Sample Chapter

Precast Concrete Structures

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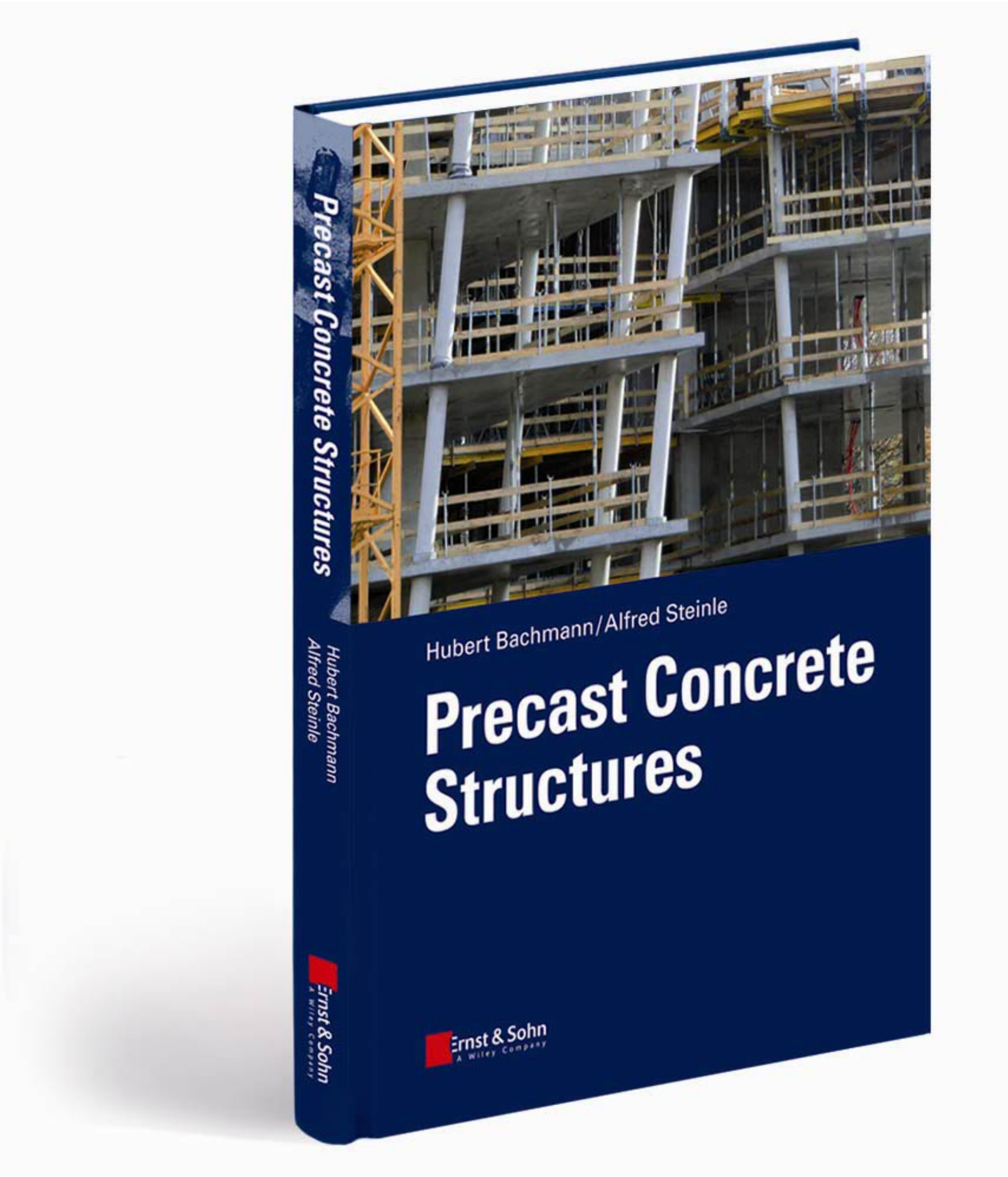

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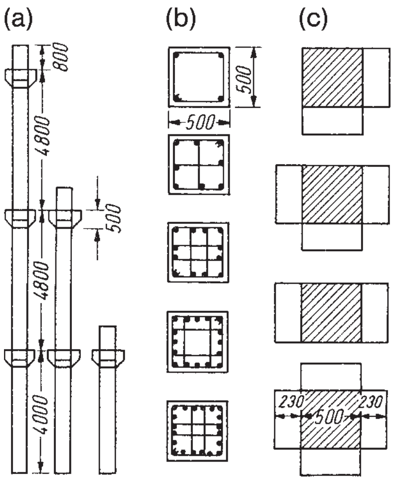


Fig. 2.88 Column types for the University of Riyadh system [92]:
(a) columns for one, two and three storeys
(b) reinforcement
(c) corbel positions

more than 100 times. These two examples, the University of Riyadh and Züblin House, show how a project-related breakdown into prefabricated parts can certainly be sensible and economic, even though these differ from the planning principles for industrialised building systems in general.

More and more storey-high precast concrete columns are being used, especially for composite precast/in situ concrete structures. One reason for this is the faster construction time for high-rise buildings, for instance, with the column splices in the form of simple butt joints according to section 3.1.1. A steel plate is usually specified to cope with the

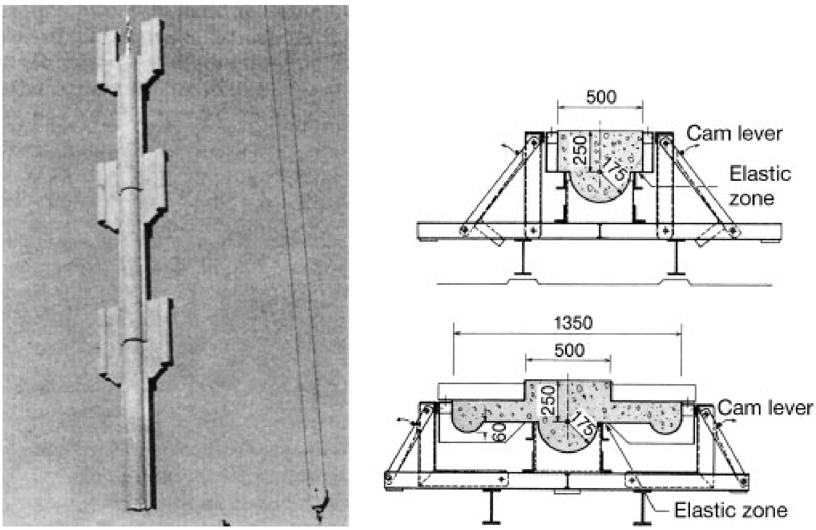


Fig. 2.89 Standard column for Züblin House; spring-loaded, “breathing“ column mould [94]

Fig. 2.90 Butt joint between precast concrete columns for Triangel Tower in Cologne (contractor: Züblin)

high loads normally encountered in high-rise buildings. The force transfer at the level of the suspended floors requires particular attention (Fig. 2.90) [104–106].

2.3.4 Walls

The precast concrete wall is the characteristic loadbearing element of large-panel construction (see [90, 98]). This section looks at internal walls only; external walls are dealt with in section 2.4 “Precast concrete façades”.

According to DIN 1045-1, a minimum thickness of 8 cm is adequate for loadbearing precast concrete walls in conjunction with continuous floor slabs. However, the wall thickness is generally governed by the minimum bearing dimension required for the floor elements. Internal walls are therefore between 14 and 20 cm thick (see Fig. 2.79d). Furthermore, it is sound insulation and structural fire protection requirements that are the main criteria for internal walls. A 14 cm thick concrete wall ensures adequate sound insulation. This same wall thickness is also adequate for a fire wall or a F 90 fire resistance rating. In addition, concrete internal walls also help to achieve summertime thermal performance requirements thanks to their good thermal mass.

Composite precast/in situ concrete walls (Fig. 2.91) represent an ideal combination of the advantages of both types of construction. The expensive formwork operations are transferred to the factory and the finished, cast wall is monolithic with a smooth surface both sides. Such walls have in the meantime secured a significant market share for themselves. They are used in almost all buildings and have also been used for civil engineering works [107]. Owing to their fast erection, such composite walls are especially suitable for those walls that would require formwork on one side only when cast on site (e.g. building against existing works, etc.). However, the design loads should not be too large because there is a limit to the amount of reinforcement that can be placed between the precast “leaves”. The in situ concrete should be at least 10 cm thick, which together with the

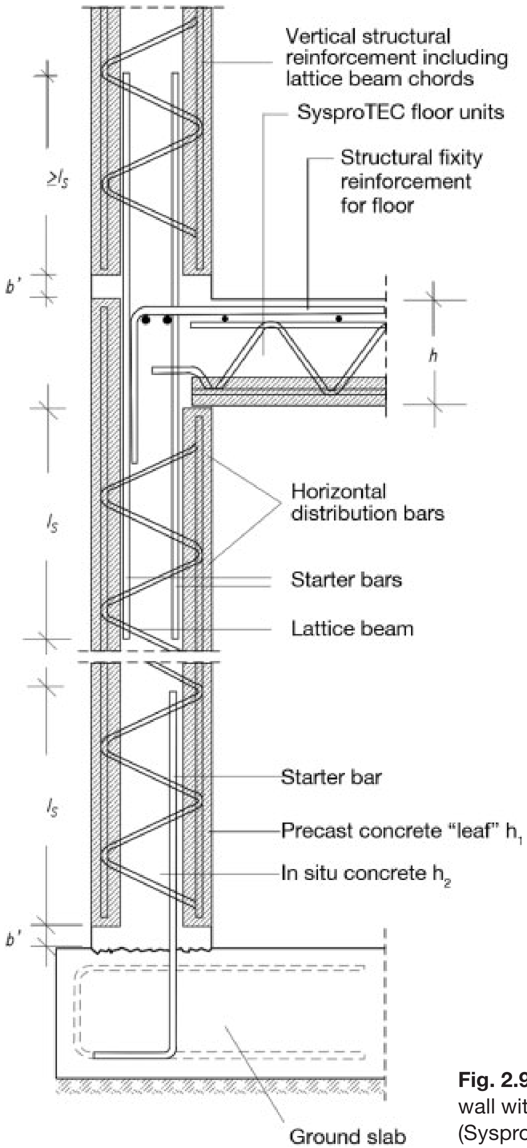


Fig. 2.91 Composite precast/in situ concrete wall with lattice beams and in situ concrete fill (SysproPART system)

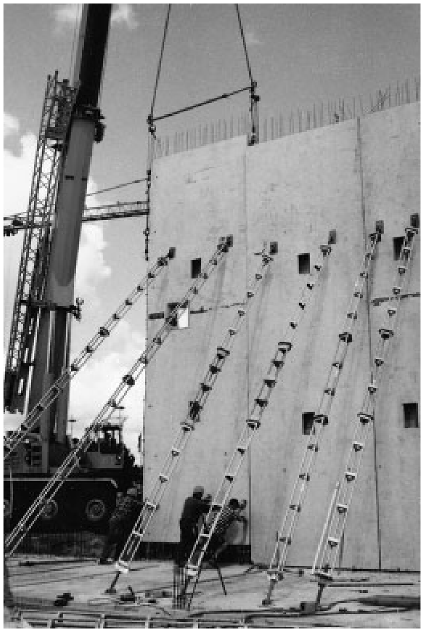


Fig. 2.92 Use of composite precast/in situ concrete wall for tall walls (SysproPART system)

two outer precast leaves each 6 cm thick, results in a minimum wall thickness of 22 cm. Slimmer walls are possible in certain circumstances but the concreting operations must then be planned in great detail.

Composite walls are also useful where, for tall walls, the weights of precast concrete panels would exceed the lifting capacities of the cranes available (Fig. 2.92).

One important application for composite walls is in basements. Initially used only for internal walls, they are being increasingly used for external walls, and also for impermeable concrete basements. The DAfStb directive covering impermeable concrete [108, 109] specifically mentions this system. A key advantage is that any cracking is restricted to the joints between the precast concrete wall elements. But in the end, good-quality workmanship at the joints and a minimum in situ concrete thickness of 20 cm are critical to their impermeability. Currently there are still misgivings in some circles concerning the discrepancy between theory and practice because the risk of flaws and the quality demands are very high [110].

2.3.5 Foundations

Foundations are heavy and therefore usually cast on site. Nevertheless, precast concrete foundations are also feasible. Fig. 2.93 illustrates the "evolution" of this form of construction. The pad foundation with separate smooth-sided pocket on top, which was common for many years, has been replaced by the true pocket foundation (Fig. 2.95) with a pocket formed in the foundation itself, which is more economic [99]. Foundations can therefore be shallower and the separate pocket, whose expensive forming and reinforcing processes always had to be carried out in a separate operation, is no longer necessary. However, a column inserted into a pocket always requires an adequate key between the base of the column and the walls of the pocket so that the axial forces can be transferred to the foundation via skin friction. It is relatively easy to fix trapezoidal battens to a drop-

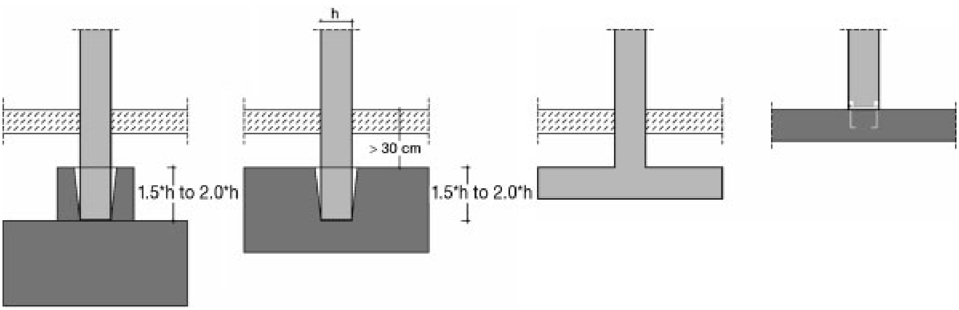


Fig. 2.93 Foundation types

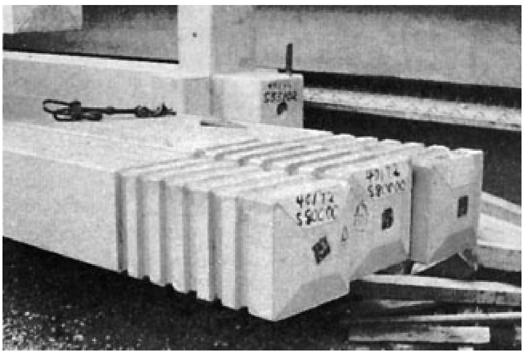


Fig. 2.94 Profiled column base

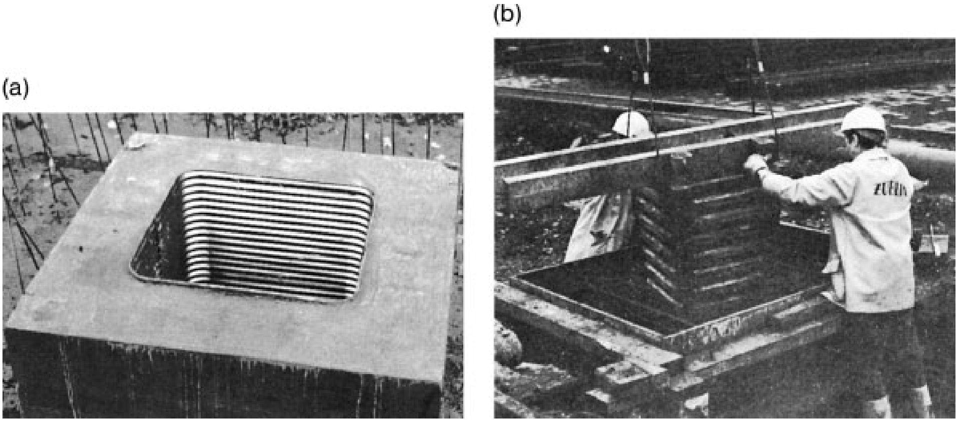


Fig. 2.95 Column pocket formwork: a) corrugated sheet metal tube, b) formwork box with special corner fittings

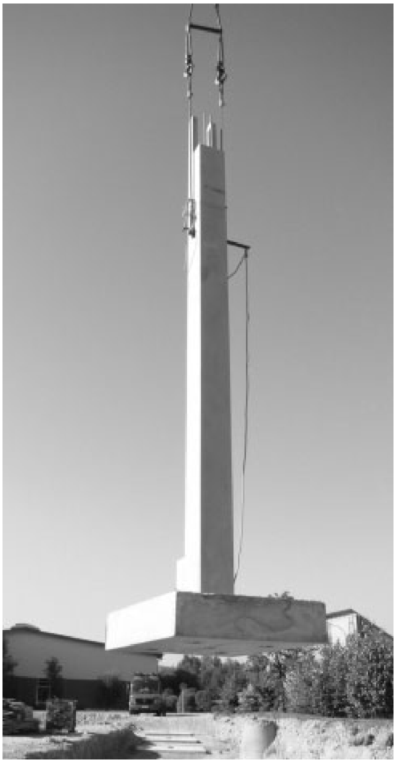
side column mould (Fig. 2.94). And pockets are in many cases formed with permanent formwork in the form of a corrugated square sheet metal tube (Fig. 2.95a).

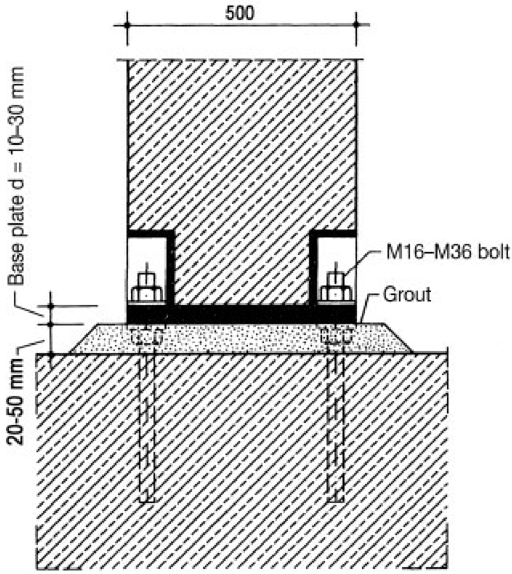
Mould boxes with special unplasticised PVC corner connections and clamping bolts are available. The bolts are undone for demoulding so that the four mould sides can be separated from the concrete with a light blow from a hammer (Fig. 2.95b). Which mould form is more economical depends on the particular costs, the particular situation.

Precast concrete columns complete with precast concrete foundation already attached have been available for some time (Figs 2.93 and 2.96). This overcomes the need for a column–foundation connection detail and the foundation can be produced in the works together with the column. Once on site, the precast concrete element is lowered onto a layer of blinding and aligned with steel shims before grout is pumped underneath to create a structural bond between the underside of the foundation and the subsoil. Vertical pipes must be provided in the foundation to ensure good distribution of the grout and prevent air pockets. The system leads to a further shortening of the construction time and to foundations at a shallower depth. The disadvantage of the system is the bulkiness of the precast concrete element (column + foundation) and the ensuing economic transport. Transport restrictions mean that in one direction the foundation can be no more than 3 m wide. However, in situ concrete can be used to increase the size of a foundation on site.

In the University of Riyadh project, the connections – as is very common in the USA – were designed by American engineers according to the principles common to structural steelwork. The columns were fitted with cast-in steel base plates that were then screwed to holding-down bolts cast into the foundations (Figs 2.93 and 2.97). This system is becoming more and more popular in Germany, too.

The disadvantage of a high steel content within the connection is balanced by the advantages of the easy fabrication of the base plate, the easy casting of the foundation (no pocket required, etc.) and the relatively shallow structural depth of the foundation. This





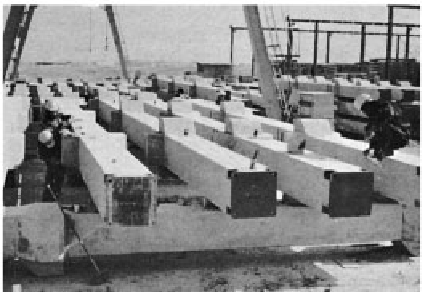


Fig. 2.96 Precast concrete column complete with precast concrete foundation (contractor: Bachl)

Fig. 2.97 Column base detail for system shown in Fig. 2.88 [91]

can be very advantageous on sites where, for example, there is a high ground water table. With moderate column loads, the steel plate can be omitted completely and separate anchorage elements used instead. It is vital to cast the holding-down bolts into the foundation as accurately as possible using a template and to protect these against damage until column erection begins. Tolerances of approx. ±5 mm are possible. The system allows the full column fixity required for the structural design to be achieved if required, but also merely temporary erection fixity. These days, it is no longer common to pack the joint; grout is used instead, which is pumped in via tubes, which also prevent air pockets.

2.4 Precast concrete façades

In contrast to the design of structural elements, where the manufacturing requirements are the primary concern, the design of components for the external envelope of a building is mainly determined by the demands of architecture and building physics. As the building envelope is in this case not a homogeneous surface, but rather an assembly of individual elements, great attention must be paid to the appearance, functions and constructional aspects of the joints and fixings. Façades made up of precast concrete elements are dealt with in general in [7, 111, 112, 134]; more recent architectural developments are presented in [9], for example.

After many years of steel-and-glass architecture, we are now witnessing a revival of "architectural" façades. The precast concrete elements used – in contrast to conventional concrete façades – are required exclusively for appearance purposes and reveal the diverse design options available with precast concrete. Another interesting development is the use of building envelopes made from small-format, thin façade panels of glass fibre-reinforced high-strength concrete.

This section will first deal with conventional façades made from precast concrete elements, the requirements they must satisfy and the details, before taking a look at new architectural developments.

2.4.1 Environmental influences and the requirements of building physics

The external climatic influences that affect façades are, first and foremost, solar radiation and rain together with wind pressure and outside temperatures. Facing these on the inside are room temperatures, the humidity of the interior air and water vapour pressure (Fig. 2.98). So in order to repel or attenuate these various influences, a façade must therefore function as reflective layer, rain screen, airtight membrane, thermal insulation, thermal mass, surface condensation absorber and vapour barrier all at the same time [113, 135].

With the exception of thermal insulation, concrete is an ideal material for satisfying all these requirements. Furthermore, concrete façades are good for sound insulation and fire protection, too, and their high strength can be exploited for loadbearing purposes.

Factory production in particular offers further options that enable concrete to be constructed in virtually any shape, with a huge variety of surface finishes and colours, possi-

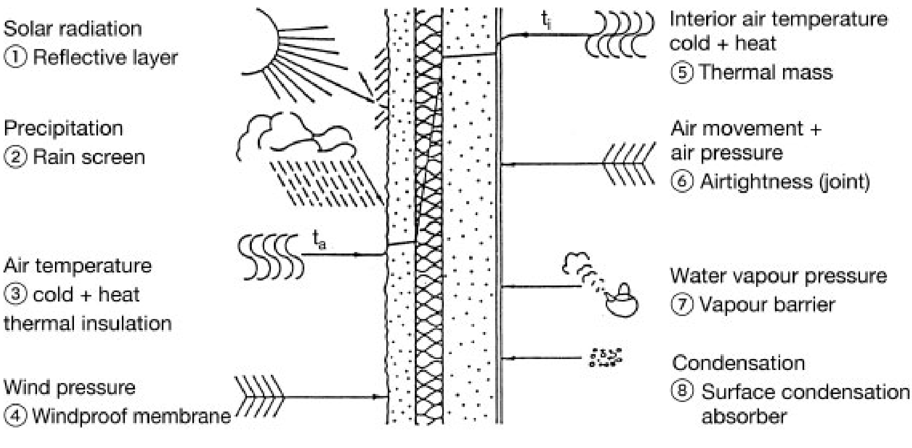


Fig. 2.98 Climate factors and wall functions [113]

bly also with facing leaves of brickwork, stone or metal. So with all these advantages it is not surprising that precast concrete façades are used not only on precast concrete buildings, but also to clad in situ concrete and structural steelwork as well.

Concrete façades are normally found in the form of three-ply sandwich panels, with facing leaf, thermal insulation core and loadbearing leaf, which are manufactured in one operation and erected as complete units (Fig. 2.99a). The layer of thermal insulation, usually made from PS or PU rigid foam boards, should preferably be positioned closer to the outer side of the wall panel. Conventional precast concrete sandwich panels with the layer of insulation concealed behind render (Fig. 2.99b), or a central layer of insulation and thin concrete facing leaf (Fig. 2.99a), or a rendered, single-leaf façade of dense lightweight concrete (Fig. 2.99d) represent good solutions for everyday room temperatures of 19–22 °C and interior humidities of 50–60 % (i.e. in office and residential buildings, including kitchens, bathrooms, etc.) and at the same time comply with the minimum thermal resistance requirements with respect to vapour diffusion. A vapour barrier is unnecessary with such forms of construction. The building physics requirements of buildings with specific requirements (cold stores, swimming pools, etc.) must be given special consideration. The diffusion behaviour of the wall construction must be checked for the wintertime thermal performance (Fig. 2.100).

By contrast, concrete walls with internal thermal insulation (Fig. 2.99c) and a lining of plasterboard are generally insufficient because condensation collecting on the cold internal surface is excessive and therefore cannot dry out properly. A vapour barrier (e.g. aluminium foil) on the inside of the thermal insulation, i.e. between insulation and lining, is essential in such situations. Such a vapour barrier may also be necessary in conjunction with a thick facing leaf.

The vapour diffusion can be improved by employing a façade with a ventilation cavity, i.e. an air space between facing leaf and thermal insulation (Fig. 2.99e), instead of a sandwich construction. This cavity, which should be at least 4 cm wide, allows water vapour to escape to the outside air. This form of construction permits the use of a much denser facing leaf, e.g. ceramic tiles, even sheet metal.

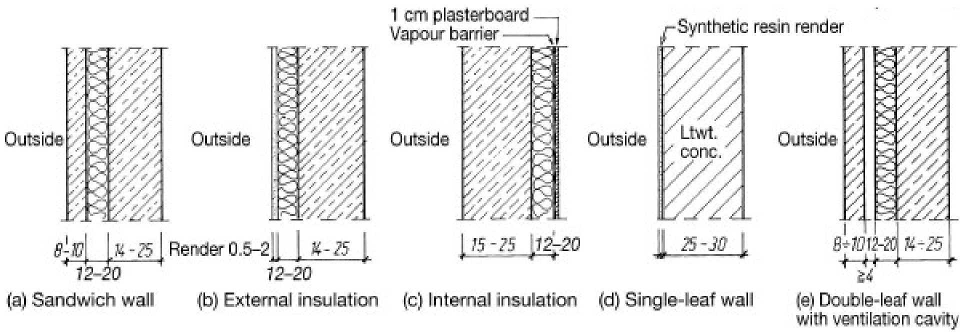


Fig. 2.99 Types of façade configuration

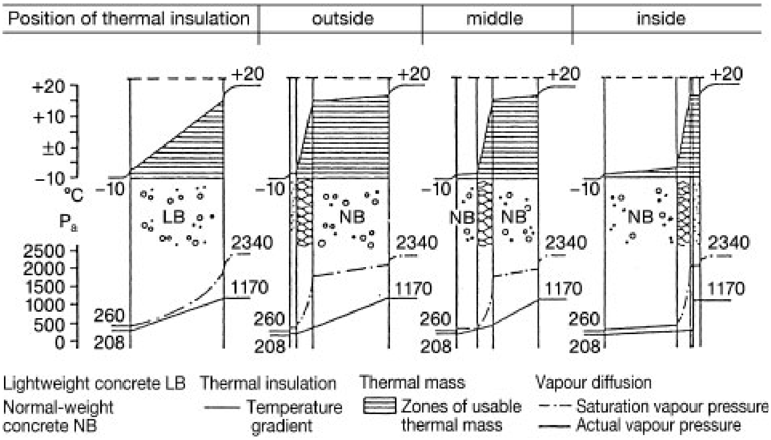


Fig. 2.100 Temperature and pressure gradients plus the zones of usable thermal mass depending on the position of the layer of thermal insulation [116]

If, for example, for production reasons, sheeting is required adjacent to the thermal insulation in order to contain, for example, mineral fibre insulation, then this may only be placed on the warm side of the layer of thermal insulation. Whether the more expensive mineral fibre insulation needs to be used for the thermal insulation at all is another matter, however. Polystyrene is less expensive, easy to work and also unaffected by water, but it is combustible. An incombustible material is therefore required around windows to prevent the spread of fire. As a rule, edges must be finished with an incombustible thermal insulation material or a fire stop detail.

The acoustic behaviour of concrete façades is essentially governed by the windows and not by the precast concrete elements themselves. This aspect will not be looked at further here.

2.4.2 Façade design

Apart from performing the building physics functions, a façade must also frame the windows. Fig. 2.101 shows basic forms for the segmentation of a façade for windows and joints. The simple horizontal ribbon façade can be varied in different ways (Fig. 2.101, left). The fenestrate façade is the typical form for large-panel construction. However, the loadbearing façade extending the full height of the building is seldom encountered in Germany, in contrast to the USA, which means that German architects have not yet fully explored the possibilities of this type of façade (Fig. 2.102).

Façade panels can be supported on the edges of floor slabs, or in the form of an L-shaped loadbearing panel can themselves span from column to column and support the floor slabs, or in the form of a loadbearing wall with internal corbels form the loadbearing structure of the external wall. The façade shown in Fig. 2.103a is a horizontal ribbon type with window mullions but no joint intersections. Here, the continuous loadbearing columns at the same time serve as façade design elements and the spandrel panels span-

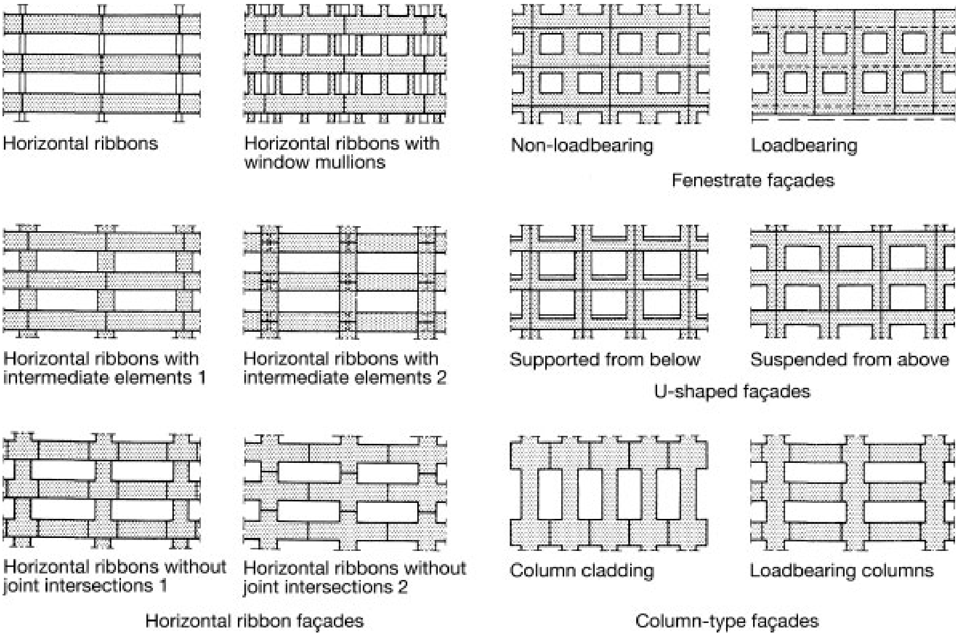


Fig. 2.101 Segmentation of façades for windows and joints

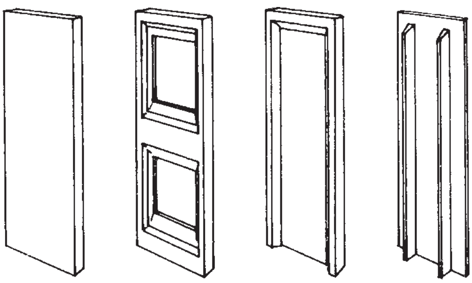
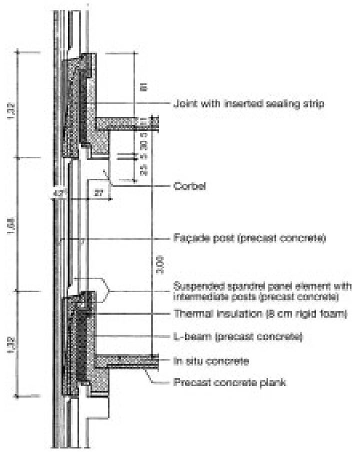


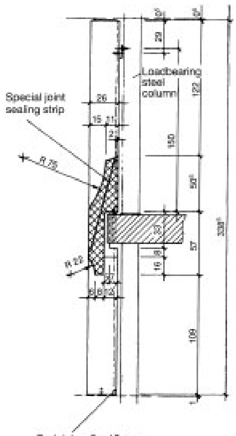
Fig. 2.102 Loadbearing façades [119]

ning between these are in the form of loadbearing L-beams with thermal insulation attached at the precasting plant. The facing leaf to the spandrel panels was mounted later (see also Figs 2.116 and 2.125). Joint intersections are likewise absent from the façade shown in Fig. 2.103b. Fig. 2.103c shows a horizontal ribbon façade that incorporates external fire escape balconies.

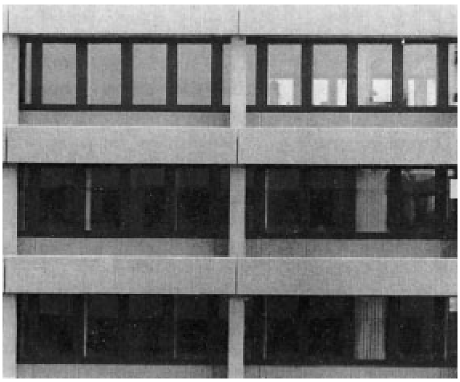
In the USA, loadbearing façades that extend the full height of the building are especially popular for buildings up to three storeys high, likewise wide, storey-high loadbearing panels for multi-storey buildings. The reinforcement required just for demoulding, transport and erection is in most cases perfectly adequate for loadbearing purposes. Production, transport and erection limitations restrict multi-storey wall panels to a height of about 12–14 m. Buildings with loadbearing façades up to 20 storeys high have been built in the USA [119].

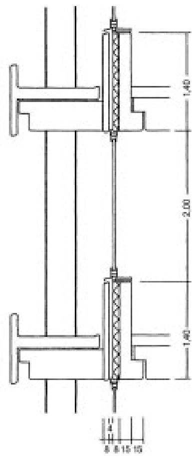


(a) Züblin-House, Stuttgart (architect: Böhm)



(b) Publicitas office building, St. Gallen
(architects: Danzeisen/Voser/Forrer)





(c) DYWIDAG office building, Munich
(architects: Bätge & Stahlmecke)

Fig. 2.103 Various façade configurations

Two-storey-high loadbearing façade panels were used for a 12-storey hospital in Chicago, with adjacent panels offset by one storey in order to avoid continuous horizontal joints. Loadbearing façades are particularly economic when they can also provide building stability functions and strengthening ribs fit into the architectural concept. However, the thermal insulation to a loadbearing façade usually has to be attached on the inside, with the associated disadvantages.

It is always more sensible to position the loadbearing structure within the thermal insulation of the building envelope (see Fig. 2.104 and [120]). It should be remembered here that the windows must be attached to the loadbearing structure, or the loadbearing leaf of the sandwich panel, and not to the facing leaf, which is subjected to deformations. Only in the case of fenestrate façades can windows also be attached to the facing leaf. Waterproof seals and avoiding thermal bridges around windows are aspects that must be given due attention.

One area that is still severely neglected is the design of precast concrete façades with respect to their weathering and ageing behaviour. Many sins were committed in the past which have given precast concrete construction a poor reputation. This can certainly be attributed to German architects' poor acceptance of construction with concrete façades, in contrast to their colleagues in the USA, for instance. This leads to the numerous design options not being recognised and therefore not being included in university curricula. It is obvious that, as with stone façades, we cannot prevent the weather from having an effect on the surface. And the weathering effects are similar to those of stone or brick buildings.

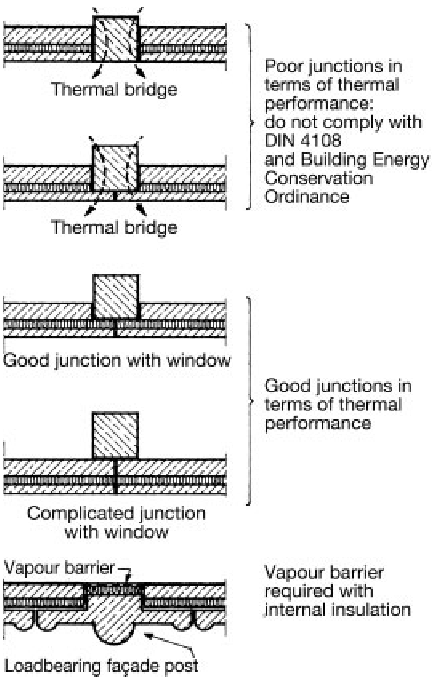


Fig. 2.104 Sandwich panels: position of thermal insulation at columns

Hubert Bachmann, Alfred Steinle

Precast Concrete Structures

The book reflects the current situation in precast concrete construction. Besides general observations regarding building with precast concrete elements, the book focuses first and foremost on the boundary conditions for the design of precast concrete structures, loadbearing elements and façades. Connections and specific structural and constructional issues are covered in detail and stability of precast concrete structures is another central theme. The requirements brought about by the emergence of the European Single Market are explained and the diverse possibilities for façade design are presented. A chapter on the production processes provides the reader with an indispensable insight into the characteristics of this form of industrialised building.
The book is a practical tool for engineers, but certainly also architects and students.
One of the authors' intentions is to demonstrate to engineers and architects the possibilities that factory prefabrication can offer, and hence pave the way towards the economic application and ongoing development of precast concrete construction.

(272 pages with 263 figures. Softcover. July 2011)

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