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Research Study on Structural Behavior of Unbonded Reinforced Concrete Beams

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Abstract **- This research investigates the structural implications of unbonded reinforcement in reinforced concrete beams, analyzing effects on flexural strength, stiffness, ductility, and shear capacity through numerical modeling and experimental data analysis. The study provides critical insights into beam behavior when the bond between reinforcement and concrete is compromised due to corrosion, delamination, or environmental factors. Findings demonstrate significant alterations in stress distribution, a reduction in ductility, and variable effects on ultimate load capacity. The results indicate that while flexural strength may be retained in many cases, the loss of bond significantly reduces stiffness and ductility, and highly reinforced sections are more susceptible to strength loss. This contributes valuable knowledge to structural engineering practice and concrete repair methodologies.**

Keywords - reinforced concrete; unbonded reinforcement; bond loss; flexural strength; ductility; structural behavior

1. INTRODUCTION

The integrity of reinforced concrete structures relies on the composite action between concrete and steel reinforcement, which is facilitated by an adequate bond. However, this bond can be compromised by various factors, leading to a condition of "unbondedness." This study examines the structural behavior of reinforced concrete beams when a portion of the tension reinforcement is unbonded over a segment of the span. The primary causes of such unbondedness include reinforcement corrosion, delamination of concrete cover, and the action of deicing salts, which are prevalent in structures like bridges and parking garages [1]. The objective of this paper is to detail the consequences of bond loss on the strength, stiffness, and ductility of beams, providing essential information for assessing and repairing deteriorated structures.

2. CAUSES OF UNBONDEDNESS:

1) Reinforcement corrosion is the principal cause of deterioration of reinforced concrete members. To extend the useful life of concrete structures, removal of concrete around affected reinforcement and subsequent reinstatement with a concrete or mortar remains the most commonly used.
When reinforcement is exposed during repair, it no longer acts compositely with concrete. Normal assumption of plane section behavior does not hold true and the pattern of strains in a beam under load is altered.

2) The bond of Reinforcement also impaired by de-lamination of concrete cover as result of corrosion.

3) By the action of deicing salts. This problem is most commonly found in bridges and parking garages that are subjected to deicing salts. The salt releases chloride ions that enter the concrete and corrode the reinforcing steel. The corrosion products increase in volume, which results in cracking of the concrete cover and progressive loss of flexural bond.

3. *Consequences of bond loss in the behavior of reinforced concrete beams:*

Numerical modeling of beam behavior:

Numerical model was developed to analyze behavior of reinforced concrete beams in which bond between reinforcement and concrete entirely lost over a portion of the span ***(Ref.2).***

a) Longitudinal deformations of reinforcement & of concrete are included in the analysis.
b) Bond Slip deformations & Load slip deformations of hooks are included.
c) Shear & Transverse deformations are neglected.
d) Non-linear stress-strain relationship is used for concrete in compression.

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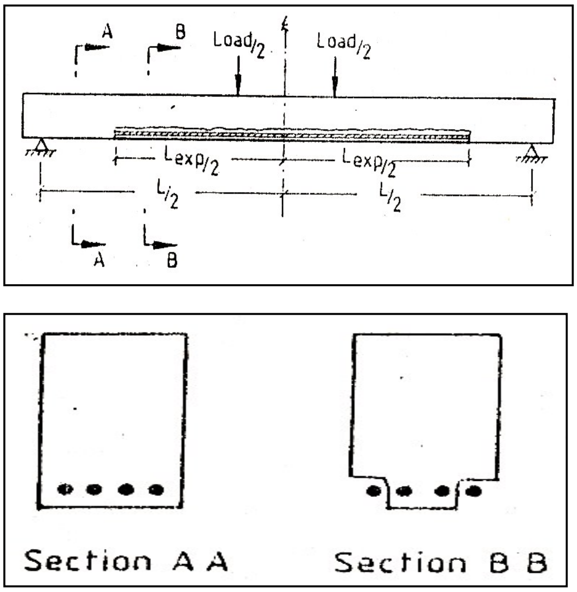
e) Tension stiffening is included where reinforcement is bonded & it is assumed to be lost where bond is lost.

For this Study of this model, ***John Cairns*** made a simply supported beam loaded in 4 point bending with a constant moment zone (L_{cm}) 0.2 times the span as shown in the ***Figure*** below**.** . It consists of a reinforcement ratio (100Ast/bd) of 1.5 % of concrete with a cube compressive strength (fcu) of 300 N/mm^2 & reinforcement with a yield strength (fy) of 460 N/mm^2 of rectangular section as shown in *Section AA* and *Section BB*. Section AA has the fully bonded bars and in Section BB two bars on each tension face are exposed over a portion of the span. The beam has been analyzed under a load equal to 30% of ultimate strength.



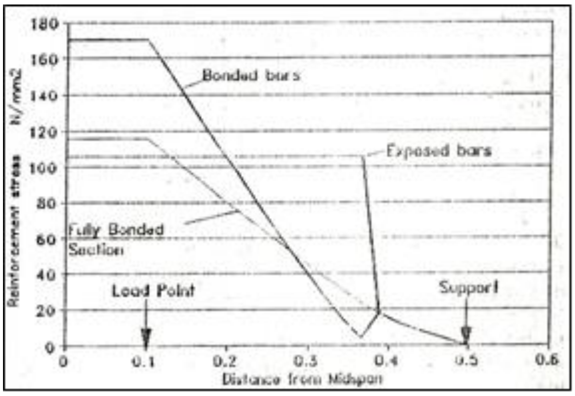


Figure 1: Beam used in Numerical Modelling part of study

Effect of unbondedness in stress along bars: Figure 2: Variation in stress along bars

As from ***Figure 2,*** it is clear that;

- Stress in exposed bars is constant throughout the exposed length and reduces over a short distance from end of the exposed length until it drops to the same level as that of the bonded bars.
- Stress in bonded bars at mid span is greater than the stress in bars in an equivalent section in which bars are fully bonded.
- Near mid span, exposed bars are less highly stressed than bonded bars, but the situation reverses towards the end of the exposed length.
- Stress in bonded bars even become compressive when the exposed length extends close to the support.

Effect of unbondedness on bending strength:

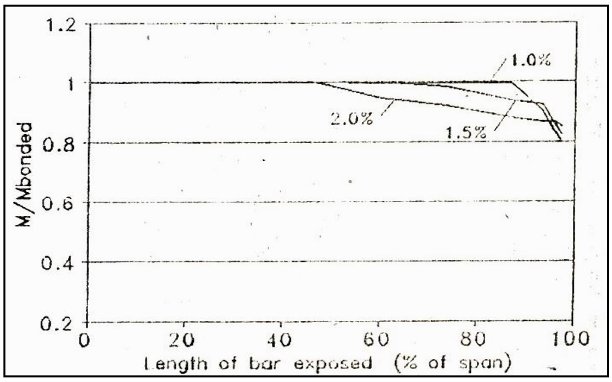


Figure 3: Loss of Bending Strength on exposure of 50% of bars in section for various percentages of steel

A reinforcement ratio of 2 % represents a balanced section.

Figure 3 shows that,

- No loss of Flexural Strength as long as the breakout is confined to the constant moment zone.
- significant loss of strength when the bars exposed bars is about 50 % of the span in the heavily reinforcement section.
- As clear from the ***Figure***, even when the bars exposed is 90% of the span, loss of strength is calculated to amount to only 12 %.

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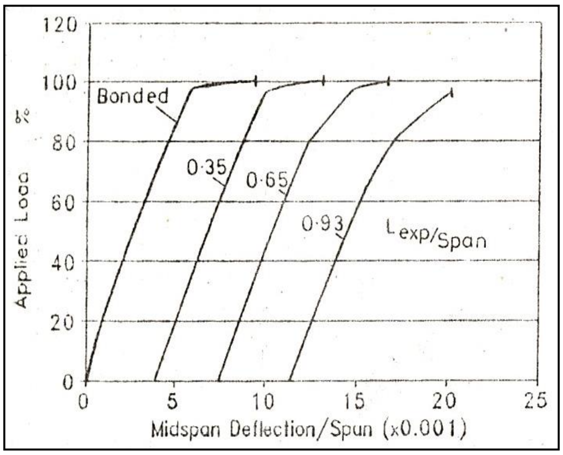
Effect of unbondedness on flexural stiffness and ductility:



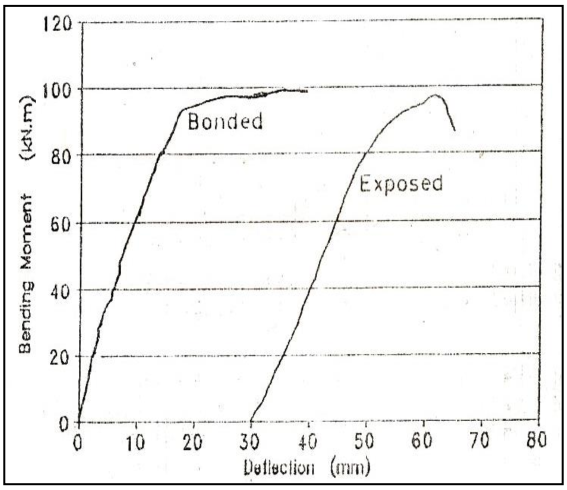


Figure 4: Load Deflection Relationship & **Figure 5**: Comparison of Load Deflection relationship for beams with bonded & exposed bars.

Figure 4 *shows that:*

- Flexural stiffness is reduced when reinforcement is unbonded.
- Although Flexural Strength may not be reduced by exposure of reinforcement in many instances, ductility of member is reduced.
- The beam with bonded reinforcement shows a well-defined elastic limit at a deflection equal to approximately half the deflection at ultimate load.
- ***Figure 5 shows*** a reduction in stiffness and ductility when bars are exposed.
-

Effect of unbondedness on shear strength:

Shear Strength of reinforced concrete beams is generally regarded to be the sum of contributions from

- Concrete Compression Zone.
- Aggregate Interlock.
- Dowel Action of Torsion Bars
- Links.

If the bars are exposed, all these contributions would be expected to reduce. Effect on Contributing Factors of Shear Strength when the bars are unbonded:

- Tension will be lost from the leg of link
- Dowel action lost when tension bar is exposed.
- When a bar is unbonded, tensile strains in concrete increases where bending moments are high, hence crack widths will be higher; which result in the reduction of aggregate interlocking effect.
- When a bar is exposed, depth of the neutral axis at mid span reduces which in turn reduces the shear capacity of the compression concrete, i.e; 50% shear capacity of a beam might be expected to reduce when half the tension bars are exposed.

Effect of Loss of Cover and Flexural Bond on the Strength of Reinforced Concrete Beams (I. MINKARAH & B.C. RINGO) (REF- 1)

- A total of 40 beams were used. Each beam had a cross section of 5”x10”x9.5’. Reinforcement consisted of 2#4 bars placed at an effective depth of 8.25”. Beams were constructed with varying amounts of cover removal and bond loss in the region of varying flexural stress as shown in the ***Figure*** below.

- The beams were loaded until failure occurred values of strain in the reinforcing steel bars, as well as load and deflection increments were recorded.

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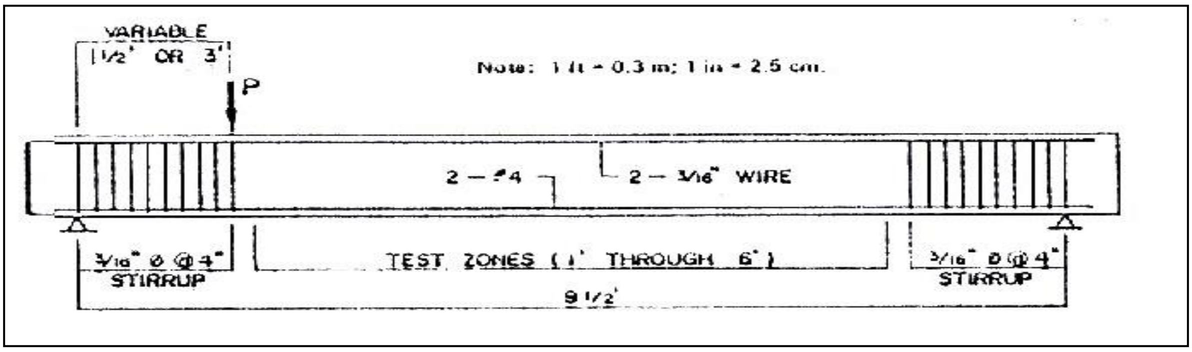
- This Study shows the beam behavior when bond or cover does not exist.



Experimental results in the tabulated form for loss of flexural bond and cover:

		Repaired		Test Results				Coefficient of Strength	
Loss of cover (ft)	Loss of Bond (ft)	Vithout Bonding Agent	Vith Bonding Agent	Maximum Load(kip)	Vith Maximum Moment(k-ft)	fc'(ksi)	fy (ksi)	Loss	Recovery
0	0	-	-	10.5	21.55	7	64	-	-
0	0	-	-	11.5	23.60	6.2	65	-	-
0	0	-	-	11.0	22.58	6.2	65	-	-
0	0	-	-	18.0	22.74	6.8	63	-	-
0	0	-	-	17.5	22.10	6.8	63	-	-
1	0	-	-	10.9	22.34	7	64	0.991	-
1	0	Yes	-	9.5	19.50	7	64	-	0.864
1	0	-	Yes	11.0	22.58	7	64	-	1
1	1	-	-	11.0	22.58	6.2	65	1	-
1	1	-	-	10.8	22.17	7	64	0.982	-
1	1	Yes	-	9.5	19.50	7	64	-	0.864
1	1	-	Yes	11.0	22.58	7	64	-	1
1	1	-	-	11.0	22.58	6.2	65	1	-
2	0	-	-	10.4	21.35	7	64	0.945	-
2	0	Yes	-	9.5	19.50	7	64	-	0.864
2	0	-	Yes	11.0	22.58	7	64	-	1
2	2	-	-	11.0	22.58	6.2	65	1	-
2	2	-	-	11.0	22.58	6.2	65	1	-
2	2	-	-	10.0	20.52	7	64	0.909	-
2	2	Yes	-	10.0	20.52	7	64	-	0.909
2	2	-	Yes	11.0	22.58	7	64	-	1
3	0	-	-	9.5	19.50	7	64	0.864	-
3	0	Yes	-	9.5	19.50	7	64	-	0.864
3	0	-	Yes	11.0	22.58	7	64	-	1
3	3	-	-	11.0	22.58	6.2	65	1	-
3	3	-	-	9.9	20.30	7	64	0.9	-
3	3	Yes	-	9.5	19.50	7	64	-	0.864
3	3	-	Yes	10.5	21.55	7	64	-	0.955
4	0	-	-	18.0	22.73	6.8	63	1	-
4	0	-	-	17.5	22.10	6.8	63	0.986	-
5	0	-	-	19.0	24.00	6.8	63	1	-
5	0	-	-	19.0	24.00	6.8	63	1	-
6	0	-	-	18.0	22.74	6.8	63	1	-
6	0	-	-	19.5	24.63	6.8	63	1	-
4	4	-	-	17.0	21.47	6.8	63	0.958	-
4	4	-	-	16.0	20.21	6.8	63	0.901	-
5	5	-	-	15.5	19.58	6.8	63	0.873	-
5	5	-	-	14.5	18.32	6.8	63	0.817	-
6	6	-	-	14.0	17.68	6.8	63	0.789	-
6	6	-	-	15.5	19.58	6.8	63	0.873	-

Table 1: Experimental Results

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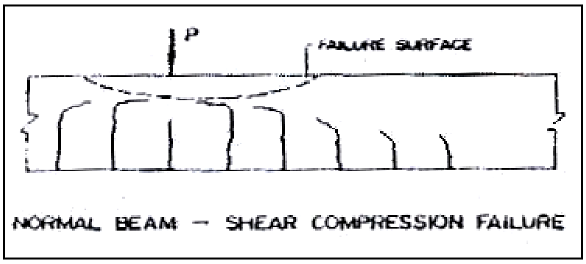
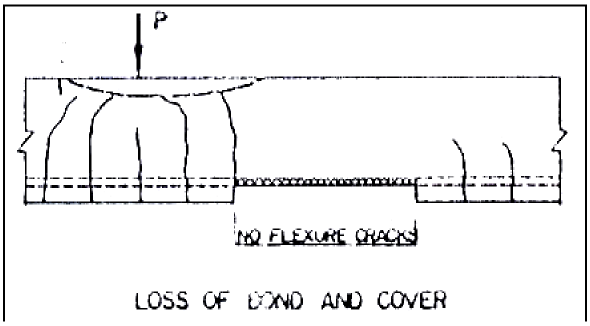
In ***Table 1***, coefficient of strength ***(CS)*** is used. It is the ratio of experimental load value, for various stations, to the load capacity of the control beam.

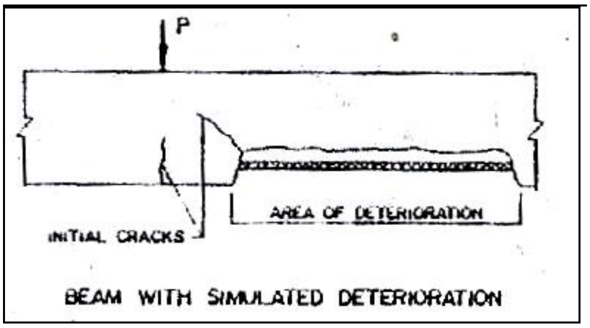
From ***Table 1*** we get the following results:

- When there is no bond and no cover over a distance of 6 ft., loss of strength occurred for the beam.
- In other words, even when the bond and cover were prevented for as much as much as 63% of the span, only 21% of the member's strength was lost.

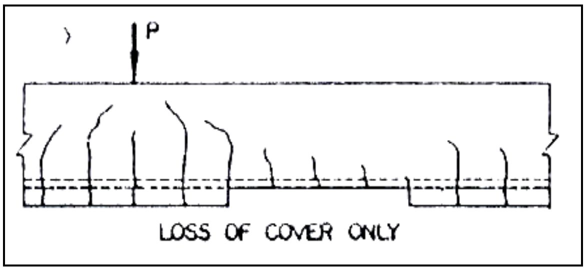
Effect of loss of Cover & Flexural Bond on the Strength of Reinforced Concrete Beam can further be explained with the help of following figures:

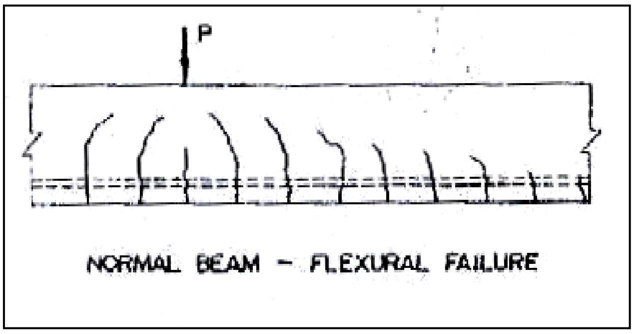






From ***Preceding Figures***, following results can be seen:





- At the point where flexural bondless begins, all of the tensile stress is directed into the reinforcing steel, which results in stress concentration.
- When bond between the concrete and steel is lost, there is nothing to reduce the tensile stress in the

Effect of unbondedness on deflection:

- The deflection of the beam with loss of bond was linear.
- At failure, the beam with loss of bond showed only a slight increase in deflection.

CONCLUSION

1. The loss of concrete cover alone has little short-term effect on the behavior and strength of a beam.
2. As long as substantial bond is maintained in the embedded parts of the bar, no practical reduction in strength is observed.
3. The loss of both cover and flexural bond significantly alters structural behavior and reduces strength, with the reduction increasing with the length of the bond loss.
4. Heavily reinforced sections are more susceptible to loss of flexural strength due to disbanding.

steel. The stress in the reinforcing steel is constant in the region of bond loss.

- Because of the lack of composite action between the concrete and the steel in beams with no bond, there were no flexural cracks in the region of deterioration.

- In some of the beams where there was loss of cover and bond, horizontal cracks formed at the level of the reinforcing steel at the far end of the test zone. The horizontal crack forms when the steel begins to pull out of the concrete.

- Most dramatic aspect of the behavior of beams with loss of cover and bond was the ultimate failure. The failure was a very sudden shear-compression failure of the concrete as shown in the figure.

5. While flexural strength may be retained in many instances, the ductility of the member is consistently reduced, leading to a more brittle failure.

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