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The stress–strain state estimation of slabs with shear reinforcement according to Armenian and foreign building codes

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ABSTRACT:
The paper presents the results of punching shear values with reinforcement based on calculations of two and four storey cast–in–place reinforced concrete flat plate system buildings with spans of 4 and 7 m in accordance with Armenian, Russian, European and American building codes under seismic action. The effect of punching shear on both interior and edge columns was carried out. All calculations by LIRA, Design Expert and RCM ACI–builder softwares were implemented. In contrast to Eurocode 2 (EN 2) and American Concrete Institute (ACI), the building codes of the Republic of Armenia (SNiP) do not include the influence of bending moment in shear stress equation. To analyze the systems finite element method (FEM) was used. The results of comparison analyses shown that according to SNiP the shear stresses do not exceed the limit even without reinforcement, whereas by foreign standards the differences between peak shear stresses with reinforcement and permissible shear reinforcement are marginal. To conclude, in shear stress condition the internal bending moments have a significant role, especially in seismic regions.

KEYWORDS:
seismic action; finite element method; building codes; flat plate; shear reinforcement

1. Introduction

Buildings which are erected by flat plate systems became widespread in the Republic of Armenia (RA), because of free planning and they are economically and ecologically profitable. Armenia is placed in a seismic region and the territory is divided in three seismic zones, where the accelerations of ground can be equal to 0.2g, 0.3g and 0.4g respectively [1] (Fig. 1). Intersection of column and slab during the seismic action is risky because the bending moments can be notable. Consequently, the effect of earthquake loading is an important task for future calculations of flat plate systems.

A flat plate floor system is a two–way concrete slab supported directly on columns with reinforcement in two orthogonal directions. This system, which is popular in residential buildings (hotels, apartments and restaurants), has the advantages of simple construction and formwork and a flat ceiling, the latter of which reduces ceiling finishing costs because the architectural finish can be applied directly to the underside of the slab. Shear stresses at edge columns and corner columns are particularly critical because relatively large unbalanced moments can occur at those locations [2]. There are several types of reinforcement to provide the shear strength, such as headed shear stud and stirrup reinforcement.

Flat plate floor system is calculated by the method of limiting equilibrium. It has been experimentally established that for flat plate dangerous loads are: strip load across the span

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and continuous throughout the area. With these loads, two schemes of the linear plastic hinges of the plate are possible.

The highest skyscraper "Burj Khalifa" in United Arab Emirates (UAE) with flat plate system in 2010 was erected. This building in Dubai city is located and has 828 m height. In the same year in Yerevan 22 and 24 storey multifunctional, multistorey cast–in–place reinforced concrete flat plate buildings were constructed which are located in Sayat Nova street 40 and 40/1. In 2012 the hotel complex "Opera Suit" from 6th to 17th floors with flat plate system was built. The "Gate Tower" flat plate skyscraper in capital of UAE with 66 floors which has 238 m height in 2013 was erected. The construction of hotel "Dvin" in 2014 was restarted of which two basement and three last floors by flat plate were implemented.

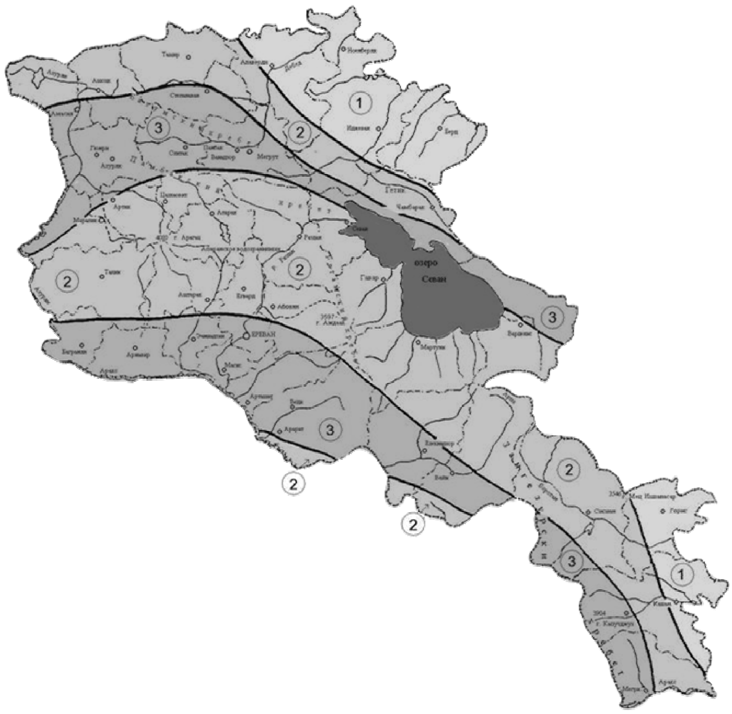

Fig. 1. Seismic zoning map of RA

One of the important roles is the opening in slabs. Openings in slabs are usually required for stairs, elevations, air conditioning, wires and pipes. Consequently, the size and location have their own influence on the stress–strain state of the slab.

Last researches [3] shown that the punching shear values according to SNiP [4] are satisfying the shear conditions without reinforcement, while in accordance with Russian standards (SP) [5] and EN 2 [6] these values are approximately 2.5–3.0 times larger than allowable, therefore it is necessary to put the additional steel bars for providing shear resistance. The main goal of the article is to obtain the shear stresses with reinforcement according to Armenian and foreign building codes, to check the general conditions of shear and to see how is affect the bending moment on punching shear observing various positions of columns, spans and storeys.

2. Input datum

The cast–in–place reinforced concrete flat plate system buildings are investigated in the paper. The buildings have two and four storeys with spans of 4 and 7 m. Each storey height is equal to 3.0 m. The strength class of concrete is C16/20 (B20) and the grade of steel bar is Grade 500 (A500C). In flat plate building the slabs have 22 cm thickness and the square columns have 50×50 cm cross sections. All loads are assumed by the building standards. For comparison analysis not only SNiP, SP, EN 2 and ACI 318 [7] are included, but also the ground accelerations 0.2g and 0.3g for first and second seismic zones respectively in accordance with [2]. Also the analyses of interior and edge columns are involved which are shown in Figure 2. As shear reinforcement for current computations was chosen stirrups. All calculations by LIRA, Design Expert and RCM ACI–builder software were performed.

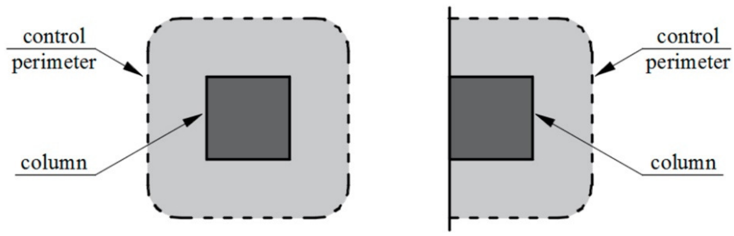

Fig. 2. Schemes of column position

3. Punching shear design of slabs with shear reinforcement

A slight difference in the forces is largely due to the difference of reliability and load combination factors. Design outline of transverse cross section is accepted locked and around the area of the load transmission is placed, when the platform of load transmission inside of the flat element is located. The calculations under punching shear are performed for flat reinforced concrete members (slabs), when the concentrated forces and the bending moments are existed.

In accordance with [4] the shear stress of slab with shear reinforcement is equal to

$$\tau_1 = \frac{F}{u_m \times h_0} \tag{1}$$

According to [5] the shear stress can be equal

$$\tau_2 = \frac{F}{u h_0} + \frac{M_x}{2W_{bx} h_0} + \frac{M_y}{2W_{by} h_0} \tag{2}$$

According to [6] at the column perimeter, or the perimeter of the loaded area, the maximum punching shear stress with reinforcement shall not be exceeded:

$$\beta \frac{V_{Ed}}{u_i d} \le 0.75 v_{Rd,c} + 1.5 \frac{d}{s_r} A_{sw} f_{ywd,ef} \frac{1}{u_1 d} \sin\alpha \tag{3}$$

Shear strength with reinforcement according to [7] is based on

$$\phi \left(0.33 \lambda \sqrt{f_c^{'}} + \frac{A_v f_{yt} d}{s} \right) \ge \frac{V_u}{A_c} + \frac{\gamma_{vx} M_{ux} y}{I_x} + \frac{\gamma_{vy} M_{uy} x}{I_y} \tag{4}$$

In the conditions (1)-(4) the coefficients and parameters are the followings: F, V_{Ed} and V_u are design values of the applied shear force by [4, 5], [6] and [7] respectively, u_m and u_i are control perimeters of concrete cross section, h_0 and d are effective depths in the orthogonal directions, f_c' is compressive strength of concrete, M_x and M_y, M_{ux} and M_{uy} are factored bending moments in X and Y directions from external load, β is a coefficient, depends on the position of column and internal bending moment, calculated by [6], λ is a modification factor, $V_{Rd,c}$ is a design value of the shear resistance without shear reinforcement, s and sr are the radial spacing of the stirrups, A_{sw} and A_v are the cross–sectional areas of shear reinforcement, θ is the angle between the shear reinforcement and the plane of the slab, Ø is the strength reduction factor, A_c is the area of concrete of assumed critical section, γ_{vx} and γ_{vy} are factors, shall be considered to be transferred by eccentricity of shear about the centroid of the critical section, I_x and I_y are the moments of inertia over X and Y axes respectively, x and y the half sides which are perpendicular to vertical axis of column.

Depends on many factors like strength class of concrete, grade of steel bar, radial spacing of steel bar and control perimeter the shear reinforcement ($V_{Rd,cs}$) according to [4] is equal to 1.20 N/mm^2, by [5] is 0.352 N/mm^2, in case of [6] is equal to 1.526 N/mm^2 and in accordance with [7] the nominal shear strengths with reinforcement for interior and edge columns are 1.174 N/mm^2 and 1.208 N/mm^2 relatively.

As mentioned above the main calculations by LIRA software were carried out. By Design Expert the shear reinforcement were checked for EN 2 and by RCM ACI–builder for ACI 318. The meshing process for column–slab intersections more detailed was done (Fig. 3).

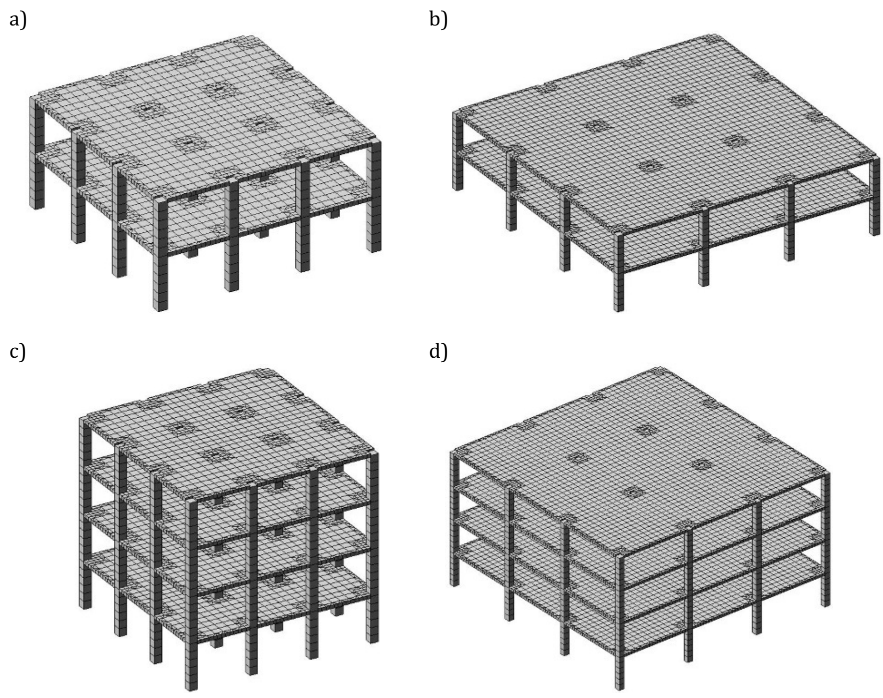

Fig. 3. FE models for simulation analyses, two storey flat plate building with 4 and 7 m spans (a, b), four storey flat plate building with 4 and 7 m spans (c, d)

3. Results

Final results of maximum shear stresses depend on accelerations, column positions, length of spans, storey and building codes are shown in Table 1.

Table 1
Results of shear stresses

Seismic zone	Column position	Span, m	Storey	Design shear stress, N/mm^2			
				SNiP 2.03.01–84* τ_1	SP63.133330.2012 τ_2	Eurocode 2 v_{Ed}	ACI 318 v_u
1	Interior	4	1	0.310	0.094	0.362	0.342
			2	0.270	0.074	0.283	0.313
		7	1	0.960	0.261	0.854	1.073
			2	0.850	0.219	0.702	0.953
	Edge	4	1	0.220	0.078	0.297	0.257
			2	0.140	0.051	0.188	0.162
		7	1	0.600	0.229	0.784	0.684
			2	0.400	0.161	0.550	0.453
2	Interior	4	1	0.310	0.184	0.719	0.350
			2	0.300	0.184	0.723	0.344
			3	0.290	0.145	0.550	0.322
			4	0.260	0.090	0.320	0.298
		7	1	0.970	0.338	1.142	1.098
			2	0.960	0.345	1.170	1.090
			3	0.950	0.304	1.002	1.051
			4	0.850	0.231	0.723	0.946
	Edge	4	1	0.540	0.191	0.584	0.359
			2	0.280	0.142	0.552	0.292
			3	0.290	0.122	0.458	0.206
			4	0.160	0.066	0.241	0.182
		7	1	0.610	0.274	0.963	0.719
			2	0.470	0.256	0.905	0.563
			3	0.610	0.265	0.901	0.501
			4	0.410	0.173	0.573	0.456

Comparing last research [3] with current one is obvious that the limited shear stress according to [4] increases about 1.33 times and as well as [6] grow 3.30 times. Consequently, in accordance with [4, 6] including seismic force for these type of buildings the shear reinforcement is necessary.

3. Conclusions

To sum up, the punching shear resistances apart from interior column of four storey building with seven meters spans are satisfy the shear strength condition even without reinforcement according to [4]. When is considered [5] the differences between shear reinforcement and maximum shear stress is approximately 4%. Furthermore, in accordance with [6] and [7] these differences are 34 and 7%. It means that the peak shear stresses with reinforcement and permissible shear reinforcement are very close values.

After all, in shear stress condition the interior bending moment has a significant role, especially when the structure is located in the seismic region.

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Badanie stanu naprężenie–odkształcenie zbrojonych płyt poddanych ścinaniu na podstawie ormiańskich i obcojęzycznych norm budowlanych

STRESZCZENIE:
W artykule przedstawiono wyniki pomiarów wytrzymałości na ścinanie w oparciu o obliczenia dla dwu- i czteropiętrowych budynków żelbetowych o rozpiętości 4 i 7 m, zgodnie z ormiańskimi, rosyjskimi, europejskimi i amerykańskimi normami budowlanymi, w strefie oddziaływań sejsmicznych. Przeprowadzono badania dotyczące przebicia zarówno dla słupów wewnętrznych, jak i narożnych. Wszystkie obliczenia wykonano w programach LIRA, Design Expert i RCM ACI–builder. W przeciwieństwie do Eurokodu 2 (EN 2) oraz American Concrete Institute (ACI) przepisy budowlane Republiki Armenii (SNiP) nie uwzględniają wpływu momentu zginającego na równanie dla naprężeń stycznych. Do analizy układów konstrukcyjnych wykorzystano metodę elementów skończonych (MES). Wyniki analiz porównawczych wykazały, że zgodnie z SNiP naprężenia ścinające nie przekraczają wartości granicznych nawet bez użycia zbrojenia, podczas gdy według norm obcojęzycznych różnice pomiędzy ekstremalnymi naprężeniami ścinającymi z użyciem zbrojenia a dopuszczalnym ścinaniem zbrojenia są marginalne. Podsumowując, dla warunków dotyczących naprężenia ścinającego wewnętrzne momenty zginające mają duże znaczenie, zwłaszcza na obszarach objętych oddziaływaniami sejsmicznymi.

SŁOWA KLUCZOWE:
oddziaływanie sejsmiczne; metoda elementów skończonych; normy budowlane; płaska płyta; zbrojenie na ścinanie