SOME TRENDS IN THE RESEARCH OF THE PREFABRICATED BUILDINGS IN SEISMIC REGIONS

DEPREM BÖLGELERİNDE YAPILACAK PREFABRİKE BİNALARLA İLGİLİ ARAŞTIRMALAR KONUSUNDA BAZI EĞİLİMLER

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ABSTRACT

The aim of the present paper is to emphasize on some specific problems which are subject of the recent investigations of researchers and specialists in the field of the prefabricated buildings in seismic regions. These investigations have been carried out mainly in the following directions: theoretical and experimental investigations, learning from earthquakes and looking for new building structure systems.

1. GENERAL

The major difference between traditional monolithic cast in situ reinforced concrete building structures and prefabricated concrete structures is that prefabricated structures are composed of various members cast in a different place of origin than their final position in the structure. The term prefabrication is generally used to denote industrialized casting of concrete elements in a specialized plant.

The advantages of prefabricated building systems are known by the specialists of the Civil Engineering. But in the same time due care should be taken of the possible problems arising from prefabricated construction. I would like to emphasize on two of them:

1. Architects may prefer more freedom to vary the style of building than is available from most prefabricated building systems.

2. The basic problem in the design of earthquake resistant prefabricated concrete buildings is in finding an economical and practical method for connecting the prefabricated elements together which provide a satisfactory structure solution. Hence the additional factors which need to be considered in the seismic design of prefabricated concrete structure systems are:

- The best means for achieving ductility in the system is sought. The term ductility" in earthquake resistant design is used as an abbreviation for "the ability to

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dissipate a significant amount of energy through inelastic behaviour under large amplitude cyclic deformations without substential reduction of strength". A well diffused number of yield zones is normally the most satisfactory way of assuring protection against collapse.

- The joints are undoubtedly the region of greatest seismic design difficulty. In moderate earthquakes the displacement of prefabricated concrete systems may be greater than of monolithic systems with similar geometry and identical structural patterns due to the reduction in stiffness of the joints. Hence particular attention should be given to achieving adequate stiffness of the joints. In addition it is most important that the joints have the necessary strength and ductility to enable the structure to survive severe earthquakes.
- The arrangement of the horizontal load resisting elements in a building should be as symmetrical as possible in order to minimize the torsional response of the building during earthquakes. Due to numerous uncertainties, the actual behaviour of an unsymetrical building is difficult to predict, even with elaborate computer models.
- It is undesirable for discontinuities in stiffness and/or strength of the structural system to exist up the height of the building. For example, the absence of some vertical structural elements in one storey of a building can lead to a dangerous concentration of ductility demand in the remaining elements of the storey.

The above problems and special requirements of earthquake resistant design define the trends in the research of prefabricated buildings in seismic regions.

2. SOME THEORETICAL AND EXPERIMENTAL INVESTIGATIONS

2.1. Modeling of the structure and accounting for the material properties

In most of the codes there are no special instructions on how to determine the design model of the structure which gives reasons to different designers to accept various design models and to achieve results that differ considerably.

1. In the paper "Seismic analysis of building structures with shear walls applying a direct integration method" [6] the author stated that for the up to now investigations of the structures carried out in accordance to the requirements of the code usually the earthquake is not considered as a time history process and this makes it impossible to assess different phenomena related especially to damping and nonlinear behaviour of the structure. The author proposes a method for dynamic analysis of space structure with shear walls by direct integration in the time domain. The proposed method has the following advantages:

- it is not necessary to determine the natural frequencies and corresponding mode shapes;
- easy modeling of viscous and histeresis type of damping;
- at any time moment while the structure is subjected to the earthquake excitation the displacements and internal forces in the considered cross-sections can be determined;
- gives possibilities for modeling of the effects of physical, geometrical or coupled non linearity.

Details on the theoretical model of the structure are presented in the development.

The described theoretical model and proposed method are implemented in a software product for VAX computer which is applicable to personal computer. This product is used to analyze a 9 storey building with 10 reinforced concrete shear walls shown in fig. 1.

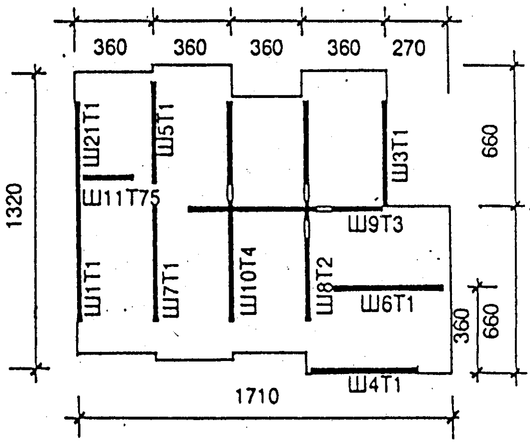

Fig. 1 Layout of the diaphragms (shear walls)

At the end the author concludes that having in mind the advantages of the proposed method it is necessary to go on with the investigations for the choice of suitable accelerogrammes and for further development of the theoretical model in order to include the nonlinear behaviour of the structure.

2. So far during the design and analysis of many structures under seismic loads, it has been considered that the structures behave in elastic range. In reality a lot of the elements under strong seismic excitations have nonlinear behaviour and this should be considered if we want to reflect more correclty and more exactly the response of the structure. An example for this is given in the doctoral dissertation of Z.Bozinovski "Nonlinear behaviour of prefabricated large panel reinforced concrete systems under dynamic-seismic loads" [1].

On the basis of the synthesis of the results from the analytical and experimental investigations of elements of large panel systems performed in the world and in Macedonia, and the investigations that are carried out for this purpose in IZIIS-Skopje, a procedure is proposed for design and analysis of stable and economic prefabricated large panel reinforced concrete systems exposed to static and dynamic effects. With the proposed procedure, the vertical panels are considered to behave in the nonlinear range, but with controlled mechanism of ductile behaviour, adequate reinforcement at their ends and several times smaller amount of vertical and horizontal reinforcement than that used in practice so far.

It consists of analysis of external effects, vertical and horizontal, static and dynamic experimental investigations of constituent elements, proportioning of the constituent elements with controlled ductile behaviour in all the phases of behaviour up to the failure and structural response to actual seismic-dynamic effects. Computer programmes are developed for analysis and proportioning of large panel elements with ductile behaviour and a programme for nonlinear behaviour of the systems as a whole and for actual seismic effects which includes the vertical wall panels as well as the vertical and the horizontal joints with their strength and deformability characteristics.

The proposed procedure enables design and analysis of stable and economic prefabricated large panel reinforced concrete structures to be built in seismically active regions, by controlling the ductile behaviour of the constituent elements and the system as a whole. The procedure requires minimal experimental investigations for verification of the strength and deformability characteristics of the principal structural elements but only for the development of a particular large panel system. For design, analysis and control of the stability and ductile behaviour, analytical methods in correlation with experimental results are used. It has to be pointed out however that the proposed procedure can be used for analysis and design of not only large panel precast systems but also other structural systems for which the strength and deformability characteristics of the bearing structural elements under static and seismic-dynamic effects can be experimentally and analytically defined.

2.2. Connections

The major object of the experimental investigations are the connections betweeen the elements. This can be explained because for the precast buildings under seismic loads the most critical locations are the connections. The stability of the structure assembled of precast elements to a great extent depends on the safety of the connections. It is not possible to see the actual behaviour of these critical locations under earthquake loads using analytical methods.

Some details of the experimental investigations carried out in Turkey follow hereafter.

In [3] data about precast concrete beams with dry joints are given, designed for multistorey buildings located in a seismic area, tested under reversed cyclic loading. In the original design the connection was intended to transfer both shear and moment. It consisted of two steel plates, one at the top, the other at the bottom, welded to the anchored steel plates in the column bracket and the beam. The design was later revised by adding side plates. Five specimens with such connections and two monolithic reference specimens were tested under reversed cyclic loading to study their behaviour under seismic action. The main variables were the presence of side plates and the joint width.

The prototype precast concrete frame and the test specimen are given in figs. 2 and 3.

Based on the test results, the following conclusions appear valid:

a) Dry joints composed of top, side and bottom plates with adequate stiffness behaved satisfactorily under reversed cyclic loading. The strength, stiffness and energy dissipation of such members were comparable to those of a monolithic member.

b) Side plates are mandatory for dry joints which are expected to be subjected to reversed cyclic loads. In members without side plates, very large deformations took place and the load carrying capacity was reduced significantly.

c) The width of the joint is an important parameter, especially when the member is subjected to reversed cyclic bending. Therefore tolerances should be checked

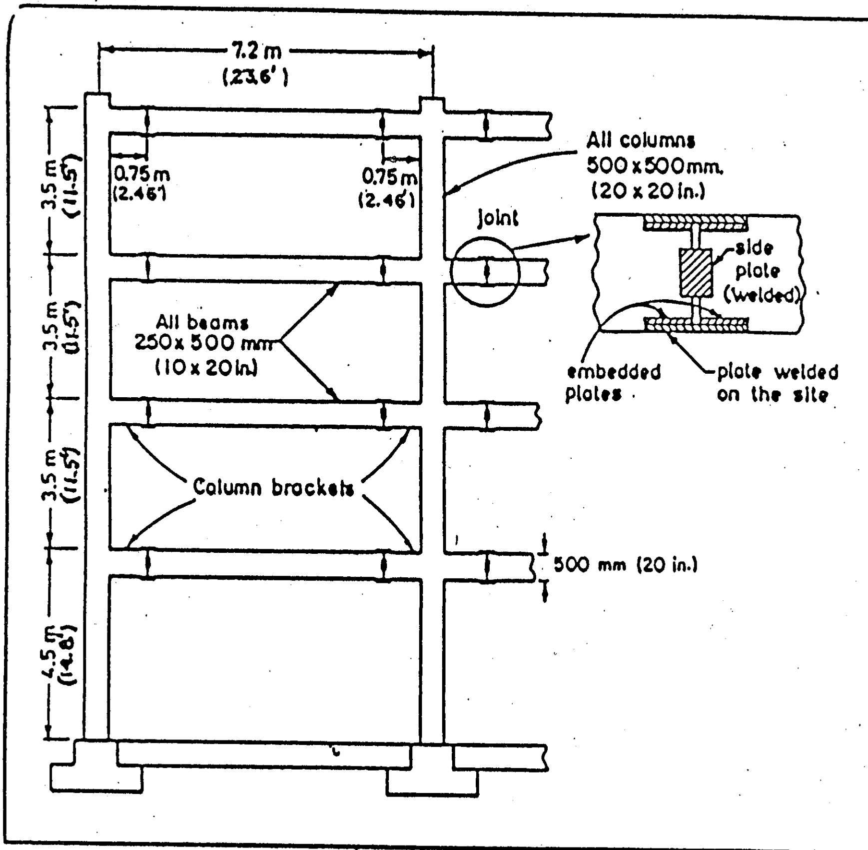

Fig. 2 Prototype precast concrete frame.

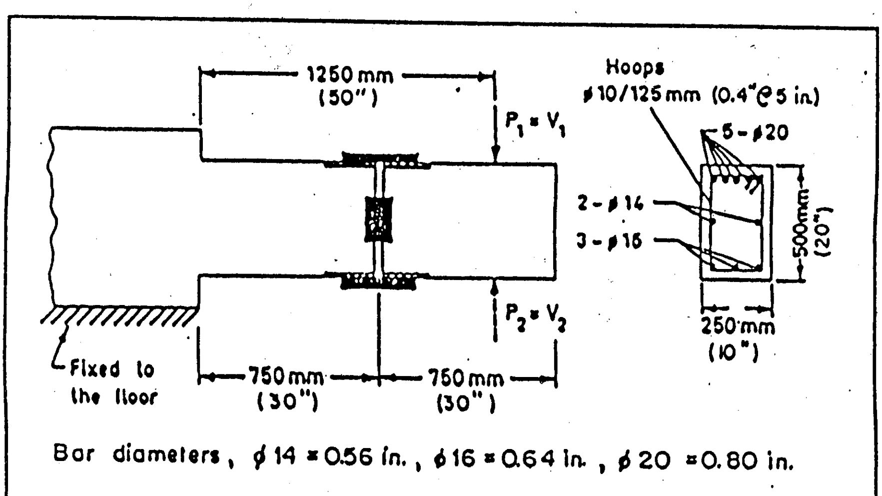

Fig. 3 Test specimen.

carefully on the project side during erection.

In the light of these conclusions the improved connection tested was used by FEGA-GAMA Construction Company.

In [4] details for the behaviour of two full-scale exterior beam-column joints are presented, which were tested under simulated seismic loading. The first specimen was a precast one in which the column and the beam were connected by a wet joint. In connecting the beam to the column, joint reinforcement was welded to the beam reinforcement. Top of the beam and the joint were than filled by concrete in-situ. The second specimen was monolithic one which served as a reference specimen, having identical dimensions and reinforcement as the precast one.

The precast specimen exhibited quite a satisfactory behaviour as regards ductility and energy dissipation, and reached almost the capacity of the monolithic reference specimen. However while the monolithic specimen failed by hinging of the beam at the column face without any significant damage in the joint, the joint of the precast specimen suffered considerable damage. To improve the joint performance of the precast specimen some modifications in the reinforcement detail were proposed.

2.3. Seismic isolation

In [8] the four authors give data for the construction of 36 9-storey large panel residential buildings with system of seismic isolation. This made possible the buildings designed for regions with intensity of 8 to be built in regions with intensity of 9 without changes in the structure. The seismic isolation system consists of slipping supports (fig. 4).

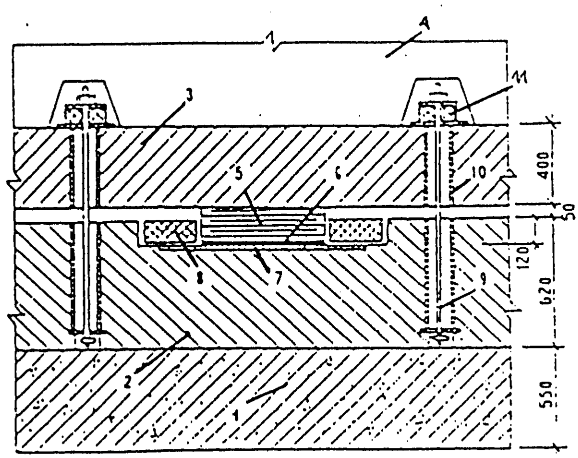

Fig. 4. A slipping support fragment

1 - part of the monolithical foundation; 2 - part of the prefabricated foundation; 3 - refabricated grid; 4 - basement panel; 5 - slipping support; 6 - special plate; 7 - inoxidable steel plate; 8 - damper; 9 - vertical link (anchor); 10 - steel tube; 11- snubber.

The construction of these buildings had been proceeded by a number of scientific investigations and tests as well as of experimental assembling of three 9-storey residential buildings. The analysis of the parameters of the seismic response of one of the experimentally tested building shows a considerable reduction (up to 4 times) of the internal forces of the elements of the structure compared to the respective forces in the same building but without seismic isolation.

At the end the authors consider that there is a persistent practical necessity for including in the code in force requirements for the design of buildings with new systems for seismic isolations.

3. LEARNING FROM EARTHQUAKES

Recent destructive earthquakes which have occurred in the last years gave new valuable information for improving the existing design approaches and seismic building code concepts. This is mainly in force for the prefabricated structural systems which in comparison to other building systems are built and used just from very short time from historical point of view. For this the specialists working in the field of prefabricated building structures pay special attention to this problem.

One can say that the learning from earthquake is the most valuable and important part of the research for developing safe structures in earthquake prone areas. The earthquake serves as natural laboratory. Unfortunately sometimes the price of the lessons is too expensive: the losses of hundreds and thousands of human lives and severe consequences for the economics and the culture.

4. LOOKING FOR NEW BUILDING STRUCTURE SYSTEMS

The prefabricated building structures have their advantages compared to the other systems and at the same time have disadvantages. For example the large panel building construction does not satisfy either the architects because of the "stiff" structural schemes which limit the architectural variety, or the users who accommodate flats which not always comply with the up-to-date aesthetical and utilization requirements, and which do not allow changes and modernization.

That is why from a number of years on investigations are carried out to make such an universal structural system on the base of a prefabrication in which the disadvantages of the prefabricated building system at present applied to be reduced or even eliminated. Some authors even aim at development of such an universal structural system which could serve for erection of residential, public and industrial buildings, located in arbitrary natural and climatic conditions including earthquake prone zones, by using elements which can be mutually interchanged. A proposal of such an universal structural system is presented by the Russian specialist Gelfand [7].

The aim of the development of "Universal Structural System" is the creating of technical basis for the transition to one "open" architectural-building system for different types of buildings.

The achievement of the so stated aim can be done by solving a lot of problems (11 in number) which are presented in details by the author.

From technical point of view the essence of the proposed Universal Structural System consists in insuring unified way of connecting all neighbouring sides of the wall and floor elements regardless of the type and thickness of the connecting elements and their location in plan. This is achieved by giving special shape of the joining sides of the wall and panel elements as well as of the elements of the skeleton (frame) and spatial block elements.

The proposed system of connecting allows maximum unification of the elements. On this basis a unified catalogue will be published from which all types of buildings can be composed in unlimited number of variants for the spatial and the layout decisions which are inscribed in the modular reference grid (mesh) of the axes.

In the base of the modular mesh of the residential buildings an enlarged module 3M (300 mm) or 6M (600 mm) is proposed, which corresponds to the recommendations of the international system for modular coordination in the design and construction. On this basis and when accepting the storey height for the residential buildings of 28M (2800 mm), and for the maximal dimensions of 3.6/7.2 m, the result is that for the inside and outside panels and for the floor panels there are totally 170 nominal sizes, which is about 12 times less than those applied up to now.

Apart from the advantages that come from this significant reduction of the nominal sizes, the author emphasizes on other advantages which are described in details. Among them the author points out the insuring of increased resistance of the building under seismic excitations by autonomic reinforcing of the joints.

The solving of the problem for insuring the standardization (unification) of the elements of multistorey buildings in regions with high seismicity in a number of cases is complicated by the necessity to increase the strength of the bearing structure in the lower storeys by increasing the reinforcement of the elements themselves. This will lead to the appearance of additional nominal sizes.

For the realization in practice of the Universal Structural System not only detailed technical development of all the elements and corresponding joints between them are needed but also carrying out scientific investigations and experimental construction. For the latter it is necessary that specialists from research and design institutes and also from the enterprises of the building industry are included in the work.

5. APPLICATION OF THE RESEARCH FINDINGS

The best way for applying the research findings in earthquake engineering practice is to incorporate them in the codes. Some countries have special codes concerning aseismic engineering. Data about EC 8 P1.3.2 Annex "Precast" are given below*. This Annex deals with the aseismic design of concrete structures made partly or entirely from precast elements.

The contents of this Annex are as follows:

1. General
   - 1.0. Field of application
   - 1.1. Identification of global systems

* A draft of this Annex was kindly given by prof. Tassios, Greece.

It is worth emphasizing on some details included in this very important Annex to the EC 8. For example the following provisions are given in terms of the connections of precast elements (fig. 5):

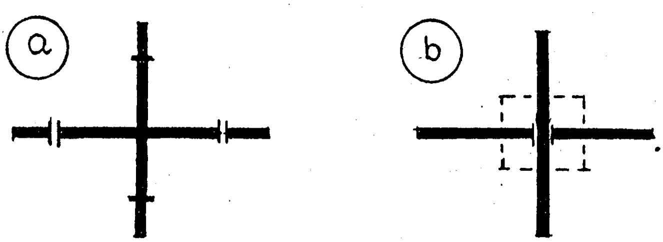

Fig.5

a) The connections outside critical regions (fig. 5a) shall observe the following design rules:

- They should be located at distances larger than "h" from the end-face of the closest critical region ("h" denoting the largest height of the connected elements).

- Their design action-effects should be further factored by 1.1 to cover uncertainties related to the analysis of precast systems.

b) The design action-effects of the connections within critical regions (fig. 5b) shall be factored by 2.0 in DC "M" or by 1.5 in DC "L". The same rule itself applies for the precast elements in an length equal to 1.5 lp, where "l_p" denotes the length of the critical region.

6. CONCLUSION

The applying of prefabricated building structures in seismic regions continues along with intensive theoretical and experimental investigations with the aim to increase their seismic safety during the expected earthquakes and on the other side to reduce or even to eliminate some of the shortcomings that accompany this method of construction.

Special attention is drawn to the study of the connections which is the crucial problem both in the design and the assemblage. Detailed investigations are being carried out to established more correct methods for design through better modelling as well as by taking into account the behaviour of the structure in nonelastic stage.

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