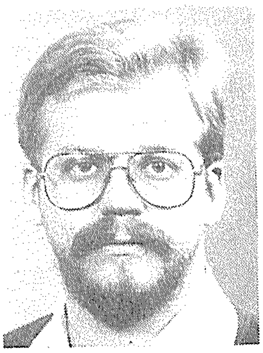
BEHAVIOUR, USE AND SAFETY OF FIXINGS IN CONCRETE 9



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In this paper fasteners available in concrete fixings as well as their failure mechanisms and suitable applications are introduced. Strength tests of fixings carried out in Finland and safety questions of fixings are also briefly discussed.

Key words: concrete, fixings, safety

1. GENERAL

The need as well as the use of different types of fixings has continuously increased. Fasteners are used in a variety of applications which range from those used in load-bearing elements or other structural members to the more simple fixings from the viewpoint of strength requirements.

The fixings embedded in the concrete structure can be divided into two main groups according to their installation time:

I The cast-in fixings

II The fixings embedded in hardened concrete

Cast-in fixings include, e.g. anchor plates, sockets, anchor bars, lifting anchors, channels and slots, anchor angles, anchor bolts and threaded sleeve sockets /2, 9/.

Fasteners embedded in hardened concrete are: expansion anchors, chemical anchors, grouted embedments, powder actuated fasteners, manually actuated nails, plugs and self-tapping screws /2, 9/.

The fixings can be divided into two groups according to their purpose of application /1/:

- structural fixings or fixings designed for loads and
- restraint fixings.

The structural fixing refers to a fixing that has to be designed so that it carries the forces acting on it. As a restraint fixing is regarded the fixing for which no load can be defined or loads are so low that there is no need for the dimensioning of the fixings as their load capacities are known /2/.

2. BEHAVIOUR OF FASTENERS

2.1 Failure mechanisms of fixings

The anchorage of the cast-in fixing is based on the bond between the concrete and the cast-in part of the fastener, on the anchorage caused by the shapes of cast-in parts or on both at a time.

The fasteners in hardened concrete can be embedded in three different ways. The fasteners can be inserted in a drilled hole, by shooting or hammering directly into concrete, or by glueing or casting the fixture into concrete. Anchorage to concrete is based on the action of wedges that exert force between the fixture and the walls of the hole and on friction, and in some cases on adhesion.

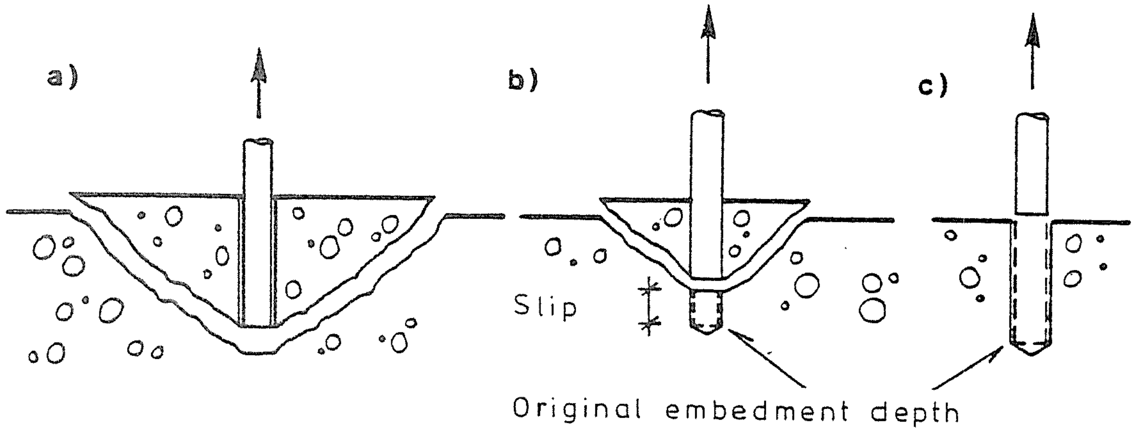
In principle the failure of fixings can occur in two ways:

a) Failure of concrete takes place when tensile stresses exceed the tensile strength of concrete, or the adhesion between the fastener and the concrete fails.

b) The fixing or its integral parts yield or fail.

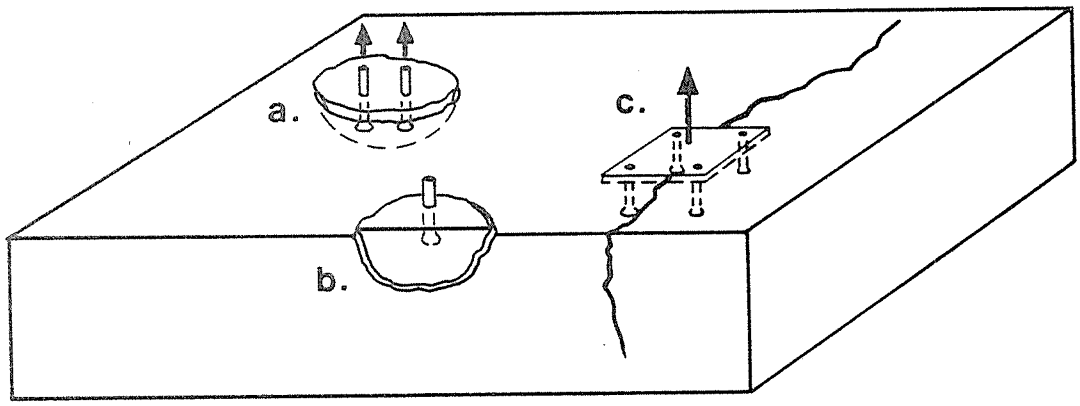
The modes of failure as stated at a) can be the formation of a complete shear cone, the slip and the intermediate forms of these. Moreover, the edge failure as well as the splitting of the fixing base are the modes of failures resulting from the excess tensile strength of concrete.

In Fig. 1 a drawing of principle illustrates the effect of slip on the size of a failure cone. Fig. 2 shows other modes of concrete failure due to the excess tensile strength.



a) no slip
b) tolerable slip
c) total bond loss slip

Fig 1. Effect of the slip of anchor on the size of failure cone /3/.



a) failure of fixings in group
b) edge failure
c) splitting of the fixing base

Fig. 2. Material failure of concrete in particular cases /5/.

2.2 Fixings joining the structures

The fixing of adjoining structures takes place, depending on the type of fixture, most frequently by welding or screwing the nuts on external threads of fasteners and the screws on internal threads of fasterners. Fixing with nails directly into concrete is carried out without intermediate phases.

The adhering parts of the fixture transmit the external force to concrete nearby the fixing point. In addition to the calculated loads, the fastener often has to carry indirect forces, too, which result e.g. from shrinkage of structures, thermal movements and deflections as well as from impacts during installation /3/. That is why the ductility of structural fixings has to be ascertained, so that e.g. the formation of the failure cone as shown in Fig. 3 does not bring about failure of fixings /2/.

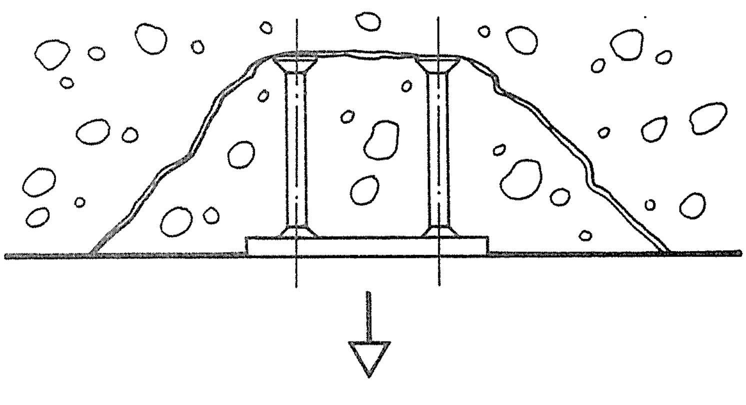


Fig. 3. Brittle fracture of fixings /2/.

When necessary, additional reinforcement has to be positioned at the fixing point, which is designed so that it is capable to transmit the forces of fixing to the structure by means of anchorage after the formation of the failure cone as shown in Fig. 3.

3. USE OF FIXINGS

3.1 General

Loading and environmental conditions, costs and fixing applications influence in the first place choice when selecting fixings. The more exacting fixings are selected generally by the designer, the selection of fixings of lesser importance can also be made at jobsite /2/.

The load capacity of cast-in fixings is generally higher than that of the fixings of equivalent size embedded in hardened concrete. When use is made of fixings embedded before concrete has hardened the fixing point has to be known quite exactly beforehand.

3.2 Cast-in fixings

The cast-in fixings are used generally in massive structural fixings applications. This is a result of the fact that in these fixings such anchoring members can be used that make possible good anchorage of fixings to concrete. Moreover, the forces transmitting to the anchoring member can be transmitted, if necessary, to the concrete structure with additional reinforcement.

The anchor plates are metal plates inserted in the concrete surface or nearby it, which are tied to concrete by means of fixing parts joining the plate. The anchor angle is a particular case of anchor plates, in which the plate remaining on the casting surface is replaced by angle bar. The anchor plates and angles are usually used for joining the different kind of precast units or in-situ concrete structures as well as for fixing steel structures, equipment and devices to concrete. Angles are also used to improve the impact strength of corners in concrete structures and to prevent the corners from splitting.

Sockets are fasteners made from metal and provided with internal threads. Sockets can be used for tying e.g. facade elements and different kind of steel members to the concrete frame. The particular case is a sleeve with threads at both ends. Hence it can be also used for splicing the reinforcing bars e.g. at the construction joint. In this case it is not necessary to break the mould for punching holes for reinforcing bars.

The channels and slots are to be tied to concrete by means of bond and forming of the rail or anchoring members. To its grooves movable connecting parts that transmit forces through the groove to the structure can be fixed. Channels and slots are applicable to strip-like fixings, and particularly in the cases where the fixing point can be set at any position along the channel or great tolerance is required in one direction. As a fixing medium between the channel and the adjoining structure or between the device a hexagonal nut or screw moving on the rail or a cap screw specially made for the rail can be used.

The anchor bolts cast into concrete are either single round steel bars or bars with steel parts fixed together, the ends of which remaining outside the casting have been threaded. The anchor bars are used e.g. for fixing the frame columns and the machines that produce great dynamic loads firmly to the foundation.

Concrete reinforcing bar anchored in concrete or other round steel bar with the one end remaining outside the concrete surface are considered as anchor bar fixings. The anchor bars can be used e.g. for fixing the steel parts by welding (steel door frames, etc.) in concrete, for masonry wall-ties or in the construction joints of concrete structures.

The lifting anchor is a fixture positioned in the structure before concreting for lifting and transporting the concrete precast units /2/.

3.3 Fixings embedded in hardened concrete

Among fasteners embedded in hardened concrete, expansion anchors and chemical anchors are suitable for structural applications. The use of caulking anchors and grouted anchors in structural applications requires that the strength of fixings is ascertained by trial tests. Other fasteners embedded in hardened concrete, are fitted for use in light, restraint fixings.

The expansion anchor is a fastener, the expansion of which and anchorage can be achieved by two different ways: either by tightening a nut or bolt head with a spanner or by mechanical or manual hammerring action. Self-drilling fixings incorporate a cutting in the lower end, there by dispensing with the need for conventional drill bit, although a special adaptor is required for the drill chuck. The expansion takes place when a cylindral or conical plug or the shell of the anchor is hammered down /9/.

The expansion anchors can be used in all kind of fixings application, if only the instructions for edge distances and embedment depth are followed. The anchors made of stainless steel are also suitable for fixings in severe corrosion environments.

Anchorage of chemical anchors to concrete is based on the adhesion produced by an adhesive. The delivery of anchors includes either an agglutination agent containing capsule that is inserted in a hole and broken in conjunction with the installation of the anchor, or an injection syringe used to fill the hole with an agglutination agent. The chemical anchor is suitable for all kind of fixings application, because the chemical anchor does not produce any splitting forces. For the long-term performance of chemical anchors and the chemical stability of adhesive as well as strength variations in the long run, there is no test data available for the time being /2/.

Anchorage of caulking anchors in concrete is achieved by caulking a lead cylinder around the anchor. Anchorage is based on the expansion of caulked lead and friction produced by expanding force. When using the caulking anchor in structural fixings applications its serviceability has to be ascertained by trial tests.

The performance of the grouted anchor in the structure is identical with that of the chemical anchor. Such metal bar as it is desired can be used as an grouted anchor. Cement based grouted anchors can be used safely in structural fixings applications, when the adhesion of fixings is evaluated using proper trial tests in each case.

The powder actuated fixings form a group of their own differing from others in their behaviour and the mode of embedment. A hole made for fixing beforehand is not required, but the fixing is forced into the concrete by using an explosive charge. Since the strength of fixings deviates greatly powder actuated fixings cannot be recommended for structural fixings applications with high level of requirements, but the HVA-installations and the electrical installations, and other light fixings are suitable objects of application. Powder actuated fixings made of stainless steel are not available, so that their use is restricted to dry indoor spaces.

Manually actuated nails are nails made of hardened steel and are manually hammered down in the concrete. Because the impact energy these nails is considerably lower than that of the powder actuated nails, they can be used to advantage in non-structural fixings applications for soft bases (e.g. rendering or plaster applications).

The anchorage of the plug in the concrete is based on the expansion of the plug due to the screw threaded on the plug as well as on the compression against the walls of the hole, and on friction resulting from this between the plug and the walls of the hole. There are several alternatives to material of plugs, the most frequently used plugs nowadays are those made from different kinds of plastics. Plugs are used in electrical and HVA-installations in the first place as well as in light fixings generally. It is to be noted that, when the plugs are being used, changes in their adhesion take place in the long run due to shrinkage in plastics and the likely decrease in the strength of plastics.

The self-tapping screw is a new product on the line of fixings embedded in hardened concrete. The screw is driven in the hole drilled in the concrete using a tool fitting the drilling machine, and no plug is used.

There is little information about the screw, and its use is not recommended for structural fixings applications without tests conducted to ascertain the fixing behaviour /2/.

4. STRENGTH TESTS ON FIXINGS IN FINLAND

4.1 General

In Finland the type approval activities in the construction field were started in autumn 1977. In spring 1979, the first type of fixings embedded in concrete met with official approval. At present three expanding anchors the expansion of which is achieved by hammer action and seven anchors the expansion of which is achieved by tightening with a spanner have met with type approval in Finland. Moreover, type tests have been conducted on one chemical anchor. The type tests on two types of anchor plates to be embedded in concrete before it has hardened have been conducted. Furthermore, pullout tests on some sockets have been conducted.

4.2 Cast-in fixings

The strength of fixings embedded in concrete before its hardening has been tested very little in Finland so far. Tensile, shear and flexural tests on anchor plates and pullout test on some types of sockets have been conducted.

The loading arrangement of the tests on anchor plates is as shown in Fig. 4. The tensile tests on sockets are conducted as those on expanding anchors. Their loading arrangement is shown in Fig. 5a of item 4.3.

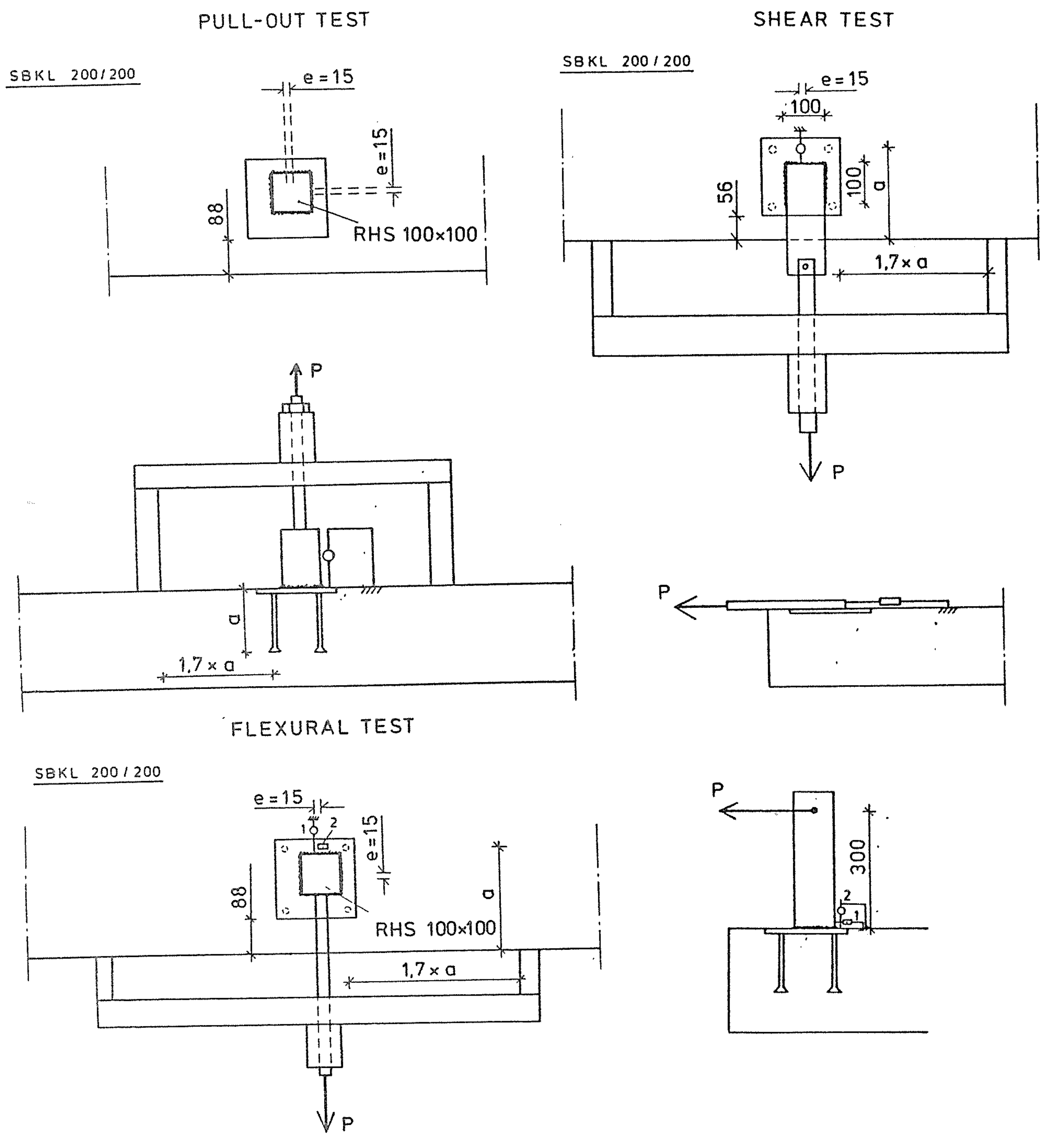


Fig. 4. Loading arrangements of anchor plates.

The surface area of the largest plate tested was 200 x 200 mm^2 and the anchorage was arranged by 4 ø 16 mm headed steel bars 150 mm of length.

With this plate the max. tensile capacity of 217 kN, the shear capacity of 117.5 kN and flexural capacity of 19.3 kNm were achieved, when the thickness of unreinforced fixing base in the tensile test was 250 mm and in the shear and flexural tests 265 mm. The distances from edges were as shown in Fig. 4. In the flexural tests the shear stress is acting simultaneously. In the case of large plates failure takes place usually as a material failure of fasteners if the edge distance will not turn out to be a decisive factor. The edge distance was decisive e.g. in the above-mentioned shear test.

In the pullout tests with sockets the greatest failure load achieved was 133 kN. Anchorage in this type of fixing was improved by inserting concrete reinforcing bar through the anchor from the hole on its base.

4.3 Fixings embedded in hardened concrete

A great number of pullout tests and shear tests have been conducted in Finland on the fixings embedded in hardened concrete. Three different types of anchors the expansion of which is achieved by hammering of M6 ja M20 size and seven types of anchors the expansion of which is achieved by tightening with a spanner of M5 to M28 size have been tested. Moreover, test on one type of chemical anchors of M8 to M20 size have been conducted. The test arrangements are illustrated in Fig. 5.

Strengths attained in the type test on expansion anchors are shown in Table 1.

Table 1 a). Results of tensile tests on expansion anchors.

		Cubic strength 20 MPa				Cubic strength 40 MPa			
Type	Thread	N min (kN)	N max (kN)	δ min	δ max	N min (kN)	N max (kN)	δ min	δ max
L	M6	7.4	9.41	0.20	0.25	7.7	10.7	0.14	0.29
	M20	46.3	58.0	0.05	0.14	66.7	77.3	0.06	0.08
K	M6	3.3	16.3	0.07	0.40	5.5	18.3	0.07	0.44
	M20	31.4	85.8	0.07	0.25	29.6	120.7	0.06	0.17
	M28	-	63.6	-	0.09	-	82.3	-	0.15

Table 1 b). Results of shear tests on expansion anchors.

		Cubic strength 20 MPa				Cubic strength 40 MPa			
Type	Thread	V min (kN)	V max (kN)	δ min	δ max	V min (kN)	V max (kN)	δ min	δ max
L	M6	7.3	9.8	0.10	0.25	9.3	10.4	0.13	0.28
	M20	41.3	65.8	0.05	0.18	58.7	63.9	0.05	0.37
K	M6	5.7	12.5	0.11	0.23	5.3	15.8	0.05	0.20
	M20	36.9	52.7	0.12	0.18	50.5	76.0	0.09	0.22
	M28	-	90.4	-	0.10	-	110.7	-	0.07

In Tables: L = expansion achieved by hammer action
K = expansion achieved by tightening with a spanner
N min = minimum average value of six indentical test
N max = maximum average value of six indentical tests
δ min = the smallest variation coefficient
δ max = the greatest variation coefficient.

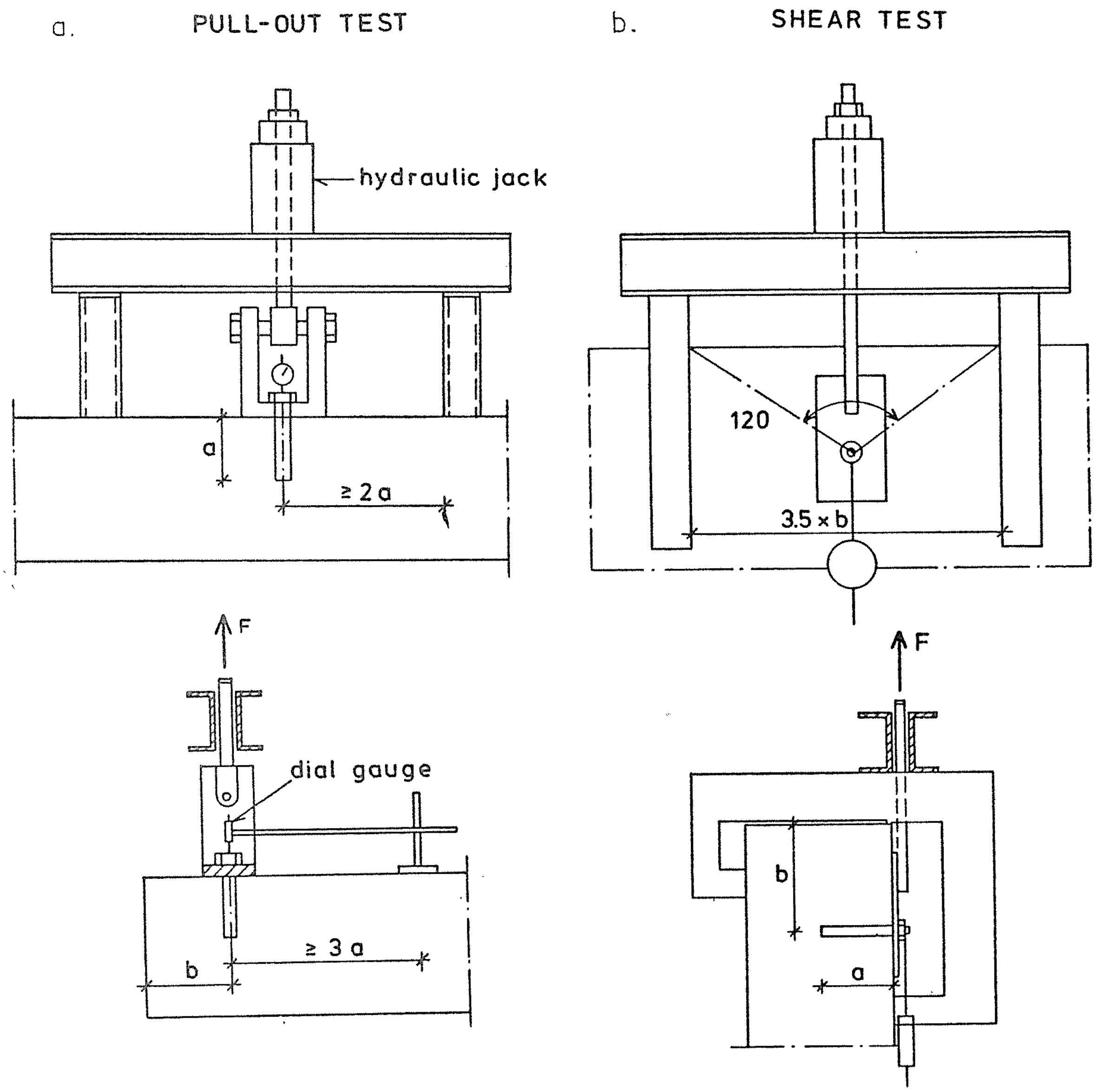


Fig. 5. Loading arrangement for type tests on expansion anchors:
a) tensile test
b) shear test.

In the tensile tests on anchors the expansion of which is achieved by hammering the most frequently occuring mode of failure was a material failure of concrete. On the other hand, in the shear tests the most frequently occurring failure has been a material failure of the fastener. In the Finnish type approval directive the failure state is for the present considered as being achieved even when the anchor has slipped 3 mm in the direction of force /4/. With the anchors mentioned above, particularly in shear tests, the slip exceeded this limit in many cases before the final failure. With the anchors M20 the load may have increased even by 70 % after the 3 mm slip had taken place.

The most frequently occurring mode of failure in the case of anchors the expansion of which is achieved by tightening with a spanner under tensile load has been the material failure of concrete. In shear loading, the failure of concrete and the shearing of the screw in the fastener have been the modes of failure of equally common occurrence. With most anchors the 3 mm slip limit was reached before the final failure. An increase in load after the slip limit had been reached was at its greatest 58 % in the tensile test and in the shear test even 145 %.

5. SAFETY QUESTIONS OF FIXINGS

5.1 Special features

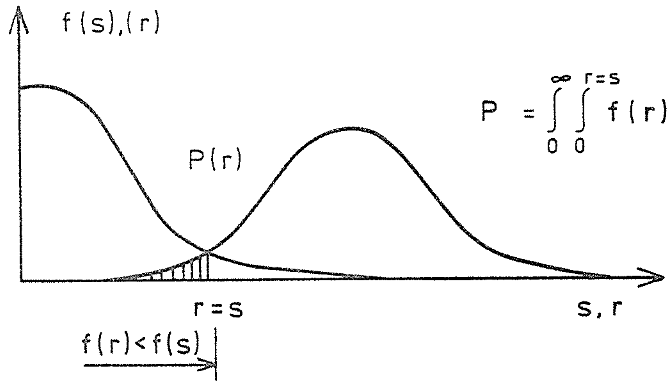
The design of fixings and the mode of safety considerations used in each case depends essentially on the performance of the fixture and the mode of failure. When the failure type based on the material failure or the tensile strength of concrete predominates, the design in most cases can be carried out by means of the calculation model based on the fixing performance. For more complicated failure cases, such as sliping, calculation models have also been developed. According to one model the tensile capacity of the expanding fixing embedded in hardened concrete is achieved as a multiple of splitting force produced by the fixing. On the other hand, splitting force is obtained on the basis of geometry of the fixing and the properties of concrete. In most cases where fixings are embedded in concrete the information available at present is not sufficient, however, for reliable safety considerations calculated theoretically, but the design has to be based more or less on experimental results.

On the other hand, experimental investigations suffer from the disadvantage of the great number of load and capacity parameters and often also from the great scattering of results. Therefore in conjunction with experimental studies one has to be satisfied with only the examination of the effects of most important parameters. Furthermore, there are still many factors that cannot be taken into account at all and which affect the strength of fixings, e.g. those associated with installation and site supervision. For example, the very method of installation and the responsibility for the installation work carried out are the essential factors that influence the reliability of the fixing, which can be, however, favourably affected only by training and by emphasizing the importance of the site supervision of structural fixings.

5.2 Dimensioning principles

In dimensioning the smallest value of capacity in question is compared in most cases with the greatest loading value supposed. If the capacity is at least of the size of the multiple of the required load, the object of design is considered to be adequately safe. In practice, neither the load nor the capacity are exactly known, therefore they can be estimated only on the basis of probability due to the scattering. The stocastic nature of the load and capacity can be evaluated by statistical means, in which case the safety of the structure is understood to be the complement of its damage probability or $P_r = 1 - P_f$.

Fig. 6. shows the damage probability by means of density functions of normally distributed load and capacity.



$$P = \int_0^{\infty} \int_0^{r=s} f(r)\, f(s)\, dr\, ds$$

Fig. 6. The damage probability by means of density functions of normally distributed load and capacity /8/.

If the above- mentioned safety questions that fail being noticed will be taken into account e.g. by means of the extra factor of safety, the total safety factors may become very great. Particularly when the scattering is great good judgement is needed in order to obtain reasonable results. There are many proposals for the suitable safety level or damage probability, which are primarily dependent on the mode of failure and the role of the fixings. It has been presented for one sufficiently low damage probability 10^{-5} - 10^{-7}. For some fixings special requirements associated with the performance of the structure and the safety of the fixing have been agreed.

It can be considered as a general guidance for the load/displacement curve of the so-called brittle fixings that the failure of one fixing, often at a very low displacement value, must not lead to the total failure of the whole fixing. This means that the fixing in question cannot be made with one fixture, and other fixings shall carry together the load transmitting from the one without harmful displacements. Correspondingly, in conjunction with the load/displacement curve of the so-called ductile fixing it has to be taken into account the whole performance of the structure so that the displacements of the fixing remain within a desired limit without preventing the designed performance of the structure. This can mean that the capacity is determined on the basis of displacement. On the other hand, the behaviour of this type of fixing in group fixing is advantageous, because it makes possible to balance the forces of different fixings or their redistribution. Moreover, the ductile performance confers an advantage in the case of impact load.

6. CONCLUSIONS

The modern industrially manufactured fixings in concrete are generally high quality products, and particularly in Finland there has not been essential defects in the type-approved fixings. On the other hand, there is room for improvement, especially in training and instruction of fixing techniques, in design and operation rules and, as a consequence of these, in installation work at sites which is carried out haphazardly either resulting from ignorance or even irresponsibility. The development of design methods, in conjunction with recent research and development work, has been gratifying, but in the most important matters, in work performance and its supervision, it has not advanced at all during the history of the fixing technique. In Finland also training in this field at every stage is lacking almost completely.

Fixing technique plays an important role in the construction field and is part of modern construction operations. If there is knowledge and skill sufficiently even difficult fixing problems with the products available can be solved economically and reliably.

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