# 1 Introduction

## 1.1 A historical review

The task of connecting building components is as old as building itself. Throughout history, the job has been handled in different ways depending on the building material, the structural system and the particular requirements of the construction.

In wood construction traditional joinery began with timbers bound with tough natural fibres and developed into various types of interlocking, screwed and doweled joints, glued and finger joints as well as embedded steel plates and ring connectors.

Steel construction, a comparatively 'young' discipline, employs connection techniques ranging from cast-iron fittings to rivets, bolts and welding, whereby only bolting and welding are in common use today.

In concrete and masonry construction, various means of anchoring are in regular use (Fig. 1.1).

The mortar used in masonry assemblies can be regarded as the oldest type of connection material. In fact, the hewn dovetails, cast metal joints and embedded metal studs or sleeves historically employed in stone masonry may be considered to be the predecessors of today's modern fastening technology. Today, these methods have been largely replaced by plastic and/or metal elements of sophisticated design inserted into pre-drilled holes and secured via friction, mechanical interlock, chemical bond, or a combination thereof. Today there are systems available that are suitable for practically any type of masonry.

Concrete and reinforced concrete construction initially borrowed fastening techniques from other building trades, either unchanged or only slightly modified. Wood lathe placed in the formwork was anchored in the concrete via predriven nails and served as an attachment point for the entire range of building systems, as well as for suspended ceilings. Later, threaded

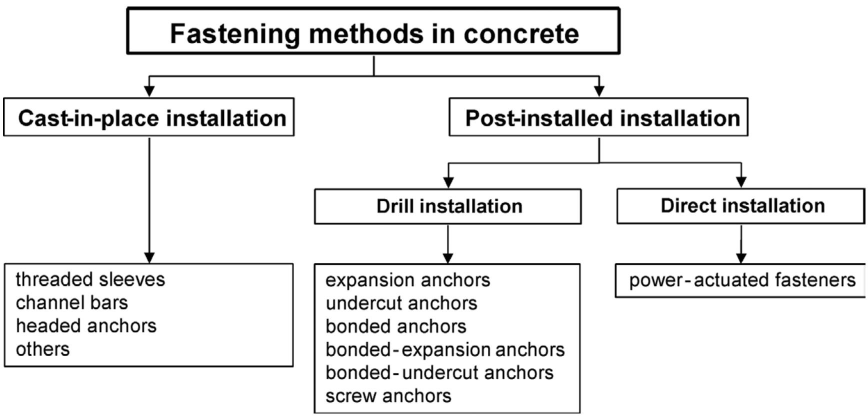


**Fig. 1.1** Fastening methods in concrete

sleeves, anchor channels and headed studs welded to steel plates were employed, these being secured inside the formwork and cast into the concrete.

These so-called "cast-in-place" techniques were later rivalled by systems designed to be installed after the concrete had cured. The evolution of drilling technology from chisels to rotary-percussion tools and the more recent development of diamond core drilling has opened up new opportunities for the field of post-installed anchoring technology.

For minor loads, the ubiquitous plastic anchor, successor to hemp and lead plugs, has all but replaced other techniques. To cope with higher loads, various types of metal expansion anchors have been developed that employ, in principle, the same functional principles but with varying construction details and attendant variations in installation and application conditions.

Bonded anchors, in which a steel rod is grouted into a pre-drilled hole, continue to be frequently used. Representing the latest stages in this chain of development are undercut anchors, hybrid systems employing bond, friction and/or mechanical interlock, and second-generation self-tapping screws.

Parallel with the development of anchors for pre-drilled holes, the technology of high-strength steel nails or studs driven into steel and concrete by an explosive or pneumatic energy source (so-called power-actuated fastening) has seen growing use over the past four decades. These systems serve to simplify the attachment of piping systems, lightweight suspended ceilings, etc., and are also widely employed for the attachment of metal deck to steel framing.

Clearly, post-installed fastening in concrete and masonry is a relatively young discipline, meaning that the state of the art is generally in a state of flux. Consequently, these systems typically cannot be regulated via prescriptive standards, as is done, say, with high-strength structural bolts. Consequently, in the member states of the European Community, the U.S. and other countries the design and installation of post-installed fastenings is usually carried out in accordance with product-specific approvals.

## 1.2 Requirements for fastenings

Fastenings must be designed in such a way that they do the job for which they are intended, are durable and robust, and exhibit sufficient load-carrying and deformation capacity. Fastenings for less critical applications, e.g. securing light-weight duct, lighting, and wiring, can be selected on the basis of the user's experience and do not usually require analysis or structural review (outside areas of seismic hazard). On the other hand, fastenings that are relevant to life safety, i.e. whose failure could pose a hazard to life or result in significant economic loss, must generally be selected on the basis of structural considerations and are typically designed and detailed by a structural engineer. The design establishes whether the requirements of the serviceability and ultimate limit states are met. The serviceability limit state includes requirements for limiting deformation, and requirements on durability (corrosion, chemical resistance). At the ultimate limit state it must be proven that the design value of the actions does not exceed the design value of the fastening resistance. Analyses of the serviceability and ultimate limit states generally make a distinction between the type and direction of the load. Section 1.3 deals with loads acting on connections and section 3.7 with the distribution of these loads to the fasteners. The capacities of the fastenings are explained in relation to the type of fastener and type of base material as well as failure mode in sections 4 to 9. The behaviour of fasteners under seismic excitations and under fire is dealt with in sections 10 and 11 respectively. Corrosion and corrosion protection is discussed in section 12 and the influence of fastenings on the capacity of concrete members in which they are installed is explained in section 13. Requirements on the suitability of fasteners for the application in question and the design of fastenings are discussed in section 14.

## 1.3 Nature and direction of actions

Actions (loads) can be classified according to the frequency of their occurrence and their duration. In addition, we can make a distinction as to whether or not inertial forces are involved. Table 1.1 provides an overview of various actions. Dynamic forces arise in cases of

**Table 1.1** Classification of actions

| Number of load cycles | | | | |
|---|---|---|---|---|
| None (constant) | Low | | High | |
| | Without inertial forces | With inertial forces | Without inertial forces | With inertial forces |
| • Self-weight<br>• Partitions<br>• People<br>• Fixtures and fittings<br>• Stored materials<br>• Snow<br>• Water<br>• Wind<br>• Restraint of deformations | • Restraint of deformations | • Impact<br>• Earthquake<br>• Explosion | • Traffic loads on bridges and basement roofs<br>• Crane rails<br>• Lifts<br>• Machines without inertial acceleration | • Machines generating high inertial accelerations (punches, presses, rams, forges) |
| | • Primarily static actions | • Dynamic actions | • Frequently alternating actions | • Dynamic actions |

impact, earthquake, explosion or machines that generate large inertial loads. If the load is permanent or occurs only a few times and does not include inertial forces, then the action is considered to be static. If the number of load cycles is large but, again, inertial loads are not present, then we refer to fatigue loading. If inertial forces are involved, then the action is dynamic, regardless of the number of load cycles.

Static actions are the sum of permanent and semi-permanent (slowly changing) actions. These actions are sometimes referred to as dead and live loads. The permanent actions result from the weight of the structural components to be anchored and any other constant loads that the attached components must carry, e.g. backfill, floor coverings, and plaster. Semi-permanent actions include, for example, foot traffic, fixtures and fittings, non-load-bearing lightweight partitions, stored materials, wind and snow. Given values for the applicable permanent and semi-permanent actions can be found in the relevant national and international standards (e. g. DIN 1055, Eurocode 1: EN 1990: 2002 (2002), ASCE 7 (*American Society of Civil Engineers* (2002)) .

Deformations can occur in anchored components, e.g. due to temperature fluctuations or due to shrinkage and creep of the concrete components. Temperature fluctuations may be due to weather conditions, as with building facades, or may simply be a result of the component function, as in the case of chimneys, silos, boiler rooms and cold storage rooms. Restraint of these deformations gives rise to stresses in the fasteners, the magnitude of which depends on the geometry and position of the fastenings as well as the mechanical properties of the materials involved. These stresses may be relevant to the fatigue-resistance of the fastener, depending on the number of temperature-induced strain cycles. For example, in the case of facade support structures, assumptions of $10^4$ to $2 \cdot 10^4$ load cycles are often used in design.

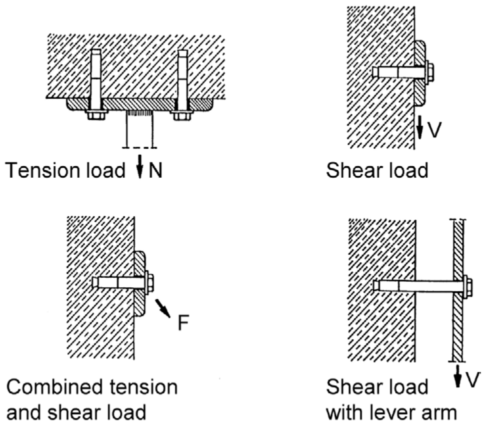


**Fig. 1.2** Actions on fasteners

Frequently alternating actions (fatigue loads) are caused by, for example, traffic loads, crane rails, lift and machines. The magnitude of the changing action required for design is again to be found in the relevant national and international standards. These standards also define whether a changing action should be viewed as a static action or as a fatigue load. For example, a wind load frequently changes in magnitude and direction but is often regarded as a static load for design purposes.

The essential difference between dynamic and static actions lies in the presence of inertial and attenuation forces. These forces arise from the induced accelerations and must be taken into account when determining the forces on the fastening. Dynamic forces are brought about by earthquakes, sudden actions such as impacts and explosions, and by machines with high inertial acceleration, e.g. printing presses. Dynamic actions generated by machines are also regarded as relevant for fatigue.

Loads can occur as tension, shear or a combination of tension and shear. In the case of shear, we distinguish between loading with or without bending of the fastener (Fig. 1.2).