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# Tests of Corroded Steel Beams Restored with Gunite

## Beams with Plain and Reinforced Encasement Tested in Comparison with Bare Beams —Bond Found to Be Excellent

By J. R. Shank

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A NUMBER of tests were made at the Ohio State University engineering experiment station last spring on scrapped plate girders and I-beams encased with gunite, some with and others without reinforcing bars. The purpose was to determine whether a corroded steel beam could be reinforced sufficiently to restore it to its original new value. The tests were suggested by C. C. Cooke, of the Fritz-Rumer-Cooke Co., railroad construction contractors of Columbus, which company prepared the test beams and assisted in running the tests. The old beams were furnished by the Pennsylvania R.R. through J. F. Leonard, engineer of bridges, Pittsburgh. The tests were directed by the writer under the advice and with the co-operation of C. T. Morris, professor of structural engineering.

*Test Beams*—The steel beams were 21-in. plate girder stringers erected 1885, and 24-in. 80-lb. I-beams of a later date. The original moment of inertia of the plate girders was 1300.97 in.$^4$ gross, or 1081.07 in.$^4$ net, that of the I-beams 2087.2 in.$^4$ gross.

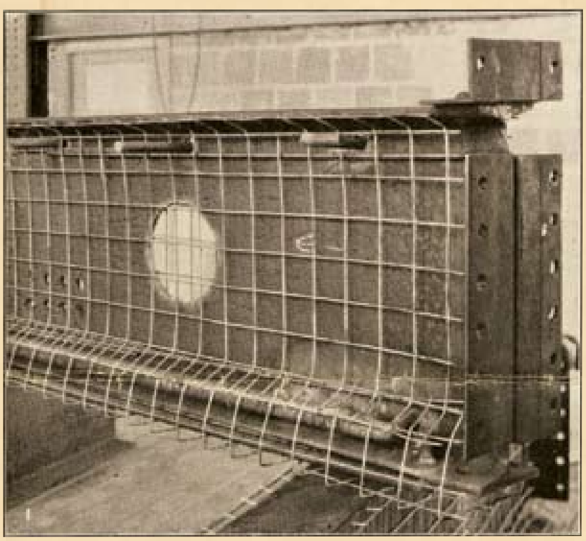
Encasement was made by shooting ordinary gunite onto the steel, over 3x3-in., No. 8, electrically welded wire mesh. The gunite was built out to a thickness of 1½ to 2 in. One test was arranged to show the effect of encasement with no steel other than the mesh, and two others the effect of restoring the reduced section by reinforcement and concrete. The reinforcing steel was welded into the web or flange of the structural steel near the ends (Fig. 1).

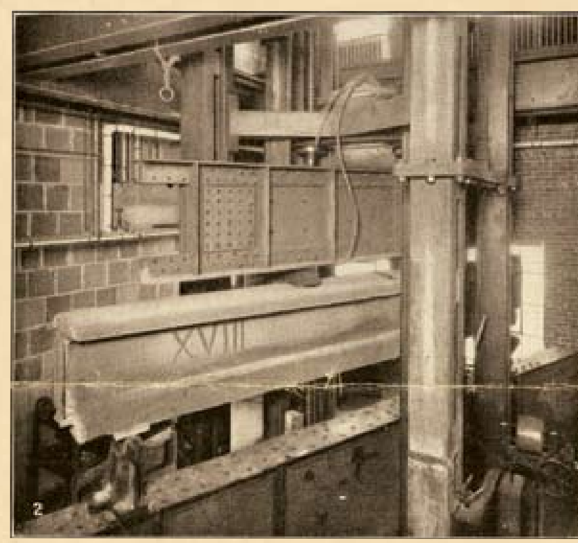
*Method of Testing*—In testing, equal loads were applied at the third-points, bearing directly on the structural steel. Deflections were measured at midspan, top deformations on both gunite and steel, and bottom deformations on structural steel and reinforcing steel.

The moment of inertia of the corroded I-beam of Fig. 1 just before the test, computed from caliper measurements, was 1008.95 in.$^4$, less than half of the original value. The combined section, Fig. 4, was reinforced to give the original strength. The design was not made by the writer.

Fig. 3 shows the load-deformation curves for this same I-beam together with theoretical curves, for comparison. The unit stresses are computed on the basis of $E$ = 30,000,000 lb. per sq. in. The bottom readings were taken directly on the structural steel.

Eight scrapped beams were tested—four plate girders and four I-beams; one of each was bare, one encased with 2 in. of gunite (tested at 7 days), and two encased and reinforced. The reinforced plate girders were tested at 28 days; one, No. XI, had bars bent up at the ends as is done for shear reinforcing. The rein-





FIGS. 1 AND 2—CORRODED I-BEAM READY FOR GUNITE ENCASEMENT, AND ENCASED BEAM UNDER TEST

24-in. 80-lb. I-beam, reinforced to make up original bending strength; tested on 13-ft. span.

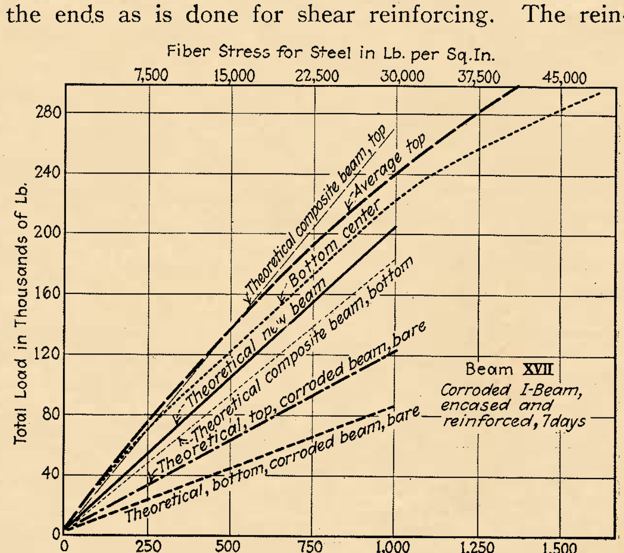



FIG. 3—COMPARATIVE STRESS CURVES, REINFORCED BEAM XVII

forced I-beams were tested at 7 and 28 days respectively. Two new Bethlehem I-beams were also tested, one bare and the other encased.

The adjoined table gives the results of the tests. The properties of the sections shown are for the beams as tested. For the gunited beams they are computed according to the straight-line principle, $n = 10$, no tension in gunite, and all steel including the mesh considered. A plot was made for each test as for beam XVII shown in Fig. 4, and from these curves were taken the values tabulated under "Observed load carried at 16,000 lb. per sq.in." All of the loads given are superimposed loads (excluding weight of test beam).

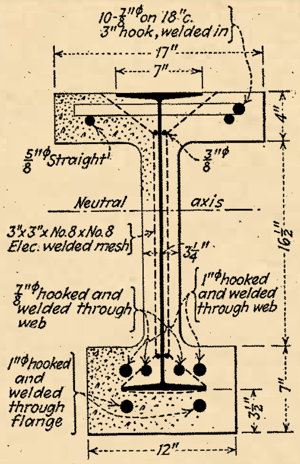



FIG. 4—ENCASEMENT AND REINFORCING STEEL BEAM XVII

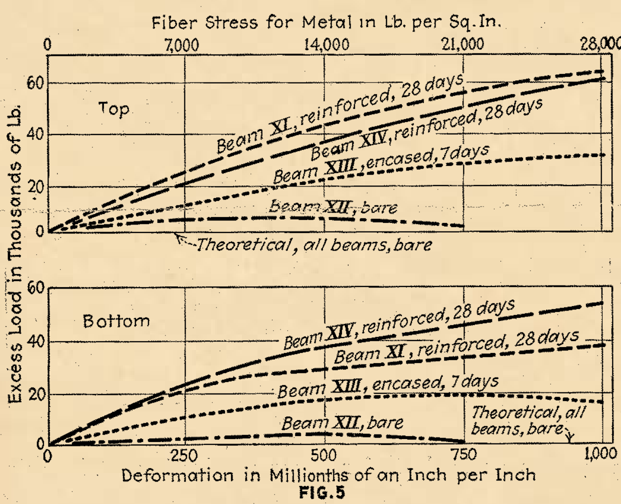
Moment of inertia of encased beam, 2385.4 in.[4]; section modulus for compression, 246 in.[3], for tension 166.8 in.[3].

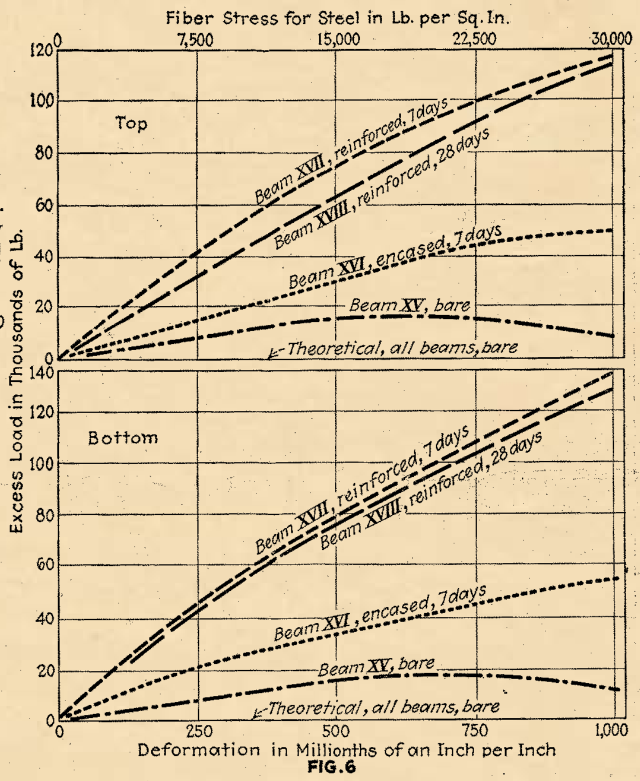
The table does not show the computed load capacity at 16,000 lb. per sq. in. for the original unreduced plate girders and I-beams. These values for the plate girders are 65,000 lb. in tension and 70,800 lb. in compression, and for the I-beams 105,700 lb. for both flanges. It will be noticed that all of the reinforced encased beams carried loads well over these values and in only a few cases did they carry less than those calculated more rigidly on the cross-section as used. The variations from the calculated values are in general less than those from the calipered values of the bare steel beams. The observed values for the bare beams are greater than the calculated ones, particularly for the I-beam; this is not strange, for an inspector will naturally have his eyes on bad spots and his measurements will very likely bear toward these.

The tension flanges seem to do better all along than the compression. There may be two reasons for this; that considerable tension was taken by the gunite, and that the value of 10 for the ratio of the moduli of elasticities was too low.

Cracks began to appear at steel unit stresses of from 8,000 to 16,000 lb. Cracks were made early visible by whitewashing the sides of the test beams.

The bare plate girder XII failed by lateral buckling




FIGS. 5 and 6—EXCESS-STRENGTH CURVES FOR I-BEAMS AND PLATE GIRDERS

TABULATION OF WORKING AND ULTIMATE LOAD DATA

| Member | Test Span | | Type and Age at Testing Days | Moment of Inertia | Section Moduli | | Observed Loads Carried at 16,000 Lb. per Sq.In. on Metal | | Loads Computed from Section Moduli 16,000 Lb. per Sq. In. on Metal | | Difference in Per Cent of Computed Load Values | | Ultimate Load | In Per Cent of Obs. Load at 16,000 Per Cent Tension |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ft. | In. | | | Tension | Comp. | Tension | Comp. | Tension | Comp. | Tension | Comp. | | |
| Plate Girders | | | | | | | | | | | | | | |
| XII | 12 | 0 | Bare— | 890.8 | 80.4 | 89.8 | 60,000 | 66,500 | 52,400 | 58,600 | +13 | +12 | 84,300 | 140 |
| XIII | 12 | 0 | Plain-7 | 975.8 | 75.8 | 120.3 | 65,000 | 76,000 | 48,000 | 77,500 | +35 | —2 | 164,300 | 253 |
| XIV | 12 | 0 | Reinf.-28 | 1,385.5 | 111.7 | 161.1 | 95,000 | 101,000 | 72,000 | 104,700 | +32 | —4 | 225,700 | 237 |
| XI | 12 | 0 | Reinf.-28 | 1,302.7 | 103.4 | 154.8 | 80,000 | 104,000 | 66,200 | 100,200 | +21 | +4 | 227,950 | 285 |
| I-Beams | | | | | | | | | | | | | | |
| XV | 13 | 0 | Bare— | 2,087.2 | 79.9 | 105.2 | 68,000 | 85,000 | 48,100 | 63,700 | +29 | +25 | 146,825 | 216 |
| XVI | 13 | 0 | Plain-7 | 1,107.2 | 67.2 | 146.4 | 73,000 | 90,000 | 38,800 | 87,900 | +88 | +2 | Local Failure | 228 |
| XVIII | 13 | 0 | Reinf.-28 | 2,385.4 | 176.8 | 241.5 | 136,000 | 135,000 | 104,900 | 144,800 | +30 | —7 | Local Failure | 186 |
| XVII | 13 | 0 | Reinf.-7 | 2,453.7 | 166.8 | 246.0 | 129,000 | 145,000 | 99,000 | 147,600 | +30 | —2 | 328,300 | 254 |
| Beth. | | | | | | | | | | | | | | |
| I-Beams—A | 19 | 0 | Bare— | 1,629.3 | 147.7 | 147.7 | 62,000 | 59,000 | 60,800 | 60,800 | +2 | —3 | 140,850 | 227 |
| —B | 19 | 0 | Plain-29 | 2,190.5 | 157.6 | 206.3 | 66,400 | ............ | 62,200 | ............ | +7 | ........ | 222,050 | 335 |

of the top flange followed by a sudden buckling of the web, most marked at one end. There were no stiffeners on the ends. In setting up the test for beam XVI a large cast-iron block was used to distribute the load to the loading girder; this block broke at 166,200-lb. load, suddenly releasing the load on the test beam, and the beam would take no further load after this. The stress-strain curves indicated that the test beam was very close to failure before the casting broke. Beam XVIII failed by the bearing block at one of the loading points crushing into the flange of the I-beam, breaking out the side of the T head which reinforced the corroded top flange. The others of the encased beams failed by a general vertical deflection with the top flange bowing somewhat to one side. Cracks in the bottom were very close together and small, no one crack opening wide. They generally took a direction at right angles to the resultant tensile stress.

The stiffening effect of the encasement is clearly shown in the amount of load taken above that which produced 16,000 lb. per sq. in. in the tension steel (see last column of table). Comparison of beams A and B shows this particularly.

Figs. 5 and 6 summarize the curves for all the tests. They show the excess-load curve for each test beam in comparison with that of its own theoretical bare corroded beam as computed from the caliper notes.

While noting the proportionate increase of the loading values of these encased beams, it must not be lost sight of that the gunite, being a portland cement concrete, has a plastic flow property. This plastic flow would tend after some time to shift somewhat more of the load onto the structural steel than these tests indicate.

*Bond*—The bonding of the gunite to the steel was good in all tests even up to very high loads. In some cases where the reinforcing was heavy, the loads carried were more than 100 per cent of that which theory would indicate for the bare beam. Beam XVII at 7 days showed an increase, at 16,000 lb. per sq. in., of 118 per cent at the top and 172 per cent at the bottom over that computed for the bare unencased beam; and at the same time exceeded that computed for the composite beam by 30 per cent on the top and showed a deficiency of only 2 per cent at the bottom. The final cracking of the gunite indicated also a good bonding. In some cases there was noticed a slight marking of the gunite at the end where the structural steel protruded, which appeared to indicate a loosening of the bond, but this did not seem to affect the test in any way. In attempting to remove gunite from the steel it was found that rapping the steel did not avail to loosen the gunite. It was necessary to wedge it off and then finish by chipping as the piece wedged off more often broke in the gunite than between the gunite and the steel.

*Conclusion*—The principal question that was asked in making of these tests was whether the gunite with its reinforcement would bond sufficiently with the steel to cause the structural steel and the reinforced gunite to act as a unit. This question was answered in the affirmative.


Fig. 1. Condition of girders, High St. Viaduct, Columbus Ohio, November, 1927, while repairs were being made with "Gunite"

## Steel Viaduct to Be Reinforced by Encasement

**Corrosion of Plate Girders Carrying High St. Over Railroad Tracks in Columbus Necessitates Strengthening**

By R. H. Simpson

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HIGH ST., in Columbus, Ohio, is carried over the tracks of the Pennsylvania R. R., the C. C. C. & St. L. Ry. and the Union Depot Co. on a viaduct of four 75-ft. spans. This structure consists of deck girders about 4½ ft. apart, carrying buckle plates to support the floor. It has a clearance of 16½ ft. above the railway tracks. The viaduct was built in 1895, at the joint expense of the city and the railroad companies. By reason of the limited clearance, the sandblast action of locomotive exhaust and the action of gases on the steel has caused serious deterioration, resulting in heavy expense for maintenance. In 1912 a careful investigation showed that the flange plates and the stiffeners of many of the girders were greatly reduced in cross-section and the web members of some of the girders were rusted through. Following this inspection, the badly rusted girders were strengthened by the addition of new flange plates, stiffeners and web plates.

Some two or three years ago a careful inspection disclosed further deterioration and indicated that the structure should be rebuilt. Accordingly, preliminary studies were made and an estimate of cost prepared for a complete renewal of the structure. At the time these studies were being made it was suggested that this structure could be strengthened by the use of reinforcing rods and cement mortar applied by means of a "Cement Gun." Such repairs to the structure, if effective, would mean that it could be put in a safe condition with no interference with traffic. This is an important consideration, inasmuch as the main entrance to the union station leads from the viaduct, and a complete renewal would require some temporary construction to provide access to the station.

About this time some tests were made at Ohio State University on a few old I-beams, which indicated that the strength of the old steel beams could be increased within reasonable limits by the addition of steel rods and the encasing of the entire assembly in cement mortar applied by means of a "Cement Gun." They also showed that the strength of such reinforcing beams might be predicted accurately by the usual theory of composite beam action. The results of these tests were given in *Engineering News-Record* of April 7, 1927, p. 574 by J. R. Shank.

Notwithstanding the successful results of these tests at Ohio State University, it was felt that this method of strengthening should not be adopted for the High St. viaduct without some further investigation as to its effectiveness when applied to the field under adverse conditions. It was therefore proposed that some tests be made on two girders of the High St. viaduct, in order to check, if possible, the results obtained on the encased I-beams tested in the laboratory. An appropriation was secured to carry on this field test. Careful caliper measurements of the actual cross-section of the two girders were made at intervals of about 5 ft., and with these measurements as a basis the reinforcing and the gunite encasement were designed to provide the required strength. Before and after encasement a test load of motor trucks was placed over the two girders and the deflections and tension in the bottom flanges of these girders measured. The results showed that the reinforcement and encasement had stiffened the girders enough to reduce deflections under live-load about 11.6 per cent and reduce the live-load unit stresses about 13.5 per cent.

These tests further demonstrated that it would be possible to design a steel and gunite reinforcement for the girders on the viaduct which would effectively strengthen them and protect the steel from further corrosion, so that the present structure would continue to give service for a long period of time, depending upon the rate of abrasion of the mortar encasement by the cinder blasts from locomotive stacks and the corrosion of the encasement due to gases from the engines.

It was estimated that the cost of the encasement of this structure, including the reinforcing steel, would be $112,000, while the construction of a new viaduct would entail an expense of $175,000 and in addition would necessitate the construction of a temporary roadway to handle traffic to and from the union station, besides seriously interfering with the traffic on High St. In view of all the facts it was decided to adopt the reinforcing plan. Financial reasons, however, made it preferable to do at this time only that part of the work which is immediately necessary. Accordingly, after receiving bids, a contract has been awarded to The Fritz-Rumer-Cooke Co., of this city, to encase about 40 percent of the girders in the viaduct, the work to start immediately. It is expected that funds will be available during 1928 to complete the work. This project, while under the general direction of the writer, is under the personal supervision of R. C. Chaney of the city engineering department. Prof. Clyde T. Morris was employed as consultant in connection with the stress deflection measurements and the design of the reinforcement.

*Reprint from Engineering News-Record - Nov. 17, 1927*

**NOTE:—The O. S. U. official report referred to above was ready for distribution in January, 1928. Interested parties should communicate directly with the Engineering School, Ohio State University, Columbus, Ohio.**

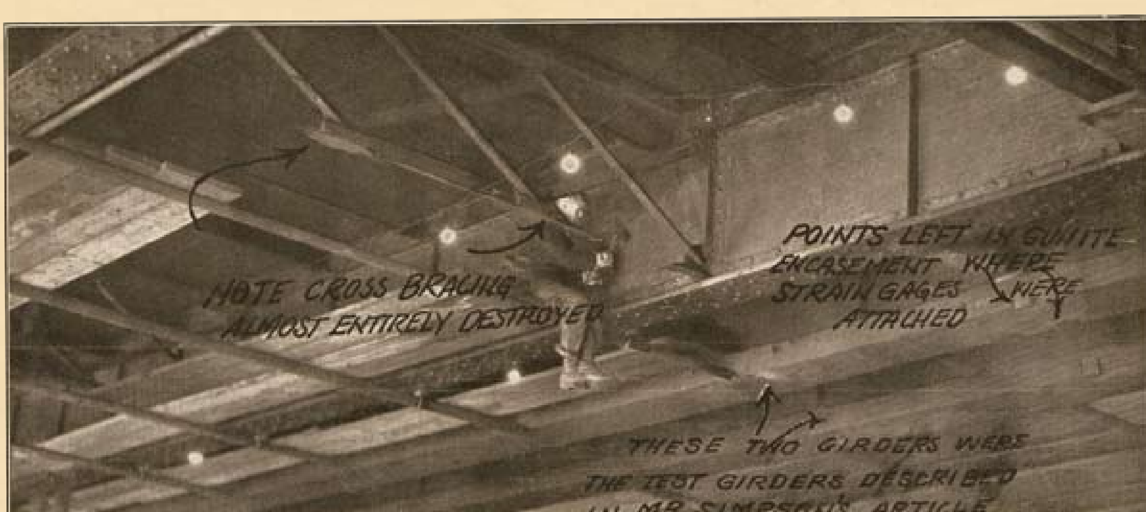


Fig. 2. Shows test girders described in Mr. Simpson's Article. Also note Cross Bracing almost entirely destroyed.

The method of repair described in these two articles is covered by U. S. Letters Patents No. 1, 648,801 issued November 8, 1927 to W. A. Fritz and C. C. Cooke. These gentlemen, however, have authorized us to advise that the use of this patent will be granted to anyone upon payment of a limited royalty, and upon request we will be pleased to obtain this authorization.

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