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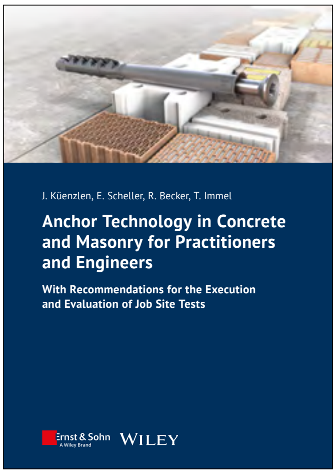
Anchor Technology in Concrete and Masonry for Practitioners and Engineers

With Recommendations for the Execution and Evaluation of Job Site Tests

- **Answers to practical questions on anchor selection and installation**
- **Instructions for installation and tests on construction site**
- **Explanations of technical regulations and European Technical Assessments (ETA)**

This book is a guide for practical anchor technology. It provides assistance in the selection of the appropriate anchor system for the fastening task as well as advice for planning and installation in the base material. The theory of load-bearing behaviour is briefly explained.



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Contents

But what is uncracked concrete? And does that not contradict the simple statement *Concrete is always greyish and cracked!* (see Section 4.1.1)?

When it comes to anchor technology, this question is relatively easy to answer:

Every piece of concrete is *cracked* until – using a numerical analysis according to EN 1992-4 (2018) – somebody proves that the concrete is *uncracked*. To do this, Eq. (4.1) must be satisfied:

$$\sigma_L + \sigma_R \leq \sigma_{adm} \tag{4.1}$$

where

- σ_L stress in the concrete caused by external loads including the loads due to the fastener
- σ_R stress in the concrete caused by deformations due to internal restraints (e.g. shrinkage of the concrete) or deformations due to external restraints (e.g. displacement of supports, temperature fluctuations); assume $\sigma_R = 3\,N/mm^2$ if a detailed analysis is unavailable
- σ_{adm} permissible tensile stress for defining uncracked concrete; DIN EN 1992-4 (2018) recommends $\sigma_{adm} = 0$

Note: The numerical analysis according to Eq. (4.1) is very involved. For this reason, the simplest solution is always to use anchors that have an ETA for 'cracked' (reinforced) concrete (see Section 4.1.2).

4.1.4 Types of Concrete

4.1.4.1 General

According to EN 206 (2016), concrete is composed of cement, coarse and fine aggregates and water. Additives, admixtures and/or fibres can be included as well. Concrete achieves its properties through the hydration of the cement, i.e. a chemical–physical reaction between the cement and the water. According to EN 206 (2017, p. 29), natural normal-weight aggregates are generally suitable.

4.1.4.2 Normal-weight Concrete

EN 206 (2016) defines normal-weight concrete as 'concrete in the oven-dry condition having a density greater than 2000 kg/m^3 but not exceeding 2600 kg/m^3' (Figure 4.5). In the standard, concrete with a higher density is designated a heavyweight concrete, that with a lower density lightweight concrete (see Section 4.1.4.3). EN 1992-4 (2018) limits the numerical analysis of anchors in normal-weight concrete without fibre reinforcement. This is why, for example, further considerations apply for normal-weight concrete containing steel fibres as an aggregate, but those considerations are not dealt with in this publication.

4.1.4.3 Lightweight Concrete

EN 206 (2016) defines lightweight concrete as 'concrete in the oven-dry condition having a density of not less than 800 kg/m^3 and not more than 2000 kg/m^3'. This – compared with normal-weight concrete – much lower density is determined by choosing different aggregates. Whereas the aggregates for normal-weight

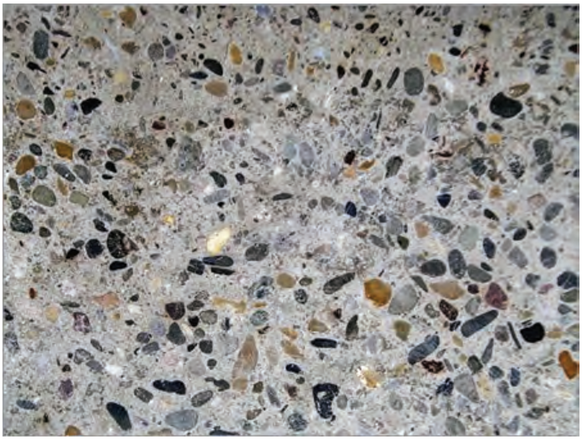


Figure 4.5 A section through a member made from normal-weight concrete (photo: Adolf Würth GmbH & Co. KG).

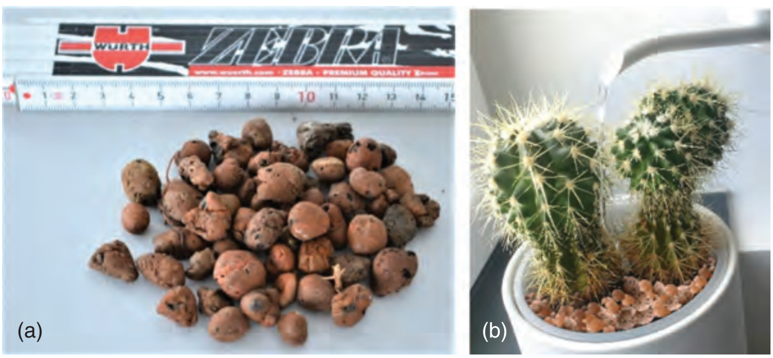


Figure 4.6 Aggregate for lightweight concrete: expanded clay pellets, (a) expanded clay or expanded slate, (b) hydroponic plant (photos: Scheller).

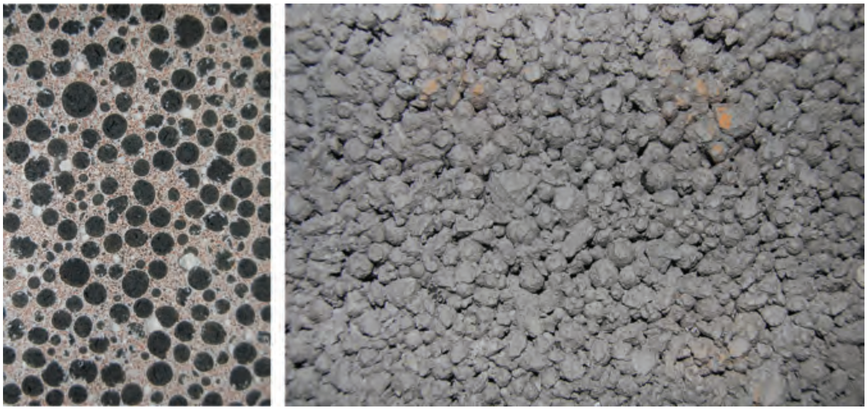
concrete essentially consist of gravel and sand (coarse and fine aggregates, see Section 4.1.4.1), the aggregates for lightweight concrete consist of materials with a high porosity, e.g. pumice stone, expanded clay or expanded slate. Expressed simply, we can also say that this aggregate in the form of lightweight expanded clay pellets is essentially nothing more than the substrate used for hydroponic plants (Figure 4.6).

It is necessary to distinguish between two types of lightweight concrete:

- *with* fine aggregate (dense microstructure, LC: Lightweight Concrete, Figure 4.7a) and
- *without* fine aggregate (no-fines, LAC: Lightweight Aggregate Concrete, Figure 4.7b).

In *LC concretes* the aggregates are surrounded completely by the cement so that, as with normal-weight concrete, there are no voids between the individual grains of aggregate, which results in a dense microstructure (Figure 4.7a).

In *LAC concretes* there is no fine aggregate and so the spaces between the individual grains of (coarse) aggregate are not completely filled with cement, which leaves small air-filled voids (Figure 4.7b).



(a) (b)

Figure 4.7 The two types of lightweight concrete: (a) *with* fine aggregate (dense microstructure, LC), (b) *without* fine aggregate (no-fines, LAC) (photos: Küenzlen).

Note: Up until now to the best of the authors' knowledge no anchor systems have (yet) been approved for anchorages in (structural) lightweight concrete or for anchorages in lightweight concrete members cast in situ (see note in Figure 3.1).

To date, anchor systems have only been approved for anchorages in *masonry* made from lightweight concrete units (metal injection anchors for anchorages in masonry and plastic anchors).

4.1.5 Compressive Strength Classes

4.1.5.1 Normal-weight and Heavyweight Concrete

The compressive strength class of a concrete delivered to the construction site in a truck mixer must be stated on the delivery documents. The site manager can thus check whether the concrete as delivered corresponds to the concrete stipulated on the general arrangement and reinforcement drawings prepared by the structural engineer. Information about the compressive strength class is given in Figure 4.8 using the example of a C20/25 normal-weight concrete.

The compressive strength specified according to Figure 4.8 is the characteristic concrete compressive strength f_{ck}, which according to EN 206 (2016) is the minimum of

- the characteristic cylinder strength $f_{ck,cyl}$ (150 mm diameter × 300 mm long cylinder) or
- the characteristic cube strength $f_{ck,cube}$ (150 × 150 × 150 mm cube).

The symbol f_{cm} represents the mean concrete compressive strength.

This means that specimens (cylinders or cubes) were specially produced to determine the concrete compressive strength and that, after curing, the specimens were loaded to failure in a testing apparatus (Figure 4.9). The test specimens must comply with EN 12390-1 and be produced and stored according to EN 12390-3

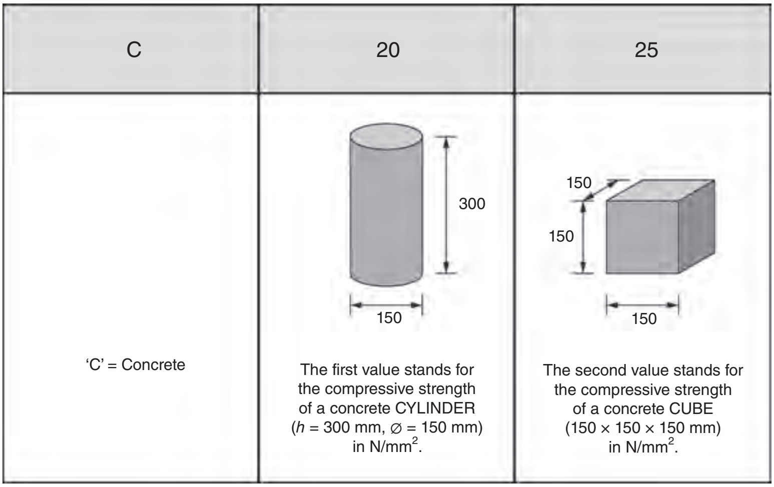


Figure 4.8 Explanation of the designation of the compressive strength classes for normal-weight and heavyweight concretes according to EN 206 using the example of a C20/25 normal-weight concrete (graphic: Adolf Würth GmbH & Co. KG).

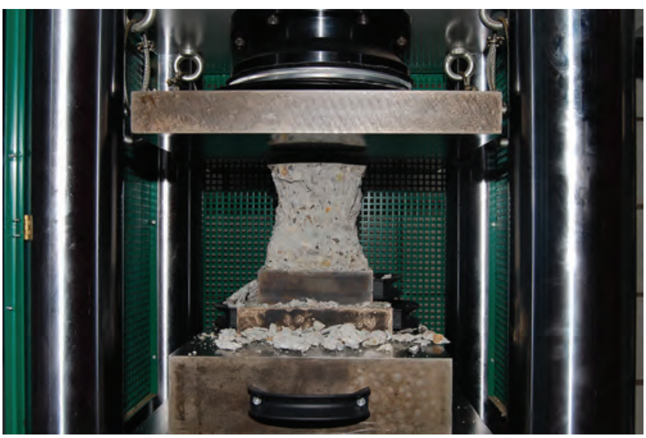


Figure 4.9 Testing apparatus in which concrete cubes are loaded to failure (photo: Kuhn).

(2019, Annex A). Sampling is carried out according to EN 12350-1. Moulds for cubes must comply with EN 12390-3 (2019).

Where the compressive strength of a concrete member in an existing structure has to be determined, then the test specimens can also be in the form of cores removed from a suitable place in that member (see also Section 3.2.2.2). Prior to compression tests, the ends of such cores must either be ground flat or any unevenness compensated for.

According to EN 12390-3, specially produced test specimens should be tested after 28 days (EN 206, 2016) in order to determine their concrete compressive strength.

This stipulation is very important because the strength class for normal-weight concrete called for in an anchor approval (see Section 4.1.1, for example) can

Figure 4.10 Example of the construction of a high-rise building: Fitting-out work (e.g. services and façade cladding) is already in progress on the lower floors while the upper floors are still being concreted (photo: Scheller).

generally only be determined, according to the standard, *after* 28 days. Consequently, only *after* 28 days can it be assured that the anchor has been installed in the right base material. The reason for this is that, as a rule, it takes 28 days for the concrete to reach the strength class on which the design of the respective anchor is based.

However, anchors certainly get (or have to be) installed in concrete that is not yet 28 days old. This can happen, for example, when constructing a high-rise building: Fitting-out work (e.g. services and façade cladding), for which anchors are frequently used, often starts on the lower floors while the upper floors are still being concreted (Figure 4.10).

Note: If concrete on the building site is not yet 28 days old, then the engineer and/or a specialist should be consulted prior to installing anchors, because a special assessment might be necessary.

Table 4.1 shows the current compressive strength classes for normal-weight and heavyweight concrete according to the standard. Currently, a numerical analysis of anchors according to EN 1992-4 (2018) is possible for classes C12/15 to C90/105. However, many anchor systems are only approved for anchorages in concrete of compressive strength classes C12/15 or C20/25 to C50/60.

At times in the past, the respective strength class has also been determined using 200 mm cubes ($f_{cube200}$). According to EOTA TR 048 (2016, p. 4), for example, these strengths can be converted to the current value for a 150 mm cube ($f_{cube150}$) using Eq. (4.2):

$$f_{cube150} = \frac{1}{0.95} \cdot f_{cube200} \tag{4.2}$$

where

$f_{cube150}$ nominal value of characteristic concrete compressive strength (based on 150 mm cubes)

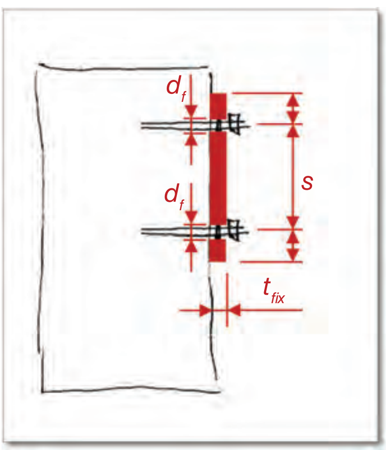
$f_{cube200}$ nominal value of characteristic concrete compressive strength (based on 200 mm cubes)

4.1.5.2 Lightweight Concrete

Table 4.2 shows the current compressive strength classes for (structural) lightweight concrete according to EN 206, Chapter 4.3.1 Table 13. The designation of the classes is similar to that for normal-weight and heavyweight concretes, with the difference that the abbreviation ‘LC’ is used instead of just ‘C’ A comparison of Tables 4.1 and 4.2 shows that lightweight concrete can achieve similar compressive strengths to those of normal-weight or heavyweight concrete.

Table 4.2 Compressive strength classes for lightweight concrete according to EN 206, Chapter 4.3.1 Table 13.

Compressive strength class	Characteristic minimum compressive strength of cylinders $f_{ck,cyl}$ in N/mm^2	Characteristic minimum compressive strength of cubes $f_{ck,cube}$ in N/mm^2
LC8/9	8	9
LC12/13	12	13
LC16/18	16	18
LC20/22	20	22
LC25/28	25	28
LC30/33	30	33
LC35/38	35	38
LC40/44	40	44
LC45/50	45	50
LC50/55	50	55
LC55/60	55	60
LC60/66	60	66
LC70/77	70	77
LC80/88	80	88



Anchor plate/fixture

Diameter of clearance hole (d_f)

Thickness of fixture (t_{fix})

Spacing (s)

7

Fixtures and Anchor Plates – What Do I Want to Fasten?

7.1 General

In the previous chapters we dealt primarily with the topic of the *base material* and the following associated issues:

- Chapters 3 and 4: Which base material do I have on the building site?
- Chapter 5: Environment – Which external influences affect my fastenings?
- Chapter 6: Member dimensions – Where do we position our fastening in the base material (near or remote from an edge)?

This chapter looks at the *fixture*, or anchor plate (see Figure 6.1), and answers the following questions:

- Does the item to be fixed have one or multiple anchorage points?
- How thick is the fixture/anchor plate?

The maximum fastening length of the anchor system to be used depends on the thickness of the fixture/anchor plate (see Figure 6.2). Therefore, the anchor system concept must also be available with the corresponding maximum fastening length (also known as the clamping range).

- Are there constraints such as predrilled holes? In other words, is there already a clearance hole in the item to be fastened which calls for a certain anchor diameter?

If the fixture/anchor plate has, for example, an electrogalvanised or hot-dip galvanised finish for corrosion protection reasons, then existing holes should not be drilled larger on site in order to use larger anchors, because drilling damages the corrosion protection.

- If there are several holes in a fixture/anchor plate, then what does the hole pattern look like?

The centre-to-centre distance between the clearance holes is called the spacing s, see Section 6.4. The current design methods are only valid for certain hole patterns.

Verification according to EN 1992-4 (2018) requires that when using metal anchors to attach a fixture to concrete, all the anchors must be of the same type and

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size (diameter and embedment depth, see Figure 6.2). Although this fundamental requirement is not explicitly mentioned in the current regulations for metal injection anchors for fastenings in masonry according to TR 054 (2022) and for plastic anchors according to TR 064 (2018), it nevertheless applies to such anchor systems as well.

Therefore, we may *not* combine different anchor types and different anchor sizes in one group of fasteners. The main reason for this constraint is that different anchor systems and different anchor sizes also result in different stiffnesses, which means that they will deform differently under load. If different systems and/or different anchor sizes are combined, it is currently not possible to determine the load distribution on the basis of the different stiffnesses.

7.2 The Theory Behind Fixtures and Anchor Plates

If we can choose any type of fixture because it has not yet been fabricated or manufactured, then the answers to the above questions depend on the actions (the loads acting on the fixture, see Chapter 8) as well as the design of the respective anchor (see Chapter 10) and the particular fixture.

In theory, this means that – using the example given in Section 1.2 for simplicity – the anchors should not be calculated on the basis of the anchor plates as supplied by the manufacturer of the pull-up bar. Instead, if at all possible, the actions (loads) acting on the pull-up bar should first be determined and the design then carried out for an anchor system that suits the actual structure and base material present on the building site. This design calculation then supplies

- the number of anchors,
- the anchor size (diameter) and associated embedment depth or effective anchorage depth,
- the spacing of the anchors,
- the diameter of the clearance holes in the fixture/anchor plate and
- the arrangement of the clearance holes in the fixture/anchor plate.

Note: For reasons of clarity, this book does *not* deal with the design of the fixture/anchor plate itself.

In this context, the reader's attention is merely drawn to the fact that, for example, when designing fastenings in concrete for metal anchors according to EN 1992-4 (2018), the design of the fixture (in the sense of prescribing the fixture thickness t_{fix} and the dimensions of the fixture) is explicitly omitted. The current design methods for metal injection anchors for anchorages in masonry according to TR 054 (2022) and for plastic anchors according to TR 064 (2018) do *not* include any information on this aspect either.

The reader is referred to, for example, EN 1993 (Eurocode 3) for the design of a steel fixture and, for example, EN 1995 (Eurocode 5) for a timber fixture.

7.3 The Support of the Fixture

7.3.1 General

According to EN 1992-4 (2018), a fixture for metal anchors in concrete may have either

- statically determinate or
- statically indeterminate

support conditions. Fixtures and members may be either

- structural or
- non-structural.

The principle behind this approach applies similarly for all other anchor systems (injection systems and plastic anchors) and is explained in Sections 7.3.2–7.3.4.

The terms *statically determinate* and *statically indeterminate* indicate that we are dealing here with structural engineering concepts. For reasons of clarity, this relatively complex topic will not be dealt with further in this book. Instead, the terms given in Figure 7.1 will only be explained in so far as they are significant for the practical application of anchor technology (i.e. without the design or structural engineering concepts).

Figure 7.1 shows, schematically, examples of items attached to the underside of a floor slab. In this situation it is possible to imagine, for example,

- linear arrangements for supporting a pipe (Figure 7.2a) and
- distributed arrangements for supporting a suspended ceiling (Figure 7.2b),

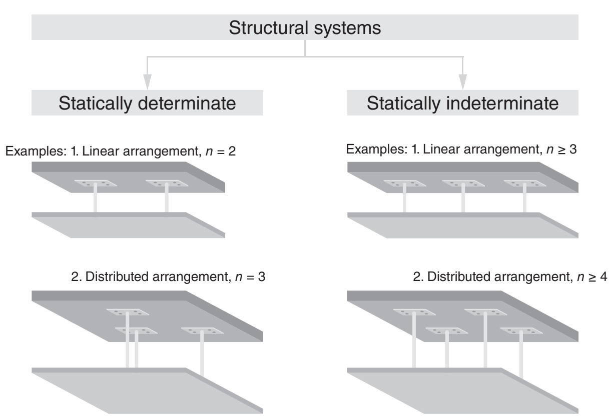


Figure 7.1 The concepts of statically determinate and statically indeterminate and the ensuing terms single fastening and multiple fastenings (graphic: Adolf Würth GmbH & Co. KG).

(a) (b)

Figure 7.2 Examples of linear and distributed arrangements: (a) linear arrangement for supporting a sprinkler pipe, (b) distributed arrangement for supporting a suspended ceiling (photos: Scheller).

which are well known in practice. In all cases, the authors of this book recommend the use of suitable anchor systems with European Technical Assessments (ETAs) when fastening such items. Such systems can make use of

- single fastenings (for structural and non-structural systems) and, in certain circumstances, also
- multiple fastenings (for non-structural systems only).

In the following, for simplicity, we shall limit ourselves to linear arrangements. However, the information applies similarly to distributed arrangements.

Note: If an anchor system with an ETA is only approved as a 'multiple fastening for non-structural systems' or 'multiple use for non-structural applications', or 'for redundant non-structural systems', then this information is generally given on the cover of the associated approval (see ETA W-UR/SHARK UR, 2021, see Figure 2.1). 'Multiple use' means the presence of several fastening points.

7.3.2 Fixture with Statically Determinate Supports – Single Fastening

Based on Figures 7.1 and 7.3 shows a typical practical example that everybody knows: attaching a pendant lamp with two fastenings to the soffit of a floor slab inside a building. The points from which the lamp is to be suspended from the floor slab are known as the fixing points. Obviously, when one of the fixing points fails, then at least one end of the lamp drops into the room (Figure 7.3b).

The next example (see Figure 7.4) is particularly easy to understand and involves a fastening for a chandelier, which has just one fixing point and is therefore obviously a 'single fastening'. According to 'anchor theory', whether this fixing point consists of just one anchor or several anchors, i.e. a group of anchors, is irrelevant (see also Section 6.4.1.2).

Both the fastening for the pendant lamp with two fixing points (Figure 7.3) and the fastening for the chandelier with just one fixing point (Figure 7.4) are relevant in

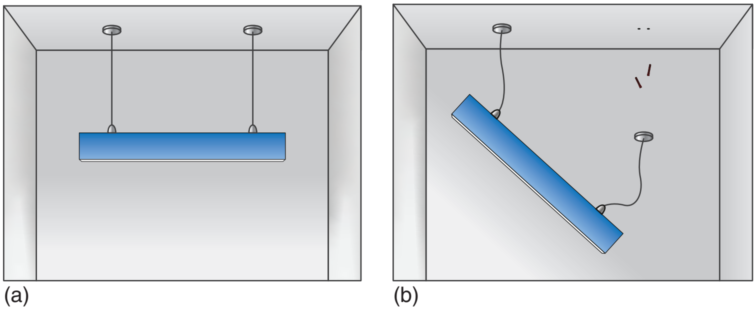


Figure 7.3 Example of a pendant lamp fastened at two fixing points: (a) initial situation, (b) failure of one fixing point (graphics: Adolf Würth GmbH & Co. KG).

Figure 7.4 Example of a chandelier suspended from just one fixing point (photo: Scheller).

safety terms because the failure of any fastenings results in danger to life and limb for any persons underneath! Therefore, these fixing points may not fail and must make use of anchors that are approved not only for multiple fastenings, but also for single fastenings.

So, when it comes to anchor technology, for simplicity, statically determinate means that an item can be fastened with just one single anchor. Consequently, that also means, however, that if this one anchor fails, then the item fastened could fall or the structure could collapse if the wrong type of anchor is chosen and/or the design contains errors.

Accordingly, it is crucial to consider the item to be fastened and whether the anchors are suitable for the intended application. Therefore, when fastening, for example, balustrades, awnings, escape stairs, balconies, canopies, etc., it is only permitted to use anchor systems with an ETA for a single fastening because

- these are structural systems (see Section 7.3.3.2) and/or
- relatively heavy loads act on these systems (see Section 7.3.3.5).

Single fastenings must function (more) reliably and, in contrast to multiple fastenings (see Section 7.3.3), may not fail, and therefore much more stringent requirements must be satisfied during the approval procedure and the testing for an approval.

7.3.3 Fixture with Statically Indeterminate Supports – Multiple Fastenings

7.3.3.1 General

According to Section 7.3.2, statically indeterminate – correspondingly simplified for anchor technology – means that an item has to be fastened not by way of just one fixing point (Figure 7.4) or two fixing points (Figure 7.3), but with a minimum of *three* fixing points (linear arrangement) or *four* fixing points (distributed arrangement, see Figure 7.1).

Figure 7.5 shows an example of a pendant lamp attached at three fixing points. This illustration makes it clear that if *one* fixing point of this multiple fastening fails, then the lamp does not drop down because the load no longer carried by the fixing point that has failed can be redistributed via the lamp housing to the two neighbouring fixing points.

For multiple fastenings as well, according to ‘anchor theory’, whether this fixing point consists of just one anchor or several anchors, i.e. a group of anchors, is irrelevant. Further examples of multiple fastenings – with one or more fasteners per fixing point – can be found in CEN/TR 17079 (2018), see Figure 7.6.

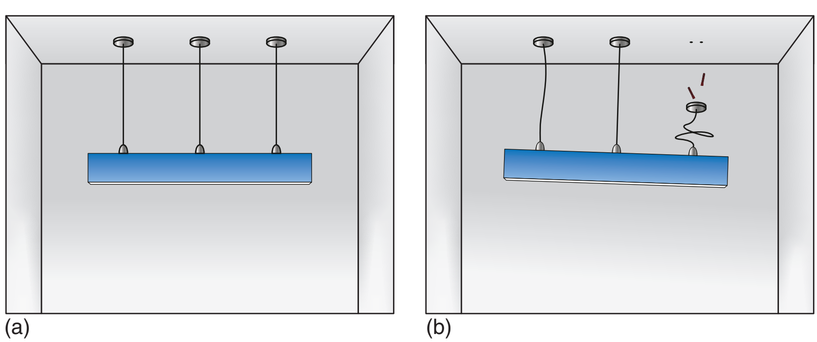
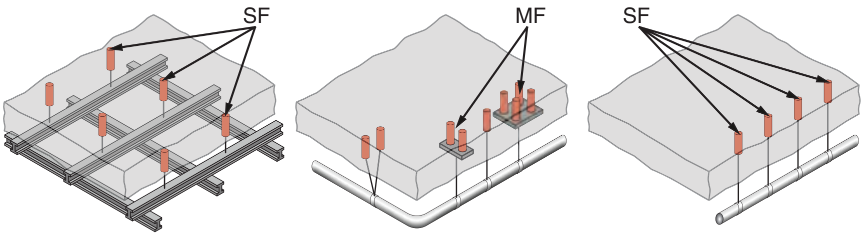


Figure 7.5 Example of a pendant lamp fastened at three fixing points: (a) initial situation, (b) failure of one fixing point (graphics: Adolf Würth GmbH & Co. KG).



SF = one fastener per fixing point
MF = two or more fasteners per fixing point

Figure 7.6 Examples of statically indeterminate non-structural systems with one or more fasteners per fixing point according to CEN/TR 17079 (2019, p. 5) (graphic: Adolf Würth GmbH & Co. KG).

CEN/TR 17079 (2018) designates 'multiple fastenings for non-structural systems' as a 'fastening for redundant non-structural systems'. Both designations can be found in publications dealing with anchor technology.

Note: 'Multiple fastenings for a non-structural system' and a 'fastening for a redundant non-structural system' are statically indeterminate systems that consist of

- at least three fixing points (linear arrangement) or
- at least four fixing points (distributed arrangement)

and a fixture or member that is to be fastened (see Figure 7.2).

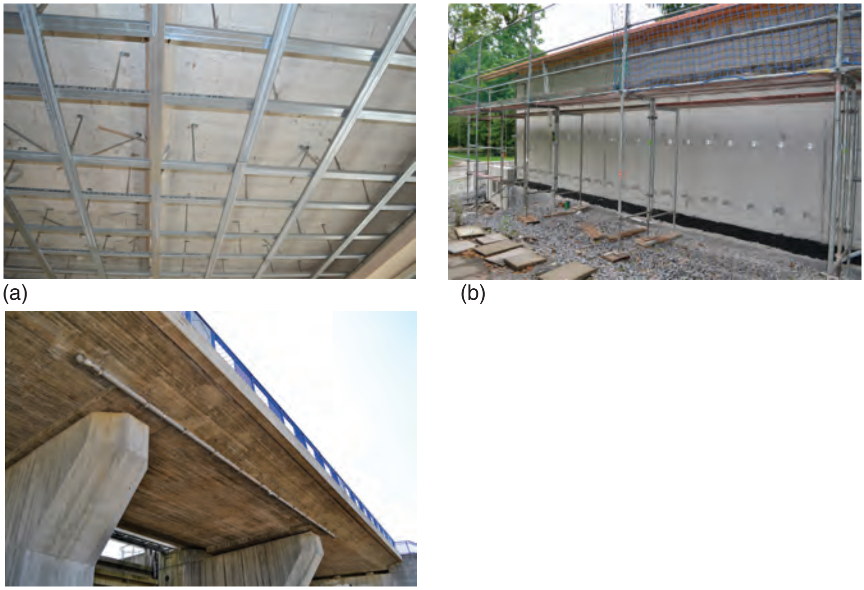
- The fixture to be fastened (e.g. a pipe or a member of a façade support structure or a suspended ceiling) must exhibit adequate stiffness so that in the case of failure of one fixing point, the loads at that fixing point can be redistributed to the adjacent fixing points.
- The loads acting per fixing point – for metal anchors in some countries and for plastic anchors throughout Europe – are limited and may not be exceeded.

The terms mentioned under 'Note' above are important and are explained in more detail in Sections 7.3.3.2–7.3.3.6.

7.3.3.2 Distinguishing Between Structural and Non-structural Systems

The design standard for metal anchors in concrete, EN 1992-4 (2018), already referred to many times, is used again and again as the yardstick or starting point for regulations covering injection anchors and plastic anchors and contains the following sentence referring to multiple fastenings (EN 1992-4, 2018):

> *'The definition of redundant non-structural systems can be found in the national regulations.'*



(a) (b) (c)

Figure 7.7 Real examples of multiple fastenings for non-structural systems: (a) fastening a support framework for a suspended ceiling (photo: Scheller), (b) fixing points for attaching continuous vertical members for a façade support structure (photo: Küenzlen), (c) fastenings for a pipe (photo: Küenzlen).

Hence, there is 'room for interpretation' in every EU member state because, as already mentioned, construction legislation is the province of the individual countries.

Figures 7.6 and 7.7 show typical, real examples of multiple fastenings for *non-structural* systems. The examples shown all have one thing in common: The fastenings essentially carry only the self-weight (dead load) of the member to be fastened. Wind loads acting directly on the member itself, e.g. the façade panel of a suspended façade (Figure 7.7b), may have to be carried as well.

Taking the above definition to its logical conclusion, *structural systems* obviously also contribute to the stability of a structure or part(s) of a structure (e.g. steel columns or steel beams that support a stair landing) and *carry* not only their self-weight and, if applicable, direct wind loads, but also imposed loads (e.g. persons on the stair landing, also snow loads if the landing is exposed to the weather). Other examples of imposed loads that can be carried by single fasteners only (see Section 7.3.2) are the loads from bracing members that stabilise the entire structure or part(s) of a structure against wind loads, or the horizontal loads generated by persons holding onto, leaning against or supporting themselves on a balustrade.

7.3.3.3 Stiffness of the Fixture

In the description of Figure 7.5 it was mentioned that the pendant lamp will only fall down when the load of a potentially failing anchor or fixing point can be redistributed via the lamp housing to the two adjacent fixing points.

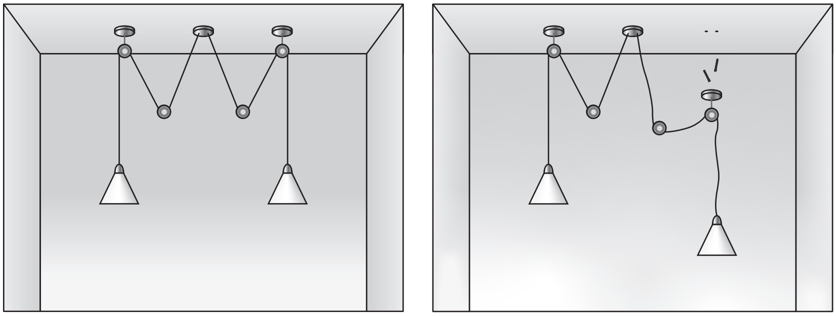


Figure 7.8 Simplified example of an insufficiently stiff pendant lamp suspended from three fixing points: (a) initial situation, (b) failure of one fixing point (graphics: Adolf Würth GmbH & Co. KG).

Figure 7.8 shows a simplified example of a pendant lamp in the form of a rope system. This system again has three fixing points, but the rope supporting the lamp cannot redistribute any load in the event of the failure of one fixing point because – unlike the lamp housing in Figure 7.5 – it is not sufficiently stiff.

CEN/TR 17079 (2018) has the following to say about this:

> *'The stiffness of the attached element shall be large enough to ensure that in case of excessive slip or failure of a fastener the load on this fastener or fixing point can be transferred to neighbouring fixing points without significantly violating the requirements on the attached element in the serviceability and ultimate limit state. The requirements in the serviceability limit state depend on the application.'*

Note: This is the reason why multiple fastenings are also called redundant fastening.

Therefore, in the case of the multiple fastening of non-structural systems, it does not depend on the magnitude of the loads acting (Section 7.3.3.5) and the loads carried by the anchors or multiple fastenings, instead depends on the member itself. Figure 7.9 (enlarged/modified version of Figure 7.2a) illustrates this statement using the example of fastenings for a pipe in a basement car park. If this pipe is to be attached with appropriate anchors in the form of a multiple fastening for a non-structural system, then the system connecting the fixing points, i.e. the pipe itself, must be sufficiently stiff in order to be able to transfer the load in the case of failure of one of the three or more fixing points required. Further regulations may need to be considered in addition to, or irrespective of, the regulations covering anchor technology.

7.3.3.4 Loads Acting on Multiple Fastenings

According to CEN TR 17079 (2018), loads on multiple fastenings are – in contrast to anchors according to Section 7.3.2 – merely quasi-static. EN 1990 (2002) defines