SEISMIC ANALYSIS OF JOINTS AND CONNECTIONS OF PRECAST CONCRETE STRUCTURES

Radomir Folić [1]
Boris Folić [2]
Miloš Čokić[3]

UDK: 624.078:624.042.7
DOI: 10.14415/konferencijaGFS2021.03

Summary: *The paper presents the provisions of the Standards that regulate the methods of the analysis and detailing of joints and connections of structural elements. Norms are covered in ACI 318, Eurocode 2 and 8, Code New Zealand, fib Model Code 2010 (2013), and their bulletins. Analyses and shaping of connections according to the mentioned norms and literature depending on the stress states to which the elements are exposed are presented. The recommendations of individual international associations were also analysed in PCI Design Handbook Precast and Prestressed concrete, ACI C 533 Guide Precast concrete, Guidelines for the use of Structural Precast Concrete (New Zealand). For some connections (loops) and other analyses, based on recent studies of their behaviour under load that simulate seismic actions, approximate analyses are also presented.*

Keywords: *Seismic analysis, precast concrete, design, connections, joints, detailing*

1. INTRODUCTION

Contrary to the experience of past earthquakes precast concrete structures has shown a generally good bahaviour even in the area of high seismicity. The structural behaviour of structural members may differ substantially from the similar cast-in-place members. The structural integrity of precast concrete structures mainly depends on the connections between structural members. All the connections should be designed according to valid codes [24]. There is often a question about the difference between the connections that are carried out on site and the precasted ones. Analytic investigation of the differences between in-situ cast and precast beam-column connections under seismic actions are shown in [30]. The results showed that under strong seismic excitations, the differences in the response between precast frames and the RC frame were significant.
Compared to monolithic ones, precast concrete structures have a set of specific features which include the necessity to consider structural safety and stability during the numerous stages of construction [19] in a structural analysis.The behaviour of precast

[1] *Prof. emeritus Radomir Folić, Univerzitet u Novom Sadu, FTN, Serbia,* folic@uns.ac.rs
[2] *Dr Boris Folić, Univerzitet u Beogradu, Mašinskog fakultet, Inovacioni centar,* boris.folic@gmail.com
[2] *Miloš Čokić, MSc Civil Eng. PhD student, FTN Novi Sad,* cokic.milos@gmail.com

concrete structures is not the same as monolithic reinforced concrete (RC) structures. It is the matter of the utmost importance to consider the design and construction of joints and connections in precast concrete structures. Their purpose is to transfer the forces between structural members and to provide stability and resistance to progressive collapse (robustness), integrity and workmanship. Unlike the in-situ cast concrete work, the design philosophy for precast connections concerns both the structural requirements and the chosen method of construction. In many instances, the working practices in the industry are also strongly influencing the connections design [28].
It is very important to distinguish the joints and connections in the precast construction industry, especially when the connections between the precast elements are considered. A joint can typically be described as an interface between two elements in a structure where the forces can be transferred whereas a connection can be described as an assembly of two or more elements that is designed to resist the applied forces (Björn, 2006) citated in [21].

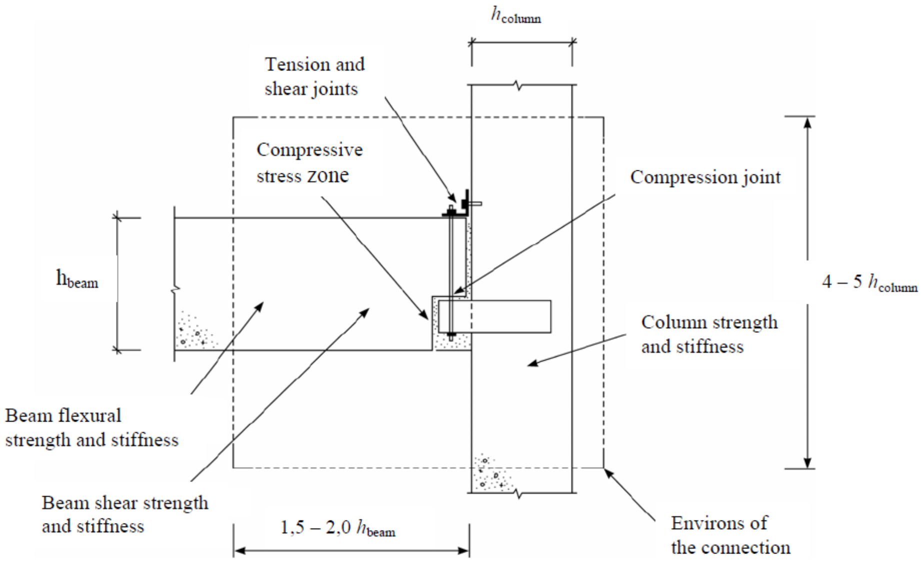

Figure 1. Definition of joints and connections, after [14]

The structural *connection* interacts closely with the adjacent structural elements, and the design as well as the detailing of the connection is influenced by the design and detailing of the adjacent elements. The connections between the precast concrete elements are in close contact with the adjacent elements of the structure, thus the design and detailing of the connections are influenced by the design and detailing of the adjacent elements. The connection must be designed so that the flow of the forces, found in the connection is logical, but also that the forces can be transferred to the overall load bearing elements of the structure [8], [14] and [21]. Shortly, within a single connection, there may be a several load-transmitting joints, and so it is necessary to distinguish the difference between a joint and a connection first. A *joint* is the action of forces that takes place at the interface between two or more structural elements. A connection is the action of

forces (tension, shear, compression) and bending or torsion moment through an assembly comprising one, or more interfaces. So, the design of the connections is therefore a function of both the structural elements and of the joints between them.
Many damages to prefabricated concrete structures in earthquakes are most often the result of inadequate design and construction of joints and bonded elements. Two examples of collapses, shown in more detail in [13a; fib 27], are shown in Figures 2, 3 and 4.

Figure 2. Failure of columns due to interaction with stiff masonry infill (1999 Kocaeli earthquake), after [13a]


,

Figure 3. Collapse of precast concrete hollow core floor (1994 Northridgeearthquake)

Overall behaviour of precast subsystems such as the diaphragm effect in floor slabs, the effect of shearing walls, etc. The design shall ensure that the joint is able to accommodate the relative displacement needed to mobilise its resistance and to assure robust behaviour of the structure [10]. Joints shall be designed to prevent premature splitting or spalling of concrete at the ends of the units and shall be dimensioned to take account of tolerances, assembly requirements; ease of execution and ease of inspection. The most frequently used types of precast concrete elements are columns, beams, hollow-core slabs, pocket foundations, etc. [24].

Failure 4. Failure of a poorly detailed beam-column connection (1976 Tangshan earthquake, China)

Articles [17] and [16] are dedicated to the problem of MBK damage and its causes. At [16], the complete demolition of a large-panel building during the Spitak earthquake 1988 in Armenia is shown. This indicates the problem of damage to this class of buildings in earthquakes.
This paper reviews some of the Codes, Guidelines, recommendations and some data from the literature related to the design connections in precast concrete structures with some illustrations. The basic types of bonds and compounds are illustrated according to the proposals from the analysed literature. The basic types of bonds and compounds are illustrated according to the proposals from the analysed literature. The latest proposals for the application of appropriate joints and connections and their analysis are also included.

2. REVIEW OF THE CODES AND LITERATURE

Papers [19] give a review of earlier research in the field of precast concrete structure (PCS) buildings and stresses the problem of joints and connections, starting from their classification, through the analyses of different influences, to their detailing. In [20] the strength and high degree of reliability is determinate. Book [5] is dedicated to the problem of the aseismic joints design and precast walls connections, similar as in a special publication of the CIB [6]. It starts from definitions and premises which are introduced in the course of designing joints and connections in seismic areas.

Detail catalogues given in paper [34] by the Dutch Association for Precast Concrete Construction are dedicated to the problem of joints. Volume one concerns mainly joint and connections in frame structures. It gives the recommendations concerning the choice and design of joints as well as performing assembly works. Volume two concerns joints and connections in floor slabs. Both volumes list criteria for classification and evaluation of the joints [19]. Many later publications and Codes (ACI, NZ, *fib*) suggest similar constructions of joints and constructions proposed in [19] even the same.

The problem of PC structures is most intensively studied within the USA Precast Construction and Prestressing Institute (PCI). This includes the work of numerous technical committees which have published the propositions of requirements for the design of different elements, joints and connections and a number of other elements connected with precast concrete construction and design [32], similar in FEMA 751 [29]. The Precast/Prestressed Institute provides the information on recommended connection details for precast concrete structures (CS). Chapter 6 in [23] is dedicated to the connections between members (Code and Commentary) with load-transfer-devices: headed concrete anchors or studs; reinforcing bars (with or without splice devices); deformed bar anchor; bolts, and post-installed anchors. In the case of concrete anchor design with steel materials, and mechanisms, transfer of the forces should be discussed. Concrete tension strength and breakout strength, consideration based on provision of ACI 318 (with introducing cracking factor, edge-distance and eccentricity factor for anchors. Structural-steel design, welding, structural-steel corbels, bearing pads, are considered in details. At the end of the Chapter, moment connections, typical connections and design aids are given.

Non-load-bearing spandrels are precast concrete components that are less than one story high. Support of the spandrel weight may be provided by either the floor or the columns (Figure 5). Different types of anchor bolts for receiving low and moderate tension forces (Figure 6). Application of alternate anchor details presented in Figure 7, as an typical column base-plate detail in case with base plate larger than column Figure 8). Similar publication, related to hollow core floor is given in *fib* B.6 [13b]. Floor panels are designed to be stiff in their plane, including mention hollow core floor. This function, namely the diaphragm effect, must be provided by joints. This effect allows the transfer of horizontal loads to all vertical elements, connected with a diaphragm, according to their stiffness. There are significantly more publications dedicated to prefabricated concrete structures, which also consider more or less prestressed, and much more nonprestressed concrete structures. Many articles also consider the application of prestressing, such as in [33] and [36]. Diaphragm action is primarily ensured with the floor panel joints and the entire system of ties, as well as by adding the concrete topping layer of the floor slabs on the spot, that is compounding concrete with concrete. In PhD thesis [3] a hibrid connection was proposed, i.e. added of an in situ solution into a precast one. Many guidelines and handbooks, also, recommend this type of connections [1], [5], [14], [22] and [32]. Continuity of joints may be assumed in design, as for monolithic joints where in-situ concrete and conventional reinforcement detailing are used; or it is ensured by bolted or welded connections [8]. Connections should otherwise be considered as hinged. However, in reality model with semi-rigid connections is more convenient.

Although published a long time ago, it is a valuable manual [15]. The provisions of EC8 [10] for precast structures strive for the design with emulation of monolithic construction. Emulation may be based either on flexural yielding at “energy dissipation” i.e.“ductile” connections between precast elements, or on “overdesigned”, i.e. “strong” connections designed to remain elastic while flexural yielding develops elsewhere. Design with elements interconnected at dry joints are not covered.

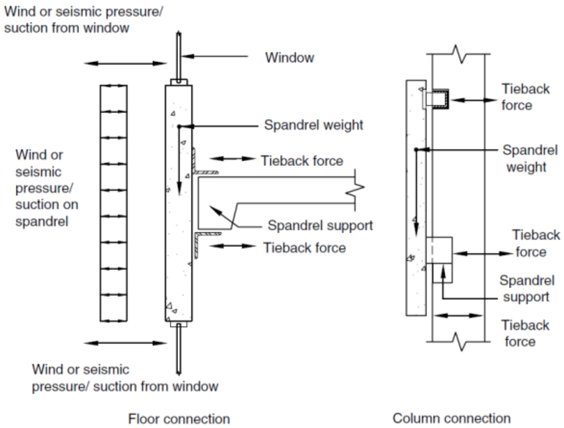

Figure 5. Forces on a spandrel panel, after [32]

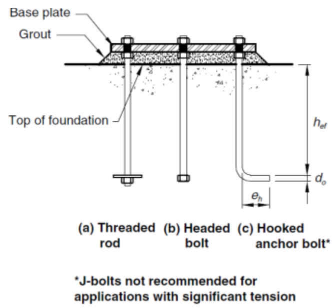

Figure 6. Typical anchor bolts

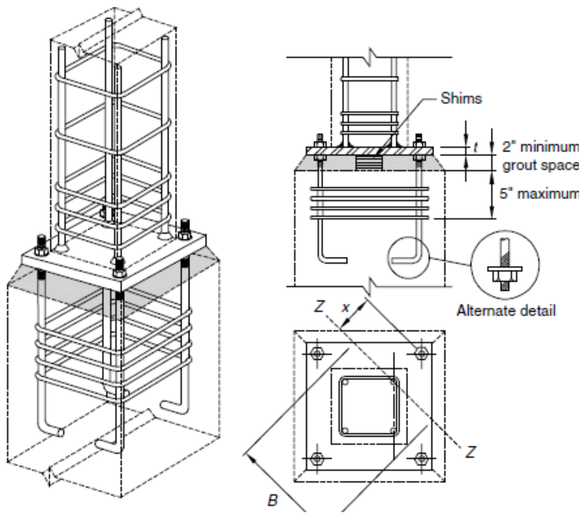

Figure 7. Typical column baseplate detail, after [32]

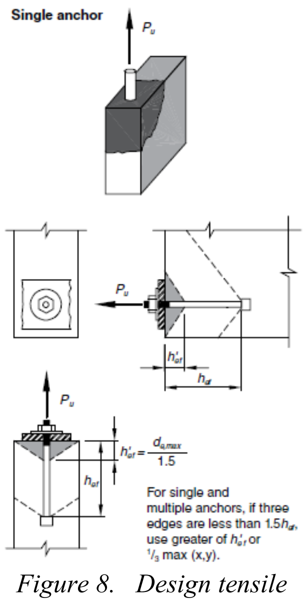

Figure 8. Design tensile strength of stud

A practical guide for detalling of the precast concrete structures that should meet the buiding code requarements in seismic regions, by emulating cast-in-place reinforced concrete design with all provisions in accordance with ACI 318, is prepared by ACI [2]. Design and the construction of the connections of the PC building strutures, applied in South Africa, is subject of work [28]. Europian Commision JRC Scientific and policy reports have published a guidelines dedicated to the frame precast system [30], similar as [7].

The benefits of the employment of the shear walls, as the main lateral forces resisting system in design of buildings has been used for a long time, but until recently the potential use of precast wall systems to resist seismic forces has not been extensively researched. Many researchers have recently advocated the advantages of precast concrete walls, noting additional benefits when detailing them with unbonded post-tensioning. This includes improved performance of the wall system under seismic loading by reducing damage and residual displacements. In order to adopt these advantages, the design methods and suitable analysis techniques for precast concrete wall systems must be established [39] and [40] from Iowa University.

Prior to the establishment procedure of the analysis and design methods, the performance of the jointed wall system, included in the PRESSS (PREcast Seismic Structural System) test building, is summarized using the test data that has been carefully processed to reflect the suitable initial conditions. Next, results from the tests completed on the material and U-shaped flexural plate (UFP) connectors that were used as the primary energy dissipation elements in the PRESSS jointed wall system is presented and a force-displacement response envelope suitable for thisconnector that may be used in the design if jointed wall systems is recommended [40].

Theprecast structural wall systems, investigated as a part of the PRESSS program, were the unbonded post-tensioned single walls and unbonded post-tensioned jointed wall systems. The unbonded post-tensioned single walls were primarily studied through analytical means and it was included in the PRESSStest building [39]. Selected experimental results are used to validate the proposed analysis procedures for these types of walls. A design methodology, introduced for the jointed precast wall systems, is based on the guidelines originally proposed as a part of the PRESSS program. Based on the results of experimental investigations in jointed walls and new ductile shear wall, *J. Sørensen* and his other colegues published papers [37] and [38].

The paper [12] presents the results of tests on slabs with punching shear reinforcement formed by prefabricated truss assemblies disconnected from the flexural reinforcement, developed to optimize the construction process. General guidelines for design, detailing, and assembly of this reinforcements are presented, based on the recommendations presented by ACI 318, Eurocode 2, and *fib* Model Code 2010 (2013). One slab without shear reinforcement and one slab with stud rails were tested as a reference for tests on two slabs with the prefabricated truss modules as punching shear reinforcement. The load-rotation response and the failure loads are presented and discussed in comparison with theoretical estimates, obtained by following the design codes. The slab with inclined prefabricated truss bars, registered similar response and resistance, compared to the one with stud rails. These tests confirm the effectiveness of this kind of punching shear reinforcement, as one of the slabs had almost twice the strength and more than three times the deformation capacity of the reference slab without shear reinforcement.

3. DESING JOINTS AND CONNECTIONS

The design and construction of the joints and connections is important to ensure the stability and robustness of the overall structure. Forces shall be permitted to be transferred between members by grouted joints, shear keys, mechanical connectors, reinforcing steel connections, reinforced topping, or a combination of these means.
The design of joints and connections at the intersection of concrete members, and for load transfer between concrete surfaces, include: connections of precast members; connections between foundations and ether cast-in-place or precast members; horizontal shear strength of composite flexural members; brackets and corbels. Transfer of forces by means of grouted joints, shear keys, bearing anchors, mechanical connections, steel reinforcement reinforced toping, or a these, shall be permitted. Methods used to satisfy the requirements for force transfer, their individual load-deformation characteristics should be considered to confirm that the mechanisms work together as intended [1].
Structural connections are supposed to transfer forces, and the magnitude of these forces will vary from connection to connection and the type of the elements. A simplicity is important in order to achieve a connection detail that is inexpensive and least likely to be used incorrectly. Consequently, all connection arrangements should aim to consist of as few as possible different pieces that need to be assembled. The following significant considerations for the design and construction of precast concrete were identified: tensile capacity, movements, durability and aesthetic [24] and [30].
The connections are generally comprised of one or more joints (compression, shear, tension joints), and there are well established methods to design the joints for the subjected forces. The choice of joints depends upon the stress levels at serviceability and/or ultimate stage in addition to the impact of fire, accidental loads etc. Eurocodes EN1990, EN1991 and EN1992 are introduced into the process of determination of the combinations and arrangement of gravity and horizontal loads that are acting on floors, beams and structures.
The ductility of the elements and joints allow the redistribution of stresses from the overloaded parts to those with less loads. This requires the interaction of stiffness, strength and ductility, especially that of joints and connections, whose role is not only to transfer loads but also to ensure the structural continuity of the whole building, by appropriate confinement [8]. Resistance to seismic action can also be achieved by pre-stressing [33].
Connections, and regional of members adjacent to connections, shall be designed to resist forces and accommodate deformations due to all load effects in the precast structural system. Adequacy of connections shall be verified by analysis and test. Connections that rely solely on friction by gravity loads shall not be permitted [1]. Design of connections shall consider the effect of tolerances specified for fabrications and erection of precast members.
Diaphragm action is primarily ensured with floor panel joints and the entire system of ties, as well as by adding the concrete top layer of floor slabs on the spot, which enables compounding concrete with concrete [13] and [25]. Floor panels are designed to be stiff in their plane. This function (diaphragm effect) must be provided by joints. This effect allows the transfer of horizontal loads to all vertical elements connected with a diaphragm, according to their stiffness [8] and [13b].

In precast concrete buildings, floor slabs are most often designed by being simply supported. However, structures which are fully or partially continual between neighbouring spans behave better. Continuation of slabs/beams reduces the deflection of floor slabs. Special measures are required for transferring moments in supporting zones, namely joints, in order to prevent chain failures. Horizontal restraint caused by friction due to the weight of any supported element may only be considered for non-seismic zones. It may only be considered where the friction is not solely relied upon for overall stability of the structure. The seismic design of precast structures can be based on the standard capacity design criteria provided that there is a good behaviour of the structures, without brittle failures [11].
Load bearing walls are connected with horizontal and vertical joints/connections, which enables them to receive horizontal loads in their plane and to transfer them to the foundation. The interaction between individual walls and parts of walls is provided by joints which are capable to transfer shear, tension and compression forces [5], [6], [39] and [41]. Non-bearing walls are connected with the load-bearing part of the structure and façade walls may or may not have the load-bearing role [32]. Interaction between walls, frames and floor slabs must also be ensured with the use of appropriate joint design. Lateral loads cause the occurrence of bending moments and shear forces in the diaphragm. It is important to achieve the best possible floor panel connections and avoid large openings in the floor slabs [5], [7] and [22].
Precast systems which deviate from those provisions [10], as a consequence, need additional design criteria and are assigned reduced behavior factors. Identification of the effect of the connections on the energy dissipation capacity of the structure:

- connections located well outside critical regions, not affecting the energy dissipation capacity of the structure (Fig. 9a),
- connections located within critical regions but adequately overdesigned, so that inelastic behaviour is shifted to areas away connections (Fig. 9b),
- connections located within critical regions which should exhibit substantial ductility (Fig. 9c).

Connection materials should be stable and durable for the normal lifetime of the structure. Chemical and physical compatibility should be checked. Materials should be protected against adverse chemical and physical influences. They should have the same fire rating as the structural elements. The strength and deformation characteristics of supporting pads should be in accordance with the design criteria [8].

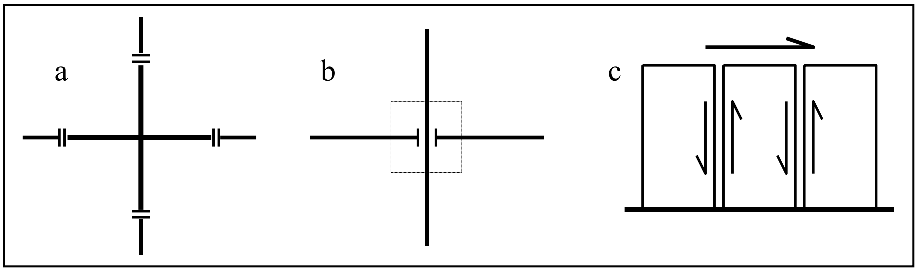

Figure 9. Identification of the effect of connections on the energy dissipation capacity

In addition to the plastic rotational capacity of critical regions, energy dissipation in precast structures may also be effected by means of post-yield shear displacements along the joints, provided that their force response does not degrade substanially within the considered duration of the action. Only regular precast structures are considered.
The design resistance of connections between precast elements within critical regions under seismic conditions should be evaluated as:

$$R_{pd} = \frac{R_d}{\gamma_{Rd} \cdot \gamma_{cycl}} \tag{1}$$

where:

R_d - design resistance under monotonic loading;

γ_{Rd} - additional model-uncertainty factor;

γ_{cycl} - reduction factor, accounting for resistance degradation.

The total minimum reinforcement ratio, of large panel walls, of 0.004 should relate to the actual cross-sectional area of concrete [9]. Force-response degradation of vertical joints should be toothed. Horizontal joints under transverse compression along their entire length may be formed without teeth. However, if they are partly in compression and partly in tension, they should be toothed along their full length. More detailed recommendations for large-panel buildings and reinforcement of walls and horizontal and vertical joints and connections are described in [6], [9], [10] and [32].
In the case of frame (skeletal) structures (Fig. 10), there are two different principles of composition. In the first one, stability is achieved through the cantilever effect of columns confined into the foundation. In other words, the joints are receiving bending moments. Beams and columns are usually connected with pin joints or moment resistant frames. Lower buildings allow the use of frames, whereas walls are necessary for taller ones. Namely, according to [8] and Fig. 11, the cantilever effect of columns is limited up to the height of 12m, mainly because of architectural reasons, because of the preservation of the cladding and partition walls from excessive deformations.

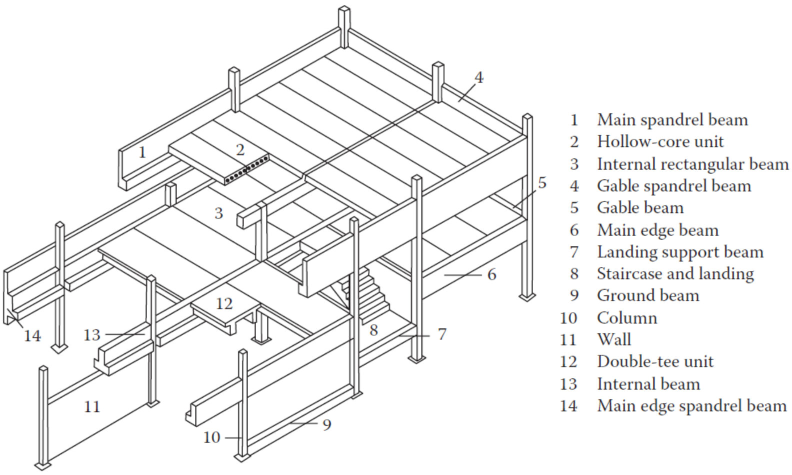

Figure 10. Skeletal (frame) structure and definition of components, after [8]

A variety of connection types that occurs in typical precast concrete frame buildings include the following [8]:

- Foundation-to-column connections,
- Column-to-column connections,
- Column-to-beam connections,
- Connections between floor slabs, and
- Beam-to-slab connection

Typical types of connections in skeletal (frame) concrete buildings are shown in Figure 11. They are formed between different elements and realized in different ways. As an example of different possibilities, the connections between the beams and the columns are indicated. These connections have the possibility to be moved outside of the critical zone. The beam to beam connections are performed similarly. The connections between columns and foundations are also shown [8].

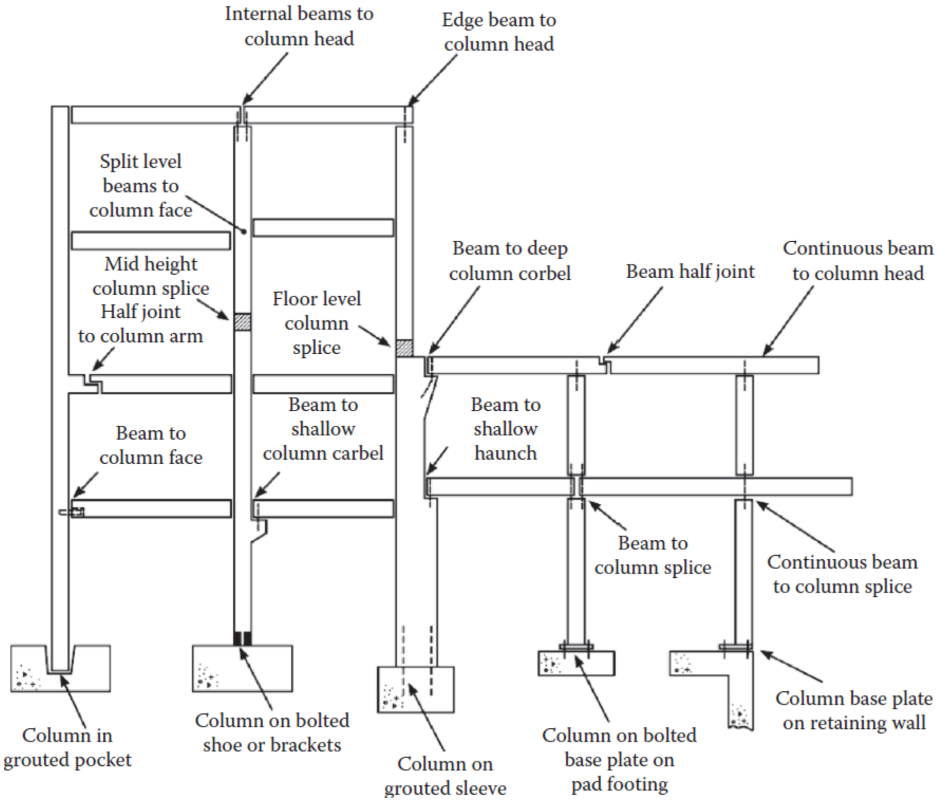

Figure 11. Types of connections in skeletal concrete buildings, after [8]

The major connections between beams and floors are designed as ‘pinned joints’, and therefore the horizontal elements (slabs, staircases, beams) are all simply supported. Vertical elements (walls, columns) may be designed as continuous, but because the beam

and slab connections are pinned there is no global frame action and no requirement for a frame stiffness analysis, apart from the distribution of some column moments arising from eccentric beam reactions [7] and [8]. The stiff bracing elements such as walls are designed either as a storey height element, bracing each storey in turn, or as a continuous element bracing all floors as tall cantilevers.
They are necessary in high seismic zones and the connections are made rigid or very ductile. It may be necessary to design either/both rigid and/or pinned connections. Rigid monolithic connections can only truly be made at the time of casting, although it is possible to cast in-situ connections that have been shown to behave as monolithic, for example cast in-situ filling of prefabricated soffit beams before and after casting as shown in Figure 12. In cold climates conditions better solution is use of bolted or welded mechanical devices. Rigid connections may be made at the foundation where there is less restriction on space.

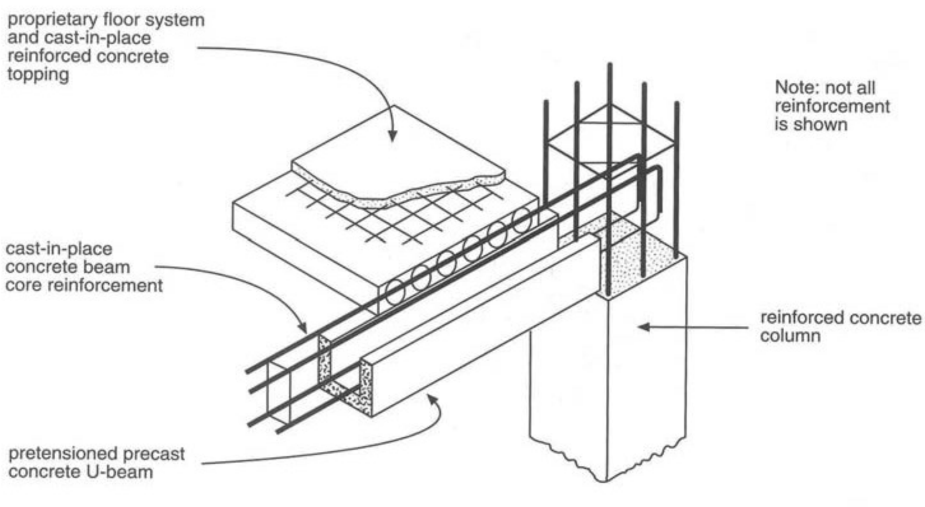

Figure 12. Precast, pre-tensioned beam shell (Centre for Advanced Eng.), after [8]

Precast frame systems can be designed and classified in the two categories, with a ductile or a strong connection. In the ductile connection, the yield caused by bending is expected to occur in the connection area. The connection may be designed to develop the yield in the location which is not adjacent to the joint, whereas in the strong connections the yield caused by bending may only occur on the structural part of the precast element outside the joint [1]. Fig. 13 shows an example of the strong connection. The location of the strong connection should be chosen carefully, to avoid concentration of strain that may produce premature cracking of the reinforcement ACI 318 [1] and [23].
Precast beam-to-slab connections are given in many references. Two types of this connections (Type 1 and Type 2) are shown in Figure 14.

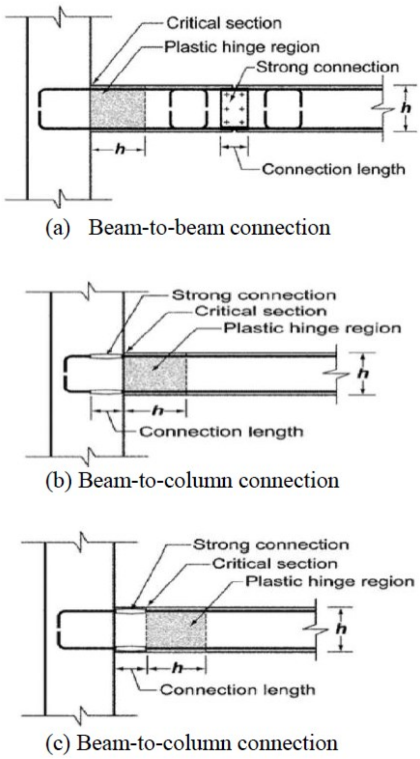

Figure 13. Beam to column connections, after ACI [1], citate in [23]

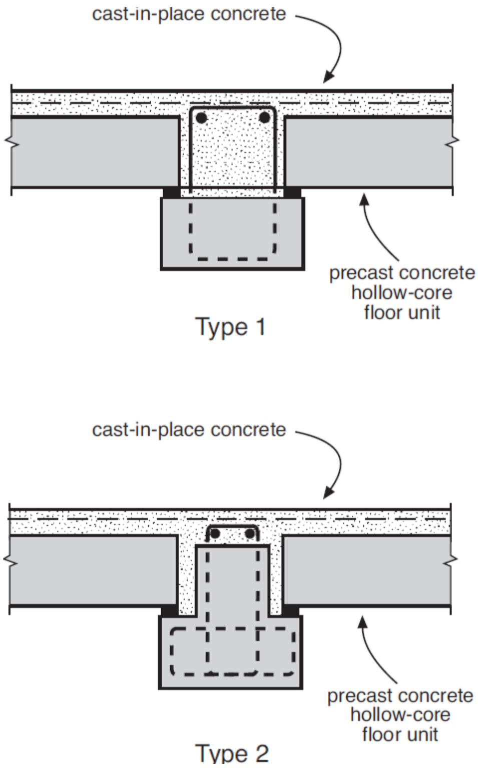

Figure 14. Two different types of beam-to-precast floor connections [22]

Compresion joints will always be composed of a several materials (mortar, steel and elastomer) with different properties (compressive stress, elastic modulus, etc.). In *fib* Model Code 2010, Bulletin 66 (2013), the continuation of the column without and with connections to the slab (floor structures) between them is shown in Fig. 15. The mortar strength has to be at least 50% of the wall/column strength.

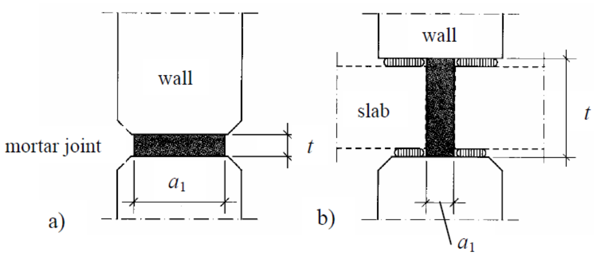

Figure 15. Continuation of the column with layer of morter (a), and with connections with slab, after fib Billetin 66 [14b]

Continuation of the column with elstomer layer is shown in Figure 16.

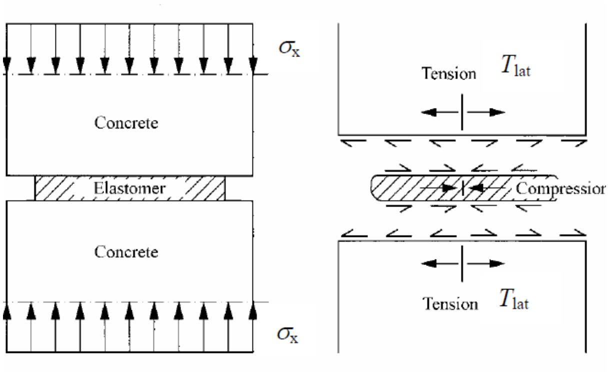

Figure 16. Compression throug the concrete and plain bearing pad, after [14]

Loop connections (Fig. 17) can be used to transfer tensile forces, bending moments and shear forces.

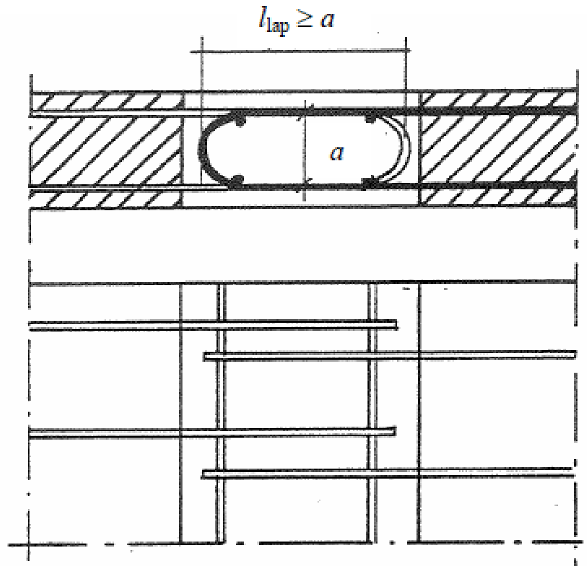

Figure 17. Loop connection

The transverse force F_t in the reinforcement at one side of the overlap is calculated as:

$$F_t = 2 \cdot N_y \cdot \cot\theta \tag{2}$$

where N_y is the yield load of one leg of the U-bar and θ is the strut inclination.

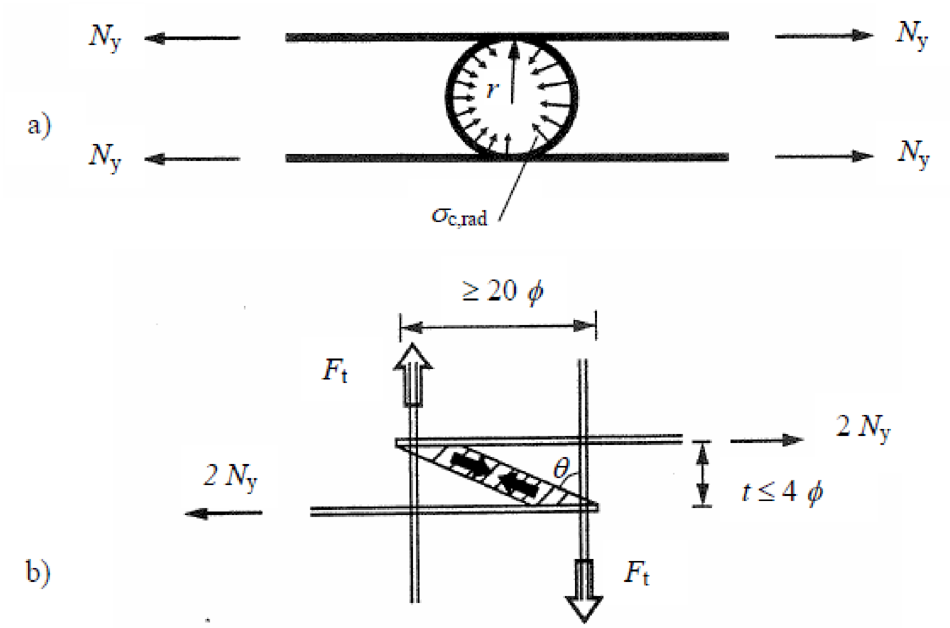

Figure 18. Transfer of forces in loop connection, a) radial stresses against the bend, b) inclined compressive strut between overlapping loops

The tensile force in one U-bar is balanced in the joint by the radial concrete stresses. A horizontal equilibrium for one U-bar gives the relation:

$$2r \cdot \Phi \cdot \sigma_{c,rad} = 2 \cdot \frac{\pi \cdot \Phi^2}{4} \cdot f_y \quad ; \sigma_{c,rad} = \frac{\pi \cdot \Phi}{4r} \cdot f_y \tag{3}$$

where r corresponds to the radius of the bend of the U-bar (Fig. 18) and Φ to the diameter of the U-bar. The following conditions need to be fullfiled:

$$\sigma_{c,rad} \leq f_{cc} \cdot \sqrt{\frac{b_i}{\Phi}} \quad ; \quad \Phi \leq 3 \cdot f_{cc} \quad ; \quad b_i = 2 \cdot \left(c_c + \frac{\Phi}{2}\right) \geq t \tag{4}$$

where c_c is the concrete cover between U-bar and edge of the element and t is transverse spacing of meeting loops. It is recommended that the following detailing condition is fulfilled:

$$r \geq \frac{\pi \cdot \Phi}{4r} \cdot \frac{f_y}{\sigma_{c,rad}} \quad ; \quad r \geq 8 \cdot \Phi \tag{5}$$

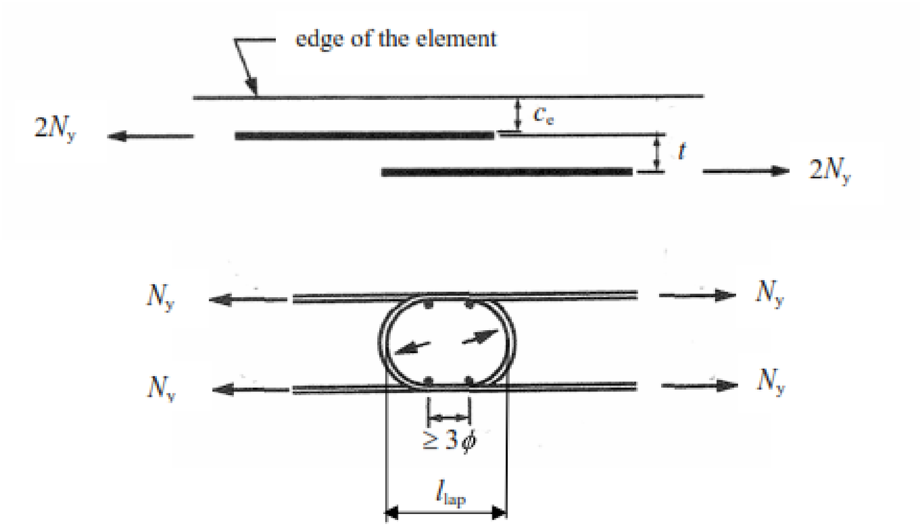

Figure 19. Detailing of the loop connection

New research within the doctoral dissertation at DTU Lingby – Denmark, and published papers [36] and [37], show a recently developed design method for keyed shear connections. The influence of the key depth on the failure mode and ductility of the connection have been studied by performing the push-off tests. These tests showed that connections with larger key indentations failed by complete key cut-off. In contrast, connections with smaller key indentations were more prone to suffer local crushing failure at the key corners. The local key corner crushing has an effect on the load-displacement response, which is relatively more ductile. In addition to the tests, the paper also presents lower bound modeling of the load carrying capacity of the connections. The main purpose of the lower bound model is to supplement an already published upper bound model of the same problem and thereby provide a more complete theoretical basis for practical design.
It is found that the test results, consistent with the extremum theorems of plasticity, are all lying within the gap between the upper and the lower bound solution. The primary benefit of the upper bound model is its simplicity (a closed-form equation). On the other hand, the lower bound model provides safe results, but it is more complicated to apply. It is therefore argued that the upper bound model may be used in cases, where the calibration with the tests has been carried out. The lower bound model should be applied in situations, where the design deviates significantly from the configurations of the available tests, see [36] and [37].

4. FINAL REMARKS AND CONCLUSIONS

The precast concrete (PC) structures that were built according to the latest seismic technical specifications, behaved very well in actual earthquakes and they remained almost undamaged or they suffered a moderate level of damage. The structural behaviour of the frame can be controlled by the appropriate design of connections. The load bearing capacity of a PC building does not only depend on the capability of its elements and their joints and connections to receive all calculated influences. The selection process of the connections must be done with the special attention on the quality of the materials and with adequate analysis and detailing. In their design, it is necessary to perceive the method of force transfer between individual elements, to ensure the ductility of joints, as well as their continuity and, therefore, the possibility of force transfer through the connections. In general, quality control, cost-effective construction and construction speed will contribute to the effective use/exploitation of the precast concrete structures.

ACKNOWLEDGEMENTS

The research described in this paper was financially supported by the Ministry of Education and Sciences of Republic of Serbia within the Project: “Multidisciplinary theoretical and experimental research in education and science in the fields of civil engineering, risk management and fire safety and geodesy.” (University of Novi Sad, Faculty of Technical Sciences, Department of Civil Engineering and Geodesy) (R. Folić, M. Čokić) and within the Project (Contract No. 451-03-9/2021-14/ 200213) (University of Belgrade, Faculty of Mechanical Engineering, Innovation Centre) (B. Folić). This support is gratefully acknowledged.

REFERENCES

[1] ACI 318M – 19: *Building Code Requirements for Structural Concrete and Commentary on BCRSC*, 2019.
[2] ACI 550.1R01: *Evaluating cast-in-place detailing in precast concrete structures*.
[3] Albarran, A. G. *Construction with reinforced precast concrete elements – Adaptation of an in-situ solution into a precast one*, PhD, IST, Lisboa, 2008.
[4] Bournas, D.A. Negro, P. Seismic performance of mechanical connections in the SAFECAST precast building, *15 World Conf. Earthquake Eng,* Lisboa 2012.
[5] Building Construction under Seismic Conditions in the Balkan Region. Vol. 2. *Design and Construction of Prefabricated Reinforced Concrete Building Systems*. United NDP. Vienna, 1985.
[6] *Draft Guide for the Design of Precast Wall Connections*. CIB Report-Publ. 88, Rotterdam, June 1985.
[7] Elliot, K.S. 2000. *Multi-story Precast Concrete Framed Structures*, Blackwell Science, Oxford
[8] Elliot, K.S. *Precast Concrete Structures*, CRC Press, Taylor &Francis Group, Boca Raton, FL, USA, 2nd edition, 2017.
[9] EN 1992 (Eurocode 2): *Design of Concrete Structures*, 1995.
[10] EN 1998-1 *Design of structures for earthquake resistance – Part 1: General rules seismic action and rules for buildings*, 2004 CEN

[11] Biondini, F., Ferrara, L., Toniolo, G. Capacity Design Criteria for Connections in Precast Structures. Paper presented at the *14th World Conference on Earthquake Engineering*. Beijing, China. 12-17 October 2008.

[12] Ferreira, P.M. et al. (2021): Experimental resistance of slab-column connections with prefabricated truss bars as punching shear reinforcement truss bars as punching shear reinforcement, *Engineering Structures*, Available online 10 February 2021;

[13] *fib*: Bulletin 23 *Seismic design precast concrete building*, 2003; and *Special design considerations for precast prestressed hollow core floors*. *Guide to good practice*, fédération international de béton, Bulletin 6, Lausanne 2000.

[14] *fib* Bulletin 43: *Structural connections for precast concrete buildings*, FIB, Lausanne, Switzerland, 2008; and *Model Code 2010*, 2013

[15] FIP-*Planning and Design Handbook on Precast Building Structures*, 1996.

[16] Fischinger, M., Zoubek, B, Isakovic, T. Seismic Response of Precast Industrial Buildings in A. Ansal „*Perspectives on European EE&Seismology, Geotechnical, Geological and Earthquake Engineering 34*", 2014.

[17] Folić, R. (1991): Classification of damage and its causes as applied to precast concrete buildings. *Material and Structures*. RILEM - Journal, Chapman & Hall, Vol. 24, pp. 276-285.

[18] Folić, R., Pavlović, P., Folić, B.: Analiza montažnih betonskih okvirnih sistema sa popustljivim čvorovima. *Izgradnja* br. 11, Beograd, 1996. str. 604-616.

[19] Folić, R., Petrović, B. (1997): Precast Concrete Structures-Status and Trends - Introductory report, *Intern. Conference - INDIS' 97*. FTN-Novi Sad, November, 1997. Vol. I. pp. 23-62. (štampano i na srpskom)

[20] Folić, R., Zenunović, D., Rašidbegović, N. Strength of connections in preca7st concrete structures, *Facta Univ. Serial A and CE*, Vol. 9, No.2, 2011, pp. 241-259.

[21] Goviata M. *Detailed design of connection for precast structures*, *Master theses,* Rep. of Cameroon and University of Padova, 2018.

[22] *Guidelines for the use of Structural Precast Concrete in Buildings*, N. Zealand CS and NZSEE, 1999.

[23] Hery, K. et al. Beam-to-beam connection of precast concrete structures: State-of-the-art, *MATEC Web Conf. 258*, 04002, 2019.

[24] Holly, I. Abramhoim, I. Connections and joints in precast concrete structures, *Slovak J. of CE*, Vol. 28, No. 1, 2020, pp. 49-56. I. Holl ́y and I. Harvan, "Connections in precast concrete elements, „*Key Engineering Materials*, vol. 691, pp. 376–387,2016.

[25] Kugan K, Kumar, N. Comparative Study and Analysis of Dry and Wet Connections of Precast Beam-Column under Cyclic Load, *International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)*, Vol. 11, Issue 2, November, 2020. Pp. 141-145.

[26] Marreiros, R.P.C. *Precast concrete wall-foundation connection*, PhD, FCT, Lisboa, 2014.

[27] Menegotto, M. 2006. A Presentation of Fib Commission 6 "Prefabrication". 13 October 2006.

[28] Mostert, L. H. *Design and construction preferences for connections in the precast concrete industry of South Africa*, Mast. theses, Stellenbosch University, 2014.

[29] Nakaki, S.E. 2008. *Precast Concrete Design*, Ch. 8 in FEMA 751

[30] Negro, P. Giandomenico, T. *Design Guidelines for connections of precast structures under seismic actions*, EC – JRC Scientific and Policy reports, 2012.
[31] Park, R. The *fib* state –of-the- art report on the seismic design of precast concrete building structures, *Pacific Conference. On EE*, No. 011, 2003.
[32] *PCI Design Handbook-Precast and Prestressed Concrete. PCI*, Chicago, Ill. 2010.
[33] Porco, F. et al. A simplified procedure for the seismic design of hybrid connections in precast concrete structures, *The Open Construction and Building Technology J.* 2013, pp. 63-73.
[34] *Precast Concrete Connection Details (PCCD) – Structural Design Manual*, STUPRE-Society for Studies on the use of Precast Concrete, Netherlands, 1978. *PCCD-Floor Connections*, 1981.
[35] Seelfi, P et al. Panel connection details in existing New Zealand precast concrete buildings, *Bull. of the NZ Society for EE*, Vol. 49, No. 2, June 2016
[36] Song, B. et al. Analytic investigation of the differences between cast-in situ and precast beam-column connections under seismic actions, *Applied sciences*, 10, 8289, 2020, doi:10.3390/app10228280
[37] Sørensen, J. H., Hoang, L.C., Olsen, J. F., Fisher, G. Test and analysis of a new ductile shear connection design for RC shear walls, *Structural concrete* (2017), 18 (1), pp. 189 – 204.
[38] Sørensen, J. H.et al. Test and lower bound modelling of keyed shear connections in RC shear walls, *Engineering Structures* 155 (2018) 115–126.
[39] Sritharan, S., Aaleti, S. Thomas, D. J. *Seismic Analysis and Design of Precast Concrete Jointed Wall Systems*, Iowa University, December 2007.
[40] Thomas, D. J. Sritharan, S. *Evaluation of seismic Design Guidelines Proposed for Precast Jointed Wall Systems*, Iowa University, June 2004.
[41] Van, R.Y. *Application of vertical profiled mortar connections in precast concrete shear walls*, Grad. Theses, TU; 2019, Delft.

СЕИЗМИЧКА АНАЛИЗА СПОЈЕВА И ВЕЗА У МОНТАЖНИМ БЕТОНСКИМ КОНСТРУКЦИЈАМА

Резиме: *У раду су приказане одредбе Норми којима се регулише начин анализе и обликовања детаља спојева и веза конструкцијских елемената. Обухваћене су норме ACI 318, Eurocode 2 i 8, Code New Zeland i fib Model Code 2010 (2013) и њихови билтени. Преказане су анализе и обликовање веза према поменутим нормама и литератури зависно од напонски стања којима су елементи изложени. Анализиране су и препоруке појединих интернационалних удружења PCI Design Handbook Precast and Prestressed concrete, ACI C 533 Guide Percast concrete, Guidelines for the use of Structural Precast Concrete (New Zealand) и други. За неке везе (петљама) и друге анализе засноване су на новијим истраживањима њиховог понашања под оптерећењем које симулира сеизмичка дејства приказане су и приближне анализе.*

Кључне речи: *сеизмичка анализа, монтажне бетонске, пројектовање, везе, спојеви, обликовање детаља*