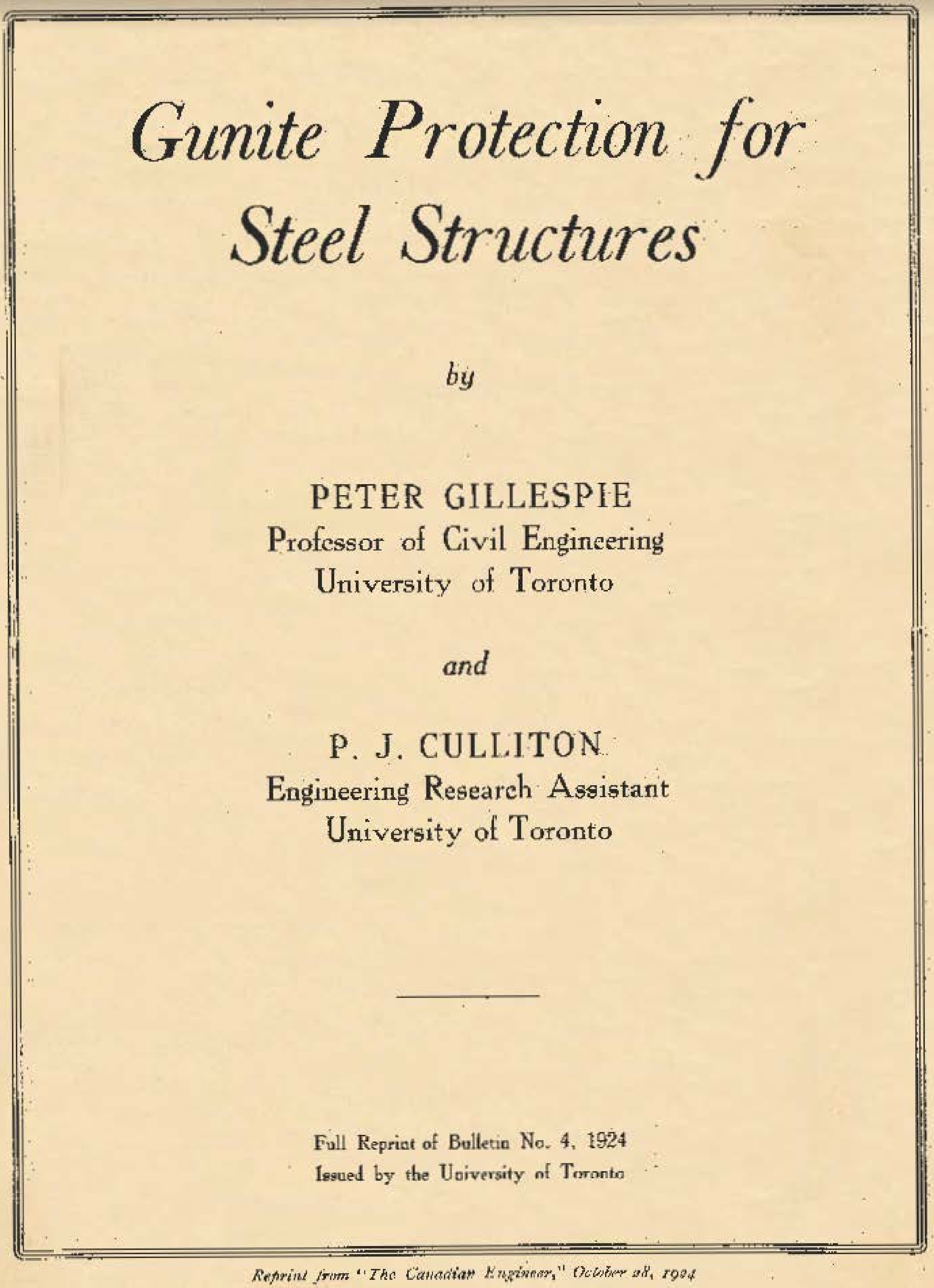

Gunite Protection for Steel Structures

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Full Reprint of Bulletin No. 4, 1924
Issued by the University of Toronto

Reprint from "The Canadian Engineer," October 28, 1924

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Experiments at Leaside, Ont., with Two 42-ft. Steel Plate Girders Covered with Gunite to Ascertain Cause of Superficial Cracks on Bridges at Hamilton — Conclusions Favor Employment of Guniting Process

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IN the month of December, 1921, two steel girder bridges in the city of Hamilton, Ont., forming part of the main highway between that city and Toronto, were covered with gunite in order to protect them from the corrosive action of locomotive blast since both pass over tracks where locomotive traffic is moderately heavy. Sometime in the month of May next following, it was observed that on both structures numerous small cracks in the gunite had developed. Their widths varied from that of a hair up to one-sixteenth of an inch and in isolated cases this latter limit was exceeded. It was almost impossible to measure their depths but it was believed that generally they did not penetrate past the plane of the reinforcing fabric. They did not lie in any general direction, some being vertical, others horizontal and still others having the diagonal direction of the reinforcing strands.

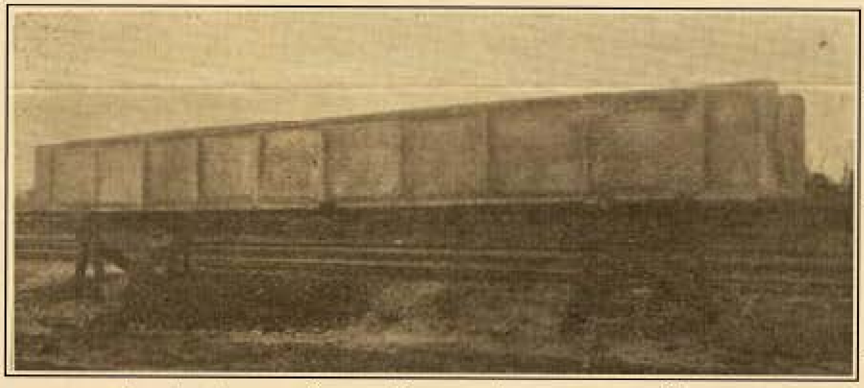

FIG. 1.—LEASIDE GIRDERS PRIOR TO APPLICATION OF GUNITE

The specifications for this work called for a coating of gunite 1½ in. thick in which an expanded metal fabric weighing 34 lb. per 100 sq. ft. was to be imbedded ¾ in. from the steel plates. The aggregate was to be graded silicious sand free from deleterious matter and capable of passing a ½ in. mesh. The mixture was to be 3 to 1. Metal surfaces were to be thoroughly cleaned of rust and scale before covering and gunite was not to be applied during a temperature lower than 35° F.

On bridge No. 4, the first to receive the coating of gunite, the cracks had not developed to the same extent as they had on bridge No. 5. On the former, cracks had extended over the flat areas between the web stiffeners and in more than one instance had continued across the stiffeners into the next panel. In many panels several cracks appeared and in each panel examined there was at least one visible crack.

The cause of the cracking, the remedy for it and the extent, if any, to which it exposed the metal beneath to corrosion were questions that naturally suggested themselves. In the effort to answer them, it was proposed to experiment on a scale somewhat larger than would be possible in a small laboratory. To that end the Canadian National Railways donated two superseded 42-ft. steel plate girders. Through the further co-operation of the Honorary Advisory Council for Scientific and Industrial Research, the Canada Cement Co. and the Cement Gun Co., of Allentown, Pa., the experiment was made possible. The girders were accordingly set up at Leaside, Ont., and to them gunite was applied, the thickness of coating, the reinforcing fabric, the ingredients and the proportions constituting the variables of the problem. The observations made on the bridges at Hamilton, on the girders at Leaside and on numerous small scale specimens in the laboratory are briefly recorded here together with such conclusions as appear warranted by the evidence deduced.

After the girders had been cleaned of old paint, the webs were drilled and three horizontal lines of ⅜ in. round rod attached to either face in order to keep the reinforcement away from the plate. To these rods the fabric was wired. In each girder there were eleven panels. The north girder was covered with expanded metal commercially designated as 1¾-14-20. The north side of the south girder was covered also with expanded metal of larger mesh designated 3-14-10. The south side of this girder, with the exception of one panel, was covered with Greening square wire mesh. Three series of tests, A, B and C, were planned according to the following schedules.

Series "A"—North Girder. Two-inch thickness of coat using 1¾-14-20 mesh. Weight of steel per sq. ft., .68 lb. Two panels, one on either side of the girder, constitute a test.

West Test No:	1	2	3	4	5	6	7	8	9	10	East 11
Mix:	1:4	1:3	1:4	1:4	1:3	1:3	1:3	1:4	1:4	1:3	1:4
Sand:	mixed	coarse	coarse	coarse	coarse	fine	fine	fine	mixed	mixed	fine
Adulterant:	lime		loam		clay		loam				clay

The percentages of adulterants were as follows:

A1 —lime, 6% of volume of cement.
A3 loam, 17% of volume of cement.
A5 —clay, 10% of volume of cement.
A7 loam, 17% of volume of cement.
A11—clay, 15% of volume of cement.

Series "B"—South Girder, North Side. One and a half inch thickness of coat using 3 14-10 mesh. Weight of steel per sq. ft., .34 lb. One panel constitutes a test.

Test No.	West 12	13	14	15	16	17	18	19	20	21	East 22
Mix:	1:3	1:4	1:3	1:4	1:5	1:4	1:5	1:5	1:2½	1:2½	1:4
Sand:	coarse	coarse	fine	fine	mixed	mixed	mixed	mixed	mixed	mixed	Ottawa

Series "C"—South Girder, South Side. One and a half inch thickness of coat using two-inch square wire mesh. Weight of metal per sq. ft. 57 lb. An exception is test No. 32, where there is no reinforcing but to which two coats of gunite were applied.

Test No.	West 23	24	25	26	27	28	29	30	31	32	East 33
Mix:	1:3	1:4	1:3	1:4	1:3	1:4	1:5	1:5	1:2½	1:5	1:4
Sand:	coarse	coarse	fine	fine	mixed	mixed	mixed	mixed	mixed	Mixed, no reinforcing on web	Ottawa

In addition to the above, eight small steel plates varying in dimensions from 18 in. by 24 in. to 24 in. by 24 in. stiffened on the edges by having light steel T's riveted to them were provided. These were coated in the field and afterwards transferred to the testing laboratory for observation. They are known as series "D."

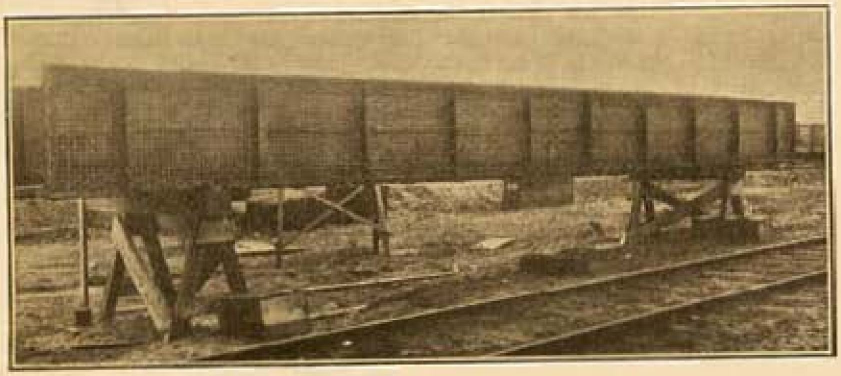

FIG. 2.—LEASIDE GIRDERS AFTER APPLICATION OF GUNITE

Materials Used

The sand used was a good grade of water-washed sand. The coarse variety was purchased in Toronto while the fine material was obtained from the Canadian National Railway stores. On certain of the tests the sands were mixed in equal proportions. Mechanical analysis by Tyler sieves is given herewith:

Coarse sand—500 gram. sample.

Sieve	Percent. Retained
4	.8
8	15.8
14	39.4
35	80.2
40	83.2
100	96.6

Fineness modulus, 3.16

Find sand—500 gram. sample.

Sieve	Percent. Retained
4	.0
8	.0
14	.4
35	48.3
40	57.0
100	98.0

Fineness modulus. 2.04

Mixed sand—equal parts coarse and fine—500 gram. sample.

Sieve	Percent. Retained
4	.8
8	9.0
14	21.0
35	67.0
40	71.0
100	96.6

Fineness modulus, 2.65

The cement was No. 1 Portland from the Canada Cement Co.

The water was taken from the mains of the City of Toronto at a pressure of 60 lb. per sq. in.

The air was dried as completely as possible, having been passed through a dryer before it reached the gun. The pressure at the gun was 25 lb. per sq. in. except in Test A2, where it was 20 lb. per sq. in.

The lime was a good grade of slaked lime.

The clay was obtained from the Canadian Fireclay Products at New Toronto and was well-dried and finely-powdered.

The loam was taken from a compost heap of rotted leaves. This was well dried out and screened through a 20-mesh sieve. Anything larger than 20 mesh was rejected.

The compressor was an oil-fired Chicago Pneumatic compressor delivering air at 90 lb. pressure.

The cement gun was the standard gun manufactured by the Cement Gun Co., Allentown, Pa.

During the application of gunite on November 21 and 22, 1922, the temperature hovered around the freezing-point, but since the finished work was subsequently warmed by salamanders, it is believed that no injury due to frost occurred.

Rebound Tests

Tests to find out what percentage of sand rebounced from the girder during the application of the gunite were made. The sand was collected on spread tarpaulins and measured. It was found that the coarse sand had the largest rebound and the fine sand the smallest. The percentages are:

Coarse sand	16%
Mixed sand	12%
Fine sand	4.7%

This is obviously not the total rebound but it is a close approximation. All of the rebounding material could not be collected since some of it had been thrown as far as 100 ft.

Early Cracks

By January 8, 1923, a number of cracks, most of them insignificant as to width or length, were observed. Of these only the larger are reported.

On panel C28 a crack 6 in. long and 3/32 in. wide developed at the lower side of the upper flange. Its depth, gauged with a piece of No. 34 copper wire, was ¼ in. On panel C31, a crack 4 in. long and less than 1/32 in. wide, was observed on the plane surface of the panel. On panel C32, which has no reinforcing metal, and to which two coats of gunite had been applied, a crack 15 in. long and 1/16 in. wide had developed, but this apparently passed through the outer coat only which was about ¾ in. thick. A hair crack 10 in. long in the lower right-hand corner was also observed. On panel B16, a very narrow crack 4 in. long just below the upper flange and another about half a panel high in the flat area were observed. A diagonal crack was also found on panel A3, having a length about half the panel width. In panel C23 a crack almost the total height of the panel occurred. Speaking generally, the 1:5 mixtures showed less tendency to check than others. Most of the cracks observed were of a character not easily recognized by a casual observer.

During the latter part of April, 1928, a number of openings were made in the gunite, exposing both the reinforcement and the steel girder web plates. The panels into which cuts were made were C25, C26, C27, C28, C29, C30, C31, C32, B18, B19, A3, A5, A7, and A11.

In breaking through at the large crack on panel C32 a pocket of unmatrixed sand was found. Some red ink had been introduced to find out if possible whether this crack extended as far as the steel. This could not be determined but there was no indication of rusting of the web. At the hair crack on the same panel water had penetrated as far as the steel and there were two patches of fresh rust on the web. The rusting had doubtless been facilitated by the loose material which was here found in contact with the steel. Where the gunite was chipped away on panel C31 in the corner made by the stiffener angle and the web, the steel was well preserved, the gunite having been well driven into the corners and around the curved fillet of the angle. Rust on the reinforcement before coating seemed to have been absorbed by the gunite. The fabric was extremely clean and absolutely free from rust. On all the other "C" tests examined the material was of a well-matrixed character, protecting perfectly the girder and the reinforcing mesh which was found to be in all cases ⅜ in. from the plate. The good quality of the gunite is evidenced by the fact that it was extremely hard to chip with a heavy hammer and sharp chisel. The bond between it and the steel was very good although there were no cases of "feather edge" fracture. In nearly every case where gunite was broken pebbles in the aggregate were fractured across.

A3 and A7 contained loam while A5 and A11 contained clay. The gunite in these panels was the same dense well-matrixed substance found in tests not containing impurities. There was, however, some rusting on the side of the reinforcement facing the girder and this was more pronounced with the clay than with the loam.

When test A7 was chipped on the north side of the girder, it was found that the reinforcement was very close to the girder web. The result of this was that behind the strands of the expanded metal there were air pockets. It is believed that the gunite did not have a chance to penetrate behind the strands sufficiently to make a compact mass. There did not appear to be any rusting on the back of the reinforcement, doubtless due to a rebound of neat cement which had adhered to the fabric. The girder web was very well protected also. When the reinforcement was cut away the paths of the individual strands could be easily picked out by a sort of serrated surface into which the grains of sand had worked themselves behind the strands.

The ⅜ in. steel rod holding the reinforcing was chiselled away on tests A3 and C30. There was no rusting visible either on the plate or on the back of the rod, the gunite having been well driven in behind the steel bar. Test B21 was chipped at a hair-line crack after a quantity of red ink had been introduced. It was found, on breaking the slab, that the crack had penetrated as far as the plane of the reinforcing mesh, but there was no indication that it had extended past it.

In December, 1928, a number of phenomena not previously observed were noticed. In practically every instance where an opening in the gunite had been made the previous spring, small cracks radiating therefrom were seen to have developed. This was particularly true where the layer of gunite was especially thick. In several instances vertical cracks corresponding to the edges of outstanding legs of stiffener angles had opened. When the material adjacent to such a crack was chipped away it was found that the gunite was less than ½ in. thick, and that the reinforcement was in close contact with the angle. Where cracks above stiffener angles had not developed, chipping showed the layer of covering to be thicker than ½ in. and the fabric less closely wrapped around the angle. In no instance, except on panel C32 which it will be recalled had no reinforcement, was it possible to follow a surface crack as far as the steel plate. In several cases, however, they were traced as far as the plane of the reinforcement. Nowhere was either the fabric or the plate in a condition other than perfect. The cracks were all of a width of .01 in. or thereabouts and in some cases due doubtless to the presence of soluble ingredients, these had completely sealed over. In all, twenty-three panels were uncovered to a greater or lesser extent.

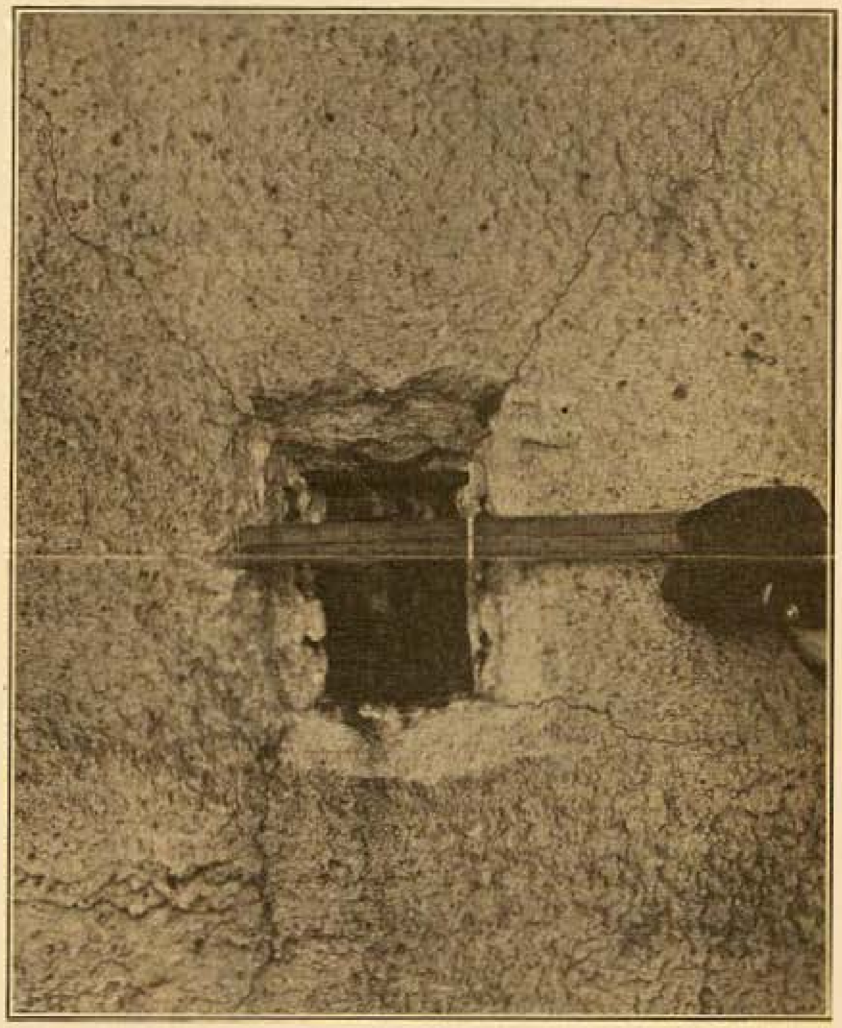

FIG. 3.—CRACKS RADIATING FROM AN OPENING CHIPPED IN GUNITE

Concrete, like wood, clay and some other materials, expands when it absorbs moisture and contracts when it is dried. Investigation has shown that some of the factors which influence the extent of this performance are quantity of aggregate, method of curing, quantity of mixing water and climatic conditions. It is known for example that a neat cement paste will "work" much more than a mortar and that a concrete will contract as much as .0005 per unit in hardening. If this tendency be resisted, as, for example, when an envelope of gunite is used to cover a plate girder, the concrete comes into a state of tension. This tension may easily be sufficient to rupture the shell. Probably the condition most favorable to cracking is where an area of gunite is not bonded to the plate beneath but is, outside of this area, together with its contained reinforcement, securely anchored to the metallic frame. This anchorage may be due to stiffener or flange angles, to rivet heads or to some favorable mechanical feature of the plate itself. The normal effect of shrinkage will be to create tension in the gunite but no stress in the reinforcement. When, however, the tension becomes great enough to rupture the gunite, tension must develop in the fabric at the region of failure and compression elsewhere. If the reinforcement be adequate in area, the stress therein will be moderate and the cracks microscopic. For this it is generally believed that one-third of one per cent. of metal is the minimum requirement. Obviously a high yield-point steel is preferred. A distributed fabric of adequate cross-section, therefore, while powerless to prevent cracks is very efficient in increasing their number and reducing their size. Where the shell of gunite is of unusual thickness, say 3 in. and where the fabric is quite close to the steel plate, it is evident that the influence of the reinforcement in controlling surface cracking is nearly non-existent. It was observed on the Leaside girders as stated above, that surface cracks which had developed to visible widths in thick shells of gunite could never be traced past the plane of the fabric. Another circumstance favoring the formation of visible cracks is the application of a surface coat of gunite which, for some reason or another, had failed to bond with the previous layer. Such a coat can easily be detected by tapping with a small steel hammer. Cracks have been observed, both at Leaside and at Hamilton, which pass through this surface coat only.

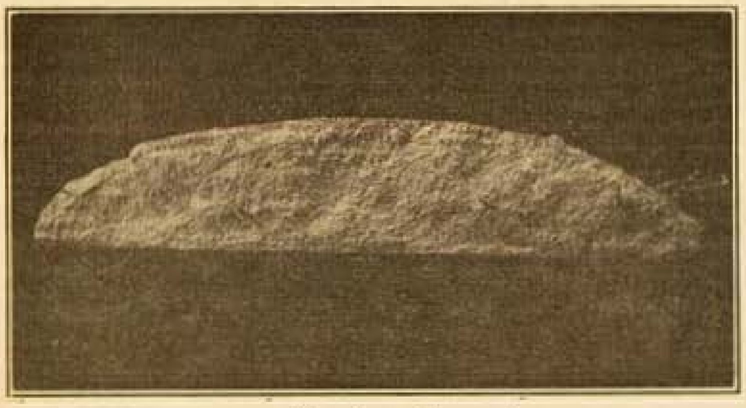

Fig. 4.—Section of Gunite Slab

Prevention of Corrosion

Neat Portland cement is known to be an effective preventive of rusting when applied to steel surfaces and on occasions has been employed as a paint for this purpose. To afford a satisfactory protection for steel reinforcement it is advisable that the metal be surrounded by a mortar rich in cement applied preferably wet, as this insures that all parts be coated. Gunite is a concrete essentially of this character, but since it is applied under pressure it possesses greater density than ordinary concrete. When the raw materials are forced under pressure against a hard metal surface there is considerable rebound—mostly of the sand. This means that the cement adheres to the surface as a matrix into which the particles of sand are subsequently driven. This matrix is a preventive of corrosion.

Figs. 4 and 5 are photographs of fractured sections of a slab of gunite and a block of hand-placed concrete respectively, the mixture in each case being 1:3. The gunite is the denser of the two and being denser is more impervious to the entrance of water. An examination with a reading glass shows that the face of the slab, which was in contact with the steel, is a film of practically neat cement, any sand present being of an extremely fine character. The imperviousness of gunite and the layer of almost neat cement in contact with the metal surface are two circumstances which render corrosion difficult. If, however, cracks occur in the gunite, what may be expected?

Whether steel reinforcement in beams of reinforced concrete is in danger of rusting through the entrance of air and moisture at the cracks which inevitably occurs when such beams are subjected to flexure has been made the subject of much experimental investigation. Some years ago, at the Royal Testing Station at Berlin, it was shown that ordinary tension cracks occurring within the limits of permissible loading, do not allow atmospheric corroding influences to affect the steel. The entrance of moisture is to be feared only when the stress in the metal has passed the elastic limit and when in consequence the cracks are relatively wide. This occurred when stresses in excess of 35,000 lb. per sq. in. existed. The atmosphere was artificially moistened and supplied with CO_2 and free oxygen.

On two occasions, April, 1922, and January, 1924, examinations of the fissured gunite on the Hamilton bridges was made by chipping the material meanwhile following the cracks with red ink. Reinforcing fabric, consisting of 3 in. by 8 in. expanded metal, was well protected in all cases. In the first case, when the gunite was chipped down to the fabric, the ink was observed to creep along the strands, indicating an imperfect bond between gunite and steel. The crack was followed beyond the plane of the fabric to within a short distance of the steel plate when it was lost. In another case the crack was easily followed as far as the steel plate. There was rust on the web plate but it is thought that this had accumulated before the gunite had been applied. Several attempts to completely surround a block of gunite three inches square by chipping down to the surface of the steel plate were made. The "island" of gunite, however, invariably fell away just as soon as its last junction with the remaining body was severed. This indicated that the bond between the mortar and the steel had not been perfect. In still another case, where tapping with a hammer produced a distinctly hollow sound, the crack could be followed only through the surface coat which had not been bonded with the layer beneath. In one instance the fractured concrete displayed clusters of magnetization lines characteristic of mortar or mud that has been frozen. The city engineer of Hamilton is of the opinion, however, that the gunite was not frozen in any case before it had a chance to set. Generally speaking the gunite at Hamilton was inferior to that on the Leaside girders. It contained pebbles of soft material and nodules of clay in places and was much more easily chipped than the gunite at Leaside. In no case on the Leaside girders had red ink, when applied, crept along the strands of metal, nor had cracks been followed past the plane of the fabric. In no case had striations or magnetization lines indicative of frost been observed there. Generally the bond between the gunite and the steel plate was distinctly better than on the Hamilton bridges. This may be the explanation of the deeper and wider cracks observed on the latter.

Fig. 5.—Showing Spots of Rust on Metal Otherwise Protected by Mortar

This test was performed to compare the wear of gunite with that of mortar and concrete. Seven fragments of 1:3 gunite weighing 2,557 grams, six fragments of 1:3 hand placed mortar weighing 2,300 grams and six fragments of

1:2:5 concrete weighing 2,744 grams were used. All samples were well seasoned. These fragments were placed in a Deval abrasion machine, together with 10 lb. of Ottawa sand, and given 10,000 revolutions. The percentages of wear were as follows:

Gunite	6.94%
Mortar	15.65%
Concrete	10.72%

After the test the number of pieces of gunite was seven, of mortar, ten, and of concrete, fifteen.

Expansion Tests

These were undertaken to ascertain the extent to which gunite will expand when immersed in water for a number of days. To this end, pieces of gunite about 12 in. long, 6 in. wide, and 1½ in. thick were selected as specimens. These slabs were perforated at two points 8 in. apart for the reception of ⅜ in. round brass plugs, 4 in. long. These plugs were inserted in the holes and secured there by a cement of litharge and glycerine, the ends protruding 1¼ in. either way. The combination was then placed in a pocket of rubber tissues through perforations in which the extremities of the plugs protruded. The tissue, having been ligatured to the projecting plugs, there resulted a water-tight envelope. The whole was then placed in a rough pine box having four vertical slots at the bottoms of which the projecting plugs rested. To the extremities of these plugs the distance pieces of Martens extensometers were attached. The method consisted in mounting the specimen after thorough drying and recording the readings on the receiving scales. The rubber pocket was then filled with water and daily readings made for a period of ten days or until expansion had apparently pretty well ceased. These readings are taken by means of telescopes and admit of great accuracy. Temperature was maintained practically constant during the period of observation. Other disturbing elements were carefully eliminated.

The expansion per unit length between the dry and the saturated condition is given herewith. It is believed that had the time of observation been lengthened, small additional changes might have taken place:

1:4 gunite in 6 days' immersion lengthened .000136 per unit;

1:4 gunite in 17 days' immersion lengthened .000245 per unit;

1:3 gunite in 9 days' immersion lengthened .000212 per unit;

1:2½ gunite in 12 days' immersion lengthened .000195 per unit.

Small Size Panels

The D series of plates were stiffened by 1½ in. by 1½ in. light weight T's which were rivetted to their edges. These plates were made up from old stock very much rusted in places and badly pitted by corrosion. Reinforcing fabric was applied to them and securely fastened on two opposite edges to the outstanding flanges of the T's which were drilled for the purpose. These plates were covered with gunite at the same time as the girders were coated and with the same mixtures. There were 8 plates in all and each plate was covered on both faces. These 8 plates were kept under cover at room temperature for three months. During that time it was observed that the gunite shrank away from two of the four flanges of the marginal T's on each specimen and that this shrinkage was along the edges to which the fabric was not attached. Practically no separation occurred between the gunite and the flanges of the marginal T's to which the fabric had been secured. These cracks varied from .015 in. to .04 in. and averaged perhaps .025 in. The widest separation was with the 1:2½ gunite. Subsequently these plates with their coverings were immersed in tanks where they remained for a period of 10 days, after which the tanks were drained and the specimens allowed to dry. This was continued for three cycles, after which they were taken out of doors and placed in a position exposed to the weather where they remained for 12 months. They were then taken inside and examined with the following results:

There were no cracks in the gunite although there were a few cases of surface "crazing."

The exposed edges of the stiffening T's were very much rusted. This rust had followed the metal inwards approximately ½ in. at the shrinkage cracks referred to above.

The fabric was in excellent condition except that the sheared edges of the expanded metal on the side toward the plates showed a very little discolouration due to rust. That the gunite may not have completely covered the remote sides of the strands is the probable explanation.

After the gunite had been completely removed it was possible to lift with a pen-knife, flakes of the original rust 1/32 in. or more in thickness. This rust had undergone no change during the months of its immersion and exposure and no additional corrosion had taken place.

Whenever an "island" of gunite was surrounded by careful chipping it separated from the plate. The separation may, however, have been the result of the impact of the hammer and chisel.

Micrometer Tests

These were made by means of a micrometer microscope, mounted on a tripod. This instrument had an accuracy of .0006 in. and by means of it the widths of a number of cracks which had developed in the gunite on the bridges at Hamilton were measured from time to time during the winter and spring of '22-'23 in order to find out what effect, if any, weather conditions had upon the material.

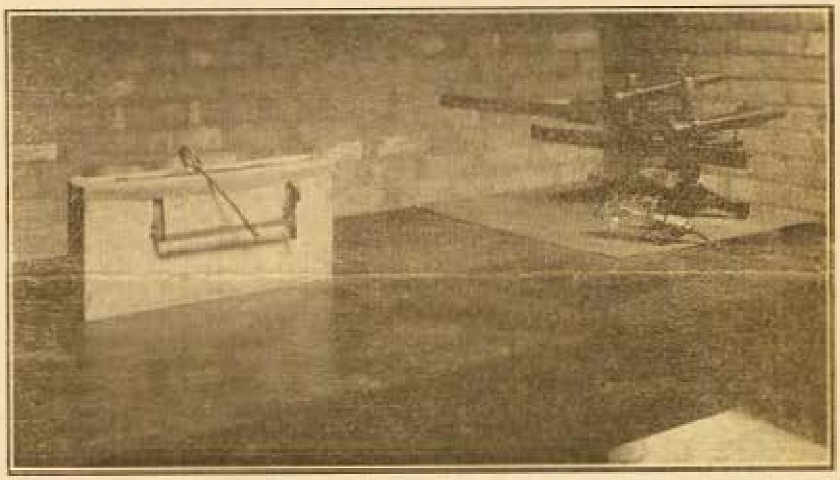

Fig. 6. Device for Measuring Expansion of Gunite Under Water

On December 21, 1922, twenty-five points or different cracks were measured for width. Some of these were on the main girders; the rest were on the floor beams. The widths of the cracks varied from .004 in. to .04 in. The sun was not shining although the atmosphere was quite clear. The temperature was 34° F.

On January 30, 1923, when the temperature was 18° lower than on December 21, the cracks at the same points were again measured, but no differences were observed. Apparently the steel substructure and the envelope of gunite had responded in the same way to the fall in temperature as indeed they might be expected to do unless the fall in temperature were a very rapid one.

A third measurement of the widths of the cracks was made on April 6, following dull wet weather. The day was fine and the temperature was 48° F. Some of the cracks had not changed in width while the rest showed some contraction. These changes as given in percentages vary from 8% to 30% except one crack which contracted 65%. Evidently a humid atmosphere for a period of two days had resulted in a swelling of the concrete and a narrowing of the cracks.

A cabinet of beaver-board was constructed over an air outlet in the wall of a laboratory. The draft in this flue could be mechanically regulated so that passage of air through the cabinet was under complete control. The front of the cabinet was the door. Steam from a small gas-heated boiler was supplied as desired at the bottom of the cabinet. Racks were provided within, upon which specimens could be placed.

A number of 1:3 mortar prisms, rectangular in form, hand-mixed and hand-placed, were made for corrosion tests. The sand was screened below 10 mesh. The specimens measured 2½ in. by 2½ in. by 12 in. long. Running axially through the centre of each was a soft steel core with projecting ends. After curing for two weeks they were stretched in a testing machine until cracks appeared in the mortar envelope. They were then subjected to a controlled humid atmosphere in the cabinet described above to ascertain whether corrosive influences would penetrate the cracks as far as the steel core. A wet and dry bulb thermometer was placed in the cabinet and the humidity therein determined from it. This was never less than 80 and in most cases it reached 100.

First Test—A number of the specimens were placed on shelves within the cabinet and alternately steamed and dried for three weeks, a slight draft meantime being maintained through the flue. The cracks in the specimens varied from .006 to .05 in. A block having a crack .04 in. wide was destroyed after the test and examined. The steel core a ½ in. square twisted bar, under the portion broken off, was observed to have spots of heavy rust. This was probably due to moisture filled cavities contiguous to the steel, where puddling had failed to bring the mortar in actual contact with the metal. These spots, however, were on the underside of the steel core. The steel exposed by the crack showed no rust but the ends of the cores had collected a heavy coat of rust and the metal parts of the wet and dry bulb thermometer showed considerable corrosion after three days. One of the small gunite covered plates was placed inside after its gunite covering had been removed. A very fine film or coat of neat cement still covered the metal. After three days the surface of the plate protected by the film was uncorroded while on the back of the plate corrosion had taken place.

Second Test—For this test the draft was completely shut out of the cupboard. The test lasted nine days with alternate steaming and drying. At the end of that time a specimen having a crack .02 in. in width was destroyed. The core, which was a ⅜ in. square bar was not rusted at the crack but the uncovered ends of all cores were heavily rusted. Several small spots of rust were found on the underside of the core. This would seem to indicate insufficient puddling of the concrete.

Third Test—One of the small plates from which the gunite had been removed, and the steel core of the specimen destroyed after the first test, were steamed. The film of cement was intact on the plate and covered most of the surface of the rod. The core gradually developed spots of rust deepening in color until at the end of the seventh steaming it was completely coated. The plate developed rust much less rapidly but when the 10th application of steam had been made, rust had formed over most of its surface, the coating of cement not availing to prevent its formation.

Fourth Test—For this test all the specimens left from the first test were used. The cracks had been widened by stretching the rods until a maximum of .08 in. was secured. The specimens were steamed twenty-five times, after which the specimen having a crack .08 in. wide was destroyed. Examination showed that there was no rusting of the steel exposed by the crack. There were three spots of rust on the underside of the steel core doubtless caused by the moisture cavities when the specimen was made.

Fifth Test—Four specimens which were not destroyed after the fourth test were used. The cracks were mechanically widened until a maximum width of .17 in. had been reached. The specimens were steamed twenty-two times after which the specimen having a crack .17 in. wide was destroyed. Examination showed no rusting to have occurred on the steel exposed by the crack. There was, however, rusting on the rod at the end of the mortar as if water had crept along the steel beneath the concrete. There were also spots of rust on the undersides of the steel core indicating insufficient puddling.

Sixth Test—Six specimens of similar form made of 1:3 hand-placed mortar and each having a burnished steel core of either square twisted or round steel rod, were exposed to a humid atmosphere in the steaming cabinet for one month after stretching. During that time the exposed ends of the metal rods rusted excessively. When the mortar was broken away rusting was observed in only three specimens and here the fractures had width of .15 in. or more. On the bottom sides of the rods rust spots were frequently found. These were doubtless due to insufficient puddling. The results are as below:

Thickness of Covering	Width of Cracks—in.	Remarks
1 inch	.01 and .03	No rust at break
1 inch	.20	Rust on all four sides of rod at break
1 inch	.14, .15, .18	Rust on all four sides of rod at break
1 inch	.05, .28	Rust at larger opening only
1 inch	.04	No rust at break
¾ inch	.02	No rust at break

Seventh Test—These were two specimens of the same form as those reported above except that the box forms had neither top nor bottom and were filled with gunite from two opposite faces instead of from one only. The depth of covering to the burnished steel cores was one inch. They were stretched in a machine until cracks of substantial width appeared after which they were exposed for three months to the action of a humid atmosphere in the steaming cabinet. Twice daily for two hours the steam was admitted morning and afternoon. Pieces of bright metal suspended in the cabinet and the exposed ends of the core rods rusted excessively. At the end of three months the gunite was broken off and although the cracks varied from .06 in. to .09 in. not the slightest evidence of rust was observable on the rods either at the cracks or elsewhere. The burnished rods were quite as bright as when the gunite was applied.

Experience With Gunite Elsewhere

The experience of a number of representative American engineers with gunite as a protective coating for steel structures has been obtained by correspondence. While the reports are not in perfect agreement the consensus of opinion is that gunite affords a very substantial protection against corrosion of steel.

Satisfactory results have been obtained by the Grand Trunk Railway System from this method of protecting steel against locomotive exhaust.

The Missouri Pacific Railroad have two bridges coated with gunite. The coating was applied over steel girders in a highway viaduct crossing tracks. The gunite is over two years old, but so far there has been no apparent deterioration.

The New York Central Railroad at Columbus, Ohio, has used gunite as a protection for steel bridges for about ten years and has found it to be quite a satisfactory covering.

The Division of Engineering Construction of the Department of Public Service of the city of Columbus, Ohio, is satisfied that gunite is an efficient protection for metal exposed to the exhaust from locomotive stacks. Columbus has two viaducts over railroad tracks which were covered with gunite, one in 1913 and the other in 1914. It has been the practice to make careful inspection of the coating every year and in January, 1923, there were no signs of cracking or disintegration. The city used wire mesh reinforcing.

In 1921 the Delaware, Lackawanna and Western Railroad used gunite as a protection on the Chenango St. viaduct at Binghampton. In this instance the work has proved entirely satisfactory, no cracks having developed, very little wear or abrasion has occurred due to locomotive blasts. The coating of gunite over reinforcement was nowhere less than ¾ in. in thickness. On flanges having button head rivets it was 1¼ in. thick. On bottom flanges with no button head rivets it was 1 in. thick, while on web plates of girders and brackets it was ¾ in. thick. It is believed that the complete removal of all scale from the metal before application of gunite is very important.

The experience of the New York, New Haven and Hartford Railroad, in respect to eleven bridges in the South Boston cut improvement is interesting. On these bridges in 1919 a 1½ in. coating was placed, using as reinforcement 2-in. Clinton wire cloth mesh, No. 12 gauge. In a number of cases the gunite has cracked and spalled so as to expose the reinforcement, but in these instances there is almost continuous switching on the tracks. Moreover, switches were allowed to pass under the bridges within a few days after the gunite had been applied. Where switching is not so continuous the coating appears to be fairly well preserved. The clearances above track vary from 17 ft. to 19 ft. 9 in.

Respecting a highway bridge at Tiverton, R.I., coated in 1913, the same company reports also. Portions of this structure were exposed to salt water spray. The coating was 1¼ in. thick, a mixture of 1 cement to 2½ sand placed on No. 16 gauge, 2-in. Clinton wire cloth. A few stiffener angles and sidewalk bracket angles now show rust through the thin layer of gunite which has cracked along the outer edge of the outstanding leg of the angle. It was found, on cutting back from the edge of the stiffener angle ¾ in., that the steel was thoroughly protected. The chief engineer's opinion is that experience has not been sufficiently extensive to determine whether gunite as a protection for steel on such low clearances as obtain in South Boston cut is the best material. Apparently it is not going to give the measure of protection that concrete jack arch construction between stringers affords. Gunite, in his experience, has been a better protection against salt water spray than against locomotive blast.

The Chicago, Burlington and Quincy Railroad have used this form of protection for about ten years and where properly applied it has not cracked. It has resisted locomotive exhaust very much better than poured concrete. Generally the protection has proved very satisfactory and it is the policy of the company to continue its use.

The experience of the Northern Pacific Railway has been that wooden blast boards constitute the most effective means of protecting steel against blast. These, on the contrary, furnish little or no protection against gases which diffuse themselves through the structure and if the design be such that these gases become confined in pockets, the corrosive action is particularly destructive.

It is the belief of the Terminal Railroad Association of St. Louis that, if properly applied, gunite is an effective protection for steel. In their opinion the cause of the falling off of gunite is improper application.

The Kansas City Terminal Railway finds that poured concrete will not last when exposed to locomotive exhaust. This company has now eleven structures protected by cement gun encasement, the first work having been done in 1913. A recent examination showed the coating to be standing up very well and to be in good condition. On one of the viaducts the overhead clearance is less than 17 feet. In other cases reinforcement protected by poured concrete was found in time to corrode, presumably owing to the penetration of locomotive gases.

During the years 1916 and 1917, the undersides of about seventeen bridges on the Boston and Albany Railroad, in the city of Newton were gunited. Prior to this paint could not be kept on these structures due to the action of locomotive blast and the steel was rapidly deteriorating. The clearance was extremely low. Gunite was used but on account of the dense traffic the work had to be done at night so that the application was probably not what it should have been. It has, however, stood up exceedingly well. The gunite did not show any indication of failure until 1922, when there was cracking on practically all the bridges and some indication that the covering was spalling. It is the opinion of the chief engineer that the trouble was chiefly due to leaking from the top through the failure of the waterproofing. The water had perculated down behind the gunite and frozen there, thus breaking the material loose. It is also his experience that so far as resistance to the action of locomotive exhaust is concerned, there is no material superior to gunite except perhaps heavy plates of cast iron.

Gunite has been used by the Chicago, Milwaukee and St. Paul Railway for the purpose of protecting against the action of locomotive blast. In one case a portion of a structure was covered with gunite without reinforcement and the remainder with gunite with wire mesh. This has been on for a number of years and recent inspections of the work indicate that where proper reinforcement has been placed around the steel before applying the gunite and where the coating has been reasonably thick, it is successfully resisting the action of fumes from locomotives. It also indicates that where gunite is placed without reinforcement, and particularly where the steel work is subjected to deflection, the coating will eventually crack and fall away.

In May, 1920, the Pennsylvania System Central Region did some guniting and repairing on two bridges spanning their tracks at Oil City. Poured concrete had proved to be unsatisfactory in resisting locomotive blasts which were rather severe since the clearances are 16 feet and 18 feet respectively. These blasts and the vibrations due to traffic caused some of the gunite to break off before it had reached final set. The steel, however, was not exposed. No cracks have developed since and the blast of the locomotive is being resisted remarkably well. The same condition obtains on work done in 1919. Recent inspections show the material to be in good condition. No cracks are observed and the gunite is meeting the conditions better than concrete.

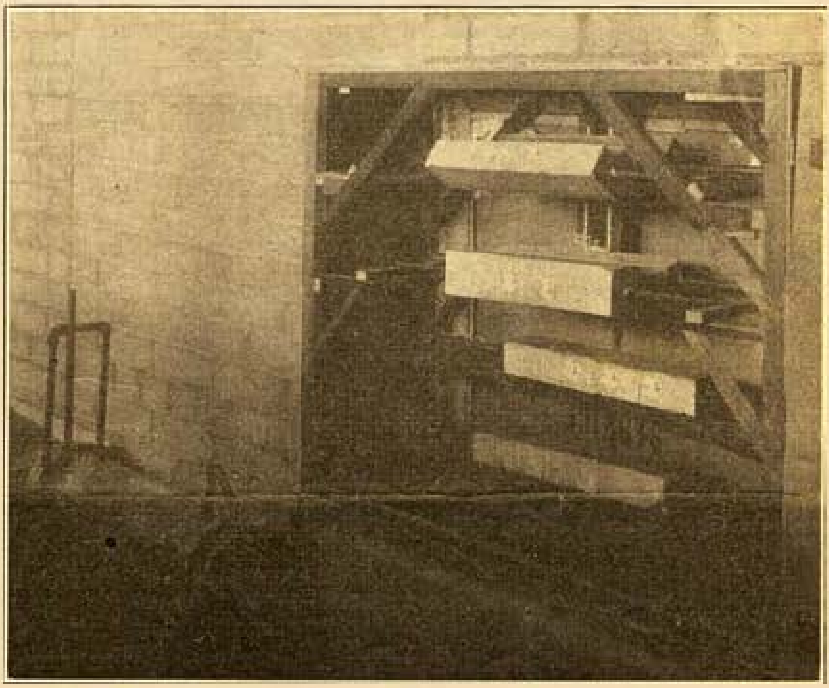

Fig. 7.—Cabinet in Which Corrosion Tests Were Carried On

The Chicago, Rock Island and Pacific Railway did some guniting in 1913 and 1914. The engineering department reports that, from the service obtained during the past seven years, it appears to be a satisfactory protective coating. Some hair line cracks have formed but apparently, through a chemical action, they closed up in a very short time, and although no inspection has been made, it is believed that no action detrimental to the steel has resulted.

The bridge engineer for the Oregon State Highway Commission cites the interesting case of a bridge built over the Williamette River at Oregon City. The location of the bridge is in the immediate vicinity of large industrial plants which employ sulphurous acid as a reagent with the result that at times the atmosphere is more or less densely charged with sulphurous anhydride. Corrosive action in this atmosphere is therefore sensibly stimulated. Part of the bridge was gunited as a protection. The covering was 1½ in. thick and was shot against the steel which was wrapped with triangular mesh. On the arrival of hot weather quite a number of hair cracks developed. None of these are of a serious nature and probably do not extend very far below the surface. The majority of them are craze cracks running in every direction with no regularity whatever. There are, however, a few well-defined radial cracks which are thought to have formed over radial reinforcing rods believed to lie too near the surface.

The Delaware and Hudson Co. has used gunite to protect the steel of roundhouses and it has given better satisfaction than other methods of protection.

The New York Municipal Railway Corporation have used gunite on a portion of their elevated railroad structures and on the girders of their shops in Brooklyn. The work was done in 1918-1920 and up to the present is in perfect condition.

The Hudson and Manhattan Railroad have used gunite for air ducts in the boiler space of the power house, where it is exposed to hot ashes, boiler gases and steam, with entirely satisfactory results.

The following conclusions appear to be warranted in the light of observations covering two years on the Hamilton bridges and nineteen months on the Leaside girders:

Conclusions

In the application of gunite, coarse sand rebounds to a greater extent than fine sand.

Local pockets of unmatrixed sand resulting from inadequate mixing of ingredients in the machine are a cause of rusting on both plates and reinforcement.

Impurities such as clay and loam seem to favor rusting of the imbedded fabric.

The expansion of gunite between the dry and saturation points is about .0002 per lineal unit.

Reinforcing fabric is necessary where steel work is to be protected by gunite. It should be sufficient in amount to enable it to assume, in event of rupture of the gunite, the tensile stresses produced therein by shrinkage.

The reinforcement should be not closer to the plate than ⅜ in. One and one-half inches should be an adequate overall thickness for the covering layer.

Where the fabric is tightly wrapped over stiffeners and the covering thereon is less than ½ in. thick, vertical cracks corresponding to the outstanding leg of the angle tend to develop. These cracks sometimes extend through to the steel angles and in several cases rusting of the reinforcement has occurred. Vertical cracks obviously permit the entry of water more easily than horizontal cracks.

The application of a top or surface coat not adequately bonded to the first favors the formation of surface cracks.

Cracks in gunite at the Leaside girders can be traced only as far as the plane of the reinforcing fabric. The only exceptions to this are in the panel having no reinforcement and on the edges of stiffener angles.

Lean mixtures check less than the rich ones.

Frequently when gunite has been chipped from the centre of a panel, cracks radiating from the opening have been observed to develop in the course of a few weeks following the chipping. This is particularly noticeable where the shell of gunite is very thick. This shows the effect of lack of continuity in the covering envelope.

Widths of cracks in gunite respond more readily to humidity changes than to temperature changes.

A layer of gunite applied to heavily-rusted steel plates resulted in the complete suspension of the rusting process when the plates, together with their covering, were alternately immersed and dried and exposed to severe weather conditions during a period of nearly 12 months. The imbedded fabric was always perfectly preserved.

A humid atmosphere failed to produce rust in three months on bright steel rods covered by one inch of gunite in which cracks .09 in. and narrower had been made. Rust, however, was produced by this same atmosphere in one month on bright-steel rods covered by one inch of hand-placed mortar in which cracks .15 in. and wider had been made. Uncovered steel rusted excessively under these conditions.

Spots of rust on steel cores of hand-made specimens appear to be the result of insufficient puddling of mortar when the specimens were made. It is believed, however, that such rusting soon ceases under the covering shell.

Fabric which had been completely surrounded by gunite was always perfectly preserved against rust.

Where good materials and workmanship are assured, and the weather during application is favorable, gunite properly reinforced is believed to afford a satisfactory protection for steel structures against corrosion.