1

General

1.1 The Advantages of Factory Production

The corporate goal behind the use of a method of production and construction that is to establish itself in the marketplace must be:

To produce and use a product *more economically* or *faster* or *better* than is possible with competing methods.

The optimum situation would be if each 'or' could be replaced by 'and'. So what is the situation with construction using precast concrete elements?

Building with precast concrete elements is based on the factory production of those elements, which are afterwards transported to the building site ready for erection there. There are merely three reasons for the economic advantage of this form of construction:

– Multiple use of the same mould for one element
– A better quality of workmanship, especially for concrete surfaces
– Pre-production for faster operations on site.

If all three advantages can be exploited, then building with precast concrete elements can be an interesting option for a project. Benefiting from even just one of these advantages can be crucial in some situations.

Without doubt, one key purpose of precast concrete construction is to reduce the cost of the formwork. Several components can be produced in the same formwork, i.e. mould. And, of course, large batches are advantageous. Although mould types suited to the method of production (e.g. rigid moulds with few fold-down parts) demand a design approach that suits the production, the high mould reuses lead to lower costs for the construction.

Production in an indoor environment results in better working conditions with correspondingly better productivity than would be the case on a building site, and that has an effect on quality in particular. Steel moulds can be used for standard elements or large batches, which enable a high degree of dimensional accuracy to be attained. Factory production also enables a specific concrete quality to be achieved. Only through factory production it is possible to produce concrete components with architectural textures and colours, especially for façade designs. As with other branches of industry outside construction, e.g. the automotive sector, factory production results in more efficient quality management.

Precast Concrete Structures, Second Edition. Alfred Steinle, Hubert Bachmann, and Mathias Tillmann.

One big advantage of precast concrete construction is the potential to shorten the construction time. For example, wall and floor elements can be produced simultaneously, even while the foundations are still being built. Production, and, to a large extent erection as well, can take place during the winter. That is an important factor in the Scandinavian countries especially. The financial savings associated with a shorter construction time and the chance of generating revenue at an earlier date are important – unfortunately often underestimated – reasons for precast concrete construction, particularly for industrial buildings.

The cost-savings achieved through simpler on-site facilities are also often underestimated. And although the weights of the precast concrete elements must be matched to the crane capacities on site, the powerful mobile cranes available these days mean that hiring them on a daily basis is not a significant economic factor any more. In particular, the fast erection of precast concrete elements saves on crane usage on site. For example, the erection of a two-storey building column takes only about 10 minutes and one lift, whereas an in situ concrete column will require at least three lifts per storey, i.e. a total of six crane lifts.

So, if the use of precast concrete elements is to be 'more economical', then the advantages of factory production must be integrated in the method of construction. Only when the overall method of construction is more cost-effective can we expect it to be employed in practice. Besides the production costs, it is necessary to consider the costs of transport, erection, connecting the elements together on site, the on-site facilities, and the fixed costs of the building site. Compared with building with in situ concrete, it is necessary to consider the economic risks associated with reworking on site and adhering to tight tolerances.

Only when the system of precast elements can actually be employed as a system can it, and will it, be more economical than other methods of construction. We can see from this that mixing the methods – in situ and precast concrete – always involves the risk of being uneconomic. This is not because precast concrete construction is uneconomic, instead because crucial advantages of building with precast concrete elements are rendered ineffective. Therefore, the task of a design using precast concrete elements is to feature the advantages of precast concrete construction outlined here and to consider the restrictions described below.

The advantages must be weighed against a number of constructional and economic disadvantages that have to be considered very carefully. The connections required between the individual concrete components must be carefully planned and carefully completed on site. In addition to the costs of the materials needed to join the elements, ensuring that such nodes function perfectly and the architectural boundary conditions, e.g. space for corbels, can lead to higher costs and greater design input. Furthermore, it is often impossible to compare the cost of materials for factory production with those achievable on large building sites.

Further, it should not be forgotten that structures made from precast concrete components often require a greater planning and design input. On the other hand, this input can be substantially reduced by using a standardised precast component system. The first CAD applications in reinforced concrete construction originated in precast concrete. A considerably longer lead time for the planning compared with the use of in situ concrete will certainly be necessary.

Changing the design on site is only possible to a very limited extent. Therefore, the planning decisions of the client must be fixed in advance.

One considerable cost factor for precast concrete construction is the cost of transport, which limits the radius of activities and, consequently, the potential market for a precasting plant and hence its size. Optimum planning of transport operations is therefore vital. Erection is another considerable cost factor in precast concrete construction. Always working with the largest possible concrete elements that can be transported and erected at a reasonable cost is essential.

Owing to the individuality and complexity of every single construction project plus the different boundary conditions such as construction time, quality requirements, it is not possible to come to a general conclusion regarding the economic viability of precast concrete construction compared with in situ concrete construction. In the end, the experience of the companies involved must be taken into account.

In terms of structural aspects, it is necessary at this point to refer to DIN EN 1992-1-1/NA, annex A.2.3(1), where a reduced partial safety factor $\gamma = 1.35$ applies for the concrete strength in a finished structure or component. However, this only applies in the case of permanent factory control of the concrete and checking the concrete strength of every single finished component. Normally, this reduction is only considered as a reserve, because the cost of measuring and checking generally exceeds the economic advantage of this reduction.

1.2 Historical Development

Prefabrication, i.e. the building of components remote from their intended location in the structure, followed by subsequent erection is a method of construction that is as old as building with reinforced concrete itself. However, the development of modern construction with precast reinforced concrete components from its origins to a form of industrialised building only took place over the past 70 years.

Even though we might not be able to designate the first reinforced concrete flower tubs or boats of Joseph Monier or Joseph Louis Lambot in the mid-nineteenth century as prefabricated 'components', the first serious trials with structural precast reinforced concrete components did take place around 1900 (e.g. Coignet's casino building in Biarritz, France, in 1891, and the prefabricated railway signalman lodges of Hennebique and Züblin in 1896, Figure 1.1) [1].

This development continued in the first half of the twentieth century throughout Europe and the United States, albeit only tentatively. The main reason for this was the lack of larger and flexible lifting equipment during this period.

The real breakthrough did not come until after the Second World War [2]. In a first phase from 1945 to 1960, it was the extraordinary demand for housing that presented the building industry with a huge challenge. During this period, it was the French (e.g. Camus, Estiot) and Scandinavian (e.g. Larsson, Nielsen) systems that provided decisive momentum for construction with large-format panels. Their patents – through licensees – also dominated the German market. In the

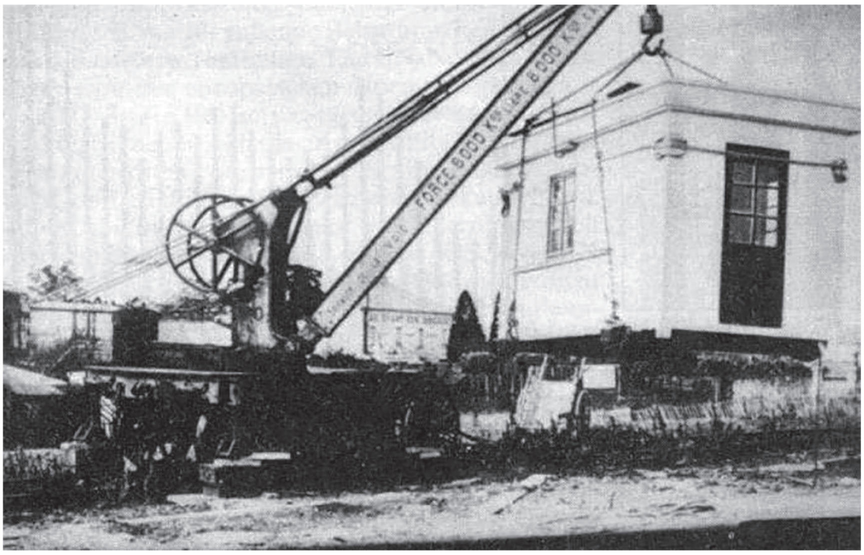


Figure 1.1 Prefabricated signalman's lodge (c. 1900).

second phase, about 1960–1973, growing prosperity led to a rise in demand for owner-occupied housing with a higher standard of comfort. Inflationary tendencies resulted in a huge amount of investment in property. The increasing shortage of skilled workers was another reason that forced production to be transferred to factories, which, in turn, helped precast concrete construction to achieve a breakthrough.

Alongside housebuilding, the increased need for more schools, colleges, and universities led to the establishment of fully developed loadbearing frame systems with columns, beams, and long-span floors (7.20, 8.40 m). Buildings for industry and sports centres resulted in standardised product ranges for single-storey sheds made from precast columns and prestressed rafters and purlins, or saw-tooth roofs.

The third phase, from about 1973 to 1985, was marked by a serious crisis for the German construction sector, first and foremost housebuilding. This was compensated for to a certain degree by increased demand in the oil-exporting countries. Housing, school, university, and office building construction projects were carried out in those countries, which opened up completely new dimensions in the industrialisation of precast concrete structures. However, the fall in the price of oil led to this compensatory business almost drying up in the early 1980s.

In the years after 1985, a general economic upturn resulted in colossal improvements for the construction sector as well. However, the high wage and social security costs forced precasting plants to switch to mechanised and automated methods of production [3, 4]. Since late 1989, we have seen renewed demand for more housing to meet the needs of immigrants plus migrants from former East Germany. The opening of the border with the former German Democratic Republic in 1990 resulted in major challenges for the building industry in the ex-GDR. New noise abatement legislation was one of the results of the growing awareness of environmental aspects, which led to an increased demand for products such as noise barriers. But the increased demand for building work after German unification was short-lived. In the period from about 1994 to about 2004, the construction sector experienced almost 10 years of decline, coupled with a drastic reduction in the number of employees and a rise in the number of insolvencies, even large companies. A period of stable economic growth began in Germany around 2000, and this brought about consolidation in the German construction industry. Fortunately, a change in fortunes has been seen since 2005.

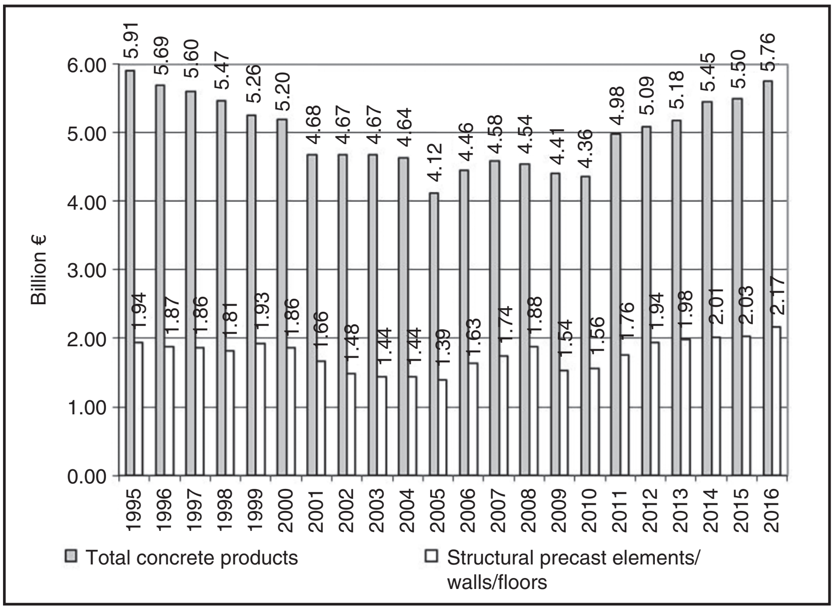
The years 2005–2008 saw annual growth rates of about 5%. The effects of the 2007 financial crisis began to be felt from 2009 onwards. Investment was stopped or substantially curtailed. And the Euro crisis (Greece) over the years 2010–2012 contributed to further uncertainty. The upturn that set in after 2011, which led to growth rates in single figures up to 2016, is thus very pleasing (Figure 1.2).

The production of structural precast concrete elements has consolidated on a relatively high level. The ongoing development of concrete technology with special concretes, e.g. high-strength concretes, fine-aggregate concretes, concretes with a high resistance to environmental influences, self-compacting concretes, or special fair-face concretes, has led to the development of new products and new concrete and component production methods. Outward signs of this development are the use of precast concrete elements in many areas that were, in the past, uncommon, e.g. lightweight façades and shell structures with textile reinforcement, highly acid-resistant drainpipes, or even furniture made from unreinforced fine-aggregate concrete.

1.3 European Standardisation

The foundation for the creation of a European Single Market was laid in 1957 when the Treaty of Rome was signed by the European Council. One milestone on the road to the Single Market was the white paper issued in 1985 by the European Commission in the light of the Single European Act. That white paper contained almost 300 measures that resulted in just as many directives and were seen as necessary for the realisation of a European Single Market.

One of those directives was ‘Council Directive 89/106/EEC of 21 December 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products’ (in short: the Construction Products Directive, CPD) [5]. In Germany, this, together with the 1992 *Bauproduktengesetz* (Construction Products Act), formed the basis for harmonising the European Single Market for construction products since 1988. In July 2013, the CPD was succeeded by ‘Regulation (EU) No. 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC’ (in short: Construction Products Regulation, CPR) [6].



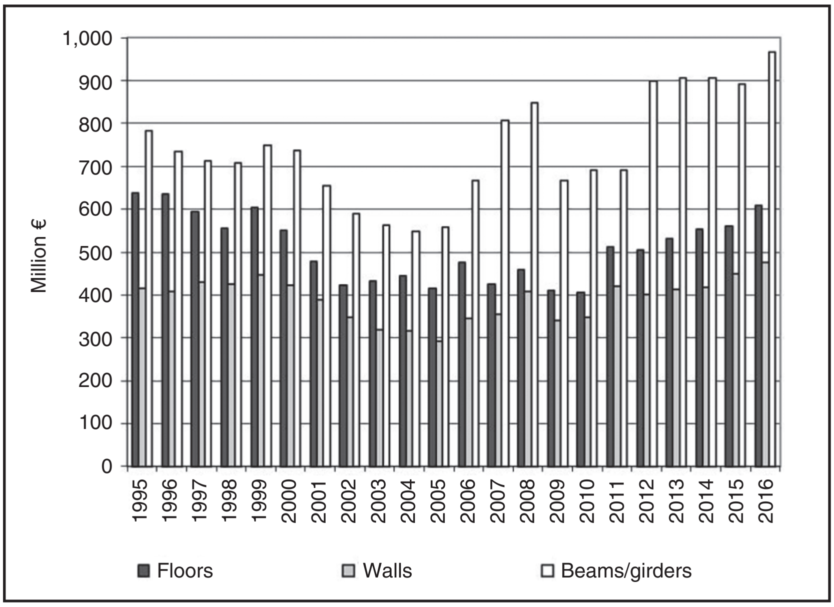


Figure 1.2 Concrete products and prefabricated elements in Germany: (a) concrete products in total compared with large-format precast concrete elements and (b) large-format prefabricated elements for structures.

Annex I of the CPR lays down the following basic requirements for construction works:

(1) Mechanical resistance and stability
(2) Safety in case of fire
(3) Hygiene, health and the environment
(4) Safety and accessibility in use
(5) Protection against noise
(6) Energy economy and heat retention
(7) Sustainable use of natural resources.

These basic requirements must be satisfied by structures with normal maintenance over an economically reasonable period of time. Furthermore, they form the basis for developing standardisation projects that the European Commission issues to the European Committee for Standardisation (CEN). These so-called mandates contain fundamental boundary conditions and lead to detailed programmes of work when drafting or revising standards. For example, mandate M/100 deals with the harmonised European product standards for precast concrete elements.

The 'essential characteristics' of construction products are specified in harmonised European product standards with respect to the aforementioned basic requirements and are listed in Annex ZA of a harmonised product standard. According to the CPR, the manufacturer of a construction product must produce a so-called declaration of performance, which contains details of how that construction product behaves in relation to its essential characteristics. By providing a declaration of performance, the manufacturer takes responsibility for the conformity of the construction product. Furthermore, the declaration of performance is the prerequisite for CE marking and the lawful placement of the product on the European Single Market. Declarations of performance and their associated technical documentation must be retained for a period of 10 years.

Moreover, Annex ZA contains details of the system to be specified in the declaration of performance for the 'Assessment and Verification of Constancy of Performance' (AVCP). This system corresponds to the attestation of conformity procedure used previously. System 2+, with defined duties to be carried out by the manufacturer (setting up factory production control – FPC, testing according to FPC test plan) and the notified body (initial inspection of factory and FPC plus continuous monitoring with assessment of FPC), applies for loadbearing precast concrete elements. System 4 applies for the case of non-loadbearing precast concrete elements (e.g. non-loadbearing wall elements), and a notified body is not required.

Once a European standard has been ratified by a majority of CEN member states, then all member states are obliged to publish this standard and withdraw any contradictory national standards. Published harmonised product standards are announced in the Official Journal of the European Union together with their phases of coexistence and, consequently, in the *Bundesanzeiger* (Federal Gazette) as well in Germany.

All harmonised product standards for precast concrete elements published up until July 2017 are still based on the CPD. Therefore, the existence of the new

CPR means it is necessary to revise all product standards. Such revision work will be carried out in the course of the regular reviews of the standards over the coming years. However, the existing product standards can also be used with the 'old' Annex ZA when the provisions of the CPR are taken into account and thus remain valid for the time being.

The large number of European product standards for precast concrete elements underscores the enormous diversity of precast concrete construction. At the same time, however, this presents the manufacturers with ever greater challenges because it is easy to become confused by the great number of European standards. Table 1.1 presents a current overview, and a general overview of the system of product and reference standards is shown in Figure 1.3.

Owing to the great number of product standards and the frequent overlaps between them, EN 13369 was drafted to provide a classification and common rules valid for all product standards. As not all precast concrete elements (e.g. solid floor elements) are covered by a European product standard, the German product standard DIN 1045-4 continues to remain valid. (A new edition was published in 2012.)

In Germany, the federal state building regulations specify that the technical codes of practice introduced by the supreme building authorities of the federal states must be observed. Up until 2015, the Deutsches Institut für Bautechnik (DIBt) published an annual model list of the technical codes of practice in which the codes were announced, and up until 2016, Construction Products Lists, too [7]. Construction Products List A, Part 1, contained construction products and their technical rules plus the assessment of conformity ('Ü mark') required.

Construction Products List B, Part 1, contained construction products that were placed on the market according to the CPR ('CE marking'). Therefore, there was, at least theoretically, a clear distinction between the 'national' Construction Products List A in conjunction with the German 'Ü mark' on the one hand and the 'European' Construction Products List B with the 'CE marking' on the other.

However, in the course of the introduction of the European product standards by the building authorities, it quickly became clear that it is not possible to maintain this clear distinction in many situations (Figure 1.3). In the past, according to German construction law, many construction products covered by harmonised European product standards also had to comply with national regulations and therefore had to be labelled with the CE marking *and* the German 'Ü mark' in order to guarantee that those construction products could be safely used in Germany. This also applied to loadbearing precast concrete elements complying with harmonised European product standards in order to guarantee that the materials used (concrete, reinforcing steel, and prestressing steel) complied with the national regulations (see Construction Products List A, Part 1, No. 1.6.28).

Changes and/or additions to harmonised product standards at national level are, however, not permitted. The main purpose of both the CPD and the CPR is to eliminate barriers to trade. The harmonisation regulations of the European Union are therefore mandatory for the Member States, and the unhindered movement of goods may not be hampered by national hurdles.

Table 1.1 European product standards for structural precast concrete elements (as of June 2015).

Product type	Product standard with date of issue	Applications	AVCP[a)]	Examples of essential characteristics according to Table ZA.1 of product standard[b)]
Hollow-core slabs	DIN EN 1168:2011-12	Floors and roofs	2+	– Concrete compressive strength – Tensile strength and yield point of steel – Mechanical strength – Fire resistance – Durability
Foundation piles	DIN EN 12794:2007-08 + Corrigendum 2009-04	Deep foundations for structures	2+	– Concrete compressive strength – Tensile strength and yield point of steel – Mechanical strength – Durability
Ribbed floor elements	DIN EN 13224:2012-01	Floors and roofs	2+	– Concrete compressive strength – Tensile strength and yield point of steel – Mechanical strength – Fire resistance – Durability
Linear structural elements[c)]	DIN EN 13225:2013-06	Girders, beams or columns in building and civil engineering works apart from bridges	2+	– Concrete compressive strength – Tensile strength and yield point of steel – Mechanical strength – Fire resistance – Durability
Roof elements	DIN EN 13693:2009-10	Roofs	2+	– Concrete compressive strength – Tensile strength and yield point of steel – Mechanical strength – Fire resistance – Airborne sound insulation – Durability
Floor elements with in situ concrete topping	DIN EN 13747:2010-08	Floors and roofs	2+	– Concrete compressive strength – Tensile strength and yield point of steel – Mechanical strength – Fire resistance – Durability

(Continued)

Table 1.1 (Continued)

Product type	Product standard with date of issue	Applications	AVCP[a)]	Examples of essential characteristics according to Table ZA.1 of product standard[b)]
Precast concrete stairs	DIN EN 14843:2007-07	Stairs for indoor and outdoor usage	2+	– Concrete compressive strength – Tensile strength and yield point of steel – Mechanical strength – Fire resistance – Impact sound transmission – Durability
Box culvert elements	DIN EN 14844:2012-02	Construction of underground voids, e.g. for transport and storage	Loadbearing: 2+ Non-loadbearing: 4	– Concrete compressive strength – Tensile strength and yield point of steel – Mechanical strength – Durability
Foundation elements	DIN EN 14991:2007-07	Foundations for columns and walls, also columns with monolithic foundation	2+	– Concrete compressive strength – Tensile strength and yield point of steel – Mechanical strength – Durability
Wall elements	DIN EN 14992:2012-09	Loadbearing and non-loadbearing walls with or without façade function	Loadbearing: 2+ Non-loadbearing: 4	– Concrete compressive strength – Tensile strength and yield point of steel – Mechanical strength – Fire resistance – Sound insulation – Durability – Construction details
Bridge elements	DIN EN 15050:2012-06	Bridge superstructures	2+	– Concrete compressive strength – Tensile strength and yield point of steel – Mechanical strength – Fire resistance – Durability
Retaining wall elements	DIN EN 15258:2009-05	Support for excavations and earth embankments, gravity walls, etc.	2+	– Concrete compressive strength – Tensile strength and yield point of steel – Mechanical strength – Durability

a) Assessment and verification of constancy of performance.
b) This information is not exhaustive.
c) The 2004-12 edition of this standard may also be used. The use of the 2013-06 edition is still limited by the building authorities.

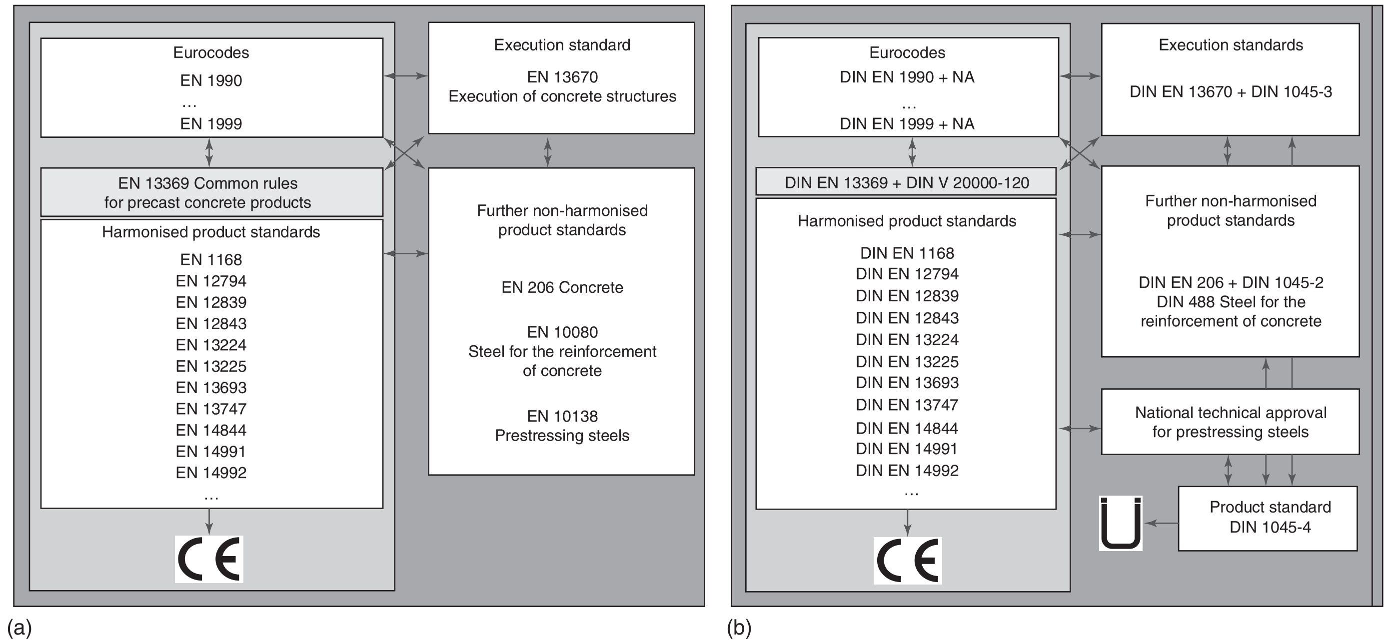


Figure 1.3 System of product and reference standards: (a) in Europe and (b) in Germany.

Therefore, according to a ruling by the European Court of Justice (ECJ) from October 2014 (case C-100/13) [8], the current German practice of 'double marking' is also forbidden for such cases in which, according to the German viewpoint, the corresponding European product standards exhibit technical deficits and, hence, do not comply with national requirements.

As a result of the ECJ ruling, German construction law was amended in the form of a revised Model Building Code and a Model Administrative Directive for Technical Codes of Practice. The new Model Building Code forms the basis for new federal state building regulations in Germany's 16 federal states. The Model Administrative Directive for Technical Codes of Practice is intended to replace the Construction Products Lists and the lists of technical codes of practice. This new legal situation results in substantial changes for the erection of structures and the use of harmonised construction products.

The ECJ ruling relates to regulations specific to construction products. Structures, on the other hand, are still the responsibility of the EU Member States. In order to maintain the level of safety of structures in Germany, the previous requirements for construction products were transferred to structures.

The aim of the revised Model Building Code and the new Model Administrative Directive for Technical Codes of Practice is to adapt German construction law to the fundamental statements of the ECJ ruling with respect to the CPR. They should also specify the performance a product has to achieve in order to be used in a structure (ground for Model Building Code, art. 85a, concerning para. 2, No. 3b).

According to that, harmonised construction products with the CE marking may be used and integrated in structures without the German 'Ü mark', but only in those situations where the declared performance of the construction product ('declaration of performance') corresponds to the requirements placed on a structure in Germany (Model Building Code, art. 16c). Those involved in a construction project must guarantee that the declared performance fulfils the requirements placed on the structure (ground for Model Building Code, art. 16c). At the time of producing this book, it was not possible to assess fully how the ECJ ruling would affect the construction sector.

With respect to loadbearing precast concrete elements, it is not unreasonable to ask the question as to whether the aim of the unhindered movement of goods in Europe is sensible and viable. Structural precast concrete components are not usually traded in the literal sense of the word because every individual component is custom-built for a certain position within a specific construction project and so its dimensions, cross-section, amount of reinforcement, and details can differ from those of other components. Furthermore, when it comes to structural precast concrete elements, there are intrinsic limits to the movement of goods in Europe owing to the high cost of transport of such elements (see Figure 2.15, for example). Cross-border movement of goods has therefore always been and will remain an exception for loadbearing precast concrete components and confined to regions near borders (see also [9, 10]).

In the light of the current discussions regarding the ECJ ruling and its consequences, it is also necessary to question whether a harmonised 'precast concrete element' construction product can be produced from the non-harmonised building materials concrete, reinforcing steel, and pretesting steel in conjunction with non-harmonised design codes (Eurocodes). The precast concrete industry has drafted a position paper on this matter and is taking a stand regarding harmonisation in general [11].

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