A Study on Anchorage Bond of Helical End Rebar for Overlap of 12 mm Dia Rebar

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***Abstract*— The bond between the concrete and steel governs strength, ductility and serviceability of reinforced concrete structures. In precast concrete structures assembling of structural components is a major part to achieve the strength and serviceability of the whole structure. In the precast system the bond is a key parameter to achieve the proper connectivity between the joints. For assembling the components there are several techniques are available, generally grouted couplers are mostly used in assembling the components in precast construction. In this study of investigation finding the bond strength, bond behaviour, stress transfer in concrete and steel, failure mechanism, load-slip response and finding the lowest development for the required bond strength using helical end rebar system instead of couplers. Laboratory experiment was carried out by casting a cylindrical specimen with helical end rebar and NS 1 power grout embedded by concrete sourrounding it, using the calculated development length of 190 mm (as per IS code) for 12 mm diameter bar considering the NS 1 power grout pull out bond strength as 8 N/mm^2. this specimen was tested Under pull out test. Using abaqus software the above specimen is simulated, both laboratory and numerical specimen valiadated successfully. Hence the behaviour of anchorage bond with helical end bar can estimated through numerical analysis by varying salient parameters. In the present study the overlap length is taken as the main parameter, keeping rest all the parametrs same.**

***Keywords*— Bond, Development length, Helical end rebar, Power grout, Load-slip, Bond strength**

I. Introduction

Precast concrete is a widely used construction method in which structural elements are fabricated in a controlled factory environment and later transported to the construction site for assembly. This approach offers advantages such as improved quality control, faster installation, reduced labor costs, and enhanced safety. However, the structural performance of precast systems depends heavily on the effectiveness of the connections between elements, which are responsible for transferring loads, ensuring stability, and maintaining structural integrity. A key factor influencing connection performance is the bond strength between reinforcing steel and the surrounding concrete or grout. Bond strength ensures proper transfer of forces such as tension, shear, and bending, and is affected by factors like surface texture, grout quality, curing conditions, and reinforcement detailing. Insufficient bond strength can result in slippage, cracking, and premature failure, compromising the serviceability and durability of the structure.

Among the available connection techniques, threaded couplers are widely used in precast construction for their mechanical interlock, ease of installation, and ability to provide adequate bond and continuity. Threaded couplers ensure reliable load transfer and structural integrity, making them a preferred choice for connecting reinforcement bars in precast elements. Despite their effectiveness, there is ongoing research to explore alternative or complementary systems that may enhance bond performance or simplify construction. One such system is the helical end rebar, which has shown potential to improve bond behavior and stress transfer. An experimental program was conducted using cylindrical specimens with helical end rebars embedded in concrete with NS1 power grout. The development length was designed based on IS code provisions, considering a pull-out bond strength of 8 N/mm². Pull-out tests were performed to investigate bond strength, load–slip behavior, stress transfer, and failure modes.

In addition to experimental investigation, a numerical model of the specimen was developed and analyzed using ABAQUS software, and the results were successfully validated against laboratory findings. This enabled a parametric study to estimate the anchorage bond behaviour of helical end rebars under varying conditions. In the present work, overlap length is considered as the primary variable, while other influencing factors are kept constant.The findings provide valuable insights for optimizing threaded coupler connections and improving the overall performance of precast concrete structures.

II. Materials

A. Grout

NS power grout is a high-performance, non-shrink, cement-based grout developed with special polymers, additives, and fillers to provide high strength, excellent flowability and a strong bond in precesion grouting applications.

It is a self-compacting, single-component system. The grout is used to fill the hallow region inside cylinder along with the reinforcement in it which gives a proper bond between the grout and reinforcement. The properties of grout material that is considered are tabulated in Table (I). This grout material mixed through hand mixing thoroughly untill it became a smooth paste care was taken while mixing, considering a water content of 16% of grout.

TABLE I
PROPERTIES OF NS 1 POWER GROUT

NS - 1 Power Grout (designation)	Properties
Wet density	2250-2350 kg/cum
Flowable consistency water ratio (IS 516 -1959)	16% water ratio
Type of mixing	Manual mixing
Pull Out Bond Strength MPa @ 28 days (IS 2770)	8-9 N/mm^2
Tensile Strength @ 28 days MPa (ASTM 190)	8.5 N/mm^2
Compressive strength N/mm2 (IS 4031 Part 6)	100 N/mm^2

B. Aggregates

Fine aggregate was taken from natural river sand, the physical properties of fine aggregates like specific gravity, gradiation of fine modules and bulk density were tested in laboratory as per IS 2386:1963 code and are mentioned in table (II).

Coarse aggregates used was crushed granite with a maximum nominal size of 20 mm, confirming to IS 383:2016. Aggregates have a rough texture and are in angular shape. The physical properties of coarse aggregates are mentioned in table (II).

TABLE II
PHYSICAL PROPERTIES OF AGGREGATES

S. no	Property	Fine aggregate	Coarse aggregate
1	Specific gravity	2.63	2.8
2	Finess modulus	2.18	6.06
3	Water absorption	1 %	0.5 %

C. Cement

Ordinary portland cement of 53 grade is used in this study of experiment confirming to IS 12269:2013 code. Physical tests were conducted on the cement and whose properties are mentioned in table (III). Cement is uniform in colour, smooth and fresh and it is free from lumps.

TABLE III
PHYSICAL PROPERTIES OF CEMENT

S.no	Property	Value
1	Initial and Final setting time	75 & 270 min
2	Specific Gravity	3.02
3	Compressive Strength:	(N/mm^2)
	3	39.06
	7	46.21
	28	56.43

D. Reinforcement

In this study Fe 500 grade of steel is used confirming to IS 1786:2008. Two reinforcing bars were considered in which one of them is a helical end rebar, it has 4.5 turns at the end with a zero clear pitch or a pitch of diameter distance to it, And another one is a straight rebar. Helical end rebar and combining of both straight and helical end rebar were shown in Figure 1.

Figure. 1 Interlocking of helical end and a straight rebar

E. Sleeve

Aluminium sleeve is taken for the experiment with a diameter of 60mm, the sleeve is used to create a hallow region in cylinder specimen.

III. METHODOLOGY

A. Mix Design

Based on the calculations and laboratory trials, the mix design presented in this study was developed and adopted for the present investigation. The objective of the design was to achieve an characteristic compressive strength of 40 N/mm². Ordinary Portland Cement (OPC) of 53 grade was used, with a water-to-cement ratio of 0.40. The fine aggregate and coarse aggregate contents were 596 kg/m³ and 1142 kg/m³, respectively. The detailed mix proportions for M40 grade concrete are provided in Table (IV).

TABLE IV
MIX PROPORTIONS FOR M40 CONCRETE

Mix proportions	**Quantities in kg/m^3**
Grade	M40
Workability	100
Type of cement	Opc 53 grade
Water cement ratio	0.4
Cement	450
Fine aggregates	596
Coarse aggegates	1142
Mix proportion	1 : 1.325 : 2.53

The M40 grade concrete mix proportion was developed using the trial-and-error method in accordance with IS:10262 and with the specified material properties. The manual calculations yielded a target strength of 48.25 N/mm² at 28 days of curing, with the corresponding mix proportions. Based on this mix, three cube specimens were casted and tested after 28 days of curing, achieving an average compressive strength of 49.48 N/mm². According to IS code the compressive strength is expected to reach the full target strength of the 28-day curing, which was satisfactorily achieved in the laboratory. Therefore, this mix design was adopted for the experimental investigation.

B. Development Length

As per IS 456:2000 (Clause 26.2.1), the required development length of bars was calculated considering a grout of bond strength 8 MPa, steel of grade 500 MPa. It is 190 mm for 12 mm diameter bar.

C. Laboratory Experiment

The laboratory investigation was carried out in two stages: casting and testing. The casting process itself consisted of two sub-stages. In the first stage, a hollow cylindrical specimen of outer and inner diameters as 150mm and 60mm and a height of 190mm was prepared by placing an aluminium sleeve of diameter 60mm with a height of 190mm at the center, as illustrated in Figure 2. The M40 grade concrete mix, prepared using a concrete drum mixer, was poured into the mould. After 24 hours, the specimen was demoulded and subjected to water curing for 28 days Figure 3. In the second stage of casting, power grout was filled into the cured hollow cylinder with reinforcement placed inside. A helical end reinforcing bar along with a straight bar was positioned within the cylinder, as shown in Figure 4. The grout, prepared by hand mixing with 16% water content, was poured into the setup and allowed to set for a few hours before being subjected to another 28 days of curing. The final specimen obtained from this procedure was designated as C1.

Figure. 2 Mould for casting the specimen

Figure. 3 Hallow cylinder after curing

Figure. 4 Grouting the specimen with rebars

Figure. 5 Placement of specimen in UTM for the test

The second stage of the laboratory investigation involved testing the cast specimen (C1). A pull-out test was conducted to evaluate the load–slip behavior. For this purpose, the specimen was mounted in a Universal Testing Machine (UTM) of 1000 kN capacity as shown in Figure 5, calibrated in accordance with IS:1828-2005. The load was applied gradually at a uniform rate until failure occurred. During the test, the specimen was positioned such that the lower end of the reinforcing bar was gripped in the lower jaws of the machine, while the upper end was subjected to upward pulling. Load and slip measurements were continuously recorded throughout the test. Once the peak load was reached, the experiment was terminated.

D. Numerical Experiment

To complement the experimental investigation, the specimen C1 was also modeled using the finite element software Abaqus. The geometry, material properties, and testing conditions adopted in the simulation were kept identical to those of the laboratory experiment, allowing a direct comparison between experimental and numerical results. The simulation of specimen C1 in Abaqus was carried out through a sequence of steps, ensuring accurate representation of the specimen and validation of the experimental findings. Following are the steps considered for modelling :

I. Parts and Properties

In this study, the geometry of the helical end bar reinforced concrete specimens was developed using Dassault Systèmes CATIA and imported into Abaqus/CAE for finite element simulation. The specimen comprised four main components: a hollow concrete cylinder with an outer diameter of 150 mm, inner diameter of 60 mm, and a height of 190 mm; a solid grout cylinder of diameter 60 mm and height 190 mm; a helical end bar with 4.5 turns and a length of 54 mm; and a straight reinforcement bar of 12 mm diameter extended by 50–100 mm beyond the cylinder. Grooves corresponding to the shapes of the helical and straight bars were created within the grout to replicate realistic interlocking between steel and concrete. The concrete was modeled using the Concrete Damage Plasticity (CDP) model to capture cracking, stiffness degradation, and crushing under compression, while the steel reinforcement bars (both straight and helical) were modeled as elastic–plastic materials with defined yield stress, modulus of elasticity, and hardening parameters consistent with laboratory data.

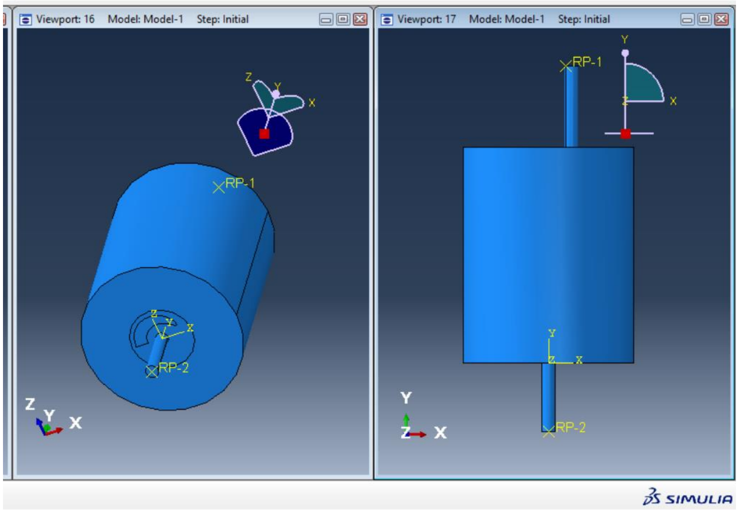

Figure. 6 Creation of model in abaqus

II. Step Definition

The analysis was performed using the dynamic explicit procedure in Abaqus to simulate the nonlinear response of the specimen under controlled loading conditions. The total analysis time was set to 0.1 seconds, with output requests defined to monitor the behavior throughout the loading phase. Field outputs, including stresses, displacements, forces, and damage parameters in both compression and tension, were recorded at every 20 intervals across the entire model. History outputs were defined at specific reference points to track displacement (U2) and reaction forces (RF2) during the test. These settings ensured that both global and local responses of the specimen could be accurately captured.

III. Mesh Generation

The finite element model was discretized using quadratic tetrahedral elements with a global seed size of 5 mm. This meshing approach provided a balance between computational efficiency and accuracy in capturing stress concentrations and nonlinear material behavior. All parts, including the concrete cylinder, grout core, helical bar, and straight reinforcement, were meshed using the same element type and seed size, ensuring uniformity and consistency throughout the model.

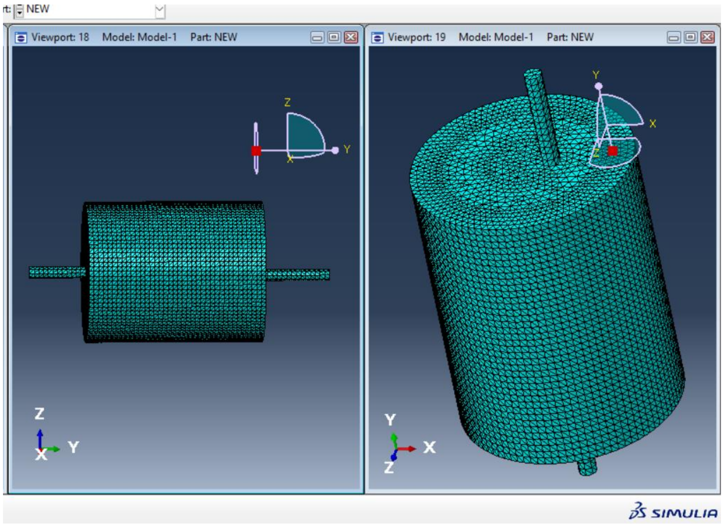

Figure. 7 Generation of tetrahedral mesh

IV. Interaction and Boundary Conditions

The interaction between concrete, grout, and steel was defined using contact properties. The normal contact behavior was modeled using hard contact to prevent penetration under compression, while tangential contact was modeled using the penalty method with a coefficient of friction of 0.6 to simulate slip resistance at the interface. Reference points were coupled with the reinforcement bars using rigid body constraints, enabling controlled application of loads and boundary conditions. One end of the specimen was fully constrained using the Encastre boundary condition, which restricted all translational and rotational degrees of freedom, simulating a rigid support. At the opposite end, a displacement-controlled boundary condition was applied with a prescribed displacement of (–3) mm along the loading direction. This method closely replicated laboratory testing where displacement control is preferable for capturing post-peak behavior and bond-slip responses.

IV. Results and Discussion

A. Laboratory Experiment

In laboratory experiment specimen C1 is tested under uniform tension load in (UTM) machine, load and deofrmation are noted continuously. In this experiment it is observed that as load increased deformation also increased simultaneously. The load deformation diagram as shown in Figure 8. The load gone upto a peak load of 66 KN after that it continued to decrease, the test is terminated. the failure of the specimen as shown in Figure 9. It is noted that the cracks are formed at a load of near to the peak, and further application of load results in formation of cracks and spalling of concrete around the sleeve. This shows that the bar experienced a perfect bond between the grout and rebar and transmitted to the tensile force developed in the grout due to bond, to the sleeve and the sleeve in turn transmitted the tensile force to the surrounding concrete.

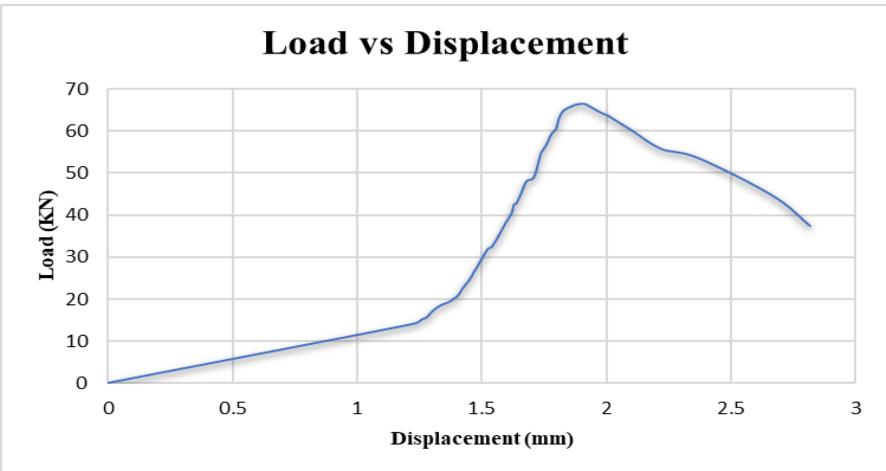

Figure. 8 Laboratory load-displacement diagram for specimen C1

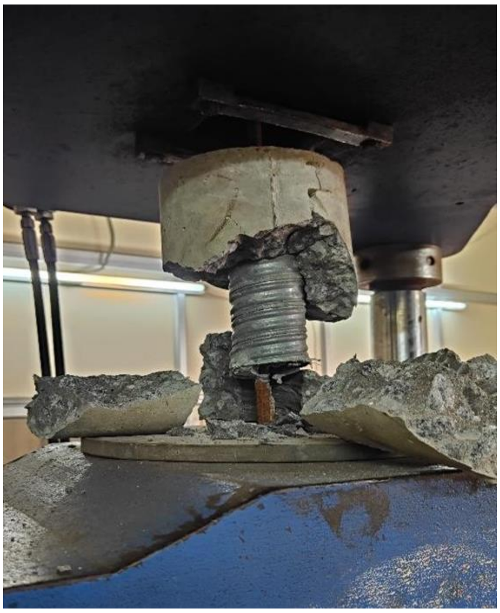

Figure. 9 Failure of surrounded concrete in (UTM)

The reinforcing bar considered is FE 500 grade, the expected yield load is 56.5 KN. The specimen has reached a load of 66 KN with 190mm provided anchorage length for this specimen taking τ_b values is 8 N/mm^2 for the grout material is well satiesfied as there were no cracks observed at 56.5 KN load.

The calculated tensile strength of M40 grade concrete is 4.42 N/mm^2 using the experssion $0.7\sqrt{f_{ck}}$ as per IS code. The tensile strength of M40 grade concrete obtained through the test is by dividing the peak load of 66 KN with the cross sectional area of concrete of 14844 mm^2 which results in a value of 4.4 N/mm^2. Through this it is clear that the reinforcing bar and the grout have effectively bonded and the tested specimen with a overlap length of 16D for bar and with a helical end for the other have effectively contributed for providing bond anchorage characterisrtic.

B. Numerical Experiment

The specimen C1 is simulated in abaqus software with same properties and parameters as laboratory experiment. The load-displacement diagram for specimen C1 is shown in Figure 10. The experiment load-displacement diagram is overlapped on the numerical analysis load-displacement diagram . It is shows that the load-displacement diagram obtained by numerical experiment almost coincides with laboratory experiment load-displacement diagram which is shown in Figure 11. Hence the behaviour of anchorage bond with helical end bar can estimated through numerical analysis by varieng salient parameters.

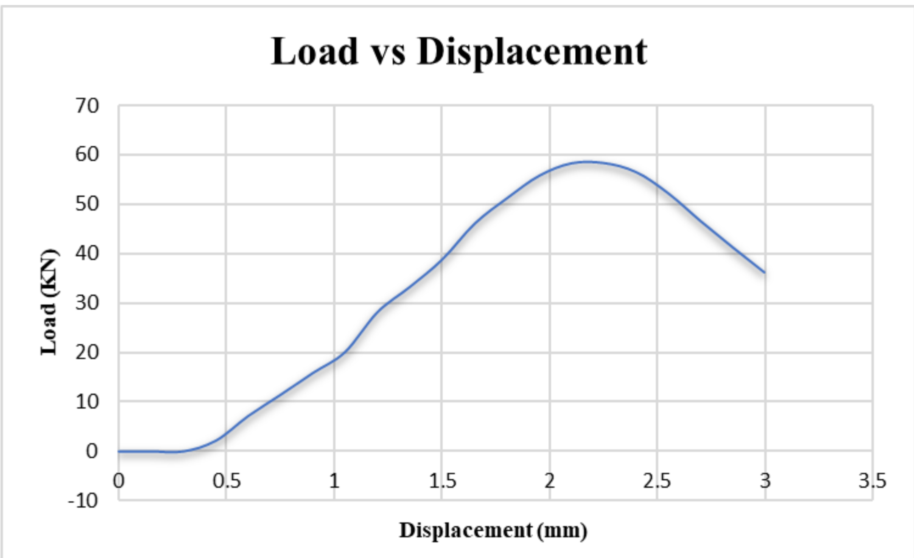

Figure. 10 Numerical load-displacement diagram for specimen C1

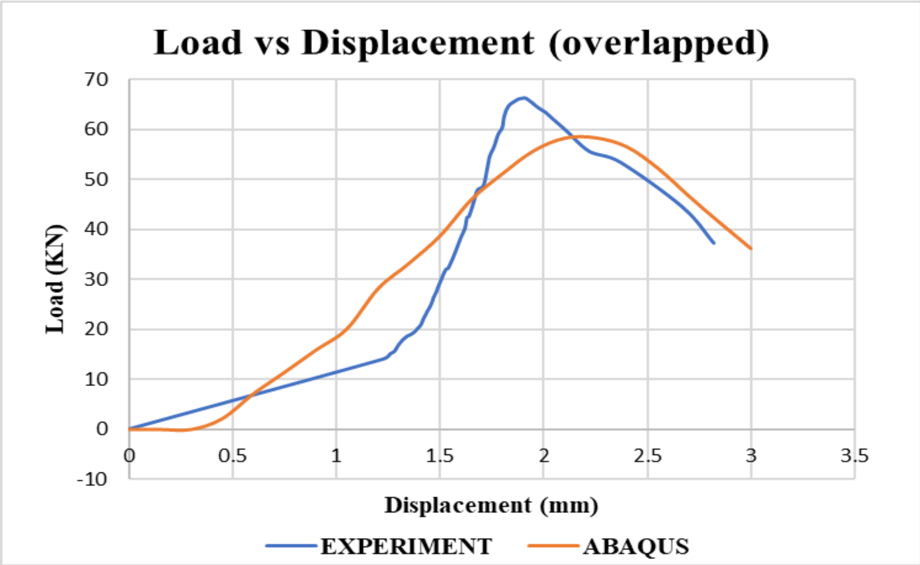

Figure. 11 Overlaping of experimental & numerical load-displacement diagram

In this study overlap length is taken as the main parameter, keeping all other parameters same. The overlap lengths taken are 14D, 12D, 10D, 8D and 6D where D is the diameter of bar that is 12 mm and they are named as C2, C3, C4,C5 and C6 respectively. Results of specimens C2 to C6 : the Load-displacement diagram for the specimens C2 to C6 obtained from numerical analysis and specimen C1 in both laboratory and numerical experiments is shown Figure 12. The load at peak obtained, stress in the rebar and bond strength are calcultaed for all the specimens and are given in Table (V).

TABLE V
PHYSICAL PROPERTIES OF CEMENT

S.no	**Specimen name**	**designation**	**Anchor length (mm)**	**Peak load (KN)**	**Stress (σ_s) (N/mm^2)**	**Bond strength (τ_b) (N/mm^2)**
1	C1	Laboratory	16D	66	583.3	9.21
2	C1	Numerical	16D	58	512.37	8.09
3	C2	Numerical	14D	50	441.84	7.89
4	C3	Numerical	12D	43	380.16	7.92
5	C4	Numerical	10D	35	309.2	7.73
6	C5	Numerical	8D	24	212.16	6.63
7	C6	Numerical	6D	10	88.32	3.68

On examination of the results shows that the bond strength is 7.9 N/mm^2 for 14D and 12D anchorage lengths, which is almost equal to the bond strength of grout. The effective anchor for a 12D overlap length specimen C3 is obtained by deducting helical portion equal to 4.5D, therefore the effective anchor is (12D-4.5D) which is equal to 7.5D. for the specimens of 10D, 8D and 6D the bond strength is less which clearly indicates that the 7.5D effective anchor length is sufficient to develop bond strength between grout and reinforcement.

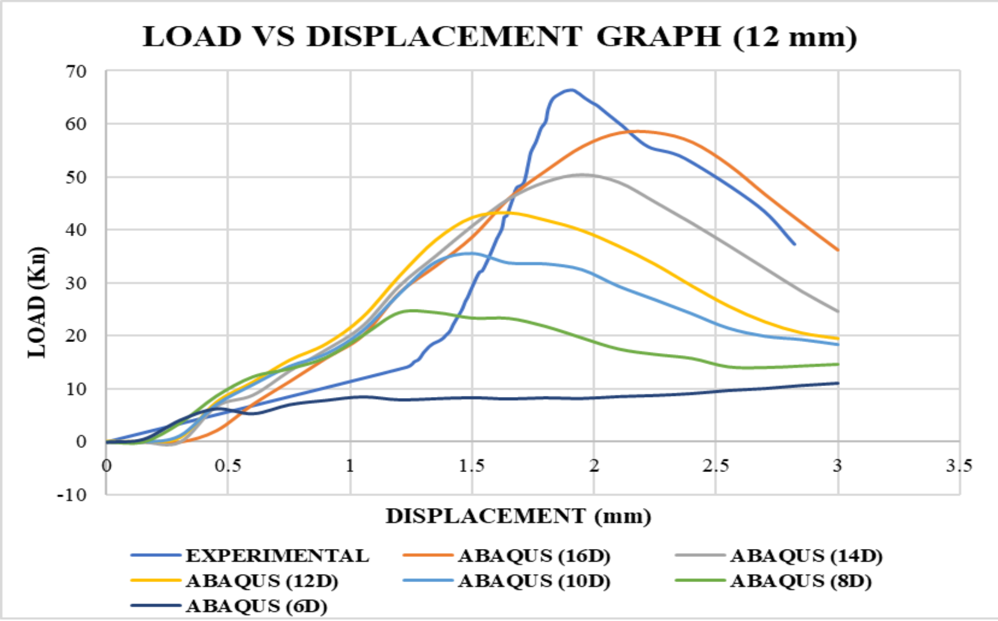

Figure. 12 Overlaping of experimental & numerical load-displacement diagrams of all specimens

V. Conclusions

From the laboratory and numerical experiments the conclusions drawn are listed below:

1. Experimental study of the specimen C1 in the pull out test reached a peak load of 66 kN with anchorage length 190 mm, against the expected yield load of 56.5 kN. There were no cracks at 56.5 kN.
2. The tensile strength of M40 concrete as per IS code is 4.42 N/mm^2 and same is observed with experimental result is 4.4 N/mm^2.
3. It is clear that the reinforcing bar and the grout have effectively bonded and the tested reinforcing bar with a overlap length of 16D for one bar and with a helical end for the other bar have effectively contributed for providing bond anchorage characteristics.
4. Validation of numerical and experimental model is satisfactory.
5. An Effective overlap length 7.5D is sufficient to provide bond anchorage for a bar with helical end.

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