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Review of research in the function of structural engineering development in Serbia*

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ABSTRACT

Research at faculties in Serbia after WWII, even though they were fruit of individual efforts, resulted in significant theoretical contributions. Organized, mostly applied research was conducted within institutes with participation of scholars and researchers of the faculties. Since 1952, the Association of Yugoslav Laboratories (AYL) consolidated the research, thus providing a considerable contribution to the structural engineering in Serbia. This contribution in the field of theory and practice was the basis for the notable achievements that glorified our structural engineering worldwide. Theoretical contributions contained in the doctoral dissertations in the field of Theory of structures and Geotechnics are significant, so they were listed in the paper. Majority of these studies became a part of research project as late as in 1976, and they are briefly presented in the paper. The synthesis of project results from fundamental and technological development research was published in numerous monographs, articles, papers and proceedings of scientific and professional meetings and some of them are commented in this paper. The necessity to introduce technical regulations which have already been adopted in the EU countries EN 1990 to 1999, i.e. the Eurocode, was emphasized. There is a brief discussion of several research directions which are topical nationwide as well as worldwide.

1 Introduction

Yugoslav Society for Testing of Materials and Structures (YUSTMS), now Society for Testing of Materials and Structures (STMS) of Serbia was preceded by the Association of Laboratories for Testing Materials and Structures founded on May 10th 1952. Subsequently, the scope of the work of the Association was discussed, and it was adopted that its activities should follow the program of RILEM, and that it should contribute to the development of the standards in the domain of methods of material and structural testing (MST) jointly with the Association for Standardization. It was agreed to establish divisions in each Republic. Publication of the Bulletin, as a precursor of the present day journal Building Materials and Structures (BMS), provided better information about obtained results in the field of material and structures. In the first phase of publication, apart from information, short abstracts of the papers delivered on the annual assembly meetings were published as well. Although in creation of the structures, the most important place belongs to designers, their relation with researchers and manufacturers (prefabricated elements building) and contractors are significant. Materials and structures are often considered jointly, as the research and improvement of materials and their properties is of special interest for the development of structural engineering.

The research described in this paper, was realized in different periods and under different conditions, and span the period from WWII till the present days. However, in the monographs [44] several periods were included. The first refers to the work of the Great school 1903-1905, the second to the operation of the Department at the Technical Faculty of the University of Belgrade with the status of teaching civil engineering over the period 1918-1941. After the WWII, the Technical faculty proposed consolidation of the studies and in1948 the Faculty of Civil Engineering was established (FCE), and its educational reforms until 1978 were described in the monograph. The faculties in other educational centres, i.e. Niš, Priština, Novi Sad and Subotica were formed with a significant effort of scholars and researchers of the FCE Belgrade. Even though several institutes were established after WWII, faculties were also engaged in scientific-

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research work and facilitated cooperation with the economy, mostly through their institutes. The research work at the faculties in Serbia after WWII was the result of enthusiasm and individual efforts with significant theoretical contribution. Organized, mostly applied research was conducted within institutes with participation of scholars and researchers of the faculties.

Association of Yugoslav Laboratories (AYL) since its foundation in 1952 unites the research work of the institutes and directs it towards topical issues in civil engineering, with strong synergy of theory and practice. Such operation, even though it was insufficiently financially supported, considerably contributed the development of structural engineering in Serbia in realization of a number of structures which represent remarkable achievements at the global level [1] and [8]. The theoretical contribution of doctoral dissertations and master thesis in the field of theory of structures and geotechnics was the basis and encouragement to the development of structural engineering in our country. Only since 1976 the work on the doctoral dissertations was connected to the research projects, which were financed from the funds of the Republic and Autonomous regions, or from other sources (economy, chamber). The list of doctoral disserta¬tions is presented in this paper along with the titles from which one may observe the themes considered and their importance for structural engineering. Only some of the research projects in the field of fundamental and technological development research were commented upon and in addition, the important publications resulting from them are listed. In Serbia, a research work on the studies and translation of technical regulations adopted in the EU countries with the designations EN 1990 do 1999, which are often called Eurocode started ten years ago. The need for further systematic work on their application into practice in our country is emphasized.

In the recent years, an increasing number of researchers is focused on publishing research results in international journals and proceedings from international scientific meetings. The synthesis of results of earlier research projects is published, mostly in our country in a number of monographs, articles in journals and proceedings from scientific and professional meetings which is only partially commented in this paper. In brief, several topical directions of future research in our country and worldwide is mentioned. In this sense, a wider list of references is made indicating the relevance to current interests of contemporary research themes in Serbia.

2 Defended doctoral dissertations at faculties of civil engineering in Serbia

2.1 Doctoral dissertations defended at the Faculty of Civil Engineering in Belgrade

Dragoš Radenković: *Bending of curved members in plane* (1953); Milan Đurić: *Theory of long prismatic polyhedral shell* (1953); Vladimir Bogunović: *On bending of rectangular plate with one degree of freedom* (1953); Nikola Hajdin: *One procedure for numerical solving ultimate (boundary) tasks and its application on some problems of Theory of elasticity* (1956); Vlatko Brčić: *Toward the solution of flat problem of the Elasticity Theory* (1956); Aleksandar Vesić: *Fundamental problems of theory and calculation of a system of piles* (1956); Dušan Krsmanović: *Impact of stiffness, continuity and discontinuity on calculation of structures supported on the soil* (1957); Milorad Ivković: *Behaviour of concrete in the area of limit equilibrium* (1962); Živojin Hiba: *Towards the theory of steel anchored suspended bridges with the beam for stiffening the incomplete flexibility* (1963); Branko Zarić: *Buckling of steel members in the plastic area* (1963); Vlade Vračarić: *Cooperation of deck and main beams of steel truss railway bridges* (1965); Dimitrije Dimitrijević: *Behaviour of RC and composite members with participation of concrete creep at dynamic load* (1973); Jakov Lazić: *Application of linear visco-elasticity in the structural theory* (1973); Miodrag Sekulović: *Thin-walled member curved in space* (1973); Mihajlo Muravljov: *Behaviour of thin-walled open-profile members of pre-stressed concrete at limited torsion with the concrete flow effects* (1975); Ratko Stojanović: *Resistance of paraseismical structures on the action of explosive shock* (1975); Vera Lazić: *Dynamic stability of curved members of visco-elastic material* (1975); Milutin Marjanov: *Solution of composite problems of thermal-elasticity in a confined environment* (1977); Milan Gojković: *Stone bridges from the 14th to the 18th century in Yugoslavian boundaries* (1977); Milan Lazić: *Parameters of general optimality when using light-aggregate concrete in panel construction of housing buildings* (1977); Boško Petrović: *Behaviour of skeletal buildings of pre-stressed concrete under the action of seismic forces* (1977); Radoje Vukotić: *Limit states of members of reinforced and pre-stressed concrete loaded by torsion and bending* (1977); Vojislav Mihailović: *Generalized procedure of design of composite and pre-stressed structures* (1978); Dragoljub Nikolić: *Some problems of non-linear analysis of curved members* (1978); Predrag Jovanović: *Towards a structural matrix analysis* (1978); Mirko Aćić: *Towards solving the issue of limit states of reinforced concrete bearing walls* (1978); Stevan Stevanović: *Towards solution of in-plane problem of the theory of elasticity for some semi-infinite areas bounded by polygonal contours* (1978); Milivoje Stanković: *Towards a design of thin-walled members with deformable cross-section* (1978); Živorad Radosavljević: *Analysis of rationality of ultimate limit state of concrete* (1978); Života Perišić*: A contribution to determination of creep and shrinking effects in cracked reinforced concrete cross sections with cracks* (1979); Aleksandar Pakvor: *Towards a study of thermal stresses and strain of concrete blocks* (1979); Šerif Dunica: *Towards a plastic analysis of spatial linear systems, composed of truss, full and thin-walled elements* (1979); Živojin Praščević: *Non-linear theory of reinforced concrete member* (1979); Miloš Manojlović: *Towards a theory of dynamic behaviour of soil* (1979); Branislav Kolunžija*: Towards a second order theory of spatial linear systems composed of truss, full and thin-walled elements* (1979); Dušan Milovanović: *Latest findings in the theory of arch dams* (1980); Čedomir Vujičić: *Towards optimizing design of reinforced concrete walls built directly on soil* (1980); Savo Vukelić: *Analysis of mechanical states of hardened concrete – thermo-dynamical approach* (1981); Milorad Ristić: *Towards an analysis of elastic, pre-stressed networks* (1981); Slavko Zdravković: *Mathematical*

modelling of bridge road decks structures to dynamic and seismic action (1981); Branislav Ćorić: *Theoretical and experimental analysis of local and lateral buckling of steel I beam of a deformable cross section* (1982); Dragoljub Grbić: *Oscillations of elastic members at ultimate displacements* (1982); Radomir Folić: *Towards a study of T beams – analysis of active slab width and ultimate states of reinforced concrete pre-stressed concrete elements* (1983); Srđan Venečanin*: Impact of thermal incompatibility of concrete components on its strength* (1983); Jovanka Zurovac: *Towards an analysis of elastoplastic behaviour of reinforced concrete beam* (1983); Petar Petrović: *Numerical solution of Lame's equations of the elasticity theory using the integral equation method* (1985); Dimitrije Rajić: *Towards a non-linear theory of thin elastic shells and its application* (1985); Kisin Srđan (then from Sarajevo): *Towards a theoretical experimental analysis of lateral buckling of mono-symmetrical beams of deformable cross section* (1985); Aleksandar Babović: *Ultimate limit state of eccentrically compressed RC columns in steel tubes* (1985); Dejan Bajić: *Towards non-linear analysis of RC linear elements* (1985); Stanko Brčić: *Dynamic behaviour of structures in fluid environment* (1987); Cvijetin Kanjerić: *Analysis of flat frame beams stressed beyond the proportionality limit* (1987); Živorad Bojović: *Elastic damped systems exposed to the load which depends on their configurations under small strain and large displacements* (1988); Miloš Lazović: *Towards a non-linear analysis of axially loaded pile* (1988); Đorđe Vuksanović: *Non-linear analysis of reinforced concrete slabs by the finite element method* (1988); Rastislav Đorđević: *Towards an analysis of long-stroke tooling machines foundation behaviour in service conditions* (1989); Gligor Radenković: *General non-linear analysis of shells based on triangular and general quadrangular finite element* (1989); Branislav Pujević: *Towards a non-linear analysis of thin-walled reinforced concrete structures* (1989); Dragan Buđevac: *Towards a design and structural formation of cold-rolled profiles of an open cross-section* (1990); Mihajlo Đurđević: *Behaviour of concrete composite prefabricate elements and connections in the area of failure* (1990); Aleksandar Prokić: *Thin-walled beams of open-closed cross-section* (1990); Ljubomir Savić: *Towards a mathematical research of some statistical problems of non-linear behaviour of structures* (1990); Gajin Slobodan: *Non-linear dynamic analysis of foundations of electro-mechanical transmissions and their vibro-insulation* (1992); Biljana Deretić-Stojanović: *Design of composite structures using strain method* (1992); Mira Petronijević: *Analysis of dynamic interaction of soil and structure applying finite element method* (1993); Rastislav Mandić: *Modelling interaction of reinforcement and concrete in reinforced concrete structures applying the finite element method* (1994); Milan V. Matović: *Towards an analysis of stress and displacement of thin-walled composite beams* (1996); Želimir J. Kovačević: *Concrete bridges maintenance management systems* (1997); Dragan Č. Lukić: *Towards a method of defining the stress state around the cavity in the form of rotating ellipsoid applying elliptical coordinates* (1998); Miroslav T. Bešević: *Towards an analysis of centrically loaded steel members of complex cross-sections of cold-rolled profiles* (1999); Petar B. Santrač: *Analysis of strip foundation behaviour on sand* (1999); Zoran M. Mišković: *Application of stress fields based on the theory of plasticity for determination of ultimate limit state of reinforced concrete bearing walls* (2000); Ratko M. Salatić: *Analysis and control of behaviour of steel frames at earthquake action* (2001); Snežana B. Marinković: *Ultimate limit state at punching shear of prefabricated pre-stressed slabs in the area of fringing columns* (2002); Dušan I. Kovačević: *Numerical modelling behaviour of reinforced concrete frames loaded by seismic forces* (2002); Milorad T. Komnenović: *Analysis of stress states of curved beams of laminated glued timber loaded by bending* (2002); Zlatko A. Marković: *Towards an analysis of bearing capacity of mechanical connectors for thin-walled steel elements* (2002); Boško D. Stevanović: *Behaviour of composite beams timber-concrete constructed with mechanical connectors at service and limit load* (2003); Vlastimir S. Radonjanin: *Parametric analysis of characteristics of repair mortar from the aspect of their application during rehabilitation of reinforced concrete structure* (2003); Nenad G. Marković: *Buckling of tin beams under the action of the local load* (2003); Mirjana Ž. Vukićević: *Application of elasto-plastic models for soil in design of flexible support structures* (2007); Ljudmila /Timofejev/ Kudrjavceva: *Thermoviscoelasticity and damage of composites on polymer basis* (2007); Vladan M. Kuzmanović: *Towards a thermal design of gravity dams of rolled concrete* (2007); Špiro L. Gopčević: *Non-linear analysis of structures with cables* (2007); Snežana Mašović: *Redistribution of impacts in subsequently extended composite reinforced concrete beams in time* (2008); Ruža Okrajnov-Bajić: *High early strength SCC in elements with prominent main tensile stresses* (2009); Ljiljana Žugić-Zornija: *Non-linear analysis of cable-stayed bridges* (2009); Dimitrije Zakić: *Research of the parameters of ductility and impact resistance of fine grain concretes micro-reinforced by synthetic fibres* (2010); Marina Ćetković: *Non-linear behaviour of laminate composite slabs* (2011). At the Faculty of Mathematical and Natural Sciences, Slavko Ranković defended the dissertation in 1973, and at E.P.F. in Lausanne Dušan Najdanović (1987).

There are several dissertations defended by the candidate from other Republics, mostly from Macedonia with very topical themes at the time dealing with earthquake engineering, and several from Montenegro, dealing with experimental and theoretical research of structures. From Slovenia, there is a dissertation related to the interaction and rheological material issues - Houška Mladen: *Interaction of the structure and foundations regarding the static and rheological characteristics of material* (1980); From Macedonia: Apostol Poceski*: Impact type earthquakes and paraseismical construction* (1968); Jakim Petrovski: *Modelling soil and structure parameters to the dynamical reaction of dug-in foundations* (1974); Dimitar Jurukovski: *Formulation of the mathematical model of two-storey high steel frame applying parametric identification of the system* (1981); Boris Simeonov: *Linear and nonlinear behaviour of reinforced-concrete diaphragms of multi-storey structures* (1982); Predrag Gavrilović: *Shear strength of reinforced concrete structures in nonlinear area for cyclic and dynamic loads* (1982); Ištvan Kladek: *Prilog kon primenata na varijacionite metodi za rešavanje na tenki ljušpi (Towards an application of variation methods for designing thin shells)* (1983); Andrej Spasov: *Model of short duration earthquake* (1984); Goce Popovski: *Experimental and theoretical*

research of connections of prefabricated and subsequently placed concrete (1988); From Montenegro Duško V. Lučić: *Towards stability analysis of thin-walled beams* (1999); Pero A. Vujović*: Influence of weathering strain on the ultimate limit states of reinforced concrete slabs stressed in their plane* (2000); Radomir M. Zejak: *Towards an analysis of obliquely bended slender reinforced concrete elements* (2003); Olga Mijušković: *Stability analysis of rectangular slabs using accurate stress function* (2008).

2.2 Doctoral dissertations defended at FCE (Faculties of Civil Engineering) in Niš, Priština, Novi Sad and Subotica

During the 1970s, there were several leading visiting researchers at FCE in Niš among whom the famous Prof. Marcel Save delivered lectures at Seminars dealing with the past and present topical field of studies of the Theory of plasticity. This inspired the scholars and researchers to fully engage in this field of studies, so a number of dissertations was written dealing with the same subject and its application for optimal structural design. The following dissertations were defended: Tomislav Igić: *Towards an optimum design of structures* (1980); Milić Miličević: *One procedure of limit analysis of transversely loaded polygonal plates with the special focus on trapezoidal plates* (1980); Dobrivoje Stanković: *Finite elements method* (1980); Tomislav Radojičić*: Main stresses and ultimate bearing capacity of elements* (1980); Sreten Stevanović: *Ultimate bearing capacity of linear beams*; Dragutin Rodić: *Towards a solution of the problem of medium columns of bridges*; Popović Branko: *Problems of ultimate failure state of linear systems of classical RC structures* (1982); Grozdana Radivojević: *Effects of variation of stiffness on the elastic stability of linear systems* (1982); Dragoljub Drenić: *Analysis of crack propagation under the action of impact load in the high strength steel* (1982); Novak Spasojević: *Forced damped vibrations of beam systems in plane with a special focus on bridge structures* (1983); Milisav Damjanović: *Towards a solution of architectonic-structural problems of high-rise buildings in the system of spatial frame structures with wall bars* (1983); Dragan Veličković: *Determination of ultimate bearing capacity of arbitrary cross section of thin-walled beam with a deformable contour* (1985); Miodrag Đinđić*: Stability analysis of tunnel structures of horse-shoe cross-section in elasto-plastic environment, depending on construction technology* (1985); Hristo Kapsarov: *Towards aseisimic design of tower-type high RC facilities* (1985); Dušan Petković: *Concrete-concrete composite* (1987); Dragoslav Stojić: *Lateral stability of glued laminated timber beams loaded to bending and torsion* (1987); Verka Prolović: *Foundations of smith hammers as sources of vibration and their influence on adjacent structures* (1992); Ljubomir Vlajić: *Behaviour of connections with friction grip bolts at service and ultimate load* (1993); Vladimir Radojičić: *Bending of beams of high early strength concrete with lateral forces* (2000); Marina Mijalković: *Analysis of stress and strain state of spatial linear girders according to second order theory* (2001); Dragan Kostić: *Towards the solution of the stability problem of double catenary systems* (2007); Zoran Bonić: *Towards a theory of calculation of failure by punching shear of foundation footings supported by deformable subsoil* (2011); Slobodan Ranković: *Experimental-theoretical analysis of ultimate limit states of RC linear beams strengthened by composition with NSM fiber composites* (2011); Predrag Blagojević: *Experimental-theoretical analysis of ultimate limit states of micro-reinforced concrete beams* (2012).

The following dissertations were defended at the Faculty of Civil Engineering in Priština: Vukomir Savić: *Mixed Finite elements method for cylindrical shells* (1986); Petar Čolić: *Ultimate limit states of composite prefabricated concrete structures* (1987); Aleksandar Ristovski: *Behaviour of pre-stressed structures in time, under long-term loads* (2001); Mirsad Tarić: *Towards the design of composite structures steel beam – concrete* (2004).

The following dissertations related to structural engineering were defended at the Faculty of Technical Sciences (FTS) in Novi Sad: Svetlana Žorić: *Experimental and analytical research of RC walls with opening under seismic load* (1990); Milan Letić: *Structure of the system for automatic designing of industrialized prefabricated housing buildings* (1991); Mitar Đogo: *Towards a theory of foundation design of finite stiffness in multi-layered system* (1996); Ratko Maretić: *Stability and oscillations of a rotating circular slab* (1997); Slobodan Krnjetin: *Towards a determination of necessary fire resistance of concrete buildings* (1999); Đorđe Lađinović: *Multi-criterion analysis of seismic resistance of structures of reinforced concrete* (2002); Jasmina Dražić: *Analysis of interdependence of functional and structural characteristics of buildings in aseismic designing* (2005); Emil Popović: *Development of the model of maintenance of locks with segmental gates at the example of the hydro-system Danube -Tisa- Danube* (2007); Vladimir Nikolić: *Exploration of the newly proposed pile with widened stem* (2007); Zoran Brujić: *Analysis of ultimate bearing capacity of RC columns bended in two axes* (2008); Tatjana Kočetov-Mišulić: *Behaviour of forged connections of bearing wooden wall panels* (2008); Todor Vacev: *Optimum design of a node of the spatial steel grid applying non-linear analysis* (2009).

The following dissertations in the field of engineering structures were defended at The Faculty of Civil Engineering in Subotica: Danijel Kukaras: *Experimental-theoretical analysis and calculus modelling of behaviour of prefabricated beams connected with friction grip bolts* (2008); Ilija Miličić: *Theoretical-experimental analysis of redistribution of the load when determining serviceability of bridge structures* (2008); Danica Goleš: *Rheologoical-dynamic analysis of RC polyhedral shells* (2012).

3 Bulletin, journal, congresses and conventions of YUSTMS/STMS

3.1 Bulletin and journal and research in YUSTMS and Institutes

Since 1952 when the Association of Yugoslav Laboratories (AYL) was founded until 1966, assembly meetings and conventions were held, where articles and latest information were presented. They were related to the activities of RILEM-a, research programs of the Institute, and in 1957 it was decided to publish the Bulletin, which is a

precursor of MS (Materials and Structure). In the later period, the publication of professional and scientific articles commenced. The works of the Institute researchers were prevailing over those from the Faculty. Until 1960, there was only the Faculty of Civil Engineering (FCE) of Belgrade. FCE in Niš was founded in 1960. In Priština, in the framework of the Technical Faculty, the Civil Engineering curriculum has been taught since 1967, and in Novi Sad since 1971, at the Faculty of Mechanical Engineering, and since 1974 as a part of the Faculty of Technical Sciences. On the same year, the FCE in Subotica was established, and six years ago FCE was founded at the State University in Novi Pazar. All the mentioned Faculties were established with engagement of the scholars from FCE in Belgrade.

At the beginning of its operation, AYL organized congresses with presentation of papers and discussions simultaneously with assembly meetings. At the congress on 12th June 1958 the main presentation was: *Materials and structures in housing construction* (Milutin Maksimović). The need for full prefabrication and assembly of large standard building elements, or application of semi-prefabricated construction was emphasized in this presentation. This was meant to save timber. Prefabrication of floors and ceiling structures was recommended and modular standard measures and usage of light concrete was prescribed. It was the initial impulse for the development of prefabricated systems of building construction. On the occasion of 12th Congress of RILEM held in July 1958, Beograd-Zagreb-Ljubljana, a jubilee issue of the Bulletin 3/1959 was published. The paper of Branko Žeželj: *About the new possibilities offered by the pre-stressed concrete applying prefabrication in skeletal structures* was published in this Bulletin. This paper was the basis for the development of pre-fabricates system IMS–Žeželj. In the Bulletin 3/59 Hubert Rüsch published a brief abstract of the paper: *A newer theory of bending of RC structures on the basis of the testing in Munich – influence of load duration*. This paper influenced the orientation of researchers in this field of studies in our country. More details on this meeting can be found in [37].

The Bulletin published the presentations of significant structures. Thus, in the Bulletin No. 1/1958 new road bridge in Belgrade (Milan Radojković) was presented. Apart from that, the results of testing of wires for pre-stressed concrete were presented and tests of steel by torsion fatigue. The model of the Hall 1 of the Belgrade Fair (B. Petrović) was presented. By testing the influence of age on the concretes with aluminate cement (Vidan Matić) it was determined that except for the increase of strength till 28 days of age and stagnation until 3 months, there was a decrease of strength of 40% after 20 years. For this reason, it was proposed to add anhydrides to aluminium cement so as to prevent the decrease of strength at high temperatures. In addition, the methodology of testing of hydraulic structures (B. Kujunždić) and adhesive for timber structures was presented as well. The review of the papers of the members of the Association in 1957 was given, in which the members of IMS stood out. For the purpose of rational application of materials in structures, resistance of concrete to corrosion and finding protective methods was investigated. Testing structures on the models (Boško Petrović and Dobrosav Jevtić) and testing structures until failure when using domestic wires for pre-stressed concrete were presented. Construction of structures of laminated timber and their application in civil engineering were studied. The structural testing with dynamic analysis of mobile load for road and railway bridges was presented. Technical conditions (specifications) for assembly of steel structures were investigated (SS-ČK).

Along with the 9th annual assembly, the Association convention was held, with two topics: Structures and materials in housing construction and Problems of bearing steel structure. The influence of RILEM and its Congresses and Meetings (colloquia) was present in the choice of topics of the Association, so the following topics were considered: international standards, concrete and influence of passage of time and physical and chemical causes to deformation, cement, mortar, technical timber, fungi infested timber, metals, masonry columns etc. The laboratory for structural testing at FCE in Belgrade became a member of the Association, and the spatial action of truss structures was studied with the presentation of tests of concrete halls and the new bridge on the Sava river, with test of welding capacity, fatigue and plastic properties of steel (designations Č52 and Č37).

An experimental multi-storey building was tested in IMS. Light cellular concrete was tested and considered (IMS), and coffered slabs made of pre-stressed concrete with hollow masonry blocks were tested as well. The issue of industrialization is related to the physics of buildings and flexibility from the aspect of architectonic functional design. A new type of skeletal structure for high-rise housing buildings form which the IMS-Žeželj system developed was presented. In IMS floor ceilings and roof rafters made of pre-stressed concrete were investigated. Relations with architectonic requirements were established (standardization of spans between the bearing walls and openings in them, floor height and other). The activities of RILEM and their recommendations (effects of age on concrete, influence of constant load and fatigue) were published in the Bulletin. Bearing steel structures were more thoroughly researched in Slovenia.

In the Bulletin No. 3/60 a review of papers– tasks in IMS was given: nature of the task, description of work, phases of production, results and publication, development and improvement of the equipment for pre-stressing, testing stress losses (B. Petrović), standardization of structures in housing construction, standardization of formwork for concreting works, prototypes of high voltage pre-stressed concrete poles, buckling of pre-stressed concrete members.

At the 10th assembly meeting in Zagreb, in 1960, the need to link the research work and "production capacities" was emphasized. In addition, linking design and building with research work was pointed out as well. The paper of B. Žeželj about the problems of scientific work in civil engineering was published in Bulletin No. 1/60 where the role of AYL was emphasized. In addition, in the other issues, the information about the activities of the Institute was provided. The expert committees were established, among which the Committee for industrialization of building (Head - B. Žeželj) and subcommittee for the research of concrete corrosion. Prof.

M. Radojković presented the paper about bridge testing. In Bulletin No. 4/61 works of the Institute "Jaroslav Černi" for hydraulic structures, for the dams with model static tests were presented along with the work on technical instructions for calculus of stress state in the silo bays (cells) and study of arch dams (buckling of arcs) were published. In addition, the work of the Committee for concrete in IMS and for soil mechanics and foundation engineering with conclusions was presented. In the issue No. 4/61 Vidan Matić published the paper on application and protection of steel cables in civil engineering (types and cables) and J. Hahamović on the fire protection.

Scholars in the Institute "Jaroslav Černi" worked on auscultation of several dams, testing pile bearing capacity and pre-stressing of linings of hydraulic engineering tunnels. The application of photo-elastic methods for testing stress states and other methods adapted to the specific properties of hydraulic structures (dams) started, not only in Serbia but in other republics as well. At FCE, steel was tested on impact, strength of welded seams for the bridges across the Danube in Belgrade. In addition, the stress concentration of gusset pieces and the effects of apertures on the mentioned bridge were tested, as well as the carrying capacity of the cranes. Stress-optical analysis was applied on the spatial models.

Similarly as in RILEM, on 3rd December 1959, the Committee for concrete was founded, whose chair was professor Dobrosav Jevtić, in order to unite the research work of concrete technology and concrete structures which the collective and individual members of the Association were conducting, and to organize conventions regarding certain issues of Concrete structures which were important for further development and improvement of concrete and concrete structures.

In issue No. 1/62 Borislava Zakić's paper on the application of the theory of failure in timber structures was published. The activities of the Institute "Jaroslav Černi" and subcommittee for concrete corrosion were described. In the issue No. 2/62 V. Joksić wrote about concrete corrosion, and L. Jovanović wrote about the devices for loading static models in the Institute "Jaroslav Černi". In the issue No. 3/62 there is a presentation of the bridge across the Danube in Novi Sad (B. Žeželj) and the prefabricated pre-stressed concrete system (PC). V. Brčić wrote about the 6th Congress for theoretical and applied mechanics in Split. In the issue No. 4/62 B. Kujundžić wrote about the state of affairs in the field of rock mechanics and underground works, and I. Karpinski from IMS wrote about research aimed at increasing concrete resistance to corrosion. In the issue No. 1/63 grouting instructions, arch dam design instructions and photo-elastic tests instructions were published and the text about brittle coatings.

Along with the 11th assembly meeting (Belgrade, 1963) the convention of the topical issues in civil engineering was held. The submitted papers considered the topical issues of materials and structures, but also, soil mechanics and foundation engineering (D. Krsmanović). In 1963 the Bulletin was renamed into Materials and structures (MS) after the RILEM journal. Very intensive activities in AYL were stirred by the earthquake in Skopje on 26th of July 1963. In Bulletin No. 2/63 Ž. Hiba wrote about insufficiently strong structures for seismic actions. In the issue No. 4/63, D. Jevtić wrote about some problems regarding the earthquake in Skopje with the program of production of technical documents, recommendations and regulations for construction in seismic areas, and authors from Ljubljana wrote about the theory of plasticity. The considerable experience of the engaged researchers of the Institute while recording the damaged buildings was used for making the first Temporary technical regulations for construction in seismic areas. A special issue was published regarding the earthquake in Skopje. In the journal MS No. 5/63 B. Zakić's paper was published - *Design, production and testing of bearing elements of solid timber and various panels of timber, and testing of wrought and glued support structures, and about durability of concrete structures made with aluminized cement.*

The work of D. Jevtić in the European Committee for Concrete (ECC) and B. Žeželj and B. Petrović in the International organization for pre-stressing FIP was very important since it initiated our active participation in the international cooperation. D. Jevtić wrote about ECC and the effects of the earthquake in the issue No. 1/65. In No. 3/65 Natalija Naerlović-Veljković published: *Towards the study of thermal deformation of cylinders of non-elastic material*, in No. 6/65: *Towards the calculation of thermal stresses in a hollow sphere*. In No. 4/65 V. Brčić published: *Application of photo-elastic coatings when testing structures and their models,* and in No. 2/66: *Towards photoviscoelastic testing of structures*. Z. Pavlović wrote the review of the technical regulations (TR) for support (bearing) steel structures. In the issue No. 5/66 V Joksić from the Institute "Jaroslav Černi" wrote: *Grouting instruction*, D. Milovanović wrote about testing of counterforts of multiple arch dams, O. Marković wrote on standardization of bridges on irrigation and drainage canals, K. Ivanović wrote about the effects of earthquakes on tall dams. Z. Pavlović and K. Ivanović wrote about the study of rational designing and construction of locks and gates. V. Brčić et al. wrote about stresses and abutments of dams, and V. Brčić and A. Pakvor wrote about photoelastic testing of the nuclear reactor casing and model tests of the stress in the system dam-rock (interaction). The themes of the Bulletin No. 4/66 were: Construction and technical regulations from the aspect of contemporary needs and adaptation of foreign regulations; about control and safety of tall dams. The emphasis was on the attitude that improvement of the regulations was a prerequisite for the improvement of the quality of BMS (building materials and structures).

The research of the calculation methods of arch dams was carried out with static model tests, on spatial models in the elastic area, and until failure. The tests of the dynamic calculation of dams *in situ* were done on the dams on Zlatibor and Modrac (B and H). Therefore, the mechanics of rocks and geotechnics was researched, by P. Anagnosti and R. Stojadinović with associates. Ž. Radosavljević with B. Kujundžić and associates in the Institute "Jaroslav Černi" developed the design methods of pressurized hydraulic structure tunnels, and published two monographs: *Grouting of hydraulic engineering tunnels and shafts under pressure* and *Pre-stressed linings of hydraulic engineering tunnels under pressure.*

In the issue No. 5/66 the general report of Milan Krstić: *New and improved structures which were prepared for the Symposium and the 12th Congress* (Sarajevo 1966) along

with the papers of the members of the Association as well as the reports were published. It is underlined that "it is necessary to construct sufficiently safe structures with the minimum consumption of material and labour. It is a basic task of structural engineers and constructors. The science should not provide theoretical elaborations of already realized practical achievements, but it should take the lead". The papers were organized into groups and presented. The first group of papers was theoretical, the second was tests of constructed buildings, the third was application of new materials in structures, and the fourth was presentation of finished buildings. R. Stojadinović wrote about the potentials of creating new engineering structures on the deposits of waste rock dumps in the industrial zone of Trepča in Zvečan.

In those circumstances, there was a tendency to use nationally conceived devices for structural testing. Thus, a domestic device for production of strain gauge with wide application in structural testing was presented in the issue No. 1/67. The cooperation of scholars at the FCE in Belgrade and Institute "Jaroslav Černi" resulted in several papers and monographs. In the issue No. 2/67 the following paper was published: *Towards the study of underground pressures* by Ž. Radosavljević, Čakarević and B. Čolić, which is important for the tunnels. In the issue No. 4/67 the paper dealing with mechanics of continuous media: *Plastic flow of COSSERAT materials* by S. Đurić was published. The decree of work on technical regulations in the field of civil engineering was issued: for pre-stressed concrete (PC); and for concrete and reinforced concrete (CRC); for the walls; for composite structures steel-concrete; for assembly of steel structures and their protection from corrosion. In the issue No. 2/68 the paper: *Towards the theory of buckling and bending of RC members* by Đorđe Lazarević was published.

Milorad Ivković wrote a paper: *Concrete behaviour in the field of plastic deformations as a part of hydraulic engineering structures*. He provided the initial impulse in this area with his research and paved the way for many young researchers to deal with concrete rheology. Multiple dams were auscultated, bearing capacity of the piles and pre-stressing of hydraulic engineering tunnels were tested. Application of photo-elastic methods in testing the stress states began, as well as other methods – adapting to the specifics of Hydraulic structures, i.e. dams, not only in Serbia but in the other republics as well.

A wider consideration of the research of FCE is given in the separate section. Here is given a review of those already published in the journal M&S. Academician Đ. Lazarević pointed out that research work is inseparable from practice, construction sites, factories and control. This work technique and basis for engineering creativity require knowledge of processing details taking place in the material used for construction, which are particularly interesting for structural engineers from the economic and environmental point of view.

The engagement of the scholars of FCE is particularly important, especially M. Ivković (instructions for calculation of cracks, deformations and rigidity of RC and pre-stressed structures) and D. Jevtić (IMS) at preparation of the Manual for implementation of Code for RC 1972 SJL, i.e. YUSTMS. M. Ivković proposed the calculation of RC member to long lasting load. Thus, he proposed the connection of the stress-strain tensor with introduction of time, that is, age of concrete. In addition, the works of J. Lazić with visco-elastic models, and M. Sekulović with thin-walled members and implementation of FEM are also important. The design of building structures under the action of earthquakes (Dimitrije Dimitrijević), and structure-soil interaction (Miloš Manojlović) are significant as well.

An extensive list of papers published in Bulletin/journal until 2010 is given in reference [10] and they are available in the office of STMS Serbia. The journal was not published over the period from 1984-1988.

3.2 Congresses and meetings

Similarly to Bulletin/Journal and apart from the papers which were published in the proceedings of the conferences, the general reports prevalently dealing with the field of material testing were published as well. Only the papers in the function of the development of our structural design were listed in this paper along with undoubtedly significant achievements published in [1] and [8]. The names of the authors were given after the titles of papers or groups of papers. The full list of the papers published in Bulletin/ Journal, which was prepared by Vladimir Denić, is published in the Journal No. 4/2010, pp. 57-116. From the list of the papers, it can be observed that at the beginning, the authors from the Institutes IMS, "Jaroslav Černi" and the others were dominant, while the authors from the Faculties prevailed from the beginning of the 1990s. Having in mind that the society of structural engineers presents the achievements in the area of engineering structures and bridges, the topics concerned with the Theory of structures and their testing during construction and under test loads for verification are dominant in this paper. Exceptionally, there are presentations of the bridges across the Neretva river (D. Ćertić) and the bay of Šibenik (Ilija Stojadinović) which were globally recognized achievements at the time. During the past 10 years, there were obligatory themes regarding application of the set of documents EN 1990 to 1999, i.e. Eurocode for structures. These topics were considered at the conferences of the Society of the structural engineers, and in 1995 and 1997 along with FCE in Belgrade, two large conventions dealing with Eurocode were organized. Papers dealing with concrete structures, metal and timber structures dominated at conventions and Congresses of YUSTMS. Significantly less paper considered masonry structures (MS). Therefore, STMS organized several Meetings.

The first was *Addition of floors on housing and public buildings* (2000) with several sections: socio-economic aspects, architectonic-town planning aspects, seismic resistance, structural aspects, geotechnical aspects, etc. Convention *Masonry structures in contemporary civil engineering practice* along with other topics was dealing with structural and aseismic aspects (2001). Scientific-professional meetings *European regulations EN 1996 (Eurocode – 6) and accompanying regulations* (2006) and (2007) covered the topic of simplified design of non-reinforced masonry structures. Durability of structures is topical globally and nationally. The Convention *Civil engineering and sustainable development* was dealing with different thematic segments, and some of them were exceptionally important for our country such as *Designing*

engineering structures from the aspect of durability – extension of their service life. Conference *Masonry structures – bearing capacity, durability and energy efficiency* was held on 24th November 2010. The list of papers presented at these conventions was given in [10]. Some papers of the participants were printed in the proceedings and mentioned further in the text.

General reports written by researchers were appointed in advance and submitted at all organized conferences. Some of them, who participated several times should be mentioned: Dobrosav Jevtić, Milan Krstić, Boško Petrović, Miloš Marinček (Ljubljana), Ljubomir Jevtović, Borislav Zakić and others. More details were given in [37].

12th Congress 1966 (Sarajevo): *About testing pre-stressed structures using the photo-elastic method* (V. Brčić and A. Pakvor); *Effects of high temperatures on characteristics of steel for pre-stressing and Influential diagrams for determinations of moments and deformations created due to pre-stressing and other influences* (D. Jevtić); *Stress and strain state testing on dams using models*, (L. Jovanović); *New possibilities of design of reactor casing of pre-stressed concrete in nuclear power plants* (B. Žeželj). Presentation of bridges: *Road bridge of pre-stressed concrete across the Neretva near Rogotin on the Adriatic highway* (D. Čertić) and *Construction of the bridge across the Bay of Šibenik on the Adriatic highway* (I. Stojadinović). Research results: *Towards an analysis of phenomena and behaviour of loaded structures* (M. Ratajac); *Some pathological phenomena in concrete structures of bridges* **(**B. Zakić); *Control and safety of tall dams* (B. Kujundžić and L. Jovanović). General report was submitted by M. Krstić (as mentioned previously).

13th Congress 1969 (Bled): Model studies of a nuclear reactor casing of pre-stressed concrete. *Tests by photo-elastic method and application of photo-elastic coatings* **(**V**.** Brčić with the associates from the institute "Jaroslav Černi"); *Contemporary fundamental research in the continuum mechanics and potential for application in our civil engineering* (R. Stojanović from Faculty of Mathematics); *Constants of stress couples* (S. Ranković); *On the remediation of several buildings by pre-stressing* **(**D. Jevtić and B. Vojinović). General report on theoretical and experimental research of the structures was submitted by D. Jevtić.

14th Congress 1972 (Haludovo-Krk): *Testing pre-stressed beams and cross sections exposed to limited torsion* **(**M. Muravljov); *Redistribution of effects of the linear systems from pre-stressed concrete* **(**D. Jevtić and V. Mihajlović); *Time distribution of impacts under the action of stress creep of concrete* (Đ. Lazarević et al.); *Influence of extremely short-term loading on the behaviour of pre-stressed concrete structures* (D. Jevtić et al.); *Ultimate bearing capacity of locally loaded concrete elements* **(**M. Ivković and M. Aćić); *Stiffness of concrete and reinforced-concrete beams at torsion and normal force before and after the onset of cracks* (R. Vukotić). General report was submitted by V. Simović.

15th Congress 1975 (Ohrid): *Fatigue resistance of laminated glued structures made of poplar wood timber* (B. Zakić); *Influence of flow and shrinking in the cross sections of RC beams* (M. Ivković and Ž. Perišić)**;** *Towards the research of parameters of transverse deformations of concrete from the aspect of integral relations between stress and strain* (M. Muravljov); *Extreme values of stress in composite structures* (J. D. Lazić); *Parametric resonance of simple beam of highly elastic material* (V. B. Lazić); *Some issues regarding dynamic testing of bridge models* (M. Radojković)**.** General report on concrete structures research was submitted by D. Jevtić, and on steel structures by M. Radojković.

16th Congress (Vrnjačka Banja): *Viscoelastic deformation of thin-walled member of open profiles of pre-stressed concrete tensioned to limited torsion at loading and unloading* **(**M. Muravljov); *Potential of generalization of relation between the stress and strain of concrete* (V. Mihajlović); *Diagram of stress of compression in cross-sections of RC beams with cracks due to long-term loads* (Ž. Perišić); *Some results of experimental tests of reinforced-concrete rectangular beams loaded by combined bending moment by torsion and transverse force (M,T,Q)* (R. Vukotić); *Equations of the moment of failure of timber beams submitted to torsion and axial force* (B. Zakić); *Ultimate stress values in concrete for the flat state of stress*, M. Aćić; *Limit bearing capacity of locally loaded concrete elements* (M. Ivković); *Scientific research support to the open industrialization of housing buildings* (B. Žeželj); *Recommendations of new regulations for testing of reinforced-concrete and pre-stressed structures of the Committee TBS-20-Rilem* (B. Zakić). General reports were submitted by D. Jevtić (BK-CS), S. Ferušić (MK-SS) and M. Velkov (seismic).

17th Congress 1982 (Sarajevo): *Experimental examination of thermal in-compatibility of the concrete components* (S. Venečanin); *Analysis of stress and strain of pre-stressed TT beams* (R. Folić); *Limit bearing capacity of complex reinforced-concrete cross-sections at symmetrical bending* (V. Mihailović)**;** *Influences in statically indeterminate reinforced concrete structures caused by time displacement of support points* (M. Muravljov); *Influence of yield on the curve of eccentrically compressed RC elements in stress state I* (Ž. Perišić)**;** *One procedure for calculation of stress in the cross sections of composite systems* (M. Ivković and M. Đurđević)**;** *Influence of non-tensioned reinforcement on the force losses of the pre-stresses* (Ž. Perišić and V. Alender). General reports were submitted by B. Petrović (CS), Lj.Jevtović (MS) and B. Zakić (timber structures).

18th Congress 1986 (Portorož): *Experimental research of behaviour of RC beams at short-term loads* (D. Bajić)**;** *Towards a study of ultimate states of RC T-beam* (R. Folić)**;** *Analysis of concrete yield in homogenous RC linear structures applying the force method* (D. Najdanović); *On the pre-stressed metal structures and on the welding of cold-rolled profiles* (Buđevac et al.). General reports were submitted by B. Petrović (CS), M. Marinček (MS) and B. Zakić (TS).

19th Congress 1990 (Novi Sad): *Testing results of laminated glued timber beams after long-term action of load* (B. Zakić et al.**);** *One of theoretical-experimental approaches to determination of elasto-mechanical characteristics of timber* (M. Gojković et al.). *Presentation of basic parameters of calculation of timber structures according to limit states* (B.

Stevanović and S. Vasić**);** *Energy aspect of behaviour of hollow brick panels reinforced with RC grillwork-grid* (R. Folić et al.**);** *Influence of caple beams on the behaviour of RC walls with openings under seismic load* (S. Žorić and R. Folić). General reports were submitted by B. Petrović (CS), T. Nikolovski (MS) and B. Zakić (TS).

20th Congress 1996 (Cetinje): *On matrix modification of stiff joints, in frames, into flexible node joints* (D. Bašić et al.*); One numerical procedure for designing anchored support structures* (M. Lazović)**;** *Bearing capacity of piles loaded by vertical compression and design of settlement of foundation slabs of finite stiffness* (D. Milović and M. Đogo); *Determination of the class of cross sections according to Eurocode 3* (D. Buđevac et al.); *Design of profiles of aluminium alloys from the aspect of local stability of the cross-section element* (B. Gligić)**;** *Basic characteristics and calculation of composite beams of timber and concrete* (B. Stevanović); *Design of composite columns* (B. Deretić-Stojanović); *On the ultimate bearing capacity of horizontally loaded frames* (R. Đorđević); *Longscrew design for composite beams* (N. Marković); *Verification testing of members and nodes of spatial steel structure* (D. Buđevac et al.); *Methodology for assessment of bearing capacity and reliability of existing railway bridges* (M. Pavišić); *Assignment of the status of silo cells for soy and grains and analysis of some test results under test load* (R. Folić, V. Radonjanin**,** M. Malešev). General reports were submitted by A. Vujović, R. Pejović and M. Ulićević (CS), G. Srećković (MS), B. Zakić (TS) and V. Brčić for theoretical analysis of structures.

21st Congress 1999 (Belgrade): *Determination of indicators of deformability of soil for analysis of interaction with shallow foundations (I): modulus of soil reaction and equivalent elastic soil constant* (M. Samardaković); *Soil-foundation interaction – incompressible substratum* (D. Milović and M. Đogo); *Procedure of formation of matrix equation of the foundation girder of variable cross section arbitrary loaded on its ends* (V. Prolović et al.). *On the assessment of the status (condition) of the Theatre building in Subotica and other structures* (S. Grković). General reports were submitted by S. Venečanin (CS), D. Buđevac (MS), B. Zakić (TS) and M. Milićević for theoretical analysis of structures.

22nd Congress 2002 (Niš): *General theory of laminate slabs – analytical solution for simply supported slabs and Composite slabs with delaminations – analytical solution for simply supported slabs* (Đ. Vuksanović, and M. Rakočević); *Calculus of bearing capacity moment of the composite cross-section to lateral torsion buckling according to Eurocode 4* (B. D. Stojanović)**;** *Influence of differential shrinking on the stress state in the cross sections composed of two concretes of different qualities* (S. Mašović); *Non-linear dynamic analysis of structures exposed to action of impulse earthquakes* (Đ. Lađinović); *Aspects of the choice of calculation mode for verification of structural testing results by testing loading* (Z.Mišković and Lj. Jović); *Testing of composite beam timber-concrete, constructed by mechanical connections* (B. Stevanović); *Experimental testing of self-tapping screws loaded to tension* (Z. Marković); *Products on the basis of carbon fibres – tests and application* and *One example of application of carbon strips for rehabilitation of RC structures* (M. Muravljov);

23rd Congress 2005 (Novi Sad): *Research of seismic reliability of old masonry buildings in Belgrade* (N. Stojanović et al.)**;** *Finite element based on the general laminate theory of plates* (M. Ćetković,Đ. Vuksanović)**;** *Some dynamic actions on foundations and dynamic properties of soil* (B. Folić and R. Đorđević)**;** *Design of structures of timber prefabricated housing in seismically active areas* (T. Kočetov-Mišulić et al.)**;** *Influence of history of loading on the ultimate limit state of pre-stressed elements cracks* (B. Popović); *Remediation of beams of glued laminated timber with carbon strips* (M. Komnenović and B. Stevanović)**;** *RC elements exposed to bending, strengthened with additional concrete and FRP (fibre reinforced polymer)* (R. Folić)**;** *Comparative methods of analysis of reinforced concrete beams strengthened with FRP* (R. Folić and D. Glavardanov)**.** General reports were submitted by R. Pejović and D. Najdanović (CS), Z. Marković (MS), D. Stojić (TS) and Đ. Vuksanović for theoretical analysis of structures.

24th Congress 2008 (Divčibare): *Application of elasto-plastic models for soil in calculation of geotechnical constructions FEM* (M. Vukičević)**;** *Approximate calculation of slender RC columns bended in two axes* (Z. Brujić); *Static treatment of concrete structures with effects of long lasting loading* (S. Mašović)**;** *Dynamical behaviour of wooden ceilings (floor structures)* (B. Stevanović and I. G.); *Maintenance models of concrete structures strengthened with composites-(FRP) elements* (R. Folić and D. Glavardanov).

25th Congress 2011 (Tara) and International Symposium: About research and application of modern achievement in civil engineering in the field of materials and structures. Papers: *FEM modelling in assessment of real structural behaviour* (D. Kovačević); Actual approach to shear design of the prestressed and reinforced concrete beams (B. Popović); *Models of failure of NSM strengthening method of RC beams-experimental research* (S. Ranković and R. Folić); *Pile integrity testing SIT method- theoretical basis and case study* (D. Berisavljević and N. Šušić); *Analysis of stainless steel members in axial compression* (J. Dobrić et al.); *Reinforcement of wooden laminated beams with carbon strip* (R. Solarov et al.); *Optimal design of rectangular RC cross-sections subjected to uni-axial bending according to EC 2* (Z. Brujić); *Modelling multy-storey RC frames for nonlinear static pushover analysis* (A. Radujković et al.); *Determination of embedding strength of wood for material dowel type fasteners* (B. Stevanović et al.).

4 Research work at Faculties until 1976 and after 1976

4.1 Research work at Faculties until 1976

It is very difficult to make periodization regarding the scientific work (SW) at FCE in Belgrade. There is a quotation in [44] that the faculty used to be almost exclusively an educational institution until the WWII and even to 1960s. Scientific work of teaching staff was mostly individual and certain number of scholars took part in activities of other

institutions, for instance, Institute "Jaroslav Černi". It was only in 1960 and 1970 when the laboratories were founded and started cooperation with industry, while the scientific work was still individual. In 1976 the Republic began funding the Faculty for three to five years lasting projects.

There is no doubt that at the very beginning academics Ivan Arnovljević and Jakov Hlitčijev, and later academics Đorđe Lazarević, Milan Đurić and Nikola Hajdin shaped the development of the Theory of Structures (Construction). Significant influence was made also by professor Vlatko Brčić, especially with his monograph *Structural Dynamics* [5], Milorad Ivković with his dissertation: *Concrete behaviour in the domain of the limit equilibrium* (1962) and Miodrag Sekulović, with the book FEM [46] at first and then with non-linear analysis of structures [47]. Academic Đ. Lazarević was the initiator of basic as well as applied research and monograph of M. Đurić *Theory of composite and pre-stressed concrete structures with original contributions to analysis of those structures* (SANU, 1963) by applying time deformations of concrete which was widely used in designing and had strong influence on younger scientists and designers of such structures.

Some of the results of individual work were widely applied in structural analysis, too. Such is, for instance, integral equations method N. Hajdin applied in calculation of arch dams. Our science was also affirmed by papers related to application of the method of holographic intereferometry in photo elasticity by V. Brčić (Udine-Itali). Papers of V. Bogunović about the slab flexion and elastic stability of slabs and grillwork were published abroad.

The condition of plastic-failure of concrete which was presented by M. Ivković according to his experiments and results gathered from other researchers still enables applying the theory of plasticity while solving the problems of limit equilibrium. Research work of D. Radenković is dealing with the problems of soil mechanics, e.g. determination of soil bearing capacity.

The monograph of Đ. Lazarević: *Slender segmented arches as one fold and stepped multiple systems of dams* and *Stress calculation of eccentrically loaded ring cross-sections* and many other papers regarding these problems, enriched applied theory of structure (constructions) and influenced the development of modern approach to the calculation of complex constructions in a domain of limit state and optimum dimensioning. He enriched the topic as well as profession with his papers [48]. By model research of parabolic hyperbolic shells of A. Božanović it was proven that deflection of a compressed field of hyperbolic surface turns two axial system into one axial tensioned stress system on the biggest part of the surface. It should be noted that M. Trojanović by publishing four books about concrete bridges established the theoretical grounds for analyzing these structures (book one and two) and the books three and four provided the analysis of chosen examples of bridges performed by RC and PCS. With his books he significantly influenced the establishment of the Belgrade school of concrete bridges which resulted in many outstanding achievements.

Apart from the mentioned contribution M. Đurić developed the general method of deformations in statics, stability and dynamics of structures with wide practical application. His doctoral dissertation is one of the first papers with matrix calculation application.

Papers of N. Hajdin and M. Sekulović with Kolbuner, were published in two monographs about founding (numerical analyses of beams, grids and plates on elastics ground, and for analysis of diaphragm embedded in elastic semi infinite space/body). In addition, the paper of Ž. Radosavljević about calculations of a group of piles was especially prominent. The papers of Stevan Stevanović in the domain of founding were outstanding as well.

The papers of Jakov Lazić about highly elastic models [39], M. Sekulović about thin-walled rods and FEM application are significant. Calculation of building structures under the earthquake effect (D. Dimitrijević), then structure-soil interaction (M. Manojlović) are noteworthy as well as the research of calculation methods of arch dams with statical models of dam testing on spatial models in elastic domain and failure. He performed the verification of a dynamic calculation of dams in situ on Zlatibor and Modracu (BiH) dams. In relation to these problems the mechanics of rocks and geotechnics were studied in significant papers of P. Anagnosti and R. Stojadinović with associates.

Professors Živorad Radosavljević and Branislav Kujundžić with associates in Institute "Jaroslav Černi" developed methods of designing hydro technical tunnels under pressure. The results of this study were two published monographs: *Grouting of hydraulic engineering tunnels and shafts under pressure* and *prestressed lining of hydraulic engineering tunnels under pressure.* In Bulletin No. 3/60 B. Kujundžić wrote a paper about observing tall dams.

4.2 Research in Serbia and Vojvodina after 1976

Scientific projects over the period from 1976-1995 were conducted mostly in cooperation between Institutes for materials and structures at FCE and Institutes "Jaroslav Černi" and "Kirilo Savić" as well as with FCE and Faculty of Occupational Safety in Niš. Projects covered a wide domain of technical sciences with a potential for individual engagement. These projects were carried out through fully individual work and organized research in this domain with aims clearly determined. The following projects were conducted:

1. *Contemporary problems in research of structures* (Milan Đurić);
2. *Theoretical and experimental methods of testing and researching of structures, materials and building environments* (Vlatko Brčić);
3. *Contemporary problems of materials, constructions and environments in Civil engineering* 1986-1990;
4. *Plasticity and stability of steel structures* 1991-1995 (Nikola Hajdin) and later (Miodrag Sekulović) as basic science project.

In the project No. 4, steel structures were studied in domain of plasticity and stability of equilibrium regarding the influence of research on the practice of design and performance. The project included the following subprojects:

1) Comparative study of scientific results in a domain of plasticity and steel structures stability and their influence on the change in standards and regulations

2) Plasticity and stability of the system with application in steel structures of buildings, with the following topics: Plasticity and stability of frame beams, ultimate capacity of rigid angles in a beam-column connection that is made by friction grip bolts and front plates; Boundary bearing capacity of structures in building including effects of diaphragms made from profiled sheets; Performance and protection of steel structures from effects of high temperature

3) Plasticity and stability of metal sheets of solid and rectangular girders with the following topics: Application of FEM on study of post critical stadium of thin sheets and ultimate capacity of solid and rectangular girders; Experimental and theoretical research of lateral stability of solid girders with or without stiffening that are exposed to the effect of concentrated load; Ultimate capacity of I girder with thin web which is exposed to repeated loads; Geometrical imperfections of sheets on constructed structures; Study of ultimate load capacity of thin-walled girders with open and closed profiles

4) Plasticity and stability of metal shells with applications included the following topic: The performance of steel shells with stiffeners and ultimate bearing capacity of cylindrical shells formed of corrugated sheet with or without stiffeners. Certain number of topics regarded fundamental features and the other topics were based on practical experience of fire consequences on steel structures of buildings and imperfections in constructed structures, which formed a base for further analysis. Part of the results from this project was presented at *International conference of steel structures* (Budva, 1986.). Project No. 3. included four topics: 1) Elasto-plastic and limit analysis of metal structures and their optimization; 2) Methods and models of numerical analysis of structures; 3) Theoretical researches in the domain of management and economics of building production and 4) Methodology of stress-deformation analysis and limit equilibrium for non linear constitutive connections and non linear criteria of failure in soil and rock mechanics. The obtained results for topics 1 and 2 were presented at symposium *Contemporary problems of non linear analysis of structures* in March 1993. The monograph was published [47] as well.

From the scope of mentioned projects several master papers and doctoral dissertations were published.

The fundamental research and technological development research have been financed in Vojvodina since 1975, as well as the development of scientific disciplines directly related to the narrow scientific fields which were studied over the period of three years. The author of this paper headed the project: The theory of concrete structures and its application in concrete structures – The development of scientific disciplines (1988 – 1990). In the field of fundamental research the focus was on the development of the joints and connection system in prefabricated building constructions and engineering structures. This was due to the orientation towards the prefabricated constructions (industrial building). The behaviour of the concrete constructions with developed layout under the durable effects was studied as well. The research from the field of Construction management was financed too, and it was supported with the funds of Chamber of commerce of Vojvodina. At that time many minor themes were researched for the Federal Chamber of commerce, and those mostly lasted a year. This contributed the affirmation of the researchers and younger associates in spite of limited funds. Better research financing started in 1985.

The projects from the field of constructions:

1. *Research of concrete and masonry structures under the dynamic load and structure-soil interaction* (1985-1990) head R. Folić.

2. *Research of the principle of design of the structures exposed to impact loads* (1986 - 1990). (V. Vračarić and R. Folić). The project was done for the National Defence.

3. *Research in the field of the design of supporting structures of electro-mechanical transmitters* (for the use of the company "Sever" Subotica, 1988/89 (R. Folić)

4. *Development of construction system of prefabricated timber houses "Špik" Ivanjica* (1994-1995) (R. Folić).

5. Joint research with the University of Berkley since 1985-1989 on a YU - USA project: *Research of the system of joints and connections of prefabricated large panel concrete buildings in seismic areas* (B. Petrović and R. Folić)

Over the period from 1991-1995 merging the Republic and Regional Scientific Communities led to the gathering of great number of FCEs and IMSs scientists around projects. The organization was superb and the Ministry kept track of the work and the results of the projects. At that time it was habitual for the heads of the projects to write an overview in which they showed the results of the research. This was serious and public verification of the achieved results. Recently, the poster presentations have been introduced into practice, which is considerably lower level of verification. There is only a part of the results showed in the overview for the Project No. 1721: *The research of the elements and structures from the aspect of bearing capacity, serviceability and durability, including the revitalization of the buildings* [23].

The paper [23] shows goals, structures and general results of the scientific research project. The research of bearing capacity, durability and serviceability of the elements and constructions; studying of the behaviour of certain engineering structures and bridges in situ and in laboratory; methods of maintaining, remediation and revitalization of concrete, wooden and steel structures; studying of the behaviour of machine and facility foundations, concrete and masonry structures under the dynamic load, as well as the application of the theory of plasticity, stability and numerical procedures in the analysis of elements and concrete, wooden and steel structures were included. In five research years more than 200 papers were published.

Extended theoretical and experimental research was undertaken in order to better understand behaviour of elements and constructions under diverse kinds of load. This was also important for finding adequate ways of designing, building, maintaining and remediation of building structures and constructions. In the course of this process many different problems of contemporary timber, steel, concrete and composite structures were explored. This was also done with different methods and types of analyses of elements and structures in order to adjust them to contemporary problems of structural engineering and enhance them. Many designing regulations given in International societies and Eurocode recommendations [6] were studied, in order to make a theoretical basis for their easier application.

The following issues were studied:

- Bearing capacity, serviceability, durability and revitalization of concrete structures,
- Research of concrete constructions and masonry under the dynamic load,
- Theory of plasticity and problems of contemporary constructions stability and
- Analysis of the steel and concrete structures and large span bridges behaviour.

The themes overlapped in many aspects since they all emerged from the common goals. Those were creation of new elements and constructions with optimization of their silhouettes, which would satisfy not only economic standards but also the needs of safety (bearing capacity, serviceability, durability and maintenance). This led to the fact that after the second year the project was treated as a single set of research tasks.

The influence of the load history on limit states of serviceability of RC and pre-stressed structures was studied. The procedure of strain state calculation in the cross sections for discontinuous actions was proposed, including the change of the active part of cross section after the onset of cracks, applying the constitutive connections of integral type. The procedures for calculation of deflection of partially pre-stressed elements were analyzed, and the procedure of ultimate state of crack openings and their behaviour after decompression was introduced. Apart from that, differential relations, i.e. Maxwell model for the state of stress and change of strain in concrete were used for the analysis of stress and strain state in RC and partially pre-stressed elements. The same model was used for the analysis of limit serviceability state in partially pre-stressed elements. The properties of the relaxation function and concrete aging coefficient obtained numerically on the basis of the concrete flow function according to Model Code 1990 and EC 2 were analyzed. Interaction diagrams moment – normal force – curve for the calculation of slender RC elements "column model" were designed.

Starting from the interaction of architectonic and structural designing, contemporary structures in high rise construction were analyzed as well as the choice of the systems for stiffening high rise buildings. Structural systems of prefabricated timber panel houses (PTH), were applied here, with the focus on testing basic materials, elements and connections. A parallel with the recommendations of EC5 is emphasized for the calculation of basic elements of PTH. The methodologies of assessment of structural status, material testing, causes of damage and remedial measures of specific timber structures were proposed. The report of the state of affairs in the area of composing timber beams and concrete slabs was produced. The theory of composing was presented with and without introduction of slipping between the layers. A number of issues regarding specific structures of foundations under the dynamic loads, that is, foundations of machines and various industrial facilities were treated (published monograph, R. Đorđević). The report of the state of affairs in many topical areas of structural engineering treating the issues of bearing capacity, durability, serviceability and maintenance of engineering structures, as well as the behaviour of elements and structures under variety of loads was submitted.

In order to include the yieldability (semi-rigid) nodes of prefabricated RC frames, the matrix of stiffness of members with the arbitrary level of fixation was developed, and the method of determining the semi rigid of corners was demonstrated. Through the numerical analysis, it was demonstrated that the redistribution of moments occurred between the cross sections in nodes and in the span, as a consequence of semi-rigid nodes, so it could not be ignored, when it came to prefabricated concrete structures [24]. It is important to mention, that in this area, the initial impulses were given by M. Đurić (INDIS, 1976) and M. Milićević (17th Congress of theoretical and applied mechanics, 1986) from Niš. In their work, they treated static analysis, stability and dynamic analysis. In the process, they used the classic strain method approach. For timber structures, the matrix analysis was developed by D. Bašić, D. Stojić and E. Mešić, and for steel structures by M. Sekulović, B. Ćorić and R. Salatić. This theme is still topical and researched both locally and globally.

Within the project *Development of scientific disciplines* which was financed by the Scientific fund of Vojvodina, the work on research of semi-rigid of joints of prefabricated large pane buildings was continued. The paper was published in 2001 [26]. In the paper, the effects of semi rigid of joints of concrete large panel buildings (LPS) with the accent on the semi-rigid of joints of walls were analyzed. For the analysis of bearing and stiffening walls and mixed systems skeleton-bearing walls the Finite elements method (FEM) is used for their analysis. Stiffness matrices used for the calculation of walls with yieldable nodes were given. At an example of a diaphragm between the RC columns of ten-storey buildings, the results were compared assuming the stiff connection of the columns and diaphragm and assuming that columns are stiff and diaphragm joints yieldable. The effects of redistribution of stress σ_y at the bottom of the diaphragm due to semi-rigid of joints were presented. It was demonstrated that this phenomenon should be included in the calculus for concrete prefabricated buildings so as to describe their behaviour under load in as realistic manner as possible.

It was very important for Structural engineering that for a long period of time, especially until 1993, many scholars and associates professionally engaged in Technical mechanics and Theory of structures took part in the realization of fundamental research. Those activities were coordinated through The Institute of Mathematics of SANU. Thanks to this fact the author of this text headed the theme from the area of Structural dynamics from 1991 to 1993. The same year many difficulties appeared when the Ministry of Science insisted on separating the fundamental and technological development research, thus preventing simultaneous work on both of them.

Scholars and associates, mainly from the field of Concrete structures from Serbia, were gathered around the realization of the research program of the Project: Research of Concrete Structures (1996-1999). The program was very extensive as well as subprojects, which can be seen in the title of the one headed by the author of this paper: Modelling the materials, connections, structures and soil behaviour as well as soil and structures interaction under static, dynamic, seismic and incident actions and during the fire. The researchers from Novi Sad, Beograd, Niš and Subotica took part in realization of this project. Here are some results:

– The problem of structures interaction – foundation – soil with special foundation structures like consoles and anchoring diaphragm walls was studied. Linear and non linear analyses were used;

– Introduction of structure interaction – foundation – soil, in order to improve the method of constructions and foundation structures design;

– Methods of concrete composition, working of contact surfaces and calculating procedures for cross-section with and without cracks, and with introduction of concrete shrinkage and yield were studied;

– Introduction of new methods of calculation and concrete composition structures modelling;

– Further analysis of static and dynamic behaviour of special structures in order to improve large span structures design;

There are some other projects on which predominantly worked the researchers from Vojvodina, and which were financed from Republic funds:

- The subproject: *EC 8 – Designing seismically resistant structures* in technical project: *Introducing the Eurocode system and adopting the new methods of designing products and technologies in Serbian structural engineering* (1995 - 2000), Head of the subproject - R. Folić.
- *Preparation of new regulations and instructions for Eurocode applications for structures in our civil engineering* (2003-2005.) – Subproject: *EC8 - Designing seismically resistant structures*; Head of the subproject R. Folić
- *New technologies in research, designing, building and service managing of engineering structures* (2003-2005), Head of the project R. Folić, coordination IMS Beograd.
- *Improving inspection, assessment, revitalization and reconstruction of structures methodology*, Ministry of Science, Technology and Environmental protection of Serbia, (2005-2008) Head of the project R. Folić.

It is important to mention the work of the researchers from Belgrade, Novi Sad and Niš Faculties on technological-development project: *Introducing the Eurocode and adopting new designing methods*, headed by Ž. Perišić. The work lasted from 1993-2000 and it continued in 2005 with the translation of the EN 1990 – 1999 document, and introduction of Eurocode into our practice (which was given recognition of merit by the Engineering Structures Society DGKJ for the best scientific work in 1996/7). The author of this paper headed the Subproject: *EC 8 – Seismic Design of Structures*. The task of introducing the European standards into our practice was taken seriously, owing to the contribution of professor Života Perišić. This is evident in the fact that two Meetings regarding this Project were held in 1995 and 1997: Eurocode and Constructive Engineering. The interest was great and the attendance enormous. This period of activities was focused on Pre-standards prEN, not towards EN being published in 2002: EN1990, until 2006. It is also important that we took part in many Congresses organized by Macedonian Constructors Society with introductory papers, such as [25].

The research from 2008 – 2010 was grouped in the following projects:

- *Experimental and theoretical research of real connections of reinforced concrete and composite structures under static and dynamic load* (B. Stevanović);
- *Research of contemporary concrete composite based on domestic raw materials with the focus on potential of applying concrete with recycled aggregate* (V. Radonjanin);
- *Development and improvement of engineering structures exposed to seismic and incident actions design* (Đ. Lađinović);
- *Research of long-term and short-term monitoring methods in engineering structures* (Z. Mišković);
- *Experimental and theoretical research of dynamic characteristics of pre-fabricated and semi prefabricated structures and elements from the aspect of serviceability* (B. Stevanović);
- *Safety, bearing capacity and stability of composite and steel structures in housing and bridge building and new technical regulations* (B. Ćorić).

4.3 Experimental and theoretical analysis of T Beam

Since many authors presented some of their papers, the work on the doctoral dissertation is presented here, as well as some later studies. This is the summary: The paper deals with experimental and theoretical research of RC concrete T-beams. Relation between width of the flange and span of girders, quantity of tensile reinforcement in longitudinal webs and occurrence of edge cross ribs to behaviour of T-beams under loading have been experimentally and theoretically studied. On the basis of personal investigations and cited data, the determination of the effective width of flange subjected to bending, torsion and normal forces is considered. Data about cracks and deflections of reinforced concrete girders are given. It is shown that relation between width of flange and span has a dominant influence on effective width of flange, while quantity of tensile reinforcement in webs has an important influence on limit state of serviceability with reference to deflections of girders.

Permanent usage of T-beams in concrete structures led to their thorough study. They can be found in monolithic and pre-fabricated construction as a combination of planar structure and beam elements, most frequently flange-web, and the box girders can be processed by the same calculation model. These girders can be exposed to bending, torsion, normal forces or combined action. However, under the term of T-beam we usually think of the elements exposed to bending. Almost all the time the linear theory of elasticity is used for influence calculation of these beams. In case of the statically indeterminate structures, the stiffness of the elements is introduced. Although the stiffness depends on the reinforcement method and condition of the cracks, it is designed for homogeneous cross section, so it is particularly important to define the cross sections as accurately as possible.

When the spacing of the webs is large, the distribution of normal stresses is not uniform, i.e. the stresses σ_x which have the highest value at the flange/web intersection and taper off with the distance away from the joint. Therefore, it is necessary to determine to what distance from the web, in load distribution, there is the interaction from the slab (flange). Thus a phrase "effective flange width" (EFW) is defined. The actual width of the slab is substituted with the smaller width, with which the value of "the highest normal stress $\sigma_{x,}$ occurring at the contact of the slab and the web"

can be correctly calculated. The distributions of stress in the flange and in EFW are determined by theoretical numerical analysis and/or experimentally. There are presented and analyzed some of the results of experimental and theoretical research of T-girders of reinforced concrete and rectangular girders of pre-stressed concrete under short-term load. Analysis of limit states relates to the serviceability states of RC girders, that is, except the EFW, the cracks, deflections are considered as well as the problem of the slab-web joint and stability of the flange.

For the purpose of the study of T girders, 7 RC models were tested and tow pre-stressed rectangular girders, under test load, until failure. The chosen form of RC model allowed analysis of two boundary cases: T-girder with cantilever slabs $b_2/b_1 = \infty$ and Π-girder with the internal slab with $b2/b1 = 0$. On all the girders longitudinal strains ε_x on the upper surface of the slab were measured in the transversal direction and along the cross-section height, and on RC models and in tensioned and compressed reinforcement. The deflections were measured at 1/6 of the span on the longitudinal webs, and at ½ of the span in the girder axis and at the ends of cantilever slabs. Onset and development of cracks were recorded for each phase of load.

The load was applied by the hydraulic press "Amsler" over the axis of the web, by a pair of symmetrically positioned forces. Design load was applied in four uniform phases each being 25% of service load.

To achieve full economic effect, it is necessary to achieve equal resistance of individual component parts until the ultimate state is reached. Therefore, a part of experimental results is focused on the study of ultimate states. The number of parameters that could vary in these calculations is high, but the program described here included only the most dominant ones. The following were studied:

- Effects of geometry of RC models expressed by the ratio of spacing of longitudinal webs and span of the girders,
- Quantity of tensioned reinforcement in longitudinal webs, and
- Existence of end (lateral) webs.

In order to study the influence of the quantity of tensioned reinforcement in the webs, the first batch of models was concreted with 3 rebars ø 16mm (1.54%), and the second batch with 6 rebars ø 16mm (3.24%) of RS 400/500. Thus, 6 RC models with end transverse webs were obtained. One girder was without end transverse webs. In order to check the validity of the solution of the theory of elasticity, the results of the experiment were compared to the results of the analytical solution of the theory of elasticity, finite element method and final strip method. In the theoretical analyses, linear theory of the first order was used.

The following assumptions were introduced:

– Thickness of the flange and longitudinal webs are significantly smaller than other dimensions, so bending of the flange is ignored, and flanges and webs are tensioned only in their planes and mutually connected along the lines on the intersection of the centreline of the flange and the web, where the deformations must correspond;

– Longitudinal webs receive the load in their planes; and Transverse girders are stiff in the direction of their centre plane and prone to bending perpendicular to that direction.

– The forces acting in the centre plane of the flange are predominant, and can be found in the equation:

– Longitudinal strain of common fibres of the flange and the beam in the centre plane of the slab,

– The curves in the centre plane of the slab and the beam in the centre plane of the slab.

– The curve of common fibres in the plane normal to the centre plane of the slab,

– The rotation of common surface of the slab and the webs.

Applying the finite element method, the effects of the type of load and end transverse webs on the stress and strain state is examined. The structure is idealized with the set of rectangular elements loaded in their plane, and mutually connected in the nodes. It is assumed that the stress is linearly distributed within the rectangle, and the resulting distribution of displacement satisfies the compatibility conditions, only in nodes.

In order to compare the efficiency of various methods and study of the surface load on the slab in respect to the equivalent linear load on the longitudinal webs, the finite band method was used.

Effective flange width of a T-beam exposed to bending depends on a number of parameters related to cross section and loading. The most important are:

– Ration of the flange width and span of the beam b_1/l or b_2/l, where b_2 is the width of the console slab, and b_1 is the ½ of the spacing between two webs,

– Static system, that is, support conditions and position of the cross section where the effective width is calculated,

– Types of load (uniform distributed, concentrated etc.),

– Shape the form of the cross-section, and

– From the fixing conditions at the ends of the beam (degree of securing the beam against torsion).

The percentage of tensioned longitudinal reinforcement has no significant effect on the average value of EFW. Apart from that the experimental research of AB (RC) girders are limited by the scope and varied parameters. They are combined with theoretical analyses, and enable recommendation of the simplified expressions for determination of EFW. The expressions are analyzed in detail in the book [45].

Comparing the size of the effective flange width under bending achieved experimentally on the full scale models, and theoretically by the application of linear theory of elasticity, acceptable compatibility was obtained in almost all the cases. Somewhat higher values were obtained in experimental research. So it can be concluded that for determining the effective width of RC and pre-stressed girders the linear theory of elasticity may be applied, because the calculation results are on the side of safety. Out of several varied parameters, the influence of the flange width and spacing the zero points of moments is important for the effective width, and the quantity of tensioned reinforcement in the webs is almost negligible. The favourable effects of end transverse webs on the effective flange width in the zone near the supports were observed. A higher quantity of tensioned reinforcement of the longitudinal webs results in economical T-beams with wide flanges, from the aspect of

stress usage, but it is necessary to ensure that the limit states of deflection are not exceeded. Existence of end transverse webs has a positive effect on the behaviour of T-beams with wide flanges, both from the aspect of the stress and the aspect of development of cracks and deflections, so they should not be deflected, unless it is really necessary. In the book [45], the recommendation for inclusion of torsion is given along with normal forces when determining the effective width of the flange.

5 Analysis of structures

Beside the experiments, numerical analysis of structures is always a theme of interest in structure research. Development of computers and their mass usage, especially in the last 50 years, enabled considerably more accurate analysis of engineering structures under mechanical, thermal and other action. Computers changed the way of calculation and enabled the development of modern numerical methods which can be applied in research and design. Finite element method (FEM) due to its simplicity, mathematic basis and clear physical meaning pushed aside other methods. M. Đurić provided valuable contribution to the application of theoretical results in practice in the field of composite and pre-stressed structures; V. Brčić in the field of structure dynamics and M. Sekulović for application of FEM in structure analysis.

For the design of engineering structures different approaches are used. Firstly, global analysis of structures is done and then analysis of its elements and cross-section. The design according to permissible stress is abandoned except in the case of pre-stressed and composite structures. Since it was necessary to provide safety in the case of failure as well as serviceability, the concept of design according to ultimate limit states was generally accepted. These are the states limited by some value the structure should not exceed according to the requirements the structure should meet in its service life. The most important of all mechanical properties of material is its relation stress – strain (working diagram) and therefore, theory of elasticity and theory of plasticity are used in the design. In addition, very important is the type of load (short-term, long-term, static and dynamic) and the influence of the environment temperature, humidity…) In the working diagram, the most important are the points of elasticity limit, beginning of plastic deformations and failure deformations.

The most complex designs are for RC structures and composite structures steel-concrete, wood-concrete, and in the last few decades concrete-concrete. It is due to the fact that concrete is a heterogeneous material, which apart from the shrinking deformations during setting also possesses the viscous properties, that is, deformations increase under constant stress in time. Geometrical structures also conditions application of appropriate models (linear, planar, and spatial) and the purpose of the structure.

For the design under the short-term stress, as it is well known, linear and non-linear analysis models are mainly used. Rise of computers and their advanced application facilitated RC structures analysis on more complex models than before, when the linear model was used. Non-linear properties of material, dominant in reinforced concrete emerged from the onset and propagation of cracks and non-linear stress-strain relation for steel and concrete and interaction of concrete and reinforcement. Non-linearity of structural relations is apart from the mentioned things a consequence of the non-linearity of the relation of bond stress and local slippage of reinforcement. Contemporary numerical models based on FEM facilitate easier analysis of real behaviour of RC structures which is particularly interesting for special engineering structures. For analysis of bended beams and planar girders under short-term loads, the models based on FEM were analyzed. For analysis of these beams, emergence and propagation of cracks, effect of bond of concrete and reinforcement, transfer of shear forces in the cracked concrete (local effects) should be studied for determination of global behaviour and ultimate load.

Three procedures are implemented: a direct procedure with classic finite elements and the material non-linearity is introduced through the effective stiffness, determined by experiments. The second procedure is with the layers of finite elements. The flat stress state defined by the biaxial relation stress – strain is assumed in the layers. The propagation of cracks along the height of the cross-section is facilitated in this way. Discretization along the height and width is used for analysis of complex stresses. The deficiency is the inability to include the emergence of diagonal (slant) cracks and shear failure, and for a more accurate analysis, a large number of layers are required. The third procedure is application of 3D finite elements. They are successfully used to analyze the beams where shearing is the key factor of concrete failure.

Constitutive relations depend on the stress state and they are based on experimental results. They do not take into account the time factor, and they describe the material behaviour: linear and non-linear elasticity theory, plasticity theory endochronic theory of plasticity and nonlinear theory of failure mechanics. The linearly elastic, non-linearly elastic, hyper-elastic and hypo-elastic model of material behaviour are based on the Hooke's law. Non-linear connections S-D irrespective of the material properties (elastic, plastic or endochronic model) are expressed by total (secant) or incremental (tangential) form. Total formulation is limited to monotones, but for its simplicity, it is often implemented for description of non-linear behaviour of concrete at in-plane and spatial pressure state. More on this can be found in the paper by Sekulović, Vuksanović and Pujević [45] and papers by T. Tassios, and other authors who included analysis under long term load, and also in [47-48].

6 Topical problems and direction of future research

In order to provide the appropriate safety of bridges to seismic action, the following factors are significant: choice of the structure as early as in the conceptual design phase, modelling and analysis of the structure, as well as the

formation of details. For the more significant structures such as the bridges of medium and large spans, in seismic areas, the first phase of the selection of structure, i.e. conceptual design is significant. In the last twenty years of the last century, the modern concept of seismic protection and control of structures was developed. Apart from the basic isolation, active and semi-active protection of structures is used [7]. These problems were considered in the paper [29]. The choice of isolation devices is very important, since through their application it is possible to ensure considerable reduction of seismic forces, so that the structure could even remain in the elastic area. The method of designing some of this protection in order to reduce the damage to the structure during earthquakes and providing adequate performances is topical. In the recent years, the application of integral bridges is topical, and they are gaining importance because of the higher durability in respect to the classic bridges [40].

For concrete bridges, and particularly for prefabricated bridges, the continuation of supports on bearings allows rational usage of material and better service performance, in particular the durability. The beam continuity is most frequently done by pre-stressing: it is monolithic, when all the cables are pre-stressed in situ, that is post-tensioning is applied; and non-monolithic when the prefabricated elements are used, such as simple beams, and continuity is effected on bearings by concreting the joint in situ [23].

Concrete structures (CS) are designed so that they can satisfy requirements regarding safety, serviceability, durability and aesthetics throughout their design service life. Present design procedures regarding CS required by national or international codes and standards such as Model Code Euro International Committee of Concrete (1993) now Federation Internationale du Beton (FIB), EN, ACI, RILEM, etc. are predominantly based on strength principles and limit state formulation. The durability aspect is a natural extension of classical resistance verification where deterioration effects are normally neglected. The review of literature and some recommendations are presented referring to the design of structures aiming to attain greater durability of CS. The accent is put on the theory of reliability, failure probability and service life probability. The basics of this analysis are given through the principles of performance and service life [12], and deterministic and scholastic methods using the lifetime safety factor [33].

Structures may be subjected to extreme events during their design-service life, which can lead to unforeseen consequences. Such situation may be caused by natural disasters such as strong earthquake, or from human errors (for instance gas explosion). Specific approach to designing PC building structures under seismic actions and abnormal loadings is described in [28]. Recommendations for design and interventions aimed to prevent progressive collapse in case of failure of part of structures are given. Alternative ways of load transmission are considered as well as measures for increasing the overall stability. Due to reduce the risk of progressive collapse, the following approaches, or tear combination are applied:

1. Reducing the risk of accidental loading.
2. Preventing the propagation of possible initial failure.
3. Designing the structure to withstand accidental loading.

In general, accidental loads can hardly be eliminated. In design all efforts should be made to reduce the risk of accidental loading as much as possible. Impact loads are the subject of an extensive book [3].

Prefabricated-monolithic structures represent a rational combination of prefabricated and monolithic structures, as they combine the advantages of one and the other. Their application accomplishes a high level of industrialization, savings in material and labour, faster construction and more reliable quality control of materials and workmanship. This contributes to their wide application in bridges, buildings and other structures. These structures are constructed faster in respect to those built in a classic way. Prefabricated elements substitute cladding and scaffold and accept the subsequently constructed concrete elements.

Partially pre-stressed structures (PPS) occupy the space between the classic RC and completely pre-stressed structures (PS). When the reinforcement is not pre-stressed, the level of pre-stressing equals zero (classical RC structure). The other end of the scale is when the degree of pre-stressing equals one, and those are completely pre-stressed structures. PPS structures contribute to a more economical construction of many kinds of buildings, industrial and engineering structures, and bridges [30]. This area of concrete structures is very topical and has a great importance for theory and practice of concrete structures.

Composite steel/concrete structures are used widely in modern bridge and building construction. The very large amount of theoretical and experimental research, design application and construction work has shown the efficiency and economy solution of composite structure. In [31] the current state of affairs related to design and analysis is presented based on quoted references, in steel-concrete composite structures.

It is important to mention that in the last 20 years adaptation of our technical regulations with Eurocode is topical. These standards were enacted over the period from 2002 to 2005. These documents were also used in the monograph with useful analyses and propositions. Adaptation of our technical regulations with EN is very topical, it is worked on in our country, and the submitted manuscript includes theoretical foundations and other aspects of analysis and design of composite structures harmonized with European standards. Since 2006 the Faculty of Civil Engineering completed translations of several documents, and on this occasion several seminars were held in Belgrade, Novi Sad, and Niš. Recently, the Institute for Standardization of Serbia formed the Working groups dealing with the final adoption of these documents. The lacking finances represent large difficulty to proceed. In the paper [51] it was emphasized that one of the main priorities of the ISS, as a national body of standardization, is the goal of obtaining the status of a full-fledged member of CEN. It is one of the conditions for Serbia to enter the EU.

Directive CPR 305/2011/EEC poses the conditions for putting the construction products (CP) on the market, by establishing the harmonized rules which would express performances relating to the important properties of CP and the requirement for CE designation. Among the important requirements are: mechanical resistance and stability, safety in case of fire. The following are specially considered: re-use or possibility of recycling construction waste (CW), materials and parts after demolition; durability of CW; usage of raw materials and recycled materials which do not endanger the environment. Harmonized standards represent the document basis for production of national technical regulations and codes. The difficult part is that there are insufficient data for national parameters. (snow, wind etc.).

Among 27 committees actively working in the area of civil engineering, the following ones are significant for structural engineering:

- U104- Concrete and concrete products;
- U125-Masonry structures;
- U167- Structural bearings in civil engineering;
- Engineering structures management;
- Concrete structures designing;
- Designing steel structures, steel-concrete composite structures and aluminium structures.
- Designing timber and masonry structures.

In the area of geotechnics, each alternate year, in the organization of the Association of Civil Engineers of Serbia, a scientific-professional meeting is held where the topics important for structural engineering are discussed: Models of geomaterial and numerical methods; Prediction and observation results of structures, observation method; Soil consolidation, reinforcing, grouting, geotextile and other; deep excavations and tunnels; piles, diaphragm and other technologies of foundation engineering; micro-zoning and seismic risk for the purpose of structural analysis to seismic action.

The still standing concept of seismic protection is still based on the design of the structure for the action of design earthquake (return period $T_r \approx 500$ y.). The bearing capacity of the structure is determined for the seismic forces which correspond to the given design level, determined by the application of the reduction factor (dependent on the capacity of deformation (ductility). From the concept based on the force which was valid in the 1990s, the approach was changed to the displacement, and nowadays, the concept based on performance and structural damage is very topical. Mathematical model for static and dynamic analysis of horizontally loaded tall buildings [18] is formulated in the paper. In the area of earthquake engineering analysis of irregular structures of buildings and beam bridges is very topical. In order to avoid irregularities, it is insisted on conceptual design and choice of regions for energy dissipation so that they are accessible for checks and repairs. In the case of extremely long bridges which rest on non-homogeneous layers of soil, additional separation (expansion) joints are introduced in order to avoid differential displacement.

Due to the small seismic resistance of masonry buildings, the issue of their reinforcement, pre-stressing and post-stressing is very topical. The latter method is very efficient for reinforcement of masonry buildings, which was used by B. Petrović on Kamchatka, Russia.

In interventions on concrete structures, authentic or repair materials which call for formation of very narrowly specialized teams are used very often. Lately strengthening of reinforced concrete element sections with externally bonded fiber reinforced-polymer (FRP) composite materials is very popular, and in which the bond of additional elements and the substrate is important [43]. Recently, the same path of application of NSM method and pre-stressing FRP reinforcement in order to strengthen concrete structures is topical in our country. Recent guidelines given by American Concrete Institute, International federation for concrete (FIB) and Concrete Society Council (UK) can be used for dealing with the design of such sections as there are no national or international standards.

Over the period **2011 – 2014** the Ministry financed the following projects related to structural engineering:

- *Development and application of scientific methods in designing and building of highly economical structural system by implementing new technologies (M. Nestorović);*
- *Research of potential for application of waste and recycled materials in concrete composites, with the evaluation of their influence on the environment, for the purpose of promotion of sustainable civil engineering in Serbia* (V. Radonjanin);
- *Development and improvement of methods for analysis of structure and soil interaction on the basis of theoretical and experimental research* (V. Prolović);
- *Development and application of comprehensive approach to design of new structures and assessment of safety of existing structures with the aim of reducing the seismic risk in Serbia* (Đ. Lađinović);
- *Research of the impact of traffic vibrations on structures and people with the goal of sustainable development of cities* (M. Petronijević);
- *Research of status and methods of improvement of engineering structures from the aspect of serviceability, bearing capacity, cost-effectiveness and* maintenance (Z. Mišković).

Topical themes dealing with seismic were present at 15th World conference of earthquake engineering (EE) in Lisbon, Portugal, from 24th to 27th September and those are: Geotechnical EE; Seismic behaviour of engineering structures; Assessment and retrofitting; Lifeline systems; Social and economic aspects of earthquake. In the paper: *Effects of multiple earthquakes on the seismic response of structures – Contemporary civil engineering practice, Novi Sad* (A. Liolios, 2012), it was demonstrated that apart from the action of an isolated earthquake, it is necessary to introduce the multiple earthquakes.

Numerous papers related to the seismic enhancement of the existing structures, mostly by applying FRP elements [27] and [34]. It is the topic of several journals, such as [2]: The overall performance of hollow clay tile infilled RC frames strengthened with carbon fibre/reinforced polymer (CFRP) materials is experimentally investigated in the paper: *Seismic strengthening of infilled reinforced concrete frames with*

composite materials (S. Ozden, et al.) and others. The mentioned journals considered several other topical issues. Control of dynamic response of structure is the new philosophy of design [7], with the potential that the structure is transformed from the passive status into active subject able to adapt to seismic action. Particularly topical are the problems of interaction structure-foundation-soil [32], and the meetings with such topics are organized [42] and tend to be organized in the future. The papers of soil-foundation interaction with introduction of viscous properties are still topical [22], and classification of damage and its causes as in the papers [16] and [17] which were the result of the work in the technical committee 104 DCC (Damage classification of concrete) of RILEM, where the author of this text worked with B. Zakić 1987-1992. In addition, B. Zakić worked in several other committees.

Improvement of Bridge Management System (BMS) is the subject of many researches such as [11], [13] and [50]. It is attested by the site http.://www.dot.wisconsion.gov (Wisconsin Department of Transportation, WisDOT Bridge Manual, Madison, WI, 2010). Very topical is the application and improvement of orthotropic slabs in large span bridges, [36], and the meeting IDE was dedicated to innovation as an important factor of development, and it was held in Niš [35].

Publication of topic issues is active in the region, too, such as: Analysis of the effects of reduction of stiffness on the seismic resistance of structures [9], paper: *Seismic dampers in engineering structures* (A. Nižić and D. Meštrović) and several papers dealing with the same issue which are published in several last issues of the journal. The forecast model for determination of fire resistance [38] and numerical model for anticipation of structural behaviour in fire [49] are also very topical and will continue to be such.

The journal CBMS published by STMS Serbia is regularly published in Serbian and English. The journal has an international editorial board and it is open for the authors from the region and other countries.

7 Conclusion

From the list of doctoral dissertations in the field of structural engineering, it can be stated, that they are, in major part, the result of individual work and enthusiasm of the individuals. From the list and brief analysis of papers published in Bulletin/Journal M&S and presented at the Conventions and Congresses of STMS, and the list of scientific-research projects at the faculties and institutes, it can be concluded that they represent a significant contribution to the structural engineering of Serbia. It is particularly important that these results were realized by the modest finances available to support science in Serbia.

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