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THE EFFECT OF CREATING SYMMETRICAL OPENINGS IN THE SLABS OF HIGH BUILDINGS ON THEIR STRUCTURAL BEHAVIOR

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ABSTRACT

Sometimes, one is forced to create large openings in the slab of an existing multistory building for various purposes for examples to construct additional stairs, lighting purpose, elevator and other architectural features. This study examined the seismic performance of multistory building with created large openings in the slabs .The main parameters, taken into considerations are: area, position of openings and number of stories. The effect of these variables on top displacement, story drift and story shear force was considered through a numerical study. Finite element analysis using ETABS 2015 program to predict the structural behavior where statically lateral loads were applied using traditional code method. The analysis was performed according to Egyptian building code. The grade of concrete was C300 and reinforcement 36/52 in all cases. The analysis was performed and the obtained results were evaluated and discussed to evaluate the effect of openings in the slabs of multistory building under seismic loads. Finally, some important conclusions declaring the effect of the created were given.

Keywords: RC Buildings - Seismic Design – Openings in Slabs– Drift Story –Top Displacement.

1. Introduction

An opening in the slabs is usually required for various purposes. For Slabs newly constructed, locations and sizes of the openings required are usually pre-defined in the early stages of design. For example, the international business centres in Asyut Fig (1). However, when a large opening is created in the slabs of an existing building, it surely has a harmful effect on its structural behavior.

S. monish et al [2], studied the effect of the presence of various opening shapes in the slab of high rise buildings with different height on their seismic performance. Opening area greater than 15 percent of its plan dimension was assumed in different shapes like (+, T, H, and C). It was observed that displacement increased with increase in building height and H shaped is the most vulnerable.

Siddhartha Y Vekariya et al [3] studied the effect of beam and column cross section size, stated that openings in the floors reduce the rigidity of the horizontal diaphragm and affect the distribution of lateral load to the lateral load resisting element. The model with an opening required higher section (Beam, Column) size model compared to that without openings in diaphragm.

Fig. 1. Large Opening in Flat Slab Floor [1].

Mahdi Hosseini et al [4] showed that, the size and location of openings should be symmetrically located, when the building increases in height and the stiffness of the structure becomes more important. Tall structures have continued to climb higher and higher facing strange loading effects and very high loading values due to dominating lateral loads.

Osama Maniar et al [5] remembered that, the maximum torsion values occur for the buildings in which the slab openings are not symmetrical and the continuity of the beams is not enabled; lateral displacements also do increase in such buildings. The increase in the number of stories, the largeness of the earthquake zone, and the poor nature of the soil do increase the negative effects of the slab openings on the structural system behavior.

Babita Elizabath et al [6] stated that, the effect of diaphragm openings located at center are more than those located at the periphery and around 4% variation has been shown for linear static analysis and response spectrum analysis.

P.P. Vinod Kumar et al [7] mentioned that, the provision of diaphragm opening alters the seismic behavior of the buildings. Models with symmetrical opening in both directions expressed similar response for all the parameters while models with change in the symmetry behaved different and when the length of opening is more, story drifts have reduced and base shear has increased in Y direction.

K. Suresh Chowdary [8] found that, the opening in the floors makes the building flexible. Fundamental period of building with diaphragm discontinuity is found to be higher than a similar building with continuous diaphragm and the empirical equation given in design codes (such as IS 1893:2002) are good for building with continuous diaphragm. The use of this equation for a building with diaphragm can be very conservative.

Wai-Fah Chen [9], said that, the creating of a large opening in the slab decreases its in-plane stiffness. Additionally, when the structure stiffness increases it can absorb greater lateral forces induced by the earthquake motion.

Although these studies proved to be contributing to understanding the dynamics of such style of structures, they didn't address the effects of diaphragm openings. This paper describes the structural behavior of multi-story buildings when an opening is created in their slabs through a purely numerical study. In this research different factors affecting the structural response have been taken into consideration such as: (a) area of openings; (b) horizontal and vertical position of openings; (c) number of stories.

2. Methodology

Symmetric multi-story buildings have been studied under an earthquake loading. The investigated models have been analyzed using ETABS 2015 "Structural Analysis Program". The method was used in this research, is the traditional code equivalent statically load method, the effect of opening slab on drift story and top displacement of the building was discussed. The seismic zone considered in this study is Asyut city which presents zone 1 in ECLF2012 and a shape of spectrum of type1 [12]. The RC buildings considered as a residential building with importance factor $\gamma = 1$. The soil considered to be stiff soil, which presents soil class "C". The reduction factor, R, is taken considering the vertical loads and the total base shear are totally resisted by the frame structure without using shear walls or bracings. It should be noted that, ECLF2012 recommends that in the application of the ESL method, the building should meet the criteria for regularity in both plan and elevation, and with calculated structural period, T, not greater than 2 sec or $4T_c$ (1 sec for the selected soil class (class "C")).

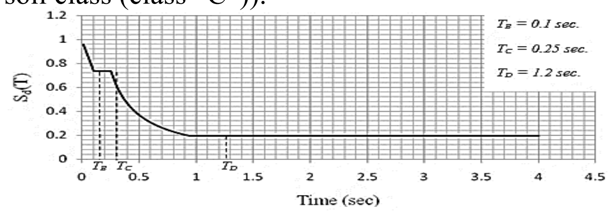

Fig. 2. Design Response Spectrum Used in the Analysis.

2.1. Ultimate base shear equation

Egyptian code states the below equation to calculate the ultimate base shear force [12],

Traditional code equation:

$$F_b = S_d\,(T_1).\ \lambda\ W\ /\ g \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where:

F_b: **Ultimate base shear force**

S_d (T_1): Design spectrum for elastic analysis at T = T_1, it depends mainly on Earthquake zone, the importance of the building, the structural system and building material as shown by the below equations

$$0 \le T \le T_B \quad : S_d(T) = a_g\ \gamma_I\ S\ \left[\frac{2}{3} + \frac{T}{T_B}\left(\frac{2.5\eta}{R} - \frac{2}{3}\right)\right], \qquad \ldots\ (2)$$

$$T_B \le T \le T_C \ : S_d(T) = a_g\ \gamma_I\ S\ \frac{2.5}{R}\eta\ , \qquad \ldots\ (3)$$

$$T_C \le T \le T_D \ : S_d(T) = a_g\ \gamma_I\ S\ \frac{2.5}{R}\left[\frac{T_C}{T}\right]\eta\ , \quad \ge [\,0.20\,]\ a_g\gamma_I \qquad \ldots\ (4)$$

$$T_D \le T \le 4\ \text{sec} : S_d(T) = a_g\ \gamma_I\ S\ \frac{2.5}{R}\left[\frac{T_C\,T_D}{T^2}\right]\eta \quad \ge [\,0.20\,]\ a_g\gamma_I \qquad \ldots\ (5)$$

T_1: Fundamental period of the building in the direction of the analysis, it depends on building total height starting above the foundation level, the structural system and material.

$$T_1 = C_t H^{3/4} \qquad \text{.....} \quad (6)$$

Where:

C_t: Constant depends on the structural system and material (C_t = 0.05, in the present study)

H: Total height of the building measured from the foundation level

a_g: Design ground acceleration

γ_1: Importance factor (for ordinary buildings $\gamma_1 = 1$, as it was taken in the present study)

R: Response modification (force reduction) factor (In case of resisting moment frames without shear walls R = 5, as it was taken in the present study)

η: Design damping factor for elastic response spectrum (In case of reinforced concrete η =1, as it was taken in the present study).

3. Modeling

To study the effects of openings size and position on seismic responses of high buildings, three dimensional (3D) geometric models of the buildings were developed in ETABS. Beams and columns were modeled as frame elements. Floor slabs were modeled as rigid horizontal plane, table (1) and figures (2) show the type and details of the studied models. The building is residential and length and width of building's = 35and 20 m respectively, the plan having 4X5 bays, thickness of slab = 15 cm, beam cross section = 25*70 cm, column cross section = 40*160 cm.

Table1.
Show different cases of opening.

Model	Area Opening(m2)	Vertical Position Opening Story	Number of Stories	Horizontal Position Opening	δ /δ all	Drift Story (m)	Story Shear Force (ton)
D1	without opening	-	15	-	.572	.0048	433.986
D2	2*5	1,2	15	at corner	.576	.00482	434.91
D3	4*5	1,2	15	at corner	.602	.00505	436.12
D4	4*10	1,2	15	at corner	.616	.005014	441.73
D5	4*5	1,2	15	at edges	.612	.00512	442.51
D10	4*5	1,2	10	at edges	.56	.004224	420.99
D10"	without opening	-	10	-	.48	.00395	411.41
D20	4*5	1,2	20	at edges	.986	.007335	587.1
D20"	Without opening	-	20	-	.82	.00679	550.79
D6	4*5	1,2	15	at internal	.616	.00515	445.78
D7	4*5	3,4	15	at corner	.603	.00508	436.12
D8	4*5	5,6	15	at corner	.608	.00508	436.12
D9	4*5	14,15	15	at corner	.544	.00499	436.12

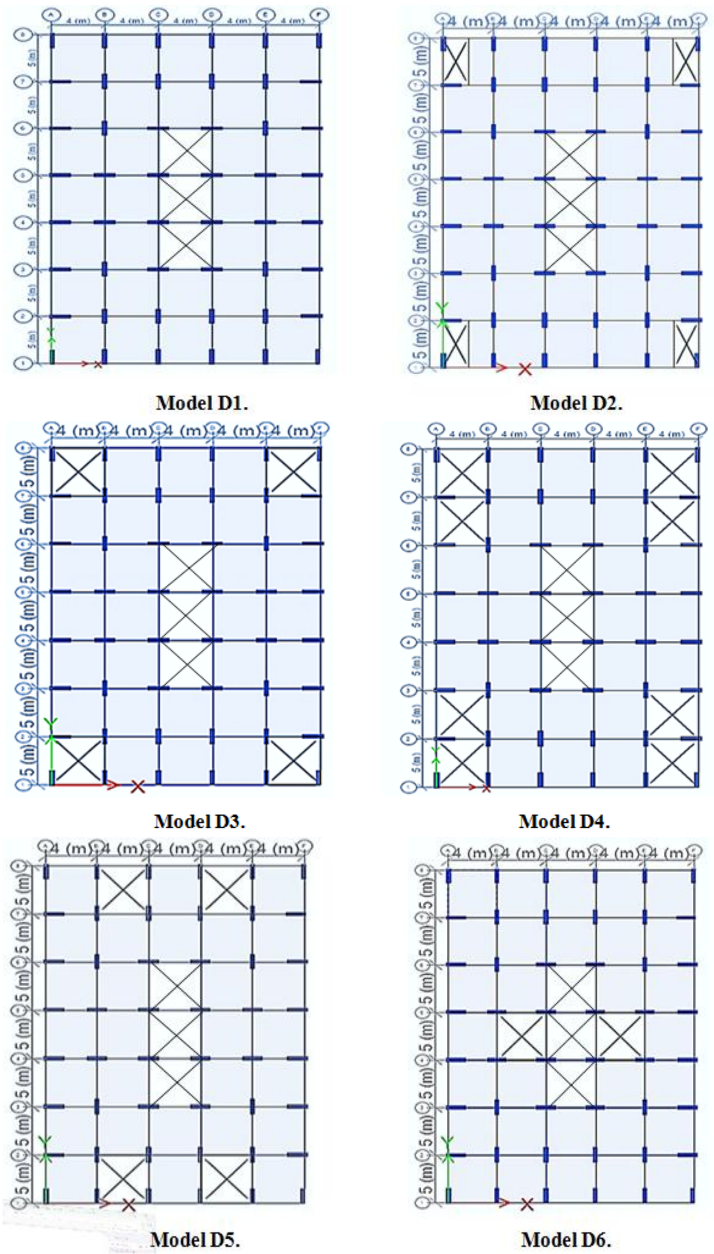

Fig. 3. Types of openings in the slab

4. Results and discussions

Analysis of the obtained results for various models using linear static method, were given in the following items.

4.1. Effect of opening size

Three models D2,D3,D4 with variable opening size at the first and second stories were analyzed and the results were given in table (1). Model (D1) was provided with the main opening along the height of the building ,without additional openings and was considered as a reference model. The obtained results for story drift,diplacement of the building and the story shear force at the first and second stories were potted for the different opening size, and given in figures (4-8). It can be seen that, as the opening area increased the story drift, displacement and the story shear force increased.The maximum increase in story drift occurred at the level where the additional opening was provided, the precentage of maximum increase in maximum story drift for models D2, D3, D4 compared with the reference model D1 were 2.58,7.33, 13% respectively.

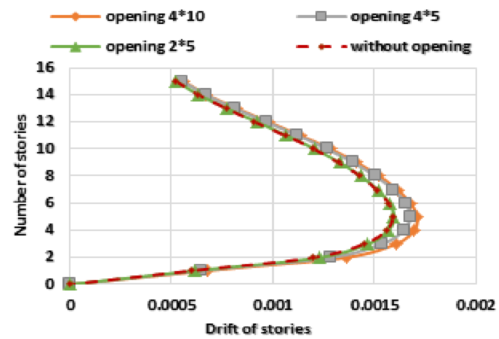

Fig. 4. Story Drift for Difference Area of Openings.

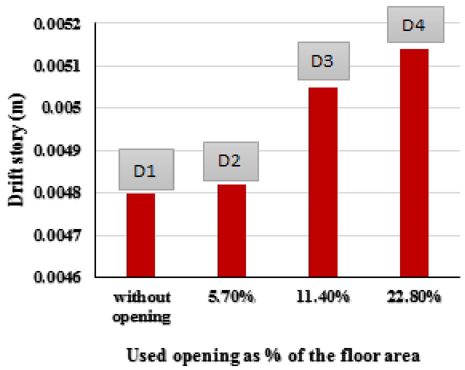

Fig. 5. Maximum Story Drift for Difference Area Openings.

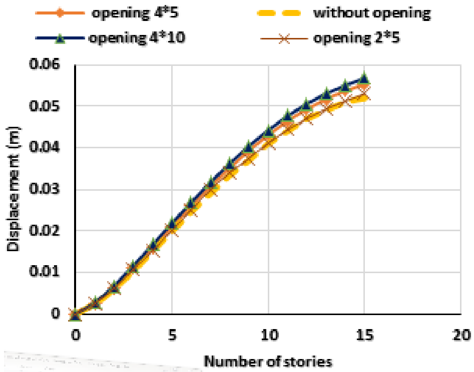

Fig. 6. Maximum Displacement for Difference Area of Openings.

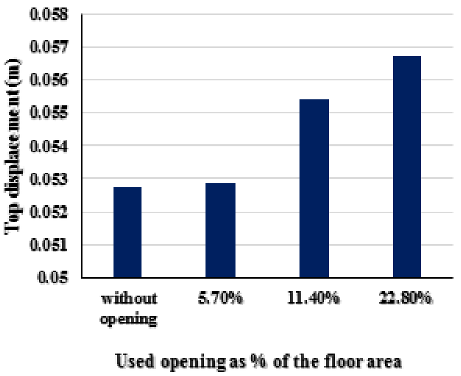

Fig. 7. Top Displacement for Difference Area of Openings.

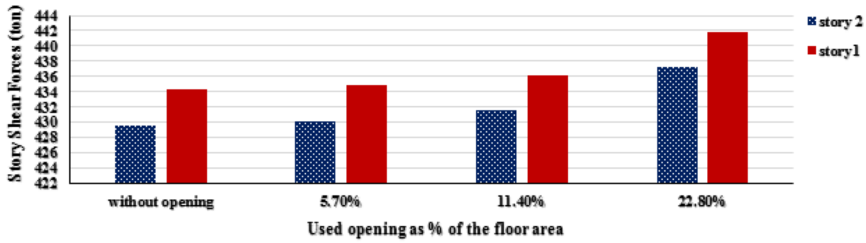

Fig. 8. Story Shear Force for Difference Area of Openings

4.2. Effect of horizontal position

Three models D3, D5, D6 with the same opening area (11.4%) but with variable horizontal postion at the first and second stories were analyzed .The obtained results for story drift, diplacement of the building and the story shear at the first and second stories were given in table (1) and potted for the different horizontal position, in figures (9-11). It can be seen that, the effect of openings was larger when they were located at internal and edges than at corner.

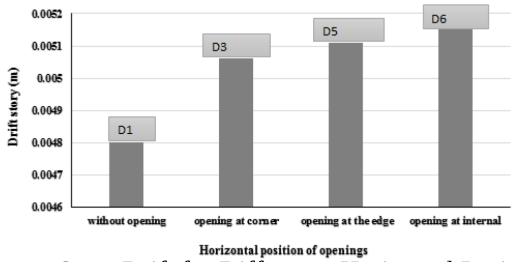

Fig. 9. Maximum Story Drift for Difference Horizontal Position of openings.

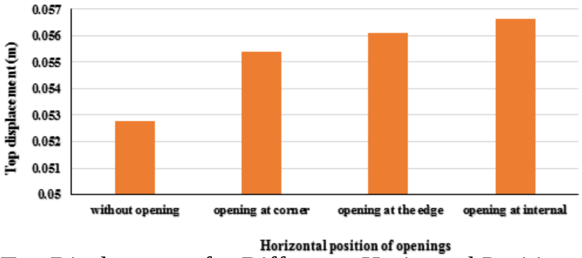

Fig. 10. Top Displacement for Difference Horizontal Position of openings.

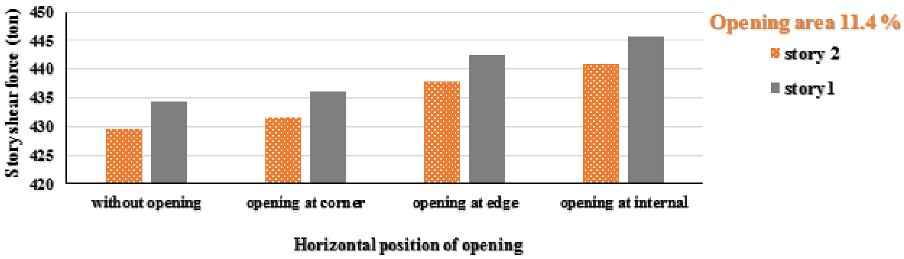

Fig. 11. Story Shear Force for difference Horizontal Position of openings.

4.3. Effect of vertical position

Four models D3, D7, D8, D9 with equal opening area located at variable vertical position at different stories were analyzed and the results were included in table (1). Model (D1) with the main openings along the height of the building and without additional openings was considered as a reference model. The obtained results for story drift and displacement of the building at different stories were potted for the different models, and given in figures (12-18). It can be seen that, the effect of the opening is more when it was located at middle stories. The precentage difference between without and with openings to Story drift at any level was maximum when the created openings were located at the same level.

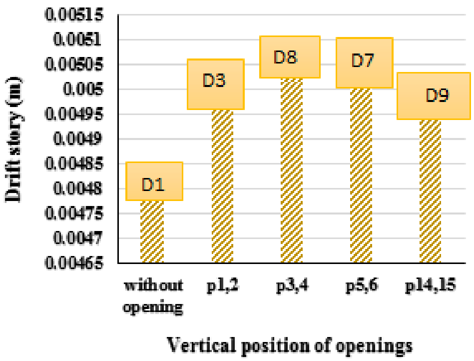

Fig. 12. Maximum Story Drift for Difference Vertical Position of openings.

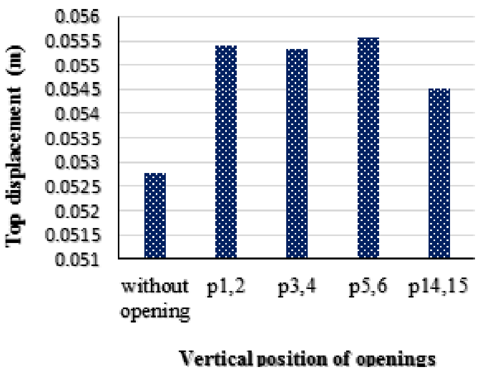

Fig. 13. Top Displacement for Difference Vertical Position for openings.

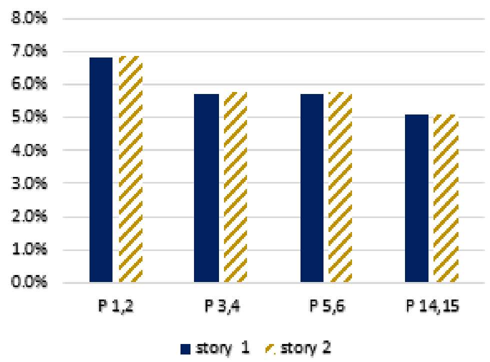

Fig. 14. % Difference of story drift of building with openings at first and second stories compared with that without opening.

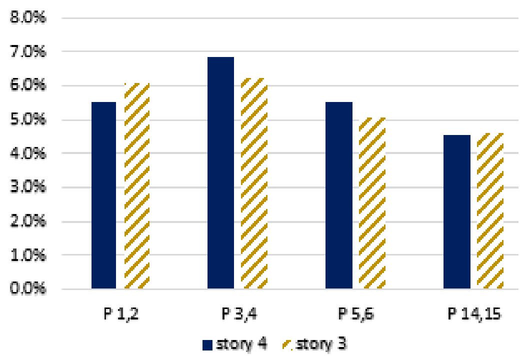

Fig. 15. % Difference of story drift of building with openings at third and fourth stories compared with that without opening.

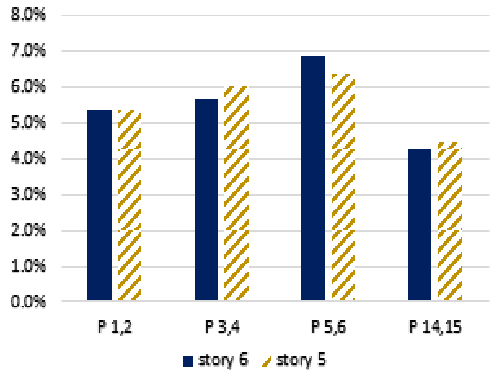

Fig. 16. % Difference of story drift of building with openings at fifth and sixth stories compared with that without opening.

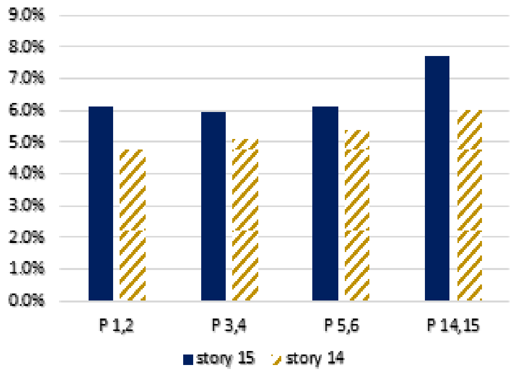

Fig. 17. % Difference of story drift of building with openings at fourteenth and fifteenth stories compared with that without opening.

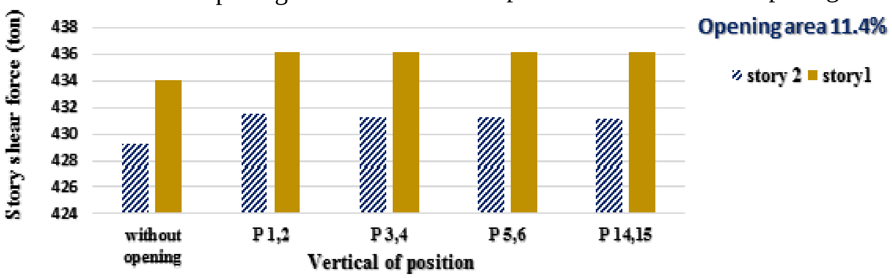

Fig. 18. Story Shear Force for difference Vertical of Position.

4.4. Effect of openings in building with variable height

The models D5, D10, D20 were analyzed to declare the effect of the created edge openings (11.4%) in the first and second stories in building with variable number of stories. D1, D10", D20" were for 15th, 10th, 20th story building without additional openings as reference models. The obtained results for story drift, displacement, story shear forces were included in table no. (1), (2), (3), (4) at openings level and plotted in figures (19-24). In general, the story drift, displacement, story shear forces increase at all stories as the number of stories increased.

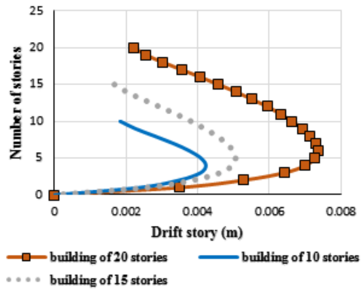

Fig. 19. Story Drift for Opening of Slab.

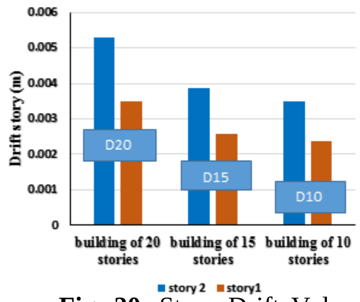

Fig. 20. Story Drift Values at Openings

Table 2.
Maximum Story Drift Values at Openings Level.

type	Building of 20 stories	Building of 15 stories	Building of 10 stories
story 2	0.00529	0.00387	0.00349
story1	0.0035	0.00258	0.00238

Table 3.
Story Displacement Values at Openings Level.

type	Building of 20 stories	Building of 15 stories	Building of 10 stories
story 2	0.008791	0.006441	0.005863
story1	0.003501	0.002578	0.002373

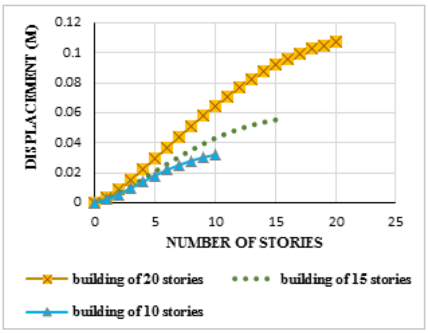

Fig. 21. Story Maximum Displacement in X Direction.

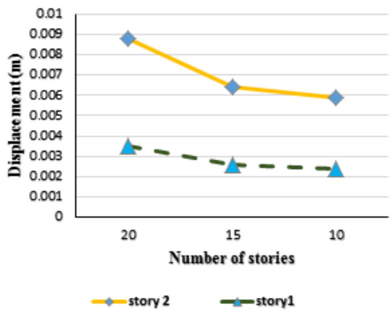

Fig. 22. Story Displacement Values at Openings Level.

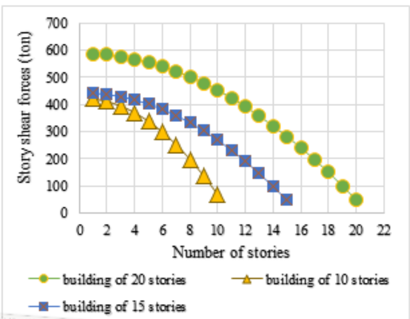

Fig. 23. Story Maximum Shear Force in X Direction.

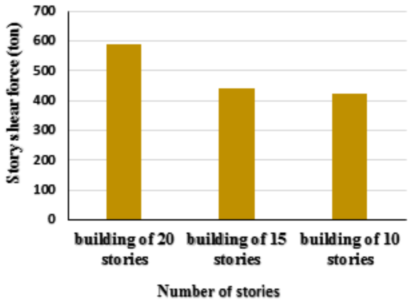

Fig. 24. Story Maximum Shear Force at first (Ground) level.

Table 4.
Story Maximum Shear Force at first (Ground) level.

Model	Building Of 20 Stories	Building Of 15 Stories	Building Of 10 Stories
Story 1	587.1	442.37	420.99

5. Conclusions

From the analysis concerning the effect of created slab opening at some levels on structural behavior under seismic loads, several important conclusions have been drawn out and can be summarized as follows:

Story drift, displacement, story shear forces decreased with decrease in opening area due to increasing of stiffness of building and they increase at all stories as the number of stories increased.

The precentage of maximum increase in maximum story drift for models D2, D3, D4 compared with the reference model D1 were 2.58,7.33, 13 % respectively.

The effect of openings was larger when they were located at internal and edges than at corner, or it was located at the middle stories of the building.

The precentage difference between without and with openings to Story drift at any level was maximum when the created openings were located at the same level.

Further research is needed to study the structural behavior of RC slabs with different percentage of reinforcement.

REFERENCES

[1] PCA, "An Engineer's Guide to: Openings in Concrete Floor Slabs", www.structure point .Org, 2006.
[2] S monish, S karuna,"A Study on Seismic Performance of High Rise Irregular RC Framed Buildings" (IJRET): International Journal of Research in Engineering and Technology, @ http://www.ijret.org, 2015.
[3] Siddharth Y Vekariya, Rajul K Gajjar," Performance Based Seismic Design of Multistory Rcc Building with Diaphragm Discontinuity"- (IJSRD): International Journal for Scientific Research and Development, 2016.
[4] Mahdi Hosseini, N. V. Ramana Rao, "Earthquakes Analysis of High Rise Buildings with Shear Walls at the Center Core and Center of Each Side of the External Perimeter with Opening" International Journal of Science and Research (IJSR), 2015.
[5] Osama Maniar, Roshni J John, "Effect of Diaphragm Discontinuity on Seismic Response of Multistoreyed Building", International Journal of Emerging Technology and Advanced Engineering, ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 5, December 2015.
[6] Babita Elizabath Baby, Sreeja S, " Analysis of Buildings with Slab Discontinuity", International Journal of Science and Research (IJSR), www.ijsr.net , Volume 5 Issue 9, September 2016.
[7] P.P. Vinod Kumar, Dr. V.D. Gundakalle , " Effect of Diaphragm Openings in Multi-Storeyed RC Framed Buildings Using Pushover Analysis", International Research Journal of Engineering and Technology (IRJET), www.irjet.net , Oct-2015.
[8] K. Suresh Chowdary," Effect of Diaphragm Discontinuity in the Seismic Response of Multi-Storeyed Building", National Institute of Technology Rourkela, 2014.
[9] Wai-Fah Chen: Earthquake Engineering Handbook, Hawaii University, Charles Scawthorn, 2003.
[10] NemaliDeepika, K.Sai Santosh, M.Tech, " Effect of Diaphragm Discontinuity in The Seismic Response of Multi-Storeyed Building", International Journal & Magazine of Engineering, Technology, Management and Research, www.ijmetmr.com , 2016.
[11] Joheb Ahmed & Syed Ahamed Raza, "Seismic Vulnerability of RC Buildings by Considering Plan Irregularities Using Pushover Analysis" GJRA – Global Journal for Research Analysis, 2014.
[12] ECP-201, 2008 - Egyptian Code of Practice - 201. Egyptian Code of Practice no-201 for Design Loads for Construction Works, Research Center for Housing and Construction, Ministry of Housing, Utilities and Urban Planning, Cairo, Egypt, 2008/ 2012.

"تأثيرتخليق فتحات في أسقف المباني العاليه علي السلوك الانشائي"

الملخص العربي

أحيانا يتم تخليق فتحات كبيرة ومتعددة في المبني القائم بغرض إجراء تغيير في إستعمال المبنى مثل إستخدامات المصاعد - سلالم ربط وحدات في مستويات مختلفه ببعضها داخليا............. الخ . كود البناء يسمح بعمل فتحات من أي حجم في أي نظام بلاطة، شريطة أن يظهر التحليل الانشائي للعنصر استيفاء جميع شروط ومتطلبات الخدمة بأمان .تحليل البلاطات التي تحتوي علي فتحات يمكن أن تكون معقدة وتستغرق وقتا طويلا. تم دراسة وفحص منشآت "فى المستوى" (13 حالة) لمنشأ متعدد الطوابق سكني .الكمرات كانت بقطاع 25*70 سم والأعمده كانت بقطاع 40*160 سم والبلاطات بسمك 15 مم و الفتحات أخذت كنسب مختلفه (22.8% ,11.4% ,5.7%) من مساحة الدور وبإختلاف أماكنها أفقيا في (الداخل ، الأطراف ، الأركان) و رأسيا عند (1,2 و3,4 و 5,6 و14,15) دور كما أننا أجرينا تحليل علي طوابق مختلفه (10،15،20) أدوار بإستخدام برنامج الإيتاب 2015 لدراسة قيم الإزاحات التي بين كل دور وأيضا قيمة الإزاحه الكليه من أعلي وسلوك المنشآت في حاله الفتحات . وقد تم الحل بإستخدام الطريقة التقليدية التى ينص عليها الكود المصري لحساب الأحمال والقوى فى الأعمال الإنشائية وأعمال المباني 2008/201. النتائج التي تم الحصول عليها بواسطة البرنامج المذكور قيمت وتم تحليلها أظهرت الدراسه أن تخليق مثل هذه الفتحات له تأثير ملحوظ على سلوك مثل هذه المباني وفي النهايه تم إستخلاص بعض النتائج المفيده للمهندس الإنشائي في مثل هذه الحالات.