PROBLEMS OF FLOOR SLABDESIGN IN TERMS OF CAPACITY, SAFETY AND ENERGY EFFICIENCY

Milan Kekanović[1]
DeagoslavŠumarac[2]
Stanko Ćorić[3]
Karolj Kasaš[4]
Arpad Čeh[5]

UDK: 692.5:697.1
DOI:10.14415/konferencijaGFS2017.077

Summary: *This article provides information about the possibilities of design and construction floor slabs concerning three very important aspects: the capacity, safety and energy efficiency.Nowadays, in the Republic of Serbia exclusively solid concrete slabs are designed and built,which are at least 20cm thick.The justification for this solution is to obtain, in its plane, a rigid plate-diaphragm that is able to endure seismic forces on the walls, proportionally to the stiffness of those walls.At the same time this solution has many disadvantages and it is a great load that limits the length of the span. That heavy load is directly proportional to the size of the seismic forces. The20 cm thick, solid concrete slab has a large heat capacity, and specific heat c (J / kgK), which are not energy efficient,as the warm air is accumulated, conductedtowards to the walls and also retained near the ceiling, while people are near the floor.There are other solutions of design and construction floor slabs that meet demands far more than a solid concrete slab.These are the reinforced concrete site-cast waffle slab.These slabs are extremely stiff and stable, optionally in both directions and can have a reduced mass up to 50% compared with solid concrete slabs.The authors will introduce one waffle-slab solution of reinforced concrete slabs, which satisfies, in addition to above mentioned, even the energy efficiency demand. It is a solution by Stirofert-technology built with structural expanded polystyrene as a stay-in-place formwork during the phase of concrete pouring and construction. This same stay-in-place formwork is a powerful insulation on ceiling with a preventing effect against heat-accumulation and heat losses towards the walls; same time equalizing the temperature of air near the floor and ceiling.*

Keywords: *concrete, waffle-slabs, slabs, load capacity, energy efficiency,*

[1]Milan Kekanović, Associate Professor Ph.D. ,Faculty of Civil Engineering Subotica, University of Novi Sad, Kozaračka 2a, 24000 Subotica, Serbia , E-mail: kekec@gf.uns.ac.rs
[2]Dragoslav Šumarac, Professor Ph.D. Faculty of Civil Engineering in Belgrad, Bulevar Kralja Aleksandra 73, 11000 Beograd, Serbia, E-mail: sumi@eunet.rs
[3]Stanko Ćorić,Assistant Professor Ph.D. Faculty of Civil Engineering in Belgrad, Bulevar Kralja Aleksandra 73, 11000 Beograd, Serbia E-mail: cstanko@grf.bg.ac.rs
[4]KaroljKasaš, Professor Ph.D. ,Faculty of Civil Engineering Subotica, University of Novi Sad, Kozaračka 2a, 24000 Subotica, Serbia , E-mail: kkasas@gf.uns.ac.rs
[5] Arpad Čeh, Assistant. ,Faculty of Civil Engineering Subotica, University of Novi Sad, Kozaračka 2a, 24000 Subotica, Serbia , E-mail: ceh@gf.uns.ac.rs

1. INTRODUCTION

Designers of construction and architectural objects and structures are often not interested to implement better solutions, but instead decide a common one, no matter even if such solutions had been already overcome and have big disadvantages. The reasons for the lack of interest are not justified, but the fact is that the design is lately much undervalued by new investors, who seek to maximize cost savings and pay cheap projects, that way increasing the profits by selling real estates. New investors have poor knowledge of profession and of investments as a special area of economics and market economy, and they are not even aware that for low-cost projects, they are getting expensive and often non-functional buildings. The victims are the buyers of such residential and business premises since they payed a high price for poor quality. Designers are content with small profits and they are not interested in the quality but just in quantity. Investors often have problems with repairs of buildings if the mistakes are to detect within the warranty period. Energy efficiency is a legal obligation in the Republic of Serbia and it must be carried out not only in design, but also through the construction. Best control of energy efficiency is the energy consumption for heating and air conditioning. The citizens and buyers of real estate must be educated that it is in their interest to keep control of energy consumption in their homes and offices. [3]If the energy consumption is larger than the purchased buildings class of energy efficiency should have, then the customers have the right to ask for a refund and compensation or elimination of the deficiencies and improvment of energy efficiency to the class that was paid. If the legal procedure would be implemented into practice, through the control of energy consumption, then everyone would primarily considering the quality of the projects and buildings. The designers and investors would not lose anything and the real estate buyers would be satisfied with small bills of energy consumed for heating and air conditioning. Republic of Serbia wants to be a modern country and as such would be have a benefit, because it would reduce the power consumption of the buildings. [2]
It is important to note the fact, that objects properly designed and constructed with less weight of floor slabs could be more reliable to avoid damage at the appearance of an earthquake (seismic load). [4], [5]

$$S = K \cdot G,\ kN \tag{1}$$

S – Horizontal forces due to the seismic action (earthquake) (kN)
K– coefficient that depends on the seismic zone, ductility, oscillation period, object type, soil type (in this study it is assumed that K=0,13)
G – the weight of the building - floor slabs, walls... (kN)

Less weight means that the floor slabs will less accumulate the heat since the specific heat of the material depends on the type of material or fluid and from the weight of the materials or liquids.

$$c = \frac{J}{kgK}\ , \tag{2}$$

That means the lightweight waffle-slabs accumulate less heat energy and therefore less energy would be lost through the "thermal bridges" and "cold areas" such as walls,

foundations, balconies, gable walls. These "cold spots" are difficult to insulate, and in these places we have large energy losses which are currently difficult to calculate.
If solid reinforced concrete floor slabs are designed and built with heavy weight and high heat capacity (specific heat), then the country has great loss as it will appear as bigger energy losses through the "thermal bridges" and "cold areas".
The country still needs to cover the difference of real energy prices since prices in Republic of Serbia paid by costumers are not yet the market prices.

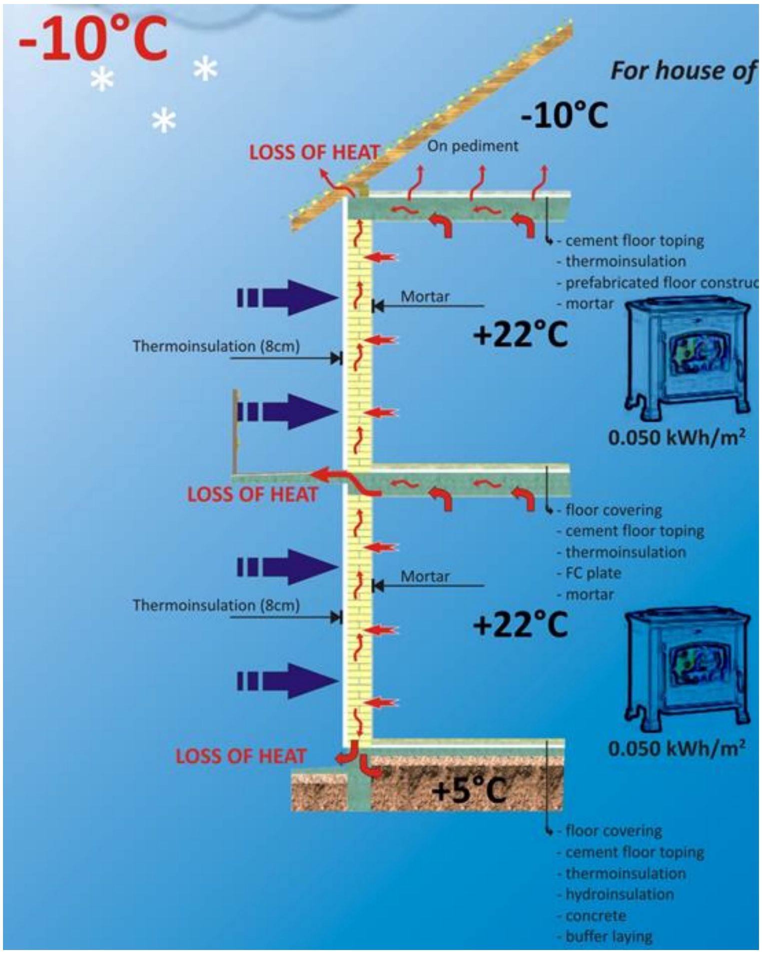

Figure 1. Losses of thermal energy that move over the ceiling through solid concrete slabs and going to the "cold areas": foundations, balconies, gable walls ... [1]

If there is an earthquake and heavy buildings with solid concrete slabs suffer damage or demolition, the country and all its citizens shall bear huge costs for the repair of such buildings which were cheaply-designed and built even more cheaper**.**

Figure 2. Heavy solid concrete slabs with weak abilities to master larger spans due to high prices, less favorable due to higher seismic forces, with high heat capacity that reduces energy efficiency, since heat is retained in the ceiling and transfered to the walls, balconies, foundations and gable walls while people are located near the floor [], [12]

2. REINFORCED CONCRETE WAFFLE-SLABS WITH REDUCED WEIGHT AND GREATER SPANS

If we want to design and build a reinforced concrete floor slabs of larger span and with increased safety in case of an earthquake (seismic action), then we need use waffle-slabs.

Figure 3. Examples of waffle-slabs with large spans, built around the world [13],[14],[15]

Figure 4. Example of coffered dome in Pantheon, Rome constructed at the beginning of a new era – a question for all of us, were those builders, in terms of the durability of their buildings, smarter and more competent than today's builders, whose buildings from the modern concrete look very bad even after less than two hundred years [16]

If we want to achieve a high energy efficient reinforced concrete waffle-slab, there is a solution to build such plates with a stay-in-place formwork made of specially shaped expanded polystyrene by Stirofert-technology. A stay-in-place formwork is structurally incorporated in the phase of concrete pouring and during the exploitation it becomes a powerful insulation on a very important place – at the ceiling. [6], [7], [8]

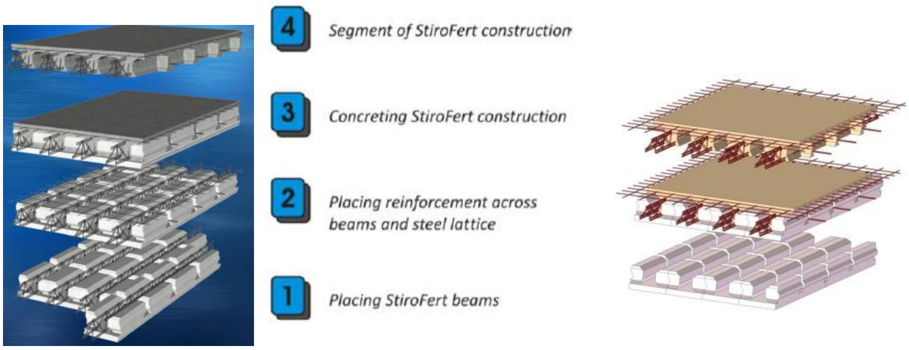

Figure 5. Solution of reinforced concrete waffle-slabs by Stirofert -technology with a built-in insulation in the construction on a very important place – at the ceiling

That way preventing the heat to enter in the concrete floor slabs. Warm air in their physical tendency of seeking colder places, starts to move around the room and thus comes to the floor. In this way, the temperature between the ceiling and the floor is completely naturally equalized. We are located on the floor and on the floor itself are our feet with the weakest blood circulation. In order to make people feel pleasant, our feet must have sufficient heat for normal blood circulation.

a)

b)

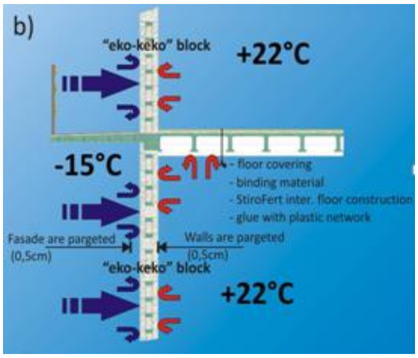

Figure 6.a) Poor circulation in the feet of people requires solutions where the warm air is located at the floor and not only at the ceiling b) a waffle-slab with a built-in thermal insulation construction in the ceiling which prevents the accumulation of the heat loss through the ceiling through the "thermal bridges" and "cold areas" [9]

3. ANALYSIS OF SEISMIC ACTIONS AND ACCUMULATION OF THERMAL ENERGY IN SOLID CONCRETE SLABS VS. REINFORCED CONCRETE LIGHTWEIGHT WAFFLE-SLABS

An analysis was made by comparing the results of weight of solid reinforced concrete plates and a reinforced concret waffle-slabs, insulated on the bottom side with a built-in constructional expanded polystyrene (stay-in-place formwork) with seismic forces (earthquake) under the assumption that we have a ten-storey building. [10] The analysis shows that the seismic force S (kN) is 45% lower in the case of waffle-slabs relative to solid reinforced concrete slabs. Please note that in this case, and in this analysis, the mass of the walls was neglected.

Parameters used in calculation of the heat capacity - which represents the energy required in order the material to gain (take) the temperature of the environment in which it is located - the physical characteristics of the material represented as a specific heat c (J / kgK): [11]

- Specific heat of concrete 960 J/kg K
- Specific heat expanded polystyrene 1260 J/kg K
- Density of concrete 2500 kg/m^3
- Density of expanded polystyrene 15 kg/m^3
- Thickness of solid reinforced concrete slab d=20 cm
- Average thickness of reinforced concrete waffle-slab d=11 cm
- Average thickness of built in expanded polystyrene in waffle-slabs d=13 cm
- Energy nedded for 1 m^3 concrete to increase (maintain) the temperature for

1K = $\frac{960}{3600} \cdot \frac{1}{1000} \cdot 2500 = 0{,}66$ kWh/m^3

- Energy nedded for 1 m^3 expanded polystyrene to increase (maintain) the temperature for 1K = $\frac{1260}{3600} \cdot \frac{1}{1000} \cdot 15 = 0{,}0053$, kWh/m^3
- Resistance of heat conducting from the air to concrete in solid concrete slabs $\frac{1}{\alpha_i} = 0{,}125$, m^{2}K/W
- Resistance of heat conducting from the air to concrete in waffle-slabs $\frac{1}{\alpha_i} + \frac{0{,}13}{0{,}041} = 3{,}295$, m^{2}K/W

Table 1. Comparison of seismic forces and specific heat values in case of waffle-slabs and solid reinforced concrete slabs

Slab with 400 m^2 surface area	Volume of concrete	Weight of the concrete slab G (kN)	Seismic force S = K x G (kN)	Specific heat c (J/m^{3}K)
Reinforced concrete waffle-slab with 7 m span	- Thickness of the concrete plate d=0,11 m V=0,11x400x10 =440 m^3 -Thickness of the expanded polystyrene d=0,13 m V=0,13x400x10 =520 m^3	440 x 25 = 11000 kN	S=0,13x11000 = 1430 kN	295,73 kWh to increase (loss) the temperature for 1 Kelvin in 440m^3 concrete and in 520 m^3 expanded polystyrene
Solid reinforced concrete slab 7 m span	Thickness d=0,20 V=0,2x400x10 =800 m^3	800 x 25 = 20000 kN	S=0,13x20000 =2600 kN	533,33 kWh to increase (loss) the temperature for 1 Kelvin in 800m^3 concrete

If we observe the specific heat c (J / m3k), we can see an the interesting result for maintaining the temperature of only 1 K (1^{0}C) for 800m^3 concrete in case of solid reinforced concrete slabs, the required amount of energy is 533.33 kWh. While, reinforced concrete waffle-slabs need considerably less energy, 293,73 kWh for a 440m^3 of concrete and for 520m^3 stay-in-place expanded polystyrene. The reinforced concrete waffle-slabs are heat insulated on the bottom side with an average thickness of 13 cm of expanded polystyrene. The insulation with such thickness is the reason that the loss of energy in the waffle-slabs are 26.36 times slower compared to solid concrete slabs.

$$\frac{\frac{1}{\alpha_i}+\frac{0,13}{0,041}}{\frac{1}{\alpha_i}}=\frac{3,295}{0,125}=26,36\,, \qquad (3)$$

The used term "slower" could be interpreted as a 26.36 times reduced energy loss (3) for waffle-slabs compared to solid concrete slabs.
From the facts stated in this article clearly can be concluded that it is particularly important that the ceiling of each floor slabs to be insulated, because mass of the concrete it big and also is the specific heat of the concrete c (J / kg K).

3. CONCLUSIONS

The paper suggests the facts and gives clear evidence that the design and construction of buildings must be analyzed from all possible aspects, particularly important aspect are the load bearing capacity, safety and energy efficiency. Designers and new investors must rationally consider and appreciate the prescribed requirements of energy efficiency and physical principles of heat transfer in the air and through solid materials. The fact that warmer air as easier will be located at the ceiling and concrete floor slabs have high heat capacity, leads to the conclusion that the ceilings must have a good thermal insulation on each floor. If the ceiling is not insulated and the concrete floor slabs are indirectly connected to "thermal bridges" and "cold areas", then we have significant losses of heat energy in accordance with Table 1. These losses of thermal energy can be reduced if we design a reduced weight reinforced concrete waffle-slab which are insulated from the bottom side (the ceiling), like as an example, by Stirofert-technology. Also, another reason to apply reinforced concrete waffle-slabs is that they have reduced weight up to 50% compared with solid reinforced concrete slabs. This means that reinforced concrete waffle-slabs can have larger spans and in case of seismic activities (earthquakes), buildings with such slabs will be safer because they have a smaller own weight and therefore smaller horizontal forces due to seismic activity, according to equations (1) and Table 1.

ACKNOWLEDGEMENTS

The work reported in this paper is a part of the investigation within the research project III 42012 "Energy efficiency enhancement of buildings in Serbia and improvement of national regulative capacity for they are certification", supported by the Ministry for Science and Technology, Republic of Serbia. This support is gratefully acknowledged.

REFERENCES:

[1] M. Kekanović, D. Šumarac, D. Gligović, S. Ćorić, Z. Kljajić: PROBLEMS OF THE DESIGN AND CONSTRUCTION OF SLAB BETWEEN FLOORS, Technical Gazette 21, 3(2014), 631-638
[2] Direktiva 2002/91/EC Evropskog Parlamenta i Saveta, Službeni list Evropske komisije, 2002.

[3] EVROKOD 6 (EC6): Muravljov M., Proračun zidanih konstrukcija, Građevinski fakultet Beograd, 1997.
[4] Evrokod 8 (EC8): Folic R., Projektovanje seizmički otpornih konstrukcija, Građevinski fakultet Beograd, 1997.
[5] Folić, R. Neki aspekti seizmičke otpornosti zgrada pri nadziđavanju i pretvaranju potkrovlja u stanove. // Zbornik radova, 1991, pp. 127-133.
[6] Kekanović, M. Priznati patent pod brojem 50224 - Mogućnost specijalnog olakšanja, izolovanja i armiranja međuspratnih konstrukcija. // Glasnik intelektualne svojine, 2009, broj 3/09.
[7] Kekanovic, M. Patent - The possibility of special lightening, insulating and reinforcing intermediate floor constructions; EP 2102426; DE 60 2006 024 757.5
[8] Kekanovic, M. Patent - Building structure of pre-cast monolithic walls and interfloor slabs, WO2013019134, WIPO 2013.
[9] Kekanović, M.; Kustudić, M.; Kljajić, Z. Katalog savremenih građevinskih konstrukcija, StiroFert d.o.o., Vrbas, 2009.
[10] B. Ćorić, R. Salatić, DINAMIKA GRAĐEVINSKIH KONSTRUKCIJA, Građevinska knjiga, udžbenik, Beograd, 2011.
[11] Skenderović, B.; Kekanović, M. Građevinski materijali-hemija-struktura-tehnologija-korozija, Udžbenik Agm knjiga, Beograd, 2011.
[12] http://www.passzivhazminosites.hu/epitkezes.
[13] http://engineering.stackexchange.com/questions/7348/how-different-is-using-styrofoam-rather-than-empty-cans-when-pouring-concrete
[14] http://www.archiproducts.com/en/products/8893/formwork-and-formwork-system-for-concrete-skydome-geoplast.html
[15] https://deniseweber.wordpress.com/2012/08/30/poetics-yale-field-trip/
[16] https://www.viator.com/Rome-attractions/Pantheon/d511-a51

ПРОБЛЕМАТИКА ПРОЈЕКТОВАЊА МЕЂУСПРАТНИХ ПЛОЧА СА АСПЕКТА НОСИВОСТИ, СИГУРНОСТИ И ЕНЕРГЕТСКЕ ЕФИКАСНОСТИ

Резиме: *Овај рад даје информације о могућностима пројектовања и изградње међуспратних плоча са три врло битна аспекта: носивости, сигурности и енергетске ефикасности. Данас се у Р.Србији искључиво пројектују и граде пуне међуспратне бетонске плоче најмање дебљине 20цм. Оправдање за ово решење је добијање, у својој равни, круте плоче-дијафрагме која је способна да пренесе сезмичке силе на зидове у омеру крутости тих зидова. Истовремено ово решење има и многе мане а то је велика маса која ограничава дужину распона. Велика маса је директно сразмерна величини сеизмичких сила. Пуна бетонска плоча дебљине 20цм има велики топлотни капацитет и специфичну топлоту c(J/kgK) који не погодују енергетској ефикасности јер топли ваздух акумулира, спроводи га према* *зидовима и задржава га при стропу, а корисници се налазе при поду. Постоје и друга решења пројектовања и грађења међуспратних плоча која задоволавају далеко више захтева него пуна бетонска плоча.То су роштиљно касетнеармирано бетонске плоче. Ове плоче су изузетно круте и носиве, по потреби у оба правца и могу имати мању масу до 50% у односу на пуне бетонске плоче. Аутори у овоме раду представљају и једно решење роштиљно касетне армирано бетонске плоче које задовољава, поред наведених захтева још и енергетску ефикасност. То је решење по техногији Стироферт с конструкцијски уграђеним експандираним полистиреном као "заробљеном оплатом" у фази бетонирања и изградње. Та иста "заробљена оплата" је моћна изолација на стропу с учинком спречавањаакумулације и губитака топлоте према зидовима и уједначавањем температуре ваздуха између пода и стропа.*

Кључне речи: *бетонске, роштиљно-касетне, плоче,носивост, енергетска ефикасност*