SURVEY OF PRECAST STRUCTURAL SYSTEMS

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Abstract

Architectural structural precast concrete components are being used on an increasing number of prestigious commercial buildings. Designers are becoming more aware of the high-quality finishes which are possible in prefabricated units, but changes have to be made in the way that the traditional precast concrete structures are conceived and designed.

Numerous proprietary and non-proprietary precast structural systems have been developed in the world in the last 30 years. This paper summarizes the essential elements of several precast structural systems suitable for office buildings, schools, healthcare facilities, parking garages, and multi-story residential and multi-story commercial structures.

Keywords: Precast concrete components, BSF-System, conventional system, Thomas System, IMS, system, Dycord system, etc.

INTRODUCTION

Precast concrete can be used in different kinds of structures, e.g. single-storey, multi-storey and high-rise buildings both in non-seismic and seismic areas. It is one of the possible answers to the frequently heard and steadily increasing criticisms such as building becomes uneconomical, there are no volunteers any more for the difficult, dangerous and dirty building work, or the building activity has to be automated.

Speed of construction is a major consideration in most building projects, and it is here that the design of precast structures should be carefully considered. The building design is increasingly becoming a multi-functional process where the optimum use of all the components forming the building must be maximized. This advantage is maximized if the layout and details are not too complex.

Designers are becoming more aware of the high-quality finishes which are possible in prefabricated units, but changes have to be made in the way that the traditional precast concrete structures are conceived and designed. The designers only have to be aware of these products and the basic design principles, i.e. how structural integrity using precast concrete can be achieved. The prefabrication has its own design approach and design principles which have to be respected to achieve the full profit that the prefabrication offers. A good design in precast concrete should therefore use details that are as simple as possible since it is in the simplicity of the details that the advantages of precast concrete are inherited.

The maximum economy of precast concrete construction is achieved when connection details are kept as simple as possible, consistent with adequate performance and ease of erection. Furthermore, complex connections are more difficult to design, make and control and will often result in poor fitting in the field.

One of the most important principles in the design of connections is to keep them simple. The main difference between cast in-situ and precast frames and skeletal structures lies on one hand in the general design philosophy and connections between components, and on the other in the possibilities for larger spans and smaller cross-sections of columns and beams. Skeletal construction is commonly used both in precast and cast-in-situ construction for low-rise and multi-storey buildings.

Utility buildings normally require a high degree of flexibility. Interior load-bearing walls are therefore avoided. A column-beam solution is normally preferred when an interior vertical load-bearing structure is needed.

There are several advantages to precast concrete construction. Precasting operations generally follow an industrial production procedure that takes place at a central precast plant. Thus, high concrete quality can be reliably obtained under a more controlled production environment. Since standard shapes are commonly produced in precasting concrete, the repetitive use of formwork permits the speedy production of precast concrete components at a lower unit cost. These forms and plant finishing procedures provide better surface quality than is usually obtained in field conditions. Precast concrete components may be erected much more rapidly than conventionally cast-in-place components, thereby reducing onsite construction time.

Precast concrete components can be designed as in situ forms for underwater construction so that the use of cofferdams may be eliminated or substantially limited. The precasting process is also sufficiently adaptable to produce special shapes economically.

Precast and prestressed concrete often has 28-day compressive strengths in the range of 28 to 55 MPa. Such concrete can be produced with a reasonable economy, provided proper care is taken in mixture proportioning and concreting operation. With proper use of water-reducing admixtures and pozzolanic materials, it is realistic and desirable to control the water-to-cementitious material ratio within the range of 0.35 to 0.43.

Precast Concrete Columns can be circular, square or rectangular. For structures of five storeys or less, each column will normally be continuous to the full height of the building. For structures greater than five storeys two or more columns are spliced together. Precast concrete columns may be single or double-storey height. The method of connection to the foundation and to the column above will vary with the manufacturer. Foundation connection may be via a base plate connected to the column or by reinforcing bars projecting from the end of the column passing into sleeves that are subsequently filled with grout. Alternatively, a column may be set into a preformed hole in a foundation block and grouted into position.

Column-column connections may be by threaded rods joined with an appropriate connector; with concrete subsequently cast around to the dimensions of the cross-section of the column. Alternatively, bars in grouted sleeves, as described above, may be used. This results in a thin stitch between columns while the previous approach requires a deeper stitch. Connections may be located between floors, at a point of contra-flexure, or at floor level.

Columns are provided with necessary supports for the ends of the precast beams (corbels or cast-in steel sections). There will also be some form of connection to provide beam-column moment connection and continuity. For interior columns, this may be by holes through which reinforcing bars pass from one beam to another. For edge columns, some form of bracket or socket is required. During an erection, columns must be braced until stability is achieved by making the necessary connections to the beams and slabs.

1. PRECAST STRUCTURAL SYSTEMS

1.1 U.S. Conventional System

U.S. Conventional precast concrete system for office structures in the United States consists of precast inverted T- beams, L-shaped spandrel beams, multi-story columns, and hollow-core slabs or double tees as floor members. The system generally uses cast-in-place concrete only for floor topping. Simple span members are generally employed, with connections resisting shear and not a moment.

1.2 Duotek System

The Duotek system was developed by the Ontario Precast Concrete Manufacturers Association and the Ontario Division of the Portland Cement Association. The system was designed specifically for office or institutional structures. The system consists of three precast concrete elements: columns, prestressed beams, and double tees, with cast-in-place connections between primary beams and columns. The system can be used for structures up to five stories in height (Stephen Pessiki,, Richard Prior., Richard Sause., Sarah Slaughter)

Roof spans can be up to 24.4 m. Three types of beams are used with this system. Type A is an inverted T-beam with horizontal openings of (711x356 mm) on a 1.52 m module. Type B, support tee slabs on one side and also include openings of (711x356 mm) on a 1.52 m module. Type C primary beams allow services to run over the beam and under the double tee floor slab (Sabah Shawkat., Richard Schlesinger 2021). The 1.22 m total floor depth is intended to accommodate the precast structural members, HVAC, plumbing, and electrical services, and ceiling and lighting systems (Fig. 1a, 1b).

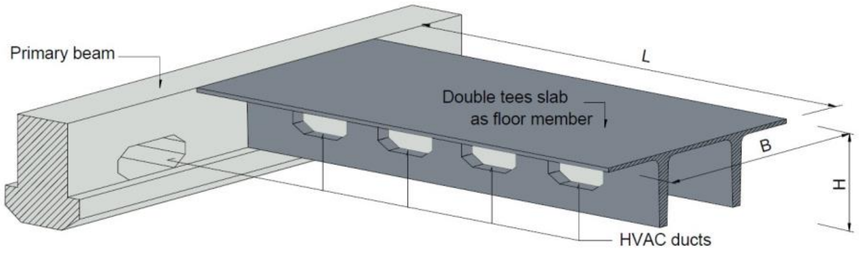


Fig. 1a. Inverted T-beam (Type A).

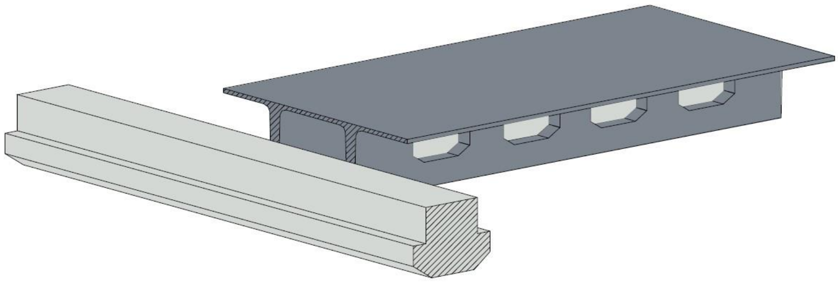


Fig. 1b. Partial Inverted T-beam (Type C).

1.3 Dycore System

The Dycore system has been used for office buildings, schools, healthcare facilities, and parking garages. Connections are composed of cast-in-place concrete. Columns may be cast-in-place or precast with multi-story precast columns containing block-out cavities at the beam level to facilitate beam-to-column connections. Prior to placement of the cast-in-place concrete, negative moment beam reinforcement is tied to the precast soffit beam and to the column reinforcement. HVAC ducts, plumbing components, and electrical system conduits can be placed on the precast soffit and embedded in the composite cast-in-place concrete (Sabah Shawkat., Richard Schlesinger 2021)

Similarly, voids in Dycore slabs can be used to house electrical conduits and plumbing components (Fig. 2).

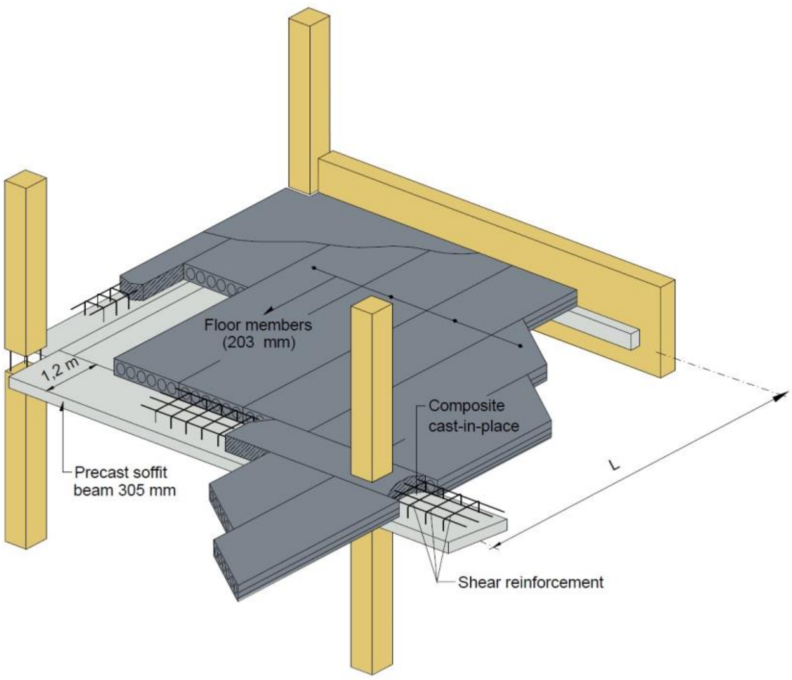


Fig. 2. Composite Dycore Structural System.

1.4 Dyna-Frame System

The Dyna-Frame system is typically used in multi-story residential structures, office buildings, parking garages, and schools. The key to this system is the column-to-column splice and the column-to-beam splice. The single-story precast columns are pre-tensioned and reinforced with a structural steel tube running longitudinally in the centre of the column that is used in the splice made at each floor. The tube or column core does not protrude from either end of the column. The inside diameter of the column core is held constant at 100 mm (Fig. 3) (Prior, R. C., Pessiki, S., Sause, R., Slaughter, S., van Zyverden, W).

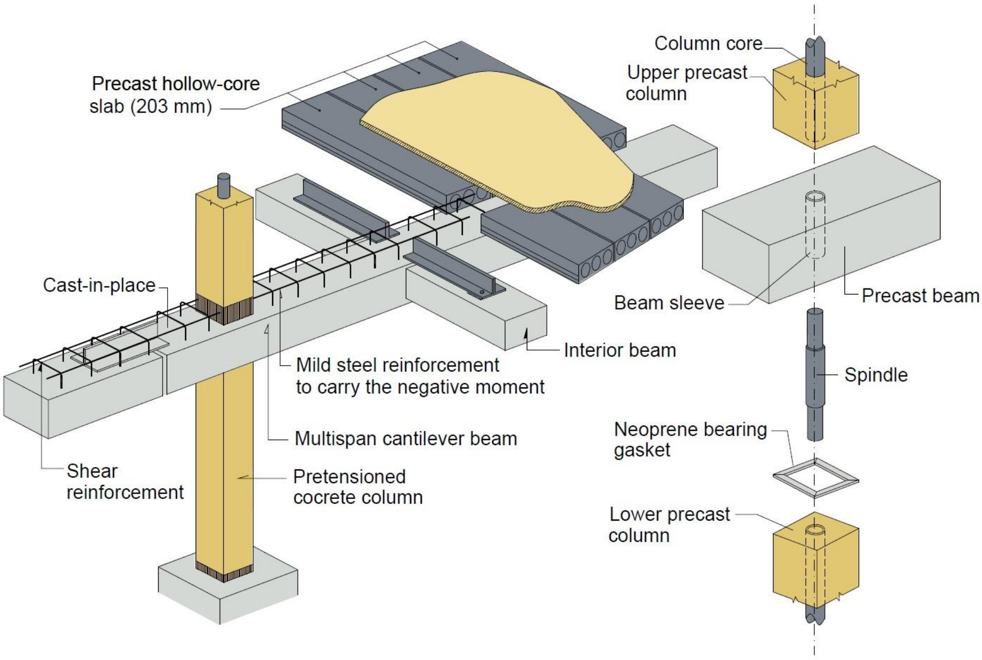


Fig. 3. Dyna-Frame System (Structural components and the detail showing column-to-beam connection).

1.5 Filigree Wideslab System

The Filigree wide slab system was originally developed in Great Britain and is presently used there under the name of OMNIDEC. This method of construction is used throughout the United States and is also used widely in Japan. Though often used for parking garages, the system has been used in residential construction, office buildings, and other multi-story commercial structures. Electrical services can be placed within the cast-in-place portion of the floor system. HVAC system components are suspended beneath the precast floor components and passed vertically through performed block-outs in the floor members (Fig. 4) (Stephen Pessiki,, Ricard Prior., Richard Sause., Sarah Slaughter).

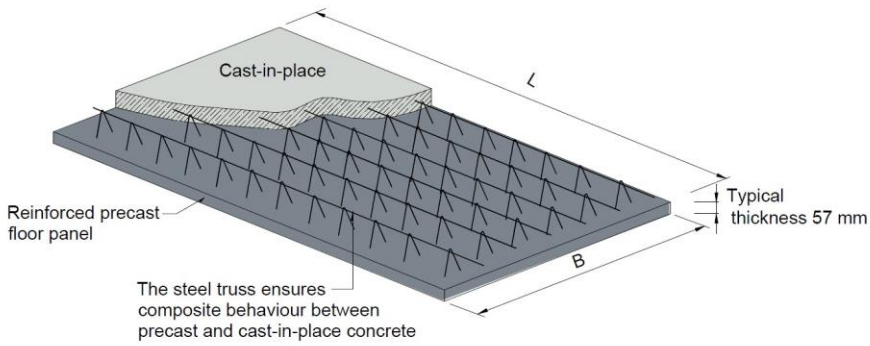


Fig. 4. Filigree precast slab with light steel truss.

1.6 PG Connection System

This system is an example of precast concrete construction in Japan today. The PG Connection system, developed by the Obayashi Corporation Technical Research Institute, employs precast cruciform beam components that are placed at column locations. The precast cruciform component is placed over the column, and beam-to-beam connections are made by welding or mechanical splices (Fig. 5) (Sabah Shawkat., Richard Schlesinger 2021).

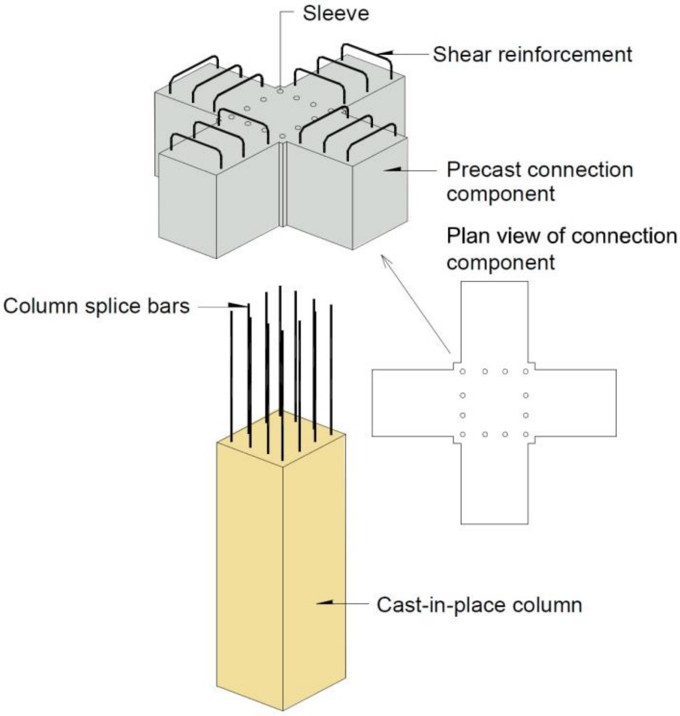


Fig. 5. PG Connection System –cross-shaped beam-to-column component.

1.7 RC Layered Construction System

This structural system, developed by the Taisei Corporation, consists of single-span members connected with cast-in-place concrete. Components of the system include precast single-story columns, precast beams, and Filigree type slabs. Single-story columns are cast with reinforcing bars protruding from their upper face for the column-to-column connections. Single-span beams rest on the precast columns.

Once the precast slabs are positioned, negative moment reinforcing steel is placed longitudinally along the top of the beam and through the beam-to-column connection zone. Two-way reinforcement is placed on the precast floor slab. The concrete structural topping is placed over the entire floor system, resulting in monolithic connections. Construction of subsequent stories begins with precast columns being slipped over the protruding reinforcing bars from the lower column. The connection is then grouted (Sabah Shawkat., Richard Schlesinger 2021).

1.8 RPC-K System

The RPC-K system, developed by Kabuki Construction Company, utilizes U-shaped precast beams that serve as stay-in-place forms for cast-in-place concrete. Other components of the system include cast-in-place columns and Filigree-type floor members (Sabah Shawkat., Richard Schlesinger 2021).

Cast-in-place concrete is used for all connections between components. Longitudinal and shear reinforcement is embedded in the precast portion of the beam. The longitudinal reinforcement protruding from the precast portion is bent upward into the column to provide anchorage. Additional longitudinal reinforcement is placed in the trough of the beam once the beam is in place (Sabah Shawkat., Richard Schlesinger 2021).

To facilitate the column-to-column connection, the main reinforcement from cast-in-place lower columns protrudes upward to tie in the cast-in-place upper column. Filigree-type slabs rest on the precast beams and reinforcement is placed across the trough of the beam to tie the components together. Negative moment reinforcing steel is placed both longitudinally and transversely on the precast slab and then embedded with cast-in-place concrete (Fig. 6).

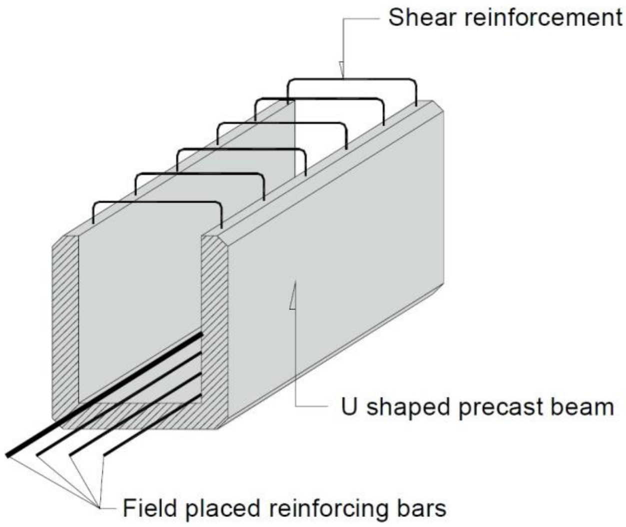
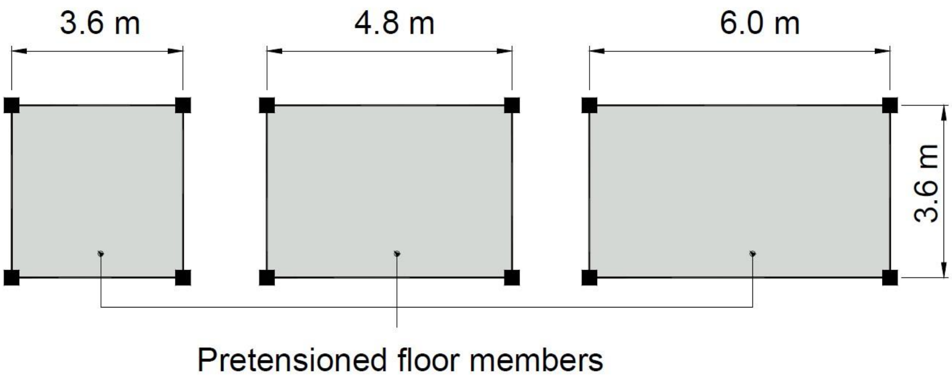


Fig. 6. RPC-K System – U-shaped precast shell beam.

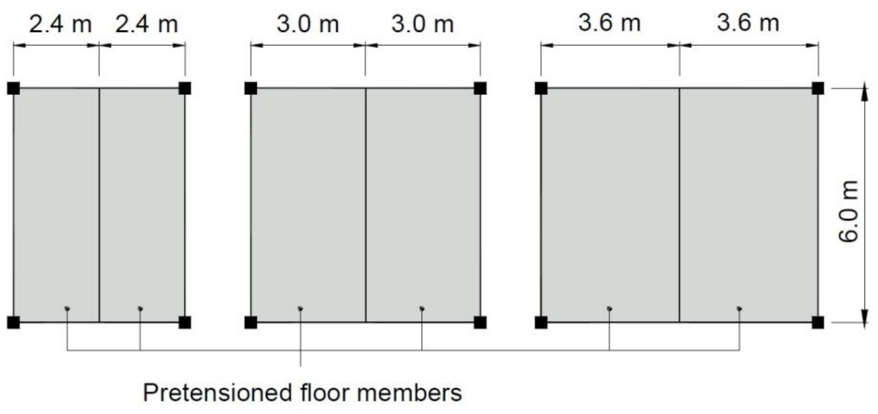
1.9 IMS System

The IMS system, also known as the IMS-ZEZELJ system, originated in Serbia, Yugoslavia, at the Institute for Testing of Materials. Because the system can be designed for seismic forces, it has gained acceptance in regions with frequent seismic activity. The State Building Co. of Baranya County, Hungary, further developed the system for longer spans and for greater flexibility in accommodating utilities. The system has been used in Cuba, Hungary, and Yugoslavia for schools, hospitals, administrative buildings, offices, and hotels (Stephen Pessiki,, Ricard Prior., Richard Sause., Sarah Slaughter).

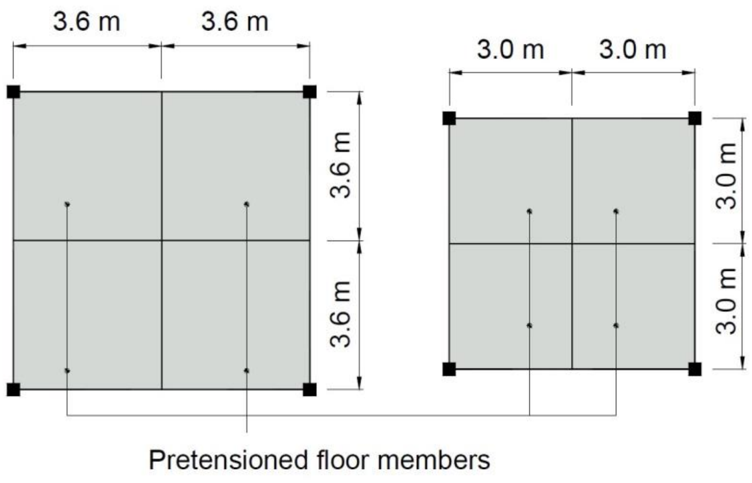
The IMS system relies on friction and clamping action produced by post-tensioning to transfer vertical loads and bending moments from floor units and edge beams to the column. The post-tensioning runs in the floor system and through the columns in both principal directions. (Fig. 7, 8).



a) Single-unit systems



b) Two-unit systems



c) Four-unit systems

Fig. 7. Modular composition possibilities for the IMS system.

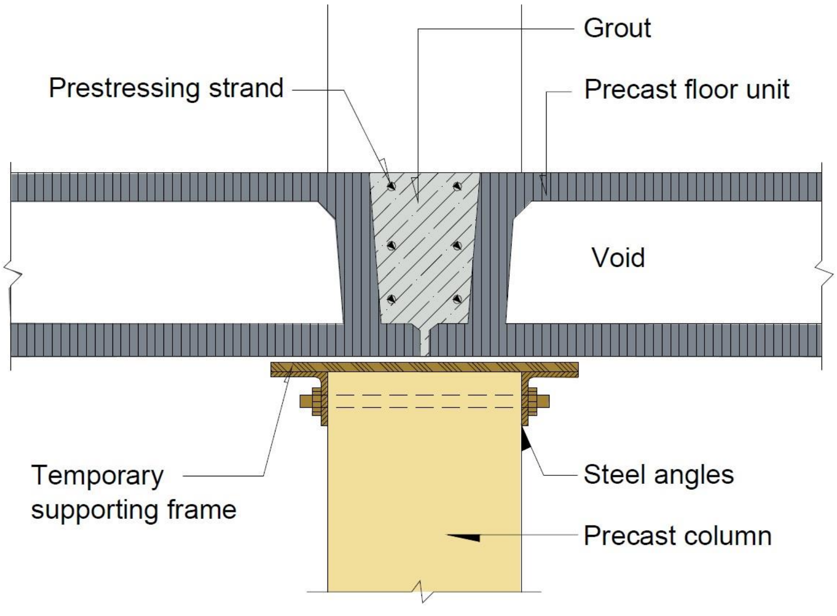


Fig. 8. IMS System-Joint between floor units and column during construction.

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The structurapid system was first used in Italy for residential and commercial buildings. The system is comprised of precast column tubes and T-beams. The columns and beams are connected by means of a tongue and groove system of joining. Reinforcing steel is placed on the precast T-beam and bent down into the hollow column core (Stephen Pessiki, Ricard Prior., Richard Sause., Sarah Slaughter).

With the placement of cast-in-place concrete in the column cavity, a monolithic beam-to-column and column-to-column joined is developed. Hollow-core floor members rest on the beam flange. Shear reinforcement protrudes from the top of the beam to achieve continuity with the floor members. Cast-in-place concrete is used as a floor topping to provide a rigid floor diaphragm (Fig. 9) (Sabah Shawkat., Richard Schlesinger 2021):

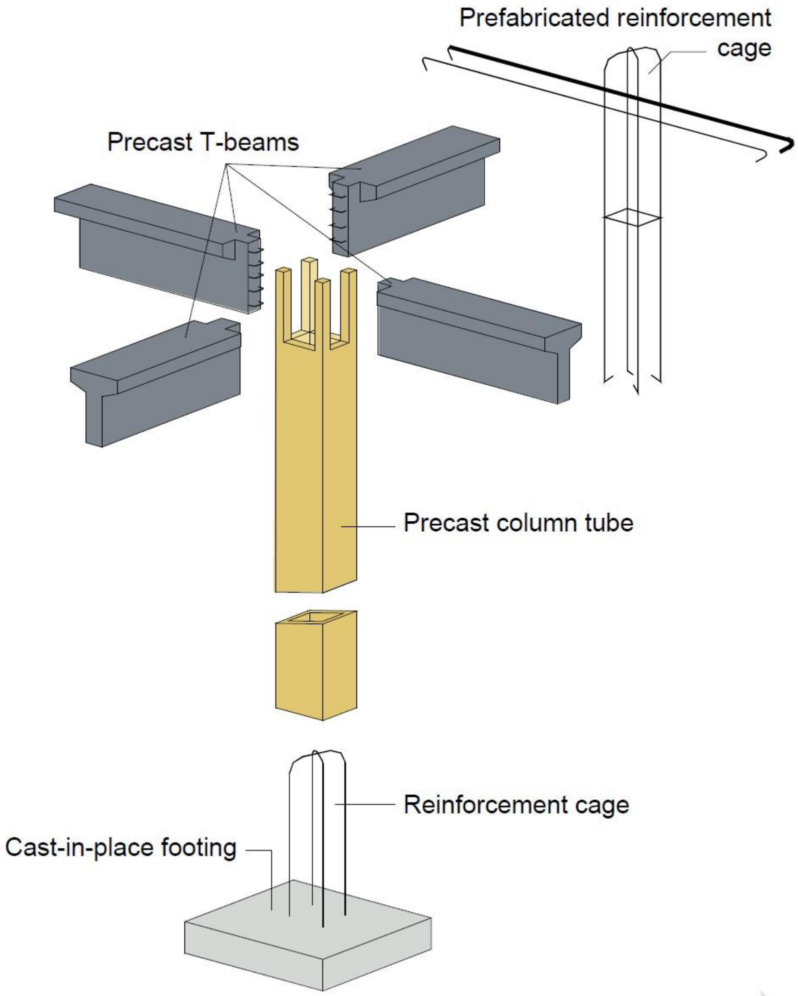

Fig. 9. Structurapid System- footing-to-column and beam-to-column connection.

1.10 Thomas System

The Thomas system is comprised of multi-story precast columns, composite shell beams, and precast double tee floor members. This system has been used in the mid-western United States for multi-story office building construction. The key structural component of the system is the shell beam, the beam flanges support the stems of the double tees, and the beam is supported by precast column corbels. The pretension single-span shell beams also serve as forms for cast-in-place concrete (Fig. 10) (Sabah Shawkat., Richard Schlesinger 2021):

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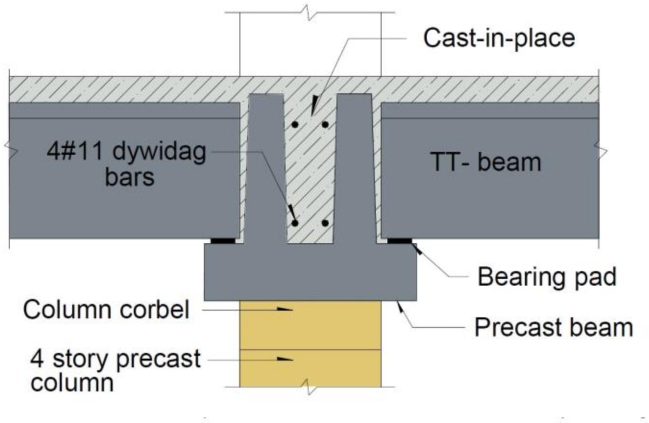

Fig. 10. Thomas system-cross section of precast beam.

1.11 BSF-System

The development of the hidden corbel system is called the BSF-System. Corbels are a necessity in all construction work. In steel structures, corbels are usually made of small brackets and do not represent much of a nuisance. For concrete construction, however, corbels tend to have rather large and bulky details, which are not very popular among architects. In office buildings, hospitals, schools etc. they may obstruct windows or block the passage of ventilation ducts. In industrial buildings, they can obstruct the passage of the roof drains or be in the way of overhead cranes. Another disadvantage of concrete corbels is that they are often rather difficult to manufacture, with much reinforcement of a complicated shape.

The ideal connection detail will have to fulfil the following minimum requirements.

(Sabah Shawkat., Richard Schlesinger 2021):

- not visible
- easily protected against faire
- minimum amount of work at the site
- uncomplicated to use, both in production and during erection
- no protruding parts.
- must function within normal tolerances at a building site.

Based on these requirements Partek set about the task of finding a solution to this challenge. Central in the process was Mr BjØrn Thoresen of Partek Østspenn A.S., and his creativity led to the basic concept behind the system, the sliding knife. This allows for deviations at the site, movement due to temperature and shrinkage, and eliminates protruding parts (Fig.11) (Sabah Shawkat., Richard Schlesinger 2021):

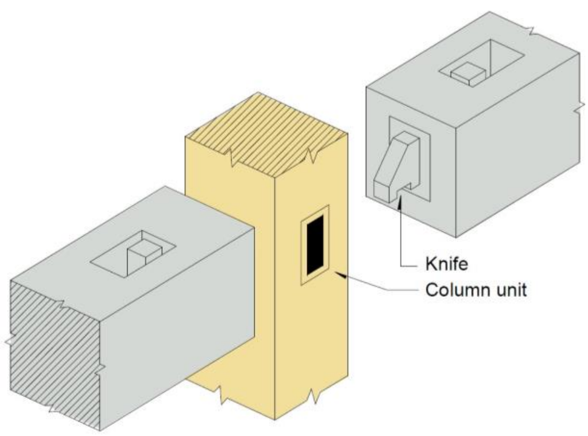

Fig. 11. BSF-System – corbel system.

This contribution has presented a view of the several precast structural floor systems that are suitable for building construction. Precast concrete floors can be used in different kinds of structures, e.g. single-storey, multi-storey and high-rise buildings both in non-seismic and seismic areas. Whether the resulting building is stylish or dull depends only on planning and design and the capability of designers.

2. SHOPPING VILLAGE- REALIZATION PROJECT

The proposed new construction of the prefabricated hall will serve as a shopping center SHOPPING VILLAGE in Liptovský Mikuláš. Buildings SO 301, SO 302, SO 303, and SO 304 are designed as single-storey buildings. Object SO 306 consists of small architecture, an engine room and a fountain. Objects SO 301, SO 302, SO 303 and SO 304 together form a U-shape.

The hall consists of a lower and an upper structure.

Design of the solution of the lower structure - the foundation of the building is designed on reinforced concrete footings. The dimensions of the foundations and the detailed method of foundation will be indicated in the drawing documentation, part of the statics.

The load-bearing structural systems of the upper part of the indoor building consist of vertical and horizontal load-bearing elements.

The vertical supporting elements consist of peripheral and central reinforced concrete columns of dimensions 500 mm x 500 mm and steel intermediate columns HE120B. Perimeter columns are placed in the longitudinal direction at mutual distances of 12000 mm x 9500 mm for SO 301, 12000 mm x 9500 mm for SO 302, 12000 mm x 9750 mm for SO 303- and 9000-mm x 9000 mm for SO 304. Columns in the longitudinal direction are placed at mutual distances of 9000 mm and in the transverse direction at distances of 9000 mm. The perimeter walls are prefabricated from Kingspan PUR panels.

The horizontal load-bearing elements consist of full-wall I-shaped trusses with a height of 1200 mm, on which T-shaped trusses with a thickness of 800 mm are laid, placed at a slope of 3%. The mutual position of the girders and girders creates an installation space under the roof covering up to a height of 345 mm.

The supporting structure of the insulation and covering is made of trapezoidal sheets. The plate’s strength and the wave’s height are determined based on a static calculation. In the two-story part of the building, the ceiling is designed from prefabricated SPIROL panels with a thickness of 300 mm.

The foundations of the fire tank and engine room are designed as a 300 mm thick reinforced concrete slab. The machine room walls have a suggested thickness of 200 mm.

The construction of fountain has foundations designed from reinforced concrete 200 mm thick and walls also made from reinforced concrete 300 mm thick.

The entire construction of the roof of the passage is designed from wood. The main supporting elements will be trussing beams with a span of 12 m and a height of 1.2 m placed at distances of 4.75 m.

The load-bearing structures of the projected object - the SHOPPING VILLAGE shopping center in Liptovský Mikuláš, consisting of objects SO 301, SO 302, SO 303, SO 304 and SO 306, respect the architectural layout solution and the requirements of professional professions and ensure the static safety and reliability of the object.

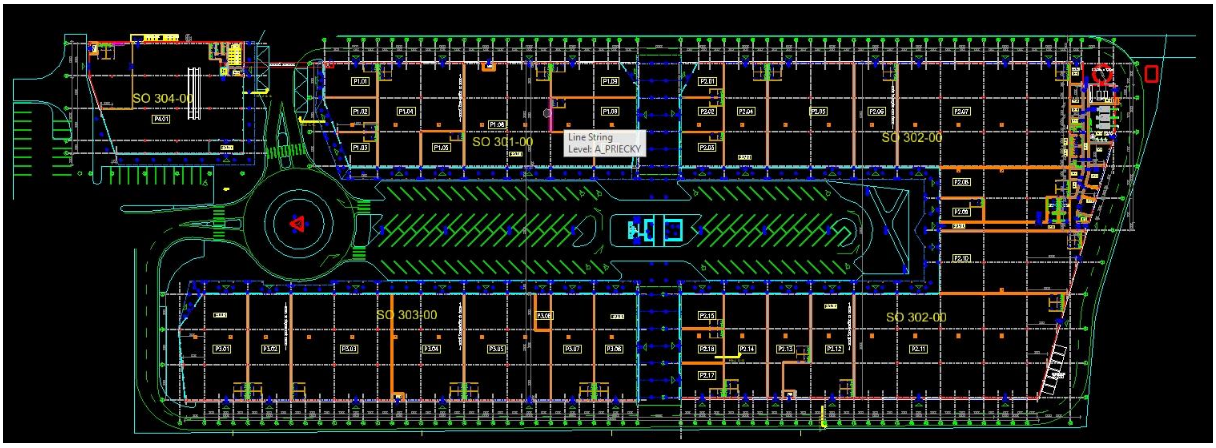

Fig. 2.1. Situation-Business center shopping village (Shawkat 2019)

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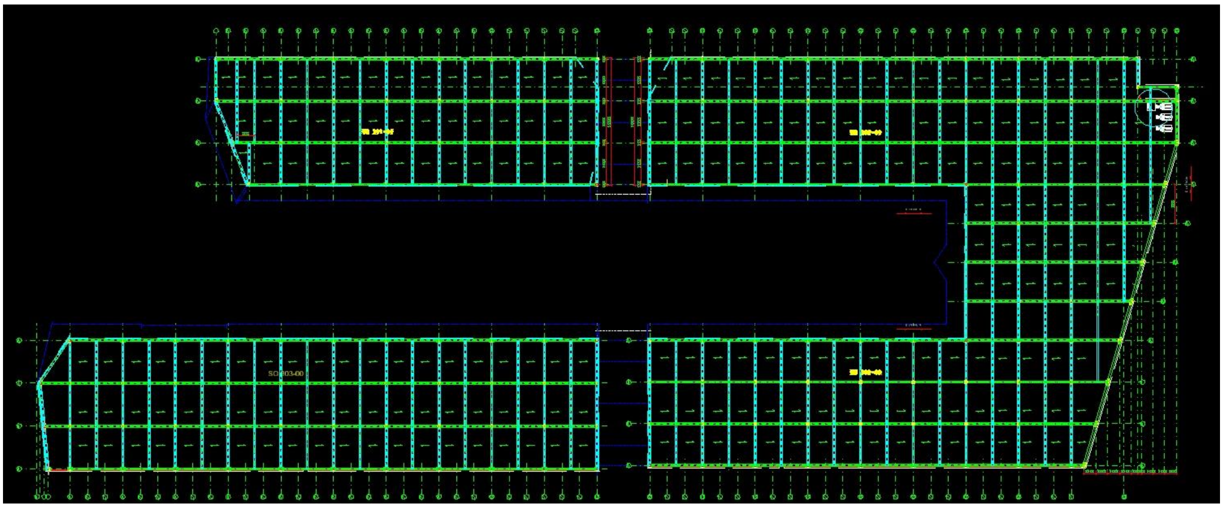

Fig. 2.2. Structural precast system-Business center shopping village (Shawkat 2019)

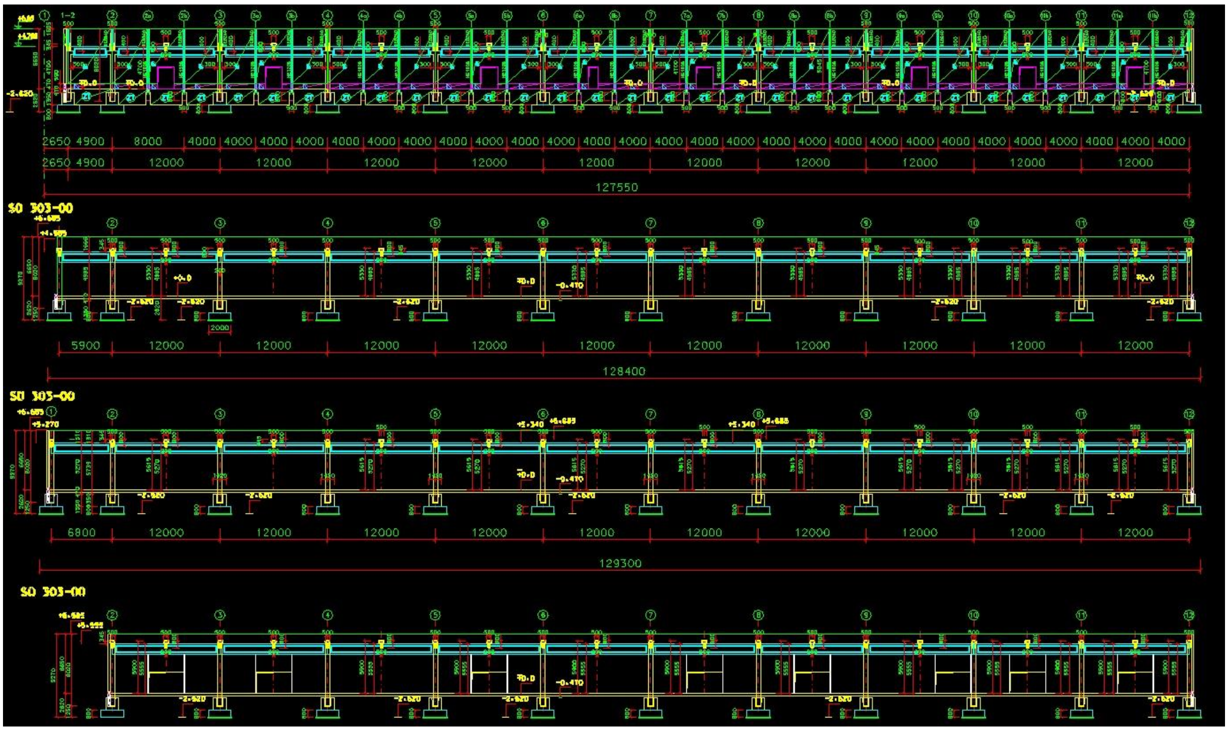

Fig. 2.3. Reinforced prestress precast frames-Business center shopping village (Shawkat 2019)

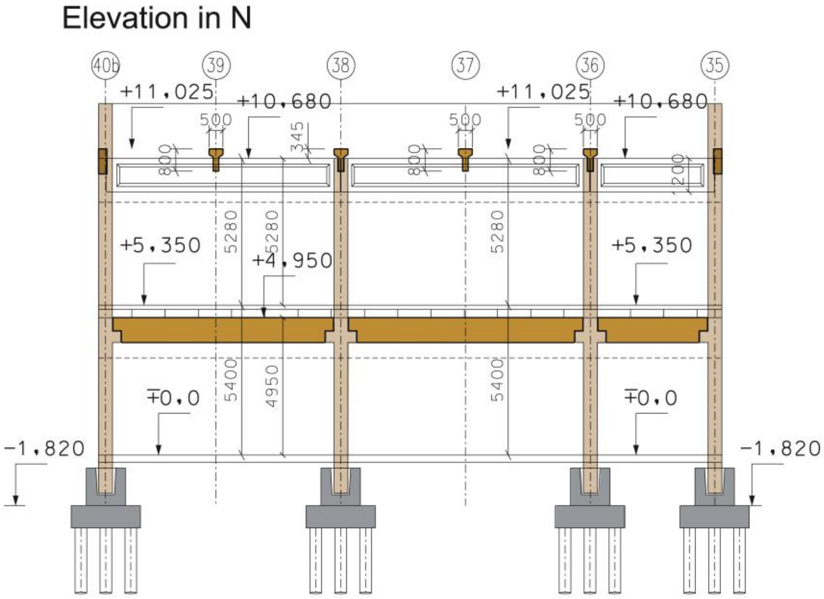

Fig. 2.4. Elevation-Business center shopping village (Shawkat 2019)

3. MINIMUM REINFORCEMENT FOR P/C BEAM, PLATE, AND SHELL ELEMENTS

For precast concrete members, the minimum reinforcing steel area shall be the largest value of the following requirements:

1. For rectangular flexural elements, the minimum reinforcement area shall not be less than A_s given by

$$A_s = \frac{\sqrt{f'_c}}{4 \cdot f_y} \cdot b \cdot d$$

and not less than $1.4bd/f_y$.

Where:

f'_c and f_y = specified compressive strength of concrete (in MPa) and specified yield strength of reinforcement (in MPa), respectively

b and d = width and effective depth of the rectangular elements

2. For slab/wall panel elements, the minimum reinforcement ratio ρ_{min}=0.004 with one-half on each face in each direction. In addition, if a precast concrete panel will bond to cast-in-place concrete as a composite member in the final structure, the minimum reinforcement steel area shall be 0.0028 times the gross cross-sectional area of the composite member.

3. For flat slab in which computed tensile stress in concrete at service load exceeds (1/6) f 'c, reinforcing steel shall not be less than A_s calculated as follows:

$$A_s = \frac{N_c}{0.5 \cdot f_y}$$

where N_c is tension force due to unfactored dead plus live load and f_y shall not exceed 420 MPa.

4. If tensile stress occurs on one face of a P/C member during construction, transportation, or in service, the minimum steel area on the tensile face of the member shall not be less than A_s

$$A_s = \frac{f_t}{f_y} \cdot b \cdot d_e$$

Where

f_t = tensile strength of concrete

d_e = effective tension zone, to be taken as $1.5c+10d_b$

c = concrete cover over reinforcement

d_b = diameter of reinforcement

2.1 The permissible ratio of effective span to effective depth for simplified analysis of deflection limit

-Precast hollow core slab: d = span / 37.5

-Precast pre-stressed Double-T beams: d = span / 25

-Precast pre-stressed planks(slab): d = span / 40

-Precast floor and wall panel system: d = span / 23.5

-Precast beams and columns with precast floor units: d = span / 15

-Single-storey precast frames: d = span / 26

-Precast column – single storey: d = height / 22.5

-Precast column – multi-storey: d = height / 13

-Precast loadbearing panel: d = span / 22.5

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