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# "BIBLIOGRAPHY OF COMPOSITE CONCRETE-STEEL BEAMS"

MISSOURI STATE HIGHWAY DEPARTMENT
UNIVERSITY OF MISSOURI - COLUMBIA
BUREAU OF PUBLIC ROADS

# BIBLIOGRAPHY OF COMPOSITE CONCRETE-STEEL BEAMS

Prepared for

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ABSTRACT

This report contains a bibliography of publications concerned with composite concrete-steel members, reported before and including the year 1962.

The report is separated into two parts; an annotated bibliography and a bibliography by year. The annotated bibliography describes the more significant publications under the general headings of research, design and construction.

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The bibliography and annotations were prepared with the assistance of Melvin H. Proctor, graduate research assistant. The investigation was under the general direction of Adrian Pauw, Professor of Civil Engineering. Barbara O'Dell Herder typed the manuscript.

ANNOTATED BIBLIOGRAPHY

I. RESEARCH

1946

Newmark, N. M., Siess, C. P., and Penman, R. R., "Studies of Slab and Beam Highway Bridges", Part I - Tests of Simple-span Right I-beam Bridges, Univ. of Ill. Engr. Exp. Sta., Bulletin 363, 1946.

Report of laboratory tests on 15 right angle I-beam bridge models of 1/4 scale. Purpose of tests were: 1) to compare measured strains at various points with values computed by an incomplete interaction theory and, 2) to determine the ultimate capacity of the bridges and their manner of failure. One of the principal variables was the effect of shear connectors.

1952

Foster, G. M., "Tests on Rolled-Beam Bridges Using H20-S16 Loading", Highway Research Board Research Report 14-B, pp. 10-38, 1952.

Report of test on a six-span bridge to determine effectiveness of shear developers and to study lateral distribution features. Six spans were nominally 60 ft.-0 in. in length and only one span (span 3) had shear connectors.

Results and conclusions regarding the composite span indicate that composite action obtained through use of spiral shear connectors reduced stresses by 20 per cent and deflection by 50 per cent. Shear developers do not affect lateral load distribution. General appraisal of test results indicate that future savings in bridge design might be obtained by taking advantage of partial composite action due to friction and natural bond and use less conservative methods in design of shear connectors.

Fuller, A. H., "Effect of Trucks Upon a Few Bridge Floors in Iowa in 1922 and 1948", Highway Research Board Research Report 14-B, pp. 1-9, 1952.

Discussion of the effect of dynamic loads on bridge floors as compared to static loading. Brief exploratory research undertaken in 1948 to observe whether composite action between floor slab and beams remained after 28 years of service even though mechanical shear connectors were not used. Results of strain measurements indicate that in a 34 ft. I-beam span, composite action was still effective, and in a panel of a truss bridge, although bond was apparently broken, the deformations and resulting stresses were less than if steel alone carried same loads.

Siess, C. P., Viest, I. M., and Newmark, N. M., "Studies of Slab and Beam Highway Bridges", Part III - Small Scale Test of Shear Connectors and Composite T-beams, Univ. of Ill. Engr. Exp. Sta., Bulletin 396, 1952.

Report of three series of tests of shear connectors for composite steel and concrete bridges: 1) push-out tests, 2) static tests of T-beams, and 3) fatigue tests of T-beams. All specimens were 1/4 scale. Push-out tests were made with various types of rigid and flexible connectors to select the type of shear connector for the T-beam tests. Principal results were: 1) standard channels as shear connectors were selected for further study, 2) behavior of channel connector is similar to that of a dowel embedded in an elastic medium. A large percentage of the transferred load is concentrated at the flange of the channel welded to the steel beam, 3) channel shear connectors when properly designed insured practically complete interaction. Tests are presented in detail. Theory for composite beams with incomplete interaction is presented in Appendix.

Viest, I. M., Siess, C. P., Appleton, J. H., and Newmark, N. M., "Studies of Slab and Beam Highway Bridges", Part IV - Full Scale Tests of Channel Shear Connectors and Composite T-beams, Univ. of Ill. Engr. Exp. Sta., Bulletin 405, 150 pages, 1952.

Test results of 43 push-out specimens using standard channels as connectors are presented. Four full-scale T-beams were tested.

Important test results and conclusions:

1) Composite T-beams with adequate shear connectors are very tough with high reserve strength after first yielding. Deflections are decreased and ultimate load occurs only after large deflection.

2) Complete interaction may be assumed if the shear connectors are properly designed.

3) Initial failure was tension yielding in bottom flange of each beam. Yielding caused excessive deformation in the vicinity of load and final failure resulted from compressive crushing of slab.

4) Ultimate strength of beams was practically the same as computed considering complete interaction. One test beam was purposely designed with inadequate shear connection and the ultimate capacity was much less than predicted.

5) Maximum difference in strain across width of top of slab was 15 per cent.

6) Shoring had practically no effect on behavior of beams of identical dimensions.

7) Natural bond is very effective but unreliable.

8) Channels proved to be very reliable as shear connectors.

9) Deformations and stresses in channel connectors may be computed with satisfactory accuracy from semi-empirical formulas derived.

10) Maximum stress in channel connectors occurred at lower fillet of channel. Maximum pressure on concrete occurred at the channel flange welded to beam.

11) At high loads maximum pressure on concrete behind connector greatly exceeded compressive cylinder strength, but no concrete failures due to compression were recorded except for push-off test with fillets.

12) Effects of variables studied in push-out tests on behavior of channels were: height of channel is negligible; effect of width is approximately linear; effect of web thickness was present, but smaller than effect of channel flange thickness; concrete strength affected the behavior.

13) Orientation of channel did not affect its behavior as a connector.

14) Tendency for slab to separate from beam in the vertical direction was present, but effectively checked by channel connectors properly spaced.

15) No effect on ultimate load-carrying capacity of beams could be detected between variable and uniform spacing of connectors.

1953

Siess, C. P., and Viest, I. M., "Studies of Slab and Beam Highway Bridges", Part V - Tests of Continuous Right I-beam Bridges, Univ. of Ill. Engr. Exp. Sta. Bulletin 416, 1953.

Laboratory tests were made on three 1/4 scale models of continuous I-beam bridges. Principal variable was presence or absence of mechanical shear connectors. All tests were made with pairs of concentrated loads simulating rear axle of trucks.

Primary purpose of tests were: 1) compare action of both beams and slab in positive moment region with previous tests on simple span beams, 2) determine action of beams and slab in negative moment region and compare strains with those in positive moment region, and 3) to determine effects of composite action on continuous bridges and compare behavior of composite bridges with and without shear connectors in region of negative moment.

Tests demonstrated profound difference in behavior of composite and non-composite bridges. Ultimate failure of non-composite bridge was by buckling of three interior beams at a load of 8490 pounds per panel. Both composite bridges failed by punching of the slab at a load of 10,400 pounds per panel. Omission of shear connectors in negative moment region did not seem to affect stresses at midspan.

1954

Viest, I. M., "Engineering Test Data", Tests of Stud Shear Connectors, Parts I, II, III, and IV, Nelson Stud Welding, Lorain, Ohio, 1954-55.

Results of push-out tests of Nelson studs with upset heads due to static loading. Variables studied included stud diameter and height, and concrete strength. Formulas for useful stud capacity are presented.

1955

Viest, I. M., "Engineering Test Data", Tests of Spiral Shear Connectors, Nelson Stud Welding, Lorain, Ohio, Sept. 1955.

Push-out tests of spiral shear connectors of three diameters, 1/2 in., 5/8 in., and 3/4 in., are presented. Results are compared with similar tests on studs.

1956

Viest, I. M., "Investigation of Stud Shear Connectors for Composite Concrete and Steel T-beams", <u>Proc</u>. Am. Conc. Inst., Vol. 52, pp. 875-891, 1956.

Push-out tests of round steel studs were made to determine the behavior and load carrying capacity of stud shear connectors. The tests have shown that a steel stud is suitable for use as a shear connector in composite concrete and steel construction. Empirical equations are presented for determining critical load.

1958

Thurlimann, B., "Composite Beams With Stud Shear Connectors", Bulletin 174, Highway Research Board, Washington, D. C., pp. 18-38, 1958.

Test of a 32 ft. span composite bridge stringer with 6 in. by 10 ft.-11 in. wide slab supported on two 18WF 50 beams is described. Shear connectors on one WF beam were 3/4 in. diameter studs with upset heads, welded to top flange. On the other beam 1/2 in. diameter studs with end hooks at right angles were used.

Loading consisted of 1,000,000 cycles at 100 per cent, and additional 250,000 cycles at 125 per cent, and a further 250,000 cycles at 150 per cent of the design live load. Final failure produced by static loading. Both types of studs behaved satisfactorily. All stud spacing was kept constant.

1959

Thurlimann, B., "Fatigue and Static Strength of Stud Shear Connectors", Journal ACI, Vol. 30, No. 12, pp. 1287-1302, 1959.

KSM L-connectors and studs with upset heads were tested in push-out specimens for static and fatigue loading. Two types of specimens were used; a flat slab and a haunched slab. A total of ten push-out tests were made; three with static and seven with cyclic loading.

On the basis of these fatigue and static tests the following recommendations were presented for the design of composite beams with 1/2 in. L-connectors. Bridge design:

1) orient hook of L-connector against direction of horizontal shear (toward middle for simple beams).

2) useful static capacity per stud in pounds is $Q_{uc} = 120\sqrt{f'_c}$, where $f'_c \geq 3000$ psi @ 28 days.

3) allowable working capacity per stud for fatigue $Q_{all} = \frac{Q_{uc}}{S.F.} \leq 2700$ lb.

4) when haunched slabs are used, check shearing stress in concrete at height of upper ends of connectors. Reinforce haunches, if necessary, in accordance with applicable requirements for web reinforcement of reinforced concrete beams.

Building design (primarily static loading):

1) useful capacity per stud, $Q_{uc} = 120\sqrt{f'_c}$ pounds.

2) Allowable working capacity per stud, $Q_{all} = \frac{1}{2} Q_{uc} = 60\sqrt{f'_c}$ pounds.

1960

Viest, I. M., "Review of Research on Composite Steel-Concrete Beams", Proc. ASCE, Journal of the Structural Div., Vol. 86, No. ST 6, June 1960, pp. 1-21.

Summarization of investigations of composite beams performed from 1920-1958. Test specimens, with and without mechanical shear connectors, are described and major results cited. Good summary of investigations performed in U. S. and abroad. Includes very good bibliography.

Hondros, G., and Marsh, J. G., "Load Distribution in Composite Girder-Slab Systems", Proc. Am. Soc. Civil Engr., Vol. 86, No. ST 11, p. 79, Paper 2645, Nov. 1960.

Report of results of series of tests on five and ten girder-slab system interconnected with channel shear connectors. Test aimed at confirmation of assumptions made with regard to load distribution and the effect of a 30 degree skew angle on ten girder, 130-ft. composite steel and concrete bridge span. Two models were skewed 30 degrees and one square. Comparison of actual and theoretical behavior is made. Considerable discussion given to the theory of variation in $E_c$ due to shrinkage of concrete and related migration (shifting) of neutral planes.

1961

Culver, C., and Coston, R., "Tests of Composite Beams with Stud Shear Connectors", Proc. Am. Soc. Civil Engr., Vol. 87, No. ST 2, Paper 2742, pp. 1-17, Feb. 1961.

Reports of studies of composite concrete-steel beams using L-shaped stud shear connectors. Static and fatigue tests were made. Present useful capacities used in design specifications are conservative.
Results indicate that:

1) Ultimate strength of studs much greater than useful capacity according to AASHO Specifications.

2) Large values of slip between slab and beam do not significantly alter the ultimate moment or the load deflection characteristics of the composite section.

Chinn, J., "The Use of Nelson Studs With Idealite Lightweight-Aggregate Concrete in Composite Construction", Part I, Engr. Exp. Sta. and Dept. of Civil Engr., Univ. of Colorado, April 10, 1961.

Report of tests of three push-out specimens using Nelson studs and lightweight concrete with Idealite aggregate. Results are compared with previous investigations.

"Research on Composite Design at Lehigh University" American Institute of Steel Construction, Proc., pp. 18-24, 1961.

A summary of investigations made at Lehigh University. The validity of plastic design theory applied to composite sections is demonstrated from results of 13 composite beams and several push-out specimens. The research work done, although not conclusive, provides sufficient information to serve as a basis for writing specifications for plastic design. Studies show that substantial savings in steel beams and shear connectors are possible. Shear connectors should be designed with a load factor such that the connectors will not fail before the ultimate moment is reached. Results indicate that this load factor need not exceed 2.0.

1962

"Composite Design for Bridges - Fatigue Tests of Composite Beams", Lehigh University, Fritz Engineering Laboratory Report No. 285.3, March, 1962.

A preliminary investigation of fatigue strength of welded stud shear connectors to determine minimum requirements and to determine possibility of formulating design specifications that would liberalize the present AASHO Specifications. Specimen tested consisted of an 8WF17 steel beam with a 2 ft.-0 in. by 3 in. concrete slab interconnected with L-studs. Testing started at 28 days and completed at 79 days (28-day concrete strength, 3030 psi). Instrumentation consisted of strain gages at midspan under top and bottom flanges of steel beam, dial deflection gage at midspan, and slip measuring devices at both ends and near midspan.

During fatigue testing the end connectors consistently failed first. Additional tests are required to determine cause of this. Important conclusions from this preliminary test are:

1) Amount of slip does not seem to be an important fatigue consideration.

2) Connector failures do not result in total failure of structural member but result in increased deflection and steel stress.

3) S-N (stress vs. cycle) curves established from fatigue of studs in push-out specimens serve as lower boundary to actual connector fatigue strength in composite members.

4) AASHO Specifications are overly conservative with respect to fatigue and a factor of safety of 2.0 may be sufficient.

"Design for Buildings", Progress Report No. 3 - Test Results and Design Recommendations for Composite Beams, Lehigh University, Fritz Engineering Laboratory Report No. 279.10 January 1962.

Several composite steel and concrete beams and push-out specimens were tested and results combined with results from investigations by others in a study to recommend applications in design of composite beams for buildings. All findings were in favor of composite beams. Important observations and conclusions are as follows:

1) Shrinkage of concrete may destroy natural bond before loading resulting in no interaction due to bond and very little due to friction.

2) Shear connectors tend to preserve natural bond and during testing the natural bond seems to provide most of the interaction, however, a definite bond failure usually occurs during testing. This bond failure often occurs at loads in the vicinity of design loads.

3) Semi-empirical formulas were developed to express ultimate strength of shear connectors and used as the basis for design recommendations. The formulas are (a) Studs:

$$q_u = 930\, d_s^2 \sqrt{f'_c};\quad h/ds > 4.2$$

$$q_u = 220\, hd_s \sqrt{f'_c};\quad h/ds < 4.2$$

(b) Spiral: $q_u = 8000\, d_s \sqrt[4]{f'_c}$ per pitch of spiral

(c) Channels: $q_u = 550(h+0.5t)w\sqrt{f'_c}$ ;

$q_u$ is the ultimate load in pounds and $f'_c$ is in psi.

4) The ultimate moment computed on basis of full plastification of steel and concrete can be reached if adequate shear connectors are provided.

5) If inadequate shear connectors are provided, a modified ultimate moment may be calculated.

6) For members with adequate shear connector strength the influence of slip upon load-deflection characteristics of member is negligible.

7) For members with inadequate shear connectors, slip does influence load-deflection characteristics because of reduced moment of inertia.

8) Ductility of shear connectors (non-rigid) permits sufficient redistribution of load such that uniform spacing of shear connectors is permissible regardless of shape of shear diagram.

9) A single test of two-span continuous composite beam attained ultimate load predicted on the basis of full plastic moment of steel being developed at negative moment region and full ultimate moment of composite section being developed in positive moment region. Cracking of concrete in negative moment region should be controlled.

II. DESIGN

1945

Hindman, W. S., Vandergrift, L. E., "Load Distribution Over Continuous Deck Type Bridge Floor Systems", Ohio State Univ. Engr. Exp. Sta., Bulletin 122, 1945.

Report of field studies made on two types of bridges in Ohio. Effects of composite bridge decks including effects of bridging were studied. Results indicated that positive ties between steel supporting beams and slabs should be used to check tendency of supporting beams to pull away from slab. Composite action may be assumed in designing for live load, but not for dead load.

1949

Newmark, N. M., "Design of I-beam Bridges", Trans. Am. Soc. Civil Engrs., Vol. 114, pp. 997-1022, 1949.

Recommendations for the design of I-beam highway bridges with simple and continuous spans, both non-composite and composite. Recommendations are based on theoretical analyses and tests.

Siess, C. P., "Composite Construction for I-beam Bridges", Trans. Am. Soc. of Civil Engrs., Vol. 114, pp. 1023-1045, 1949.

Results of analytical and experimental studies of composite construction for highway bridges are presented. Comparative designs were made to determine savings in weight for various types of beams. Empirical formulas for proportioning composite sections are given. Tests of shear connectors are described. Weight savings range from 87 per cent to 30 per cent and at same time provide stiffer construction.

1951

Newmark, N. M., Siess, C. P., and Viest, I. M., "Tests and Analysis of Composite Beams with Incomplete Interaction", Proc., Soc. for Experimental Stress Analysis, Vol. 9, No. 1, pp. 75-92, 1951.

This paper considers the effects of composite beams with incomplete interaction of shear connector between slab and beam. Tests of six composite T-beam sections are described and a theoretical expression is presented for the general case in the form of a differential equation for the force transmitted through the shear connector. The equation is solved for the case of a beam loaded with a concentrated load at the center. Expressions for the slip, shear between interacting components, strains, and deflections are given. Experimental results are compared with the theoretical solution. Results indicate that a design on the basis of full composite action would give satisfactory results in most practical cases.

1953

Viest, I. M., and Siess, C. P., "Composite Construction for I-Beam Bridges", Proc. Highway Research Board, Vol. 32, pp. 161-179, 1953.

Three subjects are discussed: 1) the behavior on composite steel and concrete T-beams, 2) the function and action of shear connectors between slab and beam, and 3) the behavior of composite I-beam bridges of both simple and continuous spans. Criteria for the design of composite T-beams and shear connectors are also discussed. Material in this paper is based primarily on results of analytical and experimental studies at the University of Illinois.

1954

Sherman, J., "Continuous Composite Steel and Concrete Beams", Trans. Am. Soc. Civil Engrs., Vol. 119, pp. 810-828, 1954.

Analysis of continuous composite concrete and steel beams based on the assumption that the composite I is effective only in regions of positive moment. Analysis is restricted to two and three span continuous beams.

1956

Villasor, A., Jr., "Computing the Properties of Composite Sections for Highway Bridge", Civil Engr., Vol. 26, No. 12, p. 67, 1956.

Procedure for tabulating computations for determining properties of a composite section is presented. Numerical example is included.

White, A., "Summary of Composite Bridge Beam Questionnaire Survey", Proc. Am. Conc. Inst., Vol. 52, pp. 1013-1014, 1956.

Questionnaire concerning use of composite construction in highway bridges was sent to highway departments of 48 states, and to similar agencies of Australia, England, France, Germany, and Sweden. Twenty-five states indicated use of shear connectors was general or standard practice, five states indicated general use for spans 30-55 ft., ten states indicated infrequent use, while only three states did not favor composite construction. Shear connectors are in general usage in the foreign countries questioned. Some common types of shear connectors used by different states are given.

1957

Fountain, R. S. and Viest, I. M., "A Method for Selecting the Cross-section of a Composite Concrete and Steel T-beam", Proc. Am. Soc. Civil Engrs., Vol. 83, No. ST 4, Paper 1313, 1957.

Simplified general formulas are developed for selecting the steel section of concrete-steel composite beams. Approximate section modulus curves for beams with built-up girders are included. Numerical examples are presented.

Subkowsky, H., "Choice of Composite Beams for Highway Bridges", Proc. Am. Soc. Civil Engrs., Vol. 83, No. ST 1, Paper 1151, 1957.

Design charts are presented for selecting composite beam sections, cover plates, and pitch of shear connectors.

Viest, I. M., R. S. Fountain, and C. P. Siess, "Development of the New AASHO Specifications for Composite Steel and Concrete Bridges", Highway Research Board Bulletin 174, pp. 1-17, 1975.

The major revisions of the new AASHO Specifications for composite steel and concrete bridges are discussed. The background information from which the specifications were based are also discussed.

1958

Viest, I. M., Fountain, R. S., and Singleton, R. C., "Composite Construction in Steel and Concrete for Bridges and Buildings", McGraw-Hill, 1958.

A book on composite design which follows the latest AASHO bridge specifications and includes the results of recent investigations.

1960

Steiner, F. D., "New Composite Beam Concepts", Civil Engr., p. 72, February 1960.

Discussion of some concepts such as steel-plate armored structures designed according to composite theory, and prestressing of composite sections.

A simplified graphical design method is presented for determining the neutral axis and moment of inertia of the section.

"Tentative Recommendations for the Design and Construction of Composite Beams and Girders for Buildings - Progress Report of the Joint ASCE-ACI Committee on Composite Construction", Proc. Am. Soc. Civil Engr., Vol. 86, No. ST 12, Paper 2692, p. 73, December 1960.

Part I - Tentative recommendations for the design of composite members (including precast reinforced concrete beams, precast prestressed concrete beams, and steel and concrete construction).

Part II - Explanation of tentative recommendations.

1962

Kuang-Han Chu, and Krishnamoorthy, G., "Moments in Composite Beam Bridges by Orthotropic Plate Theory", Proc. ACI Journal, Vol. 59, No. 5, pp. 705-721, May 1962.

The composite beam bridge is converted to an orthotropic plate and analyzed by the orthotropic plate theory and compared with values reported by a University of Illinois study.

Cain, G. B., "Composite Building Construction Comes of Age", Civil Engrs., pp. 50-53, June 1962.

The merits of composite construction with reference to current AISC Specifications are discussed. Comparative analyses are presented for a typical panel of an office building of conventional design and composite design.

## III. CONSTRUCTION

1944

Enke, G. L., "Welding to Ensure Composite Beam Action", Civil Engr., Vol. 14, No. 1, pp. 9-12, 1944.

Study of an all-welded composite bridge compared to a similar riveted non-composite structure.

1946

Wendell, E. W., "Welded Girder Bridge of Composite Design Carries Deck Area of Two Acres", Engr. News Record, Vol. 137, No. 26, pp. 856-858, 1946.

Discussion of design and construction features of welded girder bridge carrying the Erie Thruway over Cattaraugus Creek, southwest of Buffalo, New York. Bridge deck is 112 ft. wide carried on welded plate girder consisting of five 132 ft. simple beam spans (continuous spans not used because of possible differential settlement). Deck is designed for composite action between 8 in. concrete roadway slab and girders. Spiral shear connectors used.

1947

Cohen, A. B., "Repairs to Spruce Street Bridge, Scranton, Penn.", Proc. ACI, Vol. 43, pp. 241-248, 1947.

Repairs and reinforcement of the Spruce Street Bridge built in 1893 are described. The effective application of the "Alpha System - Composite Floor Design" upgraded the bridge floor system from six to eight ton capacity to 15 ton capacity without exceeding effects on trusses of a uniform LL = 100 psf on which the original design was based. Contract prices are included.

1948

"A Causeway Built to Withstand Hurricanes", Engr. News Record, Vol. 140, No. 16, pp. 568-571, 1948.

Deck for three bridges comprising 1/4 of the four-mile dual-lane causeway across Biscayne Bay at Miami, Florida were of composite design utilizing spiral shear connectors. This design reduced the steel quantity from 7,400,000 pounds required by conventional design to 5,600,000 pounds for composite design.

1951

"Continuous Girder Bridges Made Less Costly", Engr. News Record, Vol. 146, No. 22, pp. 36-37, 1951.

State Road Department of Florida estimates composite spans cost $220 per linear foot as compared to $350 per linear foot for conventional steel spans. Spans are 84 ft.-126 ft.-84 ft. continuous designed for H15-44 loading. A 24 ft. roadway is carried on stringers and floor beams which in turn are supported on two welded plate girders. Spiral shear connectors were used.

1956

Scurr, K. R., "Welded-stud Shear Connectors for South Dakota Bridge", Civil Engr., Vol. 26, No. 6, pp. 38-40, 1956.

An all welded deck girder bridge with four continuous spans of 96 ft.-120 ft.-120 ft.-96 ft. is presented. For eye appeal and economy girders were of variable cross section and entire bridge is on a vertical curve of 5000 ft. radius. Girders were specified to be of A-242 low alloy steel and made composite with lightweight concrete with f'c = 4000 psi and 90 pcf.

Continuous composite floor design combined with reduced dead load due to lightweight concrete floor held deflections within allowable limits. Previous composite bridges employed use of angles or channel connectors welded across flange of girder resulting in some warping of flange and required heat treatment to relieve stresses and to straighten the flange. Search for improved connector lead to use of Nelson Studs on basis of Siess' investigations at the University of Illinois. Time studies disclosed that both labor and material costs of the stud welds were appreciably lower than those for angle connectors in place. Time in shop for studs approximately 1/4 of that for angle connectors. Bridge was designed for AASHO H20 loading and AASHO allowable stresses.

Fish, G. D., "Composite Construction Makes Sense", Consulting Engineer, Vol. 7, No. 5, pp. 51-55, May 1956.

Discussion of the composite construction of the IBM Engineering Laboratories at Poughkeepsie, New York. Welded studs were used for shear connectors.

1958

"Shear Connectors Go In Fast", Engr. News Record, p. 71, July 10, 1958.

Description of stud shear welding apparatus capable of handling up to six studs at one time. Moves along beam flange and is adjustable for any flange width.

1959

Garfinkel, A., "Composite Design Cuts Steel 20%", Engr. News Record, p. 44, Aug. 20, 1959.

Discussion of the laboratory building for Charles Pfizer Company, Inc. at Groton, Connecticut; largest building built at that time using composite construction. Building contained approximately 1000 tons of structural steel, some 200 tons less than estimated by conventional design. Three-fourth in. diameter welded studs, 3 in. high were used in a 4 in. slab of 2500 psi strength.

1960

Hooper, I., and Hotchkiss, J. G., "Record for Composite Construction", Engr. News Record, p. 84, March 24, 1960.

Discussion of the federal court house and office building in Brooklyn, New York, using composite design. Savings of 20-25 per cent were estimated.

1961

Longoria, A., "Composite Floor Installed in an Existing Building to Carry Extra Loads", Civil Engr., p. 69, October 1961.

Load capacity of floor was increased from 170 psf to 225 psf by using Nelson studs.

1962

Mayes, G. T., "New Steels and Composite Design", Civil Engr., pp. 66-68, April, 1962.

Great National Life Insurance building in Dallas, Texas, was designed with new steels and composite construction which resulted in weight savings of 99 tons. Shear connectors were standard channels designed by AASHO formula with a factor of safety of 2.4.

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1934

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