

**BMSK - BELGRADE**

**PRECAST PRESTRESSED CONCRETE SKELETON IN CONTEMPORARY BUILDING -  
IMS SYSTEM**

**text:**

**Radovan Dimitrijevic, M.Sc., civil eng.  
Branka Gavrilovic, arch.**

**design:**

**Aleksandar Stolic, arch.**

**Belgrade 2000**

**CONTENTS**

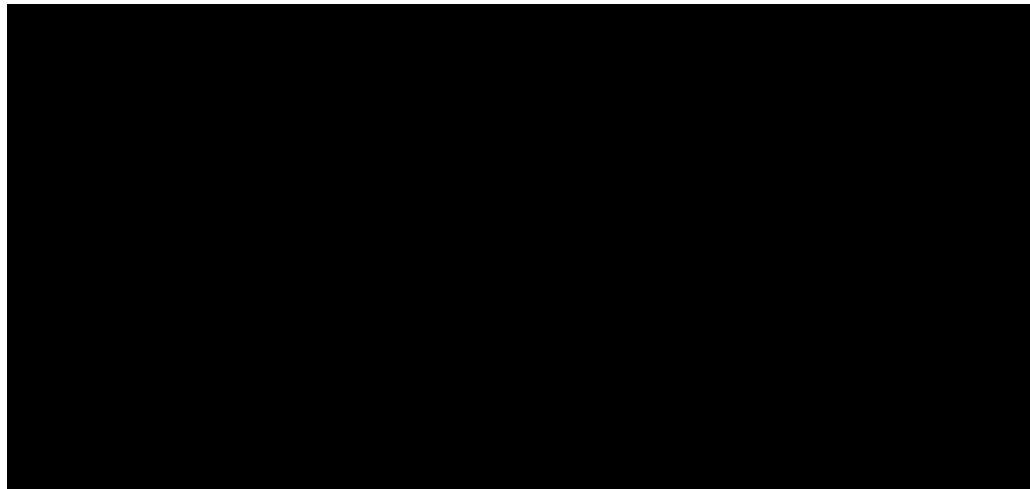
Introduction.....	1
Construction Technology Characteristics in Buildings.....	2
Contemporary Housing Requirements – Building Performances .....	3
Choice Criteria for Building, Structural System, Material, Element and Joint Technology .....	4
IMS Building Technology .....	8
IMS System Characteristics and Architectural Design.....	10
IMS Building Technology and Technologic/Constructional Requirements .....	15
References.....	25

## **PRECAST PRESTRESSED CONCRETE SKELETON IN CONTEMPORARY BUILDING - IMS SYSTEM**

### **Introduction**

Civil engineering and building, one of the eldest and most conservative human activities, seems to be faced with the challenge of industrial production, whose basic principle is serial production of standard elements. Because of numerous objective factors – urban, architectural, humanistic, aesthetic, functional, those simple principles in building are not easy to be applied. Housing fund deficit in many countries, especially in cities, establishes demands for building apartments of certain quality. Classic trade building way cannot accomplish efficient project realisation of greater scope within housing field. In those situations industrial production application is unavoidable, but only considering standard element production of a building, not standard type of house. Elements are made of various materials – wood, steel, bricks, concrete, plastic materials, which can be bought on market or produced in special factory section according to definite projects. Sections aimed for building elements production requires certain investments proportionate to section capacity and to the desired building speed. Section capacity defining factor is the economic rationality and completed building price – apartment house.

Basing on present practice experiences, positive and negative, it is possible to choose an optimal construction way for given local conditions, to organise needed sections and to resolve a social problem – building necessary number of suitable quality apartments within the required period.



**Housing settlement Cerak – Belgrade**

### Construction Technology Characteristics in Buildings

Building construction technology can be classified as following:

- **Traditional constructing** – masonry and concrete works “in situ”.
- **Advanced traditional constructing** – use of portable, sliding, space-tunnel and other forms aimed for concrete work in-situ, incorporating concrete and brick semi-prefabricates of less dimension and weight.
- **Industrialised constructing** introduces a serial production principle of standardised building parts – structure, accompanied by the classic constructing use of other building elements.
- **Industrial constructing** – total prefabrication followed by the aspiration for serial production of all building elements as standardised.

*Traditional constructing* requests significant labour capacity for the realisation of almost each building type. The building process is long lasting; trade methods are applied, without complete division of labour; machinery is not in use; all operations are realised at the site, such as processing of forms, reinforcing, plaster, concrete. Small dimensioned concrete and brick elements are used for constructing. Finishing and installation works are processed in a trade way, without any more significant parallel process, accompanied by repeated working up of finally processed building parts accomplished after trade works.

*Advanced traditional constructing* shortens the building period by the use of simple equipment and half-prefabricates employing trade constructing way and lesser plant investment. Advancing refers to concrete preparation in constant sections and delivered at the site by truck mixers, to already-made reinforced assemblies brought at the site and then incorporated and to special forms, as well, aimed for complex use, concrete incorporation plant – form or poker vibrator, small dimensioned elements – lintels, ceiling slab stems, staircase, installation assemblies of water supply and drainage, windows, doors; wall, floor and ceiling covering.



Clinical Centre – Nis

*Industrialised constructing* combines industrial principles – labour division and serial production of elements (the most usual structure prefabrication) – followed by advanced trade constructing ways for the buildings parts, where standardisation and prefabrication are not rational or offer rigid and non-functional architectural solutions (different form types for repeated use – portable, sliding or tunnel are applied). Serial production of selected standard elements, organisation and parallel activities concerning production and prefabrication process, abbreviate the constructing period, use material and labour rationally, controls work and element quality but requires significant investment in equipment, transport and erection facilities for larger and heavier elements or adequate forms.

*Industrial constructing – prefabrication* – absolutely respects the division of labour principle and a serial element production of the whole building. Elements are, as a rule, multi-functional, so that they contain, for example, installations, incorporated windows, doors or ceramics. Several various materials are used in section, which makes the production technology complex.

Prefabrication requires significant investment for section organisation, production equipment, transport and assemblage and labour specialisation, as well. Because of numerous different elements, rationality can be reached only with large series. In order to avoid the final product/building uniformity, one approaches to finishing touches and changes of the equipment, followed by an extra investment. Considering that the final product is a standard type building, it is hard to satisfy users' demands in relation with urban/architectural and aesthetic building or settlement performances, because variety according to demands of individual users is hardly provided.

*Prefabrication characteristics* can be defined such as:

- Better work conditions in factory sections, continuous work, independent from climate and season conditions over the year;
- Introduction of the equipment and machinery, which reduces physical labour;
- Serial production of standard elements;
- Better material utilisation, better quality and quality control;
- Reduced construction period, because building activities are partly accompanied with installation and finishing activities;
- Large investing in factory sections, which requires huge series of elements;
- Raising of transport expenses;
- Inconvenient element joints – key parameter for stability and functionality of the realised building, practice points out mostly objections about joints
- Real danger from building uniformity, from urban/architectural monotony, in case of a building as standard product.

*Note:*

*Optimal results in modern constructing are reached by regular estimate of element prefabrication level of a building, by estimate of economic rationality of series, relevant for building performance quality and for satisfying future users' requests, as well. According to this, previous investments in production section get lower, while necessary assortment of building elements is completed from the market. The mentioned utilisation way of element prefabrication is called "open prefabrication". According to contemporary tendencies in building, especially in housing, **open prefabrication** is considered as one of several acceptable ways aimed for project realisation of a wider scope.*

### **Contemporary Housing Requirements – Building Performances**

The quantity problem of newly built apartments is narrowly linked to financial possibilities and building performances, more exactly to future users' demands.

*Building performances* can be defined as following:

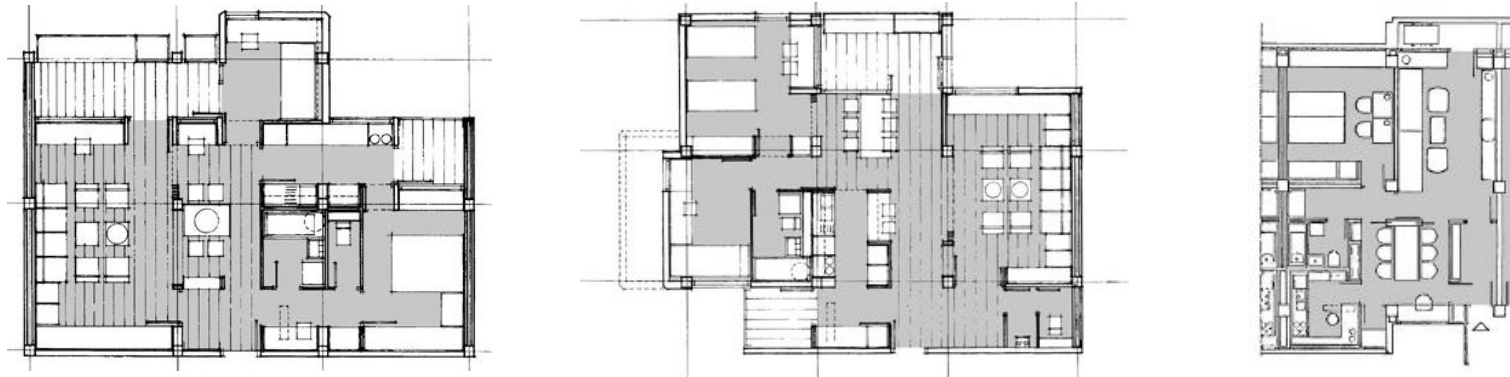
- Stability under static, dynamic, seismic, fire loads.
- Building functionality followed by appropriate comfort and architectural, urban, aesthetic and other requests.
- Preservation function – physical, thermal, acoustic, fire protection, protection from atmospheric influences, environment and identity protection, as well.

- Power savings during the construction process and premises exploitation.
- Financially acceptable price for the appropriate standard and minimally established building qualities.
- As an absolute priority request, stability is provided by the system choice of the building construction. Load acceptance and transferring form a construction system or a structural system.

**Structural systems** are classified according to load bearing elements:

- Linear girder system – columns, beams (frame system)
- Surface girder systems – bearing walls, slabs (cross and longitudinal bearing walls);
- Space girder systems – box units;
- Mixed systems – combination of linear and space girders – columns, beams, walls and slabs.

Structural system realisation is achieved by construction technologies.



Examples of apartments in IMS system

### **Choice Criteria for Building, Structural System, Material, Element and Joint Technology**

Large scope and efficient project realisation from the housing field comprises industrialised building system application. Many countries' experience confirms it, developing or developed ones, which resolved or are resolving the housing deficit problem. The most favourable results are accomplished by standardised building elements for the construction of non-standardised spatial building solutions. This is the basic criterion for the construction mode choice with the starting assumption for industrial efficiency achievement (speed, quality, price) and the possibility of getting the authentic housing quality for the definite environment and user (architectural space design, individual needs and possibilities of each participant of a building house process).

At the choice of a building system technical/technological characteristics are considered, as well as resulting financial effects, then characteristics relevant for urban and architectural design, as well as specific demands caused by the location (earthquake, storm winds, development state of a local building practice etc.). Without information relevant for definite location, only previous appraisal of the system privilege can be obtained. Final decision follows checking on architectural solution of a building definite example, as a housing quality and conditions representative, which should be realised through its materialisation.



**Frame systems** have privilege at the structural system choice because of the lowest limitations for architectural design. Those systems enable flexibility and varying of architectural-urban solutions, minimal material structure consumption, and easy prefabrication. Weight and volume can be adapted to means of transportation. Building structure requires a material, which successfully captures all kinds of loads, then concrete imposes itself as optimal, because wood and steel are sensitive at fire.

Other building elements are defined in accordance with basic dedicated functions. Frame closing is possible by non-payload-bearing elements and can be made of material possessing more favourable characteristics for thermal and acoustic protection. Frame in-filling is possible on traditional mode using available materials and labour, such as in-filling of prefabricated elements, for example: for facade and partition walls, sanitary panels or cabins – if they are present at the market or if it is financially justified to produce them in a factory section.

**Economy** is a valuable factor for the building choice technology and depends on local resources, available materials and labour, inter-relation of material prices and labour, assignment overall and execution period. Cheap labour defines technology. Relatively high price of labour requires decision about the use of larger machinery level and about the shortage of labour participation. Investment in machinery and defining of optimal section capacity per year shorten a construction period.

At the comparison of different modes and building systems economy, works that essentially differ one from another are taken into consideration, while works executed in similar way do not influence the comparison. Prefabrication requires defining of structural system elements and joints, as well. Elements are standardised by weight, material, volume, available cranes, means of transportation and public traffic conditions. Joints are essential for stability and functionality during exploitation; they depend on material and load types at the connection spot. Setting concrete on anchors in a joint – wet procedure connects concrete elements, by welding steel anchors of a joint, by prestressing – dry procedure.

*Note:*

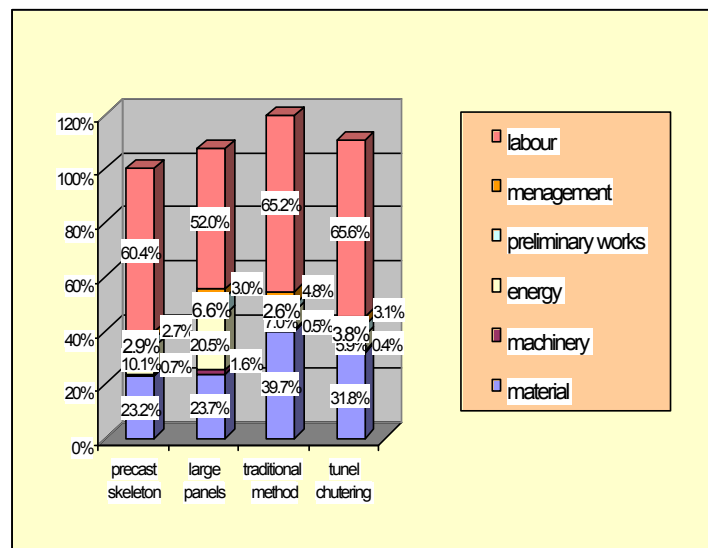
*Some prefabricated systems are not in use anymore because they show themselves as inadequate (box units systems, large panels) because of architectural-urban non-flexibility, joint function permanence lead by the activity of atmospheric or other influences. Today, total prefabrication in practice is not in use.*



**Economy analysis of building technology**

Comparative analysis of the building economy, without all relevant data of the location where it will be applied, can be significant only for preliminary decisions.

Analysis results are made for the most applied systems in Yugoslavia.



Analysis refers to:

- Traditional classic building system,
- Tunnel form system
- Large panel system
- Prefabricated prestressed concrete skeleton.

*Observed object:* Identical-housing buildings not especially designed in accord with the mentioned building system.

*Data source:* System owner statements and statements of independent experts – authors of the analysis.

*Analysed data and isolated results:*

- Market price of building material (skeleton, large panel, significantly more inconvenient tunnel form and classic building system)
- Labour price (large panel, skeleton, tunnel form, classic)
- Machinery and section power price (tunnel, classic, skeleton, panel)
- Preliminary work price (classic, skeleton, tunnel, panel)
- Management-expert service price (classic, skeleton, panel, tunnel form)
- **Total price of a building (skeleton, large-panel, tunnel form, classic)**

Diagram: **Comparative analysis of different construction type expenses**

*Note:*

System order presents an advantage expressed through the lowest expenses. Prices are variable, they depends on market; expenses are obtained through the bill of quantities, material and labour quantities for each building system. System order in relation with costs does not represent crucial and sufficient data for the final decision. Beside price, choice is influenced, as well, by the chosen system adaptation to local conditions and demands. It is based on architectural requirements and solutions, in other words, on solution assortment for definite site conditions.





Examples of constructed buildings

In Yugoslavia and many other countries, where precast prestressed skeleton is used, savings linked with structure and foundations are at least 30% in relation with the most favourable second-placed building type. Savings are the result of the prefabrication level degree (structure only – as minimal prefabrication level – or even other building elements) and the use of classic building way wherever economical it is. The system characteristic is that the bill of material and work quantities for the structure and foundations offers the lowest material and labour consumption and depending on country development and inter-relation of material and labour price and investment in machinery, might offer an optimal solution for the costs.



**Catalogue solutions of individual housing buildings**

### **IMS BUILDING TECHNOLOGY**

Modern tendencies in the field of mass construction are marked with changes within the field of architecture. Building of standard housing buildings under laws of rigid technologic functionalism, where form is conditioned by the production process, is considered today as exceeded. New trend and contemporary needs in housing caused building design and construction, where form and architectural characteristics are oriented to the user and the environment. Precast prestressed skeleton building technology, based on it, satisfy those requirements concerning modern building field and contain the following:

- **Structural system** – prefabricated skeleton made of columns, beams, floor slabs, staircases and stiffening walls – IMS frame system.



**Prefabricated skeleton**

- **Production mode** of IMS skeleton system elements.



**Element production**

- **Connecting mode** of IMS skeleton system – prestressing.



**Connecting of elements**

The IMS system is especially significant for architectural design – skeleton prestressed reinforced concrete structure encompasses:

- **Basic – standard reinforced concrete elements** (columns, floor slabs, beams, stiffening walls, and stairs) which define space, where untypical spatial solution can be realised.
- **Complementary elements** (facade and inner walls, sanitary walls, sanitary cabins, non-standard staircases etc.) defined according to definite project requirements (choice of material and technical solution), assign a building category as “low cost”, “affordable housing” or others by its quality and price.

IMS system, as flexible and open in relation with spatial building form and interior space contents, but also with styles in architectural design, seems to be convenient for the realisation of the most various urban-architectural assignments. Success of designed solution is proportional to the integration level of architectural decisions with structural element characteristics and their production process and, as well, erection at the site.

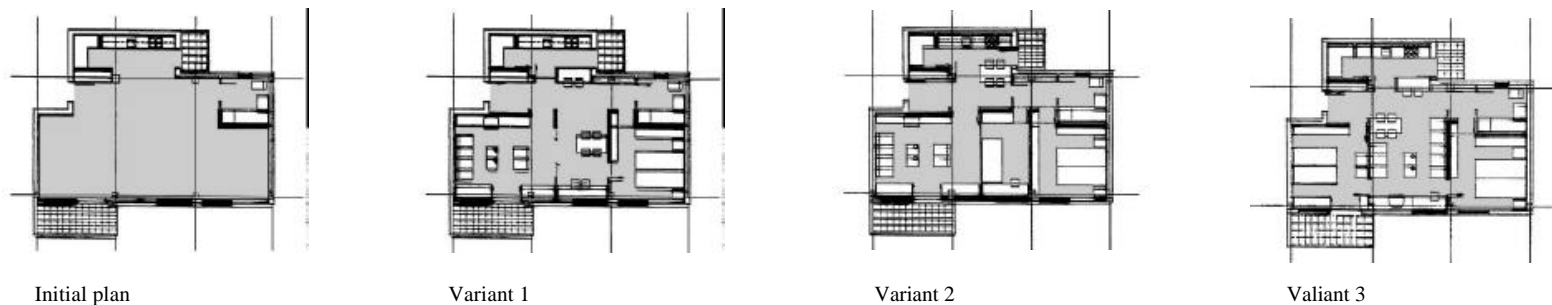
- **Spatial flexibility** (flexibility of space), possible architectural solution variant within a housing unit or building, which might be realised during designing, construction or exploitation.  
System flexibility, in both cases, enables efficient building realisation within phases. Miscellaneous comfort building realisation from the same structural elements is possible (works influencing standard and comfort do not influence essential changes of the production process).

Table: **Spatial flexibility**

Structure	Building space			Legend
	building	floor	apartment	
surface girders	*	*	*	* - low flexibility
linear girders	**	**	**	** - flexibility with confining
precast skeleton	***	***	***	*** - large flexibility

*Note:*

Prefabricated skeleton system possesses an advantage for the reasons of the lowest limitations in space



**Examples of spatial flexibility**

**Choice of structural spans**

Structural spans are defined basing on architectural building solutions, considering the building function, conditions of the element system production, transportation and erection. Rational spans are 2,4m-7,2m. Larger spans can be realised as well, but the choice is approved by economic justification.

The span choice is essential because it indirectly determines form and dimension of other system elements, but the building character in a whole, as well. Spans lower than 4,8m, in all combinations, are regularly realised through single floor slabs. Dimensions might cause a problem of public traffic transportation, in a case when elements are larger then 3,6m x 4,8m; this is the reason why larger spans are divided on two or more parts. At the same time appears the possibility of greater span number realised with the same elements. The slab example, dimensions 7.2m x 7.2m, shows that three-part slabs easily form following spans: 2.4 x 7.2, 4.8 x 7.2 and 7.2 x 7.2m, which enables architects to offer more various solutions during space shaping using standard structural elements.

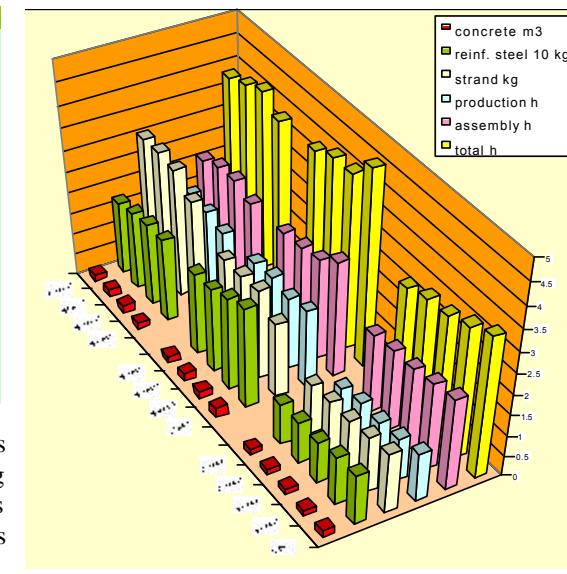
**Material and labour consumption**

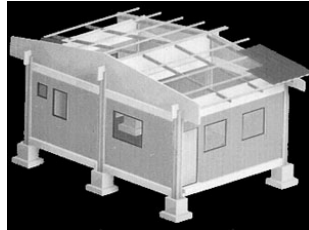
Table

Spans	Material			Labour		
	concrete m <sup>3</sup>	reinf. steel 10 kg	strand kg	production h	assembly h	total h
7.2x7.2	0.16	1.72	3.03	1.72	2.14	3.85
6.6x7.2	0.17	1.84	3.09	1.88	2.32	4
6.0x7.2	0.18	1.95	3.03	1.82	2.37	4.19
6.6x6.6	0.17	1.97	2.65	1.69	2.18	3.87
6.0x6.6	0.17	1.96	2.08	1.77	2.26	3.91
6.0x6.0	0.18	2	2.09	1.83	2.3	4.11
5.4x5.4	0.19	2.2	2.16	1.73	2.4	4.13
4.8x4.8	0.22	2.41	1.78	1.84	2.76	4.6
4.2x4.8	0.133	1	1.19	0.85	1.9	2.75
4.2x4.2	0.137	1.03	1.26	0.96	1.97	2.92
3.6x4.8	0.139	1.04	1.29	0.97	1.99	2.96
3.6x4.2	0.145	1.17	1.37	1.05	2.1	3.15
3.6x3.6	0.152	1.22	1.47	1.18	2.2	3.38

Smaller spans use narrower cross-section columns (for technological reasons minimal span is 30 x 30 – 40 x 40cm), so they are convenient for medium storey housing buildings. Larger spans are appropriate for buildings which, besides housing, possess some other function – garages, offices, and do not need a large number of columns (cross-section 60 x 60 cm). Depending on a span, material consumption discretely varies.

Diagram





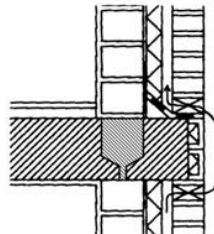
Minimal housing standard

**Standards, norms, comfort**

All system elements, basic and complementary, used for architectural solutions, are brought into accord with relevant regulations of the country where they are to be applied (designing and constructing). When minimal requirements are realised, referring to space, static and dynamic stability, fire protection; minimal housing standard buildings are obtained. Quality and comfort of the building as a whole, but the quality that defines a higher standard, as well, are determined by finishing works, amplified thermal and acoustic protection etc.



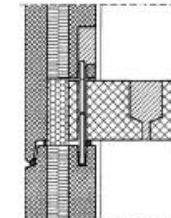
Minimal housing standard



Detail of masonry facade wall

**Facade – extern and inner walls**

Facade and inner wall position is not limited by structural requirements of the IMS skeleton system. Facade walls can be foreseen in continuity out of basic structure plane – “hidden assemblage”, or with interruptions for each storey height - “visible assemblage”. Walls can be realised in a trade way or using prefabricated panels (one-layered or sandwich) or combining the both, depending on building function and chosen materials.



Facade wall detail – sandwich



Medium standard housing

**Loggias, balconies, closed bay windows**

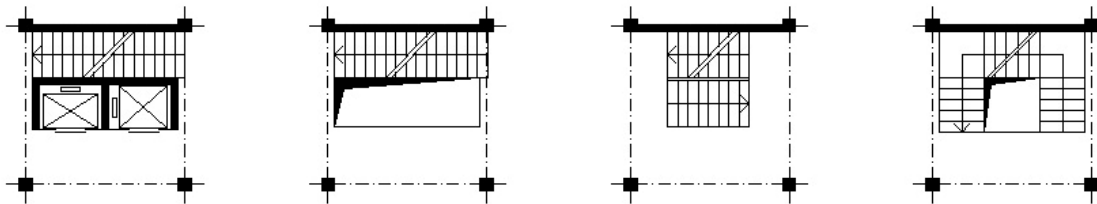
All common elements used for forming spatial plastic on building facade – loggias, balconies or bay windows can be realised by the IMS system. Cantilever floor slabs and edge beams are used for balconies and various bay windows.



Medium standard housing

***Vertical communications***

Stairs (one-flight, double-flight or other) are designed in the framework of especially defined floor slabs, easily manufactured within a plant. Architectural solutions of staircase space (stairs and elevator) are desirable, containing space between columns, so that there is no need to manufacture non-standard slabs.



**Variant stair solutions**

***Utilities***

All vertical utility ducts (plumbing and sewerage pipes, ventilation conduits, chimneys etc.) rally by the rule and are to be placed through previously defined apertures in floor slabs, which are manufacture in plant sections without changes of the production equipment. Small dimension openings for individual vertical conduits can be realised in a trade way, on erected skeleton, in situ. All other designing decisions do not especially differ at the IMS system.

***Ecological regularity***

All basic IMS system elements are made of reinforced concrete, and, by the rule, are considered as ecologically regular. Complementary elements chosen for definite design project should possess proves of the used material ecological regularity.

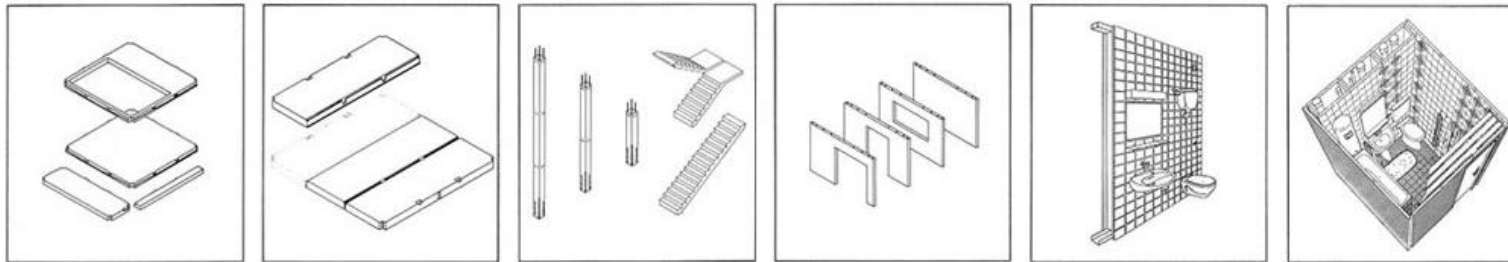
***Durability***

Basic building elements of the IMS system are made of durable materials and so are the buildings. By the material choice for complementary elements durability of the building, as a whole, is defined. High level of spatial flexibility concerning the IMS system enables, according to the needs, building reconstruction and rehabilitation, which offer functional durability.

### IMS Building Technology and Technologic/Constructional Requirements

#### *Basic IMS system elements*

IMS building technology is based on reinforced concrete prefabricated skeleton, composed by basic reinforced concrete elements of the IMS system:



- **Columns** (concrete grade M 40), continual through maximum 3 storeys (what depends on their cross-sections and storey height or possibilities of the crane used for erection), possessing square cross-section – dimensions: 30x30 – 60x60 cm.





- **Floor waffle slabs** (M 40) cover space between columns and can be manufactured with or without concrete ceiling, as one-piece (spans until 3.6x4.8 m) or multi-pieces aiming to adapt dimension for transportation and erection (ceilings made for the span 9.0x9.0 m are constructed from nine standard elements); the marginal girder and waffle web height is 20-40 cm (depending on column span between which space is covered), floor slab depth between coffer webs is 4-6 cm, and the ceiling one is 3 cm.



- **Cantilever floor slabs** (M 40), which replace edge beams in architectural solutions where balconies, loggias or other housing space out of column span are required and which are connected only to two columns (as a cantilever) and their height and length correspond to floor slabs near which they are erected, while their maximal width is limited on 1/3 of the longitudinal span. They are waffled and can be with or without concrete ceiling.

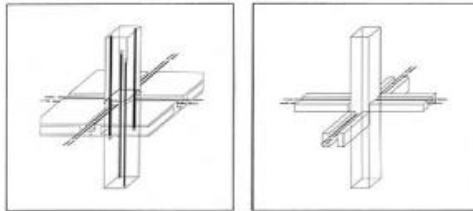


- *Stair elements* for one-flight, double-flight or triple-flight stairs, with monolith or prefabricated steps;
- *Edge beams* (M 40) have a boundary position in order to form frame beams and facade construction. Their lengths and depth are the same as at corresponding floor slabs with which they form a frame beam and their width is chosen according to architectural requirements for the adequate type of facade walls.



- *Stiffening walls* (M 40) are reinforced concrete panels (minimal depth – 15 cm), which stiffen the frame. They are positioned, by the rule, in the axis of two adjacent columns, having a function to form, together with columns, a structural element from foundations to the roof, ready to receive required intensity horizontal forces (in practice, those elements are often set in concrete in situ, especially at larger spans for the reasons of huge dimension, weight and slow frame erection);
- *Elevator manholes* – in practice those elements are set in concrete in situ, because of non-rational series (small number of elements in constructing building in relation with the mould price for manufacturing within the own section), which, by the rule serve for the acceptance of horizontal forces together with stiffening walls.

*Structural element connection of the IMS system elements*

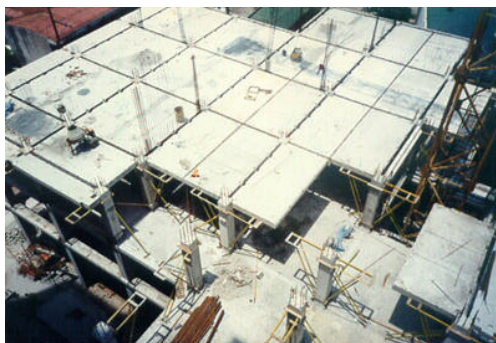


The use of post-tensioning is a specific way of joining basic reinforced concrete frame elements, so that, by the rule, all joints are exposed to the pressure, stress adequately endured by the concrete.

**Element connecting within prefabricated skeleton**



**Floor slabs** are so shaped that they form free space for positioning post-tensioning cables in both orthogonal directions, toward columns, where they are leaned on. Columns have radial openings, at this level, through which cables are threaded and positioned into space between floor slabs from one building edge to the other. Column and slab joints (depth 2-3 cm) are filled in with cement mortar or with special rapid-hardening expansive mortars, before cables are tensioned. Anchor bolts are positioned on columns or cantilever floor slabs. After tensioning, column openings are injected by a cement emulsion. After cable lowering and fixing into polygonal position, space between floor slabs is set in concrete with concrete grade established for columns and floor, because the mentioned concrete becomes a part of a frame beam aimed for dead and imposed load. It protects cables from corrosion and changes the prestressing character: from post-tensioned structure in the moment of erection to pre-tensioned structure for exploitation load. This way, rigid, firmly pulled up floor structure is obtained, aimed for the acceptance of each load to which the building will be exposed during its exploitation, followed by large coefficient of safety concerning joints (ten times bigger then required element coefficient).



**Multi-part floor slabs** are connected into monolith floor slabs before pulling up frame system cables, by post-tensioning short cables through waffle part webs. Those multi-part slabs obtain, that way, the same characteristics as a monolith slab.



*Prefabricated columns* are mutually connected by rebar overlapping of the upper and lower post, the way that one column anchors are inserted in corresponding ones of the other; then those openings are injected by cement emulsion. Mutual joints of column elements are naturally pressed transferring the entire vertical load from a floor structure to foundations.

*Stiffening walls* are composed of concrete panels connected to posts at each floor plane level and they are pulled up with cables, which, as dowels, force columns and concrete panels to have same deformation under the influence of horizontal forces to which the building is exposed during exploitation. Their mutual continual joint-action in vertical cantilever girder is then accomplished. Number of stiffening walls is defined on the fact that they can accept all expected horizontal forces. Concrete panels are lightly reinforced and have a joint element function between two columns in order to decompose expected bending moments from horizontal forces into pressing and tensioning forces bracing, which are accepted by appropriate columns – parts of a stiffening wall. In well-conceived architectural solutions complementary reinforcing steel is not necessary for the acceptance of tensioning forces in columns; and in case it is unavoidable, it is situated into the concrete carcass part near the column. From this very fact, a significant consequence appears for architectural design of a building space - in cases where stiffening walls between two housing units are not enough, which is a rule, facade or partition walls can be used, where the central concrete carcass part contains door, window or other openings. The rule is that stiffening wall carcass must be continual from foundations to the building top.

Other basic and complementary elements are connected in a common way for reinforced concrete structures or masonry or prefabricated elements, according to used materials and function.





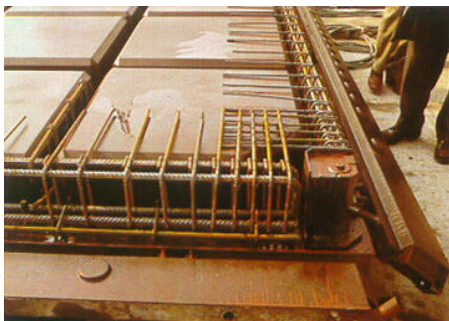
*Post-tensioning* as a method of jointing elements, contributes to larger load-bearing – concrete use as a building material; this fact contributes to less consumption of basic building materials – concrete and steel, at least for 20-30%. Various prestressing systems can be used, the most often – the IMS system with wires and SPB system with ropes. For those processes local labour can be instructed, or for this working part, an adequate specialist service can be hired, aimed for each prestressing system owner.



***Specific equipment for production and erection of the IMS system***

Besides common equipment used in concrete prefabrication and assemblage, there is a specific equipment for IMS building technology composed of production system elements moulds and equipment and devices for the assemblage and erection.

***Production equipment*** elements are composed of robust steel moulds, where minimum 2000 elements can be manufactured without special reconstruction, but followed by regular maintenance. Those moulds are so conceived to possess certain flexibility, so that, for example, storey height of some buildings can differ from the standard one, same moulds for floor slabs can be used for various column cross-sections, more exactly, for some non-standard floor with utility openings etc. Moulds aimed for floor slab coffer forming are especially favourable, they use lost Styrofoam or some other material forms, which at the same time has a function as a thermal insulation. Moulds for definite span diapason can be used, that way.





*Erection equipment and device* consist of:

- steel squares – capitals tightened to the columns at the height of each floor structure as temporary support of floor slabs and edge beams during erection until cable guying;
- diagonal steel brace for column fixing and precisely regulated vertical position till straining of the first floor plane, when columns are multi-storey;
- floor slabs buttress in case of multi-part floor slabs, as temporary support till their connecting by post-tensioning;
- devices for column erection etc.



***Plant section for production of IMS system elements***

Flexibility and adaptability possibilities of IMS building technology to local conditions show in organisation and production section of the IMS system basic elements. As steel moulds, essential production equipment, are portable, element manufacturing can be organised in permanent plants, protected from atmospheric influences or in polygonal section at the building site, more exactly, at other locations near the site.



**Apartment plant – Cuba**

***Permanent plants*** use appropriate bridge cranes, concrete plants, common equipment for concrete deposition (poker vibrators, external vibrators, vibrating plates), reinforcing sections with adequate equipment for straightening, cutting and rebar and assembly shaping, steam boiler room for steam curing of freshly set in concrete elements, workshops for equipment maintenance, laboratory for quality control of the concrete etc.



**Apartment plant – Ethiopia**

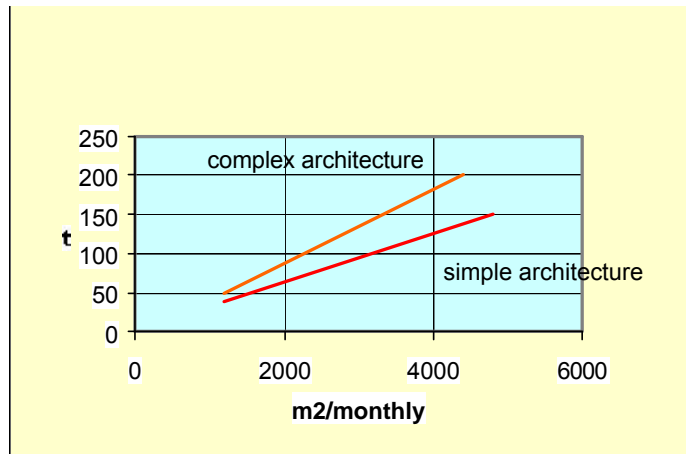


**Polygon for element production – Novi Sad  
Concrete plant at the polygon – Novi Sad**

***Production at the polygon*** enables various variants of section organisation depending on climate and other conditions: absolutely adequate to permanent plant in enclosed space; using tower cranes instead of the bridge ones; supplying with concrete with transit mixers from concrete plants; protection from directly drying (instead of steam curing) of freshly set in concrete elements with plastic foils (if climate conditions allow it) etc.



Diagram: Appraisal of the equipment weight according to section capacity



**Plant capacity** is the most significant factor for the application rationality of the IMS building technology. Experiences showed that minimal investment expenses in specific equipment for the IMS building technology are obtained for sections with annual production of 20000 – 50000 square meters of building structures. In that case, annual production absolutely depreciates investments in the equipment, while the same equipment is valuable per several years' production (8 – 10 years and more). Permanent plants are built, as well, for 100000 sq.m. but those capacities requires perfect organisation and building control, which are, in some countries, hardly realised with local labour.

Quality control of building material and production process is necessary for element production and building stability and security during assemblage, erection and utilisation.

#### **Erection organisation of the IMS system elements**

Organisation and assemblage and erection control of the entire building, using the IMS system, is worked out in detail for each location, because it is linked with local climate and other conditions, architectural building solution, storey number etc., differing from element production which is continual during the whole year.



**Transportation** of elements from the production plant to the site requires common vehicles. The heaviest elements do not overpass 7 tones, and dimension enables truck utilisation for public traffic transportation. Depending on traffic network and gas prices, rational truck transportation is about 100 km, while in practice rationality of the boat transportation is about 1000 km (Novi Sad, Yugoslavia – Odessa, Ukraine).

As at element production's, work organisation at the site comprises institutional permanent control of material and process quality, the way the technology principles define it.





*Skeleton assemblage and erection.* When building foundations are done, with precisely left openings for anchors of prefabricated columns, multi-storey columns are positioned, fixed, with the help of braces, in vertical position and controlled with geodetic surveying instruments (verticality and axis position). Temporary capitals already exists on columns on which floor structure elements are erected – floor slabs, edge beams and cantilever floor slabs. Afterwards, floor slabs, evens multi-part, are make monolith with web post-tensioning using appropriate short cables. Joints between columns and floor slabs are filled in with adequate mortar and after its hardening, the entire floor plane is post-tensioned with cables into two orthogonal directions. After this action, braces fixing columns are released, supporting capitals are transported to another storey level and the operation of floor slabs erection is repeated. When prefabricated panels are used as stiffening wall elements, they must be erected before upper floor slabs. If those elements are set in concrete in situ using portable forms, those operations can be realised later, independently of the frame erection.



Appropriate, available cranes are used for erection, or auto-elevators in number and yield depending on definite building and location. Organised group of 5-6 workers, with the crane-man, can weekly erect one storey level, about 600-1000 sq.m, which depends, as well, of the architectural building solution and the site (approach possibilities of the crane to the building, jagged building plan etc.).

*Complementary elements* of the building, facade, partitions, utility works, can be positioned on erected frame at the same time as erection of upper storeys, which influences time shortening of the building process and enables great organisation and control flexibility of building construction, as a whole.

***Quality control and building control***

The composite IMS system technology part is a developed quality control system of prefabricated elements during production, such as developed method of the process quality control concerning production and erection. Those way economic effects are realised for the investor and for the contractor.

Defining of production and erection process, with adequate norms, enables building control followed by adaptation to local conditions, so that appropriate building dynamic is realised and work dead line is reached. The IMS building technology transfer comprises local labour qualification for all those processes with temporary supervision of the IMS Institute experts.

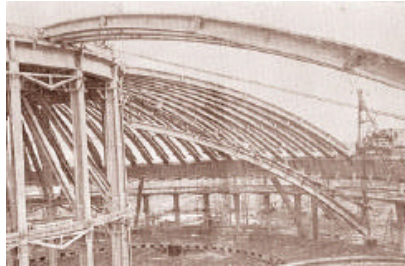
**REFERENCES**



**Initial construction of the New Belgrade**

Prefabricated prestressed skeleton application and the IMS building technology possess several decade experiences, first of al in Yugoslavia, but in countries all over the world, as well. Around the 1950-ties Yugoslavia had a great problem of housing space deficit, which represented a challenge for the great constructor Branko Zezelj, former director of the Institute of Material Research of Serbia.

With his best collaborators, first of all with the engineer Bosko Petrovic, with whom he developed and applied, at the time, a new building material – prestressed concrete, constructing bridges and halls unique in the World, he got a great idea to apply the material and technology of prestressed concrete in housing building. The greatness of the idea can be appraised only today because this is the 20<sup>th</sup> century technology. The idea is simple – we build standard buildings of standard elements, as children do with Lego cubes. The hardest problem – element conecting of the concrete frame, made of prefabricated columns and slabs, was resolved by the guying technology with steel cables aimed for the post-tensioning process. The idea was a real revolution and required numerous research and proofs, first of all, in the field of durability and stability, and the in the field of architectural design and possibilities to be justified in practice as universal technology for all kinds of buildings in high-rise constructions. All denies, such as at the time of “total” prefabrication modernity, saying that the system is not accomplished (because it is not “encircled” by all building element prefabrication), possess today a complement character. It permits all new accomplishment application from the field of new materials and products linked with building construction, which better satisfy modern users’ requirements.



Construction of Belgrade Ferry hall



Railway-road bridge in Novi Sad

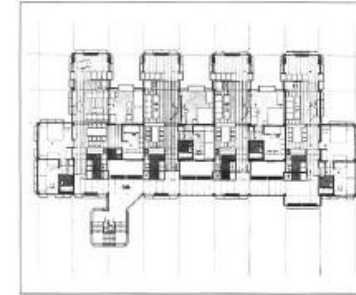
Prefabricated prestressed skeleton is tested in theory and experimentally, under all kinds of possible loads (static, dynamic, seismic, impact, fire..) and it always showed, without exception, high safety coefficients. Column and slabs joints cannot be practically destroyed, because there is a preliminary break of individual elements out of jointing area. Verification and attesting of elements, joints and structure, as a whole, are realised in Yugoslavia, Hungary, Italy, Austria, Russia, Uzbekistan, Cuba, China and USA. The research results are verified on numerous international congresses of specialised expert and scientific organisations.

During its 40 years application, all around the World, locations, where the buildings were constructed, were unfortunately exposed to natural and other catastrophes: earthquakes - 8 Richter degrees (Banja Luka, Bosnia), hurricanes (Havana, Cuba; Manila, Philippines), wars, bombings (Sarajevo, Mostar – Bosnia, Osijek – Croatia), fires, accidents... In those conditions buildings with prefabricated prestressed skeleton rested stable, as a whole, and without significant damages, so that after cosmetic remedial works, they were exploited again.

The country list where prefabricated prestressed skeleton was used in building constructions is the following: *Yugoslavia, Bosnia and Herzegovina, Croatia, Hungary, Italy, Austria, Bulgaria, Russia, Georgia, Ukraine, China, Cuba, Egypt, Ethiopia, Angola, Philippines*, even if all those countries are not so big or differ from developed society, culture, climate, geo-seismic or other conditions relevant for building construction.



In **Angola** are built two representative housing buildings, showing, in a great measure, spatial shaping possibilities and adapting to climate conditions. Works are realised in war conditions, but the work quality, with the local labour, was satisfying.



Near Cairo, in **Egypt**, 1000 apartments were constructed according to the IMS building technology, aimed to resolve housing problems for low-standard families.



In **Cuba** were raised three permanent sections for the IMS technology element production – yield 100000 sq.m (San Jose, Cien Fuegos, Santiago de Cuba), and one experimental plant section on the open space in Havana. Numerous housing buildings were constructed, kindergartens, schools.





In Nevinominsk, **Russia** an apartment plant was constructed according to the IMS building technology, which products buildings for collective or individual housing. Near Moscow, the new section is built and based on primal principles of the mentioned technology, for multi-storey public/housing buildings.



The IMS skeleton system plant is raised in Adis Abeba, **Ethiopia**, where several housing and school buildings were constructed.



Building complex (56000 sq. - apartments, offices, stores) was raised in Manila, in Makati, **Philippines**. The building possesses complex architecture with 3 underground parking levels, exclusive stores at the ground level and the first floor, and with high standard apartments placed within three towers and 20 storeys.



The highest building – 26 levels, was built according to the technology in Pec **Hungary** as a public/housing building. In Hungary are built school buildings, as well.



**Prefabricated prestressed skeleton showed the framework of possible adaptation for very various requirements of contemporary building construction all over the world.**