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# MULTISTORY FRAMED BUILDINGS WITH SLAB CAST OVER PRECAST JOISTS: RECOMMENDATIONS FOR DESIGNING CONCRETE ELEMENTS KEY JOINTS

*The role of joints which are used to provide interoperability of separate elements in prefabricated monolithic frame design systems with flat slabs was researched. Special attention is paid to key joints that are exposed to significant shear strength and provide the structures' solidity during the operation. On the basis of the experimental studies, recommendations for the joints design are suggested. In Poltava National Technical University a key joints calculation method has been developed, which considers the damage nature, a set of determining impact factors and is recommended for extensive use.*

***Keywords:** precast-and cast-in situ structural system, joint, key, strength, plasticity, cut.*

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# БАГАТОПОВЕРХОВА КАРКАСНА БУДІВЛЯ ЗІ ЗБІРНО-МОНОЛІТНИМ ПЕРЕКРИТТЯМ: РЕКОМЕНДАЦІЇ ДО ПРОЕКТУВАННЯ ШПОНКОВИХ З'ЄДНАНЬ ЗАЛІЗОБЕТОННИХ ЕЛЕМЕНТІВ

*Висвітлено роль стиків, котрі використовуються для забезпечення спільної роботи окремих елементів збірно-монолітних каркасних конструктивних систем із плоскими перекриттями. Особливу увагу приділено шпонковим з'єднанням, які сприймають значні зусилля зсуву та забезпечують монолітність конструкції в період експлуатації. На основі виконаних експериментальних досліджень запропоновано рекомендації для проектування стиків. У Полтавському національному технічному університеті імені Юрія Кондратюка розроблено методику розрахунку шпонкових стиків, за допомогою якої досліджено характер руйнування, сукупність визначальних факторів впливу; її рекомендовано до широкого застосування.*

***Ключові слова:** збірно-монолітна конструктивна система, стик, шпонка, міцність, пластичність, зріз.*

**Introduction.** The experience of national and foreign multi-story residential and public buildings construction shows that the most promising in this respect are framed systems with flat discs of slabs.

Frames are suggested to be made of precast and cast-in-place reinforced concrete, that permits their manufacture without additional costs as manifold statically indeterminate system with great potential for redistribution efforts under load between its individual components, reducing the size of sections and the amount reinforcement required, thus reducing material consumption of structures. The use of precast components improves the products' quality and promotes the development of construction industry plants.

**Analysis of recent research sources and publications.** One of the first attempts to use slab cast over precast joists with smooth ceilings is considered the «SOCHI» system [1]. It includes columns and precast-monolithic discs of the slab (Fig. 1) formed by hollow core slabs and monolithic girders with the height equal to the plates' thickness. For longitudinal slab-to-slab joints reinforcement is designed. Expansion reinforced joints between the slabs and solid-cast bearing girders form a rigid cross-system of primary and secondary beams. Leaning of plates on the girders is provided by means of concrete keys at the ends and on the side faces of the plates, formed when the girders are concrete casted due to the concrete mixture embedding of holes and cavities in plates. The system was not widely used, but it has inspired other present-day popular systems.

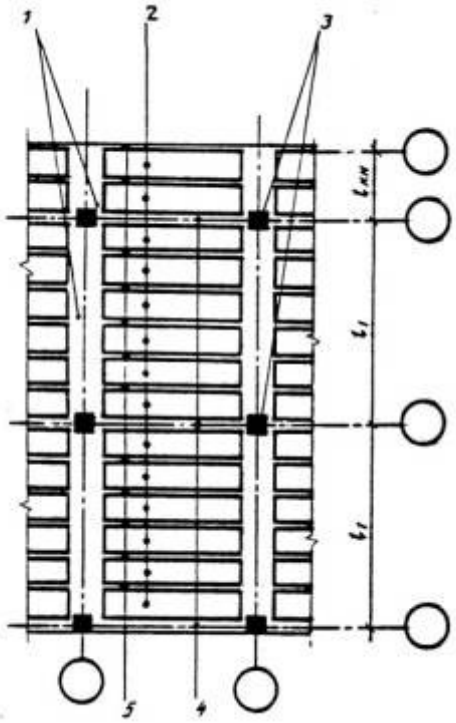



**Figure 1 – The «SOCHI» type slab cast over precast joists:**
1 – solid-cast bearing girders; 2 – precast slab panels; 3 – precast columns; 4, 5 – solid-cast beams between the columns and precast slabs

«ARCOS» structural system [2], in which: precast-monolithic discs of slabs using hollow-core panels and monolithic bearing and braced girders with the similar cross sections are made flat; reduced to the solid floor thickness is 12 – 14 cm and provides usage of spans with the length of 7.2 m or more (Fig. 2). Leaning of slabs on the bearing girders is performed due to concrete keys formed in the plates' hollows at their ends at the girders' concrete casting.

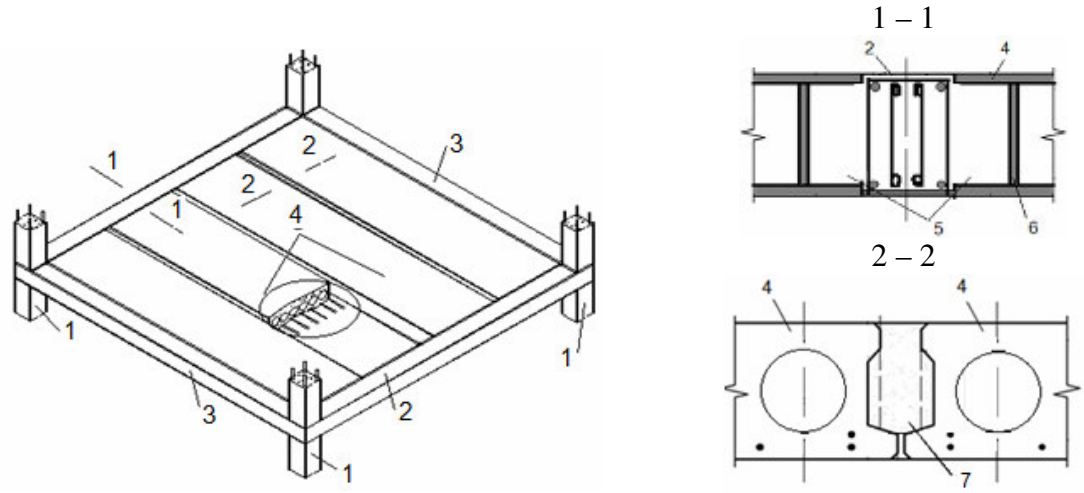



**Figure 2 – Fragment of the «ARCOS» structural system building:**
1 – columns; 2 – solid-cast bearing girders; 3 – solid-cast braced girders;
4 – precast hollow-core slabs; 5 – concrete keys of bearing girders;
6 – key size stopper; 7 – concrete keys between the slabs

The existing foreign analogues of slab cast over precast joists using hollow-core slabs (even at a higher organization and manufacturing culture) for security reasons it is not recommended to place the supporting concrete sections in the form of concrete keys. Ukraine has a number of patents that improve the joint of plates with a solid-cast girder by reinforcing concrete keys with flat or spatial frames in the form of a pyramid [3, 4], which increases their reliability.

At Prydniprovsk State Academy of Civil-Engineering and Architecture a slab cast over precast joists is suggested [5], which is different from that of Arcos in terms of the hollow-core plates size which is made shorter in each site, and the width of solid-cast bearing girders is due to it wider [6]. The hollow-core plate is connected to the solid-cast girder by means of keys, reinforced by flat frames with longitudinal reinforcement 2∅6 A240C.

Precast and cast-in-place building frame suggested by Ye.P. Gurov [7] includes columns and precast-and solid-cast girders, which prefabricated parts are made with open or hidden supporting consoles. Girders are installed on the columns floor-by-floor mostly forming corbels. Hollow-core slab panels with anchor keys in the cavities at their ends are having embedded anchoring wall ties. The keys arrangement is performed through a hole cut in the top of the concrete slab by pour concrete casting through it. The key is reinforced by a frame in which the longitudinal reinforcement is placed in the top and in the middle of its height.

To increase the height of the pier cap at high loads, a technical solution is suggested (Fig. 3), which provides key joint of the girder with the precast column without holes in the floor level [8].

The current standards [9] when calculating key joints, are taking into account the limited number of impacts, and therefore the strength standards are significantly loose compared to the strength indicators demonstrated in the experiments [10 – 12].

At PoltNTU, a variance calculation method has been developed based on the plasticity concrete theory [13], which is commonly used, accurate and simple enough, permitting to calculate the strength of key joints at cutting, with account of all the determinants totality. The method has passed a reasonable testing.

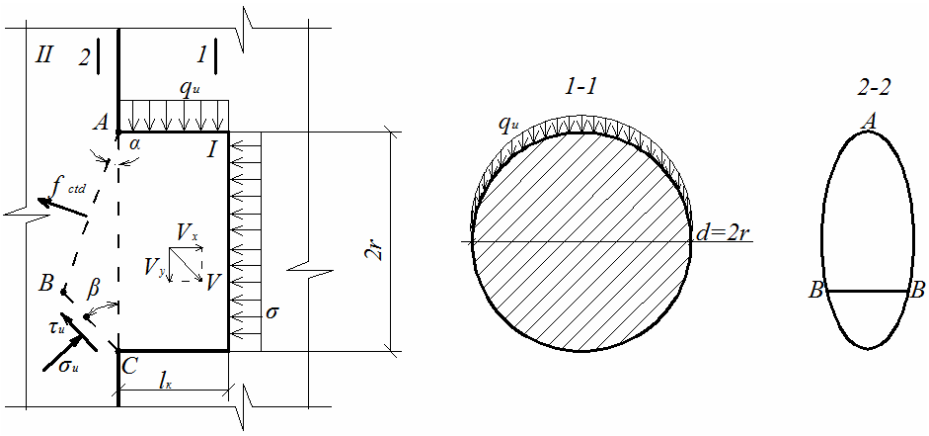



**Figure 3 – Cinematically possible diagram of round evenly reduced concrete keys at cutting**

Highlighting of still unsolved aspects of the general problem. In all the above mentioned slab cast over precast joists, key joints are available providing strength and reliability of the entire system of the building as a whole.

**Setting the objective.** The aim of the study is to submit proposals for the design of concrete elements' key joints in the precast and solid-cast systems.

**Basic material and results.** The suggested method of strength calculation is based on considering the damage nature and taking into account the main impact factors. At calculating a single-key joint, two possible cases of destruction are considered: «the key» and «the joint» destructions that define a cinematically possible scheme of destruction and the ultimate load value. The destruction type depends on the ratio of the joint's geometric parameters [14].

The hollow-core slab panels' joint with solid-cast bearing girders in the Arcos system have a round cross-section of keys. At the slab deformation a spread occurs, leading to the keys' reduction. According to the current standards [9], the round section is replaced by the equivalent square one.

The authors suggest scheme of cinematically possible destruction of evenly reduced round concrete key, which is presented in Fig. 3 [15].

According to the suggested method, the known parameters in solving the problem of durability are the dimensions of the key $l_k$, $2r$, $b_k$, the embedding concrete strength characteristics $f_{cd}$, $f_{ctd}$, reduction.

The unknown values in the present problem are: the ultimate load $q_u$, slope angle $\alpha$ of the AB platform and $\beta$ platforms BC to the vertical, the ratio of speeds $k = V_x / V_y$.

The formula for determining the ultimate load is as follows:

$$q_u = m\left[2B\left(1+\frac{1}{4}\left(\frac{ktg\beta+1}{k-tg\beta}\right)^2\right)^{0,5}-1\right]\frac{2}{3}\gamma(k-tg\beta)\frac{tg\alpha}{tg\beta+tg\alpha}+ \\ + f_{ctd}(k+tg\alpha)\frac{2}{3}\times\gamma\frac{tg\beta}{tg\beta+tg\alpha}+\frac{\pi\sigma k}{4}\gamma, \quad (1)$$

where $\gamma = 2r/h_k$,

$m = f_{cd} - f_{ctd}$,

$B = \sqrt{(1+\chi/(1-\chi)^2)/3}$,

$\chi = f_{ctd}/f_{cd}$ .

The round key's strength turned to be by 10% lower than that of the equivalent square one due to the load features and the form of the surface damaged. There is also the possibility of considering the uneven reduction force application heightwise the key.

The joint strength calculation results for a round-hollow panel with the width of 1,5 m (7 hollows) and the key diameter (the panel's cavity) $d$ = 159 mm, the length of $l_k$ = 100 mm, the embedding concrete class C25/30: $f_{cd}$ = 15,3 MPa, $f_{ctd}$ = 1,08 MPa, provided $\gamma_{c2}$ = 0,9 with account of the cross-section shape, reduction and its application place and reinforcement are presented in Table 1.

**Table 1 – Comparison of the hollow-core panel and a bearing girder joint's strength performed by different methods**

| Source / Joint type | [17] round section | [9] equivalent square section | [13] round/ equivalent square section |
|---|---|---|---|
| Load (kN) | | | |
| Concrete keys | 286,7 / – | – / 77,14 | – / – |
| Reinforced concrete keys | – / – | – / 115,1 | 202,65 / 230,16 |
| Reduced concrete keys | – / – | – / 265,2 | 341,32 (207,69) / 381,15(231,42) |
| Reduced reinforced concrete keys | – / – | – / 302,17 | 364,63 (239,2) / 412,09 (268,7) |
| * in brackets the value of the joint strength is given for the reduction applied in the lower part of the key | | | |

At the calculations of reinforced concrete keys, their smallest possible reinforcement by flat frames with longitudinal reinforcement is set 2∅3 Bp-1.

The submitted suggestions as to improving the design of the hollow-core panel with a girder, which provide the use of cylindrical frame instead of a flat frame and its being performed as a hollow triangular pyramid that will provide equal strength of the key joint both in the vertical and in the horizontal planes, will improve its reliability at seismic impacts [16].

In [8], the joint of precast column with solid-cast girder, which has thickening on support, is designed as three-keys joint (Fig. 4).

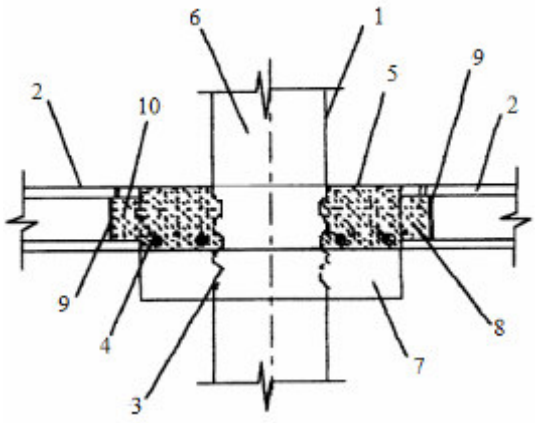



**Figure 4 – Key joint of the precast column with solid-cast girders:**
1 – columns; 2 – hollow-core panels; 3 – concrete keys; 4 – reinforcing frames; 5 – middle solid-cast girders; 6 – side of the column; 7 – thickening of the girders' bearing; 8 – end hollows of the panel; 9 – stoppers; 10 – keys of girders

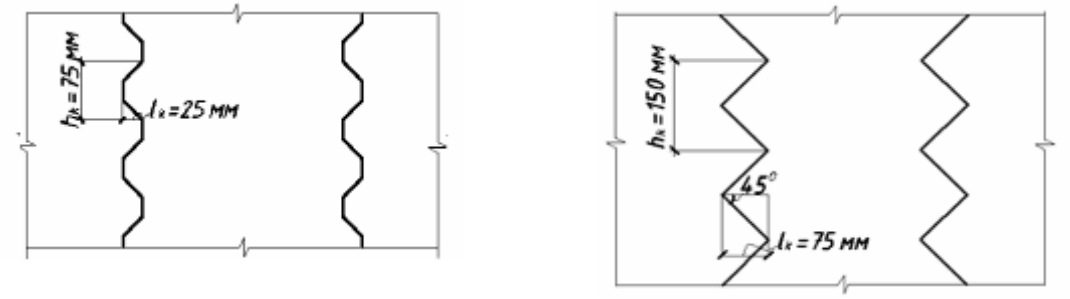
According to the results of series of experimental studies performed at PoltNTU, it is suggested to calculate the uneven behaviour of keys heightwise according to the suggested empirical dependence:

$$V_{sh,n}^{k} = V_{sh,1}^{k}\left(1+0{,}95\ln n_k\right), \tag{2}$$

where $V_{sh,1}^{k}$ – is a single key's strength,

$n_k$ – is the number of keys in the joint.

It is recommended to design keys of the trapezoidal shape, both in terms of the increased strength and the technology of manufacturing joints, or triangular joints to avoid inter-key space. The calculation method considers the shape of the key profile. The ratio of the key depth to its height should be taken within $l_k$ / $h_k$ =0,25 – 0,5.




$V_{sh,c} = 243{,}9\ kN\ \left(l_k / h_k = 0{,}3\right)$ $V_{sh,c} = 361{,}32\ kN\ \left(l_k / h_k = 0{,}5\right)$

**Figure 5 – Geometric dimensions of the column with a girder joint with the trapezoid and triangular keys**

**Conclusions.** When solving the problems of the key joints' strength in the reinforced concrete elements of the slab cast over precast joists, the circular shape of the key's cross-section was considered together with the reinforcement features and the reduction effort's location. The relation was also suggested for the uneven keys' behaviour lengthwise, which improves the suggested calculation method, increases its accuracy and opens opportunities for improvement of design solutions. All the joints considered are having the sufficient strength reserve.

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