An Overview and Analysis of Post Installed Rebar Connection on Concrete Structure

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Abstract: Post installed rebar connections are being widely used in practice. The technology of post-installed reinforcing bars is gaining importance since these bars are being frequently used in horizontal, vertical, and overhead applications in retrofit and rehabilitation of structures. Systems for installation of post- installed reinforced bars using injectable adhesive are in used in concrete structure. This paper briefly discusses about post-installed rebar connections, its failure modes, Eurocode approach to design, post-installed reinforcement approval and static effect of rebaring on concrete structure.
Keywords— Rebar, Post-installed, Anchorage length, Strut-Tie model

I. INTRODUCTION

In most of the countries in the world, the buildings and structures are ageing and needs continuous maintenance and also a repair. Also, the majority of existing constructions have deficient in the light of current knowledge and design codes. In practice, more connections between reinforced concrete element are carried out by bonding deformed reinforcing bars with adhesive mortar in holes drilled into existing concrete problem of the structural deficiency of existing constructions is serious in seismic regions. The costs of demolition and reconstruction of structurally deficient constructions are little prohibitive; also, they comprise a substantial waste of natural resources and energy. Therefore, structural retrofitting is increasing widely throughout the world.
The rise in traffic flows and increase in axle weights cause rise in impose loading on bridges which is far in excess of loads for which bridges are designed. As a result of this many bridges are subjected to strengthening schemes. So, rehabilitation works come with engineering challenge of providing monolithic connection between new and existing concrete structure.
Post installed reinforcement is a reinforcement which is installed in hardened concrete member by drilling holes and inserting bar with adhesive. Post installed reinforcement bars are used for different purposes such as attaching new concrete members to existing reinforced concrete members, enabling the flow of forces via joints or strengthening existing structure by additional straight rebars. A common application of anchoring adhesive is the installation of deformed rebar in holes drilled in concrete to imitate the behavior of cast-in-place reinforcing bars. Rebar is standing for reinforcement bar. The word rebar is used for a reinforcement bar inserted into a borehole filled with chemical adhesive in reinforced concrete structures that also means for post-installed reinforcement. Post-installed reinforcement can be split up into different applications such as Rebar as Anchor and Rebar as structural rebar. Post-installed reinforcing bars are used to develop a monolithic connection between new and existing concrete elements or structures. Post-installed rebar can be used to build most connections on site like, walls, slabs, beams, foundations or supporting columns. Most common use of rebar connections is for extensions of existing structure. It is also used to connect new components to existing structure and to strengthen existing concrete structures.

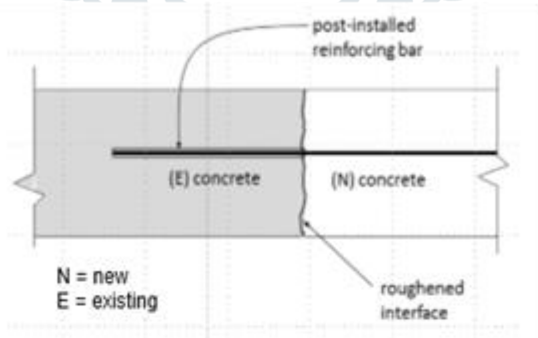

Fig. 1. Post-installed reinforcing bar

II. LITERATURE REVIEW

Rolf Eligehausen And Hannes Spieth (2001): Paper discusses post-installed rebar links and bond length comparison with manufacturer suggestions based on reinforced concrete codes. The bond length suggested by producers is much lower than reinforced bar bond length provided in various global reinforced concrete codes. Paper deals with tests of deformed bars mounted post and casts deformed bars in location. Results show that bar bond strength in well-cleaned holes in uncracked concrete bonded with suitable products is as large as cast-in-place bar bond strength. So, it summarizes that post installed rebar bond strength should be as long as strengthened concrete codes require anchorage or splice length.

Giovacchino Genesio, Roberto Piccinin, John Silva (2017): The paper describes the comparison of guidelines for the qualification of a post-installed reinforcement bar scheme developed by EOTA and ICC-ES. The qualification procedures of a post installed systems to verify their compatibility with applicable building codes which revolves around the ideas of efficiency equivalence between installed reinforcement bars and post installed bars, conducted in the Europe under provisions established by EOTA and in the U.S using ICC-ES. Paper has explained key points such as bond strength, the viability of adhesive delivery system, corrosion resistance and response to tension loading under splitting-critical conditions where shear lag is important. The assessment process, recommendations for harmonization and improvements are also discussed. With the development of new bonding materials, systems may result with significance differences in load-displacement response, bond or splitting test to address shear lag for long embedment as per AC308 is advisable and should be added in Eurocode. However, paper concludes that product could be designed and qualified in accordance with EAD330087 as its performance in cracked concrete is potentially unconservative.

Giovacchino Genesio, Roberto Piccinin, John Silva (2017): Paper compares design methods based on Eurocode 2 and ACI 318. It also discusses some case studies where post installed rebar systems are used for the moment resisting connections. Challenges and new opportunities related to post installed connections are discussed. Paper shows multiple methods which could be adopted to satisfy the design requirements of real reinforced concrete moment resisting connections. Paper highlights strong need for a unified approach capable of merging reinforcing to concrete theory.

Christph Mahrenholtz, Rolf Eligehausen, Hans-Wolf Reinhardt (2015): Paper highlights the interrelationships that are required for design between material strength parameters. Paper provided the methods of rebar building as cast-in or post installed end anchorage as per EN1992-1 and as CEN / TS 1992-4 bonded anchors. The comparison of both techniques is made using an illustration of the scenario demonstrating that the design of post-installed rebars as a bonded anchor may permit a lower anchorage length than needed if intended as end anchorages for high-strength mortars. It also addressed the design and problems of the end anchorages as part of the strut and tie models.

Hannes A. Spieth, Josko Ozbolt, R. Eligehausen, Jorg Appl (2001): Research paper describes research on a post-installed rebar connection system's bond behavior. Single rebar pull-out tests and splice tests are discussed. Influence of the separate bond rigidity on the finite three-dimensional component splice stimulations of diverse transverse splice length cracking was conducted for investigation purposes. Research demonstrates that the stiffness of the bond and the strength of the bond influence Splice length and crack along the seat length. Research demonstrates that the rebar instruments used after installation provide similar bond rigidity and no reduced bond strength than the rebars cast-in-place. The layout can be accomplished according to the reinforced concrete codes.

Finley A. Charney, Kamalika Pal, John Silva (2013): This publication offers context to ACI 318's adhesive anchor design and growth length regulations as well as provisions available in global codes for post-installed rebars. The document has recommended the creation of a new technique for the design of post installed reinforcement bars. This study has provided practical perspective to the issue of design, acknowledging the assumptions that are significant in ACI318's provision of anchorage and duration of growth. It is found that in applying this strategy to the wide range of information connected with post-installed reinforcing bars, engineering judgement is needed.

III. OBJECTIVES

1. To check static effect of rebarring on existing structure.
2. To compare natural frequency and time period using modal analysis.

IV. THEROTICAL CONTENT

The main principle of using post installed rebar connection is how the load or stress is transferred in reinforced concrete. The transfer of load or stress in reinforced concrete is based on bond between the reinforcing steel and the surrounding concrete. This transfer is provided by the resistance to relative motion or slippage between the concrete and the rib faces of the embedded steel bar. The resistance to slippage is defined as bond or bond stress. Bond between deformed steel bar and the surrounding concrete depends on three actions:

(1) Chemical adhesion between the bar and the concrete;

(2) Frictional forces arising from the roughness of the interface, forces transverse to the bar surface, and relative slip between the bar and the surrounding concrete;

(3) mechanical interaction between the ribs of the bar and the surrounding concrete.

The task of structural rebars is to take tensile loads and since concrete failure is always brittle, reinforced concrete design assumes that concrete has no tensile strength. Therefore, structural rebars can be anchored in only two situations:

- the bar is not needed anymore (the anchorage is a node in equilibrium without tensile stress in concrete)
- another bar takes over the tensile load (overlap splice)

Unlike in anchor applications, reinforcement design is normally done for yielding of the steel in order to obtain ductile behaviour of the structure with a good serviceability. The deformations are rather small in correlation to the loads and the crack width limitation is around wk ~0.3mm. This is an important factor when considering resistance to the environment, mainly corrosion of the reinforcement. In case of correct design and installation the structure can be assumed as monolithic which allows us to look at the situation as if the concrete was poured in one. Due to the allowed high loads the required embedment depth can be up to 80d (diameter of rebar).

Old concrete to new or basically concrete stitching; shear connectors and starter bars from rock. If we want to raise a foundation from a rock is something called rock anchoring that is passive rock anchoring, we can support a support to take a dowels from a rock, directly we can take a foundation instead of excavating the rock and rebar theory basically goes with; with splice and without splice. With splice is basically when the new rebars are inserted in parallel to the existing rebar, that we call it as splice, modes of failure that is load transfer to cast in rebars via the concrete bond between them that is strut and tie model. The load will be transferred from new rebar to old rebar, the existing rebar through this strut and tie principal that, here the modes of failure will be steel failure, bond failure that is steal will cut off, bond will fail and splitting. Splitting because of edge and spalling because of closed spacing. These are all the 4 failures observed in this theory and there is other theory i.e rebar without splice. Where in no rebar in the parent material to splice with. So, here the modes of failure will be steel failure, bond failure, splitting, spalling and concrete shear, concrete cone also will try to come out, when there is no reinforcement in the parent material that is PCC. The rebar theory can be applied to concrete to concrete connections where contact surface is roughened according to EC2. The rebar theory can be applied only if concrete cone failure is prevented.

V. FAILURE MODES

A) Bond Failure

Bond failure is caused by pull-out of the bar if confinement (concrete cover, transverse reinforcement) is sufficient to prevent spillting of the concrete cover. In that case the concrete keys are sheared off and a sliding plane around the bar is created. Thus, the force transfer mechanism changes from rib bearing to friction. The shear resistance of the keys can be considered as a criterion for this transition. It is attended by a considerable reduction of the bond stress. Under continued loading, the sliding surface is smoothed due to wear and compaction, which will result in a further decrease of the bond stress, similar to the case of plain bars.

B) Splitting Failure

Bond splitting failure is decisive if the radial cracks propagate through the entire cover. In that case the maximum bond stress follows from the maximum concrete confinement, which is reached when the radial cracks have penetrated the cover for about 70%. Further crack propagation results in a decrease of the confining stresses. At reaching the outer surface these stresses are strongly reduced, which results in a sudden drop of the bond stress.

C) Influence of spacing and cover on splitting and spalling of concrete

In most cases the reinforcement bars are placed close to the surface of the concrete member to achieve good crack distribution and economical bending capacity. For splices at wide spacing (normally in slabs, left part of figure left), the bearing capacity of the concrete depends only on the thickness of the concrete cover. At narrow spacing (normally in beams, right part of figure above) the bearing capacity depends on the spacing and on the thickness of the cover. In the design codes the reduction of bearing capacity of the cover is taken into account by means of multiplying factors for the splice length.

VI. DESIGN OF POST INSTALLED REBARS

A) Loads on Reinforcing Bars

There is no shear stress transferred from the new concrete element to the existing one. In a construction joint, joint surfaces are roughened and new concrete will bond with existing concrete Hence any shear forces in the connection will actually develop tension in the reinforcement bars through the strut and tie model.

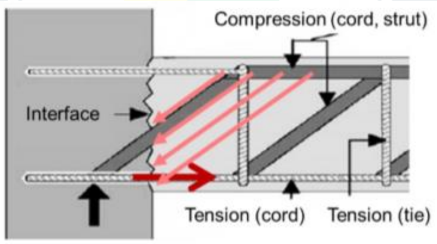

Figure 2 Strut-Tie Model

Figure shows a simply supported connection where there is only shear at the node and no moments. Even with only shear, through a strut and tie model, the bottom layer of reinforcement bars will be transferring tension stresses to the existing concrete. The tension force along the bottom layer of reinforcement bars is calculated using the following formula:

$F^{v} = (V/2) \cot g\, \theta$

Where

V = shear force at the node

θ = assumed angle of strut

F^{v} = tension on bottom bars

In a fixed connection (moment connection), the tension stresses will be depending on the direction of the moment.

To transfer tensile loads, post-installed reinforcement utilizes the existing cast-in reinforcement. In reinforced concrete design, it is fundamental to remember that the main reinforcement of every concrete element is designed to the yield strength of the reinforcement bars. This is to ensure that the structure fails in a ductile manner when the reinforcement bars take up the tension stresses within the concrete elements. In order to ensure a post-installed connection transfers stresses in the same way as a cast in connection, post-installed reinforcement bars must also be designed to fail in a ductile manner. And because post-installed reinforcement bars only transfer tensile loads in a concrete to concrete connection, it is important to ensure that the load transfer of these tension stresses will not cause a brittle failure. To ensure that, post-installed reinforcement bars have to be designed to transfer tensile stresses on to existing reinforcement within the concrete via lap splices. Without lap splices, the tension stresses will be transferred directly on to the concrete through compression struts and this will result in a brittle concrete failure.

Load transfer of a post-installed reinforcement bar must be equivalent to cast-in reinforcement bars Concrete is a relatively stiff and brittle material. A cast-in reinforcement bar design according to code requirements has direct mechanical interlock between the bar and the concrete. A post-installed reinforcement bar however, has a layer of adhesive between the reinforcement bar and the concrete substrate. Hence, in order to ensure that the post-installed reinforcement bar transfer stresses in the same manner as a cast-in reinforcement bar, the mortar or adhesive used in a post-installed solution must be checked for the stiffness behaviour and the adhesion properties. This is especially true of mortars or adhesives which are of the epoxy type. An epoxy material has a very elastic behaviour which causes displacement, a phenomenon known as creep. It is vital that this behaviour in epoxies are checked if an epoxy mortar is used in a post-installed connection.

B) Post-installed reinforcement approvals

European technical approvals are used for post-installed rebar connections. Systems getting such approvals have to be assessed according to the European Organisation for Technical approvals (EOTA) TR023. An installation system providing high installation quality for deep holes and an adhesive fulfilling the test requirements of the guideline TR023 are required for positive assessment. Obtaining the approval is basically the proof that post-installed rebar work as well as cast-in rebars with respect to bond strength and displacement; consequently, the design of the rebar anchorage is performed according to structural concrete design codes, in case of Europe this is Eurocode.

C) The Eurocode 2 Approach

The Eurocode 2 is mainly applicable to design of buildings and civil engineering works for plain, reinforced and prestressed concrete. Eurocode 2 is intended to be used in conjunction with EN 1992: Action on structures. Based on the European Technical Assessment (ETA) approval for the mortar system qualified according to European Organisation for Technical approvals (EOTA) TR023 which allows to use accepted structural code Eurocode 2 EN 1992-1-1:2011, chapter 8.4: "anchorage of longitudinal reinforcement" and 8.7: "Laps and mechanical couplers" taking into consideration some adhesive parameters. This method is called **"ETA/EC2 Design method"**

VII. DESIGN OF POST-INSTALLED ANCHORAGE EXPERIMENTAL INVESTIGATION

A) Design of Anchorage Length

Basic required anchorage length, design anchorage length and splice length are intended to ensure that the nominal yield strength of the bar can be developed under structure loading. Although Eurocode2 does not require a ductile design of the system connection, it is strongly recommended apply an anchorage length able to ensure the development of the nominal yield strength.

The basic required anchorage length $l_{bd_{req}}$:

$$l_{bd_{req}} = (\phi/4)\ (\sigma_{fd}/f_{bd})\ (\text{mm})$$

Where,

ϕ =the reinforcing bar diameter (mm)

σ_{sd} = design steel stress at the beginning of the anchorage (N/mm^2)

f_{bd} = design value of the ultimate bond stress (N/mm^2)

The design anchorage length l_{bd} is calculated from the basic required anchorage length $l_{b_{req}}$ taking into account the influence of five parameters (α_1 to α_5) and it should not be less than a minimum anchorage length. $l_{b_{min}}$.

Design anchorage length l_{bd}

Rebar under tension:

$$l_{bd} = \alpha_1\alpha_2\alpha_3\alpha_4\alpha_5 l_{bd_{req}} \geq l_{b_{min}}\ (\text{mm})$$

Rebar under compression: $l_{bd} = \alpha_4 b_{rqd} \geq l_{bmin}$ (mm)

Where

α_1 is for the effect of form of the bar assuming adequate cover

α_2 is for the effect of concrete minimum cover

α_3 is for the effect of confinement by transverse reinforcement

α_4 is for the influence of one or more welded transverse bars, along the design anchorage length.

α_5 is for the effect of pressure transverse to the plane of splitting along design anchorage length.

C) Minimum Embedment Depth

Minimum anchorage length $l_{b_{min}}$ requirement as per European standard is given by:

$$l_{b_{min}} = \max(0.3 l_{b_{req}}, 10\phi, 100\text{mm}) \text{ for bars under tension (mm)}$$

$l_{b_{min}} = \max(0.6 l_{b_{req}}, 10\phi, 100mm)$ for bars under compression (mm)

Anchorage length for post-installed rebar is calculated manually and using software.

7.1 Design Using European Standards

Anchorage length (243mm) is calculated for post-installed reinforcing bars for new simply supported slab of span 4.5 m on existing concrete structure, Rcc wall(subjected to Shear force 90.3 kN) using PROFIS Rebar software as shown below:

Thickness of wall: 300mm

Effective span of slab: 4.5m

Depth of Slab: 300 mm

Reinforcement provided at top: 4 bars of 10mm diameter

Reinforcement provided at bottom: 4 bars of 12 mm diameter

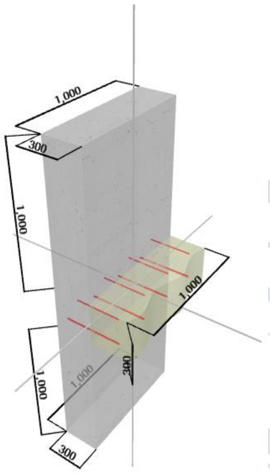

Figure 3 Wall to slab connection

VIII. ANALYTICAL INVESTIGATION

A three-dimensional model of above connection having similar geometry was modeled in ANSYS WORKBENCH.
The results of total deformations and modal analysis before and after connection are obtained in FE analysis.

8.1 Geometry

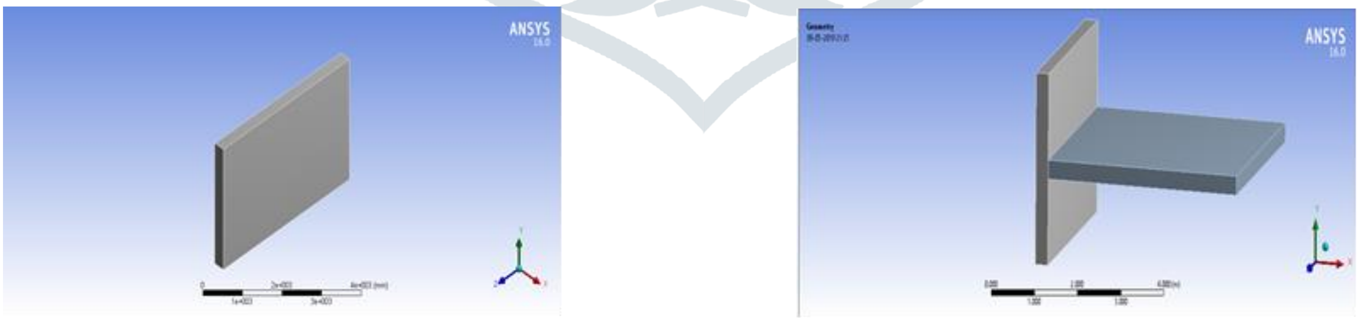

Figure 4 Geometry of Existing wall and Post-installed wall to slab connection

8.2 Modelling

Figure 5 Modelling and meshing of Existing wall and Post-installed wall to slab connection

8.3 Boundary Conditions and Loading

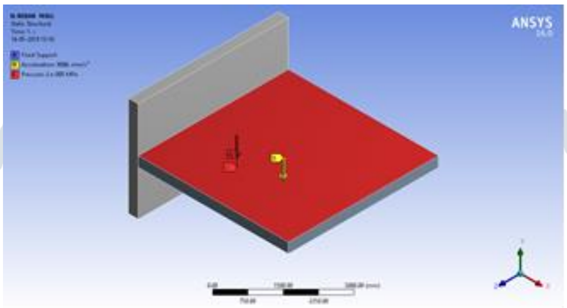

Figure 6 Boundary Conditions for Existing and Post-installed Structure

IX. RESULTS AND DISCUSSIONS

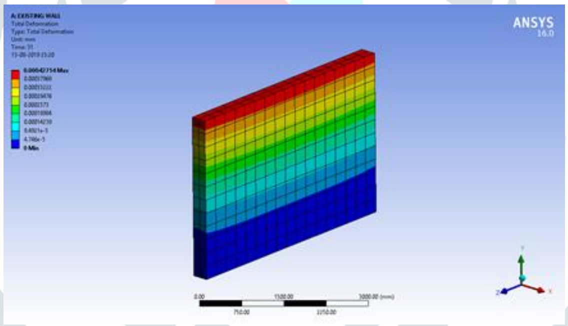

Figure 7 Total Deformation of Wall Before Post-Installed Connection

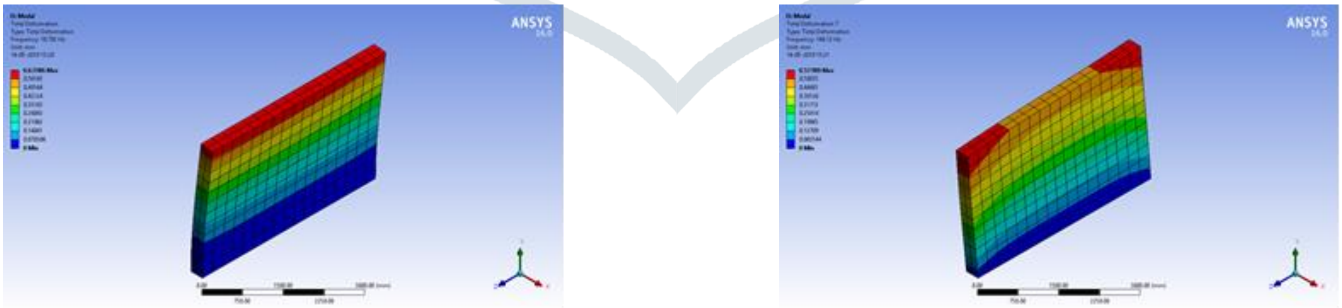

Figure 8 Modal Deformation of Existing Wall

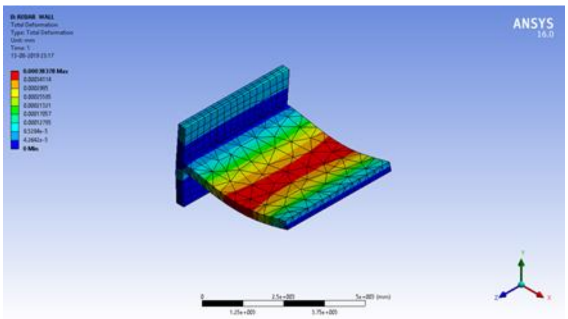

Figure 9 Total Deformation After Post-Installed Connection

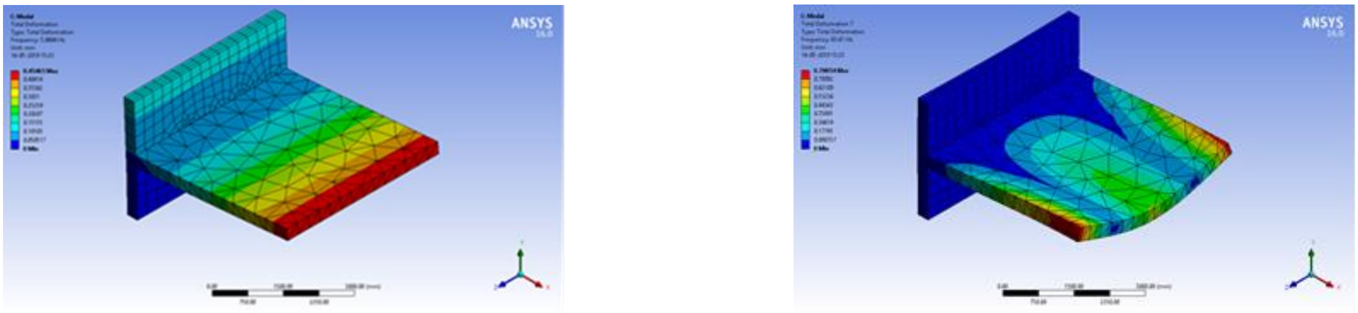

Figure 10 Modal Deformation After Post-Installed Connection

Deformation of existing wall is found to be 4.2714E -4 mm and deformation after post installed connection is found to be 3.8378E-4 mm.

X. CONCLUSIONS

In this paper effect of rebaring on existing structure is studied using FEM software ANSYS workbench. A concrete shear wall is taken for analysis. Comparative study of existing shear wall and After rebaring is taken for dead load and live load and following observations are made:

- Decrease by 15% in total deformation after rebaring is observed while structure is subjected to static loading.
- Natural frequency increased by approximately 38% in rebaring structure and hence deformation for mode shapes is also less respectively.

XI. ACKNOWLEDGMENT

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