Conceptual design of precast concrete structures

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Abstract

Precast concrete structures, as a highly developed industrialised construction method, have evolved greatly since the beginning of the 20th century until today, always being at the forefront in the application of new design methods, new materials, and techniques for the design and construction of buildings and bridges. As part of the construction is made in factories, advanced industrial technologies and methods can be beneficial to design and build with advanced materials, slender elements, and very reduced tolerances.

As most precast solutions combine different types of materials and construction elements, creating evolutive structures, construction sequences are decisive in the design process. For this reason, when designing precast structures, it is of the utmost importance to take into consideration all possibilities and constraints defined by the industrial process of fabrication, transport, erection, and the evolutive sequence of the structure until its final stage. This creates great possibilities when approaching conceptual design and detailed design of precast structures.

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1 Introduction

Precast concrete structures, as a highly developed industrialised construction method, have evolved greatly since the beginning of the 20th century until today, always being at the forefront in the application of new design methods, new materials, and techniques for the design and construction of buildings and bridges. As part of the construction is made in factories, advanced industrial technologies and methods can be beneficial to design and build with advanced materials, slender elements, and very reduced tolerances. [1] [2] [3] [4] [5]

As most of precast solutions combine different types of materials and construction elements, creating evolutive structures, construction sequences are decisive in the design process. For this reason, when designing precast structures, it is of the outmost importance to take into consideration all possibilities and constraints defined by the industrial process of fabrication, transport, erection and the evolutive sequence of the structure until its final stage. This creates great possibilities when approaching conceptual design and detailed design of precast structures. [6]

Precast concrete is acknowledged as a cost-effective, durable, environmentally sustainable, structurally robust, and architecturally adaptable construction material. The precast concrete industry consistently strives to meet the evolving demands of modern society, which include economic viability, efficiency, technical performance, safety, working conditions, and sustainability.

Sustainability is a major issue in any industrial activity today. In the building industry, prefabrication offers an important structural approach to this end. Indeed, the whole life cycle is controlled better through industrialised processes. The industrialised production of elements allows materials and energy to be saved during construction, and using materials with higher strength and quality yields better results for maintenance and the possibility of dismantlement when designed for, thus achieving true circularity. In all phases, time, waste, noise, and dust, as they impact the environment, are reduced. [7]

The prefabrication of concrete structures is an industrialised process with great potential. Novice designers often perceive it merely as a technique that varies from cast in-situ construction, where prefabrication involves casting parts of the construction in specialised plants and assembling them on-site to recreate the initial concept of cast in-situ structures. However, this perception does not fully capture the essence of prefabrication with concrete elements. Each construction system has its own characteristics that significantly influence the structural layout, span, width, and stability system. For optimal results, a design should, from the very beginning, respect the specific and particular demands of the intended structural system. [8]

The *fib* Commission 6 Prefabrication has a long history of developing specialised documents first within FIP since 1955 and then in the *fib* since 1998. [7] [8] [9] [10] [11] [12] [13] [14] [15] [16] [17] [18] [19] [20]

There are other documents related to prefabrication within the *fib* prepared by other Commissions, like Commission 1 *Concrete Structures* [21], previous Commission 3 *Environmental aspects* [22] and previous Commission 7 *Seismic design*. [23]

There is also an important bibliography about precast structures like the very well know treaty by Koncz [4] or the new documents by el Debs and others (in Portuguese) [24] [25]and Elliot [26]. The Precast and Prestressed Concrete Institute of the USA (PCI) has also a very good manual on the design of precast structures and fachades [27] and has participated in the co-edition of many of the last *fib* Bulletins related to prefabrication.

Post World War II heralded a collective recognition of humanity's shared fate and fostered a desire for global cooperation across various fields, aimed at enhancing the quality of life for all citizens and ultimately promoting peace. International organisations, spanning political, cultural, and commercial domains, were established on multiple levels, beginning with the United Nations.

In concrete prefabrication, PCI in America and FIP (which later merged with CEB into *fib*) in Europe and internationally played a key role in sharing scientific knowledge and fostering cooperation among their members. Through courses, seminars, conferences, and reports, they spread knowledge and influenced national and international standards by editing pre-normative documents. By the turn of the millennium, they began joint activities and produced common reports, leading to a convergence of standards worldwide.

The initiatives of these societies have had a significantly positive impact on practice in every country. Presently, within the *fib*, Commission 6: Prefabrication operates globally to develop, disseminate, and share knowledge on prefabrication.

The primary objective of Commission 6 is to demonstrate the advancements of precast concrete globally, highlighting the latest state-of-the-art techniques. Designers from various countries can share and learn from their experiences. The general aim is to promote a comprehensive understanding of design concepts, technology, and the application of precast concrete, not only for specialists but also for a broader audience of designers. The specific objectives include:

- Stimulating and coordinating international research and development (R&D),
- Transferring the results into planning, practical design, and construction through technical reports, state-of-the-art reports, guides to good practice, and handbooks,
- Disseminating knowledge via seminars, courses, and educational material,
- Contributing to recommendations, pre-normative documents, and codes within standardisation bodies.

Commission 6 addresses topics directly related to precast concrete, including systems, elements, connections, production, handling, assembling, and demounting. It also covers indirectly related items such as structural analysis, materials technology, building physics, equipment, environmental issues, sustainable development, and terminology.

2 Conceptual design. Specific aspects of precast structures

Prefabrication benefits significantly from the ability to produce concrete elements within the controlled environment of a factory. This protective setting shields the production process from adverse weather conditions, thereby enhancing both productivity and the quality of the concrete. It also facilitates the prestressing of elements through pre-tensioning, which is highly effective. However, prestressing is typically carried out in a straight line due to the alignment between anchorages at the ends of the benches. In some countries, the strands are deviated using intermediate anchorages within the prestressing benches and moulds. Conversely, other countries adapt the prestressing to external loads by debonding the strands with plastic tubes.

To obtain the best design, it is imperative that designers plan for a precast structure from the very outset rather than merely adapting their design from the traditional cast in-situ method. The following phases of the conceptual design stage should be respected for all to reap the considerable benefits of a precast-concrete solution.

Normally, when designing precast structures, designers will use the largest elements available for production, transport, and erection to minimise the number of connections on site. In the factory, limitations may include prestressing capacity, the number of strands that can be prestressed due to the anchorage in the benches, lifting capacity of the cranes which are typically attached to the factory structure, transport capacity, and regulations in the country, as well as lifting capacity onsite. All these constraints must be considered by the designers to create the optimal structure. These are some of the reasons why precast structures vary in different parts of the world.

Designing precast structures is much more than simply dividing a structure into pieces.

Besides production, transportation and erection constraints, there are other circumstances that need to be considered. Normally, when designing precast elements, it is important to limit the weight of the element and maximise the length while achieving safety and rigidity. For this reason, it is common to design slender beams and sometimes strict columns. When designing very slender elements, it is essential to contemplate lateral deflections, cracking, and lateral stability of the elements in the phases of lifting, transport and erection. Some elements, such as columns, will function as a beam or a cantilever during storage, transport and erection. A designer of precast structures must consider all these phases and ensure that the forces to be resisted in various phases do not damage or limit the function of the element or the structure in its final stage. There are recommendations in the Normatives regarding lateral rigidity of beams and also specialised documents from PCI and *fib* on this topic.

Considerations of structural stability during construction phases are paramount in precast structures. Some structures may initially be designed as isostatic during certain phases, necessitating thorough stability and robustness checks. For instance, a beam might begin as an isostatic element with a small cross section and evolve into a composite section with in-situ poured concrete, ultimately achieving continuity in the final structure. Precast concrete designers must assess all intermediate phases at the cross section level, evaluating both serviceability limit states (deflections, stresses, and cracking) and partial ultimate limit states, to identify the most critical for the design. Occasionally, propping or partial reinforcement or prestressing may be required during construction.

Given the often highly evolutionary nature of precast structures, designers have the flexibility to modify how elements and the overall structure function during construction and in the final phase by adjusting the construction process.

At the initial design stage, the primary task is to determine whether the building project or specific sections of it are suitable for construction using precast concrete, and to weigh the distinct advantages and disadvantages relative to other building systems.

The principal benefits of precast concrete include rapid erection, superior concrete quality, long-span prestressed floors, a controlled working environment, and overall project economy. Nonetheless, several misconceptions persist, such as perceived lack of flexibility, the variety of precast systems available, and the extended lead times required for comprehensive planning.

Precast concrete possesses many more advantages than mentioned previously, with the need for excessive repetition of products or lengthy design and manufacture periods largely eliminated in contemporary practices. On the contrary, thanks to modern production techniques and computer-aided manufacture, in combination with Building Information Modelling (BIM), its flexibility and short delivery times have become significant commercial assets for prefabrication. Even with the aid of new tools, it is highly recommended to consider modularisation, where feasible, to ensure better fitting of different parts of the structure and other specialities that are integral to the final construction, such as façades and installations.

Precast concrete offers considerable opportunities for enhancing structural efficiency. Longer spans and shallower construction depths can be achieved by using prestressed concrete for beams and floors. For industrial and commercial halls, roof spans can extend up to forty metres in length or even longer.

<u>Factory-made products</u>. One approach to industrialising the construction industry is to transfer the work from the site to modern, permanent factories. Factory production enables rational and efficient manufacturing processes, skilled workers, repetitive actions, and lower labour costs per square metre due to automation. Factory products are process-based, and advanced industrialisation concepts like lean manufacturing principles are utilised in production. Competition and the social environment compel the

industry to continuously strive for greater efficiency and improved working conditions through the development and innovation of materials, structural products, systems, and processes. Automation is gradually being implemented in most industrial plants.

Prestressing. The pretensioning of steel tendons is frequently applied in precasting due to the feasibility of using fixed prestressing beds and prestressing tendons anchored by bond. Prestressing allows for the reduction of the amount of steel and concrete in structures while simultaneously achieving longer spans and more slender elements.

Optimum use of materials. Prefabrication holds significant potential for economic efficiency, structural performance, and durability due to the optimal utilisation of materials. This is achieved through modern manufacturing equipment and meticulously studied working procedures, thereby minimising tolerances.

Additives and admixtures are incorporated into the mix design to attain the specific mechanical performance required for each product. The casting and compaction of the concrete are conducted in indoor working conditions using optimal equipment. The water content can be reduced to a minimum, and curing is carried out under controlled circumstances.

The use of higher quality materials has resulted in improved structural behaviour and increased durability of components. Structures made of high-performance concrete, produced in plants with stringent manufacturing controls, exhibit higher resistance to external attacks compared to in situ concrete structures.

Prefabrication has consistently been a means for introducing new technical developments in construction practice, including innovative quality systems that have led to the application of quality certifications for construction-related activities. [8]

From the outset, prefabricated production control has deployed the most reliable procedures. Before analytical and numerical calculation methods were widely regarded for ensuring sufficient safety, physical trials were conducted to verify the technical viability of precast products and their related structures.

The primary benefit for building structures is the enhanced structural efficiency that allows for more slender products and the optimal use of materials.

Architectural flexibility. The design of buildings is not confined to the utilisation of rigid precast elements; virtually any structure can be adapted to meet the requirements of the builder or architect. Architectural elegance and variety, combined with increased efficiency, are no longer mutually exclusive. The era when industrialisation resulted in large quantities of identical units is over; a streamlined production process, in conjunction with skilled craftsmanship, allows for contemporary architectural design within controlled costs, more effectively within an industrial plant than on-site.
Design considerations should be incorporated from the earliest phases, including planning and architectural design. Close collaboration among various specialities such as architecture, installation design, and structural engineering will yield the most well-balanced construction outcomes.

Appearance and Surface Finishing. Precast concrete elements can be produced with a wide variety of finishes. These range from intricately moulded surfaces to high-quality visual concrete. Significant architectural freedom and a broad range of expressions can be achieved using beams and columns with specialised shapes and superior finishes. Today, the definition of finishing is more a decision from the designer than a limitation imposed by production techniques.

Figure 1. Precast panels with brick finishing. The European School, Uccle, Brussels **[8]**

Integration of Building Services. The integration of building services within the precast building system offers numerous advantages. There are various solutions available that seamlessly incorporate a precast structure with building installations. One major benefit is that the precast structure can be customised to meet the specific requirements of the building's services. Elements can be fabricated with an array of apertures, and fixings can be embedded within the units. Additionally, numerous methods are available on-site after the erection of the precast building to accommodate further installations. The utilisation of Building Information Modelling (BIM) increasingly facilitates the coordination between the structural elements and the installations. In certain instances, integrating services within the structure, built into the precast elements, allows for the optimisation of the overall construction process.

3 The evolution of precast structures

The origins of prefabrication can be traced back to the early eighteenth century. The Industrial Revolution, with the advent of new materials such as steel and glass, had a significant impact on the industrialisation of architecture and concrete prefabrication. In numerous instances, architectural design underwent fundamental changes, giving rise to new styles firmly rooted in industrial processes. [3] [28]

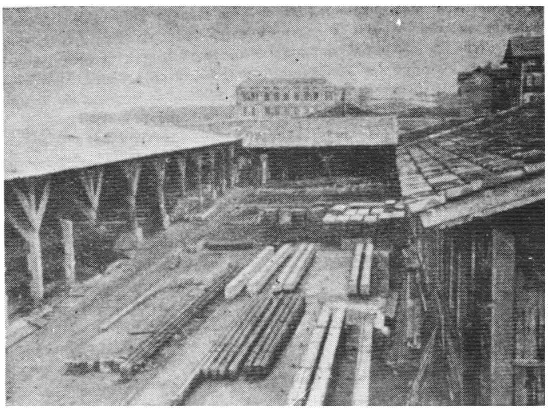

Figure 2. Coignet Factory **[5]**

Post-World War I Europe experienced a notable rise in building industrialisation. The devastation of numerous residential buildings during the war, coupled with the lack of new construction in the interwar years, created a significant demand for straightforward and cost-effective building systems, especially for housing. [8]

World War II also had considerable repercussions for building construction. Prior to the war, fewer than 1% of the dwellings in the United States were built using industrial processes. By 1945, over 200,000 housing units had been constructed, driven by both private and public initiatives.

In France, the immediate post-war needs provided architect Jean Prouvé with the opportunity to develop and refine machine-inspired techniques for industrialised building structures, primarily utilising steel.

Prefabrication with precast concrete linear members was one method to industrialise construction, but not the only one. Prefabrication with large-scale panels and closed building systems was not the sole industrialised building method in place at the time, although it played a substantial role in post-World War II housing.

In 1928, Eugène Freyssinet presented the first patent for prestressed concrete. While this breakthrough brought in-depth change to construction as a whole, it revolutionised concrete construction. Until that time, concrete had been an inert, passive material whose scant tensile strength inevitably induced cracking, the source of its ready deterioration. [29] [30]

After inventing prestressing, Freyssinet founded a prestressed concrete factory at Montargis, France [29] where he produced technically satisfactory prestressed poles.

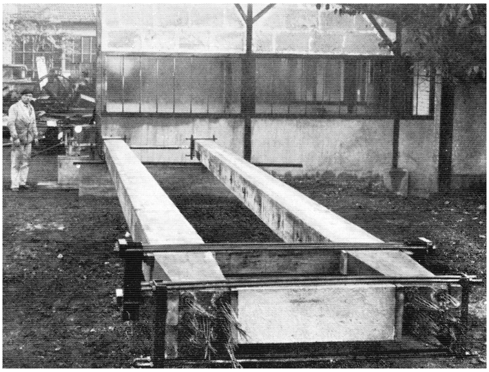

Figure 3. **Montarguis precast posts Factory [29]**

3.1 Modularisation and flexibility

Three main periods can be distinguished in twentieth-century housing prefabrication: 1945-1970, 1970-1985, and 1985-2000. The years from 1945 to 1970 were characterised by mass production, a sense of euphoria, and significant economic development.

In general, closed modular systems based on large panels prevailed in Eastern Europe, whereas they had a lesser presence in the West. These systems imposed strict rules due to the economy and speed of construction they offered, although this was often at the expense of architectural considerations and design freedom. [3] [31]

For the owner and the designer, whether a structural engineer or an architect, industrialisation meant ensuring construction economy by adhering to a "system" that placed tight constraints on architectural design. Altering any system parameters was akin to forfeiting market competitiveness. It was around this time that Camus, when asked about thermal bridges, responded: “I’m too busy selling to have time to improve.” [3]

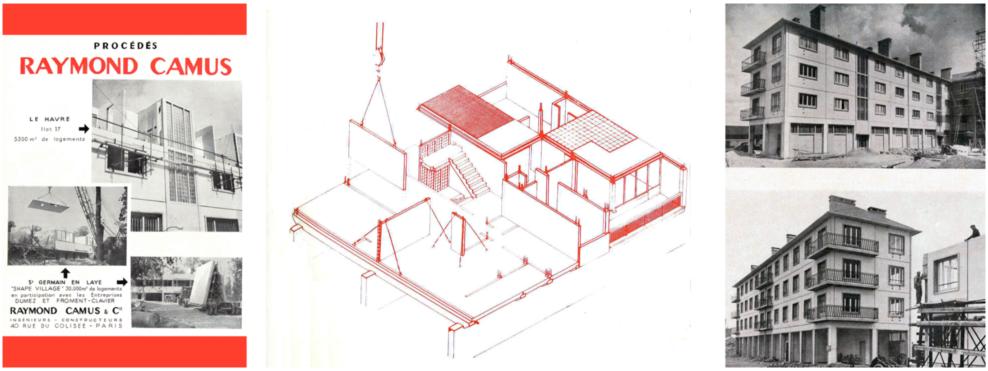

Figure 4. Competition for HLM housing in Strasbourg and construction site of the settlement (CSTB, 1951); construction site in La Corneuve (CSTB, 1964)

The second period, spanning from 1970 to 1985, was characterised by both crisis and perplexity. Efforts to utilise large-scale prefabricated components struggled to navigate inherent challenges, striving to offer more flexible and diverse products, designs, and construction methods. The EU market transitioned from a seller's to a buyer's marketplace, where end-users began prioritising design and quality. To meet this demand, some panel systems satisfactorily adjusted to small-scale requirements or the stringent climates of Northern Europe. Others opted to export to less developed markets, while some manufacturers ceased operations entirely. [5]

This era of crisis laid the foundation for the concept of open prefabrication, which saw the development of systems with multiple compatible components, adaptable to the needs of designers or end-users.

Post-1985 witnessed the evolution of prefabrication into what would later be termed subtle prefabrication. Since then, the construction of most housing elements has adhered to the component-based model. In developed nations, large-scale, inflexible industrialised construction has essentially become a relic of the past.

Figure 5. Industrial building [1]

During this later period, new designers undertook both small- and large-scale projects using innovative prefabrication techniques, yielding excellent results. The construction of individual elements was automated as far as possible to accommodate increasing customisation of structures, façades, and installations. Many of the industrialised procedures, commonly utilised in highly systematised and individualised industries, were applied to construction and, consequently, to prefabricated housing.

All the experience gained over the last century in Europe has been harnessed, combined with local expertise, to develop new methods for building affordable housing globally, always adapting to local culture and constraints.

3.2 Automatisation and individualisation

Prefabrication has significantly evolved, offering numerous advantages over traditional construction methods. Notably, when compared to conventional construction methods, prefabrication and the use of concrete materials present several beneficial characteristics for both the construction process and the final structures.

Precast elements are produced in controlled factory environments, which is fundamental to industrialising the construction sector. Transitioning from temporary construction sites to permanent modern facilities allows for rational and efficient manufacturing processes, utilisation of skilled workers, systematisation of tasks, and reduced labour costs per square metre due to automated and quality-controlled production. Factory-based production adheres to process-driven and lean manufacturing principles, benefitting the entire construction process. Automation is increasingly being implemented in factories, covering areas such as the preparation of reinforcing steel, mould assembly, concrete casting, and surface finishing on architectural concrete. It is anticipated that other stages of the production process will follow suit, enhancing efficiency and quality further.

As prefabrication makes optimal use of materials, its potential for reducing material usage and consequently the impact of CO_2 consumption is considerably greater than in cast-in-situ construction. Structural performance and durability are also enhanced through meticulous design, modern manufacturing equipment, and carefully planned working procedures. [8]

Architectural freedom is essential to create contemporary building designs. Architectural design is no longer constrained by the rigid concrete elements of the past, and almost any structure can be tailored to the builder's or architect's specifications. Architectural elegance and diversity need not conflict with increased efficiency. The era of industrialisation resulting in large numbers of identical units is over. On the contrary, efficient production can now be combined with skilled craftsmanship, enabling modern architectural design without additional costs.
In today's society, the appearance and finish of buildings often dictate construction procedures. Precast concrete elements support a diverse array of finishes, ranging from meticulously moulded surfaces to high-quality architectural concrete. The use of beams and columns with special shapes and high-quality finishes affords architects considerable creative freedom and expression.

4 Design of Precast structures

4.1 Connections

Connections have always been a key aspect of the design and construction of precast structures. The design of connections must commence at the very beginning of the conceptual design of the structure. Their performance relates to the structural limit states, as well as to the manufacture, erection, and maintenance of the structure itself. Proper design of connections is one major key to successful construction with precast elements. [14]

When designing and building a precast concrete structure, it is necessary to consider the connections that will be made on site, as they are crucial for the stability of the structure during the erection and construction phases, as well as during in situ works and the entire lifespan of the structure.

It is of the utmost importance to consider, in the design of a precast structure and its connections, the tolerances for production, transport, and erection of precast elements. Not considering these aspects at each part of the process may lead to severe problems in the construction or the life of the structure.

In the completed building, structural connections form an essential part of the structural system. The structural response will depend on the behaviour and characteristics of the connections, both as force-resisting components or as movement-resisting or allowing components. The structural layout, the arrangement of stabilising units, the design of the structural system (and its sub-systems), and the design and detailing of the connections must be done consistently and with an awareness of the intended structural behaviour during construction and in the final stage. To achieve satisfactory design, the designer should understand how the connections influence the flow of forces through a structure under vertical and horizontal loads, allowing for ductility or movements. The primary purpose of the structural connections is, therefore, to transfer forces or to accommodate movements between the precast elements to enable the intended structural interaction when the system is loaded.

Within a single connection, there may be several load-transmitting joints, so it is first necessary to distinguish between a 'joint' and a 'connection'. A 'joint' is the interface between two or more structural elements where the action of forces (e.g. tension, shear, compression) and moments may take place. A 'connection' is an assembly, comprising one or more interfaces and parts of adjoining elements, designed to resist the action of forces or moments or to allow movements. The design of the connection is, therefore, a function of both the structural elements and the joints between them.

Unlike cast in-situ concrete work, the design philosophy for precast connections encompasses both the structural requirements and the selected construction method. Often, the working practices in the factory or on-site significantly influence the connection design.

For every external load applied to a structure, it is essential to identify a force path that connects this load to its reaction in the foundation. This force must traverse structural elements and connections, which can be considered as a chain of components. When multiple loads are acting simultaneously, several force paths run parallel, allowing for a discussion of a flow of forces.
It is prudent to examine the flow of forces under vertical and horizontal loads separately, and to combine the two solutions in the development of the structural system.

The vertical loads are resisted by bridging elements such as roof and floor elements, beams, and stairs, along with supporting elements like columns and load-bearing walls. For horizontal forces, the structure must be equipped with stabilising units capable of resisting the horizontal loads and transmitting them to the foundation reactions. Ductility of the connection, and consequently the entire structure, is crucial in the design of connections in seismic areas. [16]

4.2 Buildings, high rise and mixed construction

The advantages of precast concrete are well-documented, including strength, integrity, versatility of form and use, compatibility with other structural forms, swift construction, off-site reliability, enhanced quality, durability, security, fire resistance, sound and thermal insulation, energy conservation, and increased predictability. These benefits can be realised in tall buildings, but it is crucial to adhere closely to the design philosophy of the chosen system and not simply use the precast system to replicate or modify an initial in-situ solution. Fundamental aspects of any precast system should include the following: [20]

- Standard solutions from modular design (element widths of 3M, 6M, 12M or 24M, where M=100 mm) should be considered. Producers often have standard moulds based on modular designs. Customised elements that fall outside these parameters may lead to additional work and cost; however, taller buildings benefit from repetitive floor levels which may justify customisation. Modern automated and robotic systems can also handle non-repetitive and customised solutions.
- Standard products developed by precast producers should be utilised; the repetition of floor levels in taller buildings may make it viable to develop variations of standard products to suit the building.
- Details, especially at connections, should be straightforward and repetitive. Complex details are more prone to errors and take longer to execute. It is likely that standard details used for

lower-rise buildings will need to be modified and/or strengthened for taller buildings, but the basic principle remains the same.

- Dimensional tolerances need to be accounted for. Tolerances at connections can be absorbed using mortar beds, grouts, or in-situ stitches where necessary, or by employing alternative mechanical solutions.
- Use in-situ infills where appropriate. Do not force the precaster to produce areas that are obviously unsuitable for the system.

The most common basic types of precast concrete structural systems are:

- The portal frame, comprising columns and roof beams, is employed in industrial manufacturing facilities, warehouses, and commercial buildings, among others.
- The skeletal structure, which includes columns, beams, and slabs for low to medium-rise buildings, and a limited number of walls for high-rise constructions. Skeletal frames are predominantly utilised for offices, schools, hospitals, and car parks.
- The wall frame, featuring vertical load-bearing walls and horizontal slab units, is extensively used in residential houses, apartments, hotels, and educational institutions.
- Cell structures composed entirely of precast concrete cells are occasionally employed for bathrooms, kitchens, and garage units. Historically, this system has been used sporadically for complete buildings, such as hotels, prisons, and similar edifices.

Precast concrete is often considered a viable form of construction only at a late stage in the planning process. This tendency arises because concept designers primarily focus on in-situ concrete and structural steelwork as the main structural forms. This may be due to the fact that precast design is typically carried out by producers who employ specialist engineers, and thus concept designers are not fully acquainted with the various aspects of precast systems. It is imperative that organisations address such gaps in training and perspective.

Frequently, it is only when the contractor's commercial and construction expertise is involved that alternative options are explored. In many cases, however, precast concrete is limited to substituting components that have already been detailed as steel or in-situ concrete. Consequently, many of its benefits are overlooked in the rush to begin construction and meet unrealistic delivery dates.

There is, however, an emerging trend whereby contractors have their in-house precast specialists and often possess precast production capability. These contractors evaluate the suitability of all materials concerning quality, cost, and buildability at the tender stage. Precast concrete is included in this assessment, facilitating the development of mixed or hybrid solutions in tall buildings. By utilising precast concrete, in-situ concrete, and structural steelwork together, the most advantageous solution is achieved, leveraging the unique properties and benefits of each material.

4.3 Floors

Precast concrete floors can be an integral part of tall buildings. In addition to the normal benefits of concrete (both precast and insitu) they have the added advantages of reduced construction time (time certainty), enhanced structural performance (high strength concrete and prestressing), large span capacity, minimal falsework, reduction in labour and wet trades, and a large selection of different types to suit any given application. Most flooring systems are mass produced under factory conditions and with economies of scale provide a cost effective and fixed price solution (budget certainty).

Precast concrete floors can be integral to the construction of tall buildings. In addition to the usual benefits of concrete (both precast and in-situ), they offer the added advantages of reduced construction time (time certainty), enhanced structural performance (utilising high-strength concrete and prestressing), large span capacity, minimal falsework, reduction in labour and wet trades, and a wide selection of types to suit any given application. Most flooring systems are mass-produced under factory conditions, and with economies of scale, provide a cost-effective and fixed-price solution (budget certainty).

The main types of precast floor that are generally available are:

- Reinforced filigree slabs (also known as shuttering slabs)
- Voided reinforced slabs
- Reinforced ribbed slabs
- Prestressed plate flooring
- Prestressed hollowcore flooring
- Prestressed ribbed slabs (single tees, double tees, and channels)

Figure 6. Precast hollow core and TT floors **[8]**

Figure 7. Precast composite floor-plate and beam and plate floors **[8]**

Particularly in the construction of tall buildings, precast slabs are often designed to act compositely with an in-situ structural topping. This topping not only enhances the structural capacity of the floor to support gravity loads but also connects the individual precast flooring elements to act as a plate, or diaphragm, to transfer horizontally applied loads to the vertical stability system (shear walls, stair cores, and shafts). The floor slabs can interact with various types of primary precast beams, structural steel beams, or be used as flat slabs.

The choice of flooring system varies between buildings and is often influenced by the floor depth and self-weight. Ribbed slabs, which offer low self-weight and excellent load/span characteristics, may be excluded due to their relative depth compared to constant depth flooring. Additionally, voided slabs, which also provide low self-weight, may not be considered if the spans are relatively short and offer no significant advantage. Prestressed or reinforced composite plate or filigree flooring may provide an optimal solution in tall buildings with relatively short spans.

Figure 8. Hollow core floor for large open spaces **[8]**

Precast floors are typically designed as isostatic elements and, depending on the requirements of the structure and the regional construction practices, may not always include an in-situ topping. Generally, precast flooring elements are positioned on other precast components using what is referred to as direct support, where one element is placed directly on top of another. It is also common for precast elements to be finished with an in-situ topping, varying from 5 to 10 cm or more. This topping ensures a high degree of flatness for the finishing surface and allows the floor to exhibit composite behaviour, resulting in increased stiffness and improved dynamic and deflection properties. In some instances, precast elements are utilised with an in situ topping to create a continuous floor, thereby enhancing the floor and the overall structure's rigidity. For such flooring systems, a step-by-step analysis of the individual precast element and the composite behaviour of the structure is essential.

4.4 Seismic structures

Experience in earthquakes has demonstrated a generally favourable performance of precast structures, even in high seismicity regions, provided they are properly designed and constructed. In particular, precast frame systems, which are widely used for single-storey industrial buildings, combine high resistance capacity with strong attenuation of the seismic action due to their long natural vibration period and substantial ductile deformation capacity. Conversely, the few reported instances of excessive damage, including partial or total collapse of precast buildings, have typically been attributed to poorly conceived conceptual designs, inadequate structural schemes and load paths, and/or insufficient detailing of connections between structural elements, as well as between structural and "non-structural" (e.g., claddings and heavy infills) elements. [16]

In general, for all types of structures and structural systems, good behaviour under seismic conditions depends on the following fundamental steps:

- the overall design and
- the construction details of the structure

The structural simplicity and morphological clarity of a structural system are essential from the early stages of designing a precast building, providing direct or alternative paths for the transmission of seismic loads. Regularity in plan and height is greatly affected by the geometrical configuration of the building. Each structural system should be able to resist seismic actions in both directions. This can be achieved by the proper arrangement of structural elements (columns and/or walls) in an orthogonal grid, which provides quasi-similar resistance and stiffness in both directions. Torsional irregularities should be avoided as much as possible.

Good seismic design depends on the experience and skills of the designer and the state of knowledge at local and international levels in terms of theory, analytical/numerical and experimental observations, design guidelines and codes at the time of design. In general terms, knowledge of the current “best practice” is required. This is often ahead of, and beyond, the prescriptions contained in the latest codes. Design codes, standards or by-laws, in fact and, by definition, set “minimum” requirements. It is up to the owner to discuss with the engineer and other parties involved, set the desired design targets (which may be higher than the code requirements), and investigate options and solutions to achieve them in a cost-effective manner.

Effective construction hinges on the experience, skills, available equipment, and adequate supervision and inspection to ensure all design details are correctly implemented. For in-situ concrete construction, the detailing of connections between columns and beams is crucial. Even though it is easier to develop fixed connections, they need to be designed with sufficient confinement and ductility. Issues in in-situ construction primarily arise from poor detailing. In precast construction, meticulous attention to the detailing of connections is critical from the beginning. Problems in precast construction within seismic areas often stem from a lack of conceptual design in the flow of forces and occasionally inadequate detailing of connections. However, with robust conceptual design and meticulous detailing of connections, precast structures have demonstrated excellent performance during seismic events.

Figure 9. Precast building with monolithic connections for seismic areas. India. **[16]**

In the specific case of precast construction, as opposed to monolithic construction, additional design principles, code provisions, and construction procedures are required to ensure a level of safety and ductility under seismic actions that is equal to or exceeds that of cast-in-place construction. Given the inherent characteristics and recognised advantages of precast construction—such as high-quality control, rapid erection, and modularity—it is essential to adopt an integrated and collaborative approach involving the client, design team, and construction team.

A precast structure is generally less tolerant of deviations than its cast-in-place counterpart, necessitating stricter control over tolerances and limiting the feasibility of post-design on-site modifications. Consequently, the entire structural system must be considered holistically rather than at the component level. Furthermore, particular attention must be given to the detailing of connections between elements to ensure the required structural performance while maintaining ease of constructability.

4.5 Bridges

Superstructures commonly constructed from precast concrete include underpasses, overpasses, interchange bridges, water crossings, and viaducts. These bridges are typically part of larger infrastructure projects and interact with or influence other structures or elements within the development. As such, bridges are not isolated elements that can be designed with complete autonomy; rather, a series of interconnected project considerations must be assessed. [19]

<u>Codes</u>. Each country has specific codes that define the loads to be supported and the combinations to be considered at both the ultimate limit state (ULS) and serviceability limit state (SLS). These codes

establish the expected structural performance over its service life in terms of functionality, durability, sustainability, and robustness, while also incorporating national traditions and engineering experience.

Various codes have been developed to specify the forces to be considered in the design of both highway and railway bridges, as well as regulations governing structural concrete construction. While national codes may differ in detail, their fundamental principles are often aligned.

Construction. Construction considerations are crucial in the preliminary design of a precast concrete superstructure. Factors such as fabrication conditions at precast manufacturing facilities, transportation logistics, and installation procedures at the jobsite must be carefully evaluated.

Fabrication conditions at precast concrete manufacturing facilities must align with local practices. In some cases, on-site fabrication may present alternative opportunities as well as constraints. Different countries adopt varying approaches to prestressing techniques. Some utilise post-tensioned or pretensioned draped (also referred to as deflected or harped) strands, while others employ only straight pretensioned strands. Additionally, debonding of strands is permitted in some regions but restricted in others.

Weight limitations for transportation on national highway networks vary significantly between countries, which directly impacts the size of precast concrete elements that can be utilised. To address these limitations, precasters often transport segmented precast concrete elements and subsequently join them with post-tensioning at the project site. In many cases, the length and weight of precast concrete elements necessitate an assessment of highway conditions and the use of specialised hauling equipment.

The transportation of precast concrete elements is also heavily influenced by jobsite accessibility. In some instances, inadequate highway networks prevent direct road transportation, requiring the construction of temporary access routes for hauling vehicles. These logistical challenges must be systematically evaluated and resolved to ensure successful project execution.

Finally, the installation of the precast concrete elements should be studied in detail. It is necessary to account for the following:

- height of the structure,
- accessibility and topography,
- feasibility of creating detours when traffic is affected,
- layout geometry and compatibility with the potential installation measures,
- deadline and work schedules to consider solutions compatible with these needs,
- equipment availability.

In many locations, the use of high-capacity cranes enables the installation of large and heavy precast concrete elements. Given these possibilities, a detailed study is required to ensure adequate access conditions for cranes during the installation process.

In some cases, cranes can be positioned directly on the bridge under construction, particularly for the installation of elements such as deck panels or slabs. This aspect must be carefully evaluated during the design and planning stages to ensure feasibility and structural safety.

Girder length and depth. If clearance and other constraints allow (typically associated with taller bridges requiring more earthworks and increased fuel consumption), it is generally more economical to use a deeper section of a given girder type, provided it meets local handling and transportation limitations. A 2,000 mm deep section incurs only a slightly higher cost than a 1,000 mm deep section within the same girder family, as the additional concrete cost is offset by reduced prestressing steel requirements and potentially lower concrete strength. Furthermore, manufacturing processes remain largely the same, making deeper sections advantageous in high-labour-cost regions. Weight limits vary between countries and even within different regions of the same country, often depending on the available equipment at the precast manufacturing facility.

Another key consideration is the length of precast concrete girders. Generally, girder length should not exceed approximately 50 times the widest flange width to ensure stability during transportation, handling, and erection. For girders approaching or exceeding this ratio, a lateral stability analysis is recommended. To mitigate stability concerns, bracing the top flange with a horizontal steel truss or other structural means may be required. Girders up to 65 m in length have been successfully transported by road in the United States and Canada. However, transporting such long girders requires careful planning and stability analysis, particularly when sharp road curves, sloped roadways, or challenging terrain are anticipated. The TG6.5 "Precast Concrete Bridges" group is in the final stages for publication of a document on the lateral stability of girders.

For I-girders with composite deck slabs, it is advisable to limit the overhang length (measured from the centreline of the exterior web to the deck edge) to 50% of the girder spacing. The overhang length should never be less than half of the top or bottom flange width, whichever is greater, to maintain structural integrity. Reducing the top flange width could impact stability and cause stormwater to drip directly onto the bottom flange. For U-girders, overhangs are typically larger and require, in addition to bending moment checks, specific controls for slab deflection and shear.

Girder spacing arrangement. Several factors influence the selection of the number of I-girders with composite decks and similar beam sections in a bridge cross-section:

- In some cases, it is recommended that the number of girder lines should not be fewer than four, allowing for deck replacement on one-half of the bridge at a time. However, there are also examples of bridge decks constructed with just three I-girders.
- The overhang length should be approximately 50% of the girder spacing to ensure that all girder lines of the bridge have a similar design. However, this is dependent on truck loads, which vary significantly across different design codes.
- For U-girders, the spacing can be larger, and it is common to construct bridges with just two girders. Additionally, there are Mono-beam bridges that utilise a single large U-girder as the deck.

Continuity methods. The simple span system can be structurally optimised by increasing the degree of continuity, leading to longer spans or wider spacing for the same girder depth. Increasing the girder span or spacing for the same depth significantly reduces bridge costs by using fewer elements. Additionally, continuous precast, prestressed concrete girders can be employed in long bridges with the addition of internal or external prestressing.

Bridge design loads can be categorised into three major components: girder weight, deck slab weight, and superimposed dead and live loads. Each of these components constitutes approximately one-third of the total loads for spans in the short-to-medium range encountered in girder-type bridge superstructures. For longer structures, self-weight can be a determining factor, and for railway bridges, higher loads and stiffness requirements become critical design considerations.

Partial continuity is a method that provides continuity only for the deck slab, while the beams remain simply supported. This means no distribution of vertical load effects occurs between the intermediate bridge decks. This applies to all vertical loads, including self-weight and variable loading.

Several methods are used to achieve partial continuity in beam and slab decks. In one approach, continuity is restricted solely to the slab, which deflects to accommodate the rotations of the simply supported deck beams.

Multi-span bridges with mechanical continuity between adjacent spans are realised by integrating the bridge beams into a reinforced concrete crosshead on top of the piers. The construction is carried out in steps:

- In the first step, the beams are simply supported and carry their own weight plus the load from the formwork and the wet cast concrete of the slab.

- In the second step, after hardening of the in-situ concrete, the structure becomes continuous, but only for the additional dead load and the variable loading.

Continuity for girder weight can be achieved through post-tensioning using a precast concrete pier segment. Continuity for deck weight and live loads can be achieved with threaded rod continuity methods or post-tensioning. Continuity for live loads only can be achieved using reinforcement in the deck slab over the pier. Table 1 shows different methods of continuity and, in a simplified way, their efficiency effects. For example, threaded rod continuity for deck weight, superimposed dead load, and live load allows for the maximum span length to increase by 20 percent compared to the conventional system of providing continuity only for superimposed dead load and live load.

Table 1. Efficiency improvement due to degree of continuity

<table>
<tr><th colspan="2">Continuity method</th><th>Loads on simple span system</th><th>Loads on continuous span system</th><th>Span efficiency improvement (multipliers)</th></tr>
<tr><td colspan="2">Reinforcement in the deck slab</td><td>GW, DW</td><td>SIDL, LL</td><td>10%</td></tr>
<tr><td colspan="2">Threaded rod</td><td>GW</td><td>DW, SIDL, LL</td><td>20%</td></tr>
<tr><td rowspan="2">Post-tensioning system</td><td>One precast concrete beam per span</td><td>GW</td><td>DW, SIDL, LL</td><td>20%</td></tr>
<tr><td>Pier + span segments</td><td></td><td>GW, DW SIDL, LL</td><td>25%</td></tr>
</table>

Note: DW = deck weight; GW = girder weight; LL = live load; SIDL = superimposed dead load.

In the design of multispan bridges, prestressed concrete girders are typically considered as simple spans for self-weight and deck weight, while being treated as continuous for the superimposed dead loads and live loads. This type of continuity can be referred to as “positive” design, as continuity is only introduced for the superimposed loads, with all self-weight being supported in an isostatic manner.

The cast-in-place (CIP) pier diaphragms, along with the longitudinal reinforcement in the deck over the piers, act as the means of resisting the negative continuity moment (see Fig. 5). Under this continuity method, the prestressed girders are made continuous for approximately one-third of the total load in the case of short to medium spans. Furthermore, since the majority of the dead load is applied before the continuity is activated, some bridges have experienced bottom fibre cracking near the piers. This cracking is often due to high positive time-dependent restraint moments, which arise from creep camber, particularly when large prestressing forces are involved. The effects of time-dependent redistribution of moments must be carefully considered for both serviceability limit states and ultimate limit states to ensure the long-term performance of the structure. [18]

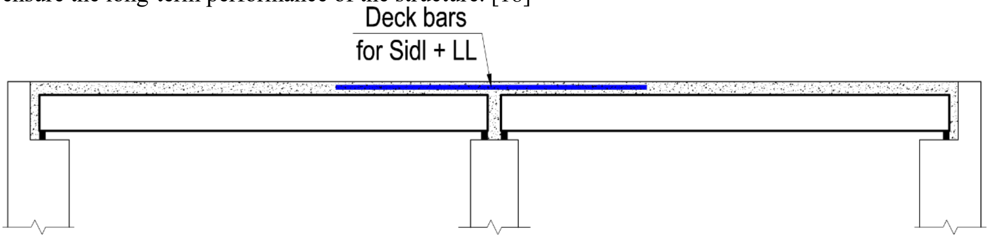

Figure 10. Conventional deck reinforcement continuity method [19]

This method of continuity is the simplest and most cost-effective compared to alternative continuity methods. It does not require additional equipment or specialised labour, making it an efficient solution. In this approach, the precast concrete girders are first installed on the abutments and piers. The diaphragm is then formed and reinforced, with approximately two-thirds of its height being cast. Following this, the deck slab is formed, with the reinforcement installed before being cast together with the haunch (the space between the top of the girder and the bottom of the slab) and the remaining portion of the diaphragm. The barriers are subsequently installed, and the railing and wearing surface are cast. Once these steps are completed, the bridge is ready to be opened to traffic.

This method is used worldwide. In some countries, no reinforcement is placed in the lower part of the connections at the piers, while in others, provisions are made to include reinforcement to resist the positive bending moment arising from the redistribution of prestressing after the connection is fixed.

An alternative solution involves temporarily supporting the prestressed beams on top of the piers. The in-situ integral crosshead is then cast between and around the beams, typically extending about 1m on both sides. However, the crosshead is narrower due to the small gap between the beams. This narrow gap can make it more difficult to achieve an adequate lap splice of the bottom reinforcement between the beams, which may complicate the construction process.

Longitudinal continuity is easily achieved with the top reinforcement in the continuous composite deck slab. The longitudinal bottom reinforcement of the crosshead is partly installed through holes in the ends of the beams, ensuring an effective connection between the girders and the slab.

Additional continuity for the deck weight can be obtained by casting the slab concrete in two stages. In the first stage, once the reinforcement over the piers is installed, only a small volume of concrete—sufficient to ensure overlap between the reinforcement and the bars on top of the girder—should be placed. This method ensures that the required reinforcement for deck continuity is in place when the deck is cast. For the remaining concrete in the second stage, continuity has already been established. While the two-stage process offers advantages in certain situations, its convenience should be evaluated in comparison to other methods.

The system using threaded rods or prestressing for continuous bridges enables the girders to be continuous for both deck weight and live loads. This form of continuity could be referred to as “negative” design, as continuity is applied to part of the self-weight of the slab and the superimposed loads, with the self-weight of the structure being supported isostatically.

In this system, the bridge becomes continuous for about two-thirds of the total load. The precast concrete I-girders are fabricated with high-strength threaded rods located at the top flange, projecting from the ends of the girders. This system is also commonly used for U-beams and other solutions where there is a need to optimise the positive reinforcement in the beams, particularly when there are limitations on the amount of prestressing that can be applied in the precast yard or constraints on the lifting capacity within the factory.

This solution has several significant advantages over the continuous-for-live-load system:

- Because the girders are continuous for most of the load, the maximum positive moment is significantly reduced, resulting in reduced prestress demand and reduced demand for high-strength concrete at release.
- The same girder size will span about 15% more than the conventional continuous-for-live-loads system only.

- The increased dead load negative moment with this system guarantees no net positive moment at piers and no possibility of cracking due to creep restraint.
- The continuity of negative moment reinforcement in the girders at time of deck placement ensures adequate resistance to girder end rotation and no diaphragm distress or cracking, which has occasionally occurred with the continuous-for-live-load method.

In this method, I-girders are fabricated with high-strength threaded rods embedded in the top flange or by using prestressing for continuity. Several solutions are available to achieve this type of continuity during the construction stages (see Fig. 6). Once the diaphragm concrete is placed, the deck slab is cast after the diaphragm has gained the required strength. This continuity reinforcement is specifically designed to resist the negative moment caused by the weight of the deck slab.

Conventional longitudinal reinforcement or prestressing reinforcement is provided in the deck, particularly in the negative moment regions, to resist the additional negative moments resulting from superimposed dead and live loads. In cases where the loads are particularly high, such as in railway bridges, prestressing reinforcement is often employed. Additionally, in U-beam bridges for long spans, external prestressing may also be used to optimise performance and manage the moments effectively.

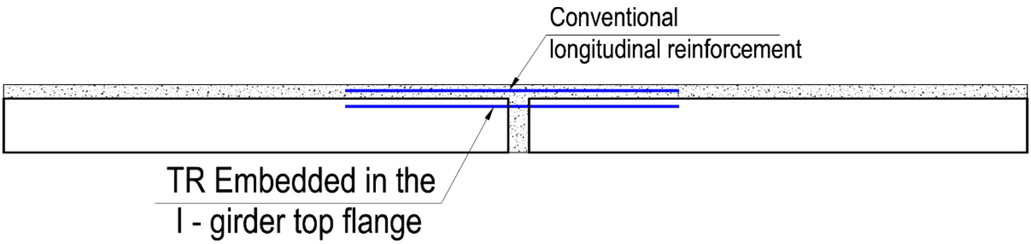

Figure 11. Threaded rod continuity schematic [19]

In places with extreme environmental conditions, the continuity reinforcement is specified to be of corrosion-resistant steel.

Spliced Girders: A well-established system for achieving continuity of the girder before the deck is placed involves the use of full-bridge-length post-tensioning. This method is particularly cost-effective when the girder splicing does not occur directly over the piers, often due to limitations related to length or weight (see Fig. 7). Post-tensioning can still be employed economically even when the splice joints are located over the piers.

However, this approach requires the widening of the typically thin webs of I-girders and other stemmed members to accommodate the post-tensioning ducts. This widening is necessary to offset the shear capacity reduction resulting from the ducts being incorporated within the precast concrete girder webs. For U-girders, there is generally more available space, and the internal space within the beam can be utilised to accommodate external prestressing, which is an additional advantage.

The addition of a post-tensioning anchorage block introduces both cost and weight to the precast concrete members. Moreover, post-tensioning is a specialised skill that is typically not provided by most local contractors, which may limit its use in certain areas. Special care must be taken when making connections between girders, which can be either match-cast or wet-cast with a grout filling to ensure proper bonding and structural integrity.

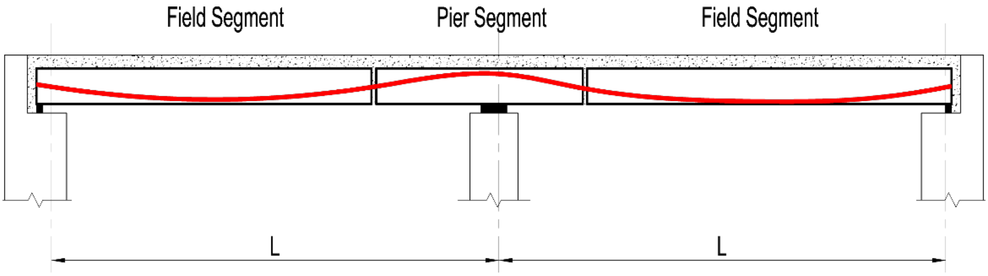

Figure 12. Splicing away from piers using post-tensioning. [19]

Adequate pretensioning is only required to support the self-weight of the girder during shipping, handling, and erection. This relatively low level of prestress results in smaller blocks and minimises the need for high-strength concrete during the transfer of pretensioning. The girder segments are first erected, after which the diaphragms are formed, cast, and cured. The beams can be supported on temporary supports or with temporary corbels made from either concrete or steel, placed on previously erected beams.

At this stage, some or all of the post-tensioning tendons may be installed and tensioned. If the appropriate level of post-tensioning is introduced, the girders become continuous for both the deck weight and construction loads. The post-tensioning at this stage must be sufficient to generate concrete stresses at acceptable levels in the continuous member for the loads applied before the next stage of post-tensioning, should one be included in the design. This second post-tensioning stage is typically introduced after the deck has cured but before the application of live loads.

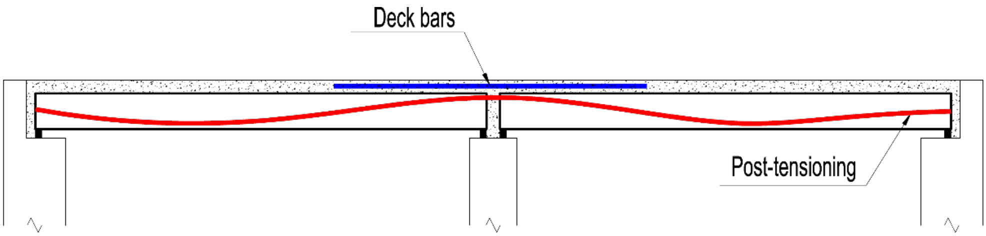

Figure 13. Post-tensioning continuity method over piers. **[19]**

Figure 14. Continuous bridge with I beams. **[11]**

Figure 15. Continuous precast box beam bridge. **[11]**

5 Sustainabiliy and resilience

In nearly every new construction or rehabilitation project, sustainability must be a key consideration when selecting the structure type, materials, and construction processes, as outlined in various fib documents, particularly the *fib* Model Code for Concrete Structures (2020) [7] [32] Producing sustainable structures should be a central goal for designers, aiming to minimise environmental, economic, and social impacts. All three pillars of sustainability—environmental, economic, and social—should be considered when developing the conceptual design of a structure, especially in the case of precast concrete structures.

A sustainable solution requires a global approach that integrates various structural, environmental, economic, and social aspects. In this context, it is crucial to minimise the consumption of natural resources while ensuring the required service life and behaviour of the structure. Prefabrication plays a particularly important role, as one of the key aims of precast design and construction is to optimise material use, which aligns with sustainability objectives.

In some ways, the adoption of sustainability as a design criterion has led to a paradigm shift in design philosophy. Previously, the challenge was to achieve greater benefits (such as increased resistance or reduced cost), whereas sustainable design now focuses on finding a balance between potential benefits and the resources needed, considering the long-term life cycle of the structure rather than just its construction. This shift presents a challenge that can only be met through experienced structural and technological knowledge, as well as a heightened sensitivity to the factors that influence the service life of the structure.

Decision-making is an essential part of sustainability when defining the conceptual design of a structure. The three pillars of sustainability must be balanced according to the needs of the local users and society, as outlined in Chapter 34 of the Model Code [32]. Various methods can be employed to analyse this challenge [33] [34] [35] and there are examples in fib Bulletin 88 [7]. This is an area that will continue to evolve in the coming years to support the right decision-making at the right time.

Figure 16. Precast mixed demountable structure. **[7]**

Sustainable design must also account for the end of life of the structure, either by preparing for the dismantling of elements and recycling the materials, or, more importantly, by ensuring the potential for reusing structural elements in other projects. This concept is currently being explored in many countries and has led to some excellent examples of precast structures designed for disassembly and reuse.

In many cases, structures are part of much larger projects, such as highways or railway lines. In such contexts, a sustainable approach should not only consider the sustainability of the individual structure but also how the structure fits into the broader sustainability goals of the entire project. This interconnected view ensures that the sustainability of the overall project is optimised, considering the full life cycle of both the structure and its role within the larger infrastructure system.

6 Future trends

Architectural freedom is essential to foster innovative building designs. Today, architectural design is no longer constrained by the rigid concrete elements of the past, allowing virtually any building to be adapted to meet the builder's or architect's specific requirements. Architectural grace and variety need not be at odds with enhanced efficiency. Gone are the days when industrialisation meant producing large quantities of identical units. In contrast, modern efficient production can be seamlessly combined with skilled artistry, enabling contemporary architectural designs to be realised without incurring additional costs.

In today's construction landscape, the appearance and finishes of buildings often dictate construction procedures. Precast concrete elements are highly versatile and can accommodate a wide range of finishes, from meticulously moulded surfaces to high-quality architectural concrete. The use of beams and columns with specialised shapes and high-end finishes provides architects with significant creative freedom and a wide scope for expression.

Another important design consideration is flexible building use. Certain types of buildings, particularly office buildings, often need to be adaptable to meet evolving user needs. In these cases, open-plan design is typically the most effective solution.

Precast concrete offers considerable potential for enhancing structural efficiency. Longer spans and shallower construction depths can be achieved by using precast prestressed concrete for beams and floors. The primary benefit for building structures is the improvement in structural efficiency, as more slender components optimise material usage. The greatest comparative advantage is found in vertical elements, especially load-bearing columns, where their bearing capacity can increase by 100 to 150% when the concrete strength is elevated from 30 to 90 N/mm². [8]

Figure 17. High rise precast building. Galaxy Towers in Brussels. [8]

Figure 18. Bella Sky inclined precast building [8]

Today, the structural component represents only a small portion of the total building construction and maintenance costs. Mechanical and electrical (M&E) services can be seamlessly integrated into the construction system, providing significant benefits in terms of efficiency and functionality. An additional advantage of precast structures is that they can be specifically designed to meet the unique needs of the building's facilities.

Prefabrication offers several advantages in relation to M&E services. For example, the thermal mass of concrete is effectively used to store thermal energy in systems such as hollow core floors, leading to substantial savings in heating costs. However, despite these advancements, the construction industry as a whole continues to place a significant strain on the environment, contributing to energy demand, resource consumption, pollution, noise, and waste production.

Precast concrete is closely associated with the most advanced construction techniques, as well as with the most sustainable practices and processes. As we look to the future of construction, it is clear that industrialisation and prefabrication will play a crucial role in shaping more efficient and environmentally conscious building methods.

Precast concrete is linked to the most advanced techniques in construction and also to the most sustainable uses and processes. The future in construction will be intimately linked to industrialization and prefabrication.

The design of a building is no longer constrained by rigid concrete elements, and nearly every structure can be adapted to meet the specific requirements of the builder or architect. There is no inherent conflict between architectural elegance, variety, and increased efficiency. Gone are the days when industrialisation meant the production of large quantities of identical units. Instead, an efficient production process can be integrated with skilled craftsmanship, enabling modern architectural designs to be realised without additional costs.

Certain building types, particularly offices, often need to be adaptable to the changing needs of users. The optimal solution for this is to create open, free internal spaces without restrictions that would limit future partitioning or modifications.

Precast concrete offers many additional advantages beyond those mentioned above. In contemporary practice, excessive repetition of products or long design and manufacturing periods are no longer commonplace. Modern production techniques, including computer-aided manufacturing combined with Building Information Modelling (BIM), enable the flexibility and short delivery times that have become a key commercial advantage of prefabrication.

Precast concrete is closely associated with the most advanced construction techniques and is integral to the most sustainable practices and processes. As we look towards the future, the construction industry will be increasingly intertwined with industrialisation and prefabrication, shaping a more efficient and environmentally conscious approach to building.

The integration of building services into the overall building system is a significant advantage of precast concrete construction. One of the key benefits is that the precast structure can be specifically designed to accommodate the unique needs of building equipment. Elements can be pre-formed with a variety of holes and cast-in fixings, providing additional flexibility and convenience on site once the precast components are erected.

In the context of sustainable construction practices and environmental responsibility, Building Information Modelling (BIM) has become an essential tool for advancing low-carbon construction initiatives. BIM enables stakeholders to make informed decisions throughout the entire project lifecycle. By providing real-time access to accurate and detailed data, BIM facilitates the selection of materials, structural systems, and design alternatives that are not only energy-efficient but also environmentally friendly and sustainable. [37] This methodology supports more responsible and sustainable construction, helping to reduce the environmental footprint of building projects.

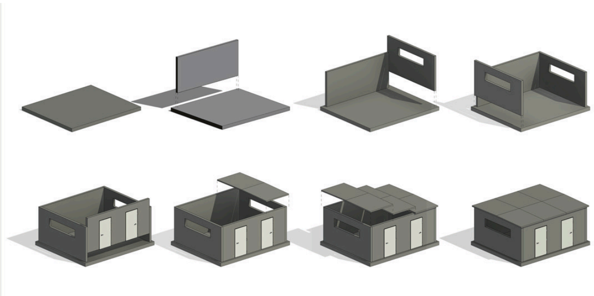

Figure 19. Precast control building. BIM model [37]

Figure 20. Precast control building. Construction. [37]

7 Conclusions

The main advantages of precast concrete include fast erection times, reduced material usage, high-quality concrete and other materials, long-span prestressed concrete floors, a controlled working environment, and overall project economy. However, there are some misunderstandings around the perceived lack of flexibility, the diversity of precast building systems, and the extended lead-in times required for a comprehensive study.

Precast concrete offers many more benefits than those listed above, and issues such as excessive product repetition or long design and manufacturing periods are no longer common in contemporary practice. Modern production techniques, including computer-aided manufacturing combined with Building Information Modelling (BIM), have enhanced its flexibility and short delivery times, making it a significant commercial advantage in prefabrication.

As a result, the latest generation of precast concrete buildings has evolved significantly over the past 30 years, leading to the creation of high-specification structures. Architectural and structural precast concrete elements are increasingly being used in prestigious commercial buildings, with materials such as steel, timber, plastics, and masonry being combined to optimise the overall building process.

Designers are becoming more aware of the high-quality finishes that can be achieved with prefabricated units, leading to changes in how traditional precast structures are conceived and designed. The construction industry now demands multi-functional designs, where the optimal use of all elements contributing to the building must be maximised. Precasting can no longer be overlooked in the initial study of buildings, whether for the entire structure or for specific components.

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