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ASSESSMENT OF THE EXISTING PREFABRICATED RC RESIDENTIAL BUILDINGS IN BULGARIA AND RECOMMENDATIONS FOR THEIR REHABILITATION AND STRENGTHENING

[Rangelova Fantina, Traykova Marina]

***Abstract*—In this paper the different categories of prefabricated building systems for residential buildings in Bulgaria are first discussed. The most important problems of the "large-panel system" for residential buildings are commented. Contemporary techniques for rehabilitation and strengthening are presented. Finally, a few general conclusions and recommendations are given.**

***Keywords*—rehabilitation and strengthening of existing buildings, FRP techniques**

I. Characteristics of the different categories of prefabricated building systems in Bulgaria

The concept of prefabricated construction includes those buildings where the majority of structural components are standardized and produced in plants in a location away from the building, and then transported to the site for assembly. These components are manufactured by industrial methods based on mass production in order to build a large number of buildings in a short time at low cost. The assembly elements are interconnected by:

- Hardening accelerated concrete in the joints between the elements. A better connection is obtained if there reinforcement in the hardening accelerated concrete, that sticks out from the neighboring elements;
- By welding in advance concreted in the elements steel units, called embedded parts.

Rangelova Fantina
University of Architecture, Civil Engineering and Geodesy
Bulgaria

Traykova Matina
University of Architecture, Civil Engineering and Geodesy
Bulgaria

During the construction of prefabricated industrial buildings are used different types of elements (Fig.1, Fig.2):

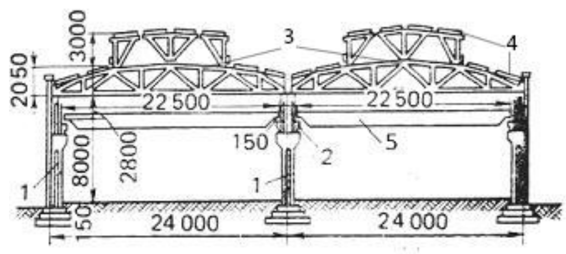

Figure 1. One story precast industrial building: 1 – column, 2 - crane beam (beam that carries rail crane), 3 – RC trusses, 4 - roof panels, 5 - crane

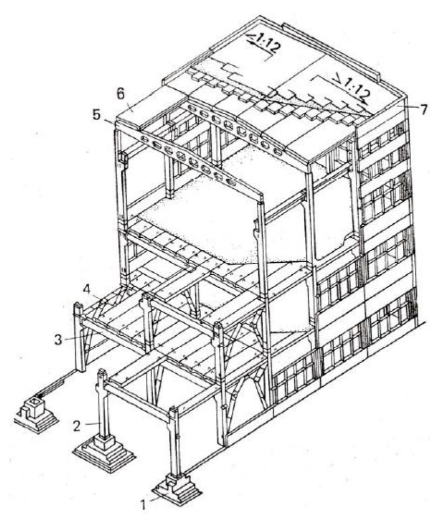

Figure 2. Multistory concrete prefabricated industrial building: 1- foundation, 2 - column, 3- beam, 4 - strengthen ties, 5 - beam, 6 - roof panel

Many countries used various prefabricated building systems during the second half of the 20th century to provide houses for the growing urban population. They were very popular after the Second World War and especially in Eastern European countries.

The most applied systems for prefabricated buildings in Bulgaria are: "large-panel systems", "frame systems" and "lift-slab system with walls".

Advantages of prefabricate construction [8]:

- The construction time is shortened, since structural work on the site is confined to constructing the foundations and erecting the prefabricated components. Because of the low moisture content the building dries out more rapidly than a building of conventional construction and is sooner ready for service;
- The quantities of materials required are reduced, as formwork and scaffolding are largely eliminated. Favorable weight - saving structural sections can be used, so that less concrete and steel is needed and the weight of the building as a whole is reduced;
- Production of precast units in large series makes it practicable to use machines whereby the required amount of manual labor is substantially reduced. Besides the units can be manufactured in the most convenient position on the casting bed;
- Less man power is needed, since the precast units are manufactured in a factory or, at any rate, under factory conditions on the building site. Instead of skilled labor, unskilled workmen can be used, who do not have to travel around from site to site;
- Better quality of the products is obtained as a result of manufacture under factory conditions with constant Quality control, the use of machines, and the better Working environment provided by the factory;
- Construction can proceed almost independently of weather conditions, since the units can be manufactured in covered buildings which can be heated and erection of the units can also carried out in winter.

A. Large - panel systems

The designation "large-panel system" refers to multistory structures composed of large wall and floor concrete panels connected in the vertical and horizontal directions so that the wall panels enclose appropriate spaces for the rooms within a building. These panels form a box-like structure. Both vertical and horizontal panels resist gravity load. Wall panels are usually one story high. Horizontal floor and roof panels span either as one-way or two-way slabs. When properly joined together, these horizontal elements act as diaphragms that transfer the lateral loads to the walls.

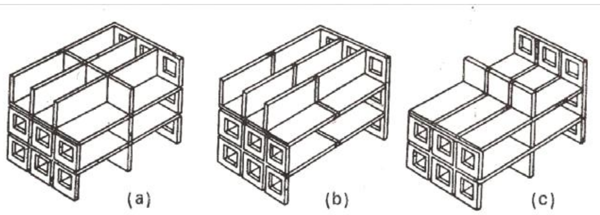

Figure 3.

Depending on the wall layout (Fig.3), there are three basic configurations of large-panel buildings [1]: 1. Cross-wall system - The main walls that resist gravity and lateral loads are placed in the short direction of the building; 2. Longitudinal-wall system - The walls resisting gravity and lateral loads are placed in the longitudinal direction; 3. Two-way system- The walls are placed in both directions.

Panel connections represent the key structural components in these systems. Based on their location within a building, these connections can be classified into vertical and horizontal joints. Vertical joints connect the vertical faces of adjacent wall panels and primarily resist vertical seismic shear forces. Horizontal joints connect the horizontal faces of the adjacent wall and floor panels and resist both gravity and seismic loads.

B. Frame systems

The "precast frame system" [1] can be constructed using either linear elements or spatial beam-column subassemblages. Precast beam-column subassemblages have the advantage that the connecting faces between the subassemblages can be placed away from the critical frame regions; however, linear elements are generally preferred because of the difficulties associated with forming, handling, and erecting spatial elements. The use of linear elements generally means placing the connecting faces at the beam-column junctions. The beams can be seated on corbels at the columns, for ease of construction and to aid the shear transfer from the beam to the column. The beam-column joints accomplished in this way are hinged. However, rigid beam-column connections are used in some cases, when the continuity of longitudinal reinforcement through the beam-column joint needs to be ensured. Hollow-core precast slabs are commonly used for floor and roof structures in this type of construction.

C. Lift - slab system with walls

The load-bearing structure consists of precast reinforced concrete columns and slabs. All precast structural elements are assembled by means of special joints. Reinforced concrete slabs are poured on the ground in forms, one on top of the other. Precast concrete floor slabs are lifted from the ground up to the final height by lifting cranes. The slab panels are lifted to the top of the column and then moved downwards to the final position. Temporary supports are used to keep the slabs in the position until the connection with the columns has been achieved. In the connections, the steel bars (dowels) that project from the edges of the slabs are welded to the dowels of the adjacent components and transverse reinforcement bars are installed in place. The connections are then filled with concrete that is poured at the site. Most buildings of this type have some kind of lateral load-resisting elements, mainly consisting of cast-in-place or precast shear walls, etc.

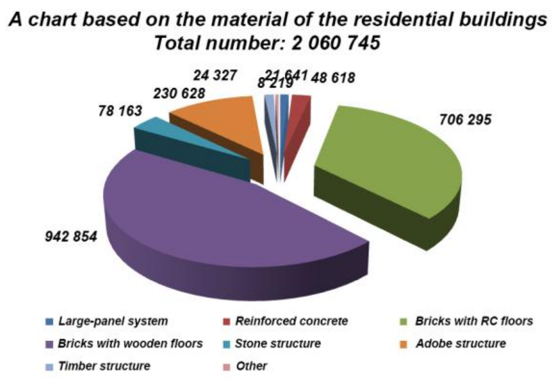

Figure 4. Number of residential buildings according to the material of the structure [5]

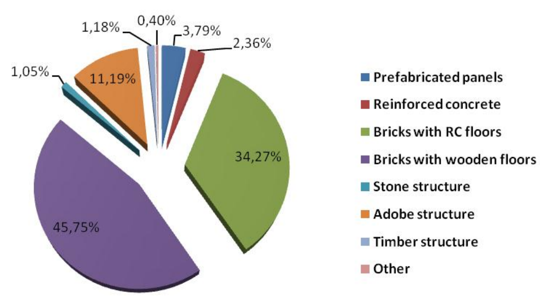

Figure 5. Residential buildings, according to statistic information- until 2011 [4]

The housing in Bulgaria is relatively "young". About 30% of the residential buildings are aged below 30 years, about 50% are below 40 years and only 4% are built before 1919.

The total amount of residential buildings in Bulgaria until 2011 is 2060745 [5] (Fig.4, Fig.5). The residential buildings constructed as "large-panel system" are 21641. More than 20% of the apartments are in this type of residential buildings.

In the cities - regional centers are located 82.3% of the total fund of panel buildings. The largest share belongs to Sofia (Fig.6) (28.5% - 200579 residential). Followed by Plovdiv (8.2% - 57468 residential), Varna (8.1% - 56821 residential), Burgas (4.9% - 34714 residential) and Rousse (4.2% - 29378 residential). In these five cities are concentrated 53.8% (378 960 residential) of all prefabricated housing (707 441 residential).

Figure 6. Sofia, Bulgaria – Lulin district

In the first years of pre-fabricated construction as a material for the surrounding wall structures scoria-concrete is used. Later, single- layer panels were manufactured by other materials. Three-layer front panels "sandwich" (concrete-light concrete-concrete) were applied also. Usually the thickness is respectively 50 mm - 100 mm - 50 mm for load-bearing wall panels and 50mm- 80mm- 90 mm for the blind facade bearing wall panels.

The "large- panel system" is very popular in the Bulgarian construction practice in the recent past. The first buildings constructed according this system are dated from 1958. They are 4-storey. Since 1962 the 8-storey variant of this type of buildings is realized. After 1972 the "large-panel system" is one of the most popular systems for residential buildings.

Figure 7. Berlin, Germany – Hellersdorf (Kaulsdorf-Nord)

One of the first countries, which sets out a strategy for the reconstruction of old residential complexes is Germany. Back in the 90's Senate Department for Urban Development and the Environment - Berlin started Umbauprogramm - a programme for transformation of cities, which includes specific renovation of prefabricated panel housing (Plattenbau). Experience is gained in the center of Berlin on sub regions, an organization that provides consultancy services to German and foreign companies in the construction industry. In the largest socialist neighborhoods in the German capital Marzahn and Hellersdorf (total 230 000 people) 165 thousand apartments are completely renovated, 64 thousand. - partially, and 41 thousand – expect remediation (Fig.7).

II. Assessment of the actual status and some problems of the "large –panel system" for prefabricated RC residential buildings in Bulgaria

Balkans is the most active seismic unit in Europe. On the current territory of Bulgaria, for a period of 536 year until now, nine large earthquakes are registered. The building structures in the country are also subjected to the effects of the earthquakes occurring in the territory of neighboring countries.

Development of a legal basis for earthquake resistance of buildings and facilities should knowledge of seismic hazards and methods for reliable estimates of risk, and the accumulation of new data on the seismic regime in Bulgaria and neighboring countries.

Since the beginning of 2013 in parallel with the national standards, and the European codes (Eurocodes) for structural design is required to be applied in Bulgaria. By the end of 2014, they must completely replace national standards in order to equalize the regulations in the European Union. Building structures are provided with a certain reliability impact as the seismic zoning map. Until 1977 it was developed based on the earthquakes occurred. After Vrancha in 1977 following the new changes, additions and instructions and territories to which the seismic design of structures required, already occupy 39% of the total area of the country. Attached map to the standards for the design of buildings and structures in seismic areas in 1987 for the first time have predictive nature. It is designed for maximum values of the expected intensity scale MSK-64 with a recurrence period of 1000 years. Same card, according to which the strict rules of mandatory earthquake insurance now apply to 98% of the Bulgarian territory is used in Regulation 2 of the 2007 National annex to Eurocode 8 includes three maps of seismic zoning of the territory of the country corresponding to the return period 90, 475 and 1000 years.

Based on experience in past earthquakes in Bulgarian, Eastern European and in Central Asian countries [1] where “large-panel system” have been widely used, it can be concluded that the seismic performance of the prefabricated RC buildings of this system has been fairly satisfactory. Due to their large wall density and box-like structure, large-panel buildings are stiff and are characterized with a rather small fundamental period.

The main problems of the existing prefabricated RC residential buildings (“large-panel system”) in Bulgaria can be resumed in the following: 1. Reconstructions of the ground floor for shops and offices- many additional openings in the wall panels in the ground floor and removing of panels; 2. Bad maintenance of the joints between the panels; 3. Incorporation of the balconies to the rooms – additional load from glazing and brick masonry; 4. Bad maintenance of the water and the thermal insulation; 5. Not effective thermal insulation.

In precast concrete construction the connections between the elements are of utmost importance. There are two types of connections, one “Wet” connection (with mortar or in-site concrete), second is “Dry” connection (with welding on bolting). While choosing a connection, so many factors we have to consider. The connection must comply with all requirements regarding the transmission of forces and moments, and permissible deformation or rotation. The connection should also satisfy the technical, economical, and if required - aesthetical aspects.

The future programme for the existing prefabricated RC residential buildings (“large-panel system”) is necessary to be developed on the basis of the following measures: 1. Extending the remaining lifetime of the buildings as much as possible; 2. Upgrading the performance to suit modern standards; 3. Improving of the seismic behavior and the global structural safety; 4. Improving the energy efficiency; 5. Creating a sustainable environment.

III. Principal structural and contemporary technological solutions for rehabilitation and strengthening of prefabricated RC residential buildings

Fiber-reinforced polymer (FRP) [7] systems have been used for more than 20 years and are becoming a widely accepted method of strengthening concrete structures. The use of FRP composites in rehabilitating structures has grown in popularity due to its advantages over conventional materials and wide range of structural applications. FRP systems for strengthening reinforced or pre-stressed concrete girders consist of externally bonded laminates or near-surface mounted bars. These systems may contain either carbon or glass fibers. Because of their light-weight and exceptional formability, FRP reinforcements can be quickly and easily bonded to even the most curved and irregular surfaces. The high strength-to-weight ratio of FRP composites makes them more structurally efficient than traditional strengthening materials. In addition, FRP composites are noncorrosive, nonmagnetic, nonconductive, and generally resistant to chemicals.

The application of advanced polymer composites [5] for the building and civil engineering industry, can be conveniently divided into some specific areas, as:

1) Building industry:
   - infill panels and new building structures;

2) Civil engineering industry:
   - civil engineering structures, fabricated entirely from advanced polymer composite material, known as all-polymer/fiber composite structures;
   - bridge enclosures and fairings bridge decks;
   - external reinforcement rehabilitation and retrofitting to RC structures (including FRP confining of concrete columns);
   - external reinforcement rehabilitation and retrofitting to steel structures;
   - internal reinforcement to concrete members;
   - FRP/concrete duplex beam construction;
   - polymer bridge bearings and vibration absorbers;

All these, other than the first, involve a combination of advanced polymer composites and conventional construction materials and are therefore often termed composite construction.

The new techniques are and one contemporary solution for upgrading the performance of the “large-panel” buildings.

The purpose of [2], [3] is to experimentally evaluate the seismic load bearing capacity of a prefabricated RC wall panel with large openings retrofitted post damage using externally bonded carbon fiber strips (CFRP) (Fig.8). Cut-out openings are often required to facilitate direct access from outside or between adjacent apartments, predominantly at the ground floor, where both gravity and seismic capacity demand is maximum. Cut-out openings performed in structural walls results in the modification of the internal force flow paths, loss of load bearing capacity and reduced structural safety.

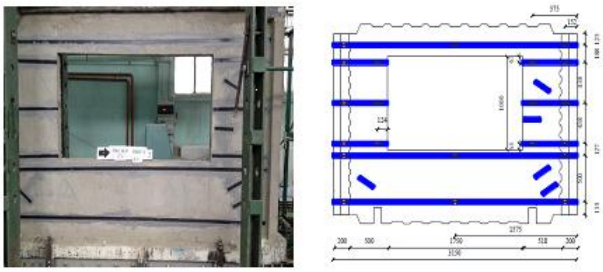

Figure 8. Experimental stand [3]

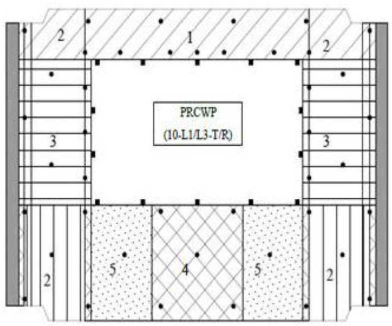

Figure 9. *The TRM strategy for the wall with cut-out [9]*

The presented experimental researches show that the retrofitting with carbon fiber strips externally bonded, in the case of panels with openings, is able to reestablish about 90 % of the initial load bearing capacity of the element and increase the drift ratio. The proposed retrofitting strategy is viable alternative to classic procedures.

The application of Textile Reinforced Mortar (TRM) was investigated in [9] as a rehabilitation manner, in order to restore the load bearing capacity of the specimen first tested before strengthening (Fig.9). TRM system can be an effective solution for strengthening elements. The punctual anchorage system used turned to be inefficient, allowing for system local debondings. Very often a mortar with glass fiber grid for reinforcement is applied.

IV. Conclusions and recommendations

1) The existing prefabricated RC residential buildings in Bulgaria represent a considerable part of the total amount of residential buildings. The most popular system in the recent past is the “large-panel system”.

2) The rehabilitation and the strengthening of the residential buildings should aim to extend the remaining lifetime and generally represent the sustainable solution for obtaining significant social effect.

3) The programme for rehabilitation and strengthening of the existing prefabricated RC buildings can serve as a basis of the national measures for renovation of the residential buildings.

4) Using new techniques is the best way for improvement the performance of the existing buildings.

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About Authors:

Rangelova:
“The high strength-to-weight ratio of FRP composites makes them more structurally efficient than traditional strengthening materials”

Traykova:
“The retrofitting of an existing building is generally more sustainable approach than its demolition and the construction of a new building”