TESTS FOR CORROSION MADE WITH STEEL MATERIALS SUBJECTED TO VARIOUS CONDITIONS FOR PROTRACTED PERIODS

By

Y. UCHIDA, *Kogakuhakushi*,
Professor of Architecture,
Tokyo Imperial University,

and

M. HAMADA, *Kogakushi*,
Assistant Professor of Architecture,
Tokyo Imperial University.

(*With Plates* I—IX)

ABSTRACT.

This paper, as the title indicates, presents the results of tests that were made for corrosion by means of steel materials subjected to various conditions for long periods of time. The ages of the test-pieces ranged from 15 to 20 years, and the treatment, as well as the conditions to which the steel were subjected, also varied widely in range. The corrosion of steel placed in concrete, which is particularly important, was tested with concrete of various mixtures as well as with protecting concrete of different thicknesses.

CONTENTS.

1. INTRODUCTION.

This report covers the results of two series of experiments made with respect to the corrosion of steel materials, the object being to compare the state and extent of corrosion under various conditions and during protracted periods of time.

The earliest experiments were taken in hand by Professor Sano in October, 1907, on behalf of the Earthquake Investigation Committee, and the changes undergone by the materials during stated intervals carefully noted. The changes that were observed at the end of 2 years and 7 months, together with those at the end of 5 years, have already been made public as reports Nos. 1 and 2 in the Reports of the Imperial Earthquake Investigation Committee, Nos. 74 and 76 (in Japanese), but owing to the circumstance that some of the test materials had been allowed to remain under the same test conditions until December, 1927, that is for a period of 20 years, they were examined again after the lapse of this long period, the results of which form a part of the subject of this paper.

The second experiment, which followed that of Professor Sano above mentioned, was begun in October, 1912, by the senior writer of us, and covered a period of 15 years. It supplements the preceding experiment by Prof. Sano, and the present note being the results of these two series of experiments thus carried out.

Owing to the very long periods of time involved, we believe that the results obtained are of value in connection with the important problem of steel corrosion. Our only regret is that owing to loss of some of the materials which were under test, they were not available for the second experiment, so that our investigation is not so complete as we could have wished.

For the benefit of those to whom our previous reports as above mentioned are inaccesible, we have included in the present paper a resume of their main results in order to avoid any discontinuity in the discussion as a whole.

2. RESULTS OF EXPERIMENT SERIES I.

These tests were made for the purpose of studying corrosion with respect to the following subjects :

A. Changes in the steel materials according to manner of use.
B. Changes in the steel materials of different thicknesses.
C. Value of preservative coatings on steel materials exposed to the atmosphere.
D. Changes in the steel material embedded in concrete as well as in its preservative coatings.
E. Changes in the steel materials embedded in concrete of various compositions.
F. Changes in the steel materials embedded in concrete of different thicknesses.

Excepting for B, the material tested upon was a $\frac{3}{4}''$ round mild steel bar made into tension test-pieces of 15″ length, and turned down at the middle for a length of 9″ to a diameter of $\frac{1}{2}''$: its mean tensile strength being 4200 kg/cm^2 and elongation 22.2%.

A. Changes in the steel materials according to manner of use. The $\frac{1}{2}''$ round test-pieces, polished, but without application of any paint or preservative coating, were placed in the following situations :—

(a) Indoors.
(b) Outdoors.
(c) Underground.
(d) Under water in a pond.
(e) Inside a brick block.
(f) Inside a block of concrete.

and the effects of corrosion noted. It is however to be regretted that the test-pieces for (a), (c) and (d) were lost, so that they were not available for the last observation made after 20 years. The results of all tests, with these exceptions, have been tabulated to enable ready comparison in Table I annexed.

Table I. Effects of Rust on Steel Materials according to Manner of Use.

Situation of test-piece	Details	Results		
		1st exam' after lapse of 2 years & 7 months	2nd exam' after lapse of 5 years	3rd exam' made after lapse of 20 years, or 15 years after the 2nd exam'
(a) Indoors	Air exposed in the model room of dep't of Architecture.	Only about 10% of the surface rusted.	About 50% of the surface rusted.	Test-piece lost; no exam'.
(b) Outdoors	Air exposed in a dry area by the old main Engineering building.	Scaly rust peeling off like bark of old pine tree. Complete removal of rust caused loss of 9% of original weight.	Appearance much as in 1st exam', but rust greatly advanced. Removal caused 27% loss of weight.	Externally as in preceding column, but extent of rust remarkably advanced. Removal caused 70% loss of weight.
(c) Underground	In red earth outside of above building.	Covered with a mixture of soil and rust, to remove which caused loss in weight of 1.7%.	Rust increased, to remove which caused loss of 3% of weight.	Test-piece lost; no exam'.
(d) Under water	In a pond in the university compound.	Only a thin rust film formed on the surface	Surface pitted here and there with rust. Removal caused 2.9% loss of weight.	do.
(e) Inside a brick block	Test-piece placed in the center of a brick block of one brick square (9″ square), and built up 2 ft high. Exposed in the open.	About 2/3rds of entire surface was covered with irregular patches of rust.	Nearly 4/5ths of entire surface covered with patches of red and black rust.	Entire surface covered with red and black rust, to remove which caused loss in weight of 2%.
(f) In a block of concrete	Embedded in a block of concrete of mixture 1:3:6 and 6″ × 6″ × 24″. Exposed in the open.	In perfect condition.	In perfect condition, retaining its original polish, except at places where owing to bad workmanship they were not airtight.	As in preceding column.
	REMARKS—	The steel preserved in concrete showed least corrosion. It seemed to be difficult to obtain same good results in brick column. Corrosion was most marked on piece left outdoors; less so embedded in earth or kept under water.	The test-pieces embedded in concrete preserved its original condition All other situations showed gradual advance of corrosion as noted in the preceding column.	Except for places where, owing to faulty workmanship, they were not air-tight, the excellent preservative properties of concrete were indeed astonishing.

B. Changes in the Steel Materials of Different Thicknesses. Round mild steel bars of the following diameters were left in the open, exposed to the atmosphere in a dry area by the old main Engineering building of the Imperial University, Tokyo, and the effects of rust carefully noted. The steel bars were all in the form of tension test-pieces of the following diameters at the middle:—

1/8, 1/4, 3/8, 1/2, 3/4 and 1 inch.

In the present examination bars of 3/8″ and smaller were found to be entirely changed into rust. The others did not differ much from the appearances recorded in previous reports, but the rust had penetrated the surface to such an extent that it could be peeled off in scales. Detaching them by gentle tapping exposed the pitted black surface, which upon being scratched by a knife soon revealed the bright surface. After the scales were thoroughly scraped off, the bars were weighed with results as shown in annexed Table II. Photo 1 shows the appearance of the bars before and after the rust was removed.

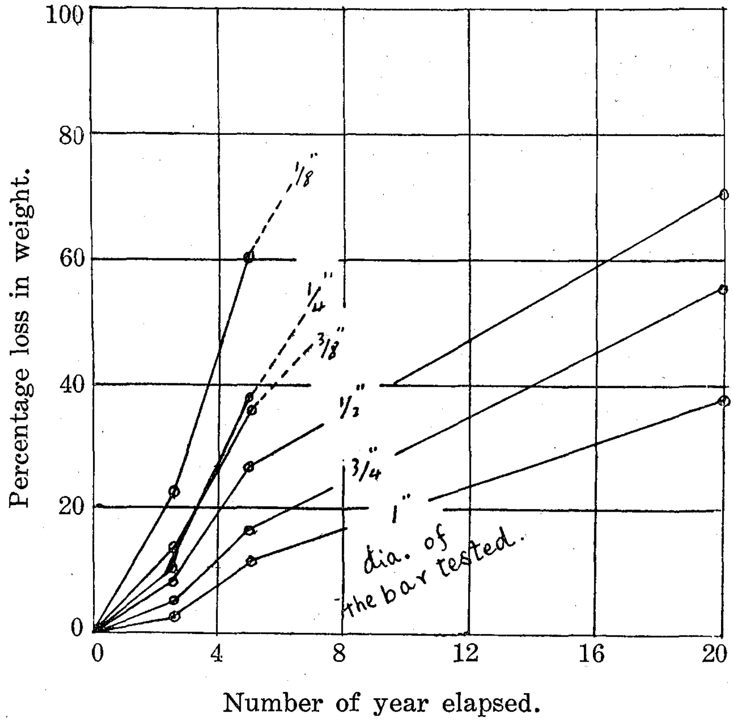
Table II.

Diameter	1/8″	1/4″	3/8″	1/2″	3/4″	1″	
Original weight of bars*	48.5	136	275	552	1077	1782	grammes.
Weights after removal of rust. Average weight of 3 bars.	0	0	0	160	580	1115	grammes.
Loss in weight	48.5	136	275	302	497	667	do.
Percentage of loss	100	100	100	71	46.1	37.2	

*These are the average weights used in the two previous reports. To consider these as the original weights of the bars in the present experiment is not quite in order, but unavoidable, owing to loss of the original records relating to the weights of the test-pieces used in the present experiments. As however the bars were polished bright we believe that the error is so slight as to be quite negligible.

The combined results of experiments B, that is the relation of the thickness of the bars to the extent of rust after periods of 2 years & 7 months, 5 years, and 20 years give curves as in the following diagram.

Fig. 1. Change in the Steel Materials of Different Thicknesses.



From the foregoing curves it is apparent that weight loss due to rust increases proportionately as the diameter of the bar diminishes, which will be obvious from the fact that as the diameter decreases, the surface area per unit volume increases with every decrease of diameter, so that the weight loss becomes proportionately greater. On this reasoning then the rate of weight loss for the same bar ought to accelerate with time, but results of our experiments do not bear this out, for on referring to the preceding figure it will be seen that the proportion of the rate of loss in the 3rd test when compared with that of the 2nd test has slightly decreased. This may be due to the protective action of the already existing rust layer against too rapid encroachment of further corrosion.

C. Value of Preservative Coatings on Steel Materials Exposed to the Atmosphere. The following five tests were made to determine the extent of rust on bars coated with paint and other preserving agents.

(g) Steel bar in the original state without any preservative coating.

(h) Steel bar polished and coated with red lead.

Table III. The Effects of Rust on Steel Materials Coated with Preserving Agents.

Test-pieces	Remarks	Results of Tests		
		1st exam' after lapse of 2 years and 7 months	2nd exam' after total lapse of 5 years	3rd exam' after total lapse of 20 years
(g) Naked state; no coating of any kind.	Bars were slightly spotted initially in places with red rust, but practically in good condition.	Growth of rust scales resembling old pine bark. Removal caused loss in weight of 9% of original weight.	Appearance as in preceding column. Weight loss 27%.	Appearance as in preceding column. Weight loss 71%.
(h) Polished and given a red lead coating.	Cleaned of rust and given two coatings of red lead.	Surface dark brown with dirt. When washed off the reddish coloured lead film, steel surface showed no changes, proving efficacy of red lead coating.	Minute spots of red rust here and there, showing that life of the protective coating had terminated.	Covered with black spots which on being washed off showed coating sound in places. Where sound the redlead was visible, but otherwise pitted and coating vanished. Weight loss 9%.
(i) Coated with cement paste.	Thickness of the pure cement paste was 3.5 mm.		Cement cracked in places parallel to direction of bar, and the portion of the bar near these cracks was rusted but in perfect condition otherwise. Hence while cement paste is a good preservative, liability to cracks curtails its usefulness.	General appearance as in preceding column, but now even at places free from cracks rust had invaded, leaving only a few bright spots on the bar. Weight loss about 9%.
(j) Coated with coal tar.	Dipped in coal-tar.	No preservative effect whatsoever. Condition practically same as that of naked bar in (g).	Outward appearance not differing materially from that of naked unpainted bar, top of this column, although weight loss here was small only about 10%.	Outward appearance much like that shown by naked bar (top of this column). Weight loss about 50%.
(k) Already rusted slightly; coated with red lead.	On the already slightly rusted test-pieces were given two coatings of red lead.	Same result as for (h).	Same result generally as (h), second in this column, but extent of rust somewhat greater.	Same result generally as in (h) but rust greater. Weight loss about 20%.

(i) Steel bar coated with cement paste.
(j) Steel bar coated with coal tar.
(k) Steel bar, slightly rusted, coated with red lead.

The general results of the examination of these tests showed that with the two previous tests, the one made after a lapse of 2 years and 7 months, and the other after 5 years, no striking changes were noticeable beyond the fact that rust had made considerable inroads on the materials. Table III annexed gives comparative results in detail of the tests made after the three time intervals mentioned. Photo 2 shows the appearances of the bar tested.

According to these results, within the limits of our experiments, red lead has proved to be the best preservative against rust but scarcely for longer period than 5 years. The value of coal-tar in these respects is exceedingly small. Cement paste is quite effective so long as cracks do not appear in the coating but as this is liable to happen with time, it cannot be depended upon.

D. Changes in the Steel Material Embedded in Concrete and also in its Preservative Coatings. In these experiments test-pieces of round mild steel bars, $\frac{1}{2}''$ dia., in conditions (l) to (p) as below were embedded in concrete blocks of composition 1:3:6, the size of the blocks being $6'' \times 6'' \times 24,''$ the whole left in the open in a dry area by the old main Engineering building of the University.

(l) Steel bar with rust scraped off.
(m) Steel bar in slightly rusted condition.
(n) Steel bar with rust scraped off and coated with red lead.
(o) Steel bar dipped in coal-tar.
(p) Steel bar coated with cement paste.

The results of these experiments, (p) excepted, were as follows:—

In (l) and (m) where the bars received no coating of any kind, preservation from rust was complete with, however, the exception of slight red spots at places where the embedding work was not carefully executed. In (n) where the bar was coated with red lead, preservation was still more complete than in (l) and (m), but the red lead film had changed to powder so that there was no contact between steel and concrete, thus showing that where steel and concrete must be used together for mutual benefit as in reinforced concrete and in steel frame concrete, the use of red lead upon steel must be prohibited. In (o) the surface of the steel was in perfect condition, but the coal-tar film had , as in the case of (n), become powdery. In this case, however, the contact between steel and concrete was closer than was the case with (n).

E. Changes in the Steel Materials Embedded in Concrete of Various Compositions. In this experiment $\frac{1}{2}''$ round test bars were embedded in concrete of various compositions in order to determine the relation of the corrosion of the steel to the particular kind of concrete employed. The concrete blocks were in every case $6'' \times 6'' \times 24''$. The mixtures stated on a volume basis were as follows:—

No. of Mixture	Cement	Volcanic ash	Lime	Sand	Gravel	Cinders
1	1			1	2	
2	1			2	4	
3	1			3	6	
4	1			5	10	
5	1		2	4	8	
6	1			2		4
7	1	1	0.25	4.5	9	

This report concerns only mixtures No. 1 to No. 6 inclusive.

These mixtures were all used in dry consistency. In the examinations made after 5 years no changes were observed in the case of mixtures 1 to 5 and 7, with a few exception of slight red spots at places where the concrete was honey combing. In the present examination made after a total lapse of 20 years, the test pieces in mixtures 1 to 3 were in sound condition, so that the preservative action of the concrete was all that could be desired. In the case of mixture 4, however, about 30%, and in the case of 5, about 10%, of the surface was covered with rust. These were due, it seems, to the concrete mixture having consisted either of improper ingredients, or in undesirable proportions, or both, resulting in air spaces in the mixture. Even in these, where the cement paste had filled every interstice, the steel bar was perfectly preserved. Again, even in the case of the first three mixtures where faulty workmanship had permitted air spaces to extend to the surface of the steel, red rust was present. Although mixture 6, the one in which cinders were used, showed considerable rust on the steel when examined after 5 years time, in the present examination 15 years later, the corrosion had reached astounding proportions, covering the entire surface of the bar, to remove which caused a weight loss of 6%. See photograph 3.

F. Changes in the Steel Materials Embedded in Concrete of Various Thicknesses. These experiments were conducted with the object of finding the extent of corrosion of steel bars embedded in concrete blocks of various sizes. The test pieces were round mild steel bars of $\frac{1}{2}''$ dia., which after having been embedded in concrete blocks of the four undermentioned sizes, were left in the open, exposed to the air outside of the old main Engineering building of the Imperial University, Tokyo.

Block	No. 1.	$2''\frac{2}{5}$ ×	$2''\frac{2}{5}$ ×	24″
,,	No. 2.	6″ ×	6″ ×	24″
,,	No. 3.	12″ ×	12″ ×	24″
,,	No. 4.	24″ ×	24″ ×	36″

The present examination covers only blocks 1, 2, and 4. When these were examined after a lapse of 5 years, all of them, excepting those in which the embedding was faultily executed, were found to be in a state of perfect preservation. In the present examination, that is 15 years later, or a total period of 20 years, those blocks in which the embedding was faulty showed great inroads of rust. Where the concrete was not very thick, as in the $2''\frac{2}{5} \times 2''\frac{2}{5} \times 24''$ block, the bar was quite rusted and expansion had caused longitudinal cracks in the concrete along the reinforcement as shown in photo. No. 4. The reinforcement of the 6″ × 6″ block was unaffected. Lastly on examining the 24″ block, we found things in a state other than we had expected, the extent of rust covering about 10% of the entire surface. The cause of this rust was found to be due to interstices that had been allowed to form in the process of placing concrete, thus permitting the surface of the steel to come in contact with the air.

3. RESULTS OF EXPERIMENT SERIES II.

The object of these experiments was to study the extent of corrosion of steel embedded in concrete, and they therefore supplement experiment series I reported in the foregoing pages. Particular attention was paid to the relation of corrosion to the manner of workmanship, that is in the reinforcing.

In the first series of experiments the mixture of the concrete was 1:3:6, but the proportion in the present case was 1:2:4, and, owing to the superiority of the latter coupled with the special care used in reinforcing so as to secure airtightness, not the slightest signs of honey combing could be detected, thus showing that the test was made under ideal conditions. In these respects our experiments series I were not satisfactory, since, as already stated, the reinforcements in favourable cases were sound, whilst in others where they were not airtight, rust had attacked the steel. The present series of experiments were quite free from such defects in workmanship.

The concrete used was of the ratio 1:2:4 and three kinds of aggregates were used, thus

(a) Ordinary gravel.
(b) Brick fragments.
(c) Cinders.

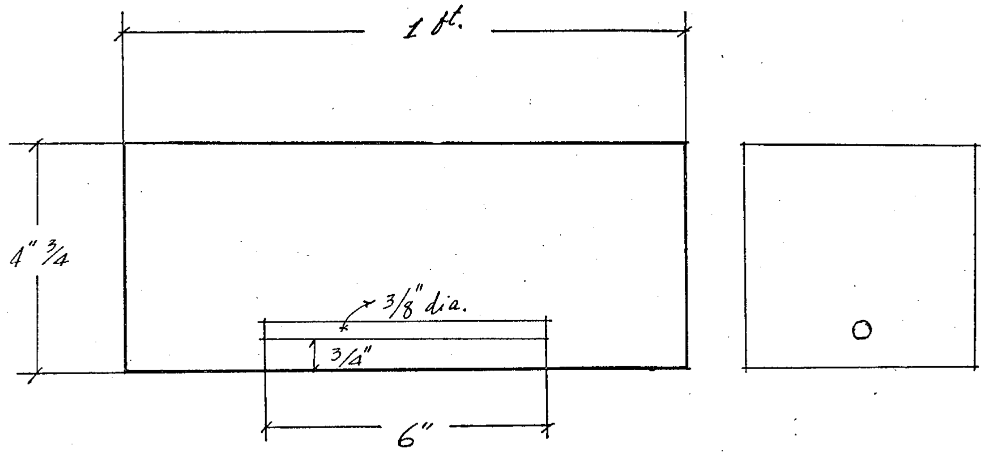


Fig. 2. Size of Test-piece of Expt. Series II.

These were made into blocks of shape shown in Fig. 2 and into each of which round mild steel bars of 3/8″ dia. were inserted. The bars were different to those used for experiment series I in that these were ordinary rolled bars, neither turned nor filed, being the ordinary rolled bars with the "roll skins" on them. The reinforced blocks were then placed in the following situations,

(1) In the open.
(2) Underground.
(3) Under water.

Unfortunately, however, (2) and (3) were lost so that our investigation is confined to the block which was placed in the open.

On breaking then the three concrete blocks (a), (b), and (c) which had been left in the open for 15 years, the reinforcements were found to be quite intact, just as they were on the day they were placed in the concrete: an eloquent testimony to the good workmanship.

In contrast to the very poor results shown by the cinder-concrete in experiment series I, the tests in the present case gave very good results, because, in addition to the reasons already given, the cinders used this time were carefully selected and then washed with water. It would seem that omission of these precautions had much to do with the poor results of the previous experiments. By washing, all acidity had been removed from the cinders and as the fine particles had also been eliminated, the concrete was made compact. Thus we know even in the case of aggregates consisting of cinder as well as of brick fragments, the reinforcement will remain its original appearance even after a lapse of this long time of test, *provided the quality of the aggregates and the mode of treatment has been proper.*

4. CONCLUDING REMARKS.

These experiments having been devised and initiated as far back as 15 to 20 years ago, we are not altogether without some misgivings as to the propriety of the methods employed by us in attacking the problem. On the other hand we are conscious that the very general nature of our methods enables application of the results obtained to general present day problems. We shall now state our conclusions on the results of our observations.

A. That steel left in the open exposed to air will soon rust is too well-known to need repetition, but our researches have thrown some light on the way in which the action takes place. Rust, at all events, never attacks steel in an even manner over the surface, but gradually pits the surface so that it is no more even but full of little elevations and depressions.

To ascertain the rate of advance of this rusting process the surface of a round bar of, say, 1″ section was assumed to be a flat surface and the thickness of the rust film was calculated from the extent of rust undergone in the 20 years, when it was found that the average rust per annum worked out to a thickness of 0.15 mm. Bars of 3/8″ and smaller had in this long period rusted right through with no more steel left. From these examples it will be possible to work out the rate of time taken by rust to reach a certain stage.

B. In the matter of preservative coatings, as far as our experiments went, red lead has proved to be the most efficaceous, although, prior to its application the surface to receive the coating must be thoroughly cleansed of any rust already existing. With our tests its life was 5 years, but with the great improvements since then in the paint manufacturing industry, and with reasonable care exercised in its application, a longer lease of life may be expected.

The efficacy of coal-tar for any length of time is not to be expected. Cement paste is a good preservative, provided the paste is applied in such a manner as to render it airtight, but owing to its liability to crack and permit air to reach the steel surface, it cannot be depended upon for any length of time.

C. In the process of reinforcing the steel must on no account be coated with red lead and such, because they interfere with the desired adhesion of the steel to the concrete matrix.

D. To preserve steel material encased in brick masonry from rusting is extremely difficult.

E. The changes suffered by steel reinforcements in the concrete is an important matter in structural engineering practice. The prevailing opinion seems to be that steel in a concrete matrix is immune from rust. At the time these experiments were initiated the question to us was one of general doubt, but thanks to the tests, some doubtful points have been cleared. The marvellous protective properties of concrete were amply demonstrated. Even with an inferior mixture like 1:3:6, so long as the workmanship was done properly, the steel retained its original lustre until the end of this long period of time, so that with concrete of 1:2:4 and due care exercised to ensure good workmanship, excellent results were obtained as above recorded.

At the same time too implicit faith in the preservative properties of concrete ought to be guarded against. Generally speaking, the chemically neutral state and acidity are both conducive to rust development, while alkalinity has the very reverse tendency. Cement on dissolving in water liberates a large quantity of calcium hydroxide, making the concrete partake of a strongly alkaline character. It is this calcium hydroxide that is the fundamental rust preventative, but with prolonged exposure of the concrete to the atmosphere, the calcium hydroxide changes by the action of the carbon dioxide in the atmosphere to calcium carbonate, the change working by stages into the interior of the concrete. Upon now breaking up any of these blocks and dropping on to the section some Phenolphthalein solution the central part assumes a deep red colour which, however, does not extend right up to the margin of the fractured surface, a proof that the concrete is losing its alkalinity from the central part towards the margin.

Photos No. 6, 7, 8 and 9 show sections of concrete in the manner just mentioned. They are the concrete blocks of different compositions alluded to in paragraph D, experiments series I. For these sections the parts showing good workmanship in reinforcing were selected. The thickness of such parts as alter to carbonate will obviously depend on the original concentration of the cement paste so that considerable variation in the extent to which the change takes place must be expected according to the composition of the concrete. In this experiment the mean thickness of the carbonated portion in accordance with the composition of the concrete mixture is shown in the table which follows.

Table IV. Depths to which the concrete lost its alkalinity. Age of material 20 years.

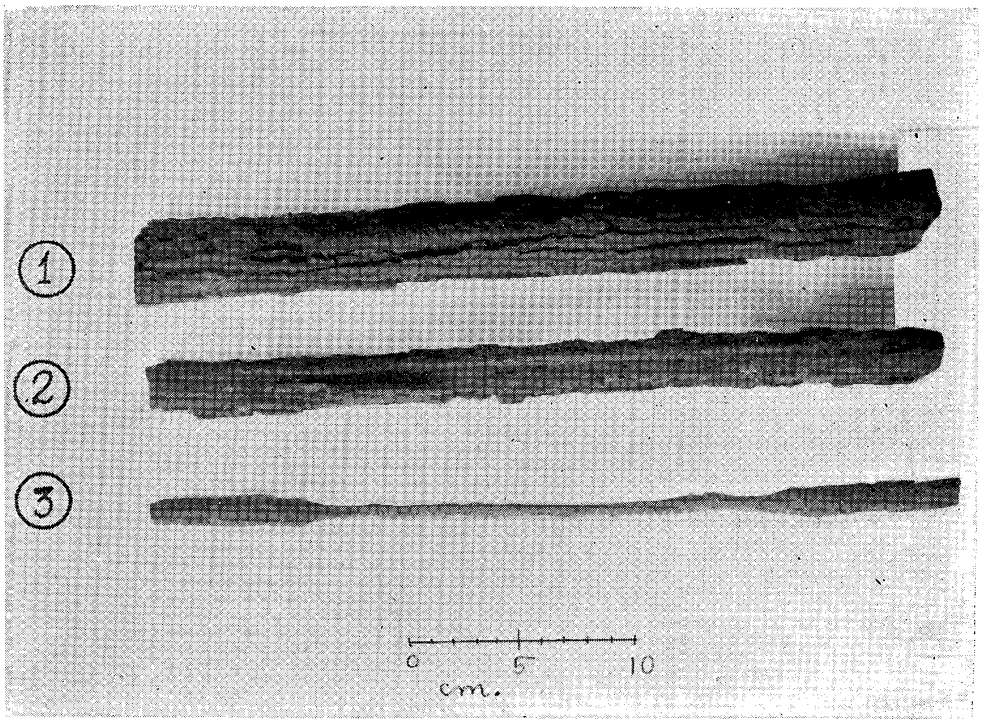
Composition of concrete	Thickness of part neutralized	Remarks
1:1: 2	0.65 cm.	Owing to loss of the detailed records covering the concrete, it is not possible to know the exact water-cement ratio or other data.
1:2: 4	1.39	
1:3: 6	3.33	
1:5:10	4.32	

The alkalinity of the concrete gradually disappears in the manner above shown. According to our observations, such parts of the reinforcements that were invariably rusted showed that the concrete in contact with it had already lost its alkalinity, whereas the concrete matrix surrounding such parts of the steel as retained its original brightness, was still alkaline. On the whole, even in blocks where the central portion was still alkaline, at places where air had penetrated deeply through interstices in the matrix, neutralizing of the concrete had advanced so that that parts of the steel surface in contact with it were bound to be rusted. This was frequently noticed in our first series of experiments, which as we have explained before, was due to unsuitable concrete mixtures and to faulty reinforcing.

F. On examining the effects in concretes where light aggregates were used, results were very unsatisfactory as in the case of the cinder concrete of experiment series I; the steel in most cases being completely rusted. This is because the cinder was not thoroughly washed before use, consequently holding small ash particles, resulting in more or less porosity of the concrete. Acidic components in the cinders also contributed their quota of deleterious effects. In the cinder-concrete that was used for the first series hardly any part of it showed alkaline reaction with phenolphthalein, whereas the cinder concrete used in the second series gave excellent results, due, apparently to previous washing of the cinders. In this concrete, while such parts of it as consisted mainly of aggregates were porous, the mortared parts were compact which accounts for the good results.

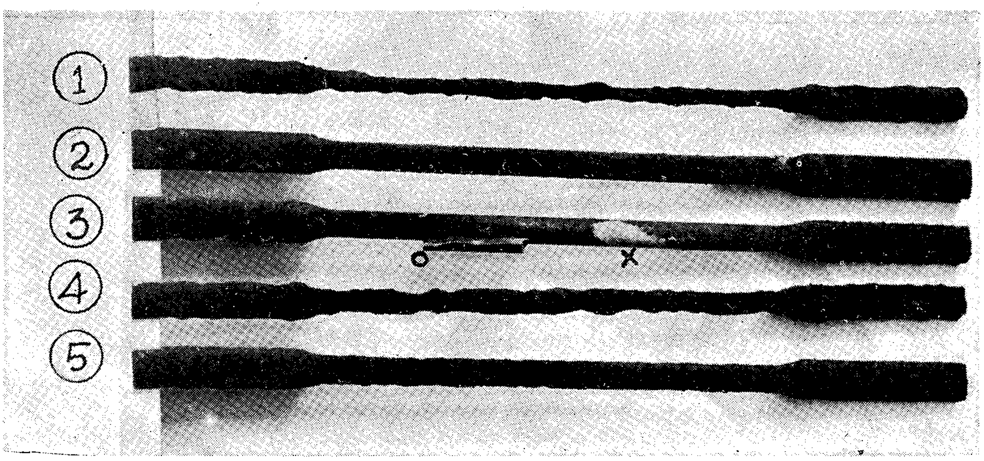
The brick fragment concrete used in series II also gave excellent results. On testing the fractured surfaces of these with phenolphthalein the depth of the neutral portion was found to be very small as shown in photos No. 10 and 11.

Photo. 1. Size of steel material versus rust.



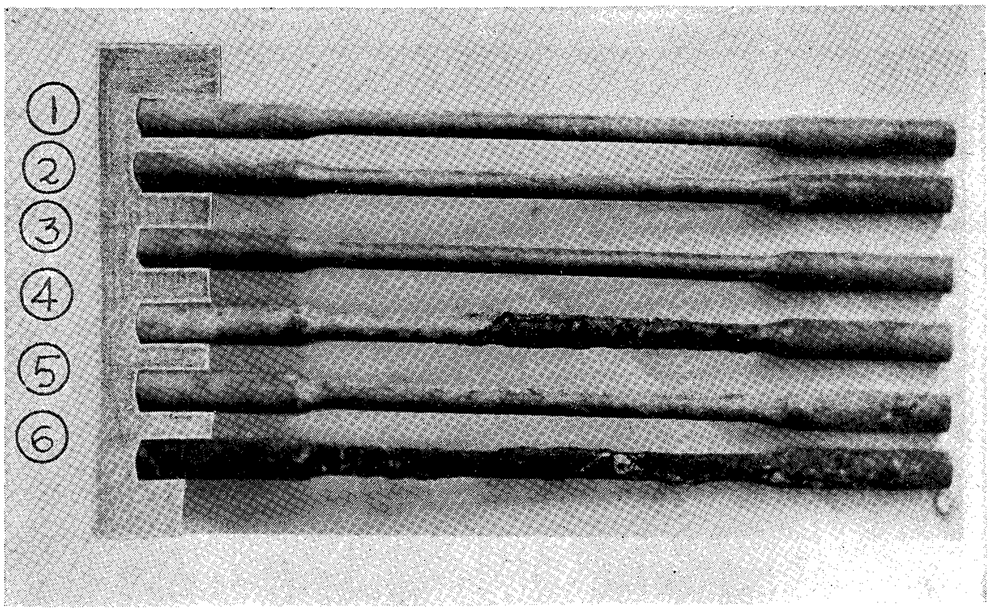
(1) Appearance of steel bar 1″ dia. left exposed in the open for 20 years showing the old pine-bark like rust scales.
(2) do. but 3/4″ dia. Some of the rust scales detached.
(3) do. but ½″ dia. All the rust scales scraped away.

Photo. 2. Changes in the steel materials coated with preserving agents and exposed to the atmosphere.



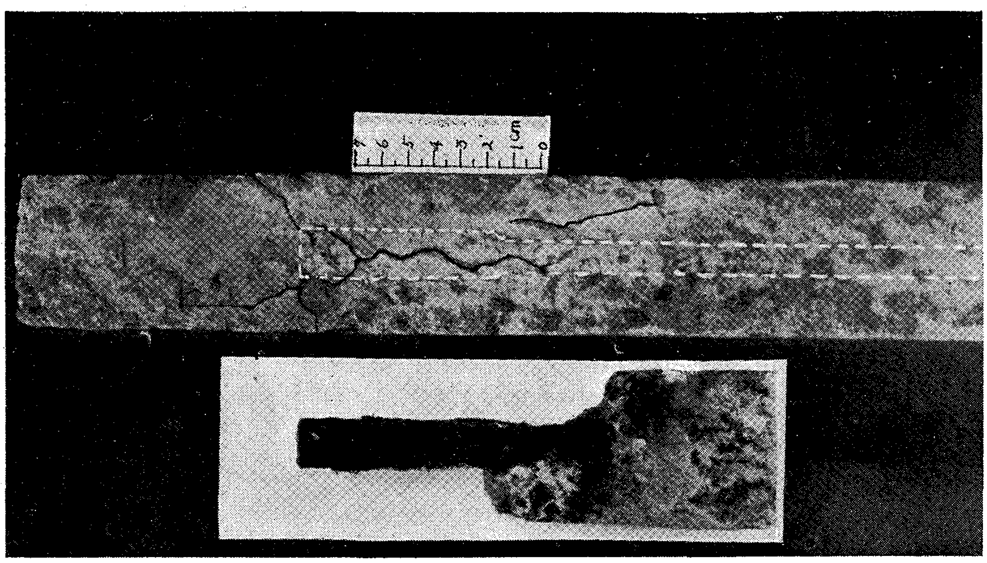
(1) Steel bar ½″ dia. without any preservative coating, exposed in the open for 20 years. Rust scales scraped away.
(2) do. but this bar was originally polished and coated with redlead.
(3) do. do. do. do. coated with cement paste. (○) shows a bit of the cement film, the rest of it having been scraped away. At (×) the film was adhering firmly to the steel, which on removal shows the bright steel surface.
(4) This bar had been dipped in coal-tar.
(5) This bar was already rusted slightly over which coatings of red lead were given.

Photo. 3. The nature of the concrete versus rust.



(1) Steel bar, $\frac{1}{2}''$ round, that had been embedded in concrete 1:3:6 block $6'' \times 6''$ and left in the open for 20 years.
(2) do. but concrete (1:2:4)
(3) ,, ,, (1:3:6)
(4) ,, ,, (1:5:10)
(5) ,, ,, (1:2 lime:4:8)
(6) ,, ,, (1:2:4 cinder)

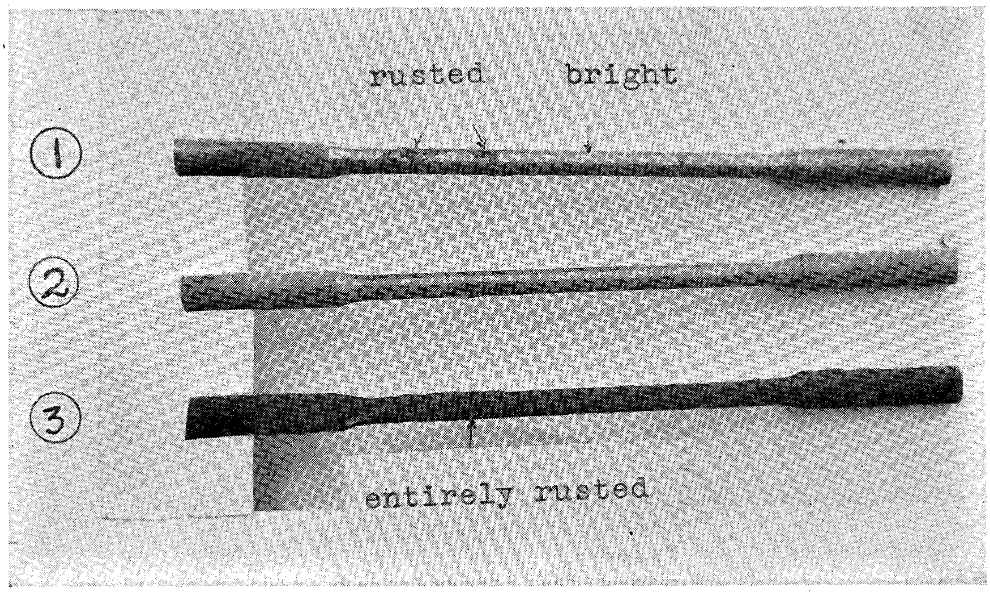
Photo. 4. Cracks in concrete caused by rusting of steel.



Above. Appearance of concrete block (1:3:6), $2''2/5 \times 2''2/5$, in which a steel bar of $\frac{1}{2}''$ dia. was embedded and then left in the open for 20 years. White broken lines indicate position of the steel reinforcement. Note cracks in the concrete.

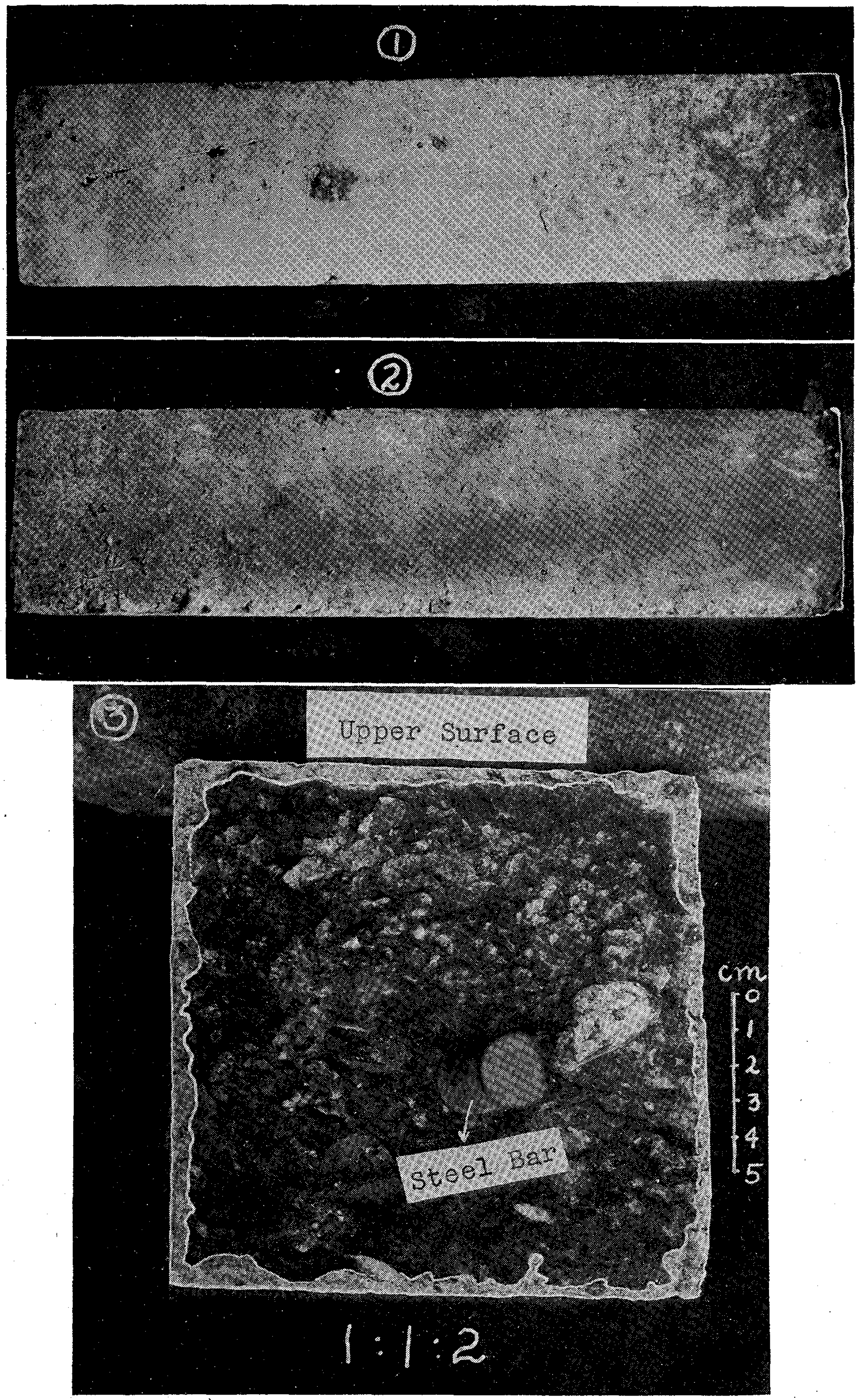
Below. As above. Part of the top concrete removed. The steel bar was quite rusted.

Photo. 5. Thickness of the concrete versus rust.



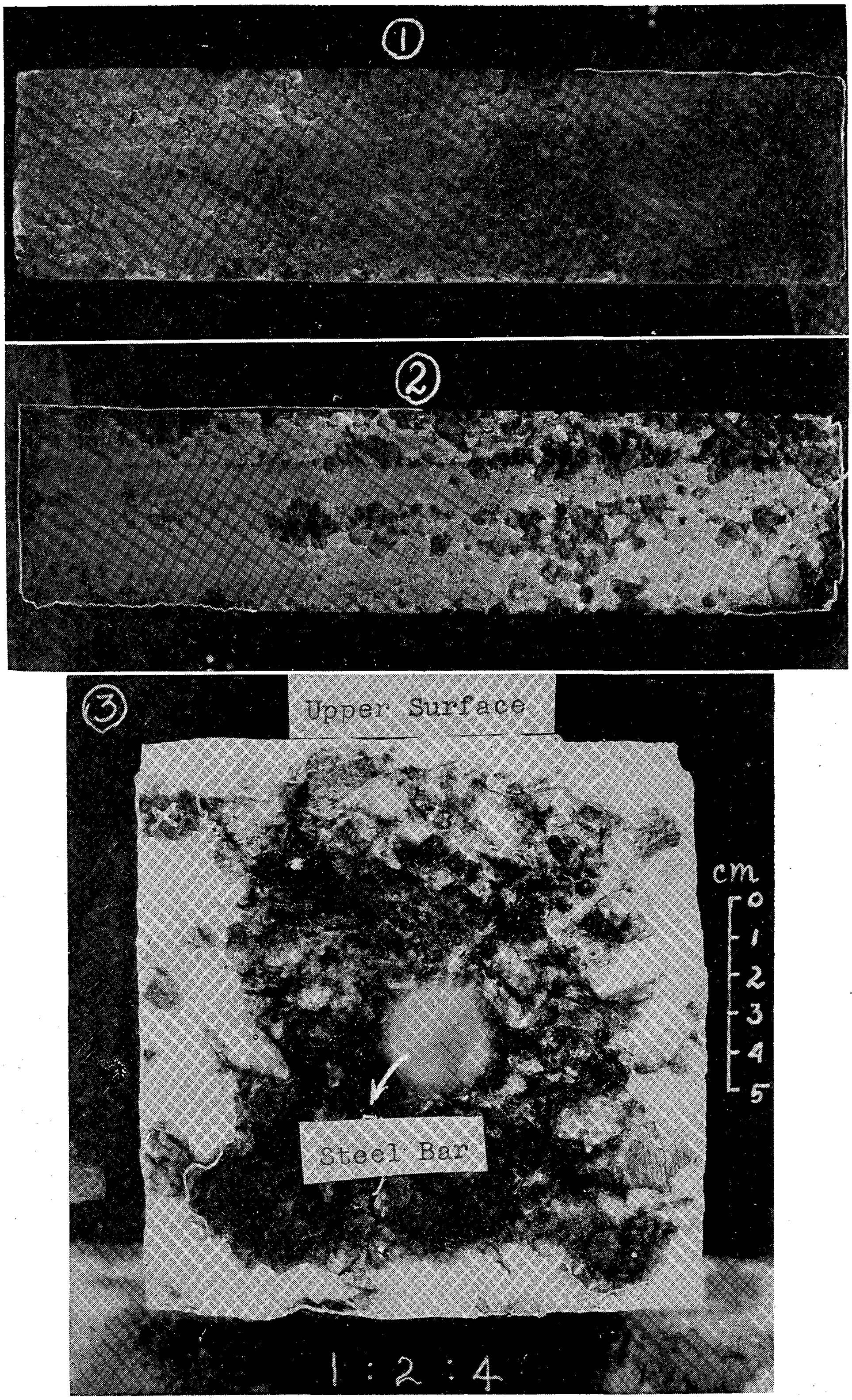
(1) Mild steel bar, ½″ round, which was embedded in concrete block (1:3:6) 24″ square, and left exposed in the open for 20 years.
(2) do. but size of block 6″×6″.
(3) ,, ,, ,, ,, 2″2/5×2″2/5 (entirely rusted).
Dark portions are rusted while fair parts are bright.

Photo. 6. Disappearance of alkalinity in concrete of mixture 1:1:2.



Concrete block (1:1:2), 6″×6″, left in the open for 20 years.
(1) Upper surface at time of tamping.
(2) Side do. do. do.
(3) Phenolphthalein applied to surface of section. Discoloured part shown off by white boundary lines. Aggregates are crossed where line is broken.

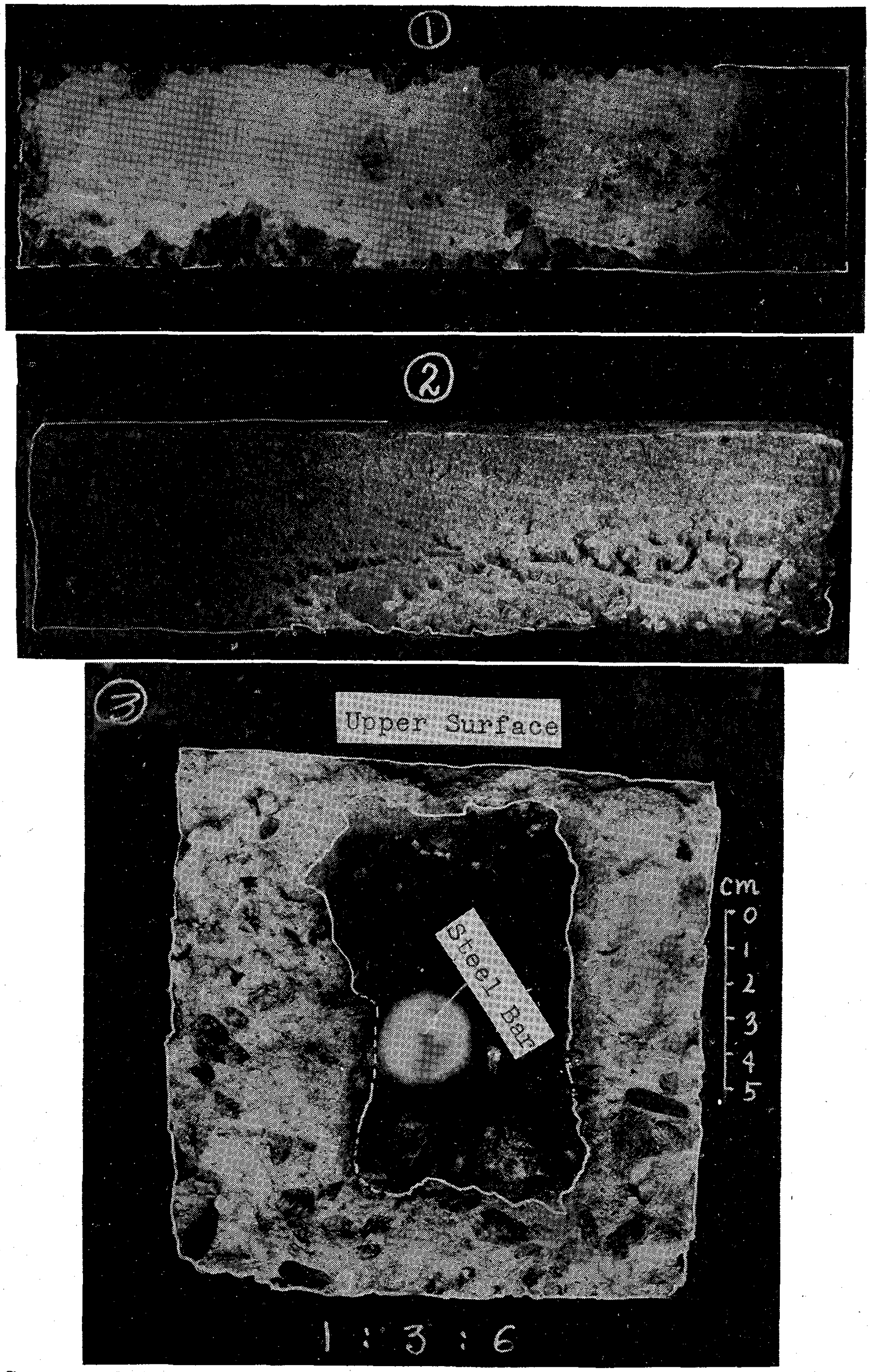
Photo. 7. Disappearance of alkalinity in concrete 1:2:4.



Concrete block (1:2:4), 6″×6″, left in the open for 20 years.
(1) Side surface at time of tamping.
(2) Bottom do. do.
(3) Phenolphthalein applied to surface of section. White lines to mark off the discoloured boundary. Aggregates are crossed where line is broken. Cross (×) shows aggregate and is not portion coloured by phenolphthalein.

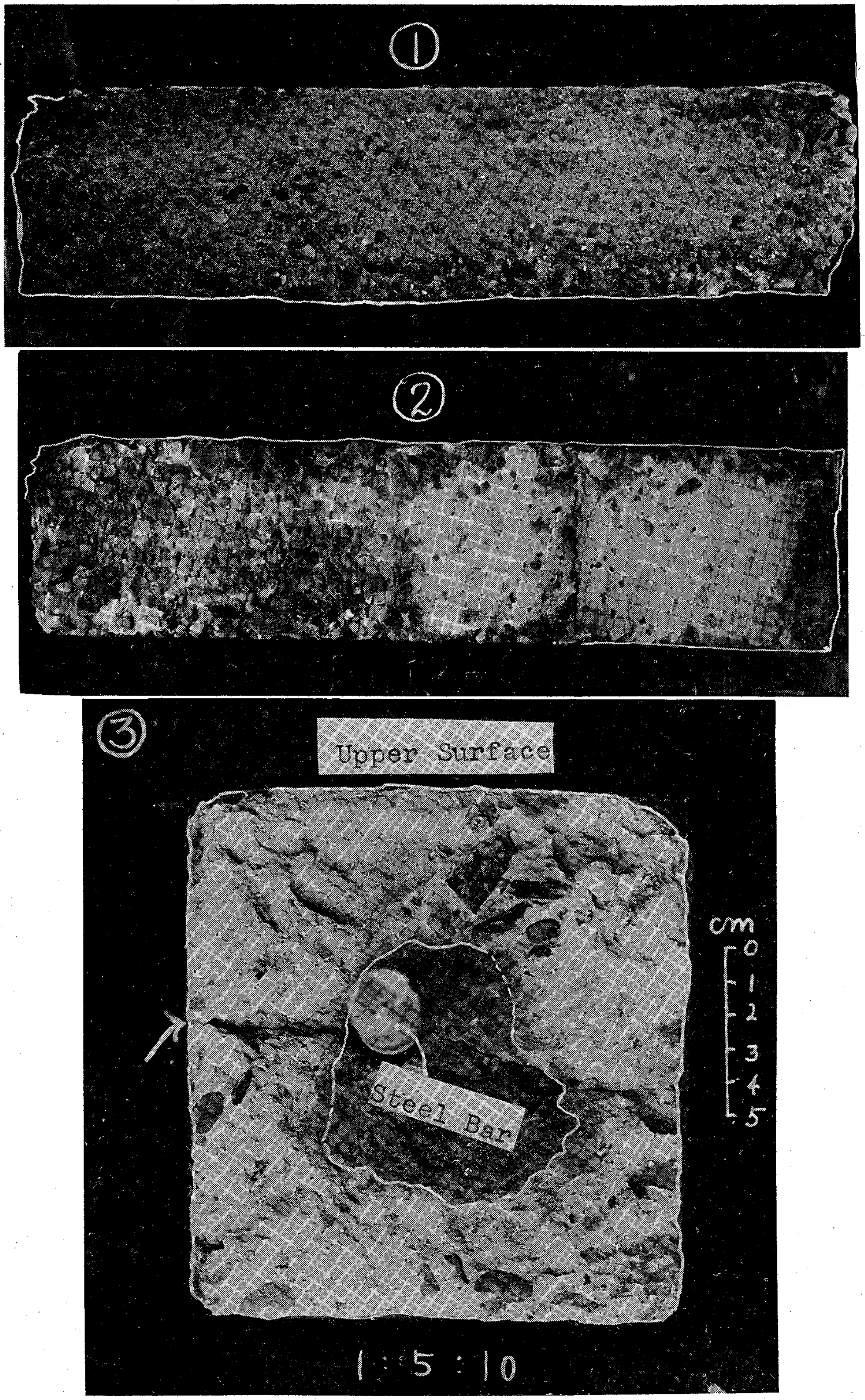
Pl. VI.

Photo. 8. Disappearance of alkalinity in concrete 1:3:6.



Concrete block (1:3:6), 6″×6″, left in the open for 20 years.
(1) Bottom surface at time of tamping.
(2) Side do. do.
(3) Phenolphthalein applied to surface of section. White lines to mark off discoloured boundary. Aggregates are crossed where line is broken.

Photo. 9. Disappearance of alkalinity in concrete 1:5:10.



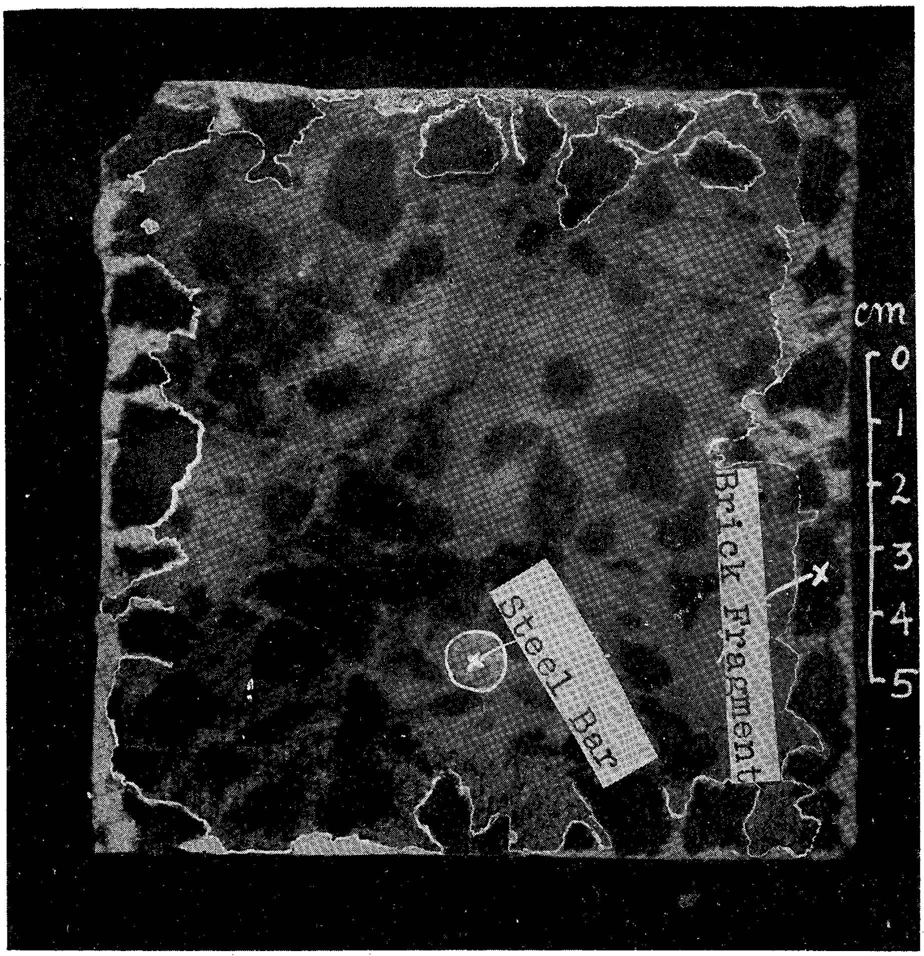
Concrete block (1:5:10), 6″×6″, left in the open for 20 years.

(1) Side surface at time of tamping.

(2) Bottom do. do.

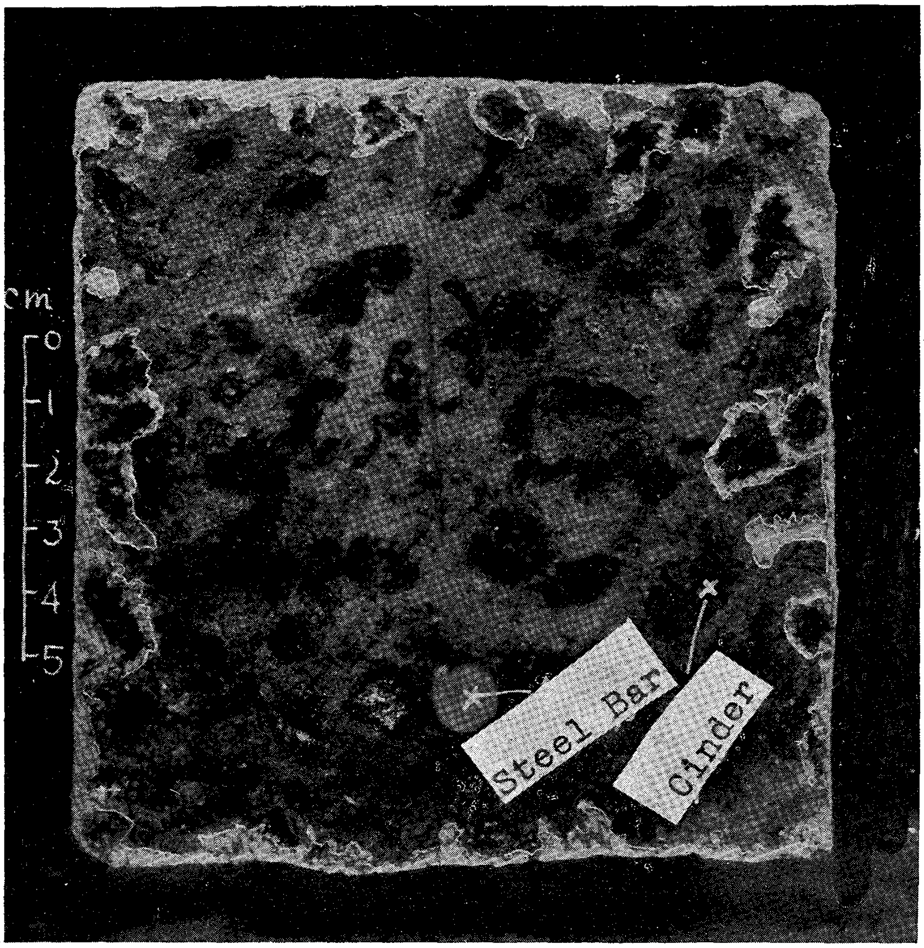
(3) Phenolphthalein applied to surface of section. White line to mark off discoloured boundary. Aggregates were crossed where line is broken. Arrow indicates where crack occurred when section was being cut.

Photo. 10. Brick-fragment concrete.



Effect of phenolphthalein solution on surface of freshly cut section of brick-fragment concrete block (1:2:4), 4″3/4×4″3/4 left in the open for 15 years. Note that the white line has penetrated deeply only along the brick-fragments found near the surface.

Photo. 11. Cinder-concrete.



Effect of phenolphthalein solution dropped on to fresh surface of section of cinder-concrete block (1:2:4), 4″3/4×4″3/4, which was left in the open for 15 years. Note that the white line has penetrated deeply only along the cinder found near the surface.