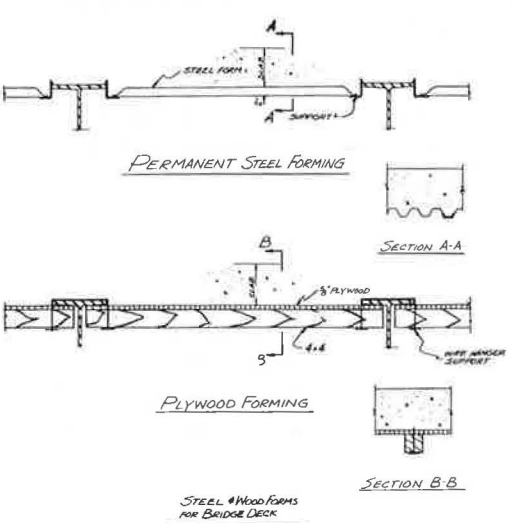

Figure 5.

Steel forms are installed from the top side of the structure and are properly attached to the stringers to provide a safe working platform, thus minimizing the need for safety nets. This is especially desirable over rivers, highways, and railroads, over electric power lines, and over great heights. Scaffolding and form stripping for the most part are eliminated and a fire hazard is avoided. The form work is completed when it is erected, and closer scheduling of other work is possible because the work can proceed on several structures simultaneously.

THE BURDICK REPORT

In 1966 a survey was conducted by Burdick (1) of the Connecticut Road Builders Association sponsored by the American Iron and Steel Institute. Burdick sent questionnaires to and received replies from those groups given in Table 1.

The purpose of Burdick's survey was to determine, among other things, the familiarity of the three groups with steel forms. Of the state highway and toll authorities who replied, 90 percent were familiar with steel forms and 53 percent used them. Of the consulting engineers who replied, 100 percent were familiar with steel forms and 73 percent used them. Of the contractors who replied, 100 percent were familiar with steel forms and 90 percent used them.

The acceptability rating of steel forms varied among the three groups. The state highway and toll road authorities who replied were 62 percent satisfied and 38 percent dissatisfied with steel forms. The consulting engineers who replied were 56 percent satisfied and 44 percent dissatisfied with steel forms. Of the contractors who replied, 61 percent rated the steel forms as being superior to other forms, 37 percent rated them as being equivalent to other forms, and 2 percent rated them as being inferior to other forms. The performance rating by those who replied is given in Table 2.

Burdick's report stated the following:

> The response to the questionnaire was sufficient to provide a fair and comprehensive expression of the attitude of owners, engineers, and contractors toward the use of permanent steel bridge forms. The great majority are familiar with the forms, and have used them and believe that they contribute to construction safety and speed in construction. The majority are satisfied with their performance and the resulting bridge deck and believe they are more economical than temporary forming. . . .
>
> It is to be expected that the acceptance of any new product, material, method or technique is predicated on increased knowledge of the application, testing, and refinement. This requires both usage and time. Eventually a pattern and a uniformity emerge. The use of permanent steel bridge forms has followed this sequence.
>
> It is apparent from this survey that steel forms have been used widely in many construction jurisdictions and a great deal of experience has been gained. It is also apparent that this experience has not been shared and that questions raised and satisfactorily resolved in one jurisdiction have not been so resolved in another. There appears to be a lack of uniform administrative policy in the use of the forms and a lack of uniformity in both design requirements and construction procedure and inspection.

The survey results and Burdick's study of the many remarks accompanying the replies encouraged industry to intensify its efforts to improve steel forms. To date, research has followed three distinct avenues: unsolicited research, joint government and industry investigation, and industrial research and development.

UNSOLICITED RESEARCH

Robert M. Barnoff of the Pennsylvania State University has made a significant contribution to the continuing development of this system and its performance. He is responsible for two studies that have established that steel forms contribute to the stiffness and durability of deck slabs.

TABLE 1

BURDICK REPORT—QUESTIONNAIRE SURVEY

Category	Canvassed	Replies From	Percent Replied
State highway and toll road authorities	69	58	84
Contractors	127	51	40
Consulting engineers	154	40	26
Total	350	149	43

TABLE 2

BURDICK REPORT—PERFORMANCE RATING OF STEEL FORMS

Category	Superior Safety (percent)	Greater Speed (percent)	Reduced Cost (percent)
State highway and toll road authorities	70	82	41
Consulting engineers	79	86	69
Contractors	87	94	69

It is interesting how Barnoff, in his research efforts, originally encountered this situation. The report (2) states that the behavior observed on two parallel, identical, continuous girder bridges located on Interstate 81 near Scranton, Pennsylvania, in conjunction with a research project, showed considerable difference in performance. One bridge constructed with steel forms was essentially free of cracking, while the bridge constructed with removable forms contained closely spaced, deep transverse cracks.

Physical tests and computational analyses were conducted and Barnoff's conclusions were as follows:

1. Corrugated forms, as designed and attached to the steel beam in this test, act as shear connectors and cause a significant amount of composite action between a concrete slab and a steel beam.
2. These forms cause significantly more composite action when the slab and beam are subject to positive moment stresses than if they were subject to negative moment stresses.
3. This composite action remains present after one million cycles of repeated loading with no apparent deterioration of the slab and beam.
4. After failure of the steel beam, a significant amount of the composite action is lost but the specimen still retains about half of the theoretical composite action.

The significance of Barnoff's study is not the recommendation for reappraisal of design concepts; however, it is an assurance that steel forms contribute a plus factor to the structure. Figures 6, 7, 8, and 9 show several views of the bridge studied.

Results of this unsolicited research prompted further study and a second investigation was conducted and reported by Barnoff (3). In this instance he conducted a series of push-out tests for various form applications. The outcome of this investigation determined that push-out test data could be correlated with full-scale test data, and, depending on design of haunch support, a significant added shear transfer was realized when steel forms were used.

JOINT GOVERNMENT AND INDUSTRY INVESTIGATION

No less significant than the unsolicited research is the joint investigation conducted by the U. S. Bureau of Public Roads and the American Iron and Steel Institute. This was the investigation of the performance of bridges having concrete decks constructed on remain-in-place steel forms conducted in conjunction with the development of a specification.

Burdick in his previously cited report (1) states that there were in excess of 1,500 structures using remain-in-place bridge forms as of 1966. Some dozen structures were reported to have had so-called failures of the form system. Before the specification was developed, it was decided to investigate these structures and ascertain whether parameters could be developed that would make future specifications more meaningful. The Pecos River bridge, described earlier, was one of those investigated.

Figure 6.

Figure 7.

Figure 8.

Figure 9.

There remained several others that were thoroughly investigated both by industry and BPR. The following are representative cases:

1. Structure A—The problem was honeycombing in the flutes. It was found that an aggregate larger than the clearance required between the reinforcing bars and the form was used. This prevented proper consolidation of the concrete and resulted in voids. This could have occurred regardless of the type of form employed.

2. Structure B—The problem occurred when a truck poked a wheel through the spongy and crumbling concrete in the deck slab. It was found that inadequate cement in the concrete caused failure of the deck slab. Reports that metal forms were weak and had fallen during construction are attributable to clip attachments to stringers and form spline connections that are no longer used by the industry.

3. Structure C—The problem was rusting of forms. It was found that the longitudinal construction joint in the median allowed passage of salt-laden moisture, which attacked forms and created a line of rust. Calcium chloride, used as a retarder in concrete, contributed to deterioration.

4. Structure D—The problem was rusting of forms. It was found that design details and the longitudinal construction joint location provided a path for salt-laden moisture to infiltrate the deck slab and attack the metal form, thus causing a line of rust.

5. Structure E—The problem was form distortions. It was found that construction abuse and dropping loads of concrete from excessive height caused buckling of the forms. Forms were also incorrectly installed upside down, as indicated by the white tags (Fig. 10) that state "this side up".

Figure 10.

Figure 11.

6. Structure F—The problem was a salt atmosphere. It was found that these forms, installed in 1958, have shown excellent durability (Fig. 11) despite being occasionally submerged when a storm occurs at high tide.

7. Structure G—The problem was the presence of honeycomb and voids (Fig. 12) in the bottom of the concrete slab and inadequate cover for reinforcement, discovered when a slab cast on steel remain-in-place forms was removed for correction in grade. It was found that the reinforcement was not securely supported and fastened during placement and the concrete was not properly vibrated during placement.

8. Structure H—The problem was revealed in cores (Fig. 13) taken from a concrete slab cast on steel remain-in-place forms that showed honeycomb and voids in the bottom of slab. It was found that the concrete was not properly vibrated during placement.

Figure 12.

The contractor, of course, has the prime responsibility for adequate cover of reinforcement and for sound concrete around the reinforcement to the bottom of the form flutes and in the flutes at construction joints.

As a result of these investigations, a manual is being prepared that will provide guidance on appropriate design and construction details. It is planned that the manual will advise against the use of longitudinal joints located parallel to and between stringers, and will note that the metal form panels are subject to attack from salt-laden moisture penetrating these joints. Where undesirable longitudinal joints cannot be avoided, clips should be installed to anchor the steel forms to the first concrete pour in order to prevent breaking the existing bond during the second concrete pour and creating voids that would entrap moisture. Transverse construction joints present a similar problem. This can be solved by locating the joint in a bottom flute and providing weep holes through the metal forms plus assuring adequate compaction of the concrete to eliminate voids.

The manual will be submitted to the Bureau of Public Roads for a review and a check that details are accurate and are or are not in conformity with requirements of the Bureau and of the American Association of State Highway Officials for bridge construction.

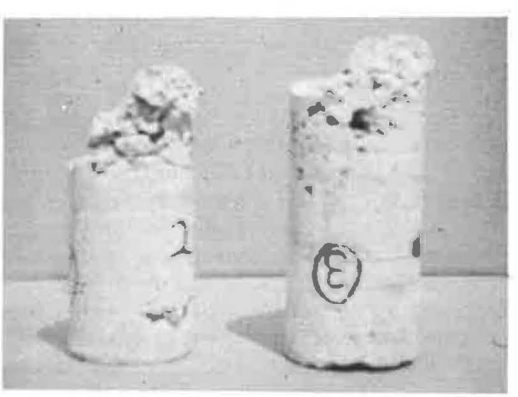

Figure 13.

INDUSTRIAL RESEARCH AND DEVELOPMENT

Research is constantly being conducted by manufacturers to improve the performance of the system. Some of the latest efforts are summarized in the following sections.

Closed End Flutes

Until recently, a special profile closure was generally provided to prevent passage of concrete through the flutes of the form resting on the support angles. Following

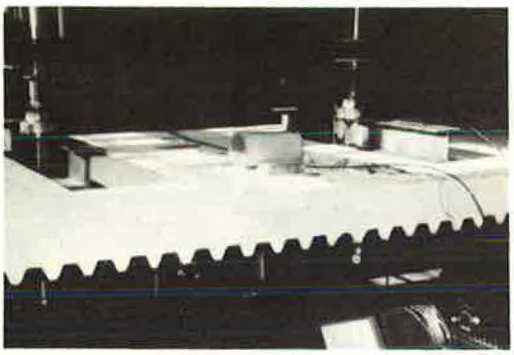

Figure 14.

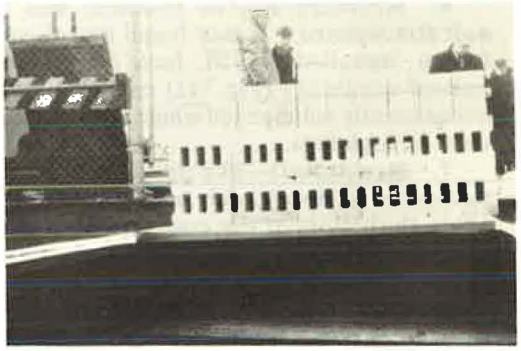

Figure 15.

extensive investigation, the industry produced a folded or tapered end finish to the flutes of the form, thereby eliminating the need for profile closures. This new feature minimizes the number of component parts and further simplifies the system. Tests of the system using closed ends have shown this scheme to be equal to or stronger than the conventional steel form sheet using profile closures.

Inspection

Obviously, one of the major points of contention is the inability of the inspector to visually check the bottom of the finished slab. The presently recommended method of post-construction inspection is to tap the underside of the form with a hammer in search of voids and to remove a specified number of form panels. Some states inspect by using a 22-caliber rifle fired at the points to be inspected for honeycomb. The impact or penetration identifies the presence of a void. These schemes are recognized by the industry and the Bureau of Public Roads as being unsatisfactory but the best available at the present time. Research is presently being directed at other methods of inspection, such as electronic, sonic, and nuclear means, for practical application to bridge decks.

Load Testing

Tests have been conducted on the performance of the entire system as well as individual component parts. As can be imagined, load-testing of the system and its parts is a continuing industry effort. Figure 14 shows a typical laboratory test (4) and Figure 15 shows a field load test.

With each change or development in this system, exhaustive tests and much investigative effort have been spent, with each manufacturer independently conducting research and testing on his product.

SUMMARY

Conversations between the Bureau of Public Roads and industry have led to the publication of a specification acceptable to both parties and recommended to all users of metal remain-in-place forms. A copy of the specification is included in the Appendix. It represents a truly constructive joint effort that has provided a standard for the industry and all users. Of course, this specification does not represent the only means of forming a bridge deck slab. The choice remains the prerogative of the bridge engineer as to whether he prefers removable forms or metal remain-in-place forms.

During the past 15 years, the American Iron and Steel Institute estimates that there have been 48,000,000 sq ft of remain-in-place steel bridge forms used in some 2,500 bridges located in 37 states. These have provided the Bureau of Public Roads and the industry with extensive experience in design, fabrication, and construction of this product.

REFERENCES

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Appendix

ATTACHMENT TO CM 32-40
DATED 9-19-69

Typical Special Provisions for Fabricated Metal Forms, to Remain in Place, for Concrete Floor Slabs of Bridges for Federal-aid Projects

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General

Fabricated metal forms, to remain in place, for concrete floor slabs of bridges shall be used only when shown on the contract plans, except that such forms may be used in unusual or extraordinary cases when approved by the engineer in a change order agreed to after award of the contract. The design and material of the forms, in the judgment of the engineer, shall be such as to give an expected maintenance free service life equal to the service life of the concrete slab. The pay quantity of concrete in the floor slabs shall be computed from the dimensions shown on the plans with no allowance for form deflection.

Materials

Typical metal forms, to remain in place, for concrete floor slabs may be of zinc-coated (galvanized) steel sheet conforming to ASTM Specification A-446 with coating class of 2.00* and shall otherwise meet all requirements relevant to steel forms to remain in place and placing concrete of the contract specifications and as specified herein.

*NOTE: Coating class 1.50 should be used instead of coating class 2.00 until April 1, 1970. Only coating class 1.50 is presently stocked by manufacturers.

Design

The metal forms, to remain in place, shall be designed on the basis of dead load of the form, reinforcement and the plastic concrete plus 50 pounds per square foot for construction loads. Unit working stresses shall be in accordance with the standard specifications for construction loads and the unit stress in the steel sheet shall be not more than 0.725 of the specified minimum yield strength of the material furnished but

not to exceed 36,000 pounds per square inch. Maximum deflection under weight of plastic concrete, reinforcement and form shall not exceed 1/180 of the form span or 1/2-inch, whichever is less. Maximum deflection under 60 pounds per square foot of live load shall not exceed 1/360 of the form span or 1/4-inch, whichever is less. The form span for design and deflection shall be the clear distance between the flanges of the supporting beams less two inches, measured parallel to the form flutes.

Physical design properties shall be computed in accordance with requirements of American Iron and Steel Institute Specification for the Design of Cold-Formed Steel Structural Members, latest published edition.

All reinforcement shall have a minimum concrete cover of 1-inch. Bars in the bottom layer of the main reinforcement shall be approximately centered over the valleys of the forms when necessary to achieve the minimum 1-inch concrete cover. The distance from the top of the slab to the bottom layer of main slab reinforcement shall be not less than that shown on the plans. Provision shall be made for positive lateral support by the concrete slab of steel beam or girder top flanges in compression except where shear connectors are provided.

Metal forms to remain in place should not be used in panels where longitudinal slab construction joints are located between stringers.

Construction

All forms shall be installed in accordance with detailed fabrication plans submitted to the engineer for approval. The fabrication plans shall clearly indicate locations where the forms are supported by steel beam flanges subject to tensile stresses.

Form sheets shall not be permitted to rest directly on the top of the stringer or floor beam flanges. Sheets shall be securely fastened to form supports and shall have a minimum bearing length of 1-inch at each end. Form supports shall be placed in direct contact with the flange of stringer or floor beam. All attachments shall be made by welds, bolts, clips, or other approved means. However, welding of form supports to flanges of steels other than ASTM A 36, A 441, A 588 and A 572 of a weldable grade and to those portions of a flange subject to tensile stresses shall not be permitted. Welding and welds shall be in accordance with the provisions of AWS D2.0 pertaining to fillet welds, except that 1/8-inch fillet welds will be permitted.

Any exposed form metal where the galvanized coating has been damaged shall be thoroughly cleaned and wire brushed, then painted with two coats of zinc oxide-zinc dust primer, Federal Specification TT-P-641d, Type II, no color added, to the satisfaction of the engineer.

Transverse construction joints shall be located at the bottom of a flute and 1/4-inch weep holes shall be provided in the field at not less than 12 inches on center along the line of the joint.

Placing of Concrete

Concrete shall be placed in accordance with the contract specifications. Particular emphasis should be placed on proper vibration of the concrete

to avoid honeycomb and voids especially at construction joints, expansion joints and valleys and ends of form sheets. Pouring sequences, procedures and mixes shall be approved by the engineer. Calcium chloride or any other admixture containing chloride salts shall not be used in the concrete placed on metal forms, to remain in place.

Inspection

The contractor's method of construction should be carefully observed during all phases of the construction of the bridge deck slab. These methods include installation of the metal forms, to remain in place; composition of concrete items; mixing procedures and particularly the concrete placement and vibration; location and fastening of the reinforcement; and finishing of the bridge deck.

The contractor shall remove at least one section of the forms at a location and time selected by the engineer for each concrete pour on each span in the contract. This should be done as soon after placing the concrete as practicable in order to provide visual evidence that the concrete mix and the contractor's procedures are obtaining the desired results. An additional section shall be removed each time the concrete mix or the contractor's procedures are changed.

After the deck concrete has been in place for a period of two days, the concrete shall be tested for soundness and bonding of the forms by sounding with a hammer as directed by the engineer at least 50 percent of the area of at least 25 percent of the individual form panels, the individual form panels to be selected by the engineer on a random basis. If areas of doubtful soundness are disclosed by this procedure, the contractor will be required to remove the forms from such areas for visual inspection.

At locations where sections of the forms are removed, the contractor will not be required to replace the forms but the adjacent metal forms and supports shall be repaired to present a neat appearance and assure their satisfactory retention. As soon as the form is removed, the concrete surfaces will be examined for cavities, honeycombing and other defects. If irregularities are found, and in the opinion of the engineer these irregularities do not justify rejection of the work, the concrete shall be given a Class 1, Ordinary Surface Finish in accordance with the contract specifications and shall be repaired as the engineer may direct. If the concrete where the form is removed is unsatisfactory, additional forms, as necessary, shall be removed to inspect and repair the slab, and the contractor's methods of construction shall be modified as required to obtain satisfactory concrete in the slabs.

The amount of sounding and form removal may be moderated, at the engineer's discretion, after a substantial amount of slab has been constructed and inspected, if the contractor's methods of construction and the results of the inspections as outlined above indicate that sound concrete is being obtained throughout the slabs.

The contractor shall provide all facilities as are reasonably required for the safe and convenient conduct of the engineer's inspection procedures.