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The Influence of structural irregularities on response of the RC buildings subjected to mining tremors and earthquakes

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Abstract

The seismic design of structures seems to be a completely recognized subject. There are requirements and guidelines that must be looked at by planners in seismic zones. The problems occur while irregular structures are concerned especially while structures are subjected to dynamic earthquake-like excitements. An example of such vibrations is mining tremors. In Poland, the problem of seismic behavior of irregular buildings subjected to mining-induced seismicity is still an unsolved problem. In this paper numerical studies are carried out for five-storey building models with six various types of irregulars in plan. In this article, the response of the studied models was compared by linear dynamic analysis (Response Spectrum). The difference between the response of the structure to earthquakes and mining tremors is presented. Lately, several numerical simulations have been done to research the building behavior under mining tremors and earthquake shaking. There is still a necessity to research and compare the results of numerical analyses prepared for the same subject and the same soil cases. The aim of this paper is to present the differences between mining tremors and earthquakes.

Keywords: Irregular building, Time of vibration, Earthquake, Mining tremor, Reinforced concrete, Resopne spectrum analysis.

تأثير المباني غير المنتظمة على استجابة المباني البيتونية المسلحة تحت تأثير هزات التعدين والزلازل

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الملخص:

إن تصميم المنشآت على الزلازل موضوع معروف علمياً. إلا أن هناك متطلبات وارشادات يجب أن ينظر لها المصممون في المناطق الزلزالية. حيث أن المشاكل تحدث عندما يتعلق الأمر بالمنشآت غير المنتظمة وخاصة عند تعرضها لتأثير هزات ديناميكية تشبه هزات الزلازل. مثال على هذه الاهتزازات هي هزات التعدين. على سبي المثال في بولندا لا تزال مشكلة السلوك الزلزالي للمباني غير المنتظمة والمعرضة للزلازل الناتجة عن التعدين مشكلة لم يتم حلها بعد. تم في هذا البحث اجراء الدراسات العددية لنماذج مباني مؤلفة من خمسة طوابق مع ستة أشكال مختلفة من عدم الانتظام في المسقط. كما أجريت مقارنة استجابة النماذج المدروسة بواسطة التحليل الديناميكي الخطي (طيف الاستجابة). وقد درس الفرق بين استجابة المنشأ لهزات الزلازل والتعدين. وقد اجريت في الآونة الأخيرة العديد من الدراسات العددية للبحث في سلوك المباني تحت تأثير هزات التعدين والزلازل. إلا أنه لايزال هناك ضرورة للبحث ومقارنة نتائج التحليلات العددية المعدة لنفس الموضوع ونفس حالات التربة. الهدف من هذه الورقة البحثية هو عرض الفروق بين هزات التعدين والزلازل.

الكلمات المفتاحية: المبنى غير المنتظم، مدة الاهتزاز، الزلازل، هزات التعدين، الخرسانة المسلحة، تحليل بواسطة طيف الاستجابة.

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Introduction

The regular structure is more practical and idealization. The majority of structures are irregular in nature. The major earthquake codes classify building irregularity into irregularity in plan and in elevation, while structural irregularity is usually a mixture of both. The irregularity in structures due to the asymmetric status of stiffness, strength, and mass along the plan, resulting in a torsional response, causes the most severe damage as it leads to ground rotations [Archana J. Satheesh, B.R. Jayalekshmi, Katta Venkataramana, 2020]. It is well known that through past earthquakes, a lot of the structures have sustained harm due to their irregularities. [S. Gerasimidis, C.D. Bisbos, C.C. Baniotopoulos, 2012]. Based on this case, structural irregularities may be considered a significant factor in disproportionate fail resistance or durability. Irregularities cause great and unlikely damage to many buildings. Therefore, irregularities can be considered significant parameter for abrupt fall resistance or durability. [S. Gerasimidis, C.D. Bisbos, C.C. Baniotopoulos, 2012]. Code provisions and design approaches to irregular structures described, among others, were analysed. in the European and Syrian standards [Ravikumar C M, Babu Narayan K S, Sujith B V, Venkat Reddy D, 2012 - Eurocode 8]. The subject of the analyses was also instructions and guidelines for the design of objects in the areas of paraseismic tremors [Arab Syrian Code annex nr 2 - Wytyczne do projektowania budynków kubaturowych na terenach sejsmicznych]. Poland, especially its southern part, is exposed to the occurrence of random mining tremors whose nature resembles natural earthquakes [Zembaty Z, Jankowski R, Cholewicki A, Szulc J, 2007]. The intensity of mining tremors is comparable to that of a weak earthquake. As regards the analysis of the current state of knowledge, a query concerning the analysis of parameters characterizing natural earthquakes and mining tremors was also performed [Chopra, Anil K., Goel, Rakesh K, 2000 - Chopra, Anil K., Goel, Rakesh K, 2002]. Despite the similar nature of these phenomena, there are a lot of differences between mining tremors and earthquakes. [F. Pachla, A. Kowalska-Koczwara, T. Tatara, K. Stypuła. 2019 - Furumura T, Takemura S, Noguchi S, Takemoto T, Maeda T, Iwai K, Padhy S. 2011 - Kufner SK, Schurr B, Haberland Ch, Zhang Y, Saul J, Ischuk A, Oimahmadov I. 2017 - Maciąg E, Kuzniar K, Tatara T, 2016 - Tatara T, Pachla F, Kubon P. 2017]. In this paper numerical studies are carried out for five-storey building models with irregular shape RC subjected to six various types of irregular plans and placed the shear core in the plan. This is due to the distinctions between the earthquake phenomenon and mining tremors. Lately, several numerical studies have been behavior to research the building behavior under mining tremors and earthquake shaking there is still a necessity to research and compare the results of numerical analyses prepared for the same subject and the same soil cases. This paper is interested in the dynamic response of irregular structures due to mining tremors and earthquakes.

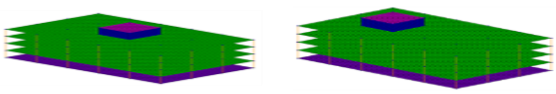
1. FEA model

A model structure was chosen for the analysis, in which it is possible to introduce horizontal irregularities by modifying the stiffening walls. It is a five-storey of a reinforced concrete building with a typical slab-column system. The spatial stiffness is provided by a reinforced concrete shaft in which the communication system is located. The dimensions of the building are 30 x 18 m. The height of the building is 20 m. The dimensions of the structural elements are as follows:
column 40x40 cm, floor slabs with a thickness of 20 cm, foundation plate thickness of 40 cm, and shear walls thickness of 25 cm. Columns were modeled using beam elements (2 nodes) with 6 degrees of freedom in each node, while slabs and walls were modeled using shell elements (3 or 4 nodes) with 6 degrees of freedom in each node. The building model takes into account all the important structural elements that affect stiffness and mass distribution. Initial calculations were made with the use of a linear elastic model. The input data of the constitutive model include mass density, Young's modulus, and Poisson's ratio. The model takes into account the reinforcement of structural elements in both directions. The embedded reinforcement model was used. The model parameters were adopted from the Eurocode. The properties of the materials are presented in Table 1. The boundary conditions in the model were realized by fixing the foundation slab, blocking the freedom of displacement and rotation of the nodes in the horizontal foundation. In order to determine the impact of irregularities on the dynamic response, six computational models with varying degrees of irregularity were analysed. The models are shown in Fig. 1. The projection of the analysed models is shown in Fig. 2. All selected models have the same total storey height of 4 meters and the axial spacing of the columns is 6 meters for the two directions X, and Y. Detailed data on the tested models are shown in Figure 2. Figure 2 also shows the distance between the center of gravity of the calculation model and the shear center.

Table (1) Material properties

Material	Density (kg/m^3)	Young's modulus (N/mm^2)	Poisson's ratio (-)
Columns	2350	33550.6	0.20
Walls	2350	33550.6	0.20
Slabs	2350	33550.6	0.20

a. b.



c. d.

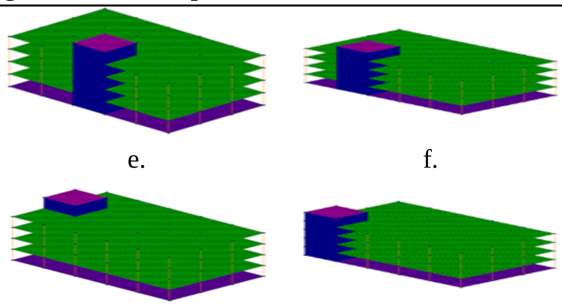


Fig (1) FEA models of the building

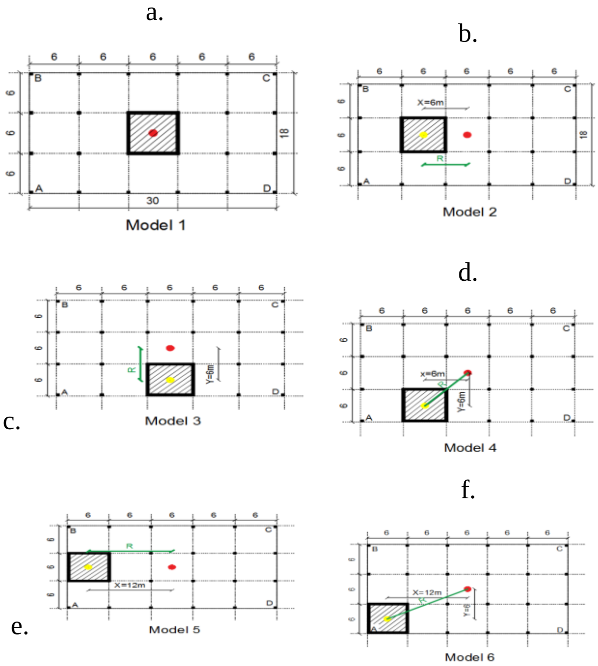


Fig (2) Plan models of the building

2. Dynamic Analysis

The dynamic analysis of the structure required the creation of a spatial calculation model using the finite element method (FEM). The analysis was performed with DIANA FEA software using response spectrum analysis (RSA). [DIANA, 2017]

The influence of irregularities on the frequencies and forms of vibrations of the analysed models was verified. The values of the first ten calculated natural frequencies are shown in Table 2. The selected mode shapes of natural vibrations obtained from the analysis are shown in Fig. 3 to Fig. 8. The spectrum of the basic vibration frequency varies from 2.02 to 3.53Hz. The difference in changes is close to 75%.

Table (2) Natural Frequencies, Hz

Frequency no.	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
1	3.531	2.854	2.852	2.537	2.185	2.020
2	4.326	4.275	4.307	4.304	4.306	4.280

3	4.343	5.073	5.112	5.474	5.265	4.616
4	7.991	7.377	7.254	6.443	6.418	6.468
5	7.992	7.978	7.982	7.977	7.724	6.822
6	8.092	8.053	7.988	8.028	7.976	7.975
7	8.091	8.382	8.081	8.054	8.049	8.037
8	8.506	8.438	8.095	8.331	8.307	8.055
9	8.507	8.498	8.350	8.387	8.370	8.312
10	8.668	8.522	8.411	8.528	8.394	8.362

a. b.

c.

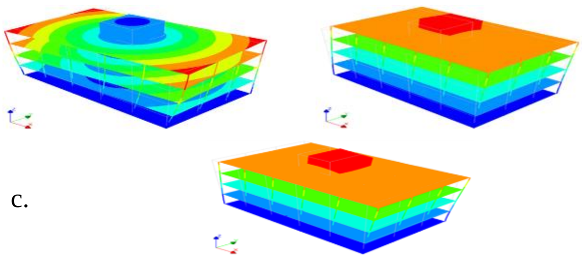


Fig (3) Frequencies of Model 1 a. F1, b. F2, c. F3

a. b.

c.

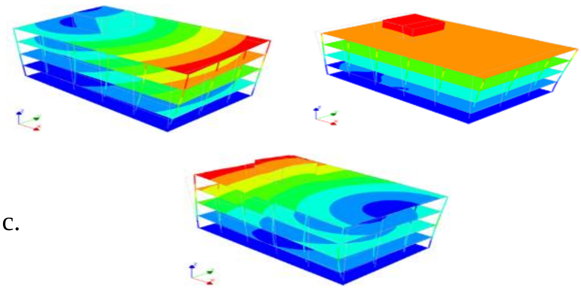


Fig (4) Frequencies of Model 2 a. F1, b. F2, c. F3

b.

a.

c.

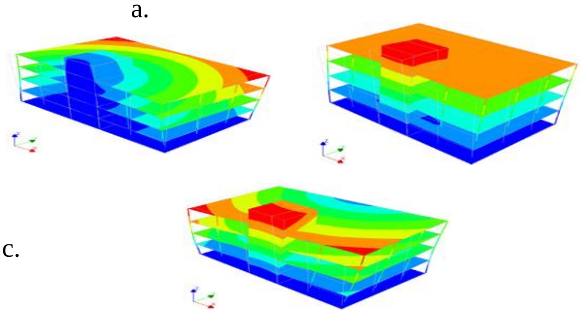
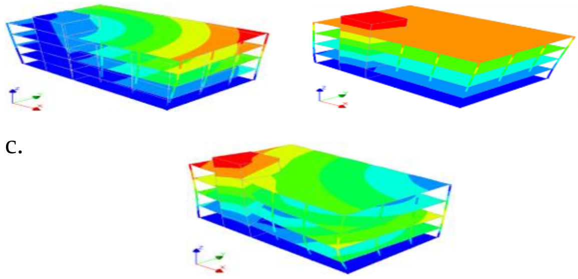


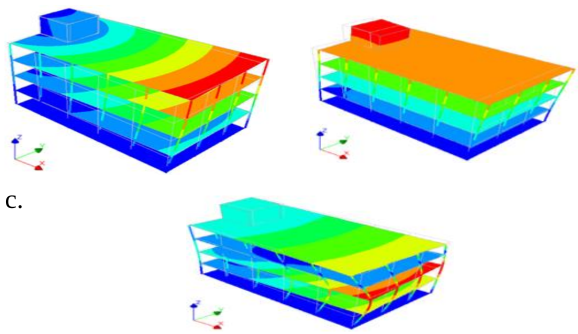
Fig (5) Frequencies of Model 3 a. F1, b. F2, c. F3

a. b.



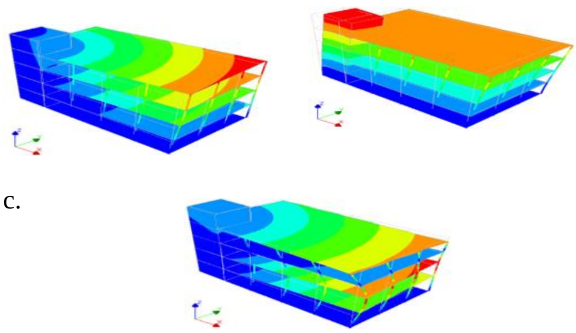
Fig(6)Frequencies of Model 4 a. F1, b. F2, c. F3

a. b.



Fig(7)Frequencies of Model 5 a. F1, b. F2, c. F3

a. b.



Fig(8)Frequencies of Model 6 a. F1, b. F2, c. F3

In the calculations using the RSA method, the following response spectrum curves were adopted: GZW (Upper Silesian Coal Basin) and LGOM (Legnica-Głogów Cooper District) according to [A. Cholewicki, T. Chyży, J. Szulc, 2003], LGOMzz for soil types A, B, C according to [Z. Zembaty, S.Kokot, F.Bozzoni, L.Scandella, C.G.Lai, J.Kuś, P.Bobra, 2015], EC 8 for soil types A, B, C [Eurocode 8].

A collective comparison of the response spectra used in the response spectrum analysis in the domain of the natural period is shown in Fig. 9.

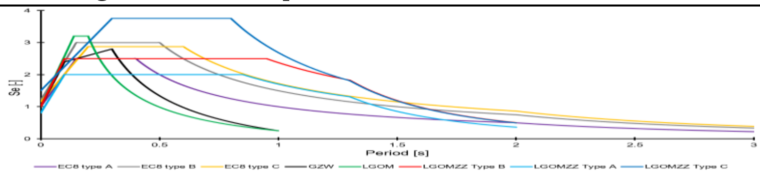


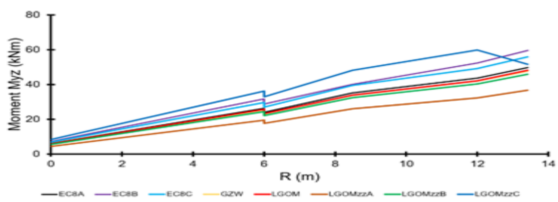
Fig (9) Acceleration Response Spectrum - comparison

3. Results

Differences in the seismic behavior of the structures were evaluated due to the inclusion of deflection in the planned irregularities along with the height. Variations in the initial normal period were studied. their absolute maximum responses to base shear, bending moment, and storey drift were obtained. The primary natural period of vibration is an important characteristic of the structure. The initial periods of regular and irregular buildings were obtained using finite element analysis (FEA). The major purpose of the analysis is to determine the quantitative and qualitative relationship between the degree (measure) of irregularity and the seismic forces generated in the building during vibrations. An additional goal is to assess the applicability of selected calculation methods in terms of the impact of vibrations on irregular building structures. All calculations were made with the use of the Diana FEA calculation program. The Bending moment is the maximum moment experienced at a corner column of a building when it gets affected by an earthquake. In model 1 when don't have any irregularity in the plan and without the eccentricity the bending moments are the smallest, in other models are increase the bending moments when the irregularity is increased and the eccentricity is increased also but in model 3 decreases and then continues to increase the moments. Table 3 shows the results of the variability of bending moments in the extreme C column (see Fig. 10, 11).

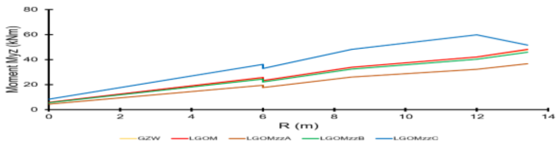
Table (3) Moment results M_{yz} in column C, kNm

Response Spectrum	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
GZW	5.80	25.43	23.06	33.70	41.93	47.72
LGOM	5.84	25.66	23.20	33.92	42.15	48.08
LGOMzz A	4.46	19.43	17.68	25.98	32.26	36.75
LGOMzz B	5.58	24.34	22.14	32.42	40.26	45.88
LGOMzz C	8.28	36.14	32.89	48.16	59.80	51.60
EC8 A	6.05	26.33	23.98	35.14	43.61	49.69
EC8 B	7.25	31.66	28.79	40.01	52.34	59.63
EC8 C	6.79	29.60	26.95	39.50	49.08	55.87



Fig(10) Curves Moment at Column C for all Response Spectrum.

a.



b.

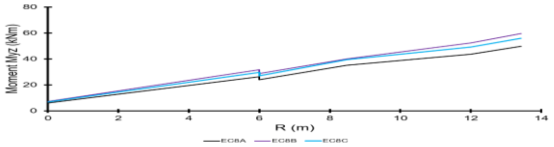


Fig (11) Curves Moment at Column C a. Mining Tremor b. Earthquake Vibration

Table (4) Results Base shear, MN

Response Spectrum curve	Base shear					
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
GZW	0.068	0.110	0.102	0.129	0.158	0.164
LGOM	0.069	0.111	0.103	0.130	0.159	0.165
LGOMzz A	0.052	0.084	0.079	0.099	0.122	0.126
LGOMzz B	0.065	0.105	0.098	0.124	0.152	0.158
LGOMzz C	0.097	0.156	0.146	0.184	0.226	0.234
EC8 A	0.071	0.114	0.107	0.134	0.165	0.171
EC8 B	0.085	0.137	0.128	0.161	0.198	0.205
EC8 C	0.080	0.128	0.120	0.151	0.185	0.192

Figure (12) shows the selected results of the maximum horizontal force (base shear) calculated using the response spectrum method for the considered calculation models.

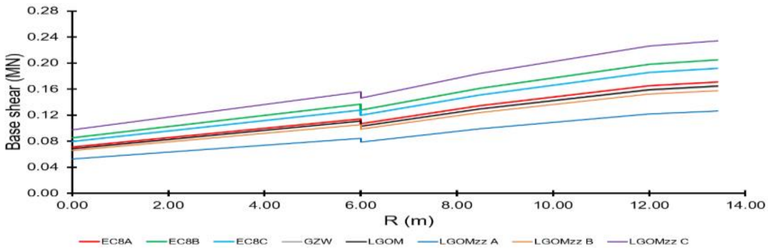


Fig (12) Maximum horizontal force (base shear)

Table (5) Displacement Results D_{xy} in last floor, mm

Response Spectrum	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
GZW	2.63	5.85	5.34	7.86	10.48	12.65
LGOM	2.64	5.89	5.37	7.91	10.55	12.75
LGOMzz A	2.02	4.49	4.11	6.05	8.06	9.75

LGOMzz B	2.53	5.56	5.14	7.56	10.08	12.18
LGOMzz C	3.76	8.27	7.62	11.22	14.98	18.14
EC8 A	2.74	6.02	5.56	8.19	10.94	13.21
EC8 B	3.29	7.24	6.68	9.83	13.07	15.85
EC8 C	3.08	6.78	6.13	9.20	12.32	14.82

Table (6) Storey Drift Results Dxy, mm

Response Spectrum	Storey level	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
GZW	2	0.41	1.64	1.49	2.20	2.80	3.25
	3	0.68	1.87	1.7	2.57	3.52	4.36
	4	0.79	1.41	1.28	1.87	2.60	3.21
	5	0.75	0.93	0.86	1.22	1.56	1.83
LGOM	2	0.42	1.65	1.50	2.22	2.81	3.28
	3	0.68	1.89	1.72	2.59	3.55	4.38
	4	0.79	1.41	1.29	1.88	2.62	3.23
	5	0.76	0.95	0.86	1.23	1.57	1.87
LGOMzz A	2	0.32	1.26	1.15	1.70	2.15	2.50
	3	0.52	1.42	1.31	1.97	2.72	3.35
	4	0.60	1.06	0.99	1.43	2.00	2.47
	5	0.58	0.77	0.66	0.95	1.20	1.44
LGOMzz B	2	0.40	1.57	1.43	2.12	2.69	3.12
	3	0.65	1.79	1.64	2.47	3.39	4.19
	4	0.75	1.32	1.22	1.79	2.50	3.08
	5	0.73	0.90	0.83	1.17	1.50	1.79
LGOMzz C	2	0.59	2.33	2.13	3.14	3.99	4.65
	3	0.97	2.64	2.43	3.68	5.03	6.21
	4	1.12	1.99	1.83	2.66	3.68	4.60
	5	1.07	1.32	1.22	1.74	2.28	2.68
EC8 A	2	0.43	1.70	1.55	2.29	2.92	3.39
	3	0.71	1.93	1.78	2.68	3.67	4.53
	4	0.81	1.45	1.34	1.94	2.72	3.35
	5	0.78	0.96	0.89	1.27	1.64	1.95

EC8 B	2	0.52	2.04	1.87	2.75	3.50	4.06
	3	0.85	2.32	2.13	3.22	4.41	5.44
	4	0.98	1.74	1.60	2.33	3.22	4.01
	5	0.94	1.16	1.08	1.53	1.96	2.33
EC8 C	2	0.49	1.92	1.74	2.58	3.28	3.81
	3	0.80	2.17	2.00	3.02	4.12	5.09
	4	0.91	1.62	1.51	2.18	3.05	3.71
	5	0.88	1.09	0.89	1.43	1.87	2.21

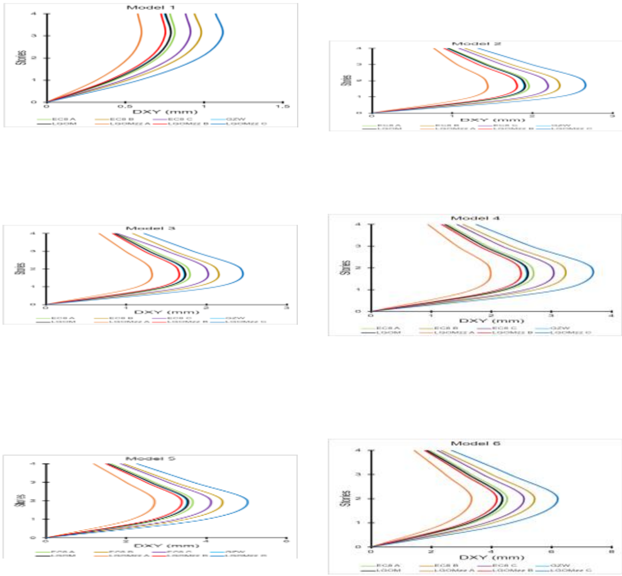


Fig (13) Inter-storey drift

The maximum moment experienced at a corner column of a building when it gets affected by an earthquake. In model 1 without regularity in the plan and without the eccentricity the bending moments are the smallest value. In other models, the bending moments are increasing when the irregularity and eccentricity increase.

The base shear in model 1 is the smallest value because without regularity in the plan and without eccentricity. In other models increasing value for earthquake and mining tremors in the same percentage for model 1. For bending moment, Model 2 increases by 438%, model 3 increases by 397%, model 4 increases by 580%, model 5 increases by 720%, in model 6 increases by 8.2%. For base shear, Model 2 increases by 160%, model 3 increases by 150%, model 4 increases by 190%, model 5 increases by 230%, in model 6 increases by 240%. Storey drift is the displacement of one level of a multi-storey building relative to the level below it. All results storey drift is between 1% and 1.5% so the results are good for all models in the earthquake and mining tremor when compared to the notes in code EC8.

4. Conclusions

In the paper, four types of seismic responses were analysed - one was earthquakes and three were mining tremors.

A building with six models was selected for analysis, one of which was regular and five of which were irregular in the x and y directions with different eccentricity values it was verified by measurement results subjected to all five types of response spectrums.

The results of the calculations display an important effect on the response spectrum of the irregular structure. Comparing the three types of response spectrum of mining tremors and the response spectrum of the earthquake EC -8, it can be seen that the results are different for the studied models. The results were obtained in terms of bending moments, inter-storey drift, and base shear force.

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REFERENCES

[1] Arab Syrian Code annex nr 2: Design for earthquake resistance of buildings structures.

[2] Archana J. Satheesh, B.R. Jayalekshmi, Katta Venkataramana, Effect of in-plan eccentricity on vertically stiffness irregular buildings under earthquake loading 2020.

[3] A. Cholewicki, T. Chyży, J. Szulc. Projektowanie budynków podlegających wpływom wstrząsów górniczych – Instrukcja ITB 391/2003. Wydawnictwo ITB, Warszawa 2003.

[4] Chopra, Anil K., Goel, Rakesh K. (2000), Evaluation of NSP to estimate seismic deformation: SDF systems, Journal of Structural Engineering, Vol. 126, No. 4, 482-490.

[5] Chopra, Anil K., Goel, Rakesh K. (2002), A modal pushover analysis procedure for estimating seismic demands for buildings, Earthquake Engineering and Structural Dynamics 2002, 31, 561–582.

[6] DIANA (2017) Finite Element Analysis User's Manual release 10.2

[7] Eurocode 8: Design provisions for earthquake resistance of structures.

[8] F. Pachla, A. Kowalska-Koczwara, T. Tatara, K. Stypuła, The influence of vibration duration on the structure of irregular RC buildings, Bulletin of Earthquake Engineering, 2019.

[9] Furumura T, Takemura S, Noguchi S, Takemoto T, Maeda T, Iwai K, Padhy S (2011) Strong ground motions from the 2011 off-the Pacific-Coast-of-Tohoku, Japan (Mw=9.0) earthquake obtained from a dense nationwide seismic network, Landslides 8, pp 333–338.

[10] S. Gerasimidis, C.D. Bisbos, C.C. Baniotopoulos. (2012). Vertical geometric irregularity assessment of steel frames on robustness and disproportionate collapse. Journal of constructional steel research, 74, 76-89.

[11] Kufner SK, Schurr B, Haberland Ch, Zhang Y, Saul J, Ischuk A, Oimahmadov I (2017) Zooming into the Hindu Kush slab break-off: a rare glimpse on the terminal stage of subduction. Earth Planet Sci Lett 461:127–140. https://doi.org/10.1016/j.epsl.2016.12.043

[12] Maciąg E, Kuzniar K, Tatara T (2016) Response spectra of the ground motion and building foundation vibrations excited by rockbursts in the LGC region. Earthq Spectra 32(3):1769–1791. https://doi.org/10.1193/020515eqs022m.

[13] Ravikumar C M, Babu Narayan K S, Sujith B V, Venkat Reddy D, "Effect of Irregular Configurations on Seismic Vulnerability of RC Buildings", Architecture Research, vol. 2, Issue 3, 2012, pp. 20-26.

[14] Tatara T, Pachla F, Kubon P (2017) Experimental and numerical analysis of an industrial RC tower. Bull Earthq Eng 15:2149–2171. https://doi.org/10.1007/s10518-016-0053-y.

[15] Wytyczne do projektowania budynków kubaturowych na terenach sejsmicznych

[16] Zembaty Z, Jankowski R, Cholewicki A, Szulc J (2007) Earthquakes in Poland in 2004 (in polish). Czasopismo Techniczne 2-B:115–126.

[17] Z. Zembaty, S.Kokot, F.Bozzoni, L.Scandella, C.G.Lai, J.Kuś, P.Bobra. A system to mitigate deep mine tremor effects in the design of civil infrastructure. International Journal of Rock Mechanics and Mining Sciences, 74:81 – 90,2015.