PAPER No. 82.

Notes on the rusting of steel in contact with lime mortar.

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The object of this paper is to show that, on account of the liability of rust to set in it is doubtful construction to put steel in contact with lime mortar, particularly where water may reach the steel.

Examples will be given where rusting has occurred and others where the steel has not been affected.

Before giving instances which have come directly under the author's observation, experience in the United Provinces and in the Bombay Presidency will be briefly mentioned.

In 1905-1906 experiments were made in the United Provinces on lime concrete roofing slabs reinforced with wire or iron bars. The results were published in Public Works Department papers collection No. 5 of 1907 and were considered to show that a satisfactory form of roof might be constructed with these materials. A number of roofs of this type were then actually made some of which were satisfactory while others cracked and leaked, but in reviewing the results of practical experience Mr. C. E. V. Goument* concluded that if constructed under close supervision reinforced lime concrete roofs were satisfactory. At the same time he wrote "As the strength of the roof depends on the wires and these are liable to corrosion in course of time from leakage through cracks in the concrete it cannot be said to be structurally so substantial a class of roof as the jack arch which is comparatively imperishable". In response to enquiries addressed to the Public Works Department of the United Provinces, information has kindly been furnished from which the following extracts are given:—

"The District Surveyor, Pilibhit, reports that the Kotwali buildings and District Engineer's Office at Pilibhit were roofed with wire lime concrete. On examining the roofs, it was found that steel work in the roof of the Kotwali office room shows distinct signs of rusting for which he states there is no apparent cause. The slope is good and there are no depressions in the roof concrete. He states that probably the roof sweats and this is causing steel work to rust, but there is nothing serious at present. No signs of rust appear in the roofs of all other quarters attached to the Kotwali as well as in those of the District Engineer's office. The same is the case with the combined sub-deputy opium agent's residence and office at Budaun built in 1908 with wire lime concrete in roofs."

"No rusting has been observed in any of the buildings in this circle of superintendence except in the Female Students' Hostel, Medical School, Agra, which was constructed in 1907-1908. Its verandah roof was

*Note by Chief Engineer, United Provinces, P. W. D., Buildings and Roads Branch, on the use of wire lime concrete in roofs in the United Provinces.

examined in December 1919 and the surface of the wires found to be discoloured and slight rusting is also visible. The wires however seem to be in order in all other respects and the concrete is in perfect order."

Apart from these official sources the author has information of a roof constructed over a workshop at Roorkee as in Fig. 1. It was dismantled in December 1911 and the wires were found to be completely corroded. The concrete was made of brick ballast, surkhi, and kankar lime.

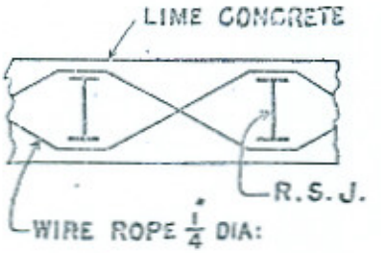


FIG. 1

The Bombay Government* made a series of experiments to ascertain the breaking strength of plain lime concrete arches up to 30' span and the effect of reinforcement, and in the course of a general review† on reinforced concrete work in that Presidency noticed favourably a few minor instances of reinforced lime-concrete in roofs and slabs. The case of the stables at the Secretariat Poona has however come to the author's notice ; the building was erected in 1912 and dismantled in 1914 and had a roof of lime-wire-concrete as in Fig. 2.

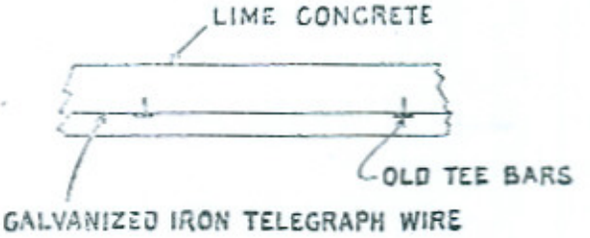


FIG. 2

The concrete was composed of washed gravel graded from 1/8" to $\frac{1}{2}$", river sand and stone lime (Shelavadi) in proportions 1 : $1\frac{1}{2}$: 2. The wires

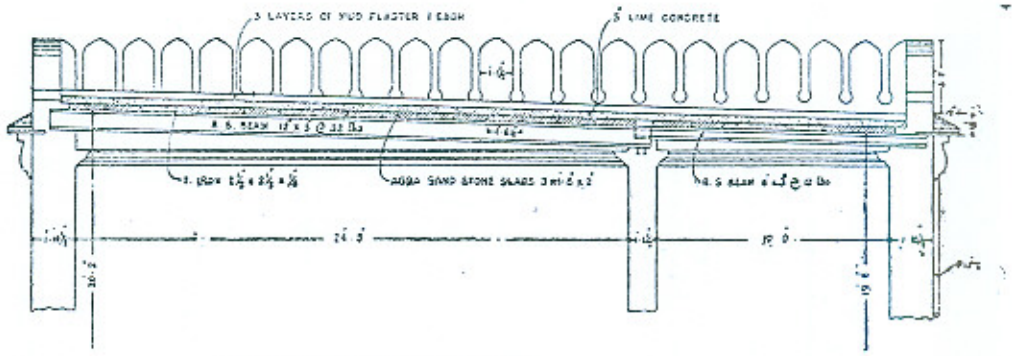
* A report on testing concrete and reinforced concrete arches by H. F. Beale, Superintendent, Government Printing, India, 1909.

† Bombay P. W. D. Technical Paper No. 5 Reinforced concrete work in the Bombay Presidency, J. C. Gammon, 1917.

were found to be so badly corroded that in many places they could be broken between the fingers. Coming now to the author's personal observation :—

In 1917 the author was asked by the Imperial Bank of India to examine and report on their premises in Lahore, a large flat roofed double storied brick building which had, from causes unknown, developed cracks to such an extent that fears were entertained of its safety.

The cracks were more numerous and larger in the upper storey than in the lower. The building was erected in 1907, by a well-known engineering firm of Calcutta from designs prepared by a qualified architect. The structure was substantially built with walls of brick in lime mortar resting on concrete of brick ballast in lime mortar bedded on alluvial sand. The ground floor is of concrete, the first floor is also of concrete over Agra stone slabs laid on steel tees supported by rolled steel beams. In short the building was not one where failure of any kind was to be expected. The foundations were examined, levels were taken of the plinth, the mortar was analysed, the cracks were mapped and tell-tales inserted. No defects were discovered to which the cracks could be attributed, but it was proved that the cracks were slowly and steadily increasing both in number and extent. A kiosk on the skyline and part of the brickwork in the facade supporting it, being in a dangerous state were dismantled and in removing the portions of roof attached to these parts of the building the origin of the trouble was discovered. The roof consists of three inches of mud plaster, on 5 inches of lime concrete with broken brick aggregate carried on Agra sandstone slabs two inches thick, supported by T-bars $2\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$ on rolled steel joists. There is no drip course in the parapet well. A section through the roof is shown in Figure 3.



IMPERIAL BANK OF LAHORE
MAIN ROOF

FIG. 3.

The webs of the T-bars when exposed during the process of demolition were found to be very heavily corroded. The sound section of the bar had in many instances been reduced from $\frac{1}{4}''$ thickness to $\frac{1}{8}''$, and in some places the web was completely perforated by rust.

The strength of the T-bars had been seriously reduced by this loss of sound metal. The rust had caused the web to swell to about double its original thickness, rust being more bulky than the steel from which it is formed.

It will be seen from the section that with this type of roof only the exposed face of the flange of the T-bars is accessible to the paint brush, the rest of the T-bars being completely built in.

The roof was not quite water-tight and drops of rusty water frequently fell from the roof and marked the floor beneath. In the excessive and unusual extent of the rusting which has occurred in 10 years, lies, undoubtedly, the cause to which the cracks in the upper part of the building must be due. It also explains the slow but continuous growth of the cracks, and the fracture of the cement tell-tales which were put in at various times.

The cumulative effect of the T-bars swelling with rust and bringing to bear an irresistible outward thrust on the walls, can readily be appreciated. The Agra stone slabs fit closely against the web of the T-bars and the joint has been roughly filled with a surkhi-lime mortar. An analysis by the Chemical Examiner to Government, Punjab, of a sample of mortar taken at random from the walls of the billiard-room gave

1 part of lime
6 parts of Surkhi } by volume.

Probably similar mortar was used for setting the slabs.

The Lahore P. W. D. specifications provide that lime mortar should consist of kankar lime without any admixture of surkhi or sand, but in actual practice the lime burning contractors are liable to permit a large proportion of sandy clay to be burnt with the kankar and the burnt lime as supplied from the kiln may not in reality be neat kunkar lime. The bars may not have been properly painted before being erected ; no traces of paint could be found on the webs of the dismantled T-bars. The ends of some of the rolled steel joists where they rest on the walls and are built in, had also been attacked by rust, though not to the same extent as the Tee-bars.

The floors are of similar construction to the roof except that Indian Patent Stone takes the place of the three inches of mud on the roof, but whereas the roofs are liable to absorb rain water the floors are not. For this reason one would naturally expect that rusting would not be in progress in the T-bars of the floors.

Nevertheless when a portion of the floor of the billiard-room was opened up and examined and distinct rusting was observed but to a much less extent than in the roof. No drops of rusty water have been observed to fall from the floors to the rooms below and no rust is noticeable on the underside of the T-bars.

The building has since been re-roofed with two layers of flat tiles laid on deodar battens, with a covering 5 layers of mud plaster each 1 inch thick. Since the re-roofing the growth of the cracks has ceased and no fresh cracks have appeared.

The Main Hall of the Aitchison College, Lahore.

Erected 1886. The roof is of the type shown in Fig. 4. In 1913

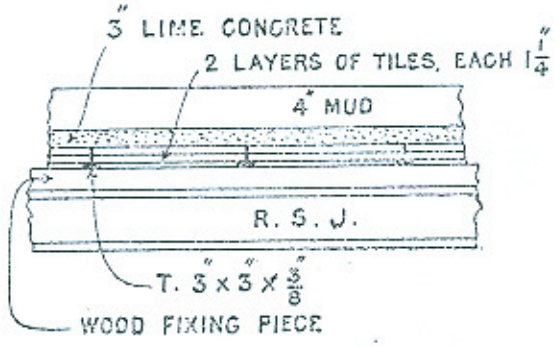


FIG. 4

it was noticed that the main walls were bulging outwards, that there were a number of long cracks in the roof, and that the two middle tiles and the T between them had humped themselves as sketched, in Fig. 5.

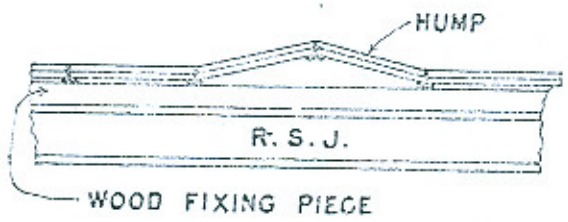


FIG. 5

The tees were found to be coated with rust and thereby increased in thickness from $\frac{3}{8}$" to $\frac{3}{4}$". The undersides of the tees were not much rusted and showed evidence of having been coal-tarred.

The Treasury Strong Room in the Fort, Lahore.

Erected 1902. The roofing consisted of 4" mud on 3" lime concrete, on jack arches $4\frac{1}{2}$" thick springing from the lower flanges of rolled steel joists 12"×5" with the usual tie rods in the end bays. In 1913 cracks were observed in the walls, rust scales $\frac{1}{4}$" thick were found on the webs of the rolled steel joists in some parts, while other parts were unaffected. Remains of oil paint were found.

Cook House of the old General Post Office, Lahore.

Date of erection not known. Jack arch roofing similar to the Treasury strong room roof; when the building was dismantled it was found that out of four rolled steel joists the webs of two had been completely perforated by rust.

Army Head Quarters, Simla.

Erected 1884. The floors in this building are constructed as in Figure 6.

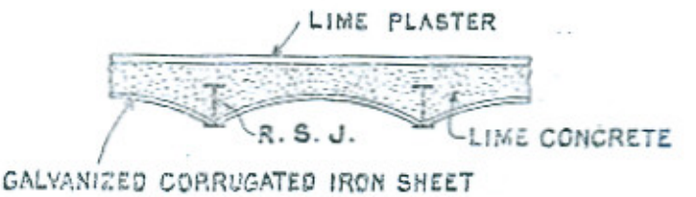


FIG. 6

The lime concrete is made with stone ballast, lime and surkhi, the lime being burnt from a local dolomite. The floors were examined in 1917 and found to be free from rust.

Postman's Quarters, General Post Office, Simla.

Erected 1912. Concrete as in Army Headquarters, Simla. Examined 1917 and steel found free from rust.

In the last two cases the floors are not exposed to the weather and no water is likely to reach the steel.

The conditions under which rusting of iron and steel occurs.

The following statements with regard to rusting are abstracted from results published by Mr. J. Newton Friend *:—

Rust is not produced at ordinary atmospheric temperatures by—

(1) water alone, *i.e.*, water entirely free from air whether the water is in the form of liquid or of water-vapour;

(2) dry air, or oxygen;

(3) a mixture of water vapour and air provided no liquid water is allowed to condense on the surface of the iron.

* J. Newton Friend on the Corrosion of Iron and Steel, at the Concrete Institute, 22nd Nov. 1917. See also Appendix V of the Report of the Committee appointed by the Board of Trade to enquire into the loss of strength in steel rails through use on Railway (1909), Prof. W. Dunston, F. R. S.

For the formation of rust oxygen and liquid water are essential. Under ordinary atmospheric conditions temperature changes occur which cause the condensation of moisture on exposed-metallic surfaces, such moisture is of course liquid water and contains air in solution.

Rust is hydrated ferric oxide, the extent of hydration varying considerably according to circumstances. In colour rust ranges from brown to red. Some ferrous oxide is generally present, particularly if the metal has not been completely oxidised away. Ferrous oxide is blackish and may be found in the innermost layers close to the metal. Hence iron in concrete may be preserved from rusting by—

(1) Exclusion of air.

(2) Exclusion of water.

Mr. Friend considers also that by maintaining alkaline the concrete, which is in contact with the iron, rusting will be inhibited. This point will be referred to again later.

The prevention of rust in reinforced concrete.

In 1909 the Concrete Institute * made careful enquiries on the corrosion of steel in portland cement and arrived at the following conclusions :—

Concrete.—The materials (cement, sand, and stone) must be of good quality. They must be most carefully and thoroughly mixed and scientifically proportioned, so as to be practically water-proof and air-proof.

The mixture must be fairly wet and must be well punned into position, so as to minimise voids. The aggregate should be as non-porous as possible, and any aggregate, which is known to have a chemical action on steel should be avoided. The aggregate should all pass through a $\frac{3}{4}$ inch mesh. The concrete covering should, in no case, be less than $\frac{1}{2}$ inch, and it is suggested, that if round or square bars be used, the covering should not be less than the diameter of the bar. In structures exposed to the action of water, or damp air, the thickness of covering should be increased at least 50%, or the size of the aggregate should be reduced so as to insure a dense skin. In the case of structures exposed to very severe conditions, the concrete might be covered with some impervious coating as an extra precaution.

Steel.—The reinforcement should be so arranged, that there shall be sufficient space between one piece and its neighbour, to allow the concrete to pass and to completely surround every part of the steel. All steel should be firmly supported during the ramming of the concrete, so as to avoid displacement. It should not be oiled or painted, and thick rust should be scraped and brushed off before placing.

General.—The scantling of the various members of the structure should be sufficient to prevent excessive deflection. If electric mains are laid down, very great care must be taken that no current is allowed to pass through the reinforced concrete. Fresh water should be used in mixing, and aggregates charged with salt should be washed.

These recommendations have regard only to the prevention of corrosion of steel, and not to fire resistance or any other property of reinforced concrete.

(*) Building News, March 17th, 1911.

Effect on adhesion of coatings applied to the steel.

In connection with the recommendation of the Concrete Institute that in the case of structures exposed to very severe conditions some impervious coating should be applied to the steel, it should be remembered that any coating applied to the steel has a marked effect on the adhesion between the steel and the concrete. Experiments* on this, taking the adhesion between concrete and uncoated steel as the basis of comparison, gave the results in the table.

Coating steel with	Adhesion.
Red lead	Reduced by 90%
Linseed oil	Reduced by 80%
Neat portland cement kept damp for several days ..	Increased by 35%

These results support the views of the Concrete Institute that if the reinforced concrete is designed to utilise the property of adhesion between steel and concrete the steel should not be oiled or painted.

Evidence that lime has any effect on the rusting.

Lime water has long been known as a preservative from rust and in England grooms commonly keep their burnished steel bits in a bucket of water containing freshly slaked white lime. Precise experiments on this are reported in the Professional Memoirs of the Corps of Engineers, United States Army (Vol. IX, No. 44, March—April 1917).

Angle iron, sand blasted on all faces except one and polished on one sand blasted face.

Specimen (a) immersed in Mississipi water for 14 months.

Specimen (b) immersed in Mississipi water for 14 months with slaked lime to a depth of $\frac{1}{2}$ inch.

Results (a) very much rusted—

original weight of metal .. 328·72 grams.

weight of rust formed .. 11·03 ,,

(b) unaffected.

In attempting to protect iron permanently with free alkalies, such as lime, Mr. Friend † states that it is necessary to consider, not merely the protection afforded by fresh caustic lime, but that which will be afforded when the atmosphere has converted the lime into carbonate. The influence of an aqueous solution of calcium carbonate upon the corrosion of iron depends upon its concentration and the temperature of the solution. At ordinary temperatures a very dilute solution of calcium carbonate is considerably more corrosive than tap water.

*Concrete and Constructional Engineering, 25th September 1917.

† J. Newton Friend, D. Sc., Ph. D., F.I.C. (Carnegie Gold Medallist), on the Corrosion of Iron and Steel, at the Concrete Institute, 22nd November 1917.

SUMMARY.

Evidence.—Cases are described where steel has rusted when in contact with lime mortar where water could reach the steel and others where rusting did not occur where water was absent. Scientific investigations are quoted to show that these results might be expected. The conditions under which steel in reinforced portland cement concrete may be considered secure from rust are stated and it will be generally conceded that the necessary precautions are likely to be absent in ordinary lime concrete made with broken brick.

Conclusion.—Reinforced lime concrete, or steel in contact with lime concrete is doubtful construction if there is any possibility of water reaching the steel.

DISCUSSION.

MR. A. ST. G. LYSTER in the absence of Mr. Astbury introduced the paper. He hoped the discussion would elucidate the problem as to what were the causes of the damage to steel embedded in lime concrete and enquired whether it was chemical action, the presence of water or both. He also drew attention to the lime in use at Simla which was quite different to that used in Lahore. It would not slake without grinding but shewed an appreciable increase in volume after storage. It was also found by the examination of steel work embedded in Simla lime concrete both in the Secretariat and Army Head Quarters that it caused very little corrosion.

MR. JOHNSTON drew attention to the fact that in India no proper arrangements were made for slaking. At home lime was usually slaked for twenty-four hours before use.

MR. K. G. MITCHELL remarked that in spite of what Mr. Lyster had said about steel in Simla lime concrete he did not consider lime should be used in contact with steel. The Simla lime was an exceptional case which could not justify what was bad general practice. He pointed out that the P. W. D. Specifications now laid down that R. S. Beams should be embedded in cement concrete, but personally he considered that the jack arch should spring from the upper flange of the beam in that kind of construction, in preference to relying on concealed work to protect the steel.

MR. COCKBURN described his experience in repairs to the General Post Office at Lahore where the roof consisted of R. S. Beams and jack arches covered with concrete and mud. On opening up he found that the beams had rusted badly and were covered with heavy scale. The remedy adopted was to cut out sections and replace with cement concrete so as to encase the beams. His experience was that Lahore kankar lime was very bad. He enquired with reference to the experience at Army Head Quarters at Simla noted on page 32 whether the non-rusting of the corrugated sheets was due to good galvanizing or not. In his opinion whether water got to the steel or not the combination of steel and lime concrete was doubtful construction.

MR. DORMAN asked whether the analysis on page 30 had been purely mechanical, and mentioned that his own efforts to ascertain whether the lime concrete used in Lahore contained any constituent harmful to steel had been fruitless. He had examined the roof of the Aitchison College when it was being dismantled and had found that the tees had only rusted under cracks in the concrete. Where the terraced roof was water proof and where the ends of the tees were built into the walls there had been no-rusting. Similarly, at Barnes Court, in Simla, where he had just dismantled a terrace consisting of lime concrete over corrugated iron sheets, where the concrete was sound the sheets were intact, but where

the concrete had cracked the sheets were corroded. Referring to Mr. Cockburn's remarks he stated that he had also examined the Post Office roof and had found the concrete porous, so that moisture had been able to collect in the haunches of the jack arches and attack the webs of the joists. At the Mayo Hospital there had been an interesting though unfortunate example of rusting. The cement plastered ceilings had a metal lathing foundation. This was clipped to furring bars, which in turn were suspended from the bottom flanges of the joists supporting the jack arched roof. After a time it was noticed that some of the ceilings were sagging and, when examined, it was found that the steel clips which held the furring bars had completely rusted where they had been bent round the flanges of the joists. The rest of the steel work was intact, and the explanation appeared to be that a certain amount of moisture had been imprisoned in the spaces between the jack arches and the ceilings, and, not being able to escape, used to condense on the soffits of the arches and then trickle down till it collected on the edges of the joists where it attacked the clips, which had rusted and failed.

The whole secret was to get a waterproof concrete. If moisture could be kept away from the steel there would be no trouble, and Mr. Astbury's opening remark that it was doubtful construction to put steel in contact with lime mortar, where water could reach it, would apply with equal force to cement concrete. This was brought out in the report of the committee which had recently been appointed by the Bombay Government (Development Department) to investigate the utility of reinforced concrete in Bombay City. This committee found that most of the buildings were quite sound, but in the Victoria Technical Institute hostel, built in 1907, they found that the beams and floors had split along, and had separated from, the reinforcement which had oxidised, scaled, and destroyed the surrounding concrete. The committee also found that the lintels in front of the General Post Office were cracked and disintegrated, and that in places the reinforcement had practically disappeared by oxidation, while on the other hand the floors and domes of this building (1913) were quite sound.

COL. BATTYE referred to the common experience that where a steel structure was partly in sea water and partly in air, rusting usually occurred between wind and water. Those portions of the structure always above or below water level remained in good condition. In his opinion rusting depended on whether the concrete was porous or not and he suggested that steel if bedded in lime concrete should always be protected with a little cement concrete. On the Simla Hydro-Electric Scheme lime concrete buttresses were reinforced by rods which were enclosed in short lengths of pipe, which were simultaneously filled with rich cement concrete, the pipes being hauled up as soon as the lime concrete surrounding the pipes had been laid, thus allowing the cement and lime concrete to mix and bond together.

MR. VESUGAR considered that water only as the cause of rusting of steel could be definitely ruled out. Even cement concrete was not sufficiently impervious to prevent water reaching the steel. Water only acted as the catalytic agent the presence of CO_2 or some other oxidising agent causing the rust.

MR. TINSLEY disagreed entirely with Mr. Vesugar. He pointed out that steel would not rust in water which was free of air, nor in dry air. The presence of both moisture and free oxygen was necessary before conditions were favourable for rusting. If therefore, lime concrete could be made as water tight as cement concrete it would do well.

MR. LYSTER in closing the discussion remarked that he agreed that the example of Simla Army Head Quarters did not prove that steel in lime concrete was good construction. This was a special case applicable to Simla only where both lime and *surkhi* were manufactured by Government. He agreed with Mr. Tinsley's remarks and in support described Sir William Ramsay's investigations in connection with the failure of the Coolgardie Water Main. In these experiments ordinary tap water produced rust in a sample in a week while water which had been passed through a vacuum chamber left the sample clean.

The general trend of the evidence produced by different speakers was that the destruction of steel was due to the presence of air and water and if the engineer could give protection from these, especially the former, he might feel confidence in the durability of the structure.

MR. ASTBURY wrote that he had nothing to add to the discussion.