Research Paper on the of Effects of Sodium Chloride on Bond Strength between Steel & Concrete

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Abstract — The corrosion of steel strands due to the chloride contamination is one of the most common causes for the degradation of prestressed concrete infrastructure. In this project, an experimental study was performed to investigate the bond behaviors between steel strands and concrete after suffered the chloride corrosion. Total nine central and off-center pull-out specimens with different corrosion levels were prepared and tested on UTM. The effects of corrosion rate, concrete to the steel strands on the bond behaviors of steel strands were studied and compared, in terms of the failure mode, bond-slip relationship, bond strength. In this Project, total Nine cube has casted of size of 15m×15cm×15cm. The grade of the concrete was M40 and Mineral Admixture was fly ash, chemical admixture was super plasticizer and the proportion of the mineral admixture was 20% of the cementious material 0.6 % of super plasticizer. Steel bar of diameter of 8mm and length is 1m is used for providing inside of the cube at a depth of 100mm. Proper Mix design has done and all material required has collected before casting the cube. For casting ,Material is prepared with proportion for first three cube and mixing has done for that three cube and that process has done every three cube and the prepared concrete has filled in cube with proper compaction after determining the slump of that prepared concrete and steel bar is immersed upto 100mm from top in concrete. After painting, testing has been performed that is pullout test and calculation has been done. The result was, bond strength was more than mentioned in the IS 456-2000 and development length was 100mm for every cube that was same as actual provided and development length was 350mm to 400mm for different cube. So we are on safer side as guidelines of the IS code.

Keywords: Corrosion, Concrete, Steel, Sodium Chloride

I. Introduction

Tremendous increase in demand for resources and acute shortage of the same is like a double edged sword. Codes and construction practices are emphasizing durability to cope with the situation. One of the most important concerns with reinforced concrete construction is deterioration due to reinforcement corrosion. Corrosion effects on structures cannot be ignored and replaced.

Corrosion is defined as the destruction or deterioration of a material because of its reaction with environment. In case of corrosion formation, an oxide of iron due to oxidationof the iron atoms in solid solution is a well-known example of electrochemical corrosion, commonly known as rusting. These oxides are usually weaker than steel. Chloride ingress into the concrete is a major cause of steel corrosion. Presence of chlorideions at the rebar level leads to the breakdown of passive firm thin film layer and consequently initiates the corrosion (Pradhan and Bhattacharjee, 2009). Rust produced as a result of corrosion increases its volume 2 to 6 times than that of original steel; it causes increase in volume of tensile stresses in concrete (Bhaskar et al. 2010).

The process of corrosion is initially slow and later it progresses exponentially. Corrosion initiation process in RC structures depends on the atmospheric conditions, thickness of cover,quality of concrete present at the cover depth, stress levels of corrosion in rebar, cracking effect etc. Macro corrosion cell-both the anodic and cathodic reactions frequently take place in different places with some distance apart (Browne, 1975). Physical model for steel corrosion in concrete sea structures is proposed by Bazant, (1979). Effects of reinforcement corrosion on the performance of RC elements are summarised in Fig.

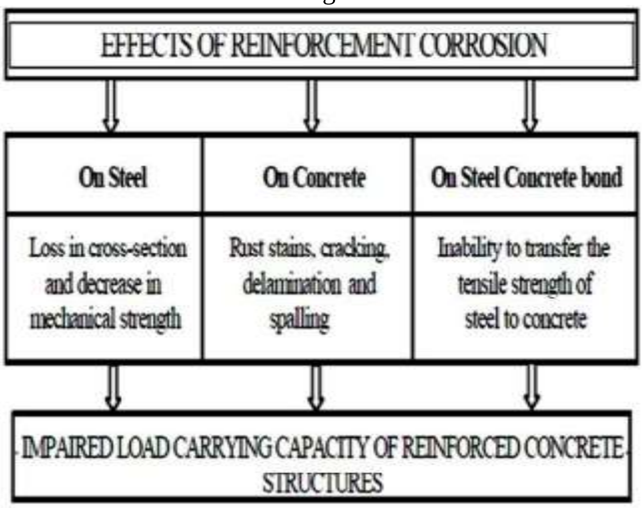

Fig. 1: Effect of Reinforcement Corrosion on the Performance of RC Elements

The basic cycle of micro cracking, cracking of concrete and influence of various environmental factors, resulting in the corrosion of embedded steel contribute to further cracking and reprocessing, until the steel corrodes extensively and/or concrete gets deteriorated or delaminated.

II. Objectives of study are:

1) Better compressive strength.
2) The price of fly ash is low.
3) Eco-friendly.
4) Sustainable.

III. Methodology:

A. Materials

1) Cement:

OPC 43 cement shall conform to IS:8112-1989 and the designed strength of 28 days shall be minimum 43 MPa or 430 kg/sqcm. Even though 43 Grade cements early strength is lessas compared to that of 53 Grade, with time it will attain the same ultimate strength as that of 53 Grade cement.

In the case of 43 Grade cement, the initial setting of cement is slower as compared to 53 Grade cement. In other words, the hydration process and consequently, the release of heat is moderate and therefore, occurrence of micro cracking is much less and can be easily controlled by proper curing of the concrete / masonry work.Unless a project requires very high strength cement, the use of 43 Grade OPC is generally recommended in general civil construction work such as residential, commercial and industrial structures. It is used in RCC works, preferably where the grade of concrete is upto M-40.

2) Aggregates:

Aggregates are inert granular materials such as sand, gravel, or crushed stone that, along with water and portland cement, are an essential ingredient in concrete. Aggregatesstrongly influence concrete's freshly mixed and hardened properties, mixture proportions, and economy. Consequently, selection of aggregates is an important process. Although some variation in aggregate properties is expected, characteristics that are considered include:Grading,Durability,particle shape and surface texture, abrasion and skid resistance, unit weights and voids,absorption and surface moisture Needless to say, the selection of these aggregates is a very important process.

In this project, Two sizes of the coarse aggregate have been used. The size of the coarse aggregate is 20mm and 10mm. The proportion of the coarse aggregate of size of 20mm is 60 percent of the total quantity of coarse aggregate required. In the case of 10mm size of coarse aggregate, proportion was 40 percent of the same and the specific gravity of coarse aggregateis 2.74.

3) Fly ash:

The use of fly ash in portland cement concrete (PCC) has many benefits and improves concrete performance in both the fresh and hardened state. Fly ash use in concrete improves the workability of plastic concrete, and the strength and durability of hardened concrete. Fly ash use is also cost effective. When fly ash is added to concrete, the amountof portland cement may be reduced.

Benefits to Fresh Concrete. Generally, fly ash benefits fresh concrete by reducing the mixing water requirement and improving the paste flow behavior. The resulting benefits areas follows: Improved workability. The spherical shaped particles of fly ash act as miniature ball bearings within the concrete mix, thus providing a lubricant effect. This same effect alsoimproves concrete pumpability by reducing frictional losses during the pumping processand flat work finishability. Decreased water demand. The replacement of cement by fly ash reduces the water demand for a given slump. When fly ash is used at about 20 percent of the total cementitious, water demand is reduced by approximately 10 percent. Higher fly ash contents will yield higher water reductions. The decreased water demand has little or no effect on drying shrinkage/cracking. Some fly ash is known to reduce drying shrinkage in certain situations

Reduced heat of hydration. Replacing cement with the same amount of fly ash can reducethe heat of hydration of concrete. This reduction in the heat of hydration does not sacrificelong-term strength gain or durability. The reduced heat of hydration lessens heat rise problems in mass concrete placements.

Fly ash is used 20 % of cementious material

4) Super plasticizers:

When superplasticizer is used, concrete tends to lose workability rapidly. High strength concrete containing such materials must therefore be transported, placed, and finished before they lose their workability. Many modern superplasticizers can retain reasonable workability for a period of about 100 min, but care is still needed, particularly on projects where ready-mixed concrete delivery trucks require long journey times. Often, to avoid drastic reduction in slump and resultant difficulty in placing, only part of the superplasticizer is mixed during batching with the balance being added on site prior to pouring.

The same production and quality control techniques for normal strength concrete should also be applied to high strength concrete. In fact, the importance of strict control over material quality as well as over the production and execution processes cannot be over- emphasized for high strength concrete. In general, production control should include not only correct batching and mixing of ingredients, but also regular inspection and checking of the production equipment, e.g. the weighing and gauging equipment, mixers and control apparatus. With ready-mixed concrete supply, this control should extend to transport and delivery conditions as well.

The main activities for controlling quality on site are placing, compaction, curing and surface finishing. Site experience indicates that more compaction is normally needed for high strength concrete with high workability than for normal strength concrete of similar slump. As the loss in workability is more rapid, prompt finishing also becomes essential. To avoid plastic shrinkage, the finished concrete surface needs to be covered rapidly with water-retaining curing agents.

5) Epoxy Paint:

Epoxy coatings are used to protect concrete and steel marine structures as formulations are available to adhere to wet substrates. The use of epoxy paint is to resist the water or moisture to enter inside the cubes, It has applied on all side, except top side because it is required to calculate the bond strength from top side of the cube.

Typical applications for the protection of marine structures include:

- Coating piles, piers, sea walls and abutments in the splash zone.
- Coating water tanks, fish ladders, dams, and outfall structures.
- Coating piles, piers, seawalls and abutments underwater.

6) Steel bar:

Reinforcement for concrete is provided by embedding deformed steel bars or weldedwire fabric within freshly made concrete at the time of casting. The purpose of reinforcement is to provide additional strength for concrete where it is needed. The steel provides all the tensile strength where concrete is in tension, as in beams and slabs; it supplements the compressive strength of concrete in columns and walls; and it provides extra shear strength over and above that of concrete in beams.

In this project , The deformed bar of size of 8mm has been used and total number of barwas Nine. Each bar has been cut at 1m length and marking of 10cm has been made fromone side for immersion into concrete up to marking.

7) Water:

Generally, water that is suitable for drinking is satisfactory for use in concrete. Water from lakes and streams that contain marine life also usually is suitable. When water is obtained from sources mentioned above, no sampling is necessary. When it is suspected that water may contain sewage, mine water, or wastes from industrial plants or canneries,it should not be used in concrete unless tests indicate that it is satisfactory. Water from such sources should be avoided since the quality of the water could change due to low water or by intermittent tap water is used for casting. The potable water is generally considered satisfactory for mixing and curing of concrete, Accordingly potable water was used for making concrete available in Material Testing laboratory. This was free from any detrimental contaminants and was good potable quality.

8) Concrete mix design:

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required strength, durability and workability as economically as possible is termed as the concrete mix design. The compressive strength of hardened concrete which is generally considered to be an index of its properties, depends upon many factors, e.g. quality and quantity of cement ,water and aggregates; batching and mixing; placing, compaction and curing. The cost of concrete is made up of the cost of materials, plant and labour.

9) Requirements of Concrete Mix Design

The minimum compressive strength required from structural consideration.

The adequate workability necessary for full compaction with the compacting equipment available. Maximum water-content ratio and/or maximum cement content to give adequate for the particularsite conditions.

10) Factors to be considered for mix design

The grade designation giving the characteristic strength requirement of Concrete The type ofcement influences the rate of development of compressive strength of concrete.

Maximum nominal size of aggregates to be used in concrete may be as large as possible within the limits prescribed by IS 456:2000.

The cement content is to be limited from shrinkage, cracking and creep.

The workability of concrete for satisfactory placing and compaction is related to the size andshape of section.

Quantity and spacing of reinforcement and technique used for transportation, placing andcompaction.

IV. PROCEDURE:

1) etermine the mean target strength ft from the specified haracteristic compressivestrength at 28-day fck and the level of quality control.
$$ft = fck + 1.65S$$
2) Where S is the standard deviation obtained from the table of contents given afterthe design mix.
3) Obtain the water cement ratio for the desired mean target using the empirical relationship between compressive strength and water cement ratio so chosen is checked against the limiting water cement ration. The water cement ratio so chosenis checked against the limiting water cement ratio for the requirements of durability given in table and adopts the lower of the two values.
4) Estimate the amount of entrapped air for maximum nominal size of the aggregatefrom the table.
5) Select the water content, for the required workability and maximum size ofaggregates (for aggregates in saturated surface dry condition) from table.
6) Determine the percentage of fine aggregate in total aggregate by absolute volumefrom table for the concrete using crushed coarse aggregates.
7) Adjust the values of water content and percentage of sand as provided in the table for any difference in workability, water cement ratio, grading of fine aggregate and for rounded aggregate the values are given in table.
8) Calculate the cement content from the water-cement ratio and the final water content as arrived after adjustment. Check the cement against the minimum cementcontent from the requirements of the durability, and greater of the two values is adopted.
9) From the quantities of water and cement per unit volume of concrete and the percentage of sand already determined in steps 6 and 7 above, calculate the content of coarse and fine aggregates per unit volume of concrete.
10) Determine the concrete mix proportions for the first trial mix. xii. Prepare the concrete using the calculated proportions and cast three cubes of 150mm size andtest them wet after 28 days moist curing and check for the strength.
11) Prepare trial mixes with suitable 11adjustments till the final mix proportions arearrived at.

V. CASTING OF CONCRETE ELEMENT:

A. Process of Manufacturing:

1) Aggregates

The coarse aggregate was kept completely immersed in clean water for 24 hours; the aggregate was gently surface dried with dry cloth. It was then spread out exposed to the atmosphere until it appears to be completely surface dry. For fine aggregate, considering the huge time to be taken to become surface dry from wet condition, it was immersed in water. Instead the water was sprinkled then it was spared out and exposed to the atmosphere until It appears to be completely surfacedry.

2) Batching:

Taken the required quantities of Cement, fine aggregate, coarse aggregate, fly ash, superplasticizer and water.

3) Mixing:

In this project, to make concrete, cement and fly ash and fine aggregate were first mixeddry to uniform colour and then coarse aggregate and superplasticizer added and mixed with the mixture of cement, fly ash and fine aggregates. Water was then added and the whole mass mixed.

4) Workability:

Concrete workability is a broad and subjective term describing how easily freshly mixed concrete can be mixed, placed, consolidated and finished with minimal loss of homogeneity. Workability is a property that directly impacts strength, quality, appearance,and even the cost of labour for placement and finishing operations.

5) Casting:

Clean the moulds and apply oil. (150X150X150mm)

Fill the concrete in the moulds in layers approximately Sem thick.

The steel bar have been kept in moulds upto 100mm from top with providing thecover of 50mm at bottom.

Compact each layer with not less than 25strokes per layer using a tamping rod (steelbar 16mm diameter and 60cm long, bullet pointed at lower end)

Level the top surface and smoothen it with a trowel.

6) Curing:

After applying the epoxy paint on each cube on all side excluding top side , Allnine cube have put in water for 28 days , Six cube have been cured in salty waterand Three cube in normal water. The proportion of salt in salty water was 300gm/litre of water.

So in this manner, All cube have been kept submerged in clear fresh water andsalty water until taken out prior to test.

B. Testing of Element

1) Testing Machine:

The testing machine may be of any reliable type, Of sufficient capacity for the testsand capable of applying the load at the rate not greater than 2250 kg/min, or at no-load speed of the machine head of not greater than 1.25 mm/min. The bearing surface of the concrete cube shall be supported on a square machined steel plate of size not less than the size of the test cube and 20mm thick, with a hole drilled through its Centre of sufficient diameter to accommodate the reinforcing bar. If a cross-bar measuring apparatus similar to that shown in Fig. 1 is used, this plate should be supported on a steelblock at least 125 mm in diameter and 75 rom thick. This block should have a central hole to accommodate the reinforcing bar, and in addition, on its top side should have a diametral slot and central hole of dimensions sufficient to accommodate the cross-bar.

This slotted block shall rest in turn on a spherically seated bearing block at least 125 mmin diameter and having a central hole at least 40 mm in diameter.

C. Test Specimens:

1) Size of the specimen-

The test specimens shall consist of concrete cubes of size given below, with a single reinforcing bar embedded vertically along a central axis in each specimen.The bar shall project down for a distance of about 100mm from the bottom face of the cube as cast, and shall project upward from the top face whatever distance is necessary to provide sufficient length of bar to extend through the bearing blocks and the support of the testing machine and to provide an adequate length to be gripped for application of load:

2) Diameter of the Bars

Size of the cube(mm)	(mm)
Up to and including 12	150

3) Ages at Test:

Tests shall be made at recognized ages of the test specimens, the most usualbeing 28 and 56 days.

4) Number of Specimen –

At least three specimens, preferably from different batches, shall be made fortesting at each selected age.

D. Apparatus:

1) Moulds for the test specimens:

The moulds shall be of size suitable for casting concrete cubes of dimensionsspecified in 3.2.1 and shall conform to the requirements of compression test specimens specified in IS : 516.1959.

The moulds shall be watertight. Watertightness may be accomplished by using grooved joints, or a sealing compound may be applied at the joints after assembly. The moulds shall be designed to hold the bars rigidly in place and shallallow for easy removal without disturbance of embedded bars.

2) Tamping rod:

The tamping rod shall be a round, straight steel rod 15 mm in diameter and approximately 0·6 m in length, having the tamping end rounded to a hemispherical tip, 15 mm in diameter.

3) Test procedure:

The test specimen shall be mounted in a suitable testing machine in such a manner that the bar is pulled axially from the cube. The end of the bar at whichthe pull is applied shall be that which projects from the top face of the cube as cast.

In assembling the testing apparatus on the specimen the distance between theface of the concrete and the point on the loaded end of the reinforcing bar at which the device for measuring slip is .attached, shall be carefully measured so that the elongation of the bar over this distance may be calculated and deducted from the measured slip.

The load shall be applied to the reinforcing bar at a rate not greater than 2 250kg/min, or at no-load speed of the testing machine head of not greater than 1·25 mm/min, depending on the type of testing machine used and the means providedfor ascertaining or controlling speeds.

The movement between the reinforcing bar and the concrete cube, as indicatedby the dial micrometers shall be read at a sufficient number of intervals throughout the test to provide at least 15 readings by the time a slip of 0·25 mm has occurred at the loaded end of the bar. The dial micro-meters shall be read at the loaded and unloaded ends and reading recorded to an estimated 0·1 of the least division of the dial

The loading shall be continued and readings of movements recordedat appropriate intervals until:

- the yield point of the reinforcing bars has been reached,
- the enclosing concrete has failed (the type of failure shall benoted), or
- a minimum slippage of 2-5 mm has occurred at the loaded end.
- 6.3.1.1 The maximum load for each type of failure shall be recorded

VI. CALCULATION

The slip at the loaded end of the bar shall be calculated as the average of the readings of the two dial gauges, corrected for the elongation of the reinforcing bar in the distance between the bearing surface of the concrete block and point onthe reinforcing bar at which the measuring device was attached.

From the recorded data the bond strength is calculated and by using the bondstrength the development length is calculated.

After that again the development length calculation has been done by using thebond strength mentioned in IS 456:2000 to compare the actual development length gotten.

VII. Mix Design:

A) Proportioning		
A	Grade designation	M40
B	Type of Cement	OPC 43 grade conforming IS 8112
C	Maximum nominal size of	20mm aggregate
D	Minimum cement content	340 Kg/m3
E	Maximum water cement ratio	0.35
F	Workability	75 mm (slump)
G	Exposure condition	Very Severe
H	Method of concrete placing	Manual
I	Degree of supervision	Good
J	Type of aggregate	Crushed Aggregate
K	Maximum cement content	450kg/m3
L	Chemical admixture	Super plasticizer conformingIS 91023

B)Test data for materials :		
A	Cement Used	OPC 43 grade (Ultratech)
B	Specific gravity of cement	3.15
C	Specific gravity of Aggregate	
	Coarse aggregate	2.74
	Fine aggregate	2.65

Target Strength For Mix Proportioning

$$f'ck = fck + 1.65\ s$$

where f'ck = target average compressive strength at 28 days
fck=charactrstic compressive strength at 28 days, and
s = standard deviation.

From Table I, standard deviation, s =5 N/mm2• Therefore, target strength =40 + 1.65 x 5 =48.25 N/mm2•
Development of stress in Reinforcement by IS 456: 2000:
Bond strength in concrete and steel:
Design bond stress in limit state method for deformed bars in tensionshall be:

Grade of concrete	Design bond stress in(N/mm^2)
M20	1.92
M25	2.24
M30	2.4
M35	2.72
M40	3.04

Development length of bars:

$$L_d = \frac{\phi\, \sigma_s}{4 \tau_{bd}}$$

The development length Ld is given by
where
Q= nominal diameter of the bar,
6 = stress in bar at the section considered at designload, and
t bd = design bond stress.

VIII. Results

		Cube 1	Cube 2	Cube 3
Cubes Cured In Normal Water	Failure load	29 KN	29 KN	29 KN
	Bond Stress	11.538 N/mm^2	12.85 N/mm^2	11.538 N/mm^2
	Stress in bar	576.93 N/mm^2	642.58 N/mm^2	576.93 N/mm^2
	Development length	100.005 mm	100.012 mm	100.005 mm
	Development length by using IS code	379.55 mm	422.75mm	379.55mm

Sr. No		Cube 1	Cube 2	Cube 3	Cube 4	Cube 5	Cube 6
1.	Failure load	32.3 KN	29.1 KN	30 KN	31.1 KN	30 KN	30.4KN
2.	Bond Strength	12.85 N/mm^2	11.578 N/mm^2	11.936 N/mm^2	12.374 N/mm^2	11.936 N/mm^2	12.095 N/mm^2
3.	Stress in bar	642.58 N/mm^2	578.92 N/mm^2	596.83 N/mm^2	618.71 N/mm^2	596.83 N/mm^2	604.788 N/mm^2
4.	Development length	100.012 mm	100.003 mm	100.005 mm	100.001 mm	100.005 mm	100.006 mm
5.	Development Length by using IS Code	422.75 mm	380.86 mm	392.65mm	407.04mm	392.65mm	397.88mm

IX. Conclusion

In this project The bond strength for every cube is varying in the range 11.50N/mm^2 to 12N/mm^2 and as par IS 456-2000 The bond strength for deformed bar and for M40 grade of concrete it is 3.04 N/mm^2, so the actualbond strength between steel and concrete is conservative by approximately 4 by factor of safety.

Similarly in the case of development length, The development length provided is 100mm and As per IS 456:2000, After doing of calculation the development should be in the range of 350mm-425mm, But As we have provided the development length of 100mm, Then Also the bond strength isin the range of 11.50 N/mm^2 to 12N/mm^2 which is grater than As per IS 456:2000 provisions.

So, Here the bond strength and development length is safe side orconservative by factor of safety of 4.

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