INSTITUTION OF MECHANICAL ENGINEERS HONG KONG BRANCH
EVEING LECTURE "LATEST ANCHOR BOLT DESIGN AND TECHNOLOGY"
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Mr. Isaac Mak, Head of Engineering of HILTI (Hong Kong) Ltd., presented in The Hong Kong Polytechnic University on 7/3/2018 [Paul Chan]

Mechanical installation on concrete structures uses anchor bolts. Long, large and heavy mechanical facilities such as lift rails in lift shafts, air ducts in buildings and jet fans in tunnels are hung at elevations with the anchor bolts fastening their steel structure with the concrete surface. A few rightly sized anchor bolts can hold tonnes of weight securely in the air, or the improperly use of anchor bolts can lead to fall of objects and lethal consequences of loss of life, health, production and reputation. Anchor bolts may be small and light in size; yet their right selection and installation can never be neglected.

Since anchor bolts hold things and hold human lives, they must be right in quality, design and installation in order to warrant safety and reliability.

Principles

Anchor bolts can be classified into three (3) principle types, namely Friction, Keying and Bonding.

Friction – Expansion

This type of anchor bolts is represented by torque-controlled expansion anchors and push-in / deformation-controlled anchors. The former anchors character the application of torque on the nut which results in the tensile force on the bolt, pulling the expansion sleeves and thus expanding the wedges into the concrete member. In the latter anchors, conversely, the expansion takes place over a distance that is predetermined by the geometry of the anchor in the expansion state. Inside the bolt is an expansion plug which, upon being pushed into the borehole, pushes the anchor body to expand inside the borehole. Both torque- and deformation-controlled anchors exert an expansion force against the concrete member of the borehole as a result of the displacement of a cone relative to a sleeve, permitting the longitudinal force to be transferred to the anchor by friction. Simultaneously, this expansion force causes permanent local deformation of the anchor bolts.

Keying – Undercut

This type of anchor bolts characters the bolt tip diameter expands above the borehole diameter. Upon installation, the bolt with cone is driven into the borehole and the sleeves at the bolt tip are pushed by the cone to expand towards the concrete member. This results in a mechanical interlock between the anchor bolt and the undercut concrete member.

Bonding – Chemical

This type of anchor bolts characters the usage of chemicals to bond themselves to the concrete member. The synthetic resin is poured into the pocket where the adhesive anchor embeds and infiltrates into the pores of the concrete member. After it has hardened and cured, a local keying action in addition to the bond forms.

Failures

Failures can happen. They are principally caused by either tensile or shear load. In tensile load, pull-out failure, concrete failure and steel failure may occur. Shear load may cause concrete and steel failure to happen.

Pull-out failure is found in the chemical anchors, which cause is often unclean pocket. Chemical anchors demand high standard of pocket cleanliness in order to warrant proper adhesion to the concrete member in the pocket wall. After drilling, the pocket is to be blown three (3) times by dust pump and then surface polished three (3) times by steel brush for ensuring the pocket is contaminated by no dust particle during the chemical is filled into the pocket with the bolt inserted. If the pocket is not properly cleaned, the trapped dust particles may reduce the surface area of the bonding of the chemical, compromising the bond strength.

Concrete failure under tensile load is the dislodgement of the concrete member on which the anchor bolt anchors. This is caused by the decay of the strength of the concrete in result of age in conjunction with the application of excessive tensile load on the anchor bolt.

Concrete failure under shear load, conversely, can be divided into break-out and pry-out. If the anchor bolt is installed too close to the edge of the concrete member, break-out may occur whereby the edge of the concrete member from the pocket top to the depth approximate to the length of the anchor bolt may shear along the highest shear force and break. Alternatively, if the anchor bolt in anchored far from an edge, pry-out failure may happen whereby the concrete member around the pocket may shear along the highest shear force from the concrete surface to the bottom of the anchor bolt.

Steel failure can happen under tensile load and shear load. The former and the latter failure refer to the anchor bolt breaks along its cross section upon subject to a tensile load and the section of the bolt above the concrete surface shears from the bolt centreline respectively. It may occur if both the chemical bonding and the applied installation torque are excessive.

Cracked Concrete

A concrete slab bends upon subject to an external load. The top surface or the floor, to which the external load is applied, is in compression; conversely the bottom surface or the ceiling is in tension, and the tensile force pulls the concrete at the bottom apart and induces cracks. These cracks are micro in size and as small as 0.3 mm; yet they compromise the load-taking capacity of an anchor bolt. Extra attention is to be paid for choosing the suitable anchor bolts for anchoring objects on the ceiling.

Design

Material

Combating against corrosion, the anchor bolts are either galvanised or made of corrosion-resistant material.

Galvanised anchor bolts are the anchor bolts coated with 5 µm thick of zinc by electrolysis. Their relatively thin zinc coating permits the galvanised anchor bolts to be suitable for moderate environments. For harsher environments such as high humidity and permanently outdoor, the anchor bolts adopted should be hop-dip galvanised, whereby the anchor bolts were immersed into a molten zinc bath to receive a coating of 45 µm in thickness.

For more critical and corrosive environments, anchor bolts made of A2 and A4 stainless steel are suitable. A2 and A4 stainless steel for anchor bolts is equivalent to ASTM grade A304 and A316 material respectively. ASTM grade A316, is the highest corrosion-resistant commercial product in the market and, considering the rainfall environment in Hong Kong which results in 2 to 3 µm of coating erosion per annum, the local regulator for building safety, Buildings Department (BD), approves only the A4 stainless steel-made anchor bolts for outdoor fixtures. Seaside applications should also adopt A4 stainless steel.

Even so, the A2 and A4 steel materials degrade before nitrogen oxide (NO) and chlorine (Cl_2). Should anchor bolts be required to withstand the presence of NO and Cl_2, High Corrosive Resistant (HCR) material should be adopted. HCR is an alloy of copper and stainless steel, enabling the material to resist the chemical reaction of NO and Cl_2.

Design and Spacing

Installing anchor bolts in series does not warrant the total weight-taking capacity is the sum of each anchor bolt. If an anchor bolt locates too close to its neighbour, the concrete zones of bearing the loading of the anchor bolt, in a cone geometry, overlaps which compromises the concrete member load-bearing capacity. The cone flat is 1.5 times the embedment depth in radius on the concrete member surface. This means that to avoid overlapping the cone, the anchor bolts should be spaced minimum three (3) times of the embedment depth.

Overall, the maximum anchor capacity is determined by the anchor bolt material, anchor bolt spacing and concrete strength, and the factor with the least value prevails.

Anchor bolts suitable for seismic applications are under development. They are designed for installation on cracked concrete and tested in accordance with the required performances in seismic conditions in ACI 318 Building Code of American Concrete Institute.

Performance Requirement

To warrant the performance of an anchor bolt, its design must satisfy the requirements of Eurocode 2 / EN 1992 under European Committee for Standardization it must obtain European Technical Approval by the compliance with European Technical Approval Guideline under European Organization for Technical Approval, as represented by the “CE mark” on the product. They qualify an anchor bolt is rightly designed and constructed and hence fit for purpose.

The use of anchor bolts for fixing installations on structures shall be subject to BD approval and BD only accept the anchor bolts for application on cracked concrete irrespective of the actual installed condition. In other words, only use the anchor bolts remarked “Tensile Zone”, which means designed for applying on cracked concrete, for BD submission.

Anchor bolts are vigorously tested at shop to assure their quality and performance. By the testing of vast samples, an anchor bolt loading capacity curve is plotted following normal distribution. The 95-percentile vale is Characteristic Resistance, which is also the guaranteed performance of the anchor bolt and 1.5 times of Design Resistance. For sizing the suitable anchor bolts, the required loading shall adopt Recommended Loads which is half of Design Resistance or one-third of Characteristic Resistance. It is the BD requirement that Recommended Loads shall embed a factor of safety of 3.

Even under Recommended Loads of the same anchor bolt, the permissible loads for non-cracked concrete are higher than cracked concrete. Designer should choose the correct permissible loads according to the concrete installed is cracked or non-cracked.

Installation

With the correct selection of anchor bolts with the right specification, quality and design, proper installation is prerequisite for the anchor bolts to function as expected. The boring of the hole for the insertion of the anchor bolt must be in correct diameter and depth. Then the borehole is to be thoroughly cleaned and removed of dust and debris. If otherwise, the debris may obstruct the friction and keying types of anchor bolts from reaching the borehole bottom and the dust may compromise the bonding of the chemical anchor bolts as described above.

For torque-controlled expansion anchors, even though the borehole provides the full embedment depth and is thoroughly cleaned, the installation is complete only with the correct application of torque. It is a common mistake that the torque-controlled expansion anchors are excessively torqued, which causes the wedges to over-expand in the concrete member and results in reduced load-taking capacity. It is essential to torque a torque-controlled expansion anchor with a torque wrench.

For deformation-controlled anchors, the common installation mistake is the expansion plug inside the anchor is not pushed to the right depth, resulting in insufficient expansion of the anchor inside the borehole. An effective solution of ensuring sufficient advancement of the expansion plug is to use the correct manual setting tool.

For adhesive anchors, in addition to the stringent cleanliness of the borehole as described, they can only be installed in dry condition and they take 12 hours to cure the synthetic resins.

The anchor bolts qualified for use in Hong Kong have been tested by the independent laboratories accredited under Hong Kong Laboratory Accreditation Scheme. Besides, BD may require the anchor bolts installed to be subject to load test on site. For each anchor bolt type used, either 1 % of the total number installed or five (5) whichever lower, is tested at 1.5 times of Recommended Load.

Since installation is so critical to the integrity of the anchoring systems, the installer must be competent for the task and perform the installation with the correct procedures and tools at all time. Therefore, training is provided to the installers and qualification is granted to them to demonstrate their installation competence should their assessment on their knowledge and skills be satisfactory.

Remarks

Although small in physical size, the impact of the anchor bolts on integrity of systems and safety is significant and great effort has been made to ensure the anchor bolts, which can hold tonnes of weights at elevation safely, can be relied upon. The supply end of the anchor bolt products is backed by stringent design, testing, quality control and assurance, while the user end must size, space and install them correctly in order to finish the file mile of safe use of anchors.

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