Proceedings of 14th IOE Graduate Conference
Peer Reviewed
Year: 2023 Month: December Volume: 14
ISSN: 2350-8914 (Online), 2350-8906 (Print)

Pullout Capacity of Rebars as Anchor Rods in Nepali Construction Context

Sujan Chapagain [a], Rajan Suwal [b]

[a, b] *Department of Civil Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[a] 078msste019.sujan@pcampus.edu.np, [b] rajan_suwal@ioe.edu.np

Abstract

Rebars are commonly used as anchor rods in Nepali construction practice because of their accessibility and low cost. Understanding of anchorage behavior and load capacity of rebar anchor rods (RARs) is crucial for the design and global safety of a structure. The performance of RARs depends heavily on the rebar-concrete bond. In this study, the bond strength between deformed rebars and concrete is used to predict the pullout capacity of RARs. The bond strength and development length of deformed rebar in concrete are compared between NBC 105:2020 and four other bond strength prediction models. Results indicate that the required development length in NBC 105:2020 is very conservative with as much as 5 times the length required by other bond models. Improvement in these could lead to more economic construction in Nepal in anchorage as well as general concrete structures.

Keywords

Anchorage in concrete, Bond, Concrete, Deformed rebars, Development length

1. Introduction

Anchor rods (also called fasteners) are commonly used in structures to fasten steel columns to concrete pedestals or foundations. In Nepal, they are also used in hospital supply lines, truss supports, highway signs, street lighting, etc. In Nepal, cast-in-place anchors are used more than post-installed anchors. Design, detailing, and construction of anchor rods and anchorage to concrete is vital because they often connect not just non-structural components but also structural elements to supporting concrete base. However, the design practice regarding anchorage has not yet matured in Nepal. During reinforced concrete construction, due to the cut-off length of rebars in finite construction dimensions, short pieces of rebars are often discarded - also known as 'scrap rebars.' These otherwise discarded rebar pieces have found use as cost-effective replacements for traditional cast-in anchors. By imposing safe design criteria, due to their low cost and ease of access, rebars could be used for anchorage in concrete with reliable performance and improved economy.

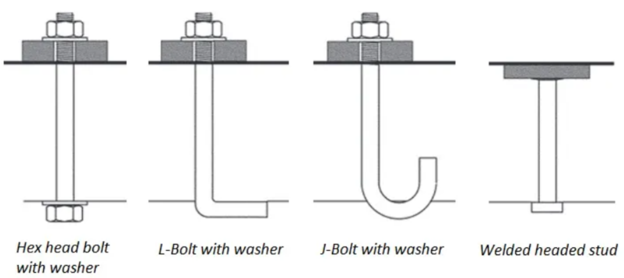


Figure 1: Some traditional cast-in anchors

The potential application of Rebar Anchor Rods (RARs) is shown in Figure 2. These rebar pieces may be used by either threading the rebar and using nuts (Option 1) or by welding to the underside of an embed plate (Option 2). The rebar may be either of straight length or hooked (J-hook or L-hook). While the associated cost and construction time are roughly similar for either option, the performance and dominant failure mode in the different options are starkly different. This study focuses on the use of straight-length rebars monotonically loaded in tension in an embed plate. The connection between rebar and steel plate is outside the scope of this study.

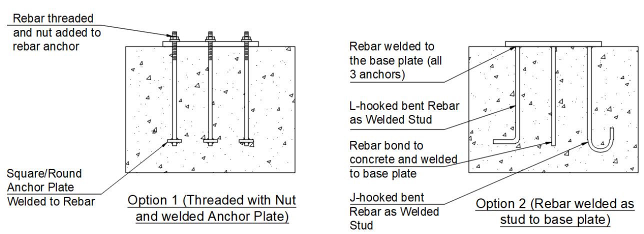


Figure 2: Options for Rebar used as anchor rods - Section only

The load applied to anchors can be transferred to the embedding concrete by three major mechanisms as follows [1]:

- Mechanical interlock: bearing between anchor head and concrete as in headed anchors
- Frictional interlock: friction between anchor shaft and concrete as in some mechanical anchors
- Chemical bond: the chemical attraction between anchor body and concrete as in adhesive anchors

Depending on their structure, RARs may be subjected to either of the three load mechanisms. But, when anchor heads/plates are not considered, load transmission in RARs occurs via bond with concrete. The bond between deformed rebar and concrete depends on all three load transfer mechanisms.

2. Research Significance

Steel structures are being increasingly used in Nepal for structure construction. This means a proportionately rising use of anchorage in concrete. However, there is a lack of code of design guidelines in Nepal for anchorage design although many countries and regions have codified the design of anchorage [2, 3]. Despite the ubiquitous use of anchors and RARs, this is a relatively new topic of study compared to rebar and concrete. Studies are still ongoing and experimental results from tests on RARs are scant [4]. Most current design equations are based on CCD (Concrete Capacity Design) method [1].

But in the absence of code provisions, designers in Nepal have also used the development length of rebars to calculate the embedment length and corresponding anchorage capacity of anchors. This could lead to inaccurate capacity assumptions as most bond strength predictions are made for rebars in beams, and, as will be shown in this study, the code provisions in NBC 105:2020 [5] differ significantly from others such as in fib MC2010 [6]. Additionally, studies have shown that using RARs could lead to concrete breakout cone failure which is not accounted for by the development length approach [7]. However, this study is focused on the pullout failure of bonded rebar subjected to tension.

3. Bond Between Rebar and Concrete

In this study, RARs are assumed to fail by either steel rupture or pullout failure. Provided that the steel strength of the rebar is higher than the pullout capacity, RARs can be assumed to always fail by pullout from concrete. Steel failure is generally seen in deep anchors and in High Strength Concrete (HSC). In Normal Strength Concrete (NSC) without deep embedment, anchors seldom fail by steel rupture. Under pullout failure, anchors of all kinds get pulled out of the concrete block in which they are embedded. For RARs, pullout failure is controlled by the bond strength. The bond mechanism is a complex mechanism that depends on many factors. Bond failure may occur by pullout or by splitting. In this study, pullout failure is focused on, but the considered bond strength prediction equations take into account both pullout failure mode and splitting failure mode.

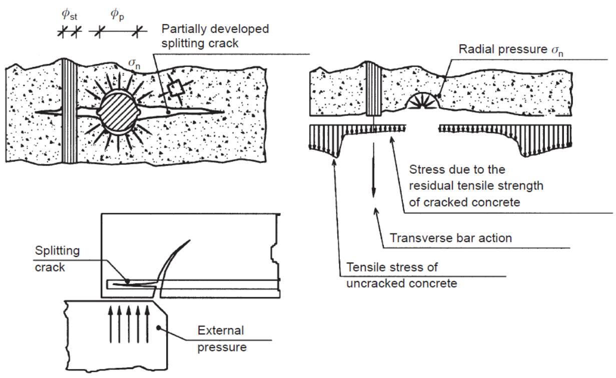


Figure 3: Splitting and confining actions around a deformed rebar from Plizzari et al (1998)

When rebar is in low tension force, slip (relative displacement) is resisted by the chemical attraction between rebar steel and concrete. Then a small slip occurs corresponding to frictional force. Chemical attraction and friction constitute a small part of the overall bond strength of deformed rebar. The rest of the strength is provided by the interlocking of concrete and transverse ribs in rebars. As further tension is applied, concrete between rebar ribs gets damaged, and slip increases. After a certain slip, bond strength reaches its peak value and begins to decrease. The overall phenomenon results in the local bond strength of deformed rebar bonded to concrete. The bond strength is affected by many parameters. They can be listed as:

- Concrete strength in compression and tension and bearing
- Confinement to rebar due to concrete cover (side cover, bottom cover, rebar spacing) and transverse reinforcement (transverse reinforcement strength, spacing, area, number)
- Rebar strength (yield strength generally)
- Rebar condition (surface coating, rebar steel type)
- Rebar rib properties (rib spacing, rib height, rib face angle, rib width, relative rib area)

Many studies have been conducted to improve the bond mechanism [8, 9, 10, 11]. All studies on bond mechanisms seem to agree that bond strength depends on the above-mentioned parameters. However, the degree of dependence on a parameter varies from study to study. For example, ACI 318M-19 and Harajli assume $\sqrt[2]{f_{cm}}$ term to describe bond strength. But Model Code 2010 assumes $\sqrt[4]{f_{cm}}$ term instead. Similar differences exist for other parameters. Further interpretation of the effect each of these parameters has on bond mechanism may be found in the literature [8, 9, 10, 11, 2].

4. Prediction of Bond Strength

Different codes and studies have suggested different methods to predict the bond strength of rebar bonded to concrete. Most of these studies are based on spliced rebars in beams. Explicit tests on rebars designed to act as anchors are uncommon. However, in this study, an attempt has been made to modify the boundary conditions in each prediction model wherever possible to circumvent the lack of experimental data to support the bond strength of RARs. In each bond strength prediction model considered in this study, the output is either bond strength or development length based on the yield capacity of rebar. The output values are given in the literature to avoid bond failure through splitting failure as well as pullout failure.

The following assumptions are necessarily made to compare the results of different bond prediction models:

1. Unit conversion has been explicitly considered to equate the output in SI units and imperial units.
2. The concrete strength and other parameters are normalized to negate the differences caused by parameters such as characteristic cube concrete strength in NBC 105:2020 and mean cylinder concrete strength in fib Model Code 2010, differences in the definition of minimum cover defined in bond prediction models, etc.

3. Development/splice/embedment/bond lengths are defined as the length of the bonded rebar from its end to the start of the critical section (e.g. the splice length of two adjacent rebars).
4. Although prediction models may not explicitly consider failure mode, both pullout and splitting failures have been considered.
5. The bond length required for spliced rebars, developed rebars, and anchored rebars are the same in all cases.
6. Uniform Bond Model (UBM) has been assumed to be valid throughout the bond length for the sake of simplicity. It is assumed that the bond stress is constant throughout the bond length while tensile stress in rebar linearly varies along the length. For rebar of diameter ϕ, and yield strength f_y, at a bond length of L_b, the bond stress τ_b developed between rebar and concrete is expressed as:

$$\tau_b = \frac{\phi f_y}{4L_b} \quad \text{i.e.} \quad \frac{L_b}{\phi} = \frac{f_y}{4\tau_b} \tag{1}$$

The UBM equations are intended for when rebar is stressed to a permissible limit - usually f_y/γ (γ is the factor of safety for rebar yield strength). When rebar is stressed below f_y, codes allow the required development length to be decreased by a factor of the ratio of provided rebar area and required rebar area for yielding (A_{prov}/A_{req}). Similarly, a minimum development length (e.g. 300 mm) is specified in codes to account for the variations in bond strength due to construction imperfections, local geometric non-linearity in rebars, and probable local damage due to short bond length. In this study, it has been assumed that bond strength is calculated for the yield strength of rebar without a limiting factor of safety or excess reinforcement. Minimum bond length and $L_b/\phi$is also ignored during comparison.

The different bond prediction models considered in this study are listed here. The equations are in SI units unless otherwise mentioned.

4.1 Orangun, Jirsa, and Breen, 1977

This paper presented an equation to calculate the development/splice lengths of rebars bonded in concrete [8]. The equation was based on a statistical analysis of tests on beams with lap splices. The bond capacity could be expressed in imperial units as:

$$\tau_b = \sqrt{f_c'}\left(1.2 + \frac{3\,C_{min}}{\phi} + \frac{50\,\phi}{L_b} + \frac{A_{tr}\,f_{yt}}{500\,S_{tr}\,\phi}\right) \tag{2}$$

Here, f_c' represents the mean compressive strength of concrete in psi. f_{yt} is the yield strength of transverse reinforcement bars in psi. A_{tr} and S_{tr} are the cross-sectional area (in^2) and center-to-center spacing (in) of the transverse reinforcement respectively. As per the study, an upper limit was set for the benefit of transverse reinforcement as $(A_{tr} f_{yt})/(500 S_{tr}\phi) \leq 3$. Also, a limit was imposed for the influence of concrete cover as $C_{min} \leq 2.5\phi$.

This bond prediction model takes into account the effect of concrete strength, rebar diameter, rebar bond length, and transverse reinforcement (spacing, cross-section area, and yield strength). It however does not take into account the effect of rib geometry of rebar or rebar coating. The influence of concrete cover is also based on a single parameter.

4.2 Harajli (2004)

This bond prediction model was based on results from experiments on spliced rebars in beams [10]. The rebars had a short bond length of 5ϕ only. The author proposed a local bond-slip model as well based on test results. From the study, the following expression can be obtained for bond strength:

$$\tau_b = \gamma\sqrt{f_c'}\left(\frac{C_{min}}{\phi}\right)^{2/3} \tag{3}$$

Here, γ depends on the concrete strength. Its value is taken as $\gamma = 0.95$ for HSC (≥ 48 MPa) and $\gamma = 0.75$ for NSC. C_{min} is the minimum of the side cover to rebar, the bottom cover to rebar, or half of the center-to-center spacing of the rebars in tension. The author proposed a limit of $\tau_b \leq 2.57\sqrt{f_c'}$ for maximum bond strength.

This model takes into account the effect of rebar diameter, concrete grade, and concrete cover on bond strength. However, it does not consider the effect of rib geometry and confining reinforcement. The equation also considers a more conservative approach to the consideration of concrete cover as the effect of the smallest effective cover is considered. The benefit of a large concrete cover in either direction is not taken into account. This model also does not consider the effect of bond length and rebar coating (or surface condition).

4.3 fib Model Code 2010

fib Model Code 2010 provides an equation for the calculation of mean stress in a deformed rebar [6]. The equation was based on the experimental results of over 800 tests. The equation is intended for uncoated rebars with relative rib areas between 0.05 and 0.14 and bonded in concrete with strength between 15 MPa and 110 MPa. By using UBM Equation (1), the bond strength can be calculated as:

$$\tau_b = 13.5\left(\frac{f_{cm}}{25}\right)^{0.25}\left(\frac{25}{\phi}\right)^{0.2}\left(\frac{\phi}{L_b}\right)^{0.45} \left[\left(\frac{C_{min}}{\phi}\right)^{0.25}\left(\frac{C_{max}}{C_{min}}\right)^{0.1} + K_m K_{tr}\right] \tag{4}$$

Here, f_{cm} is the mean cylinder compressive strength of concrete. C_{min}, C_{max} are the minimum and maximum of half of center-to-center rebar spacing, side clear cover to rebar, and bottom clear cover to rebar respectively. K_m is a confinement factor taken as 12. The following additional limits are set:

$$K_{tr} = \frac{n_{tr}\,A_{tr}}{S_{tr}\,\phi\,N_b} \quad but \quad K_{tr} \leq 0.05 \quad i.e. \quad K_m\,K_{tr} \leq 0.6$$

$$\text{Also, } 0.5 \leq \frac{C_{min}}{\phi} \leq 3.5 \quad ; \quad \frac{C_{max}}{C_{min}} \leq 5 \quad ; \quad L_b \leq 10\phi$$

In this bond model, concrete strength, cover distance, rebar diameter, and transverse rebar area and spacing are considered. A_{tr} and S_{tr} are the cross-sectional area and center-to-center spacing of the transverse reinforcement respectively. But rebar rib geometry and rebar surface condition are not explicitly considered. The effect of rebar yield strength is implicitly considered in Equation (4). N_b in K_{tr} refers to the number of rebars in tension.

4.4 ACI 318M-19

ACI 318M-19 is the metric version of American concrete building code [2]. Using UBM in the code provision of L_b/ϕ, the following expression can be obtained for bond strength between deformed rebar and normal-weight concrete:

$$\tau_b = \frac{0.275}{\psi_t\,\psi_e\,\psi_s\,\psi_g}\,\frac{C_b + K_{tr}}{\phi}\,\sqrt{f'_c} \tag{5}$$

Here, for code comparison, f'_c is taken as the mean compressive strength of concrete instead of characteristic strength. ψ_t is the term for top bar position (or casting position). $\psi_t = 1.3$ when at least 300 mm of fresh concrete is poured below rebar. For other cases, $\psi_e = 1.0$. ψ_e relates to epoxy coating on rebar. For uncoated rebars, $\psi_e = 1.0$. The effect of rebar diameter is additionally considered by ψ_s. $\psi_s = 1.0$ for $\phi \le 19mm$ and $\psi_s = 0.8$ for $\phi \ge 22mm$. The effect of rebar yield strength is considered by ψ_g where $\psi_g = 1.0$ for Grade 280 or Grade 420 rebar, $\psi_g = 1.15$ for Grade 550 rebar, and $\psi_g = 1.3$ for Grade 690 rebar. In this study, linear interpolation has been used for Grade 500 rebar.

C_b is the least of side cover (measured to rebar center), bottom cover (measured to rebar center), and half of the center-to-center spacing between rebars. $K_{tr} = (40\ A_{tr})/(S_{tr}N_b)$ take into account the effect of the cross-sectional area A_{tr} and center-to-center spacing S_{tr} of the transverse reinforcement. N_b in K_{tr} refers to the number of rebars in tension. The effect of concrete cover and transverse reinforcement on bond strength is controlled by the following limit:

$$\frac{C_b + K_{tr}}{\phi} \le 2.5$$

This bond prediction model does not consider the effect of rib geometry on bond strength.

4.5 NBC 105:2020

NBC 105:2020 is a code for seismic design of buildings in Nepal [5]. Using rebar yield strength and characteristic cube compressive concrete strength f_{ck}, a L_d/ϕ ratio is obtained.

Table 1: L_d/ϕ for deformed rebars (NBC 105:2020)

Rebar grade	Concrete strength (grade in MPa)				
(MPa)	M20	M25	M30	M35	≥ M40
Fe - 415	47	40	38	33	30
Fe - 500	57	49	45	40	36

While the origin of these values is not clarified, it is likely from an assumption of 60% increase in bond strength in deformed rebar from bond strength in plain rebar with bond strength in plain rebar being given as:

$$\tau_{b,plain} = 0.16 f_{ck}^{2/3} \quad \text{which gives} \quad \frac{L_d}{\phi} = \frac{f_{st}}{1.024 f_{ck}^{2/3}} \tag{6}$$

$f_{st} = f_y/\gamma$ is the permissible stress in rebar with $\gamma = 1.15$ as the factor of safety. For comparison in this study, concrete strength is taken as mean cylinder compressive strength and γ is ignored. This bond model does not consider the effect of rib geometry or surface condition of rebar. The effect of concrete covers or rebar spacing and number is not considered. The variation due to bond length and transverse reinforcement area and spacing is also not considered. Bond strength for Fe-550 grade is also not specified in NBC 105:2020.

5. Comparison of Bond Models

A parametric study is made to compare the results of bond prediction models by using the Equation (2) to (6). Some assumptions have been made to normalize the differences in variables involved in the equations. The parameters varied during the comparison process are:

Table 2: Variations in parametric study

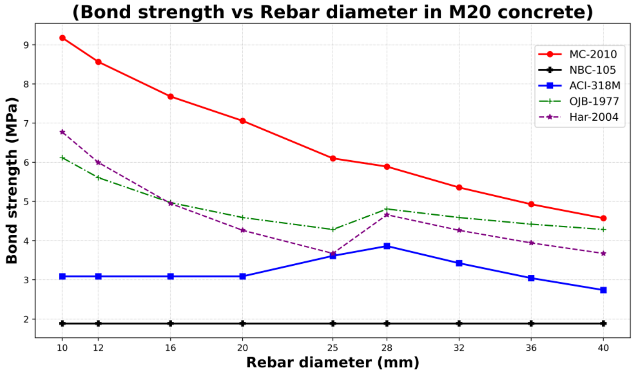
Varying parameter	Range of value of parameter
Concrete grade	M20 to M95
Rebar grade	Fe-415, Fe-500, and Fe-550
Rebar diameter	#10 mm to #40 mm
Confinement	None and 2L-#10mm @ 75mm c/c

To consider the variation due to confinement, two confinement levels were considered - no transverse reinforcement and two-legged #10 mm rebars at 75 mm center-to-center spacing. The transverse rebar effect was assumed to be constant throughout the bond length. Concrete grade listed in the parametric study relates to the mean cube compressive strength. The conversion between cube strength and cylinder strength was made as per fib Model Code 2010 [6].

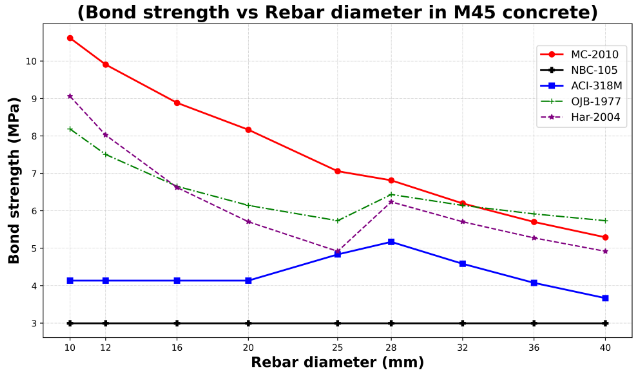
When necessary, bond length of 15ϕ was assumed for calculation. To account for the concrete cover in relation to rebar size, minimum covers were set to 25 mm for rebar size ≤ #25 mm and 40 mm for rebar size ≤ #40 mm.

The variation in bond strength due to rebar size is shown in Figure 4 for different bond prediction models. Then, assuming uniform bond model, we can calculate the corresponding development length. The variation in development length due to rebar size is shown in Figure 5. For parametric study of rebar size variation as well as concrete strength variation, rebar grade Fe-500 is chosen. For study of concrete strength variation, rebar size of #20 mm is taken. Similarly, development length variation is also seen for different concrete strengths. The results are shown in Figure 6 and Figure 7 for bond strength and development length respectively.

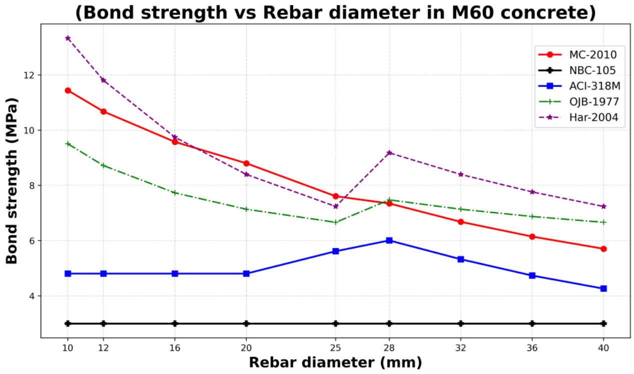
In order to study the differences in bond prediction models due to rebar grade variation, the bond strength for NBC 105:2020 was taken according to Equation 6, as the code does not provide L_d/ϕ values for Fe-550 grade. The concrete grade was taken as M25 while rebar size was #25mm. For anchorage of rebar in concrete, the confinement provided plays a big role. Anchors could be embedded in plain concrete without any confining reinforcement, but cover is generally much larger than those provided in beams. Here, the effect of confining reinforcement is studied by considering the presence and absence of transverse reinforcement only. Cover is not increased.



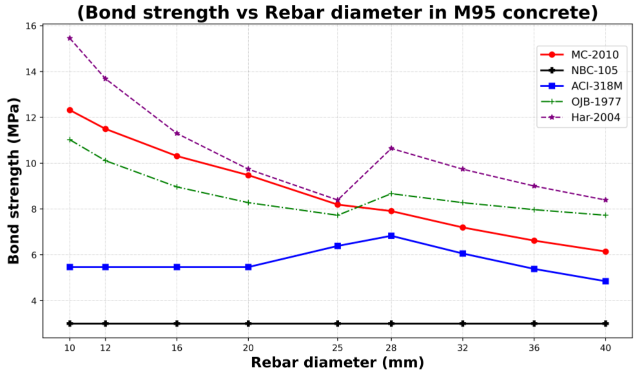
(a) Bond variation in M20 concrete



(b) Bond variation in M45 concrete

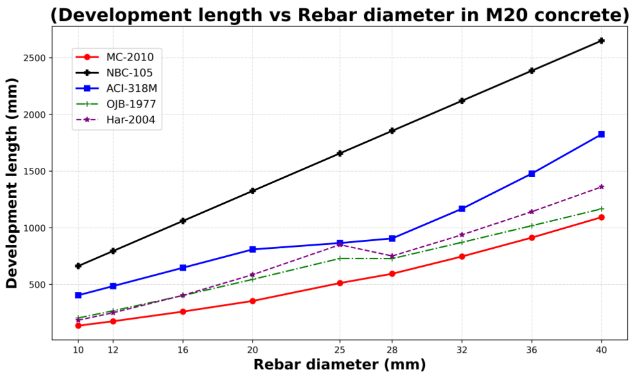


(c) Bond variation in M65 concrete

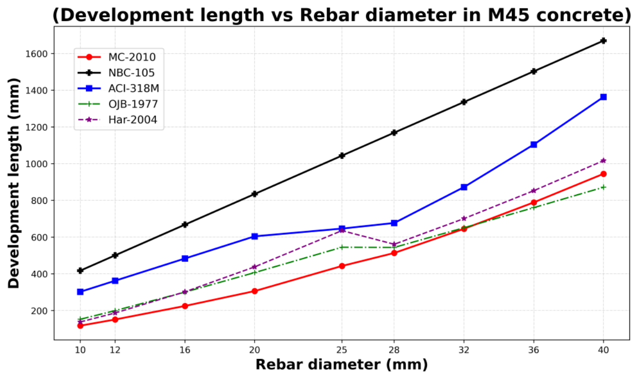


(d) Bond variation in M95 concrete

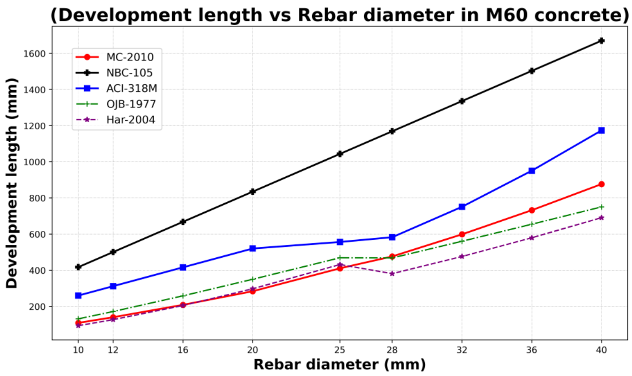
Figure 4: Bond variation with rebar diameter



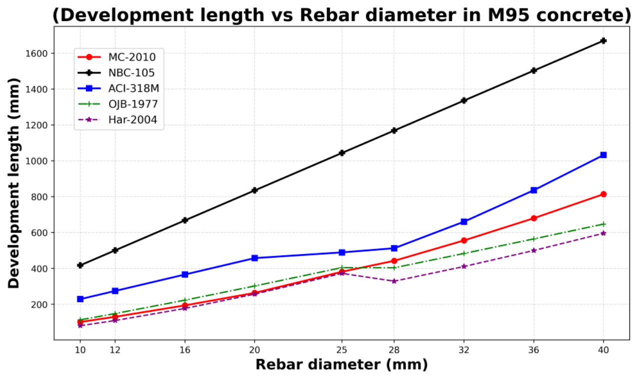
(a) Development length variation in M20 concrete



(b) Development length variation in M45 concrete



(c) Development length variation in M60 concrete



(d) Development length variation in M95 concrete

Figure 5: Development length variation with rebar diameter

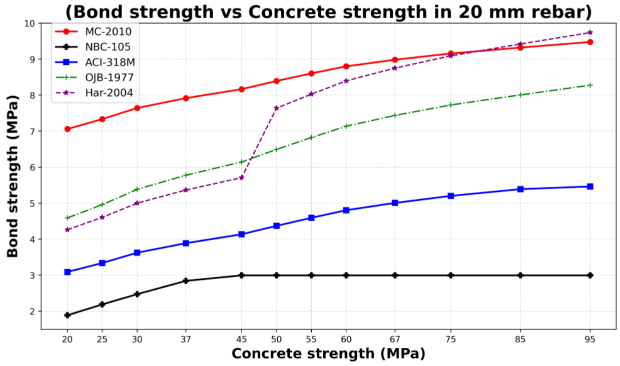


Figure 6: Bond strength variation in #20mm rebar with concrete strength

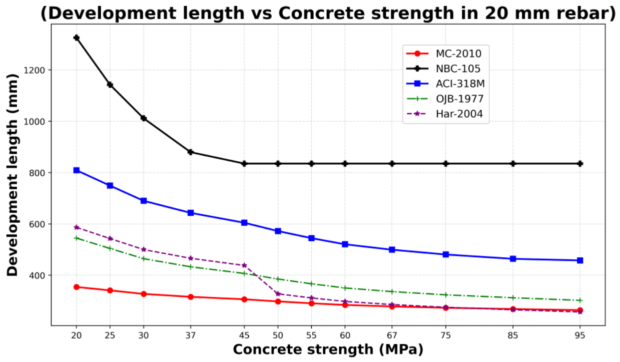
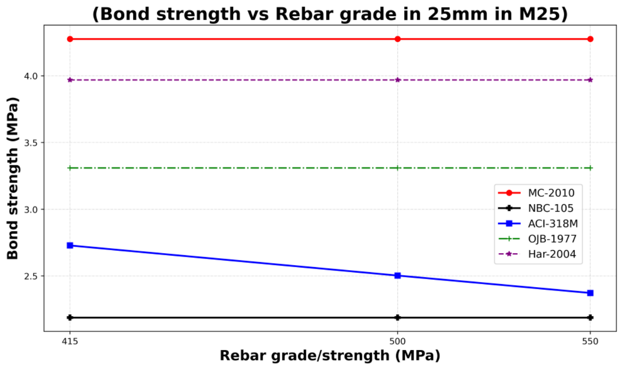
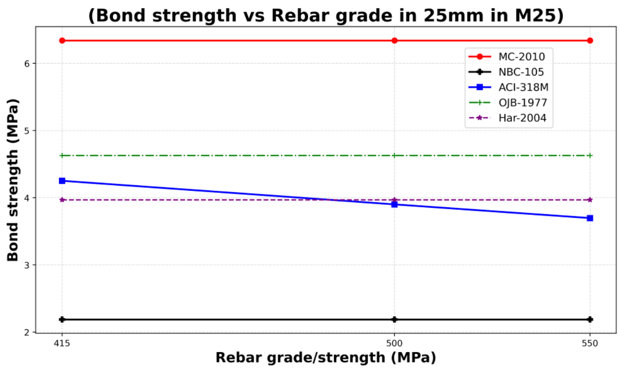


Figure 7: Development length variation in #20mm rebar with concrete strength

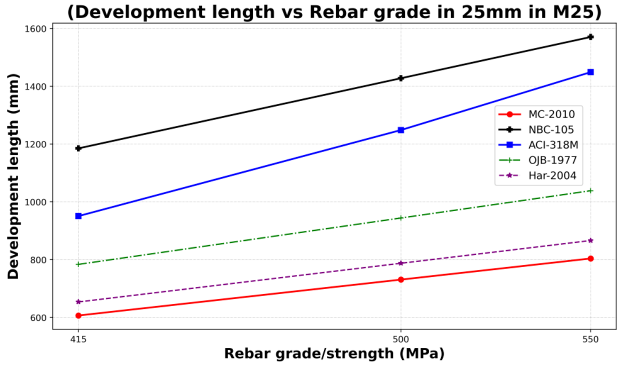


(a) Variation without any transverse reinforcement

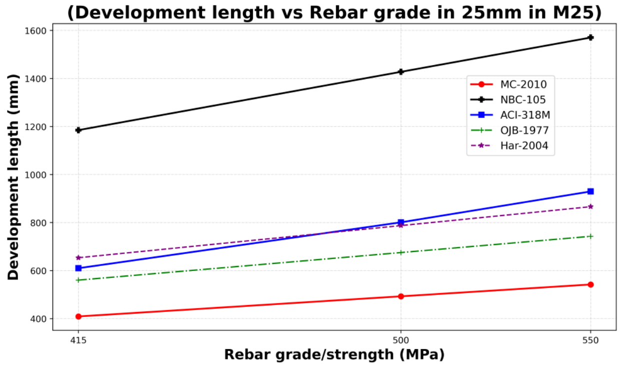


(b) Variation with transverse reinforcement provided

Figure 8: Bond strength variation with rebar grade



(a) Variation without any transverse reinforcement



(b) Variation with transverse reinforcement provided

Figure 9: Development length variation with rebar grade

The results are presented in Figure 8 and Figure 9 for variations in bond strength and development length respectively. The variation caused due to transverse reinforcement are shown as well.

The pullout capacity of RARs due to bond can be given by $N_u = \pi \phi L_b \tau_b$. For a RAR with a fixed embedment length and diameter, the pullout capacity is proportional to the bond strength. As seen from the parametric study, the bond strength predicted by NBC can be significantly less than that predicted by other models. For HSC of 95 MPa cube compressive strength with 25mm rebar of Fe-500 grade with large concrete cover and confining reinforcement, NBC 105:2020 [1] can underestimate the bond strength by 72% compared to Model Code 2010 [2]. For NSC of 30 MPa strength, this underestimation is 74%. In beams with 25mm concrete cover, this value is 67%.

It is clear from the results that NBC 105:2020 demands a much higher development length for rebars compared to other models. The pullout capacity of a single RAR with large confinement (high concrete cover and transverse reinforcement) is also compared in this study based on NBC 105:2020 [5] and fib Model COde 2010 [6]. Two cases are considered with concrete strength of 20 MPa and 30 MPa, and the results of the capacity ratios [3] are shown in Table 3 and Table 4 respectively.

[1] NBC in Tables 3 and 4 refers to capacity from NBC 105:2020 $N_{u,NBC-105}$

[2] MC in Tables 3 and 4 refers to capacity from fib Model Code 2010 $N_{u,MC-2010}$

[3] Ratio in Tables 3 and 4 refers to $N_{u,NBC-105}/N_{u,MC-2010}$

Table 3: Pullout capacity comparison (M20 concrete)

Rebar	$N_u(KN)(L_d = 10\phi)$			$N_u(KN)(L_d = 15\phi)$		
ϕ (mm)	MC	NBC	Ratio	MC	NBC	Ratio
# 10	37.7	5.9	15.7%	47.1	8.9	18.9%
# 12	52.4	8.5	16.3%	65.5	12.8	19.6%
# 16	87.9	15.2	17.3%	109.9	22.8	20.7%
# 20	131.4	23.7	18%	164.2	35.6	21.7%
# 25	196.3	37	18.9%	245.3	55.6	22.6%
# 28	240.7	46.5	19.3%	300.8	69.7	23.2%
# 32	306.1	60.7	19.8%	382.6	91	23.8%
# 36	378.4	76.8	20.3%	472.9	115.2	24.4%
# 40	457.4	94.8	20.7%	571.7	142.2	24.9%

Table 4: Pullout capacity comparison (M20 concrete)

Rebar	$N_u(KN)(L_d = 10\phi)$			$N_u(KN)(L_d = 15\phi)$		
ϕ (mm)	MC	NBC	Ratio	MC	NBC	Ratio
# 10	41.7	7.8	18.6%	52.2	11.7	22.3%
# 12	58	11.2	19.3%	72.4	16.8	23.2%
# 16	97.3	19.9	20.4%	121.6	29.8	24.5%
# 20	145.4	31.1	21.4%	181.7	46.6	25.6%
# 25	217.2	48.5	22.3%	271.5	72.8	26.8%
# 28	266.4	60.9	22.9%	332.9	91.3	27.4%
# 32	338.7	79.5	23.5%	423.4	119.3	28.2%
# 36	418.7	100.6	24%	523.4	151	28.8%
# 40	506.2	124.2	24.5%	632.6	186.4	29.5%

It can be seen from the tables that the pullout capacity predicted using NBC 105:2020 is significantly less than that by using Model Code 2010. On average, for M20 concrete, NBC predicted 81.5% lower capacity with $L_d = 10\phi$ and 77.8% lower capacity with $L_d = 15\phi$. Similarly, for M30 concrete, it predicted 78.1% lower capacity with $L_d = 10\phi$ and 73.7% lower capacity with $L_d = 15\phi$. This prediction ratio is presented in Figure 10. It can be seen that the difference is higher for smaller rebars and lower concrete grades.

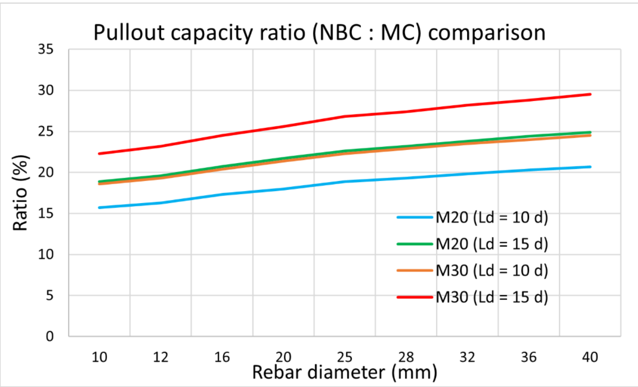


Figure 10: Pullout capacity comparison ratio (NBC : MC2010) by rebar size

6. Conclusions

The following findings were reached as a conclusion of this study:

- The bond strength increases with an increase in concrete strength. Prior studies have indicated that this is due to enhanced connection between rebar steel and cement matrix in HSC. The effect of concrete strength in bond strength is significant in lower strengths, but less so in higher strength concrete mixes.
- The bond strength in rebar generally decreases with an increase in rebar size. The required development length increases with an increase in rebar diameter. This is directly due to the assumption of validity of uniform bond model (Equation 1). Pullout ratio also similarly increases with rebar size.
- There is a significant effect of confinement to rebar on the bond strength. As much as 50% decrease in bond capacity was seen when transverse reinforcement was discarded.
- As RARs are generally placed in concrete with large covers and confining reinforcement, the pullout capacity indicated by NBC 105:2020 could be highly uneconomic.
- Compared to other models, NBC 105:2020 predicts a much lower bond strength between deformed rebars and concrete. The calculation for development length is simplistic and does not consider the beneficial influence of parameters like rib geometry, transverse reinforcement, concrete cover, etc. As a result, the required development length in NBC is very conservative.
- An improvement in the bond prediction model in NBC 105:2020 could lead to significant savings in the rebar cost not just for RARs, but also for splice/development length of rebars in reinforced concrete structures. Due consideration should be given to improve the bond prediction model in NBC 105:2020.

References

[1] Rolf Eligehausen, Rainer Mallée, and John F Silva. *Anchorage in concrete construction*, volume 10. John Wiley & Sons, 2006.

[2] ACI Committee 318. *(ACI 318M-19) Building Code Requirements for Structural Concrete and Commentary Metric.* 2019.

[3] CEN/TS 250. *(EN 1992-4) Eurocode 2 - Design of concrete structures - Part 4: Design of fastenings for use in concrete.* 2018.

[4] C Mahrenholtz, R Eligehausen, and HW Reinhardt. Design of post-installed reinforcing bars as end anchorage or as bonded anchor. *Engineering Structures*, 2015.

[5] Ministry of Urban Development. *(NBC 105:2020) Seismic Design of Buildings in Nepal.* 2020.

[6] CEB fib. *fib Model Code for Concrete Structures.* 2013.

[7] R Chicchi, AH Varma, J Seo, T Bradt, and E McCarty. Experimental testing of tension-loaded deformed anchors in concrete. *ACI Structural Journal*, 2020.

[8] CO Orangun, JO Jirsa, and JE Breen. A reevaulation of test data on development length and splices. In *Journal Proceedings*, volume 74, pages 114–122, 1977.

[9] Giovanni A Plizzari, Massimo A Deldossi, and Stefano Massimo. Transverse reinforcement effects on anchored deformed bars. *Magazine of Concrete Research*, 50(2):161–177, 1998.

[10] MH Harajli. Comparison of bond strength of steel bars in normal-and high-strength concrete. *Journal of Materials in Civil Engineering*, 16(4):365–374, 2004.

[11] Hongwei Lin, Yuxi Zhao, Josko Ozbolt, Peng Feng, Cheng Jiang, and Rolf Eligehausen. Analytical model for the bond stress-slip relationship of deformed bars in normal strength concrete. *Construction and Building Materials*, 198:570–586, 2019.