Comparison of RC frames periods with the empiric expressions given in Eurocode 8

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COMPARISON OF RC FRAMES PERIODS WITH THE EMPIRIC EXPRESSIONS GIVEN IN EUROCODE 8

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Subject review

For the earthquake design of RC structures, period of vibration is not known immediately, and because of that the simplified expressions are given in the construction rules, which usually link the base period with the height of the construction. The aim of this paper is to verify these empirical expressions, which are given by different authors and Eurocode 8 and to conclude whether the expressions are good enough as a starting assumption for the design of earthquake resistant buildings. Most attention will be devoted to the RC frame structures. When modeling, besides the general requirements on the structures, typical requirements for particular types of structural systems will be applied. Results of the models and empirical expressions will be compared and the conclusion about applicability of the expressions will be drawn.

Keywords: *empirical expresions, Eurocode 8, periods of vibration, RC frames*

Usporedba perioda vibracija AB okvirnih konstrukcija s empirijskim izrazima danim u Euronormi 8

Pregledni rad

Za potresno projektiranje armiranobetonskih okvirnih konstrukcija period vibracija se ne zna odmah i zbog toga se koriste pojednostavnjene jednadžbe u građevinskim pravilnicima koje najčešće povezuju osnovni period s visinom konstrukcije. Cilj ovoga rada je provjeriti da li su empirijski izrazi dani različitim autorima i Euronormom 8 dovoljno dobri kao početna pretpostavka prilikom potresnoga projektiranja. Najveća pozornost će se posvetiti armiranobetonskim okvirnim konstrukcijama. Prilikom modeliranja osim općih zahtjeva na konstrukciju, primijeniti će se posebni zahtjevi za odgovarajući tip konstrukcijske. Rezultati modela i empirijskih izraza će se usporediti i izvući će se zaključak o primjeni izraza.

Ključne riječi: *AB okviri, empirijski izrazi, Euronorma 8, period vibracija*

1 Introduction
Uvod

Determination of the base period of vibration of reinforced concrete structures is an important part of earthquake design and evaluation of structural behaviour during earthquake. That behaviour depends on mass, stiffness and strength of the structure and it is influenced by many factors. Some of them are regularity of the structure, number of storeys and indents, dimensions of the cross sections, the characteristics of the filling, magnitude of the loads, reinforcement and cracking of the concrete. For the earthquake design of reinforced concrete frame structures, base period of the vibration is not known immediately, and because of that the simplified expressions are given in the construction rules, which usually link the base period with the height of the construction. These expressions are usually obtained by regression analysis of the periods measured during earthquake.

2 Empirical expressions
Empirijski izrazi

2.1 Eurocode 8
Euronorma 8

Approximate expressions may be used for the preliminary design in order to calculate the base period of vibration T_1 of the structure. These expressions are given further in the text.

For the structures with height up to 80 m, value of T_1 can be approximate with the expression:

$$T_1 = C_t \cdot H^{3/4} \tag{1}$$

where is:
T_1 – base period of vibration of the structure, s
C_t=0,085 – for steel structures
C_t=0,075 – for reinforced concrete frame structures and eccentrically stiffen steel structures
C_t=0,050 – for other cases
H – height of the structure, m

Value of C_t for structures with reinforced concrete or masonry bearing walls may be calculated with expression:

$$C_t = \frac{0,075}{\sqrt{A_c}} \tag{2}$$

where

$$A_c = \sum \left[A_i \cdot \left(0,2 + \frac{l_{wi}}{H} \right)^2 \right], \tag{3}$$

Where is:
A_c – total design area of the bearing walls on the first storey of the building, m^2
A_i – design area of the bearing wall cross section "i" on the first storey of the building, m^2
l_{wi} – length of the bearing wall "i" on the first storey of the building in the direction of the acting force, m
l_{wi} is with limitation

$$\frac{l_{wi}}{H} \le 0,9 \,.$$

C_t is equal to 0,075 for reinforced concrete frame structures and H is height in meters. This form of the expression is obtained with theoretical derivation using Reyleigh method with following assumptions:

a) Equivalent static horizontal forces are linearly distributed along the height of the structure;
b) Distribution of the stiffness along the height is made in that way that the movement of the structure with linearly distributed horizontal forces is equal on every storey;
c) Base shear is proportional to $1/T^{2/3}$;
d) Strains are controlled by the serviceability limit states.

Numerical value of the C_t is obtained from measured periods of vibration from the structures after the earthquake in San Fernando in 1971.

2.2 Kobayashi
Prema Kobayashiju

Kobayashi measured microtremors of the undamaged structures in Ciudad de Mexico after the earthquake which occurred in July 19, 1985. and based on that data he set the expression for the base period of vibration and damping factor. He gathered data for reinforced concrete frame structures with 5 to 30 storeys and set the relation between the base period and number of storeys:

$$T_1 = 0{,}105 \cdot N. \tag{4}$$

2.3 Navarro
Prema Navarru

Navarro and others researched periods of real structures, reinforced concrete structures with height from 3 to 16 storeys, in the area of Granade in Spain using microtremors. Results show very clear and linear relation between the base period, T_1, and number of storeys, N:

$$T_1 = (0{,}049 \pm 0{,}001) \cdot N. \tag{5}$$

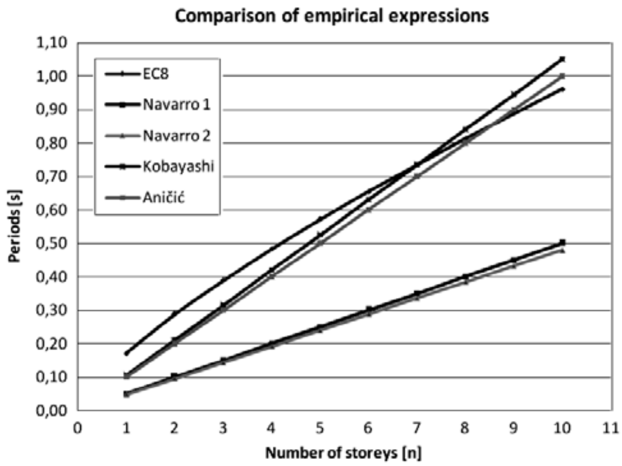
2.4 General empirical expression
Opći empirijski izraz

General empirical expression for determination of the base period of vibration of the multi-storey frame buildings is:

$$T_1 = 0{,}1 \cdot N. \tag{6}$$

Expression is given among the others for various construction systems in the book "Ispitivanje konstrukcija" by professor Aničić.

Display of the base periods of vibration for reinforced concrete structures and comparison by its height (number of storeys) is given in Table 1 and on Diagram 1.



Digram 1 *Comparison of empirical expressions*
Dijagram 1. *Usporedba empirijskih izraza*

3 Model of reinforced concrete frame structure
Model armiranobetonskog okvira

Dimensions of cross sections of all elements of the structure were modelled in accordance with necessary requirements given in Eurocode. Since we wanted to describe the relationship between the number of storeys and the base period of vibration, structures were modelled with different layout dispositions and number of storeys. Basic layout model was 3D space frame model with beam span of 5 m in the direction of both x and y axis and with height of 3 m (Figure 1). All the models were generated by modular combination of the basic model. The largest model is set to be ten basic models in length and height and three basic

Table 1 *Comparison of empirical expressions*
Tablica 1. *Usporedba empirijskih izraza*

Number of storeys	Height H	Periods / s				
		EC8	Navarro 1	Navarro 2	Kobayashi	Aničić
n	m	$0{,}075 \cdot H^{3/4}$	$0{,}05 \cdot N$	$0{,}048 \cdot N$	$0{,}105 \cdot N$	$0{,}1 \cdot N$
1	3	0,171	0,050	0,048	0,105	0,100
2	6	0,288	0,100	0,096	0,210	0,200
3	9	0,390	0,150	0,144	0,315	0,300
4	12	0,484	0,200	0,192	0,420	0,400
5	15	0,572	0,250	0,240	0,525	0,500
6	18	0,655	0,300	0,288	0,630	0,600
7	21	0,736	0,350	0,336	0,735	0,700
8	24	0,813	0,400	0,384	0,840	0,800
9	27	0,888	0,450	0,432	0,945	0,900
10	30	0,961	0,500	0,480	1,050	1,000

models in width. Dimensions of the basic model were obtained by observation of the real structures in our surroundings, in that way the results were more proximate to the periods of vibration of the real structures. In such manner, total of 300 models were analysed.

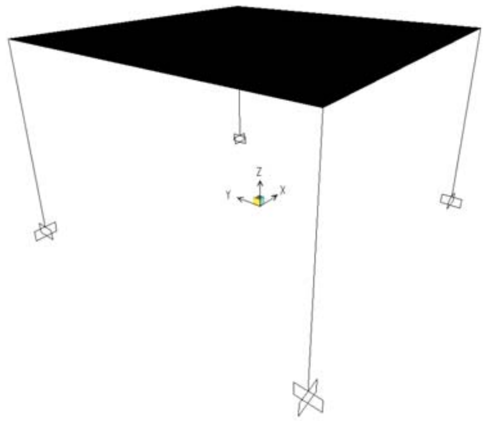


Figure 1 *The basic model of the structure (1-1-1) in SAP2000*
Slika 1. *Osnovni model konstrukcije (1-1-1) u SAP2000*

Table 2 *Description of model tags*
Tablica 2. *Opis oznaka modela*

MODEL TAG	DESCRIPTION	FINAL MODEL
1-1-1	1 width – 1 length – 1 height	1-10-10
2-1-1	2 width – 1 length – 1 height	2-10-10
3-1-1	3 width – 1 length – 1 height	3-10-10

3.1 Determination of the column dimensions
Određivanje izmjera poprečnog presjeka stupova

Dimensions of the columns are determined using ductility criteria:

$$\frac{N}{A} \leq 0{,}3 \cdot f_{Cd}\,, \tag{7}$$

where is:
f_{Cd} – design compression strength of the concrete, kN/cm^2
N – axial force, kN
A – cross section of the column, cm^2.

Three cases were studied. Models with the width and the length of one, two and three basic models and the height of ten basic models. Then the coefficients were calculated using ductility criteria. Calculation of the column forces was made using SAP2000 and also the manual calculation was made in order to make a quick control of the results. Control was made on three models with the width and length of one, two and three basic models and the height of one basic model. Self weight of the structural elements and a variable load of 2 kN/m was taken as a construction load in the models. Control showed that the differences in the forces obtained by computer and manual calculation are less than 10 %, which was satisfactory. This showed that we can

Table 3 *Coefficients for the model with a basic width and length*
Tablica 3. *Koeficijenti za model s jednom osnovnom širinom i duljinom*

Number of storeys	Height, m	N_{sd}	η_1	η_2	η_3	η_4	η_5
1	3	84,326	0,08	0,06	0,04	0,03	0,02
2	6	185,156	0,18	0,12	0,09	0,07	0,05
3	9	277,734	0,27	0,19	0,14	0,10	0,08
4	12	370,312	0,36	0,25	0,18	0,14	0,11
5	15	462,891	0,44	0,31	0,23	0,17	0,14
6	18	555,469	0,53	0,37	0,27	0,21	0,16
7	21	648,047	0,62	0,43	0,32	0,24	0,19
8	24	740,625	0,71	0,49	0,36	0,28	0,22
9	27	833,203	0,80	0,56	0,41	0,31	0,25
10	30	925,781	0,89	0,62	0,45	0,35	0,27
		b/h	25/25	30/30	35/35	40/40	45/45

Table 4 *Coefficients for the model with two basic widths and lengths*
Tablica 4. *Koeficijenti za model s dvije osnovne širine i duljine*

Number of storeys	Height, m	N_{sd}	η_1	η_2	η_3	η_4	η_5	η_6	η_7	η_8	η_9	η_{10}
1	3	334,375	0,32	0,22	0,16	0,13	0,10	0,08	0,07	0,06	0,05	0,04
2	6	630,997	0,61	0,42	0,31	0,24	0,19	0,15	0,13	0,11	0,09	0,08
3	9	906,636	0,87	0,60	0,44	0,34	0,27	0,22	0,18	0,15	0,13	0,11
4	12	1156,88	1,11	0,77	0,57	0,43	0,34	0,28	0,23	0,19	0,16	0,14
5	15	1382,888	1,33	0,92	0,68	0,52	0,41	0,33	0,27	0,23	0,20	0,17
6	18	1587,396	1,52	1,06	0,78	0,60	0,47	0,38	0,31	0,26	0,23	0,19
7	21	1773,768	1,70	1,18	0,87	0,67	0,53	0,43	0,35	0,30	0,25	0,22
8	24	1945,334	1,87	1,30	0,95	0,73	0,58	0,47	0,39	0,32	0,28	0,24
9	27	2105,084	2,02	1,40	1,03	0,79	0,62	0,51	0,42	0,35	0,30	0,26
10	30	2255,56	2,16	1,50	1,10	0,85	0,67	0,54	0,45	0,38	0,32	0,28
		b/h	25/25	30/30	35/35	40/40	45/45	50/50	55/55	60/60	65/65	70/70

Table 5 *Coefficients for the model with three basic widths and lengths*
Tablica 5. *Koeficijenti za model s tri osnovne širine i duljine*

Number of storeys	Height, m	N_{sd}	η_1	η_2	η_3	η_4	η_5	η_6	η_7	η_8	η_9	η_{10}
1	3	282,885	0,27	0,19	0,14	0,11	0,08	0,07	0,06	0,05	0,04	0,03
2	6	553,639	0,53	0,37	0,27	0,21	0,16	0,13	0,11	0,09	0,08	0,07
3	9	818,513	0,79	0,55	0,40	0,31	0,24	0,20	0,16	0,14	0,12	0,10
4	12	1074,841	1,03	0,72	0,53	0,40	0,32	0,26	0,21	0,18	0,15	0,13
5	15	1321,544	1,27	0,88	0,65	0,50	0,39	0,32	0,26	0,22	0,19	0,16
6	18	1558,118	1,50	1,04	0,76	0,58	0,46	0,37	0,31	0,26	0,22	0,19
7	21	1784,581	1,71	1,19	0,87	0,67	0,53	0,43	0,35	0,30	0,25	0,22
8	24	2001,33	1,92	1,33	0,98	0,75	0,59	0,48	0,40	0,33	0,28	0,25
9	27	2209,007	2,12	1,47	1,08	0,83	0,65	0,53	0,44	0,37	0,31	0,27
10	30	2408,4	2,31	1,61	1,18	0,90	0,71	0,58	0,48	0,40	0,34	0,29
		b/h	25/25	30/30	35/35	40/40	45/45	50/50	55/55	60/60	65/65	70/70

proceed with the computer calculation what is more timesaving than the manual calculation. Control was also checking whether or not the elements, materials and loads were well enough modelled on the computer. Close review of the column forces is given in Tables 3, 4 and 5. Required dimensions of the column cross section by increasing the height of the structure is obtained from those forces.

From the obtained results we could now determine necessary dimensions of the column cross section, which would satisfy ductility criteria. It is now possible to determine which cross section is needed for which height directly from the diagrams (Diagrams 2, 3 and 4). Analysis of the results shows that the dimensions of the cross sections can be gradually increased by 5cm in every storey, and that this will not produce large deviations from the required 0,3. Control was also carried by increasing the length of the structure in order to see the variations in the column forces, but the analysis shows that the forces tend to unify around certain value which is somewhat smaller than the one obtained in the analysis of the basic models and the coefficients are approximately equal. This showed that it was not necessary to vary dimensions of the column cross section while length of the structure is increased in order to compensate for the increase of the force value.

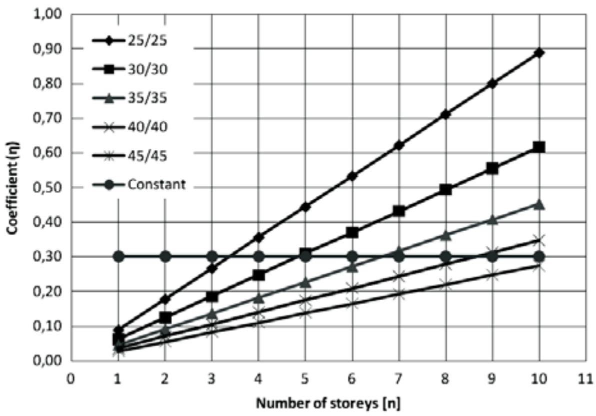


Diagram 2 *Display of the Coefficients for the model with a basic width and length*
Dijagram 2. *Prikaz koeficijenata za model s jednom osnovnom širinom i duljinom*

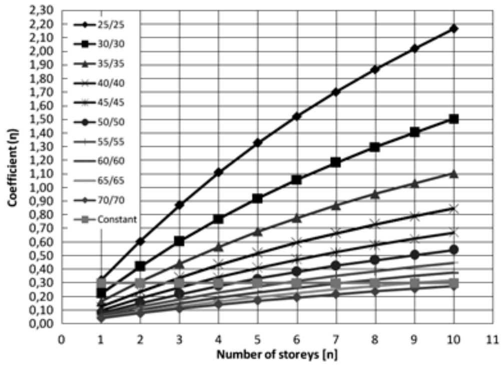


Diagram 3 *Display of the Coefficients for the model with two basic widths and lengths*
Dijagram 3. *Prikaz koeficijenata za model s dvije osnovne širine i duljine*

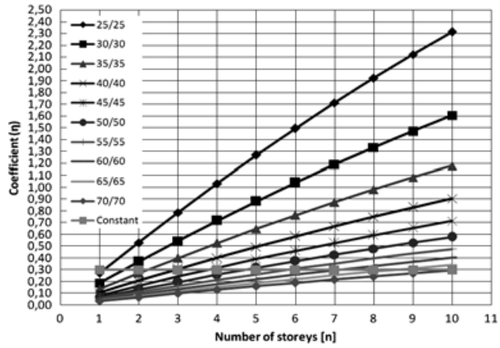


Diagram 4 *Display of the Coefficients for the model with three basic widths and lengths*
Dijagram 4. *Prikaz koeficijenata za model s tri osnovne širine i duljine*

Table 6 *Review of obtained and chosen dimensions of the column cross sections by number of storeys*
Tablica 6. *Prikaz dobivenih i odabranih izmjera stupova po katnosti*

Number of storeys	1-1	2-2	3-3	Chosen
1	25/25	30/30 ili 35/35	25/25 ili 30/30	25/25
2	25/25	40/40	35/35 ili 40/40	30/30
3	25/25	45/45	45/45	35/35
4	30/30	50/50	50/50	40/40
5	35/35	55/55	55/55	45/45
6	35/35	60/60	60/60	50/50
7	40/40	60/60	60/60	55/55
8	40/40	65/65	65/65	60/60
9	45/45	65/65	70/70	65/65
10	45/45	70/70	70/70	70/70

4
Comparison of results
Usporedba rezultata

Review of the periods for frame systems.

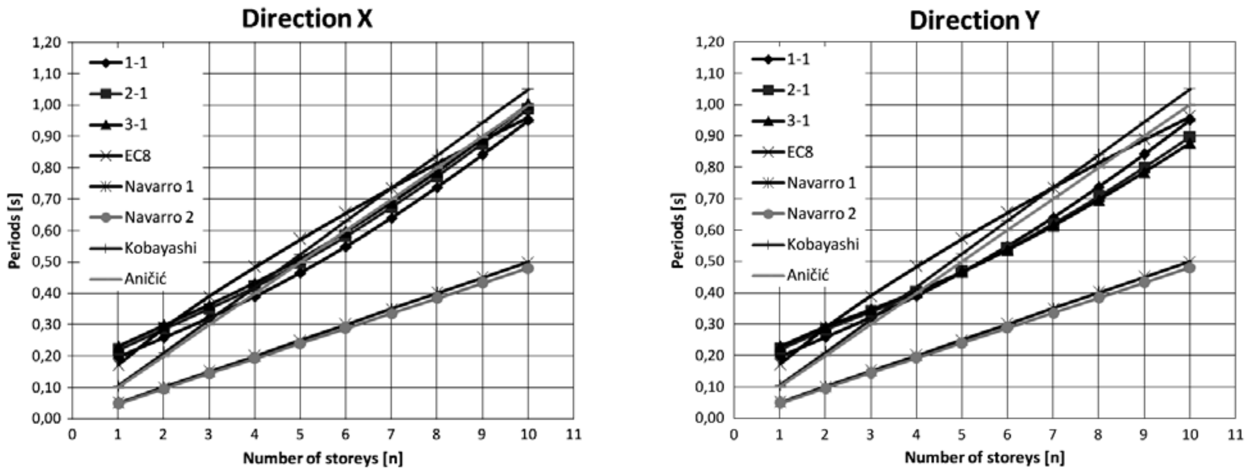


Figure 2 *Periods for models with length of one basic model*
Slika 2. *Periodi modela duljine jednog osnovnog modela*

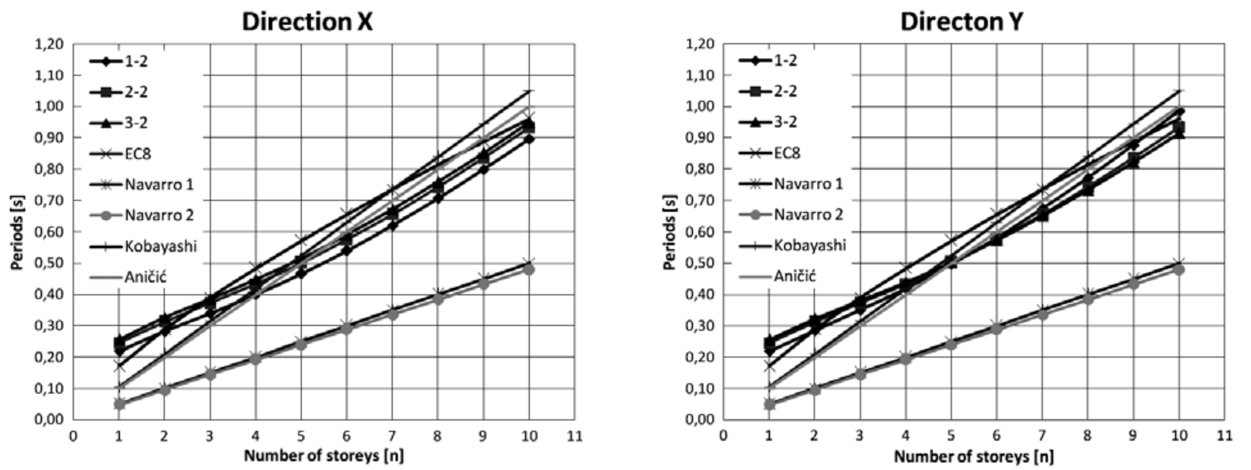


Figure 3 *Periods for models with length of two basic models*
Slika 3. *Periodi modela duljine dva osnovna modela*

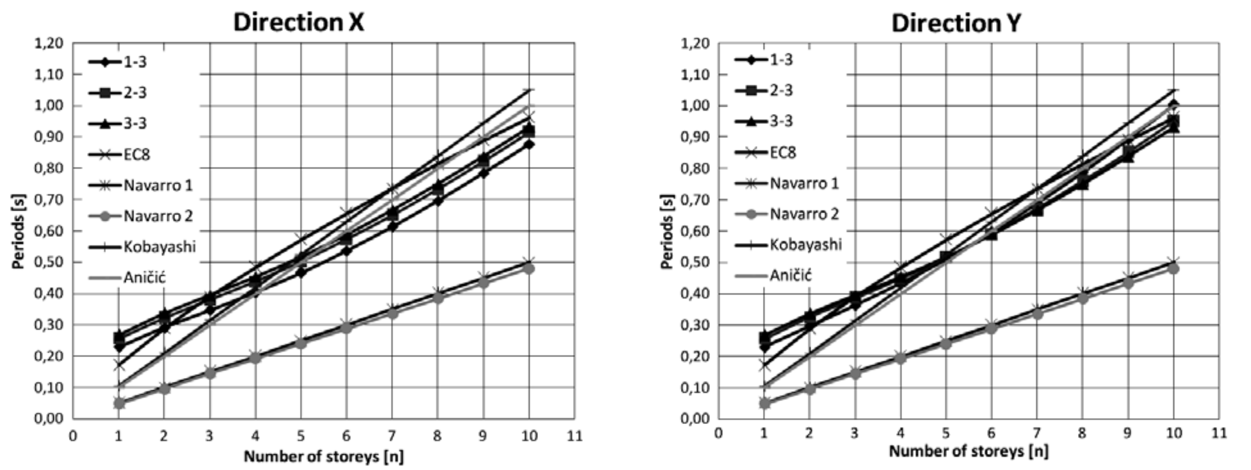


Figure 4 *Periods for models with length of three basic models*
Slika 4. *Periodi modela duljine tri osnovna modela*

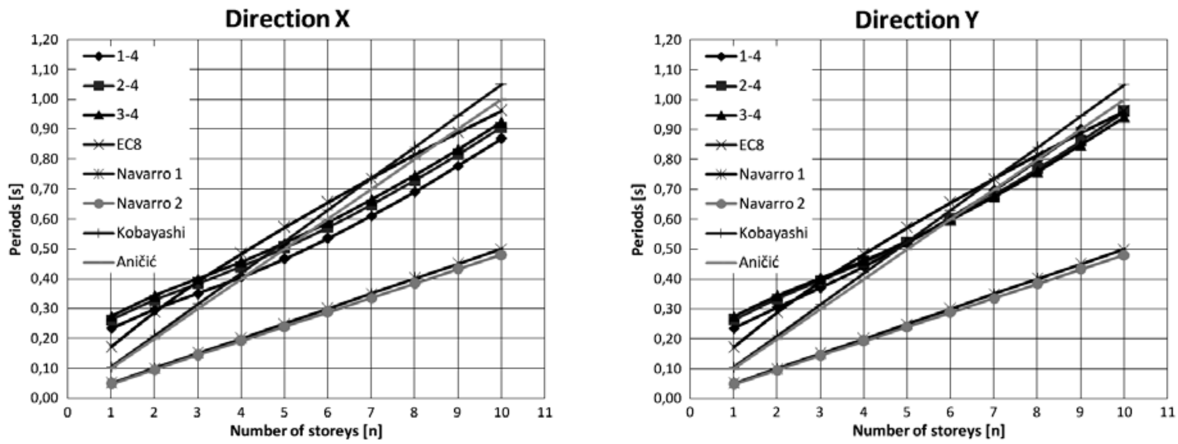


Figure 5 *Periods for models with length of four basic models*
Slika 5. *Periodi modela duljine četiri osnovna modela*

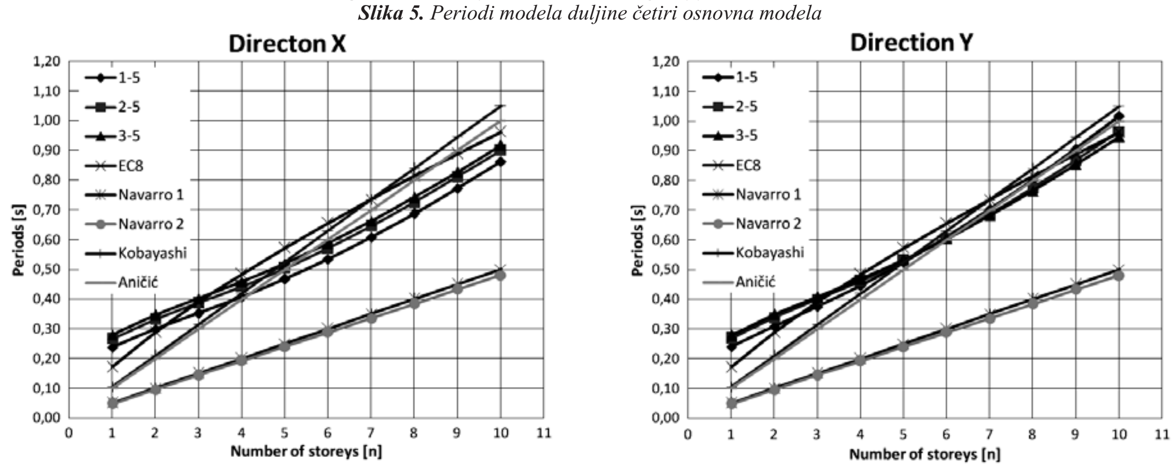


Figure 6 *Periods for models with length of five basic models*
Slika 6. *Periodi modela duljine pet osnovnih modela*

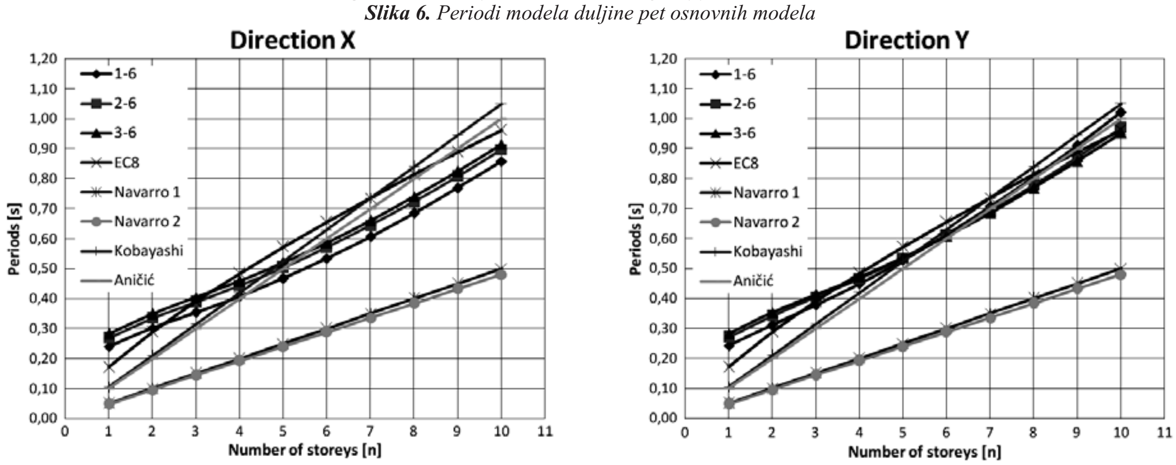


Figure 7 *Periods for models with length of six basic models*
Slika 7. *Periodi modela duljine šest osnovnih modela*

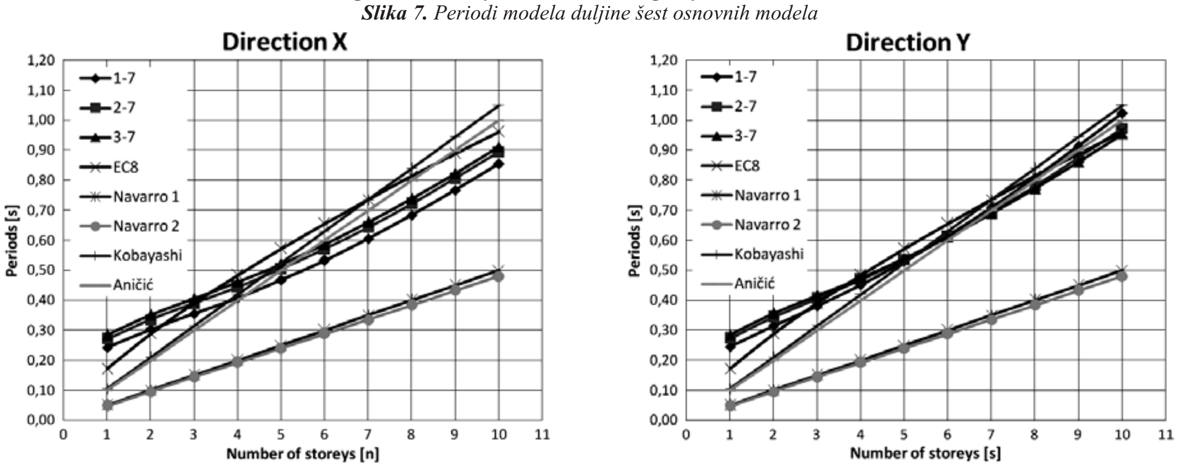


Figure 8 *Periods for models with length of seven basic models*
Slika 8. *Periodi modela duljine sedam osnovnih modela*

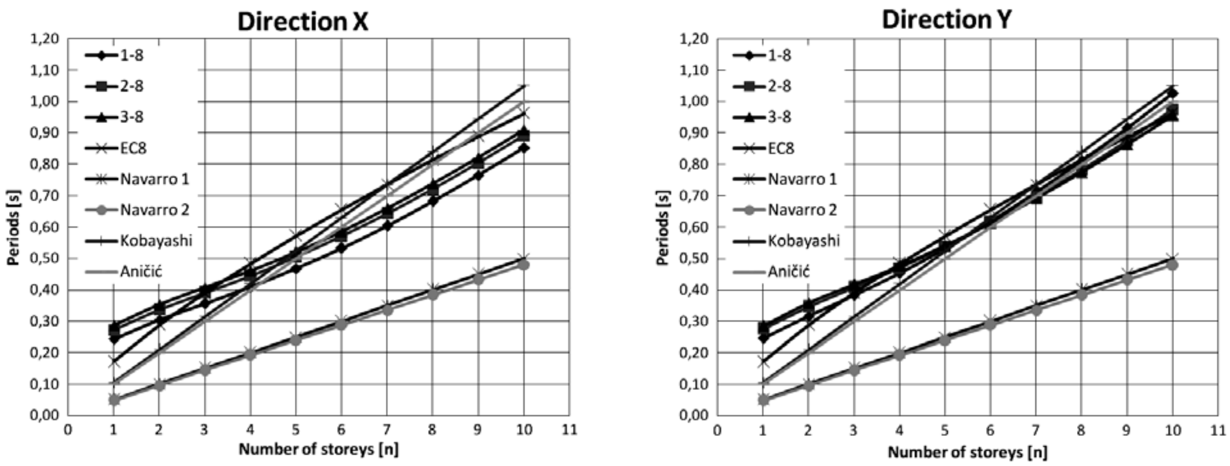


***Figure 9** Periods for models with length of eight basic models*
***Slika 9.** Periodi modela duljine osam osnovnih modela*

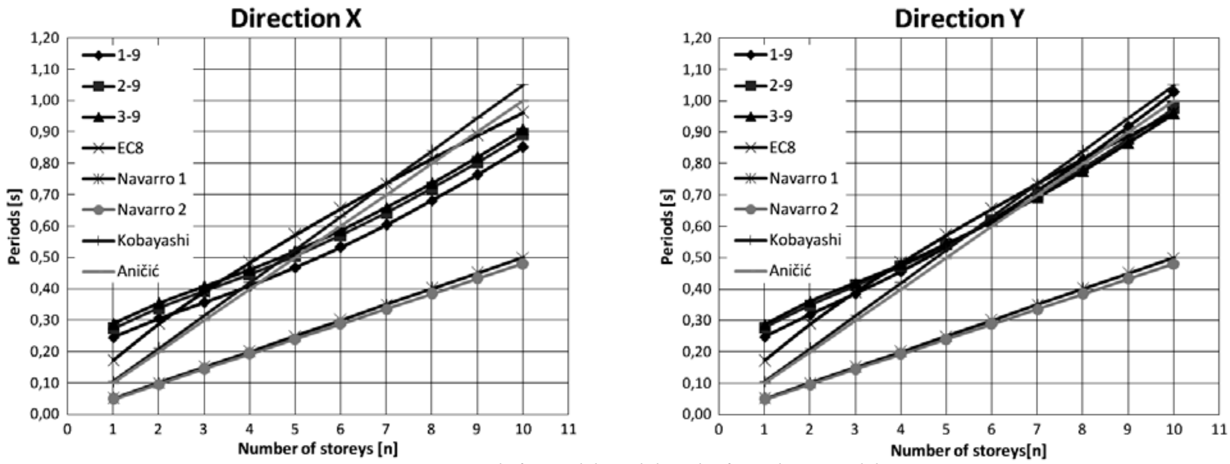


***Figure 10** Periods for models with length of nine basic models*
***Slika 10.** Periodi modela duljine devet osnovnih modela*

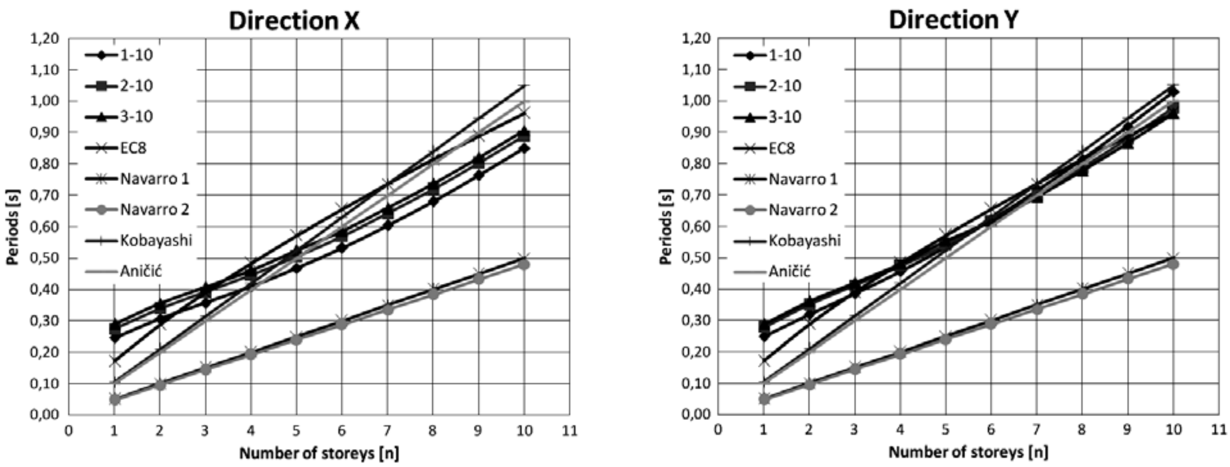


***Figure 11** Periods for models with length of ten basic models*
***Slika 11.** Periodi modela duljine deset osnovnih modela*

5 Conclusion
Zaključak

Comparison of the results shows very good agreement with empirical expressions. From this we can conclude that the application of all necessary conditions prescribed by the Eurocode 8 during the design, leads to a very good approximation of the value of the base period of vibration by empirical expressions. The results are even smaller than those obtained with empirical expressions, which is good because this is on the safe side. This is very important in order to comply with the fundamental requirement of the earthquake design which is preservation of human life and prevention of structural collapse.

It is also observed that the approximation of the base period of vibration by empirical expressions makes sense because it speeds up the process of calculating the earthquake forces. In the same time this was also the control of the computer calculation of periods using the method of the eigenvectors, which largely coincides with the results of empirical expressions. Models on a computer were modelled according to the provisions given in Eurocodes in order to model structural behaviour and not the appearance of the structure, which is not the same.

Comparison of the results shows matching the given frame periods with the expressions given by Eurocode 8, Aničić and Kobayashi, noting that it was necessary to change the cross-section dimensions of the columns while the height of the structure is increased. The results do not mach with Navarro expression, and the cause is a type of reinforced-concrete structure on which empirical expression is determined. Navarro expression applies to the reinforced-concrete frame structures with filling and diaphragms which stiffen the structure and thus reduce the periods of vibration. This is the difference with models that are modelled with computer, those models were pure reinforced-concrete frame structures.

During the modelling and calculation of the periods, the dimensions of the columns cross-sections of minimum 25 cm proved to be insufficient. Periods of such structures are shown as excessive, since the structure was too "soft". It did not have sufficient rigidity. Increase of the number of storeys leads to large differences in the periods obtained with empirical expressions and computer. In order to achieve satisfactory system stiffness and reduce the differences in periods, but also in order to transfer the static forces due to its selfweight, dimensions of the column cross-section were determined using ductility criteria.

Reviewing and comparing the obtained periods with periods of spectral response of soil we come to the conclusion that the increase of the frame model number of storeys periods very quickly emerge from the critical areas of the spectrum for which we will get the maximum spectral ordinate and consequently maximum earthquake forces. Critical values of the period range from 0,5-0,6 s. These values are exceeded with number of storeys over 5-6, for which periods are larger than 0,6 s and for which values of the spectrum ordinate are smaller, ultimately we get smaller earthquake forces. This is true for models of all lengths and widths. Stiffer structures take on much larger earthquake forces, so that great attention has to be given in their design and performance. Special attention should be paid to how the planned response should be implemented by design and detailing, but also by proper construction process so that the structure can behave in the way that we anticipated.

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