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-Post-Installed Fastening in Concrete in the Context of Retrofitting of Structures

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Abstract – As the vulnerability of structures to different hazards has increased at a significant rate, the concept of retrofitting has gained more and more relevance to restore to original condition without undergoing heavy dismantling of the same. It is the process of adding of new features to a structure or altering an existing structure in order to improve its performance characteristics, address the deficiency and the same time comply to the current standards and regulations. A comprehensive plan from health inspection through selection of retrofitting method is prepared keeping in mind the purpose of use, performance requirements, safety, and durability perspective, giving due consideration to feasibility as well as overall economy. And with the evolution of multiple engineered solutions to increase the feasibility of retrofitting work, post installed fastening has emerged as one of the most commonly adopted techniques by practicing engineers.

Keywords – Retrofit, post installed anchor; EAD; failure modes; cracked concrete; correct installation

INTRODUCTION

In the present scenario, the loss of strength and structural stability and hence the need to retrofit may be attributed to number of reasons. These can be in terms of improving performance of the structure post hazards like seismic, fire, explosion, etc., mitigating defects due to inadequate design or faulty construction, lack of awareness about important codal provisions or requirement to accommodate the change in regulations for design. There can be a need to upgrade the structure due to enhanced load acting on it, either because of change in occupancy and/or increase in the superimposed load. And most importantly, retrofitting is undertaken when the structure cannot afford, with accepted reliability, the same performance level because of ageing.

The decision to repair, rehabilitate or retrofit a structure depends on the extent of damage and the target performance level. Therefore, it is extremely important that the method to be adopted should be derived after assessment of the structure and making a thorough analysis of the cost-benefit ratio. Health monitoring aims to evaluate the in-service performance of structures with the objective to detect the presence of damage, identify the location, severity, and possible consequences of the same.

Non-destructive testing (NDT) methods are of paramount importance to correctly assess the existing condition and the extent of damage in the structural components or the structure without damaging them or adversely affecting their usefulness in the process.

Within the local framework, several guidelines relevant to retrofitting measures are available like IS:4326-1993: “Earthquake Resistant Design and Construction of Buildings - Code of Practice”, IS:13935-1993: “Repair and Seismic Strengthening of Building – Guidelines”, IS 15988-2013: “Seismic Evaluation and Strengthening of Existing Reinforced Concrete Buildings – Guidelines”.

Standards like IS 13311 (Part 1 & Part 2) provide details of non-destructive tests like UPV test, Rebound Hammer test, etc. The “Handbook on Repair and Rehabilitation of RCC Buildings” by Central Public Works Department is a comprehensive document for the said topic. There are other standards as well which also throw light on the technology adoption.

DIFFERENT METHODS FOR RETROFITTING

In case the retrofit design is targeted to seismically deficient structures, there are global-level strategies which are adopted. These primarily include addition of lateral load resisting elements like infill walls, addition of shear walls, steel braces, etc. to improve the stiffness of the structure.

Introduction of such members can be made without causing much disruption to the building use. Reduction of building irregularity in terms of geometry or mass (weak and soft storey) is another important incorporation towards achieving the same. Seismic isolation and supplemental damping are rapidly evolving techniques for improving the seismic performance of structures.

Member level modification shall be undertaken to improve strength, stiffness and/ or ductility of deficient members and their strengthening measures shall include concrete jacketing of columns, beams, foundations, slabs, and walls.

Steel encasement for strengthening RC structures has been extremely effective and as the surface area of concrete covered by steel jacket increases the effect of confinement also increases.

Use of fibre laminates to strengthen concrete elements and enhance the flexural, shear and axial capacity of a member have been common in the recent past.

The choice of technique depends on the deficiency of the existing structure and the expected mode of failure, goal of

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intervention, consequence of retrofitting, physical constraints, and economic considerations.

POST INSTALLED ANCHORS FOR STEEL TO CONCRETE CONNECTIONS

As part of the retrofitting strategy, the application of post installed fastening is one of the most widely used technology.

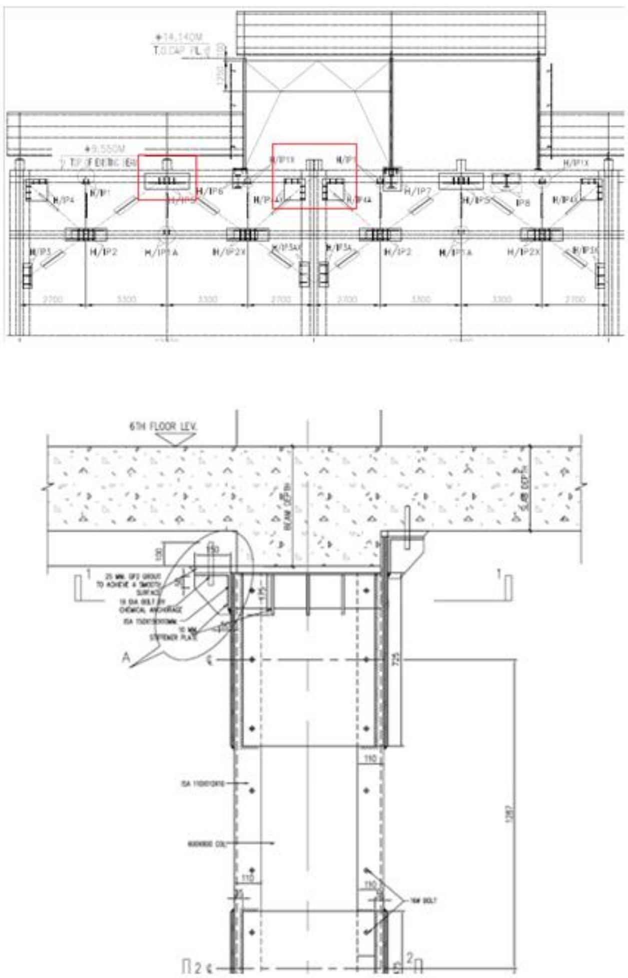

Fig. 1 Different application of plate jacketing and bracing fastened with post installed anchors

A structure is as strong as its weakest link. And as part of any detailing practice, a connection design is one of the key elements to ensure the overall safety and stability of the structure.

Safety of a connection is a trifecta and can only be achieved when all the components can be stitched together–

1. Using a qualified anchor
2. Abiding by the state-of-the-art design & installation practices

The first part is the assessment and verification of constancy of performance under different conditions. The European Assessment Document (EAD) or Technical Report developed by European Organization of Technical Assessment is used to assess the performance of a fastening system. The results are captured against each anchor in the form of European Technical Assessment (ETA) which enables designers and contractors to safely and efficiently select the fasteners that are most suited for the application, in terms of load, exposure class, lifetime, etc.

The European Technical Assessment thus ensures high reliability of the product performance and the same is aligned with the design methods in the relevant Eurocode (EN 1992-4). The anchor assessment concerning seismic qualification have been an extremely critical development and has enlarged the application area for fasteners. This can resonate well when read in conjunction with the Vulnerability Atlas of India which clearly mentions that almost 59% of our country is susceptible to earthquake and 10.9% is liable to severe earthquake (intensity MSK IX or more). Broader coverage of fatigue loads, low installation temperatures and the EAD for assessing service life performance for chemical anchors up to 100 years have broadened the scope of fastening applications for the adverse conditions as well as for infrastructure and industrial projects. Design methods translate this individual ETA certificate into actual applications and the alignment of ETA and design standards provides an ideal basis for safe and reliable connection.

A post installed fastener can be classified further depending on the working mechanism. And every type of fastener is associated with individual test regime and therefore, exclusive EAD for their performance conformity. Most commonly used EAD are as follows -

1. EAD 330232-00-0601 “Mechanical Fasteners For Use In Concrete”
2. EAD 330499-01-0601 “Bonded Fasteners For Use In Concrete”
3. EAD 330011-00-0601 “Adjustable Concrete Screws
4. TR 049 “Post Installed Fasteners in concrete under seismic action

A safe and reliable design of a connection involves selection of the correct anchor parameters - diameter, effective embedment in concrete, number of anchors and their orientation with respect to the base material. The performance of post installed connection is significantly influenced by different factors as follows –

1. Magnitude, type and direction of load
2. Dimension of existing concrete member
3. Edge Distance of anchor
4. Spacing between anchors
5. Grade of existing concrete
6. Concrete condition (cracked or uncracked)

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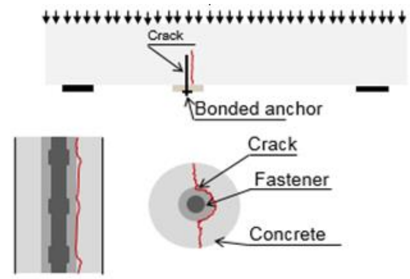
In the light of limit state method of design for reinforced concrete structures, the surface width of cracks should not, in general, exceed 0.3 mm in members where cracking is not harmful and does not have any adverse effect upon the preservation of reinforcing steel nor upon the durability of structures. In members where cracking in the tensile zone is harmful either because they are exposed to the effects of the weather or continuously exposed to moisture or in contact with soil or ground water, an upper limit of 0.2 mm is suggested for the maximum width of cracks. For aggressive environments, the assessed surface width of crack should not, in general, exceed 0.1 mm. The above is in accordance with IS 456:2000.

Cracks can develop in a structure because of multiple reasons – these can be flexure cracks in the tension zones, diagonal shear cracks, cracks due to creep & shrinkage, fatigue, freeze and thaw cycles, differential settlement, due to corrosion of steel reinforcement, etc. The location of cracks cannot be easily determined due to complexity of a structure. If a fastener is located in the position of a crack, it may slip out at low load levels. On an average, the pull-out capacity of any anchor is reduced by 30% when tested in cracked zone as compared to uncracked concrete. The effect of cracked concrete on anchor behaviour and the reduction in resistance is indicated in Fig. 2. A simple guideline to follow is: if a concrete member is designed to limit state principles, then cracks are expected to occur over the service life of the structure, hence fastenings in the selected member should be considered as "cracked".

In absence of a local framework published by the BIS, one accepted standard for design of steel to concrete connections is EN 1992-4:2018 "Design of Concrete Structures Part 4: Design of fastenings for use in concrete". Different failure modes are observed in an anchor design. These are highlighted in Tables 1 and 2 and also indicated in Fig. 3.

It is therefore important that while determining the safety of a connection, the design of anchors is given due importance and should not be restricted to comparing headline parameters found in manufacturer catalogues for different anchors. It is relevant to mention here that on-site pull-out tests, by no means, should be considered as a measure or validation of the resistance of the anchor against direct pull-out load, nor for determining or comparing the safe embedment depth. Random tests might be conducted to validate the level of workmanship. In the design of such a connection, multiple failure modes are checked which include yielding of the steel, pull-out of the anchor, cone failure and splitting of concrete, which cannot be verified by a mere on-site test.



Pullout failure					
HST3					
Effective embedment depth	$h_{ef,2}$	[mm]	47	60	70
Characteristic resistance in cracked concrete C20/25	$N_{Rk,p}$	[kN]	8,0	15,0	20,0
Characteristic resistance in non-cracked concrete C20/25	$N_{Rk,p}$	[kN]	12,0	22,0	25,0

Threaded rod, HAS-U-..., HIT-V-..., AM...8.8				M8	M10	M12	M16
Combined pullout and concrete cone failure for a service life of 50 years							
Uncracked concrete C20/25 in hammer drilled holes and hammer drilled holes with Hilti hollow drill bit TE-CD or TE-YD and diamond cored holes with roughening with Hilti roughening tool TE-YRT							
Temperature range I:	40°C / 24°C	$\tau_{Rk,ucr}$	[N/mm²]	19	18	18	17
Temperature range II:	70°C / 43°C	$\tau_{Rk,ucr}$	[N/mm²]	14	14	14	13
Cracked concrete C20/25 in hammer drilled holes and hammer drilled holes with Hilti hollow drill bit TE-CD or TE-YD and diamond cored holes with roughening with Hilti roughening tool TE-YRT							
Temperature range I:	40°C / 24°C	$\tau_{Rk,cr}$	[N/mm²]	7,5	8	9,5	9,5
Temperature range II:	70°C / 43°C	$\tau_{Rk,cr}$	[N/mm²]	6	7	7,5	7,5

Fig. 2 Effect of cracks on capacity of post installed anchor

Table 1 – Required verification for post installed fasteners in tension

	Failure mode	Single fastener	Group of fasteners	
			most loaded fastener	group
1	Steel failure of fastener	$N_{Ed} \le N_{Rd,s} = \frac{N_{Rk,s}}{\gamma_{Ms}}$	$N^h_{Ed} \le N_{Rd,s} = \frac{N_{Rk,s}}{\gamma_{Ms}}$	
2	Concrete cone failure	$N_{Ed} \le N_{Rd,c} = \frac{N_{Rk,c}}{\gamma_{Mc}}$		$N^g_{Ed} \le N_{Rd,c} = \frac{N_{Rk,c}}{\gamma_{Mc}}$
3	Pull-out failure of fastener [a]	$N_{Ed} \le N_{Rd,p} = \frac{N_{Rk,p}}{\gamma_{Mp}}$	$N^h_{Ed} < N_{Rd,p} = \frac{N_{Rk,p}}{\gamma_{Mp}}$	
4	Combined pull-out and concrete failure [b]	$N_{Ed} \le N_{Rd,p} = \frac{N_{Rk,p}}{\gamma_{Mp}}$		$N^g_{Ed} \le N_{Rd,p} = \frac{N_{Rk,p}}{\gamma_{Mp}}$
5	Concrete splitting failure	$N_{Ed} \le N_{Rd,sp} = \frac{N_{Rk,sp}}{\gamma_{Msp}}$		$N^g_{Ed} \le N_{Rd,sp} = \frac{N_{Rk,sp}}{\gamma_{Msp}}$
6	Concrete blow-out failure [c]	$N_{Ed} \le N_{Rd,cb} = \frac{N_{Rk,cb}}{\gamma_{Mc}}$		$N^g_{Ed} \le N_{Rd,cb} = \frac{N_{Rk,cb}}{\gamma_{Mc}}$
7	Steel failure of reinforcement	$N_{Ed,re} \le N_{Rd,re} = \frac{N_{Rk,re}}{\gamma_{Ms,re}}$	$N^h_{Ed,re} \le N_{Rd,re} = \frac{N_{Rk,re}}{\gamma_{Ms,re}}$	
8	Anchorage failure of reinforcement	$N_{Ed,re} \le N_{Rd,a}$	$N^h_{Ed,re} \le N_{Rd,a}$	

[a] Not required for post-installed bonded fasteners.
[b] Not required for headed and post-installed mechanical fasteners.
[c] For cases which require verification see 7.2.1.8 (1).

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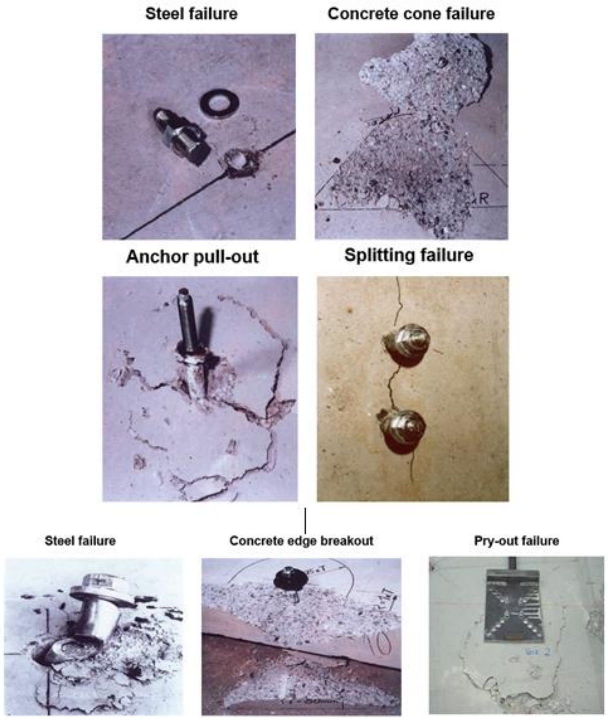

Fig. 3 Typical failure modes of an anchor

Table 2 – Required verification for post installed fasteners in shear

	Failure mode	Single fastener	Group of fasteners	
			most loaded fastener	group
1	Steel failure of fastener without lever arm	$V_{Ed} \leq V_{Rd,s} = \frac{V_{Rk,s}}{\gamma_{Ms}}$	$V_{Ed}^{h} \leq V_{Rd,s} = \frac{V_{Rk,s}}{\gamma_{Ms}}$	
2	Steel failure of fastener with lever arm	$V_{Ed} \leq V_{Rd,s,M} = \frac{V_{Rk,s,M}}{\gamma_{Ms}}$	$V_{Ed}^{h} \leq V_{Rd,s,M} = \frac{V_{Rk,s,M}}{\gamma_{Ms}}$	
3	Concrete pry-out failure	$V_{Ed} \leq V_{Rd,cp} = \frac{V_{Rk,cp}}{\gamma_{Mc}}$		$V_{Ed}^{g} \leq V_{Rd,cp} = \frac{V_{Rk,cp}}{\gamma_{Mc}}$ [a]
4	Concrete edge failure	$V_{Ed} \leq V_{Rd,c} = \frac{V_{Rk,c}}{\gamma_{Mc}}$		$V_{Ed}^{g} \leq V_{Rd,c} = \frac{V_{Rk,c}}{\gamma_{Mc}}$
5	Steel failure of supplementary reinforcement [b]	$N_{Ed,re} \leq N_{Rd,re} = \frac{N_{Rk,re}}{\gamma_{Ms,re}}$	$N_{Ed,re}^{h} \leq N_{Rd,re} = \frac{N_{Rk,re}}{\gamma_{Ms,re}}$	
6	Anchorage failure of supplementary reinforcement [b]	$N_{Ed,re} \leq N_{Rd,a}$	$N_{Ed,re}^{h} \leq N_{Rd,a}$	

[a] Exception see 7.2.2.4 (4).
[b] The tension force acting on the reinforcement is calculated from V_{Ed} according to Formula (6.6).

As we move on to the third factor of the trifecta, it is worth mentioning here that incorrect installation of an anchor is one of the primary reasons for failure of connections. Poor installation may lead to reduction in the factor of safety that are built into the anchor design process and result in failure during the design service life. Some anchors are more sensitive to installation errors than others but in any application, the full performance expected from an anchor can only be achieved if the correct installation process has been followed.

For an expansion anchor, torqueing of the anchor is a critical step to help assure performance and clamping of fixture. Applying torque to the nut activates a mechanism whereby the displacement causes the wedge to expand into the concrete. When the wedges expand, a tension preload develops in the anchor along with compression clamping load between the fixture and the concrete. Preloading reduces the amount of displacement the anchor undergoes when subjected to external tension load and also anchor fatigue under cyclic loading.

A commonly observed practice to torque anchors on most sites is by using either a spanner or uncalibrated torque wrench, which do not deliver the exact torque needed to set the anchor and mostly results in an under-torqued anchor. Conversely, a few sites use impact drivers that do not regulate the power output and result in over-torqued anchors. Both scenarios may lead to adverse performance of these anchors

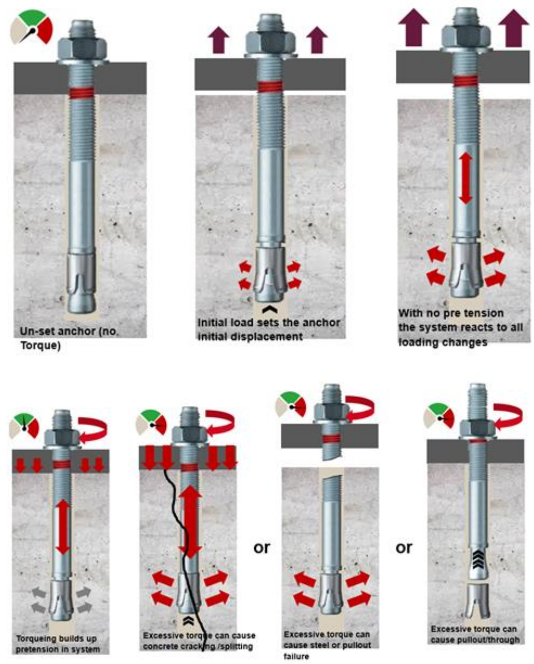

Fig. 4 Effect of incorrect torqueing of anchors

For installing a chemical anchor, adequate measure should be taken to ensure proper cleaning of holes to avoid accumulation of dust particles (which may lead to debonding of the mortar over period of time) either through compressed air or automated. Fig. 5 indicates the different steps associated with installation of a bonded anchor and schematically demonstrates the reduction of bond strength and resulting higher displacement in an improperly cleaned hole.

Adoption of mechanical systems to ensure correct and uniform dispensing of mortar into the drilled hole is another important aspect. For deeper holes, use of piston plugs to avoid formation of air gaps is recommended.

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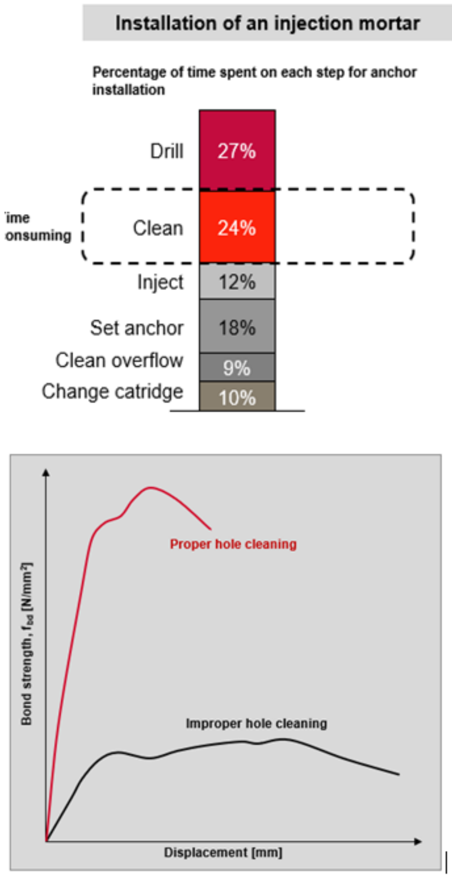

Fig. 5 Variation of bond strength with cleaning of drilled hole

CONCLUSION

Retrofitting currently is one of the key topics in civil engineering. Examples from different parts of the world and within our country have clearly demonstrated the need of repairing the deficient structures. The same has featured in the priority bucket of many bodies across the country in the recent past and there has been steady progress to undertake such projects. The type of retrofit, as mentioned, depends on the extent of damage and feasibility of the method. Before adoption of any technique it is critical that proper assessment of the current state of the structure is made.

Adoption of post installed fastening for connection of steel to concrete for increasing the resilience of the structure is an integral part of the current retrofit strategy and an extremely essential component in the entire workflow. Hence proper care should be taken to design every connection, in compliance to relevant standards. Selection of the correct anchor for a given application is extremely crucial and this needs to be complemented by best installation practices. Any complacency in this regard can bring about catastrophe.

The standards and recommendations in the Indian framework for retrofitting need to be more readily available to the practicing engineers to ensure rapid adoption and the design manuals and codes of practice should be updated from time to time. In absence of a design guideline for post-installed connection in the local framework, reference should be made to global standards. Any non-engineered solution should be strictly avoided.

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