DOI: https://doi.org/10.54338/18294200-2024.1-02 ***CONSTRUCTION***

COMPARISON ANALYSIS OF PUNCHING BUILDINGS WITH FLAT PLATE UNDER STATIC AND SEISMIC LOADS

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The structures with the same frame system (flat plate), but with different spans (6 m and 7 m) and slab thicknesses (20 cm, 22 cm, 25 cm and 40 cm), static and seismic calculation was carried out by the finite element method using "LIRA SAPR"and "ETABS" software packages. Design of structure in accordance with Armenian building codes were implemented. In order to analyze the results of calculations, comparative graphs and tables with a number of variables were built. From the results of the analysis it became clear that the average value of punching shear is 14,58 %, and the average difference of the shear reinforcement area is 38,7%. Consequently, the anchorage length also should be checked by the American building standards for structure design.

Keywords: *punching shear, flat plate, seismic load, static load, reinforced concrete, shear reinforcement*

Introduction

In modern construction, cast in situ reinforced concrete buildings with flat plate system have become widespread, where the traditionally used beams (girders) are absent and all the load from the floor is taken by the inter-floor, directly transferring it to the columns. This construction scheme has unique advantages and a unique vision of modern construction. Compared to buildings with frame system, they have a number of advantages, among them: a variety of architectural solutions, a sense of spaciousness in the structure, ease of installation of communications and formwork, etc. [1, 2].

Researches with flat plate systems were carried out by both domestic and foreign scientists: Babayan H.H., Dorfman A.E., Kodish E.N., Mordich A.I., Pekin D.A., Chizhevsky V.V., Dilger V.H., Fanella D. etc. The calculation of flat reinforced concrete elements (slabs) according to compression is carried out in the case of the effects of forces and bending moments concentrated on them. The most common case, for which it is necessary to take into account the phenomenon of crushing, is the part of the slab that is located immediately around the column. Compression can be considered as sliding of the slab against the loaded section. The surface damaged by punching has the shape of a truncated pyramid. The first factor to be determined in terms of punching shear is the perimeter of the contour of the calculated cross section obtained from that pyramid. The appearance of the border differs from each other according to different construction norms. According to the Armenian and Russian reinforced concrete standards, the edge of the transverse section has a quadrangular shape (square or rectangular), and according to the European and American reinforced concrete standards, the appearance of the edge is curvilinear [3, 4]. Borders in the shape of a rectangle or a square slightly deviate the actual calculations, but make further calculations quite easy. Another advantage of rectangular or square borders is that if there is a need for reinforcement, then it will be possible to reinforce the entire surface in the border of that shape, because usually the reinforcement nets have a square or rectangular shape.

At first, the construction of buildings with flat plate was widely used in non-seismic zones. However, in recent years in the Republic of Armenia (RA), there is also a tendency to build buildings with flat plates. That is why the article is devoted to the analysis of the results of static and seismic calculations, which provides an opportunity to make the article more readable by recruiting a wider audience of readers. At the same time, taking into account that the entire territory of RA is located in a seismically active zone, the scientific works related to the work of load-bearing elements of buildings will be considered even more valuable when the effect of seismic force is taken into account according to the normative documents in RA.

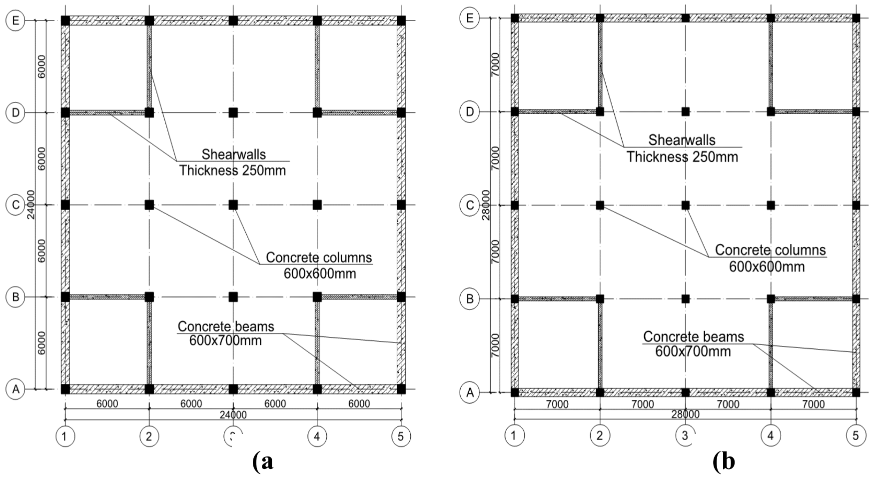
It is obvious that the need to study the stress-strain state of flat plate system [5] in high-rise buildings is becoming relevant in the case of the most favorable spans and thicknesses of the slab from the point of view of structural design. At the same time, during the research, it is very important to correctly describe the real stress-strain state of the calculation models in the case of different loads. Therefore, the studies aimed at the most accurate description of the stress-strain state of the structures with flat plate are highly relevant and important.

Materials and Methods

In the article, five-storey structures with a flat plate system of monolithic reinforced concrete with two uniform design models, with different slab thicknesses were presented: 20 *cm,* 22 *cm,* 25 *cm*, 40 *cm*, proportional in both directions, with spans of 6 *m* and 7 *m*, respectively, where the height of the floors is 3,3*m* (floor plans are shown in Fig. 1a, Fig. 1b). The plan of the building is chosen simply so that additional torsion do not occur and stress-deformation states can be more clearly assessed. The position and number of shearwalls are selected according to the current RA seismic codes: at least two solid diaphragms in both directions, proportional to the axes of the building and continuously along the height of the entire building.

All loads were accepted as arbitrary (Table 1). The calculation of the building structures was carried out by main and special combinations of static and dynamic loads, with two software packages: “LIRA SAPR” and “ETABS” (three-dimensional models see correspondingly Fig. 2a, Fig. 2b) [6-9]. Class of concrete B25 was used in the calculations (cubic strength of concrete: 25 *MPa,* design strength of concrete: 14,5 *MPa*, modulus of elasticity: 30,600 *MPa*). Longitudinal reinforcement A500c and transverse reinforcements class A240 were adopted as reinforcing steel. Seismic zone second (0,4*g*) and soil category first were taken [10, 11].

In accordance with HHSHN 20.04-2020, the “EI” stiffness of the element section was reduced by 25 *%*, the permissible deviation was accepted H/270. The following coefficients were used during the seismic calculation: correction coefficient – 1,0; coefficient of ground conditions – 0,8, coefficient of permissible injuries – 0,4 (for node shear design 0,7), coefficient of responsibility – 1,0, coefficient of the relationship of horizontal and vertical accelerations of the ground – 0,7, coefficient of the relationship between the foundation and the structure – 1,0 [12].



(a (b

Fig. 1. Building plans with 6m (a) and 7m (b) spans

According to the building codes HHSHN 52-01-2021, the punching shear calculation was performed for the reinforced concrete slab under the influence of locally applied stresses, concentrated force and bending moment. The boundary of the calculated cross section, which is located around the stress transfer zone normal to the longitudinal axis of the element, is taken as $h_0/2$, where h_0 is the working height of the slab section. In the case of the concentrated force, the tangential stresses, which are taken over by the concrete and the reinforcement, are assumed to be evenly distributed over the entire surface of the calculated cross section. In the case of the influence of the bending moment, the tangential stresses, which are taken over by the concrete and the shear reinforcement, are taken along the calculated cross section, with the opposite sign at the edges of the calculated cross section, in addition, with the maximum tangential stresses in the direction of the moment effect, linearly changing [13, 14].

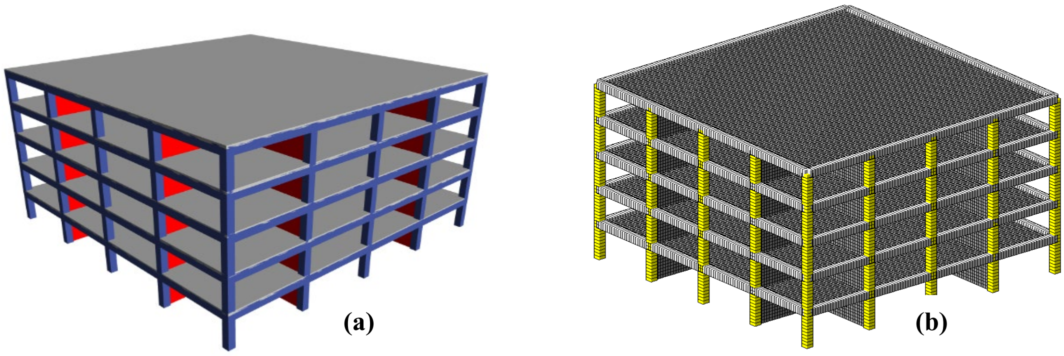


Fig. 2. 3D design models of "ETABS" (a) and "LIRA SAPR" (b)

Table 1

Applied static loads

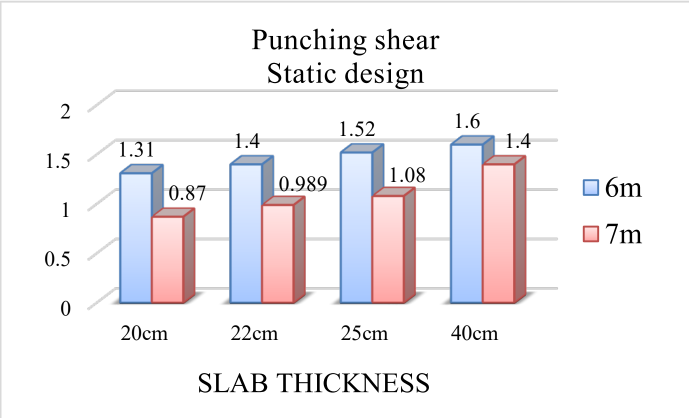
Type of loads	Design loads (t/m^2)
Dead`	
• **Floor finish**	0,24
• **Partition**	0,2
• **Wall**	1,0 (*t/m*)*
Total`	0,44
Live`	
• **Long term (1-4 storey)**	0,036
• **Short term (1-4 storey)**	0,144
• **Short term (roof)**	0,112
Total (dead+live)`	
• **For 1-4 storey**	0.62
• **For roof**	0.588

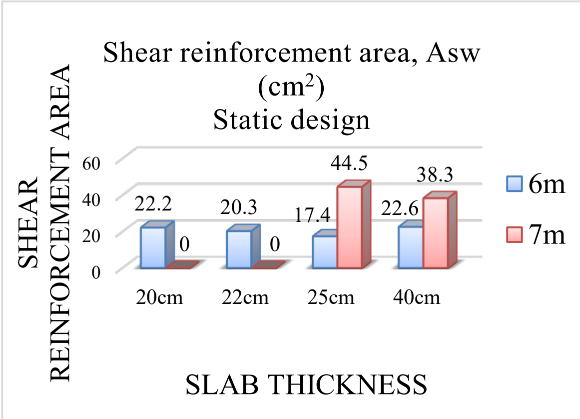
** The exterior wall load is linear distributed.*

Results and Discussion

Analysis of static calculation results with "LIRA SAPR" and "ETABS" software packages.

According to the "LIRA SAPR" software package, transverse reinforcement is required in sections where punching shear value in flat plates is 1… 2, for values smaller than 1, shear reinforcement is not required, and for values of 2…3, it is necessary increasing of slab thickness or the cross section of the column, because all our calculation schemes are uniform, and the increase in the size of the structure implies only a change in the thickness of the slab, that is why the case of increasing the area of the cross section of the column is not discussed in this article [6, 7]. As we know, in practice, it is customary to use 6 *m* as the optimal maximum span. According to the static calculation, in the case of a 6m span, the preferred thickness of the slab is 20 or 22 *cm*. Static design results are shown in Fig. 3.



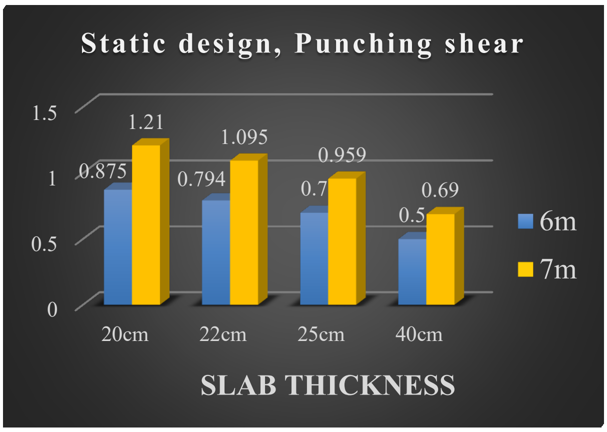


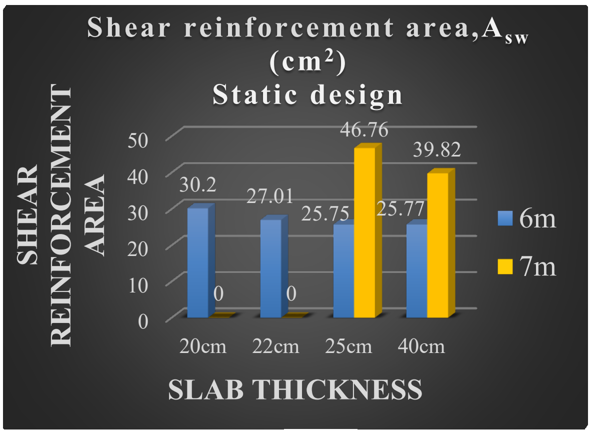
(a) **(b)**

Fig. 3. Punching shear (a) and shear reinforcement (b) results via "LIRA SAPR" software

As a result of the static calculation analysis (Fig. 3ab), it becomes clear that unlike the 6 *m*, the 20 *cm* and 22 *cm* thick slabs of the structure with a 7 *m* span do not satisfy to punching shear condition, that is why it is necessary to increase the thickness of the slab. Also, it became clear that in the case of a 7 *m* span, the minimum slab thickness is 25 *cm*, which can be considered the necessary minimum for the given span. Let's take a look at the analysis of the static calculation results using the "ETABS" software package. In this case, the meaning of the value of the punching shear condition is different: if it is less than 1, it satisfies the punching shear condition, otherwise it does not [8, 9, 15, 16].

Comparing the results of the static calculation of the "ETABS" software package (Fig. 4ab), we see that it is again recommended to use a minimum slab thickness of 25 *cm* in the case of a 7 *m* span.





(a) **(b)**

Fig. 4. Punching shear (a) and shear reinforcement (b) results via "ETABS" software

The seismic calculation results of "LIRA SAPR" and "ETABS" software packages are presented in the Table 2 and Table 3, respectively. From the observation of the results of the "LIRA SAPR" software, it can be seen that the punching shear value in the case of a 6m span, both in the static and seismic calculations [17], is also satisfactory. However, in the case of a 7 *m* span, the threshold of the minimum slab thickness has increased to 40 *cm*.

Table 2

Characteristic results via "LIRA SAPR"

LIRA SAPR	Seismic design							
Span (*m*)	6				7			
Slab thickness (*cm*)	20	22	25	40	20	22	25	40
Shear reinforcement area (*cm*^{2})	27,1	28,6	32,2	39,6	Error	Error	Error	85,3
Punching shear ratio	1,21	1,24	1,25	1,39	0,87	0,892	0,882	1,02
Period of vibration (*s*)	0,253	0,256	0,260	0,278	0,256	0,259	0,264	0,285
Drift (*mm*)	3,030	3,121	3,242	3,609	2,394	2,485	2,545	2,758
Column reinforcement ratio (%)	4,61	4,81	5,13	6,45	6,14	6,22	6,60	7,38
Shear stress (*N/mm*^{2})	9,10	9,41	9,81	11,30	7,78	8,24	8,38	9,20

Table 3

Characteristic results via "ETABS"

ETABS	Seismic design							
Span (*m*)	6				7			
Slab thickness (*cm*)	20	22	25	40	20	22	25	40
Shear reinforcement area (*cm*^{2})	23,3	21,7	24,9	20,0	Error	Error	25,4	25,9
Punching shear ratio	0,864	0,831	0,800	0,799	1,100	1,041	0,980	0,920
Period of vibration (*s*)	0,208	0,211	0,216	0,238	0,206	0,210	0,215	0,240
Drift (*mm*)	2,641	2,758	2,926	3,628	2,519	2,643	2,792	3,622
Column reinforcement ratio (%)	1,57	1,64	1,71	2,25	1,63	1,70	1,78	2,25
Shear stress (*N/mm*^{2})	9,71	10,10	10,81	13,74	10,46	10,10	11,76	15,38

Observing the calculation results of the "ETABS" software, we see that there is no problem of punching shear even in the case of a 6 *m* span, but as in the static calculation, in the case of a 7 *m* span, the minimum thickness of the slab can be accepted as 25 *cm*. In the seismic calculation, in addition to the punching shear calculation, a number of other variables were also compared, such as the periods of vibrations of the structure in two directions (T_{xy}), the values of which were obtained the same for both directions, because the calculation scheme of the structure is symmetrical in both directions. From this it can be assumed that the structure does not have the problem of torsion. The second variable that was observed is the storey drift (δ_{xy}), as it was mentioned in the "main part" of the article, according to the seismic codes of RA the permissible drift of the storey is 12mm. The third variable is the longitudinal reinforcement ratio of the column section expressed as a percentage (μ_{col}), the maximum value of which is 4 % according to Armenian building standards. The last fourth variable is the tangential stresses occurring in the shear walls (τ_{xy}), the allowable value in accordance with seismic codes is calculated by the following formula τ_xy≤0,7√Rb, where Rb is the design compressive strength of concrete (*N/mm*^{2}).

After analyzing the results of static and seismic calculations, a decision was made to select the most different calculation results for software comparison, the seismic calculation of the 7 *m* span of the structure. As it was mentioned above, the meaning of the punching shear values of “LIRA SAPR” and “ETABS” software packages is different, for this purpose their values were presented in the form of a percentage relationship, where the negative value of the percentage means an insufficient punching result (Fig. 5).

As a result of the analysis of Fig. 5, we can see that in the case of 20 *cm* and 22 *cm* slab thickness, both software packages gave a negative value: in the case of 20cm, the difference in punching shear values was 3 *%*, in the case of 22 *cm* 6,7 *%*.

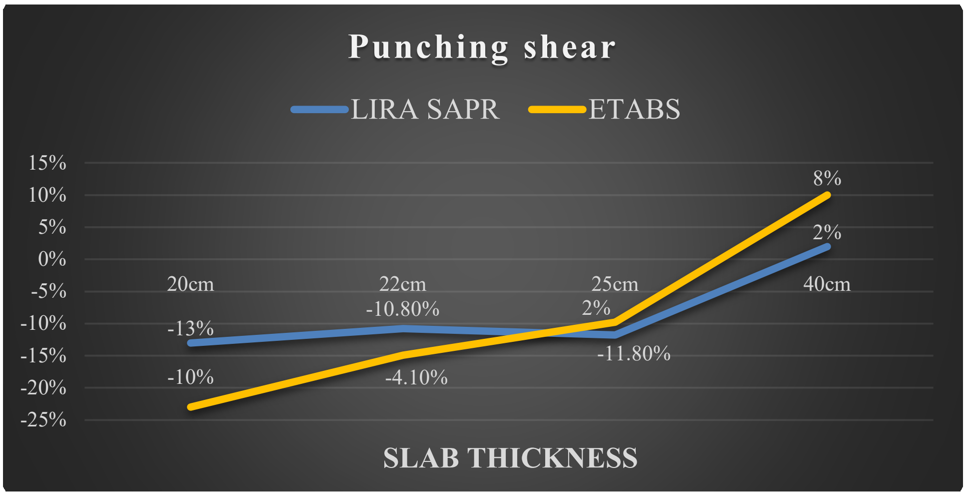


Fig. 5. Punching shear comparison analysis via “ETABS” and “LIRA SAPR” software

For a slab thickness of 25 *cm*, the difference was 9,8 *%*, but the punching shear value of the “ETABS” software package is positive, so the transverse reinforcement is required, which is 25,4 *cm*^{2}. At 40 *cm*, the difference in the punching shear value was 6 *%*, both software packages gave a positive value.

Conclusion

Comparing the results of static and seismic calculations, we see that the average difference in the value of punching shear is 14,58 *%*, where the margin of the result of the static calculation is greater than that of the seismic calculation. And the average difference of the shear reinforcement area is 38,7 *%*.

Comparing the results of the static calculation of the structure with a 6m span, according to the “LIRA SAPR”software package, we will see that the average difference of the compression value depending on the thickness of the slab is on average 16,9 *%*, and the average difference of the shear reinforcement is 18,64 *%*, in the case of the “ETABS” software package, respectively, 15,2 *%* and 16,78 *%*. In the case of seismic calculation, the average difference in the compression value of the “LIRA SAPR” software package depending on the thickness of the slab is 6 *%*, and the average difference of the shear reinforcement is 13,7 *%*, in the case of the “ETABS” software package, it is 2,17 *%* and 15,54 *%*, respectively.

As a result of the software comparative analysis, the difference in the punching shear value between the two software packages can be accepted as 6,4 *%* on average.

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ԱՆՊԱՐԶՈՒՆԱԿ ՀԻՄՆԱԿՄԱԽՔՈՎ ՇԵՆՔԵՐԻ ՃԶՄԱՑՄԱՆ ՀԱՄԵՄԱՏԱԿԱՆ ՎԵՐԼՈՒԾՈՒԹՅՈՒՆ ՍՏԱՏԻԿ ԵՎ ՍԵՅՍՄԻԿ ԲԵՌՆՎԱԾՔՆԵՐԻ ԴԵՊՔՈՒՄ

Հովհաննես Արմենի Ավագյան, Դավիթ Արսենի Կանդալյան*

Ճարտարապետության և շինարարության Հայաստանի ազգային համալսարան, ք. Երևան, ՀՀ

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Աշխատանքում նույն հաշվարկային սխեմաներով (անպարզունակ հիմնակմախք), բայց տարբեր թռիչքներով (6 մ և 7 մ) և ծածկի հաստություններով (20 սմ, 22 սմ, 25 սմ և 40 սմ) կառույցներում իրականացվել է ստատիկ և սեյսմիկ հաշվարկ վերջավոր տարրերի մեթոդով՝ օգտագործելով «LIRA SAPR» և «ETBAS» ծրագրային փաթեթները: Հաշվարկն իրականացվել է համաձայն ՀՀ-ում գործող շինարարական նորմերի: Հաշվարկների արդյունքների վերլուծության նպատակով կառուցվել են համեմատական գրաֆիկներ և աղյուսակներ՝ մի շարք փոփոխական-ներով: Վերլուծության արդյունքներից պարզ դարձավ, որ սալի ճզմացման միջին արժեքը 14,58 % է, իսկ լայնական ամրանավորման մակերեսի միջին տարբերությունը՝ 38,7 %: Հետևաբար, ամրանի խարսխման երկարությունը պետք է ստուգվի նաև ամերիկյան շինարարական նորմե-րով՝ կառույցները նախագծելիս:

Բանալի բառեր. *ճզմացում, անպարզունակ հիմնակմախք, սեյսմիկ ուժ, ստատիկ ուժ, երկաթբետոն, լայնական ամրանավորում*

СРАВНИТЕЛЬНЫЙ АНАЛИЗ НА ПРОДАВЛИВАНИЕ ЗДАНИЙ С БЕЗРИГЕЛЬНЫМ КАРКАСОМ ПРИ СТАТИЧЕСКИХ И СЕЙСМИЧЕСКИХ НАГРУЗКАХ

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Для конструкций с одинаковой каркасной системой (безригельный каркас), но с разными проле-тами (6 м и 7 м) и толщиной плит перекрытий (20 см, 22 см, 25 см и 40 см), проводился статический и сейсмический расчет методом конечных элементов с использованием программных обеспечений “LIRA SAPR” и “ETABS”. Проектирование конструкции осуществлялось в соответствии с строительными нормами и правилами РА. Для анализа результатов расчетов были построены сравнительные графики и таблицы с рядом переменных. Из результатов анализа стало ясно, что среднее значение плиты на продавливание составляет 14,58 %, а средняя разница площади попереч-ного армирования - 38,7 %. Следовательно, при проектировании конструкций длина анкеровки также должна быть проверена американскими строительными нормами.

Ключевые слова: *продавливание, безбалочный каркас, сейсмическая нагрузка, статическая нагрузка, железобетон, поперечное армирование*

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