Abstract

Lifting anchors are widely used in the precast concrete industry. If anchors are failing, lives are endangered and considerable material damage can occur. Therefore anchors for lifting and handling should be chosen carefully and the anchor design should be done by engineers. Technically, three major questions have to be answered:

a) How to determine the type and magnitude of loads and how to distribute it on the anchors?
   The most important loads like self weight, adhesion, form friction and dynamic actions will be described and discussed.

b) What are the possible failure mechanisms and which one is governing?
   The most important failure mechanisms depending on the shape, size and reinforcement of the precast element, on the lifting situation and equipment, and on the type and size of the anchor will be described and discussed. Failure can occur by fracture of the anchor, fracture of the reinforcement, breakout of a concrete cone, pullout of the anchor, pullout of the reinforcement, splitting of the concrete or local lateral breakout of the concrete.

c) How to get characteristic resistance values for the different failure modes?
   Design models which allow design by calculation are only available for very few situations and failure modes. In all other cases values are taken from tests performed by anchor manufacturers or by precast concrete manufacturers. A common basis how to perform tests and how to evaluate the results is not established up to now. Different test methods will be shown. Their significance on real applications and the effect of the test method on the results will be discussed.
1. Introduction

Precast elements are taking an increasing part in concrete construction. These elements have to be moved, in the precast plant as well as on the construction site using cranes or similar devices. In most cases cast in lifting anchors are used to connect the elements to the lifting equipment. The design of anchors for lifting and handling of precast concrete elements is not regulated in European design standards because the anchors are used temporarily and not loaded permanently. National regulations show major differences between European countries. Nevertheless in case of an anchor failure, lives can be endangered and considerable economic damage can be done.

2. Origin, Magnitude and Distribution of Loads

Lifting anchors are loaded by the self weight of the concrete element, by forces due to adhesion and form friction and by dynamic actions due to acceleration.

The self weight of the precast concrete element can be calculated using a specific gravity of 23 to 25 kN/m³ for normal weight concrete, depending on the percentage of reinforcement. Mostly this value is already known from the static calculation.

Inertia forces act when the element is accelerated or decelerated by the lifting equipment. These forces must also be transferred by the lifting anchors. The size of the inertia forces scatters between 5 and 50 % of the elements weight depending on the type of crane and the ratio between the weight of the element and the capacity of the crane. Under normal conditions it should be conservative to calculate inertia forces with 30 % of the self weight. Additional considerations have to be made for special situations like transport of elements through rough terrain, for example with an excavator. Inertia forces up to 300 % of the self weight can be expected in such cases.

When the concrete element is lifted out of the mould, forces between the concrete and the formwork surface, due to adhesion and form friction must be added to the self weight. As long as the formwork is fixed to the floor or heavy enough to stay in place (it normally is), dynamic actions must not be considered together with adhesion and form friction. Only in cases where the form is not fixed and not heavy enough to stay in place, inertia forces have to be taken into account on the mass of the element and on the mass of the formwork as well. Later, when the element is moved in the precast plant or on site, self weight and inertia forces both have to be considered.

After the estimation of the forces acting on the element, forces on each anchor have to be calculated, taking into account the position of anchors, number and length of ropes or chains and the static system. In most cases, the aim is to have a statically determinate system, because then the forces on each anchor and on each rope or chain can be clearly calculated. In statically indeterminate systems, load distribution depends on length and stiffness of the ropes, which are mostly unknown. If statically indeterminate systems are
used for special reasons, only the statically determinate part should be used in calculating the load distribution, and additional ropes or chains should only be used for stabilisation.

Figure 1a: statically indeterminate system Figure 1b: Statically determinate systems

3. Failure Mechanisms of Lifting Anchors

Analogous to other fastening elements, many different failure modes are possible depending on the anchor itself, the concrete, edge distances, anchor spacing, loading direction and, of course, reinforcement.

Within the limits of this paper, the failure modes described in the following will only refer to common lifting situations with anchors in slabs, beams and walls loaded in tension, shear, or combined tension and shear. The following drawings and photos will illustrate the various failure modes obtained in anchor testing.

3.1 Failure in pure tension:

Figure 2: Anchor failure and steel failure of special hanger reinforcement /2/, /3/
Figure 3: Concrete cone failure for anchors in top surface (lifting of slabs) /3/

Figure 4: Concrete cone in tension for anchors in edge surface (lifting of walls) /2/

Figure 5: Splitting failure in tension for anchors in edge surface /2/
3.2 Failure in pure shear

Pure shear can occur, when wall elements have to be erected from the mould, when anchors in beams and columns are placed on the side surface and when walls are mounted with the tilt up method (almost pure shear).

Figure 7: Erection of wall element, Small cone starting at anchor position, big cone starting at the anchorage depth of the reinforcement

Figure 8: Steel failure in shear (anchor far from edges)
3.3 Failure under combined tension and shear

Combined tension and shear mostly occurs due to inclined ropes or chains, but also in tilt up mounting or when precast elements must be turned while they are lifted. The failure mechanisms in the following pictures are representing examples observed in tests done by the author.

Figure 11: Steel failure (fracture of the insert), angle of loading 45° /2/

Figure 12: Concrete cone failure angle of loading 45° /2/
4. Effect of reinforcement

Only two of the above described failure modes, concrete cone failure and splitting failure may be significantly influenced by placing reinforcement in the area of the anchor. Forming of a concrete cone does not lead to failure, when stirrups are placed closely around the anchor. The stirrups have to be designed with sufficient anchorage length in the cone itself and in the concrete outside of the cone and they have to be placed parallel to the loading direction. A mash reinforcement perpendicular to the loading direction (parallel to the surface in slabs) does not significantly increase the failure load (see Figure 3). In case of splitting of the concrete, reinforcement can keep the cracks small and take up the splitting forces.

The best example for effective reinforcement are stirrups on both sides of the anchor in thin wall elements. These stirrups can act as a hanger reinforcement for concrete cone failure and also as a splitting reinforcement. In addition, horizontal U-shaped stirrups (shear stirrups) are usually placed around the anchor as a hanger and splitting reinforcement for the shear components of the load. Figure 15 demonstrates this kind of reinforcement for a wall element.
Very special types of hanger reinforcement can be seen when wall elements are cast horizontally and shall be erected for transport and assembly. The anchors then are positioned in the middle of an edge surface and a hanger reinforcement is normally placed around the anchor to transfer the load as far as possible towards the unloaded side of the wall (Figure 16).

Figure 16: Shear reinforcement for walls to be erected

a) Lifting socket  
b) Frimeda erection-anchor
5. Test Procedures for Lifting Anchors

The optimal way of testing cast-in lifting anchors is to perform pullout tests in
unreinforced concrete with minimum embedment, minimum edge distances, and
minimum member thickness, and always keep a distance of at least 2 times the anchors
length between the anchor and the support of the load on the specimen. This procedure
has only one negative: it is not possible to do it this way! Therefore, test procedures have
to be chosen in such a way that yields results relevant to the practical applications and
therefore should be standardised to a point which ensures comparable results for
different test series. In the following, test procedures for the most common situations
will be presented and discussed.

5.1 Test procedures for tension

5.1.1 Steel failure of the anchor
Steel failure of the anchor under tension can usually be tested in a universal testing
machine on anchors which are not cast in concrete. The test setup has to be chosen
according to the anchors construction and dimensions.

5.1.2 Tension tests on cast in anchors in concrete slabs
For tests on anchors far from edges frequently used test configurations can be divided in
two fundamentally different systems. The system illustrated in Figure 17 is based on a
simple beam and results in bending cracks in the area of the anchor, leading to an anchor
position in a concrete crack. On the other hand a system based on a cantilever beam can
be used, resulting in cracks underneath the support (Figure 18). The load level of crack
initiation depends on the spacing of support and on the member thickness. The
advantage of the simple beam setup is, that cracks which can also occur during a real
situation are included in the testing procedure. On the other side bending reinforcement
is needed in the area of the anchor to prevent a bending failure of the concrete specimen.
In addition this setup is not possible in corner situations with small edge distances.

Figure 17: beam setup
5.1.3 Tension tests on cast in anchors in concrete beams and walls

In beams and walls longer anchors are used than in slabs to compensate for smaller edge distances. Therefore in the plane of the wall the necessary edge distances for full concrete capacity and the necessary spacing of supports are high. In addition splitting failure and lateral blow out failure become more likely. Therefore anchorage principles with distributed load transfer along the anchor i.e. with reinforcement bars are used in many cases.

For very long anchors the minimum distance between the anchor and the end of the wall or beam is usually smaller than 1.5 times the anchors length. Therefore no support should be placed between the anchor and the end of the wall or beam. This is only possible using the cantilever setup very similar to the setup for oblique loading shown in Figure 19.

For anchors anchored by bond of reinforcement it is very difficult to keep a distance between the anchor and the support of 2 times the anchors length which is needed to allow a complete concrete cone breakout. Because for anchorage by bond this failure mode is not likely, a smaller clearance can be used but not smaller than 1.5 times the anchors length for reinforcement bars with hooks or similar anchorage devices and 1.0 times the anchors length for straight bars. It should never be smaller than twice the thickness of the wall or beam.

5.2 Test procedures for combined tension and shear

5.2.1 Steel failure of the anchor

For anchors loaded in combined tension and shear, the supporting action of the concrete is needed for the performance of the anchor and therefore in many cases tests have to be performed on cast in anchors. The test configurations can be chosen like described for concrete failure below. Simplifications are possible because no large spacing is needed between supports.
5.2.2 Tests on cast in anchors under angled tension in concrete slabs, beams and walls

Oblique testing of cast in anchors can be performed using a strong floor. Other testing procedures such as tests on two anchors together (so that the equilibrium between the horizontal forces on both anchors is satisfied) is not dealt with in this paper. An example for a configuration in a testing frame with a stiff baseplate acting like a strong floor is shown in Figure 19. This setup provides sufficient spacing of supports for vertical and horizontal load components as well. It is therefore usable for tests with horizontal load - components towards the free edge like shown in Figure 19, but it can also be used for tests with the horizontal load component towards the centre of the wall.

Figure 19: Cantilever setup for oblique loading with a test frame on a stiff baseplate /2/

5.3 Test procedures for shear

Pure shear is not a very common load situation in lifting and handling, but it can occur, when wall elements are cast horizontally and have to be erected from the mould. Anchors designed for this situation are positioned in the middle of an edge surface and a hanger reinforcement is normally placed around the anchor to transfer the load towards the unloaded side (Figure 16). Testing is possible using the beam system or cantilever system. Using the beam system requires large bending reinforcement over the anchor which may increase the failure load, while cracks in the area of the anchor lead to lower failure loads. It is not known which effect governs depending on other parameters like the dimensions of the anchor, the shape and dimensions of the hanger reinforcement, and the elements thickness. Therefore the cantilever system appears to be the better solution. Figure 20 shows an example for a setup which was already used successfully.
6. Summary and conclusions

Anchorage points for lifting and handling of precast concrete elements must be designed for the self weight of the element and forces due to adhesion, form friction and dynamic actions (inertia forces due to acceleration). These forces must be distributed to the anchors in accordance with the static system. Depending on the steel and concrete strength, on the principle and length of the anchorage to the concrete, on the loading angle, on the amount and position of reinforcement, and on the edge distances of the anchor many different failure modes are likely to govern the behaviour of the anchor. In many cases the relevant failure mode and the capacity of the anchorage can only be identified by testing. Test conditions have to be chosen very carefully in order to get representative results with minimised influence of the reinforcement and the dimensions of the specimen. Test procedures should be harmonised to a point which allows comparable results in different test series in order to increase basic knowledge and maintain certain safety levels.

7. References

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