



PULLOUT TEST OF POST INSTALLED BONDED ANCHOR TO COMPARE WITH THEORETICAL TENSILE CAPACITY FOR LOCAL APPLICATION IN BANGLADESH

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Abstract

Introduction: Application of post installed bonded anchor is very frequent for retrofit and structural strengthening of seismically vulnerable public as well as private buildings in Bangladesh. To assess the tensile capacity of bonded anchor, required formula has been adopted from Japanese Guidelines and incorporated in retrofit design manual published by PWD Bangladesh. Primarily it is expected that the epoxy adhesives should comply the bond strength requirement as per material brochure and technical data sheet. In reality there is necessity of confirming the performance level of bonded anchor (in terms of actual bond capacity) for local application. There are very limited and discrete tests & case studies have been performed so far in Bangladesh regarding the issue.

Pullout test of bonded anchor: A series of pullout tests have been performed under the project on “Promoting Building Safety for Disaster Risk Reduction (BSPP)”, which is a joint collaboration project of JICA & PWD Bangladesh. The experiment is intended to prepare specification on bonded anchor work for local application (especially for low strength concrete) and to assess the applicability of relevant formula taken from Japanese Guidelines in comparison with actual test outcome and introduce required modification if necessary. To address proper field condition, a number of variables and test combinations have been introduced for this specific research work. Range of low to standard strength concrete, different anchor bar diameters along with variation in embedment depths, different moisture conditions for bond surface, locally available epoxy materials of various manufacturer and/or brand origin have been used. Anchoring has been performed on reinforced concrete members in several orientation also. Relevant ASTM and ACI standards have been adopted for sampling and testing.

Conclusion: Based on test results, specification has been proposed for tensile capacity of post installed bonded anchor related to concrete strength. In addition to that, modification factors have been proposed for existing tensile bond capacity formula in BSPP (CNCRP successor project) Seismic Retrofit Design Manual.

Keywords: tensile capacity; post installed bonded anchor; low strength concrete; seismic retrofit; Bangladesh.



1. Introduction

Epoxy resin bonded/adhesive anchor is a widely adopted method of anchor bar post installation which is applied significantly for retrofit, strengthening and modification of structures. In general, post installed anchor bar is supposed to deliver similar structural performance in concrete as it is obtained from the usual procedure of rebar placement followed by concrete casting. In broader terms, factors like bonding capacity of epoxy resin between concrete surface-reinforcing bar, strength of base concrete, strength of steel bar, rebar spacing, moisture condition of concrete surface etc. play role on the characteristic performance of the post installed bonded anchor. Primarily, tensile capacity and shear strength is observed as performance level measurement of bonded anchor.

Few years back conventional retrofit of seismically vulnerable buildings has been initiated in Bangladesh while strengthening and structural modification are also being practiced regularly. Post installed bonded anchor (especially on old & low strength concrete) is largely used as a popular component for the cases mentioned above. Major quantity of the available epoxy resins for anchor work in Bangladesh are imported from foreign originated manufacturers while a small quantity is manufactured locally. Those product specifications refer different codes and standards as quality indicator. Local professionals and practitioners follow widely acceptable international guidelines for capacity calculation of bonded anchor. Grossly the theoretical capacity of the epoxy resin may be acceptable as per technical data sheet of the product but it's merely authenticated by testing for local implementation. Since, both the quantitative and performance significance of this item is very high, capacity verification by physical test is necessary to grow confidence on its safe application. Therefore, pullout test has been performed with made up samples and analyzed with a view to investigating the tensile capacity of post installed bonded anchor using locally available epoxy resin and correlate the outcome with theoretical capacity derived from the formula been mentioned in the "Retrofit design manual" [1] published by PWD Bangladesh, which is based on Japanese Guidelines [3].

2. Test methodology

2.1 Variable sampling parameters

- Concrete strength: 25 MPa & 19 MPa with stone aggregate; 13.5 MPa & 9 MPa with brick aggregate.
- Anchor bar size: Deformed bar diameter of 10mm, 12mm, 16mm and 20mm.
- Concrete surface condition during anchoring: Dry, Wet and Submerged.
- Locally available (imported) epoxy bonding materials: Pure epoxy and Hybrid resin.
- Anchoring direction: Downward on foundation, horizontal on column & upward on beam.



Fig. 1 – Pullout test set up at site. a) Work group, b) Pullout test machine

2.2 Pullout test plan & procedure

Epoxy anchoring, pullout test and other relevant works have been conducted based on guideline of “CNCRP Manual for Retrofit Construction and Supervision” [2] and instructions of other international standards [3,4,5,6,7,8]. Concrete blocks of different strengths have been cast according to mix design. Considering the usual anchoring in existing RC element, top & bottom layer reinforcement mesh is used in concrete block (Fig. 1). In case of unreinforced concrete block, possible presence of crack (in mass concrete) would affect tensile capacity of anchoring.

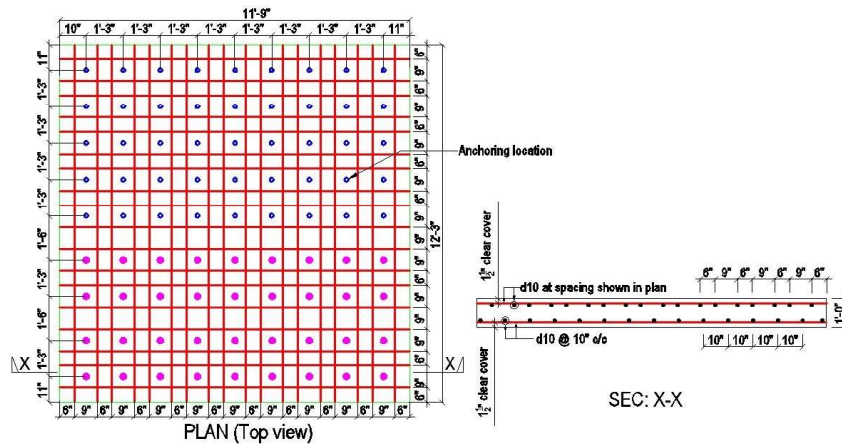


Fig. 2 – Concrete Block Sample for Anchoring

Different dimensions of holes (depth and diameter) for various anchor bar sizes are made after concrete curing period. In this case, same drill hole diameter and specific embedment length have been used irrespective of individual product guidelines. Installation of adhesive anchors are done maintaining proper surface condition followed by pullout test after prescribed hardening period. Test result is recorded in terms of tensile strength and failure mode.

Table 1 - Drill hole dimensions

Anchor Bar diameter (mm)	Drill hole depth (mm) for different concrete grades							Drill hole diameter (mm)
	Normal strength concrete				Low strength concrete			
	25MPa	19MPa			13.5 & 9MPa			
10	100	75	100	125	100	125	150	14
12	-	100	125	150	125	150	175	16
16	-	150	175	200	175	200	225	20
20	200	175	200	225	200	225	250	25

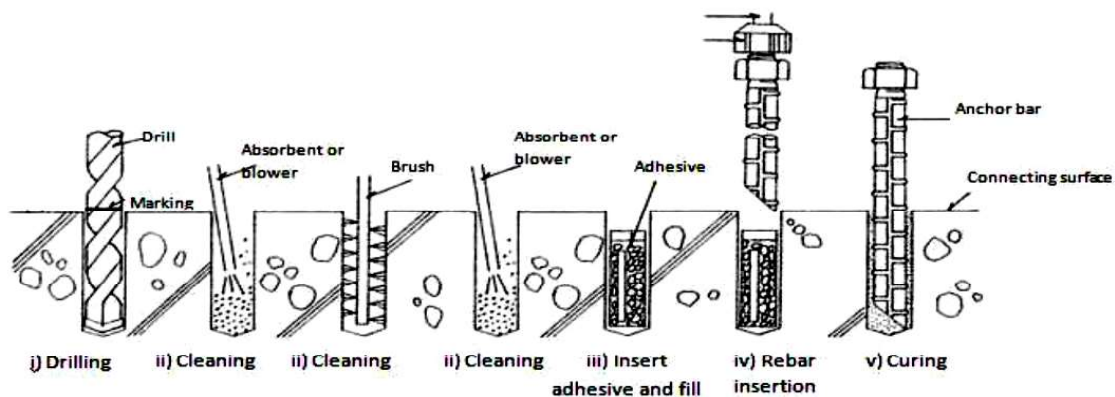


Fig. 3 – Step by step Procedure for Post Installed Anchor Work
(Source: Japanese Guidelines [3] and CNCRP Manual [2])



Table 2 – Epoxy Material properties and application surface conditions

Sl. No	Company/ Brand	Product Name	Type of material	Applied Surface Condition	Temperature Range*	Jell/Set time*	Curing time*
1	Index	MO-H-410	Hybrid resin	Dry	25 to 30 °C	4 (min)	40 (min)
		MO Pure	Pure epoxy	Dry, Wet, Submerged	25 to 30 °C	8 (min)	6 (hr)
2	Fischer	FIS V 360 S	Hybrid resin	Dry	21 to 30 °C	4 (min)	45 (min)
		FIS V 410 C	Hybrid resin	Wet	21 to 30 °C	4 (min)	45 (min)
		FIS EM 390 S	Pure epoxy	Dry, Wet, Submerged	21 to 30 °C	14 (min)	10 (hr)
3	Mungo	MIT-SE Plus	Hybrid resin	Dry	20 to 34 °C	6 (min)	90 (min)
		MIT 600 RE	Pure epoxy	Dry, Wet, Submerged	30 to 40 °C	20 (min)	8 (hr)
4	Fastfix	WE-400	Pure epoxy	Wet	30 °C	7 (min)	5 (hr)

* Temperature range, Jell/Setting time and Curing time mentioned here have been taken from manufacturer's guideline. For this experiment purpose, anchor bars were kept undisturbed at least for 24 hours after anchoring.

2.3 Failure Modes

Possible three basic failure modes are considered in case of tensile stress in bonded anchors.

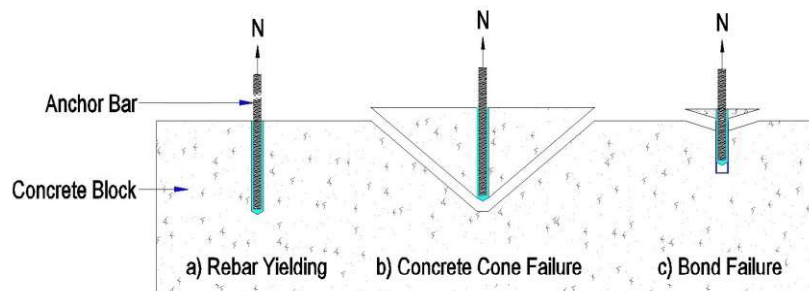


Fig. 4 – Failure modes of bonded anchor in tension

Table 3 – Test plan summary

Concrete Strength	Anchor location	Anchor Bar diameter for test	Concrete Surface condition			Anchor Direction
			Dry	Wet	Submerged	
25MPa	Base	10 & 20mm	✓	✓	✓	Vertically downward.
19MPa	Base	10, 12, 16 & 20mm	✓	✓	✓	
13.5MPa	Base	10, 12, 16 & 20mm	✓	✓	✓	
	Beam	10 & 16mm	✓	✓		Vertically upward.
	Column	10 & 16mm	✓	✓		Sideways direction.
9MPa	Base	10, 12, 16 & 20mm	✓	✓	✓	Vertically downward.



a) Anchoring on base



b) Anchoring in beam



c) Pullout on column

Fig. 5 – Epoxy anchoring and pullout test



3. Formulae and Terminology

From the basic failure modes, the theoretical tensile capacity of bonded anchor is taken from “CNCRP MANUAL FOR SEISMIC RETROFIT DESIGN OF EXISTING REINFORCED CONCRETE BUILDINGS” following Japanese guidelines. We need to know whether these formulae are equally applicable for epoxy material available in Bangladesh or any modification is required for low strength concrete.

$$T_a = \min. (T_{a1}, T_{a2}, T_{a3}) \quad (1)$$

$$T_{a1} = \sigma_y \cdot a_o \quad (2)$$

$$T_{a2} = 0.23 \sqrt{\sigma_B} \cdot A_c \quad (3)$$

$$T_{a3} = \tau_a \cdot \pi \cdot d_a \cdot l_e \quad (4)$$

$$\tau_a = 10 \sqrt{\frac{\sigma_B}{21}} \quad (5)$$

Where;

T_a = Tensile capacity of an anchor (N)

T_{a1} = Tensile capacity of an anchor determined by yielding of steel material (N)

T_{a2} = Tensile capacity of an anchor determined by concrete cone failure (N)

T_{a3} = Tensile capacity of an anchor determined by bond failure (N)

l_e = Effective embedment length of an anchor (mm)

d_a = Diameter of anchor; nominal diameter of anchorage bar for bonded anchor (mm)

a_o = Effective cross section area of threaded steel bar, or nominal cross section area of anchorage bar (mm²)

σ_B = Compressive strength of existing concrete (N/mm²)

σ_y = Specified yield strength of steel bar (N/mm²)

A_c = Effective projected area of anchor at the surface with 45 degree of cone failure (mm²)

τ_a = Bond stress at strength of bonded anchor against pullout force (N/mm²).

Therefore, the tensile capacity of bonded anchor is defined as minimum of the three strength values calculated from failure conditions. Theoretical tensile capacity will refer this value for later part.



Fig. 6 – Typical Failure patterns of anchor bars observed during experiment

4. Test Outcomes

In general, the bond capacity has an increasing trend with increase of embedment depth. Except a very few cases all the anchors failed in bond capacity (as shown in Figure – 6). Therefore, the modification was considered related to bond strength for existing tensile capacity formula.

With a general reduction factor “ f_{rb} ” the Tensile Bond capacity formula (eqn. – 4) becomes as follows,

Modified Tensile Bond capacity of anchor,

$$T_{a3(m)} = f_{rb} \cdot 10 \cdot \sqrt{(\sigma_B/21)} \cdot \pi \cdot d_a \cdot l_e \quad (6)$$



4.1 Comparison of pullout test result and theoretical capacity in dry surface:

4.1.1 With pure epoxy:

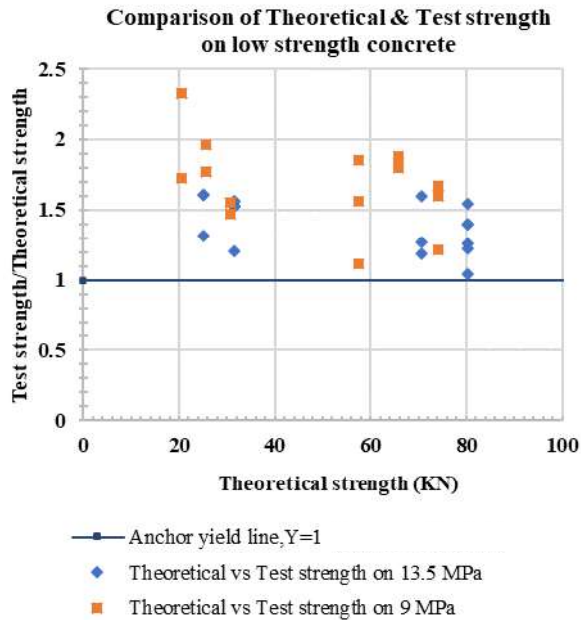


Fig. 4 – Bond strength on concrete base

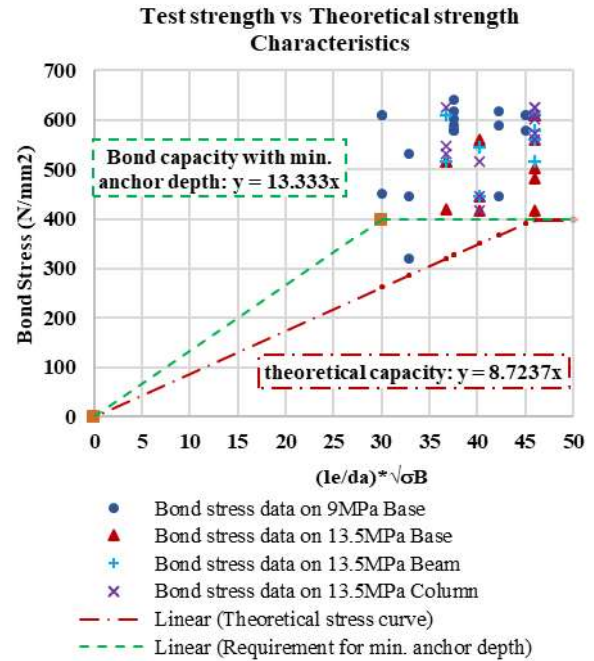


Fig. 5 – Bond strength on base, beam & column

Fig. 4 shows, all the pullout test data with pure epoxy for low strength concrete in dry condition remain above theoretical capacity line from original Japanese Guidelines formula. Therefore, no reduction factor is required for anchoring with pure epoxy.

Fig. 5 shows theoretical bond capacity, $y = 8.723(le/da) * \sqrt{\sigma_B}$. But, from the experiment, it's found that all test values (except one case) achieve anchor yield capacity with proposed capacity line, $y = 13.33(le/da) * \sqrt{\sigma_B}$. Using the equation, the required anchor depth with pure epoxy for a target bond strength of $y = 400$ MPa has been determined as follows.

Table 4 – Embedment depth requirement of anchor bar at dry surface condition with pure epoxy for low strength concrete (from test results)

Serial	For following data set	Theoretical; $le/da = (y/8.723/\sqrt{\sigma_B})$	From capacity line derived from Test; $le/da = (y/13.33/\sqrt{\sigma_B})$	Remarks
1.	$\sigma_B = 13.5 \text{ N/mm}^2$ $y = 400 \text{ N/mm}^2$	12.5	8.2	Min. anchor depth may be adopted as $12.5d_a$ for this case.
2.	$\sigma_B = 9 \text{ N/mm}^2$ $y = 400 \text{ N/mm}^2$	15.3	10	

No variation of test result has been observed for anchoring in different directions (horizontal, vertically upward and downward) on different concrete members.



4.1.2 With hybrid resin:

Since the expense of pure epoxy is relatively higher, hybrid resin is often recommended by professionals for dry surface anchoring as economic solution. There's local availability of hybrid resin as well and been considered for this research.

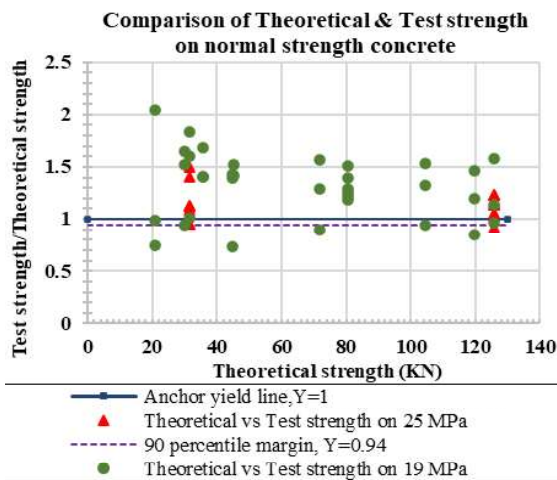


Fig. 6 – Bond strength on 25 & 19MPa (Dry)

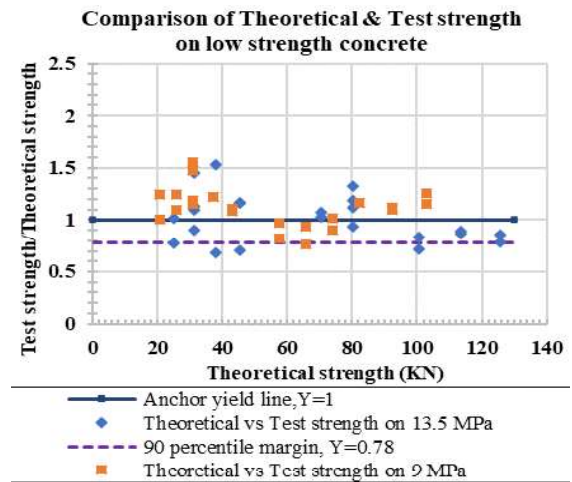


Fig. 7 – Bond strength on 13.5 & 9MPa (Dry)

Pullout test data has been analyzed for normal strength (25 & 19 MPa) and low strength (13.5 & 9 MPa) concrete separately. Primarily, we've observed that there are many cases where pullout strength value falls below theoretical line. Hence, a reduction factor with adopted bond capacity formula is required to stipulate the actual tensile capacity for local application of bonded anchor. Therefore, consideration of 90 percentile data margin was fixed to pick out the value of reduction factor for different cases. However, 90 percentile margin for normal strength concrete is $Y=0.94$ (Fig. - 6) & for low strength concrete is $Y=0.78$ (Fig. - 7). For hybrid resin in dry Surface condition,

Proposed, reduction factor, $f_{rb} = 0.90$ [for normal strength concrete]
 $= 0.75$ [for low strength concrete]

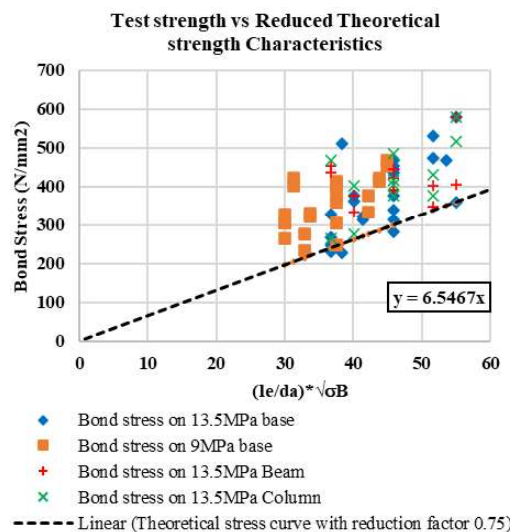


Fig. 8 – Bond strength on base, beam & column for low strength concrete with hybrid resin

No variation of test result has been observed for anchoring in different directions.



4.2 Comparison of pullout test result and theoretical capacity in wet surface:

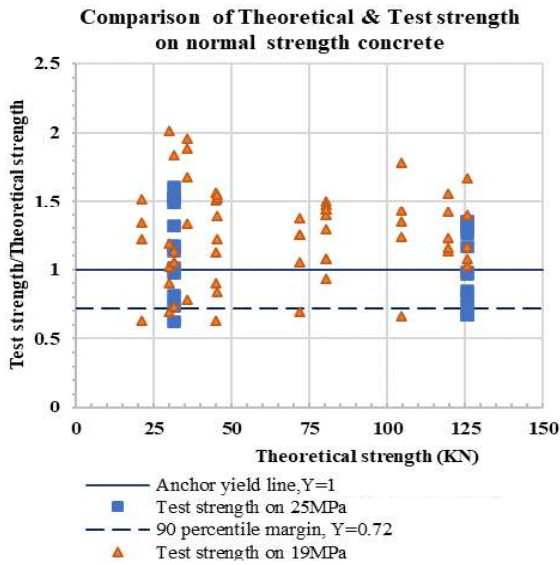


Fig. 9 – Bond strength on 25 & 19MPa (Wet)

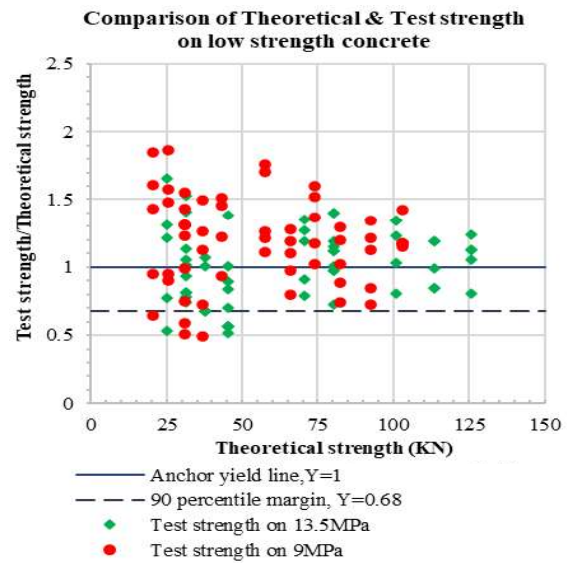


Fig. 10 – Bond strength on 13.5 & 9MPa (Wet)

Here, 90 percentile margin for normal strength concrete is $Y=0.72$ (Fig. - 9) & for low strength concrete is $Y=0.68$ (Fig. - 10). For pure epoxy in wet Surface condition,

$$\begin{aligned} \text{Proposed, reduction factor, } f_{rb} &= 0.70 \text{ [for normal strength concrete]} \\ &= 0.65 \text{ [for low strength concrete]} \end{aligned}$$

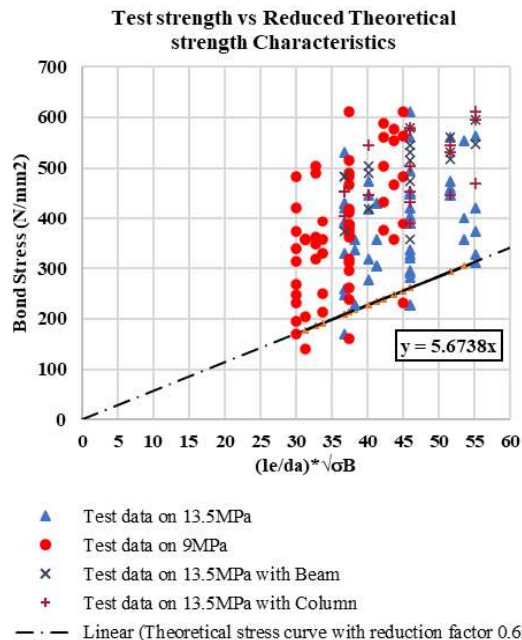


Fig. 11 – Bond strength on base, beam & column for low strength concrete with pure epoxy
No variation of test result has been observed for anchoring in different directions.



4.3 Comparison of pullout test result and theoretical capacity in submerged surface:

Anchor work with submerged condition is supposed to be like an anchor work to foundation with water filled environment.

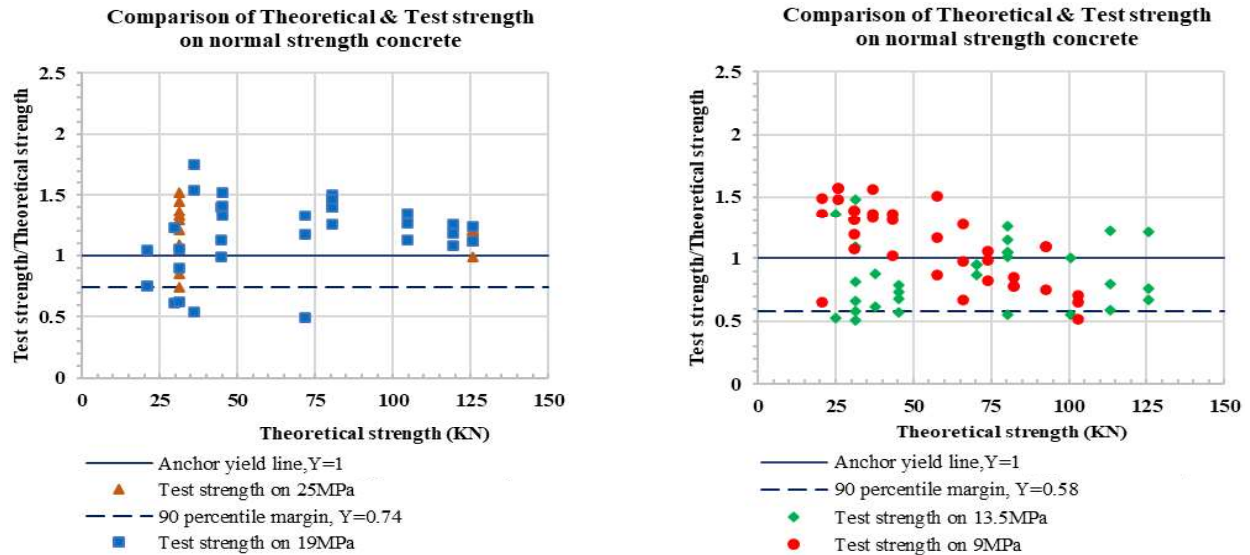


Fig. 12 – Bond strength on 25&19MPa (submerged) Fig. 13 – Bond strength on 13.5&9MPa (submerged)

Here, 90 percentile margin for normal strength concrete is $Y=0.74$ (Fig. - 12) & for low strength concrete is $Y=0.58$ (Fig. - 13). For pure epoxy in submerged Surface condition,

$$\begin{aligned} \text{Proposed, reduction factor, } f_{rb} &= 0.70 \text{ [for normal strength concrete]} \\ &= 0.55 \text{ [for low strength concrete]} \end{aligned}$$

To compare the target concrete strength for anchor test with actual strength of the structural members, compressive strength test on concrete cores has been conducted. For 25MPa target strength, 28days average test strength was found 27.8MPa (between 21.5Mpa to 34.5MPa) and for 19MPa target strength, average test strength was 19.7MPa (between 18.6Mpa to 20.9MPa). For 13.5MPa target compressive strength, average strength was obtained to be 15.8 (between 13.2Mpa to 19.9MPa) and for 9MPa target strength, average test strength was 12.3MPa (between 11.0Mpa to 14.6MPa). Due to restriction of laboratory facility during COVID-19 pandemic, core sample test for 13.5MPa and 9MPa concrete base, beam & column couldn't be performed at 28days whereas almost 365 days passed for test after casting date. Therefore, with 28days moist curing, near about 22% reduction from test compressive strength obtained at 365 days for 13.5MPa & 9MPa may be considered to obtain strength at 28days in accordance with typical strength gain trend of concrete over time [8].

5. Limitations

The limitations regarding the anchor tests are mentioned as follows.

- × The experiment has been performed on newly cast concrete blocks of representative strengths while the actual retrofit work is done usually on old structures.
- × Controlled environment was maintained for test purpose while at field condition, execution level often found substandard due to lack of supervision, improper application, poor workmanship, use of expired material, low quality equipment etc.
- × Characteristics of individual bonded anchor is observed only but group character of closely spaced anchors may vary than that of individual anchor.
- × As per general concrete cone failure theory, failure surface area increases with increase of embedment



depth. In this experiment we were not able to allow higher value of lateral spacing for different embedment depth due to space limitation. Finally, no overlapping of concrete cone failure surface was observed between adjacent anchor bars during pullout.

- × Target concrete strengths for the experiment were 25MPa, 19MPa, 13.5MPa and 9MPa. But variation of actual cylinder strengths and concrete core strengths with target strengths weren't correlated for analysis.

6. Conclusion

Proposition based on experiment results are summarized as follows.

- In terms of tensile bond capacity of adhesive anchors, this experiment shows for many cases test results remain below the theoretical capacity as per Japanese Guidelines. If we consider local application factors like workmanship quality, available material quality, technical standard etc. a reduction factor may be adopted with existing Japanese Guidelines bond capacity formula.
- No requirement of additional reduction factor is observed for anchoring in sideways direction (column) and vertically upward direction (beam) with respect to downward anchoring (base) work.
- For anchor bar size between 10mm to 20mm range, Minimum embedment depth may be adopted $12.5d_a$ considering practical allowance.

Table 5 – Proposed minimum embedment depth of anchor bar

Anchor bar diameter, d_a (mm)	Recommended minimum embedment depth, $l_e = 12.5d_a$
d10	125mm (5inch)
d12	150mm (6inch)
d16	200mm (8inch)
d20	250mm (10inch)

- Proposed modification of Japanese Guidelines formula to calculate tensile capacity/strength of bonded anchor for local application in Bangladesh;

Tensile capacity of anchor, $T_a = \min. (T_{a1}, T_{a2}, T_{a3})$ [Unchanged]

Tensile capacity by yielding of steel material, $T_{a1} = \sigma_y \cdot a_o$ [Unchanged]

Tensile capacity by concrete cone failure, $T_{a2} = 0.23\sqrt{\sigma_B} \cdot A_c$ [Unchanged]

Tensile capacity by bond failure, $T_{a3} = f_{rb} \cdot \tau_a \cdot \pi \cdot d_a \cdot l_e$ [Modified]

f_{rb} = Bond capacity reduction factor in tension for adhesive anchor (Table 6).

- Bond capacity reduction factor, “ f_{rb} ”:

Table 6 – Proposed Bond capacity reduction factor “ f_{rb} ” for local application of epoxy anchor in Bangladesh

Surface Condition	Epoxy Material type	Concrete strength range, σ_B	Proposed “ f_{rb} ”	Remarks
Dry	Pure epoxy	$\sigma_B \geq 9\text{MPa}$	1.00	Both pure and hybrid resin is applicable for dry surface anchoring.
	Hybrid Resin	$19\text{MPa} \leq \sigma_B \leq 25\text{MPa}$	0.90	
		$9\text{MPa} \leq \sigma_B \leq 13.5\text{MPa}$	0.75	
Wet	Pure epoxy	$19\text{MPa} \leq \sigma_B \leq 25\text{MPa}$	0.70	Only pure epoxy is recommended for wet surface anchoring.
		$9\text{MPa} \leq \sigma_B \leq 13.5\text{MPa}$	0.65	
Submerged	Pure epoxy	$19\text{MPa} \leq \sigma_B \leq 25\text{MPa}$	0.70	Only pure epoxy is recommended for submerged surface anchoring.
		$9\text{MPa} \leq \sigma_B \leq 13.5\text{MPa}$	0.55	

* Linear interpolation is recommended to calculate “ f_{rb} ” for concrete strength in between 13.5 to 19 MPa.

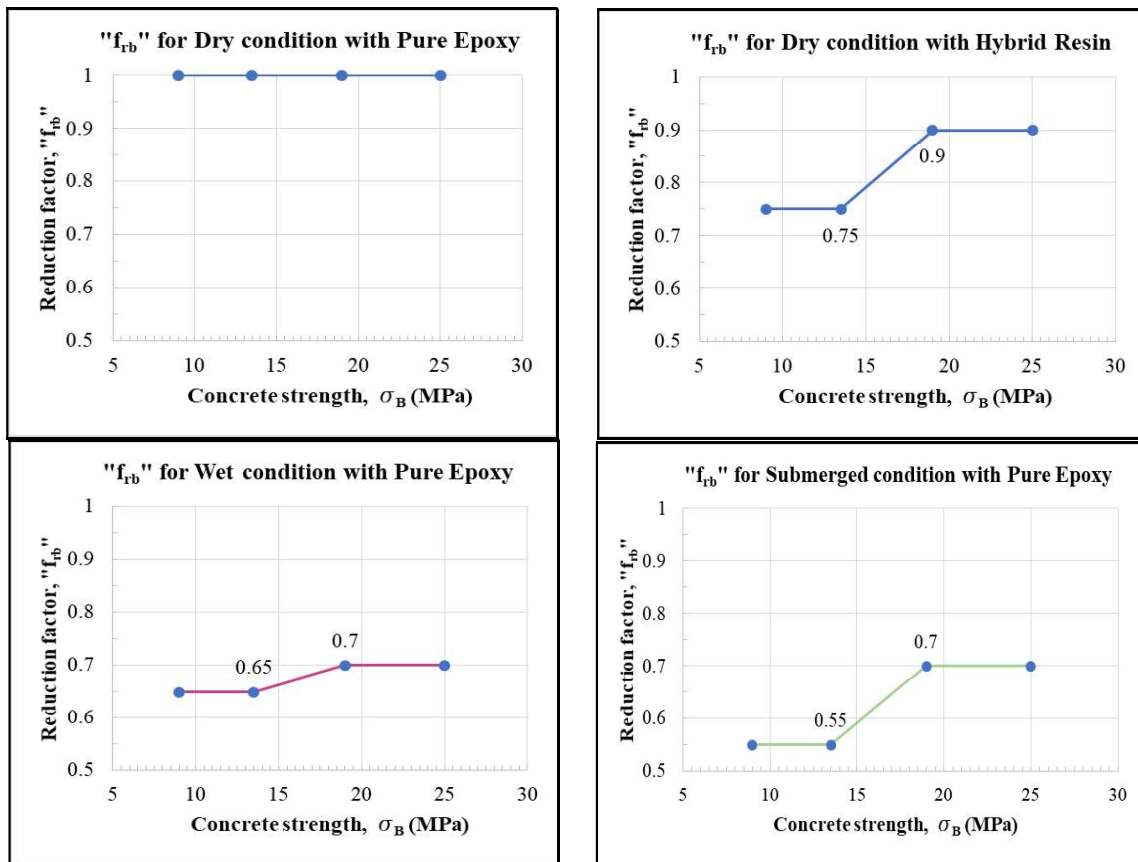


Fig. 11 – Bond capacity reduction factor “f_{rb}” for different surface condition and concrete strength

7. Acknowledgements

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8. References

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