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Case Study Paper on Field Inspection Guide for Rust on Reinforcing Bars by "IS / ACI / ASTM Norms" (A State of an Art Review)

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Abstract: Reinforced concrete (RC) is an economical, versatile and successful construction materials as it can be moulded to a variety of shapes and finishes. In most cases, it is durable and strong, performing well throughout its services life. However, in some cases, it does not perform adequately due to various reasons, one of which is the corrosion of the embedded steel bars used as reinforcement. Concrete provides an almost ideal environment for protecting the embedded steel from corrosion due to the passive film surrounding the steel rebar. However, the breakdown of this passive film, either due to chloride attack or due to carbonation, results in the corrosion of rebar. Thus rebar corrosion is one of the main causes of damage and premature failures of the RC structures worldwide, causing enormous costs for inspection, maintenance, restoration and replacement. Therefore, early detection of corrosion and timely remedial action on the affected portion can facilitate an optimum utilization of the structure, imparting longevity to it.

Concrete reinforced with steel is the literal foundation of our modern society. Reinforcement within concrete creates a composite material, with the concrete providing strength against compressive stress while the reinforcement provides strength against tensile stress. But, while steel reinforcement solves one of concrete's greatest limitations, it creates an entirely new problem: Corrosion of embedded steel rebar is the most common form of concrete deterioration. Although unprotected steel is naturally prone to corrosion, or rusting, when it gets embedded into concrete, certain factors usually work to protect it. First is the obvious protection of simply being shielded from the outside environment by a relatively impermeable and durable material. Water and contaminants usually can't make their way through the concrete to the steel. The second form of protection is the alkaline environment. The strength and performance of reinforced concrete depend on a good bond between the steel and the concrete. It is only possible to achieve this if the steel is in good condition. All reinforcement should be protected from contamination by grease, oil, mud, mould oil, excessive rust (especially if it is flaky) and ice, plus any mill scale or concrete that is loose. Once the reinforcement has been fixed, do not leave it exposed to the weather for long otherwise rust might form. Some of this could be washed off on to the formwork, and it would later make a permanent stain on the concrete. Starter bars sticking out of the tops of columns and walls are a frequent source of rust stains on the concrete below. So if such bars will be exposed for more than, say, a couple of weeks, they should be covered. Mortar or grout droppings that are adhering firmly to bars need not be removed. If they will not come off easily, leave them.

The effect of rust on the bond between reinforcement and concrete is debated endlessly on site. There is no doubt that in many instances rust has been removed unnecessarily, at considerable cost. A little rust is not harmful, but loose mill scale and excess flaky rust should not be left in place. This need not be a difficult problem since both will usually drop off during normal handling. If loose rust is still in evidence when the reinforcement cage has been assembled it should be removed, e.g. with a wire brush, but care should be taken to ensure that soffit and other formwork is not contaminated in the process, which could lead to staining of the concrete. teel that has been stored outside for a long time may have rusted so much that its diameter is reduced; if there is any doubt, the diameter should be checked. Any reinforcement that is deeply pitted with rust should be discarded.

Keywords: Corrosion, preventive measures, Rust, Reinforcement, causes, tolerances, chloride, chemical reaction, deterioration, bond, flaky, formworks, harmful, pressure etc.,

I. INTRODUCTION

Typical construction quality control measures require removal of surface rust on reinforcement due to a concern for reduced bond capacity or continued corrosion development when embedded in concrete. Inspectors often refer to ACI 301 (2005) Standard Specifications for Structural Concrete, or some variation thereof, which states: "when concrete is placed, all reinforcement shall be free of materials deleterious to bond." Field work required to clean reinforcing bars has significant time and expense implications. This Construction Technical Note (CTN) provides practical recommendations for rust and mill scale presence on reinforcing bars at the time of concrete placement, and how much rust is tolerable before it is detrimental to proper reinforcing bar performance.

Ferrous materials (those containing iron) naturally corrode when exposed to humid atmospheric conditions, and thus plain “black bars” (uncoated reinforcing bars) will likely exhibit light brown corrosion on the bar surface due to natural weathering. On the other hand, heavy rust formation is a very slow process; it may take years of usual jobsite exposure to lose a few percent of the reinforcing bar weight and consequently bar cross-sectional area. Steel reinforcing bars that have been extensively corroded and pitted should only be used if the various ASTM requirements for deformations and cross-section area are still within tolerance upon cleaning. Typically, if the reinforcing steel is stored under cover, the mill-scale will help “preserve” the steel.

II. CODE REQUIREMENTS

ACI 318 (2008) states that “steel reinforcement with rust, mill scale, or a combination of both shall be considered satisfactory, provided the minimum dimensions (including height of deformations) and weight of a hand-wire-brushed test specimen comply with applicable ASTM specifications.”

AASHTO (2002) requirements for handling, storage, and the surface condition of the reinforcement are similar to ACI, yet a little more descriptive. Section 9.5 from the Division II Construction requirements state: “Steel reinforcement…shall be protected from mechanical injury and surface deterioration caused by exposure to conditions producing rust. When placed in the work, reinforcement shall be free from dirt, loose rust or scale, mortar, paint, grease, oil, or other non-metallic coatings that reduce bond… Reinforcement shall be free from injurious defects such as cracks and laminations. Bonded rust, surface seams, surface irregularities, or mill scale will not be cause for rejection, provided the minimum dimensions, cross-sectional area, and tensile properties of a hand wire brushed specimen meet the physical requirements for the size and grade of steel specified.”

III. ACCEPTABLE RUST

Quantifying the level of rust on a reinforcing bar becomes an exercise in judgment, especially when viewing the reinforcement from an inspection standpoint. When considering newly fabricated reinforcement delivered, stored, or placed on the jobsite, rust on the reinforcement should be considered normal. The following definitions are offered as guidance for evaluating the range of rust appearing on a reinforcing bar.

Light Rust –This rust is characterized by a red, orange, or light brown colour. The amount of rust on the steel is dependent on the mill scale thickness, humidity conditions, environmental exposure, and bar age. This rust, depicted in Figures 1 and 2 (next page), is minor and not astructural concern. In fact, if the rust is tightly adhered to the bar, the rust will enhance the bond characteristics of the bar to the surrounding concrete. Removal of this rust type is not warranted.

Figure 1 – Light rust on the bar is acceptable.

Fig 2 Although these hoops look fairly rusty, this rust is Superficial and has no impact on bond behaviour.

Heavy Rust –Past research has shown that normal environmental exposures for 18 to 24 months will not create any significant section loss on new bar to be of concern. The reinforcing bar appearance may look poor, but the corrosion

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by-product occupies a volume of about seven (7) times the original cross section. For heavy rust, the loose, flaky or laminar sections of rust should be removed from the bar surfaces. Normal handling and placing of the reinforcing bar will usually knock this rust off the bar. Alternatively, lightly striking the bar with a mallet or club hammer should suffice to remove the loose rust. Ultimately, a rusty surface having a tightly adhered rust pack is desirable. Tightly adhered rust that has not altered the bar deformations will likely enhance the reinforcing bar bond behaviour.

Fig 3 The "heavy" rust on the bars is tight and does not alter the deformations. The surface is acceptable & cleaning is not required.

Figure 3 illustrates a medium to heavy rust build. The rust pack is tight, well adhered, and exhibits some minor pitting. This and similar bar conditions would be considered acceptable.

With respect to exposure time, Figures 4 to 7 are provided as representative examples of rust conditions over time. Figures 4 and 5 show the surface condition of #3 coiled, Grade 60, **ASTM A706 (2009)** reinforcing bar stored outdoors for 20 months. The bar has tightly adhered rust on the surface; the deformation pattern is clearly visible and has not been affected by the surface rust.

Figures 6 and 7 illustrate the surface condition of a #9 bar bundle left exposed in outdoor storage for 22 months. The specific material conformed to **ASTM A615, Grade 75 (2009).** In both photographs, the bar has an almost brown hue on the surface due to the rust, with no damage to the deformations. Any loose rust would be “knocked off” the bars during normal handling, and they would be permissible for use in concrete.

IV. CLEANING

Some reinforcing bar fabricators may warehouse their reinforcing bar outdoors prior to fabrication. Light rust on the black bars is to be anticipated at this stage, based on normal atmospheric conditions. The fabrication process (handling, bending, shearing, etc.) is usually “rough” enough, so that any loose rust developed will get knocked off in the process. The fabricated bar is then readied for shipping to the selected jobsite. Cleaning is not warranted for the fabricated bar at this stage.

Fig 4 Overall view of #3 bars left exposed outdoors for 20 months

Fig 5 Close-up view of the #3 bars showing a Tightly adhered rust pack and Good deformation definitions.

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Fig 6 Tightly adhered rust on a bundle of #9 bars for 22month

Fig 7 The tight rust has not altered the deformations Left exposed to normal atmospheric Conditions on the #9 bar surface.

At the jobsite, how long the bar sits in temporary storage is dependent on the project and contractor's schedule. Some inspectors become insistent on field cleaning the reinforcing steel to remove medium to heavy rust, such as that shown in Figures 3 through 7. Aggressive cleaning with a wire-brush or flapper wheel can actually be detrimental to the bar. If the cleaning is too aggressive, the cleaning can actually serve to polish the bar and reduce its surface roughness. In these instances, the bond characteristics of the reinforcing bar could be negatively influenced.

Salt water or brackish humidity induced corrosion may result in more significant issues. The presence of chloride ions in salt water promotes corrosion. Reinforcing steel that has been corroded due to salt water exposure should not be placed in concrete without approval of the Engineer of Record; the concern is that the chloride in the rust by-product may not diffuse sufficiently in the wet concrete and will cause additional corrosion, because the bar is in a moist environment. Because of this, cleaning is recommended through either low-pressure water washing with a conventional garden hose or power washing at low to medium water pressure. High pressure water blasting should be used with caution; the bars will get very clean through this process, but the salt residue within the rust build-up could get driven into any remaining corrosion product that is not removed by the water blasting.

V. DEFORMATION REQUIREMENTS

Table 1, and Figures 8 and 9 (next page) shows the standard deformation requirements for reinforcing bars. Should the inspector require a verification of the bar deformations, the dimensions are provided in Table 1 for reference (ASTM A615 – 2009). Measuring these dimensions on a rusted bar is difficult, and not recommended. As these measurements are intended to be made at the steel mill during bar production, a more accurate field measurement would be made on a cleaned section of reinforcing bar to confirm any negligible section loss.

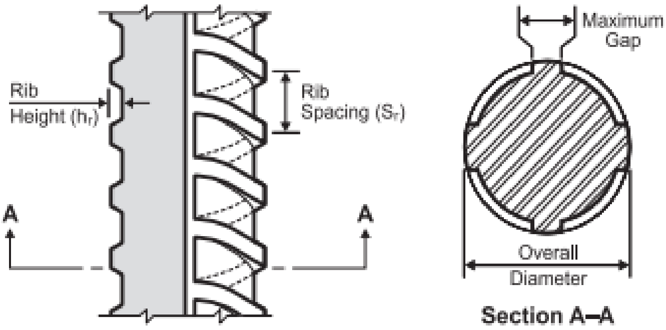

Figure 8 – Reinforcing bar deformation definitions.

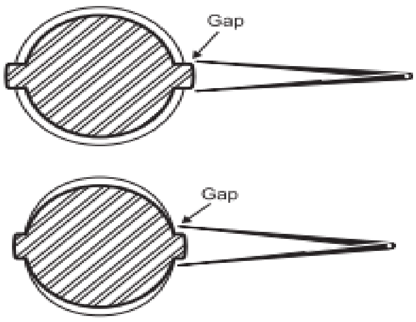

Figure 9 – Measurement of deformation gap.

VI. CORROSION OF STEEL REINFORCEMENT: CAUSES, EFFECTS AND REMEDIES

Concrete, in itself, has poor tensile strength. To increase the tensile strength of concrete, steel reinforcement is used. Steel bars are embedded within the concrete mass. These steel bars carry most of the tensile load applied to the concrete. The concrete renders the steel bars passive due to its highly alkaline nature, thus preventing them from corrosion. Still, due to various other reasons, the steel bars may get corroded over a long period of time. And due to the corrosion of the steel bars, various weaknesses arise in the concrete structure, which may eventually collapse if not taken proper care of within suitable time. Corrosion of steel reinforcement bars is basically an electrochemical reaction.

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Small anodes and cathodes are created and a flow of ions between these two electrodes lead to the corrosion of the steel bars. There are two types of corrosion observed in the steel reinforcement bars:

Crevice corrosion – In small crevices within the concrete structure, solutions may get stagnated. Anodes and cathodes may be created within the solutions due to uneven reaction of solute ions over the volume of the solution. Flow of ions is triggered by these electrodes, thus slowly causing corrosion.

Pitting corrosion – It is related to de-passivation of small areas on the steel reinforcement bars. This type of corrosion is extremely localized and small holes or pits are created in the steel.

Causes of Corrosion in Reinforcement Steel

Corrosion of the steel reinforcements may occur due to localized failure of the passive film on the steel by chloride ions or a general failure of the passivity by neutralization of the concrete due to reaction with carbon dioxide from the atmosphere. The main factors responsible for corrosion of reinforcement bars are:

Loss of alkalinity due to carbonation: When the steel surface is left unprotected in the atmosphere, rust begins to form on the steel surface and gradually flakes off.
Loss of alkalinity due to chlorides: Chlorides ions tend to de-passivate the steel surface by destroying the alkalinity of the concrete.
Cracks in concrete: Cracks may expose the steel bars to the atmosphere and hence increase carbonation.
Moisture Pathways: Regular wetting of the concrete may lead to water reaching the steel reinforcement bars by diffusion through the pore structure of the concrete or cracks present in the concrete. Rusting of the steel bars follows thereafter.
Insufficient Cover: Insufficient dimensions of the concrete cover.

Figure 10 –Corroded steel Reinforcement possibly due to insufficient concrete cover

Effects of corrosion on steel Reinforcement

Once the steel bars corroding, the reinforced concrete member gradually begins deteriorating going through the following stages;

Formation of White Patches: Atmospheric carbon dioxide reacts with calcium hydroxide present in the cement paste forming calcium carbonate. This calcium carbonate is carried out by moisture and deposited onto the concrete surface forming white patches.
Brown patches along the reinforcement: When the steel bars start corroding, a layer of iron oxide is formed on it. This iron oxide also gets carried out to the surface of the concrete by moisture.
Formation of Cracks: The products of corrosion occupy a greater volume than the original material. Hence they expert pressure on the concrete and crack it. With more corrosion occurring, more and wider cracks are formed.
Spalling of concrete cover: Due to loss of the bond between concrete and steel, the concrete starts forming multiple layers of scales and peels off. The steel bars also get reduced in size.
Snapping of bars: Due to reduction in the size of the steel bars, they finally snap. Also, there is a considerable reduction in the size of the main bars.
Buckling of bars: Spalling of the concrete cover and snapping of bars lead to buckling of the main bars. This bulges the concrete in that region and eventually the whole structure collapses.

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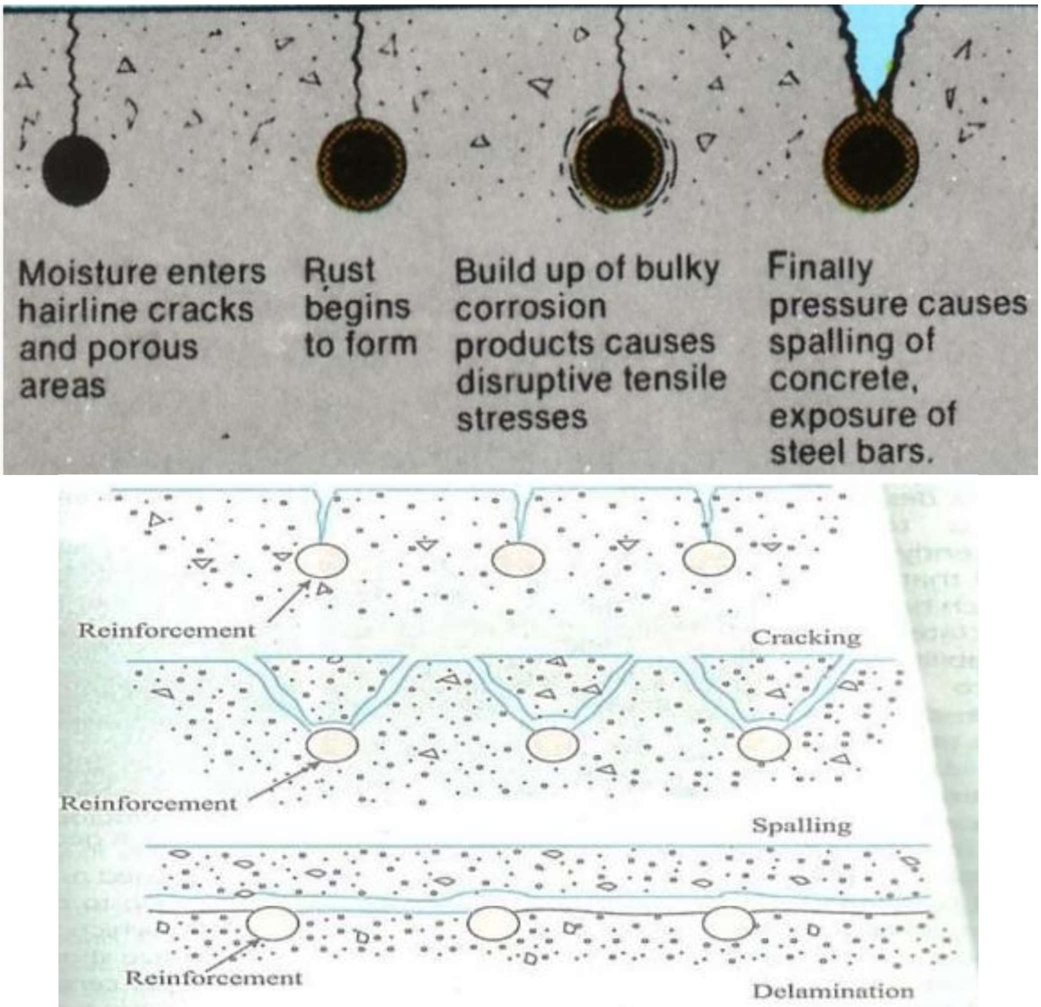

Figure 11 – Various process or stages of Corrosion on steel Reinforcement

<u>How to avoid corrosion on steel Reinforcement</u>

Corrosion of steel reinforcement bars may be prevented or at least delayed by practising good measures. Also, damaged steel bars can be repaired and the concrete structure can be restored properly. Some steps are given below:

Providing Sufficient Concrete Cover: A good amount of concrete cover should be provided over the steel reinforcement bars. This ensures proper maintenance of the alkaline nature within the concrete and the passivity of the steel bars. The steel bars should be precisely placed in position.
Use of Good Quality Concrete: High quality concrete must be used. It helps to maintain proper alkaline nature. For the concrete, a water/cement ratio of 0.4 or less is to be maintained. Excessive water may damage the steel bars.
Proper Compaction of Concrete: Concrete must be completely compacted such that there are no air voids or pockets present inside.
Use of FBE coated bars: Fusion bonded epoxy coating (FBEC) may be applied on the steel bars to prevent them from corrosion. Epoxy powder is spread electrostatically on to the steel bars. The powder melts and flows over the bars upon heating, forming a protective coating. They are thermoset polymer coatings because application of heat will not melt the coating. Apart from rebar it also has wide application in pipeline construction.
Use of Cement Based Polymers: Cement based polymers can be used in the concrete to enhance its protection against corrosion capabilities. The cement based polymers act as a binder in the concrete. They also increase the durability, tensile strength and vibration damping of the concrete.
Corrosion Resistant Steel Deformed Rebar's (CRSD): Mechanism of resistance to corrosion begins with the formation of initial layer of protective oxide or rust. (Hypo oxides). Unlike common rust on normal rebar, the CRSD rust is passive, tenacious and self-renewing. The protective oxide is fine textured, tightly adherent and a barrier to moisture, oxygen, carbon dioxide, Sulphur dioxide and chloride effectively preventing further corrosion. Scale on normal bars of steel is coarse textured flaky oxide that does not prevent moisture or oxygen from reaching the underlying bars and continuing the corrosion. As corrosion resistance is in the chemistry of the grade, if the passive oxide layer gets removed somehow, a new passive layer is formed immediately.

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RCPT test to assess degree of Corrosion: The rapid chloride permeability test (RCPT) may be performed to assess the degree of corrosion. The quantity of electrical current that passes through a sample 50mm thick and 100mm in dia in 6 hours is measured. Based on this a qualitative rating is made of the permeability of the concrete.
Use of Migratory Corrosion Inhibitors: Migratory corrosion inhibitors may be used in the concrete mix or may be applied on the hardened surface of the concrete. These inhibitors diffuse through the concrete cover and reach the steel bars to protect them against corrosion. Calcium nitrite based inhibitors are quite common.

Comparison of Epoxy coated rebar vs CPCC rebar vs CRS rebar

Now-a-days for controlling rust/corrosion of rebar some extra treatment is being carried out on rebar, making it more resistant to rusting/corrosion under unfavourable circumstances. Some of these treated rebar's normally used are:

(1) Fusion bonded epoxy coated rebar,
(2) Cement-polymer composite coated rebar,
(3) Corrosion resistant steel (CRS) rebar. The following comparison is being made aiming to give a clear cut idea on advantages/disadvantages of each type, which might help and give an idea to construction industry for decision making of selection of any particular type.

Comparison of Epoxy coated rebar vs CPCC rebar vs CRS rebar				
Sr. No	**Parameter**	**Fusion bonded epoxy coated rebar**	**Cement-polymer composite coated (CPCC) rebar**	**Corrosion resistant steel (CRS) rebar**
1	Corrosion Resistance Technology	For protection of reinforcing bars against corrosion, epoxy coating is done on these bars by electrostatic spraying of fusion bonded epoxy powder.	For protection of reinforcing bars against corrosion, coating of rapid setting primer followed by a coat of cement polymer sealing product is done.	For protection of reinforcing bars against corrosion, chemical composition of rebar is made such as to develop inherent corrosion resisting property.
2	BIS code	BIS13620-1993	No BIS code available. Developed by CECRI, Karaikudi. They have the detailed specification of chemicals and quality control with them.	No BIS code available for CRS yet. Complying with BIS1786-2008 500D.
3	Manufacturing process control	Difficult, as it needs to pass some critical procedures as per BIS.	Difficult, as it involves various steps like surface preparation, coating application on rebar.	Easier to control, as it is dependent on mother billet composition.
4	Damage possibility	A coating of 0.1-0.3mm on external surface of rebar and liable to damage. Performance of the system depends upon least defect in the coating.	It can be brush applied or sprayed and hence defects in the coating can be patch repaired.	Inherent property of rebar itself. No chance of damage/change in property.
5	Bond strength of rebar	About 20% less strength than conventional reinforcing bars, due to the coating.	Has good bond strength and hence bond between coated rod and concrete unaffected, as per CECRI.	No effect on bond strength.
6	Handing	Special procedure is there for handling such rebar, otherwise the coating may get damaged. Even dropping or dragging such rebar is prohibited.	Care to be taken while handling such rebar, otherwise the coating may get damaged.	No restriction in handling procedure.
7	Fabrication (Cutting)	Chance of damage in coating during fabrication. Exposed edge of rebar will be affected by corrosion.	Chance of damage in coating during fabrication. Exposed edge of rebar will be affected by corrosion.	Normal practice like conventional rebar.
8	Bending	Chance of dis-bonding in	Chance of dis-bonding in	Normal practice like

		coating during bending.	coating during bending. Bending of rebar to be completed prior to coating.	conventional rebar.
9	Welding	Not advisable as coating get damaged during welding.	Not advisable as coating get damaged during welding.	No special care is required.
10	Usage of couplers	Threaded portion of rebar without coating for fixing couplers leads to corrosion.	Threaded portion of rebar without coating for fixing couplers leads to corrosion.	Threading and coupler usage is not an issue due to inherent property of rebar.
11	Extent of protection	No measurement of extent of protection to rebar due to the coating, as per BIS. Smallest damage in coating can initiate corrosion under severe environment.	This system is newly developed by CECRI and the long term results are not known.	About 25% lower rate of corrosion compared to conventional rebar.
12	Cost saving	Cost higher compared to conventional rebar typically by Rs 6000-13000/MT, due to the coating. Moreover, due to less bond strength, more development length required, leading to more cost.	Cost higher compared to conventional rebar typically by Rs 5000-8000/MT, due to the coating.	Cost higher compared to conventional rebar by Rs 2500-3000/MT.

Comparison (CPCC – FBEC – CRSD)			
Parameter	**CPCC**	**FBEC**	**CRSD**
Thickness of Coating	175 mm - 300 mm	300 mm - 675 mm	No coating required
Type of Protection to rebar	Extrinsic	Extrinsic	Extrinsic
Pre-treatment	Pre-treatment is required before coating	Pre-treatment is required before coating	No pre-treatment required
Treatment to surface	Before coating the surface made little rough when some damage is introduced	Before coating the surface made little rough when some damage is introduced	The surface of the finished good is not disturbed or damaged at all.
Temperature Treatment	The whole process is done at room temperature.	230°C - 400°C	No treatment required
Special Bending Requirements	Modified mandrel diameter is specified by Indian Standard	Modified mandrel diameter is specified by Indian Standard	Same as other TMT rebar's of Fe 500D grade
Defects Introduced	Holiday Effect	Holiday Effect	Nil

SECTION A:-"General Principal of Rebar tying"

Although the practice of carrying ties wire varies somewhat in different localities across the country. In most areas tie wires is available in 3 to 4 pound coils. The coils are readily placed in a tie wire holder or reel especially designed for this purpose. These reels are suspended from a man's belt for easy accessibility and use.

Wire used for tying reinforcing bars is usually 16 gauge black, soft-annealed wire. There are some cases when a heavier gauge wire may be used. #15 or #14 gauge tie wire (or double #16 gauges) may be used when tying bars in heavily reinforced caissons or walls to maintain the proper position of the horizontal reinforcement.

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There are various types of ties used when securing reinforcing bars. Much of the tying is done on flat, horizontal form work such as floor slabs, and many backaches can be saved if one learns to bend and tie stiff-legged instead of squatting. Several of the most common types of ties are illustrated and described on below:

A snap of single tie (Figure 1) is normally used in flat horizontal work to secure the reinforcing bars in position against displacement due to work done by others trades and by concrete placing. This is a very simple tie, and wrapped once around the two crossing bars in a diagonal manner with two ends on top. The ends are then twisted together with a pairs of pliers until they are very tight against the bars. The loose ends are cut with pliers and then flattened, to prevent them from snagging clothing and from protruding through the top of concrete slabs. This type of tie also used when tying bars in caissons, at times using #15 or #14 gauge wire.

The snap or single tie may be made stronger by doubling the wire rather than using the heavier gauge wire. The tie would then be called a double snap tie or a single tie-double wire.

The wrap and snap tie (Figure 2) is normally used when tying wall reinforcement, holding the bars securely in position so that the horizontal bars do not shift during the construction progress or concreting. The ties are made by wrapping the wire 1 ½ times around the vertical bar, and then diagonally around the intersecting horizontal bar, completing the tie in the same manner as a snap tie (Single Tie).

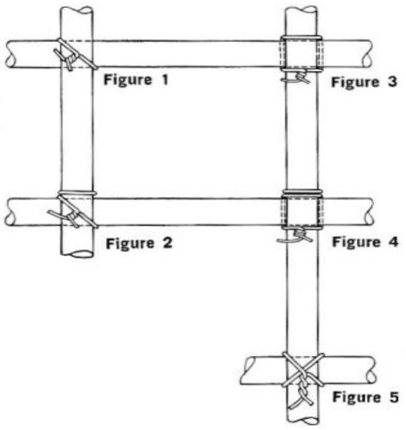

Figure No. 12 Various types of Tying of Reinforcing bars

A saddle tie (Figure 3) is more complicated than the two just described but is favoured in certain localities. It is used particularly for tying of footing or other mats to hold hooked ends of bars in position; also it is used for securing column ties to vertical bars. The wires pass halfway around one of the bars on each side of the crossing bar, then up and around the first bar where it is twisted as shown:

The wrap and saddle tie (Figure 4) is similar to the saddle tie except that the wire is wrapped 1 ½ times around the first bar, then completed as described for figure 3. This type is sometimes used to secure heavy mats that are lifted by crane and for securing column ties to verticals where there is a tendency for considerable strain on the ties.

A figure eight tie (Figure 5) is occasionally used in walls, instead of wall tie in Figure 2, but it is not particularly recommended because of the time required to make the tie.
In addition, there is the nailhead tie (Figure 6) used when nails are employed as spreaders to hold wall bars away from the forms. The wire is wrapped once around the nailhead. Then around the outside bar of the wall mat, drawing the bar securely against the nailhead by twisting the ends of the wire.

The tools and equipments usually carried by the iron-workers are as follows:

6 foot folding rule	Leather gloves
Coloured marking crayons	Safety belts
Side cutting pliers	50 - foot steel or
Reel	Cloth Tape
Straight claw hammer	Hard hat

The tools and equipments furnished to the ironworker are as follows:

Hoisting apparatus such as: small pole derrick, gin pole, portable scaffold, tower with casters and possibly a cantilever cathead.

Bolt cutters	Hickey
Sledge hammer	Manila rope
Acetylene torch	Slings
Arc welding equipment	Chokers

Set of double or triple blocks falls

All of the above tools and equipments should be kept in good condition, clean, sharp, free – working well-oiled and ready for use.

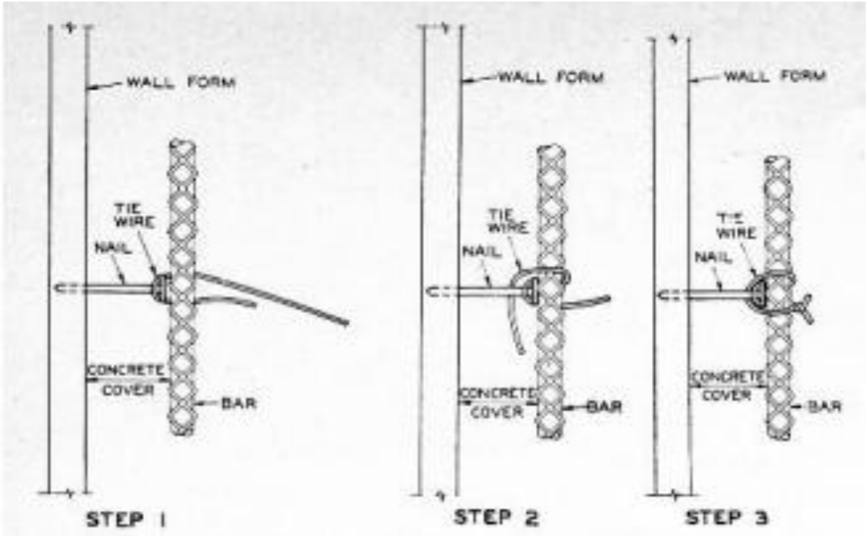

Figure No. 13 Nailhead Tie

We have all seen at our construction sites these huge grids of steel bars; Concrete is poured over these bars to create huge concrete slabs of various shapes and sizes. These steel bars are reinforcement bars (Rebar's in short), used to reinforce the concrete and improve its tensile strength.

During the creation of rebar grid, rebar does have to be tied to ensure that they do not get displaced when concrete gets poured over the grid. Displaced rebar do not optimally contribute to tensile strength.

In the developing world, the rebar's are tied manually using a pair of pliers (Quite a monotonous and back-breaking job). In the developed world, rebar's are tied with specialized "Rebar tying machines" as shown in the below adjoining photos. Tools manufacturers are constantly attempting to improve the tool and make it faster, better, cheaper. Predominantly, there are four key parameters that the rebar tying tools attempt to improve – tying time (or effort), worker ergonomics, tie strength (function) and tie length (related to cost).

Slab Reinforcing: When assembling reinforcing bar in place, usually with snap ties, the spacing of ties should be governed by the bar size. The example below shows typing every fifth intersection.

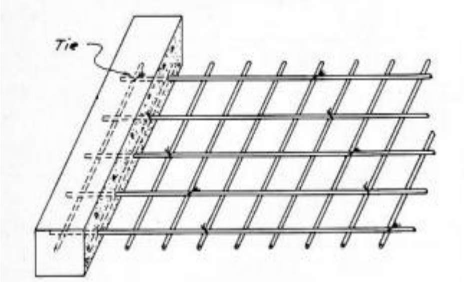

Figure No. 14 A tie at every fourth or fifth Intersection is usually sufficient

Wall Reinforcing: When assembling wall reinforcing bars in place, the spacing of ties should be sufficient to prevent shifting of the bars as concrete is being placed. CRSI recommends that a snap or snap and wrap tie is generally used, but in most cases the snap tie is adequate. The example below shows ties at every third intersection, each way.

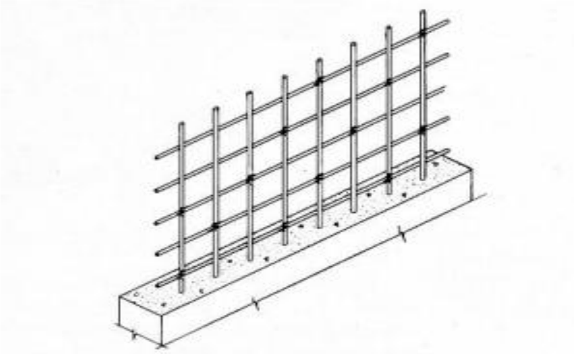

Figure No. 15 Tie walls bar sufficiently to prevent Shifting when concrete is placed

Preassembled Mats: For preassembled mats, a sufficient number of bar intersections should be tied to make the mats rigid enough for handling. When snap ties are used, every bar intersection around the perimeter and alternate intersections within the interior of the mat should be tied as shown below.

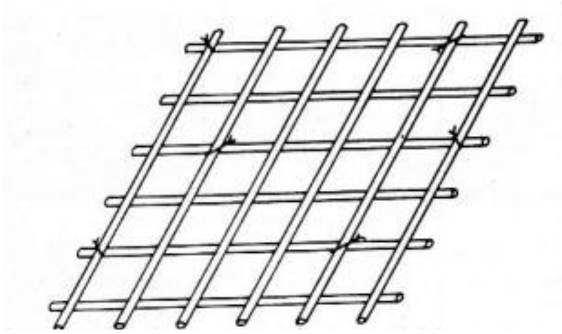

Figure No. 22Snap ties alternated for added rigidity

SECTION B:- "Anti-Corrosive Treatment for Reinforcement Bar"

Treatment of reinforcements with proper materials and agents one of the defensive layers against corrosion attacks in aggressive environments. There are many reinforcement treatment methods for instance anticorrosive treatment using acid or alkali agents and fusion bonded epoxy coating.

The basic principle of these treatment methods is to prevent the reaction between aggressive substance like chloride ions and steel reinforcement. Hence, the time that needed for the reaching such harmful materials to steel bars are increase and consequently the durability of the structure is increased substantially.

This standard (revised) specifies the recommended practice for surface preparation, surface pre-treatment and anti-corrosive treatment based on inhibited and sealed cement slurry as an in-situ process for corrosion protection of mild steel reinforcement/HYSD bars in conventional reinforced concrete structures and conventional .reinforced brickwork constructions.

Anti-corrosive Treatment

The Anticorrosive treatment is applied after the rods are cut and bent to shape. The treatment is done in a covered area. The treated rods are stored above ground in a covered area on wooden / masonry supports. Average thickness of coating is 0.3 ± 0.1 mm. The procedure for anti-corrosive treatment of reinforcement is as follows:

- The reinforcement rods are immersed in de-rusting solution for about 15-30 minutes till rusts are removed and bright surface bars are achieved.
- De-rusting solution is prepared by mixing inhibitor-de-rusting solution plus hydrochloric acid plus water; a mix ratio of 5 litres inhibitor: 50-liter hydrochloric acid: 50 litres water can be used for the production of 100 litres of de-rusting solution can be considered.
- Then, remove the bars out of the solution; clean it with wet waste cloth.

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- After that, immerse the bars in a solution which is produced by mixing alkaline powder with water; 1. Kg of powder shall be mixed with 400Liters of water. The bars should be left in this solution for 5 minutes then cleaned and removed.
- Phosphating Jelly is then immediately applied on the surface of the rods by means of a fibre brush. The jelly shall be allowed to react with the rod surface for 45-60 minutes and the jelly removed by means of rinsing in water or wet cloth.
- Corrosion inhibitor solution is then applied on the reinforcement surface by brushing/dipping.
- The corrosion inhibitor solution is mixed with ordinary Portland cement in the ratio of 500 CC of inhibitor to 1 kg of OPC and a brush able slurry is prepared. This slurry is then being applied on the rebar surface by brushing. All above steps should be applied in the same day and the steel allowed to air dry for 12 – 24 hours.
- Corrosion sealing solution is then be applied by brushing / dipping.
- Inhibitor is mixed with ordinary Portland cement in the ratio of 600 CC of inhibitor to 1 kg. Of cement and a brush able slurry is prepared. This slurry is immediately applied on the reinforcement surface. The coating is then allowed to dry for 12 – 24 hours.
- Corrosion sealing solution is applied on the reinforcement surface. This coating is again repeated after 4 hours of air drying.

Fusion Bonded Epoxy Coating

This process shall be done as per **IS: 13620 – 1993.** This process is carried out by the specialized agency in their Plant. The following procedure shall be considered when fusion bonded epoxy coating is used. More details regarding this treatment method can be found in **IS: 13620 – 1993.**

- Clean the surface of steel bars with abrasive blast cleaning till near white surface is obtained. The surface profile shall be free from mill scale, rust and foreign matter when viewed under well-lit conditions.
- Apply coating to the cleaned surface as soon as possible. The maximum period between cleaning completion and start of applying coat is eight hours.
- The coating shall be applied as an electrostatically charged dry powder sprayed onto the grounded steel bar using an electrostatic spray gun.
- The powder may be applied to either a hot or cold bar.
- The coated bar shall be given a thermal treatment specified by the manufacturer of the epoxy resin that would provide a fully cured finish coating. Temperature shall be controlled to avoid blistering or other defects.
- 90 percent of all coating thickness measurements shall be 0.1 mm to O-3 mm after curing.
- The coating shall be visually inspected after curing for continuity of the coating and shall be free from holes, voids, contamination, cracks and damaged areas.

The reinforcement is purchased from well-known brand of corrosion resistant rods. The mechanical properties like tensile strength, elongation etc. should conform to the requirements of the corresponding class of bars, like Fe 415, Fe 500 etc. as per IS-1786.

Anticorrosive treatment process sequences - The anticorrosive treatment should necessarily include the following sequential steps

(a) **Surface preparation (de-rusting**) - Since presence of oil, grease, dirt, heavy scale and rust will adversely affect the performance of any anticorrosive treatment, it is essential to adopt suitable surface preparation technique. Surface preparation can be either by acid pickling or by sand blasting.

(b) **Surface pretreatment** - Surface preparation should be immediately followed by a surface treatment step to ensure temporary protection during the time lag between the de-rusting and finish coating. This pretreatment should not adversely affect either the adhesion of the finish coal or corrosion performance. (c) Inhibited cement slurry coating - A minimum of 2 coats should be applied to ensure full coverage. (d) Sealing treatment - Sealing treatment should make the coating harder and less permeable.

Procedure for surface preparation

Sand blasting - Sand blasting of the steel surface to SAE 21 /2 if standards cm be done

De-rusting by picking - The pickling weld should be preferably based on hydrochloric acid and should include an efficient inhibitor to prevent base metal attack.

A typical de-rusting solution should have the following characteristics

- Inhibitor efficiency should not be less than 97 per cent
- Weight loss of a polished standard mild steel reinforcement / HYSD bars specimen when dipped in the solution for 10 minutes should not be more than 2 g per sq. meter.
- Specific gravity when tested using a standard specific gravity bottle should be around.

Procedure for surface pre-treatment

De-rusted should be immediately convened by using phosphating treatment. It should be ensured by a suitable rinsing process that no residual acid is remaining on the surface at the time of phosphating. A typical phosphating composition of brush able consistency should have the following characteristics:

- Coating weight when tested as per test procedure A given hereunder should be around 4.5 gms./Sq.m.
- Density of the product should be in the range of 1.22 to 1.4 kg/liter.
- Presence of fungicide shall be tested by dissolving the jelly in deionized water; the resulting solution shall be yellow in color.
- Presence of phosphating chemical in jelly shall be ensured with ammonia molybdate test.
- PH of the composition when tested in a standard specific gravity bottle should be

Around 2.5 ±0.1 (f) Nail scratch tea should clearly leave a mark on the specimen. This indicates i.e existence of the coating.

Procedure for inhibited cement slurry coating

A typical inhibitor admixture used should have the following characteristics:

- It should in liquid form ready for mixing with i.e ordinary Portland cement.
- Specific gravity when tested using a standard specific gravity bottle should be 1.04 ±0.02 (iii) pH when tested using pH meter should be 12.75 ±0.25 (iv) Tolerable limit for chloride in inhibitor- admixture when tested using anodic polarization technique (as per lest procedure B) should be 300 ± 25 ppm
- Ordinary Portland cement - This should conform to IS 269 and should be sieved to pass through 75 microns IS sieve.
- Cement and inhibitor admixture should be mixed in specified proportion to have suitable consistency. Coating should be applied preferably by brushings. However, under specific circumstances spraying dipping is also allowable.
- Sufficient time tag should be allowed in between successive coatings to ensure final setting of the undercoat. A minimum of 6 to 12 hours may be necessary.
- A minimum of two coats with sufficient time lag in between should be applied.

Sealing treatment

The sealing treatment should be performed over the coated surface immediately after final selling of the top coat. Sealing treatment can be applied by brushing, spraying or dipping.

A typical sealing solution should have the following characteristics

- Specific gravity when tested using a standard specific gravity bottle should be 1.09 ±0.02
- P_H when measured using a pH meter should be -12.25 ±0.25
- Tolerable limit for chloride in sealing solution using anodic polarization technique should be 450 ± 25 ppm (as per test procedure B)

Epoxy-coated Reinforcing Bars

Pre-cleaned reinforcing bars are protected with a coating of powdered epoxy that's fusion-bonded to the steel in an assembly line process. Typically, manufacturers have the capability to coat straight bars, but only a few can coat bent bars. The coating physically blocks chloride ions.

Performance: Poor to excellent
Possible Problems: Unless the bars are coated after bending, there's a potential for cracking and chipping of the epoxy coating during bending. Damage to the epoxy coating also may occur during field-handling of the bars.
Relative cost: Medium.

SPECIFICATIONS FOR FINISHED END PRODUCT

- Finished coating when visually examined should be fairly uniform in thickness and should be devoid of any defects such as cracks, pinholes, peeling, bulging etc. No surface area should be left uncoated. No rust spot should be visible to the naked eye.
- Thickness of the coating - The minimum thickness of the coating shall be 200 microns. Preferable range is 200 to 400 Microns.
- Bond strength of the coated rebar's - The bond strength of the coated rebar and concrete shall not be less than that specified in IS: 456-2016 as per clause No. 0, 2, 5, II and 44.1.2 and tested as per IS; 2770 (Part-1).
- Hardness of the coating when measured using a pencil hardness tester shall be around 5H to7H.
- Tolerable limit for chloride in 0.04 normal NaOH medium using anodic polarization techniques (as per test procedure B) shall be around 4500 to 5000 ppm.
- No film failure as evidenced by evolution of hydrogen gas at the cathode or appearance of corrosion products at the anode shall Lake Place during one hour of testing (as per test procedure C).

General remarks - It is advisable that severely rusted and heavily pitied reinforcements are not accepted for treatment.

Test procedure A
Determination of phosphate coating weight.

7.5 cm x 2.5 cm or 7.5 cm x 5 cm mild steel polished and degreased specimens are to be used for this test. First the blank loss of un-phosphated specimen is to be found out. For this, the initial weight (W_1) is accurately weighed. The specimen is kept immersed in the Clark's solution or patented inhibited de-rusting solution for I minute, The specimen is removed, rinsed in distilled water and dried using hot air blower. The specimen is immediately weighed (W_3). The difference between W, and w, is termed as blank loss. Another specimen (polished and degreased) is brushed with phosphating jelly and kept for 45 minutes. Then the specimen is washed free of jelly, rinsed in clean water and dried using hot air blower. The phosphated specimen (W_1) is accurately weighed. After weighing, the specimen is kept immersed in Clark's solution or patented inhibited de-rusting solution for one minute. Then the specimen is removed, rinsed in distilled water and dried using hot air blower. The specimen is immediately weighed (W_4). Coating weight = W_3 - W_4 - blank loss.

Test procedure B
Anodic polarization technique.

Mild steel reinforcement / HYSD Bar lest specimens of size 10 mm in dia and 100 mm in length with stems of size 5 mm in dia and 50 mm in length is polished, degreased and sealed at bottom edge and at the stem with suitable sealers like wax, lacquer. Then test specimen ii kept immersed in test solution and potential is monitored using high impedance multi-meter against suitable reference electrode such as saturated calomel electrode/ copper-copper sulphate electrode. After getting stabilized potential using appropriate current regulator (0-100 mA), the lest specimen is anodicallypolarized at a constant current density of 290 mA cm using a platinum/ stainless steel/TSIA/ polished mild steel reinforcement/HYSD Bar as cathode. Potential with time is followed for 5 minutes after current is applied. The maximum chloride concentration up to, which the potential remains constant for 5 minutes, is taken as a measure of tolerable limit.

Test procedure C
Resistance to applied voltage test

Two mild steel reinforcement / HYSD bars of size not less than 10 mm in dia and 800 mm in length shall be given anti-corrosive treatment as per specified procedure. The end of the rebar's shall be soldered with insulated copper electrical connecting wire (14 gauges) to serve as electrical contact point. Coated rebus at the two ends shall be sealed with an insulating material to a length of 25 mm at each end. Test area shall be the area between the edge of the bottom sealed end and immersion line which shall not be less than 25 mm in this case.

The coated rebar shall be suspended vertically in a non-conductive plastic container of size not less than 150 mm X 150 mm square and S50 mm high. The rebar shall be so suspended as to have a clearance of 25 mm at bottom, 45 mm at

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the sides and 40 mm in between the rods. Container shall then be filled to a height of 800 mm with aqueous solution of 7 percent NaCI. A potential of 2 V in between the coated rods shall be impressed for a period of 60 minutes using a high resistance volt meter for direct current having an internal resistance of not less than 10 mega Ohms and having a range up to 5 V (minimum). Storage batteries may be used for impressing the voltage. During these 60 minutes of testing, there shall not be any coating failure as evidenced by evolution of hydrogen gas at the cathode or by appearance of corrosion products of iron at the anode.

VII. CONCLUSION

Rust or corrosion on reinforcing steel is not necessarily a bad condition. Present specification requirements contain very conservative language; this is not fully supported by the research evidence. In spite of these known facts, most engineers and inspectors alike take a conservative approach by requiring the removal of such materials from reinforcing bar. Rust can enhance the bond characteristics of the bar to the surrounding concrete. Obviously, loose material should be removed from the bar. Tightly adhering rust or mill scale is permissible, and will not be detrimental to bond. Therefore, CRSI does not endorse any requirements mandating excessive rust cleaning measures for normal corrosion developments on reinforcing bars.

The effect of corrosion of steel reinforcement on the tensile strength and bond strength of steel reinforcement, and the flexural strength of steel-reinforced concrete beam have been investigated and from the analysis of the test results, the following conclusions can be drawn from the study:

- Corrosion of steel reinforcement reduces the tensile strength of steel reinforcement.
- Corrosion of steel reinforcement impairs the bonding between steel reinforcement and concrete.
- Corrosion of steel reinforcement reduces the flexural capacity of steel-reinforced concrete and this reduction is primarily due to the reduction of the tensile strength and bond strength of steel reinforcement as a result of the corrosion.
- The effect of corrosion of steel reinforcement on other strength properties of steel reinforced concrete (e.g. resistance to shear) has not been investigated in this study. However, given that corrosion adversely affects the tensile strength and bond strength of steel reinforcement, and such strength properties are greatly influenced by the tensile and bond strength of steel reinforcement, then such strength properties are also most likely to be adversely affected by corrosion of steel reinforcement.

It is thus recommended from this study and the foregoing conclusions that:

- Non-corroded steel reinforcement should be used in favour of corroded steel reinforcement in steel-reinforced concrete construction.
- Steel reinforcement, especially those kept in long storage (on site, or with suppliers/manufacturers, etc.) before being finally used in construction, should be protected from corrosion inducing environments/substances such as moisture, and chlorides.
- Further investigation should be undertaken to consider several degrees/extents of corrosion of steel reinforcement and how they affect the strength of steel reinforcement and the strength of steel-reinforced concrete. Such a study could be useful in providing insights for some kind of allowable threshold of corrosion of steel reinforcement and more importantly for prompting remedial action in the case of corrosion of steel reinforcement during service.

“Steel reinforcement shall be stored above the surface of the ground on platforms, skids, or other supports and shall be protected from mechanical injury and surface deterioration caused by exposure to conditions producing rust. When placed in the work, reinforcement shall be free from dirt, loose rust or scale, mortar, paint, grease, oil, or other non-metallic coatings that reduce bond. Epoxy coatings of reinforcing steel in accord with standards in this article shall be permitted. Reinforcement shall be free from injurious defects such as cracks and laminations. Bonded rust, surface seams, surface irregularities, or mill scale will not be cause for rejection, provided the minimum dimensions, cross-sectional area, and tensile properties of a hand wire brushed specimen meet the physical requirements for the size and grade of steel specified.”

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