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COMPOSITE DESIGN FOR BUILDINGS

PROPOSAL FOR THIRD SERIES OF TESTS

by

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Project 279: Composite Design For Buildings

Proposal For Third Series Of Tests

1. Introduction

As stated in the original proposal to the American Institute of Steel Construction(1)*, the design of composite beams can be based on three different approaches:

- (a) Design of beams without, or with only a nominal amount of, shear devices.
- (b) Design of beams with shear devices on an allowable stress basis.
- (c) Design of beams with shear devices on ultimate load capacity (plastic design).

To devise possible design procedures covering all three approaches, the study of the following four detail problems was proposed:

- (1) Interaction created by bond and friction only.
Behavior of beams after breaking of bond.
- (2) Strength and deformation characteristics of shear devices.
- (3) Influence of slip on the load-deformation curve of composite beams. Limiting value of slip to be established if such a provision appears to be necessary.

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* Investigation of Composite Design for Buildings,
submitted to AISC, April 9, 1959

(4) Distribution and spacing of shear devices
along the beam.

The first series of tests was planned with the intention of giving results on problems (1) to (3). The results obtained from this first series of tests are given in "Tests of Composite Beams for Buildings", Progress Report 1.

Recommendations concerning problems (1) to (3) are contained in this report. The second series of tests which is presently in progress, is essentially a supplement to the first series.

The primary purpose of these tests is to compare the behavior of 1/2-inch and 3/4-inch diameter studs. Information concerning problem (2) and recommendations for the design of 3/4-inch studs should result from these tests.

The remaining problem to be solved is that of the distribution and spacing of shear devices along the beam. An additional problem has been presented, namely: The application of composite design to continuous beams.

This proposal recommends a third series of tests, consisting of a thirty-foot continuous beam test and three simple span beam tests, with the objective of giving results on the problem of the distribution and spacing of shear devices and on the application of composite design to continuous beams.

2. Objectives of the Tests

Each test in the series has a definite purpose, and an explanation of the objective of each test should clarify why that particular specimen was included in this series. The tests are grouped according to the problem to be investigated.

A. Distribution and Spacing of Shear Devices

In a composite beam designed elastically, the shear connectors would be spaced in accordance with the shear diagram. If, however, a plastic design procedure is used, this method for determining the connector spacing can no longer be used ($\frac{VQ}{I}$ is valid only over the elastic portion of the beam).

If the shear connectors possess sufficient ductility, a redistribution of shear forces is possible and the shear connection will behave similar to a riveted or bolted joint, i.e., at ultimate each connector would be resisting an equal portion of the shearing forces. On this basis, a uniform distribution of shear connectors along the beam designed by considering equilibrium of the slab at ultimate load between sections of zero moment and full plastic moment should suffice.

Experimental verification of this supposition is required before formulating a design procedure. Three beam tests, B10, B11, and B12 are included in this portion of the tests, and are described in part 3 and Appendix A of this proposal.

Uniform connector spacing over regions of varying shear has never been used before. For this reason, two identical specimens, B10 and B11, were proposed. Two identical tests should provide some indication of the experimental scatter inherent in a design approach of this type.

B. Application of Composite Design to Continuous Beams

Several design procedures exist for continuous composite beams. A design in which shear connectors are provided throughout the length of the member is possible. In this case, the moment resistance in the positive moment region is computed in the usual manner (either elastically or plastically). The moment resistance in the negative moment region is computed, using only the steel section and the tensile reinforcing in the slab, since the slab in this region will be cracked and cannot be considered. The added moment resistance from the tensile reinforcing is small and there is little advantage in considering it.

The addition of cover plates in the negative moment region to increase the moment resistance is also possible. Shear connectors for this case would be designed only for the positive moment region, with a nominal amount provided for tie-down in the negative moment region.

In order to establish the behavior of a continuous composite beam, a continuous beam without cover plates was designed for this series of tests. From this test, the basic behavior of a continuous composite beam will be established, and the advisability of further tests in which cover plates or other refinements are made to the composite section will be pointed out. A description of the specimen and the test procedure are given in part 3 and the Appendix of this proposal.

3. Description of Specimens

The physical properties of the materials for all the specimens will be kept constant. This will be accomplished by obtaining the WF-sections from the same rolling, and pouring all beams from a single concrete mix. In addition, all the stud material used for these tests will be the same.

The beam specimens in these tests will be the same as those in the first and second series of tests. Each

specimen will consist of a 12WF27 beam with a 4' wide and 4" thick concrete slab. Each beam will have a 15'-00" span except for the continuous beam which will have two spans of 15'-00" each. For the single span specimens additional reinforcing will be added to the slab over the center third of the beam, and the nominal mesh reinforcing will be moved from mid-depth of the slab to within 1" of the top of the slab. The relocation of and addition of reinforcing was necessary since the slabs in the first series of tests developed longitudinal cracks due to transverse bending moments set up in the slab. The reinforcing in the continuous beam was designed to keep the cracking of the slab to a minimum.

The loading arrangement and the shear connection are the only variables for the various beam specimens.

The loading arrangement for the beams in which the variable to be investigated is the shear connector spacing (B10, B11, B12), is given in Fig. 1. This loading produces shear and moment diagrams which approximate those for a uniform load. An elastic analysis using $\frac{VQ}{I}$ would dictate a variable connector spacing. The beams are designed on an ultimate basis, and thus $\frac{VQ}{I}$ cannot be used for computing the connector spacing. For this reason the total number of connectors required was computed by considering equilibrium of the slab at ultimate. In B10 and B11 a uniform spacing of shear connectors was used, and in B12

a variable spacing in which the total number of connectors required by a consideration of equilibrium of the slab at ultimate load, was spaced proportionally in accordance with the shear diagram.

The shear connection in the continuous beam specimen (B13) was also designed by considering equilibrium of the slab between sections of full plastic moment and zero moment in the positive moment region. A nominal amount of shear connectors were provided in the negative moment region to serve as tie-down for the concrete slab.

The designs for the various specimens are given in Appendix B, and the test procedure for each beam is summarized in Appendix A.

4. Further Experiments

Answers to the first three problems stated in the original proposal to the AISC concerning the design of composite beams, were provided from the first series of tests. The results obtained were reported in "Tests of Composite Beams for Buildings", Progress Report 1.

This third series of tests should provide information on the distribution and spacing of shear devices. Essentially all the problems initially proposed for this study will have been answered upon completion of this third series of tests. Establishment of a complete design approach and formulation of a design procedure seems feasible upon completion of these tests.

Appendix A
Summary of Tests
Beams B10 and B11

A. Shear Connectors

One-half inch diameter L-shaped studs - two studs per row spaced at 9" along the beam.

B. Loading

Five loads applied to the top of the slab (see Fig.1).

Spacing - Loads spaced uniformly along length of beam. Distance between loads equals $L/6 = 30"$.

C. Purpose of Test

To determine the feasibility of using uniform spacing of connectors for beams with a variable shear diagram.

D. Test Procedure

1. Apply loads in increments up to $P_p/1.85$.
Unload to record permanent deformations.
2. Apply $P_p/1.85$ ten times and record additional deformations.
3. Apply $P_p/1.85$ and maintain this load for 72 hours. Release load and record creep effects.

4. Reload to $P_p/1.85$ and increase loads in increments up to shearing of the studs. Stud failure should occur at approximately 95% of M_p .
5. If stud failure does not occur prior to reaching 99% of M_p , the spacing of loads (1) and (2), and (4) and (5) (see Fig.1) will be changed and the specimen retested to failure.

E. Measurements

1. End and intermediate slips.
2. Strains in steel beam and concrete slab.
3. Deflections at centerline and quarter-points.
4. Separation of slab and beam at intermediate points.

Beam B12 (Simple Beam)

A. Shear Connectors

One-half inch diameter L-shaped studs - two studs per row spaced according to the shear diagram (see Fig.1).

B. Loading

Same as for Beam B10

C. Purpose of Test

To determine the difference in behavior as influenced by variable spacing versus uniform spacing of shear connectors with a varying shear diagram (B10 and B11 compared to B12).

D. Test Procedure

Same as for Beam B10

E. Measurements

Same as for Beam B10

B13 (Continuous Beam)

A. Shear Connectors

One-half inch diameter L-shaped studs - two studs per row spaced uniformly throughout the positive moment region with a nominal amount provided in the negative moment region (see Fig.3).

B. Loading

1. Two loads applied to top of slab alternately on each span. (Stages 1 and 2, Fig.2).
2. Two loads applied to top of slab on both spans. (Stage 3, Fig.2)

C. Purpose of Test

To determine:

1. The effect of loading one span of a continuous beam.
2. The applicability of composite design to continuous beams.

D. Test Procedure

1. Apply loads to one span in increments up to $P_p/1.85$. Unload to record permanent deformations.
2. Apply $P_p/1.85$ ten times, and record additional deformations.
3. Transfer loading to second span and repeat procedures 1 and 2.

4. Apply loads to both spans and increase in increments up to stud failure.

E. Measurements

1. End and intermediate slips.
2. Strains in steel beam and concrete slab.
3. Deflections at intermediate points.
4. Separation of slab and beam at intermediate points.
5. Crack pattern and crack width in slab.
6. Moment-rotation characteristics over center support.

Appendix B

Design of Specimens

Refer to pages 17-21 of "Proposal for First Series of Tests" for applicable formulas.

The specimens for the third series of tests were designed, using values for material properties obtained from the first series of tests. Significant quantities appear below:

1. Steel section 12 WF 27

$$f_y(\text{flg}) = 39 \text{ ksi}$$

$$f_y(\text{web}) = 44 \text{ ksi}$$

$$I_s = 204.1 \text{ in}^4$$

2. Concrete section

$$d_c = 4''$$

$$b_c = 48''$$

$$f'_c = 3.6 \text{ ksi}$$

3. Composite section

$$I = 587.7 \text{ in}^4$$

$$m = 45.1 \text{ in}^3$$

$$a_{st} = 11.60 \text{ in}$$

4. Yield moment

$$M_y = 1975 \text{ k-in.}$$

5. Plastic moment

$$M_p = 2930 \text{ k-in.}$$

6. $Q_p = 16.0 \text{ k}$

A. Design of Test Specimens

Beam 10, Beam 11, and Beam 12

1. Spacing of Connectors

a. B10, B11

Connectors per row = 2

$$\text{Number of connectors} = \frac{C}{Q} = \frac{324}{16} = 20$$

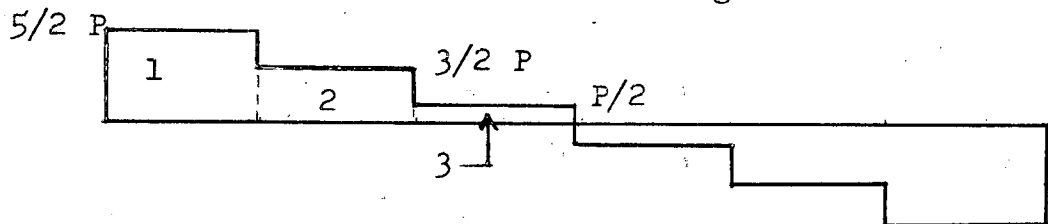
Use uniform spacing of 9" over entire length

b. B12

$$c = 2$$

Total connectors required = 20

The connectors will be spaced according to the proportions of the shear diagram



$$(1) + (2) + (3) = \frac{9P}{2}$$

$$(1) = \frac{5}{9} = 55.5\%$$

$$(2) = \frac{3}{9} = 33.3\%$$

$$(3) = \frac{1}{9} = 11.2\%$$

N = 11 connectors

N = 7 connectors

N = 2 connectors

Beam 131. Spacing of Connectors

Connectors per row = 2

$$\text{Number of connectors} = \frac{C}{Q} = \frac{324}{16} = 20$$

L_s = length between zero moment
and full plastic moment

$$L_{s1} = 72 \text{ in.}$$

$$L_{s2} = 81.1 \text{ in.}$$

Twenty connectors, at two connectors per row,
must be uniformly spaced over L_s .

$$S_1 = \frac{81''}{10} = 8.1'' \quad \text{make } S_1 = 8''$$

$$S_2 = \frac{69.7''}{10} = 6.97'' \quad \text{make } S_2 = 7''$$

See Fig. 3 for diagram of connector spacing.

2. Design of Slab Reinforcement

If plastic design is to be applied to continuous composite beams, special attention must be given to the slab reinforcement. Large inelastic rotations must occur in the negative moment region over the interior supports if a redistribution of moment is to take place. The concrete in this region is in tension and will therefore be cracked. If sufficient reinforcement of the slab is not provided, cracking will be excessive.

It is not the purpose of this investigation to determine the proper amount of slab reinforcement, but merely to determine if plastic design is applicable to continuous composite beams.

A wire mesh will be used in the negative moment region. Since this reinforcing was not considered as contributing to the moment resistance of the section over the negative moment region, it was designed only to keep the crack widths in this region small.

In addition, the mesh used in the other beam tests will be provided along the entire length of the slab. Reinforcement to resist transverse bending of the slab will also be provided in the vicinity of the ultimate moment.

SUMMARY OF THIRD SERIES OF TESTS

| Specimen | Variable Investigated | Shear Connection (all 1/2" diameter L connectors) | Type of Loading | Failure Type |
|----------|--|---|--|----------------------|
| B10 | Distribution of Shear Connectors | Uniform Spacing | Five equal loads at the Sixth- points | Connector Failure |
| B11 | Distribution of Shear Connectors | Uniform Spacing | Five equal loads at the Sixth- points | Connector Failure |
| B12 | Distribution of Shear Connectors | Staggered Spacing | Five equal loads at the Sixth- points | Connector Failure |
| B13 | Application of Composite Design to Continuous Beams | Uniform Spacing in Positive Moment Region | Two-point load- ing applied symmetrically with respect to the centerline of each span | Connector Failure |

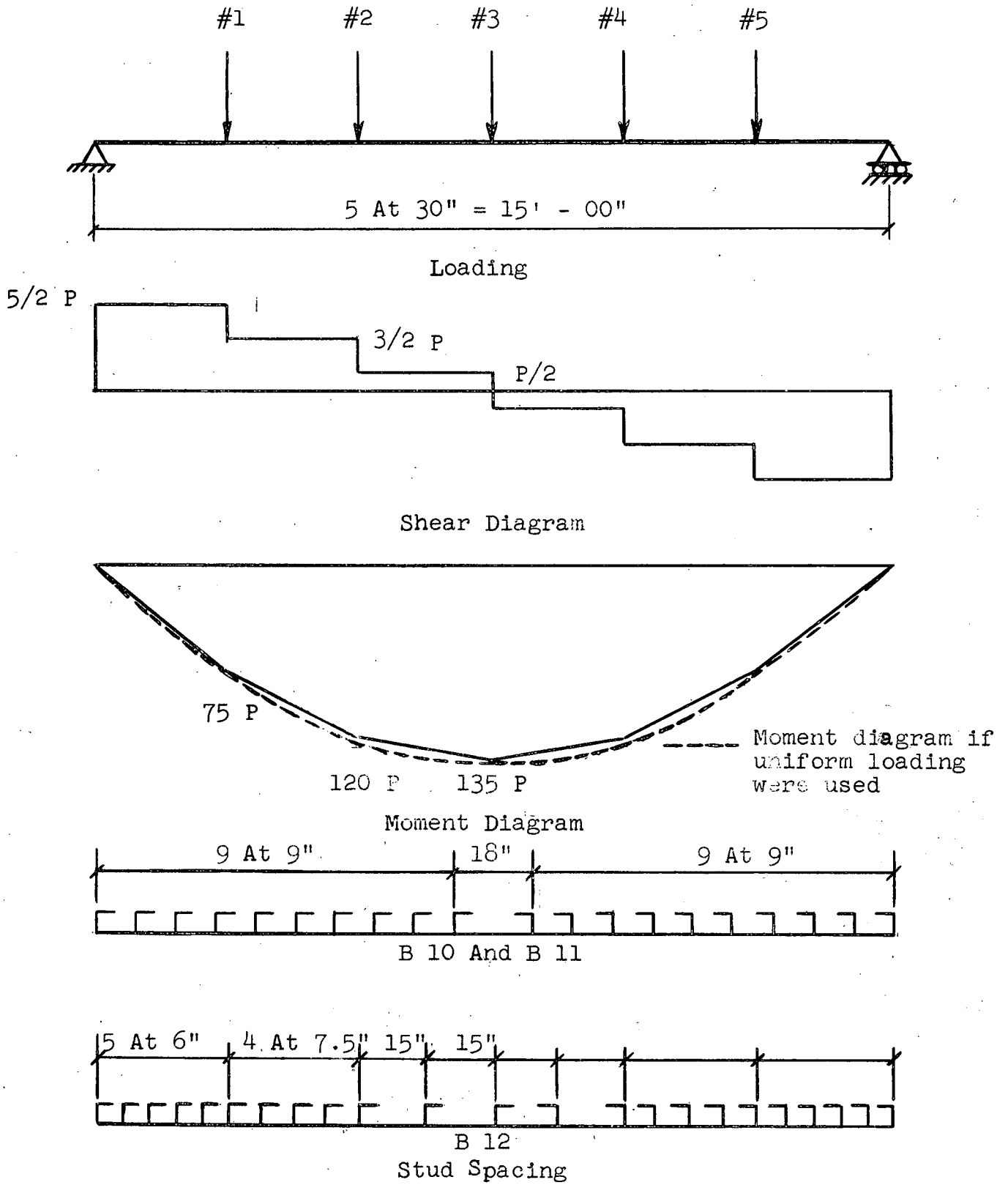
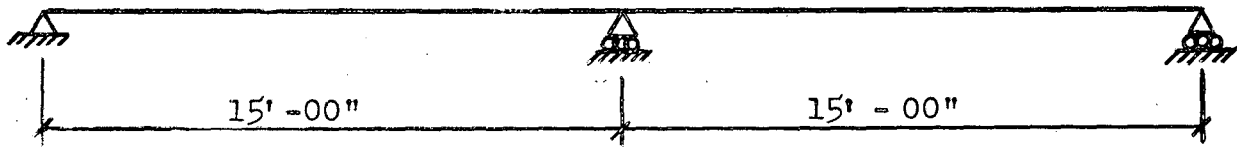
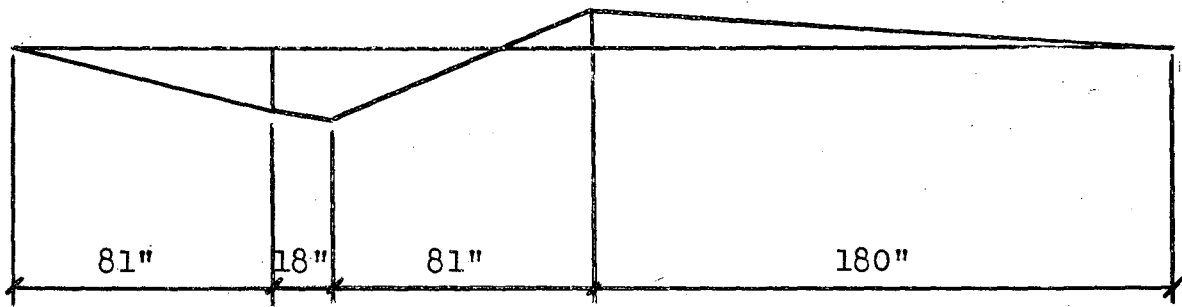
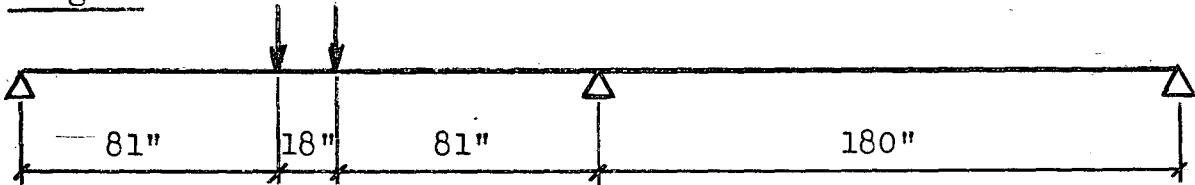


Fig. 1 - Loading Arrangement and Connector Spacing
(B 10, B 11, B 12)



Stage 1



Stage 2 - same as Stage 1, except load right span only

Stage 3

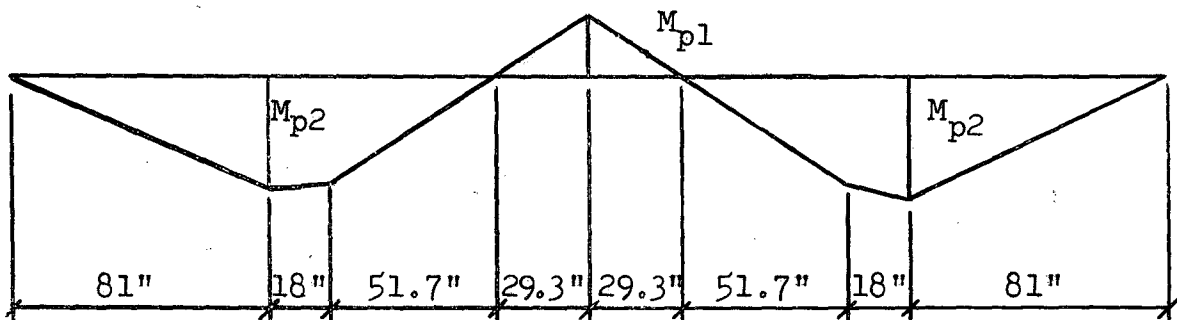
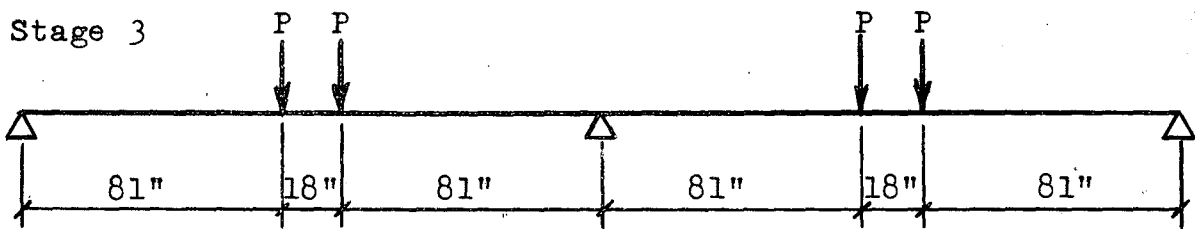


Fig. 2 - Loading Arrangement for Beam B13

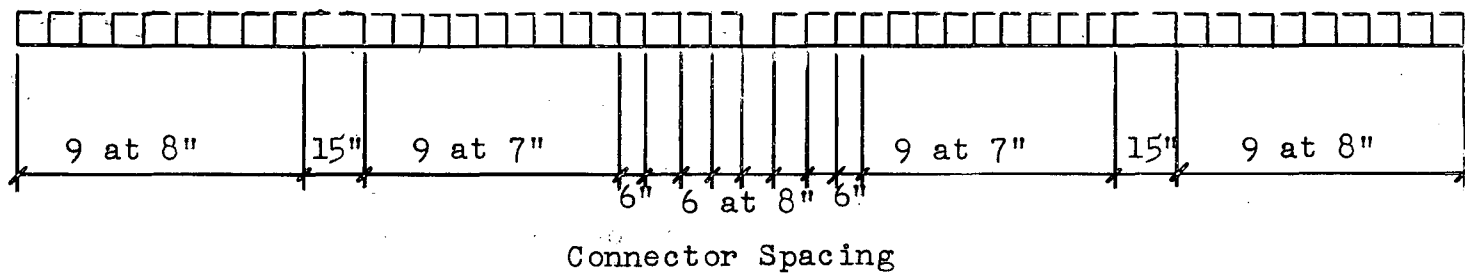
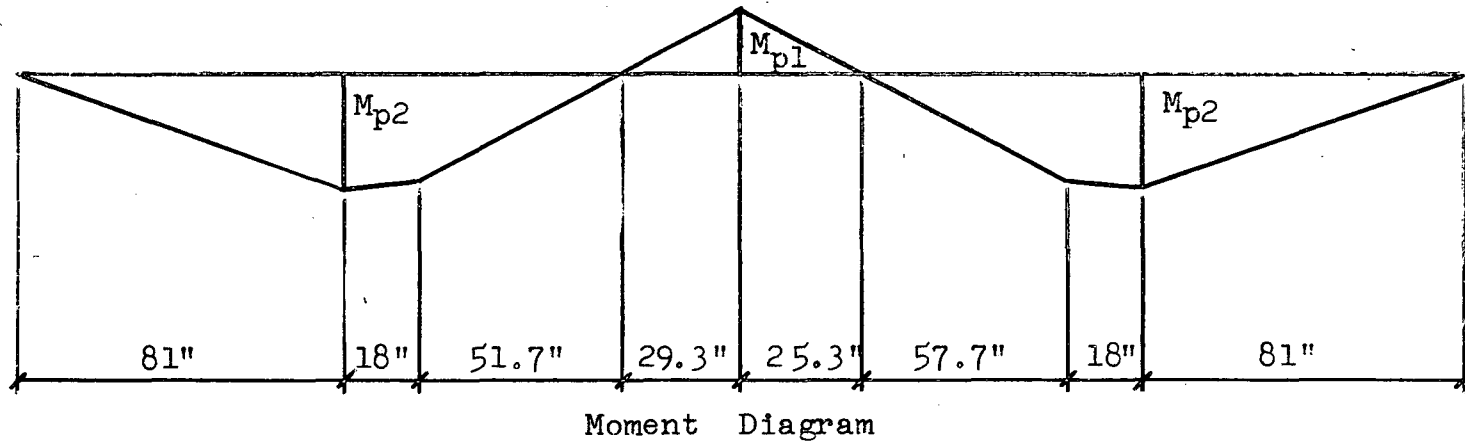


Fig. 3 - Connector Spacing for Beam B13