COMMENTS FROM THE CODEMILL

The following points were suggested for
the next revision of the Code:

1. The reference to 'a' in the code
2. The need for additional
3. The improvement of the explanation

The Code is currently being

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Synopisis

This paper concerns the research on grade separation bridges in
progress at the Portland Cement Association Laboratories. The bridges
consist of separately placed pre-cast-pre-tensioned girders, combined with
a cast-in-place roadway slab. Continuity is established by addition of
normal bar reinforcement over the girder ends acting together with girder
end diaphragms. The research includes studies of component parts as
well as integral behavior of the bridge as a whole.

Continuity in Precast Bridges

The importance of the typical grade separation bridge to our arterial roads is
quite apparent. It would be difficult to travel 10 miles without crossing under or
over at least one of these bridges. Most of these bridges are of medium span
length—60 ft or so—and many consist of simple spans with roadway joints at the
end of each girder. Some bridges have been improved by making the roadway
continuous, and enclosing the girder ends in diaphragms. While some degree of
continuity can be obtained by making the roadway continuous, few designers have
included this advantage in their calculations. This subject of continuity is of
major interest for several reasons:

1. Bending moments and deflections are reduced by establishing contin-
unity in a multi-span girder system. It follows, then, that the girders re-
quired to carry a given load can be smaller in cross-section when continuity
is effective, or if standard sections are used the reinforcing required will be
less. In either case, the net result is the same: more bridge per dollar.

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The reserve load capacity of a simply supported girder can be governed by a single cross-sectional region. In a continuous structure, however, overload will lead to moment redistribution so that several sections govern ultimate strength. Accordingly, continuity tends to minimize reductions in overload capacity caused by variability in properties of concrete and reinforcement.

If the roadway deck is made continuous, the drainage of water and ice removal salts can be easily controlled. The elimination of the roadway joint will also improve the riding surface and reduce maintenance.

Why were such obvious advantages in bridge design not incorporated into these structures long ago? Why have so many bridges of multiple simple spans been constructed? The first reason concerns the fabrication of prestressed concrete girders. Since labor is expensive in this country, designers and fabricators have both sought mass production techniques using minimum labor. The pretensioning type of prestressing is best suited for this mass production and has become immensely popular for this reason. These separate girders can most easily be used as simply supported spans.

While some designers were quick to see the advantage of added reinforcement over the girder ends to establish some degree of continuity, there was very little information available regarding the degree of continuity. Because of this lack of data designers frequently added the improvement without considering it in their calculations.

Precast-prestressed girders used in conjunction with a continuous roadway deck were therefore selected for development study to provide better design criteria.

**Forms of Continuity Connection**

Various methods have been used for establishing continuity in separately placed concrete girders. Probably the earliest solution was developed by Freyssinet by a “cap cable,” shown in Fig. 1. By this method cables spanning the junction between simple span girders were post-tensioned so the joint was prestressed. Anchoring post-tensioned rods in the roadway deck is another form of establishing continuity.

The design innovation of adding normal reinforcing bars in the roadway over the girder junction seems to be the simplest of on-site construction procedures and therefore the cheapest. Fig. 2 shows the sequence of construction. The precast girders are first placed on the piers, the ends being spaced about six inches apart. At this stage they are merely simple-span girders. Forms for the roadway deck are then placed, the girders supporting the forms. The normal deformed bars are then placed in the roadway spanning the girder ends and over the piers. At the time the roadway is cast, diaphragms are also formed which enclose the ends of the girders and fill the space between them. Thus, the dead load of the bridge is supported by a series of simple-span girders, but live loads are supported by an integral and continuous structure. Positive mid-span moments are resisted by the girders and deck slab acting as a composite T-section. Negative moments over the supports are resisted by the normal deformed bars embedded in the deck, acting together with the bottom flange of the precast girder as a reinforced concrete section. Over the whole bridge structure,
PRECAST GIRDER  
STAGE I - PRECAST GIRDER PLACED ON BRIDGE PIERS BY CRANE  

CONVENTIONAL DEFORMED BAR REINFORCEMENT  
STAGE II - CONVENTIONAL DEFORMED BAR REINFORCEMENT FIXED IN PLACE OVER SUPPORT  

DIAPHRAGMS  
STAGE III - DECK AND DIAPHRAGMS CAST IN PLACE. CONVENTIONAL DEFORMED BAR REINFORCEMENT NOW BONDED TO PRECAST GIRDERS  

Fig. 2—Construction of Precast-Prestressed Continuous Bridge.

Composite action between roadway deck and girders is achieved by bond between the roadway concrete and the rough top face of the girder, aided by stirrups projecting from the girder into the roadway slab.

Experimental Program

The following subjects relating to such bridges were investigated in a comprehensive laboratory project directed toward providing data for more economical design:

1) Girder Continuity

The first phase of the project involved tests to establish the effectiveness of the type of continuity connection discussed above. Pretensioned girders without end blocks and with straight strands were used in the study, since these lead to the most severe conditions possible at the connection. In this case, the precompression at the bottom flange of the girder will be greater than in girders with either end blocks or deflected strands. The connection behavior when compression from prestress and from applied negative moments are combined at the bottom girder flange can then be studied to clarify a possible detrimental influence of precompression in the bottom flange of the girders. Connections of this type were tested by joining two six-ft. long girder stubs over a central support as shown in Fig. 3. The ends of the girder stubs were loaded, producing maximum negative moment over the single support. Variables consisted of three different amounts of deck reinforcing steel combined with three different amounts of prestressing. Deck reinforcing might be termed light, medium, or heavy, corresponding to 0.83, 1.66, and 2.49 per cent, based on girder depth times width of the bottom flange. The prestress amounts can be described as none, medium, and large, corresponding to initial concrete precompression in the bottom flange of 0, 2100, and 3200 pounds per square inch.

The theoretical ultimate strength of each connection was computed, first neglecting any influence of the precompression of the bottom flange, and secondly assuming precompression over the full girder flange length. An important characteristic of pre-tensioned girders is the prestress transfer length in which the steel stress is gradually transferred to the concrete. There actually is no precompression at the end of the girder. Then too, precompression from prestress and compress from negative bending are not additive, because compression from flexure releases prestress in a similar manner as prestress is reduced in a loaded...
Prestressed concrete column. By comparing test results with the calculated strengths, it was determined that for the practical range of continuity reinforcement from 0.5 to 1.5 per cent deck steel, the influence of the precompression at the bottom flange may be neglected in the calculation of the ultimate negative bending moments. The experimental results from this project are fully discussed in PCA Development Department Bulletin No. D34, “Pilot Tests of Continuous Girders,” to be published in mid-1960.

(2) **Horizontal Shear Connections Between Girder and Roadway**

In order for the girder and cast-in-place roadway to perform as a structural unit, the horizontal shearing strength at the girder-slab junction must be effectively developed. The second stage of our program concerned a study of the transfer of horizontal shear across a structural joint. The variables studied in these test specimens were: shear keys, stirrups, roughness of the contact surface, and adhesive bond.

The first tests involved pushing off a short length of simulated girder flange from the girder web, as shown in Fig. 4. The next step, shown in Fig. 5, was to test a complete composite girder, dial gages being placed so that the relative slip between deck and girder could be measured. It was concluded from the girder load-deflection curves that composite action ceased when the roadway slab moved 0.005 in. relative to the girder. The corresponding horizontal shearing stress for this 0.005-inch movement was 500 psi for a rough contact surface and 300 psi for a smooth contact surface. Strengths of the concrete were typical—5000 psi for the girder and 3000 psi for the roadway.

The tests indicated that keys artificially formed in the girder top were of little help because by the time the roadway had slipped enough to bring the key into use, composite action had begun to break down.

Stirrup reinforcement protruding from the girder into the slab was found to be essential for effective composite action. Stirrups required by ordinary design
Fig. 4—Horizontal Shear Test Using Push-Off Test Specimen.

Fig. 5—Horizontal Shear Test using Composite Girder.
for vertical shear in the girders of this type and protruding into the roadway slab are sufficient for composite action. A complete description of these tests and the developed data is included in the forthcoming PCA Development Department Bulletin D35, "Horizontal Shear Connections."

(3) Bridge Design Studies

A two-span two-lane continuous highway bridge to carry the AASHO standard H20-S16 loading was next designed, with dimensions as shown by Fig. 6. All phases of the preliminary design, with the exception of the girder connections and the horizontal shear connections, conformed either to the 1957 edition of AASHO "Standard Specifications for Highway Bridges" or to the ACI-ASCE report “Recommended Practice for Prestressed Concrete.” Design criteria for the exceptions noted were based on laboratory tests. This design emphasized the need for additional development work as described in the points following.

(4) Shearing Strength

Shearing strength of the girders in the region of the continuity connection was investigated by a series of tests on the type of specimen shown in Fig. 7. (The blocks suspended from the girders are not part of the loading but are an added dead weight to produce the same dead weight stresses in the one-half scale model as would exist in the prototype.) A half-scale girder, together with a cast-in-place roadway deck and including a tied-down cantilever were used for the test specimen. By varying the tie-down force, rotation of the joint was prevented, thus simulating continuity. The variables were the spacing of the stirrup web reinforcement and the location of the applied loads. These loads simulated the distribution of loads in the AASHO H20-S16 design truck. Fourteen combinations of stirrup spacing and load location have been tested. The prestress in the girder was found to exert a favorable influence on ultimate shear strength in the specimen.

(5) Flexural Strength

A fully continuous girder and deck slab were tested in flexure as shown in Fig. 8. The loading simulated the distribution of loads in the AASHO equivalent lane loading and was arranged to produce maximum bending moments at the interior support. The specimen behaved in a very satisfactory manner, the maximum load sustained being about seven times the design live load plus the weight of the girder. The girder section was designed for 1.5 times dead load.
Fig. 7—Shear Test of Composite Prestressed Girder.

Fig. 8—Continuous Precast-Prestressed Bridge Girder under Test.

plus 2.5 times live load plus impact with no tension in the bottom face of the girder. Moment redistribution occurred to a very large extent, and hence the girder was in effect over-designed from the point of view of ultimate strength.
(6) Creep and Shrinkage Studies

Two 66-ft. continuous girders fabricated to half-scale have been under long-time study, as shown in Fig. 9, to better evaluate the effects of creep and differential shrinkage on composite prestressed continuous structures. These members have now been in place almost two years. During this time measurements have been made of concrete and reinforcing strains, deflections, and support reactions. Small reverse moments attributable to creep deformations were noted at interior supports. Anchors protruding into or through the diaphragm may be needed to insure continuity over long time periods.

(7) Fatigue Tests

A typical connection under repeated load test is shown in Fig. 10. The loads were arranged to produce maximum bending moment at the girder junction by pulsating loads applied at the girder stub ends. The only variable involved was the maximum value of the pulsating load. A composite connection designed for a static ultimate strength of two and one-half times the service load moment sustained without failure over ten million cycles of one and one-half times the service load moment.

(8) Reverse Bending Tests

In continuous bridges of more than two spans it is possible for small positive moments to develop at girder connections. Structural connections joining the girders at the bottom flange area and therefore resisting positive moment, have been tested to develop design criteria for this detail.

(9) Bridge Test

A complete two-lane two-span highway bridge was constructed to one-half scale after this exhaustive series of bridge component tests. The test bridge is shown in Fig. 11. The testing of the bridge fell into two classes, service load
tests and overload tests. In the service load tests, 10,000 or 20,000 lb, concrete blocks were applied separately to 50 different locations on the bridge roadway to determine lateral distribution of loads and influence curves. At the conclusion
of the service load tests, the bridge was loaded to destruction by application of loads simulating the distribution of axle loads in the extraordinary equivalent military truck load, for which bridges on the Interstate Highway System must be designed. The mass of data obtained is still being processed and will appear in a series of Portland Cement Association Development Department Bulletins.