Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (43) No. (4) October . 2021

Comparison between Response Modified Factor of Outrigger and Ordinary structural systems Using ECP-201/ECP-203

MOHAMMED ELSAYED ABDELMAGIED ELSAYED **[1]**
AMIN SALAH ALY **[2]** AND MOHAMED MOHAMED ATABBI**[3]**

[1] Postgraduate researcher; Faculty of Engineering; Ain Shams University; EGYPT
EMAIL:Mohammedelsayed866@GMAIL.COM

[2] Prof. of Structural Analysis and Mechanics; Faculty of Engineering; ain Shams University; EGYPT
EMAIL:Aminsaly2000@GMAIL.COM

[3] Prof. of Structural Analysis and Mechanics; Faculty of Engineering; ain Shams University; EGYPT

الملخص العربى :

مع التطور الكبير في نظم المباني العاليه جعلنا في امس الحاجه الي تطوير انظمه إنشائية لمقاومه الاحمال الجانبيه كاحمال الزلازل والرياح. ومن بين هذه الانظمه, نظام النواه المركزيه المقاوم للزلازل الذي ييستخدم في المباني العاليه التي تصل الي 200 طابق. والكثير من الباحثين قاموا بابحاث و دراسات ركزت علي كفاءه النواه,الموقع المثالي للنظام في البناء علي ارتفاع المبني والشكل البنائي للمبني وتاثيرها علي الازاحه والانحراف والازاحه العلويه وقد قمنا باستخدام اصدارين من برامج التحليل الانشائي والهيكلي الايتاب للتاكد من الوصول لادق النتائج تحت تاثير احمال الرياح ومعاملاته والزلازل لكن وفقا للاكواد المصريه وكود الرياح والزلازل ولكن معامل تخفيض القوه ومقاومه المبني للزلزال لم يذكر ولذلك يجب الوصول لادق النتائج وهذا ما نختص به في دراستنا للوصول الي نظام انشائي متكامل يكون المهندس الانشائي قادر علي استخدامه .

ABSTRACT:

Nowadays we have a huge devolvement in building technology that made us in the most need to have new structural systems to resist lateral loads as earthquakes and wind loads. Among those systems, outrigger system that is used in high-rise building and efficient for building that have height up to 200 floors. many researchers made studies and papers that focused on efficiency of outrigger, optimum locations of system in building along its height and topologies of outriggers and its effect on displacement and drift index.

The analysis of the structural building was done with ETABS 2019 v19.0.0 and ETABS 2016 v16.0.3 software's under effects of wind and earthquakes loads according to Egyptian codes 2018 and lateral loads code 2012 using pushover analysis to get the most accurate results.

However, in this study shows the difference between R-factors (Response Modified Factor) with and without outrigger by Egyptian codes ECP-201/ECP-203 (2018). For this purpose, used square building with 30 stories reinforced concrete structure with two outriggers placed in optimum locations. This study use the shear walls that ties core with exterior columns only in outrigger floor that made outrigger the best system used nowadays in height building and found that R-factors and their parameters are more efficient to resist earthquakes than normal system and compare between these two systems.

Keywords: Outrigger structural system, Ordinary structural systems, High-rise Building, Response Modified Factor, R factors, Drift, displacement.

INTRODUCTION:

First we should define the systems that used. two systems are used in study, the first system is Outrigger system **[1]** defend as a resistant structural system used in high rise building **[2]** because it is more safe and economic This system helps in reducing the lateral deflections, and overturning moments. Overall, the major advantage of using the outrigger is to resist the rotation of the core and significantly reduce the lateral deflection and overturning moment. This system nowadays is used in many tall building **[3]** like the-Shard-London-uk **[4]**as shown in fig.1, Shard London Bridge and formerly London Bridge Tower, is a 72-storey skyscraper, designed by the Italian architect Renzo Piano, in Southward, London, that forms part of the Shard Quarter development. Standing 309.6 meters (1,016 feet) high, the Shard is the tallest building in the United Kingdom, and the seventh-tallest building in Europe. Jeddah Tower the-kingdom tower**[5]** as shown in fig.2, The building has been designed to a height of at least 1,000 meters (3,281 ft.) (the exact height is being kept private while in development, similar to the Burj Khalifa, At about one kilometer, Jeddah Tower would be the tallest building or structure in the world to date, standing 180 m (591 ft.) taller than the Burj Khalifa in Dubai, United Arab Emirates. Burj Khalifa**[6]** as shown in fig.3, known as the Burj Dubai prior to its inauguration in 2010, is a skyscraper in Dubai, United Arab Emirates. With a total height of 829.8 m (2,722 ft.), just over half a mile) and a roof height (excluding antenna, but including a 244 m spire) of 828 m (2,717 ft.) and more building used it and ordinary building using building frame system which consisting of column, central core and beams as shown in fig.10.

Fig 1. the-Shard-London-uk with outrigger

Fig 2. Jeddah Tower the-kingdom tower

Fig 3. Burj Khalifa Burj Dubai outrigger system

Outrigger system consists of, rigid structural elements "beams or trusses" ties interior shear wall or core with exterior columns to mobilize the axial strength and stiffness of these columns to resist the rotation of the shear wall or core. Thus, it reduces the lateral deformations of the building and bending moments in the walls. On the other hand, it causes irregularity between stiffness of stories and transfer vertical loads between shear walls and exterior columns.

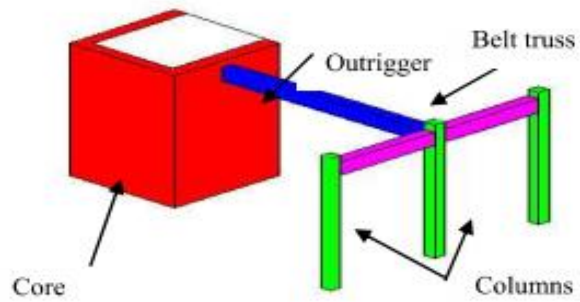

Fig 4. core with outrigger

The ideal base of outrigger system is to couple the perimeter and the internal structure as a whole to resist lateral load. Considering the structure as shown in Fig4 **[7]**, both the internal core and the perimeter frame (or tube) are uncoupled. Therefore, the core and perimeter frame resist the lateral load by means of pure cantilever action only. In theory, if the internal beams between core and perimeter are getting deeper and stiffer, the core and perimeter frame can work together to resist lateral forces as shown in fig5. However, it is very difficult to provide beams which are stiff or deep enough to couple the core and the perimeter frame.

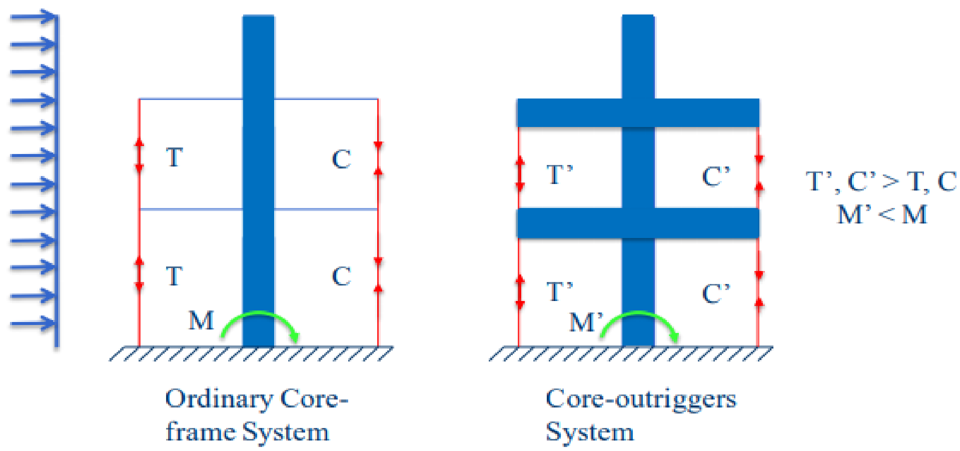

Fig 5. Difference between ordinary core-frame and core-outriggers system

the outriggers are draw as a deep wall as shown in Fig 6 **[8]**, Assuming the outriggers are strong enough to generate restraining moment M1 and M2, the moment at the base, oMbase will be reduced by

(M1+M2), i.e. Mbase = oMbase + M1 + M2 (1)

Equation (1) can be rewritten in the following form:

oMbase = Mbase - Σ Mi (2)

where; Mi is the restraining moment of the i-number of outriggers.

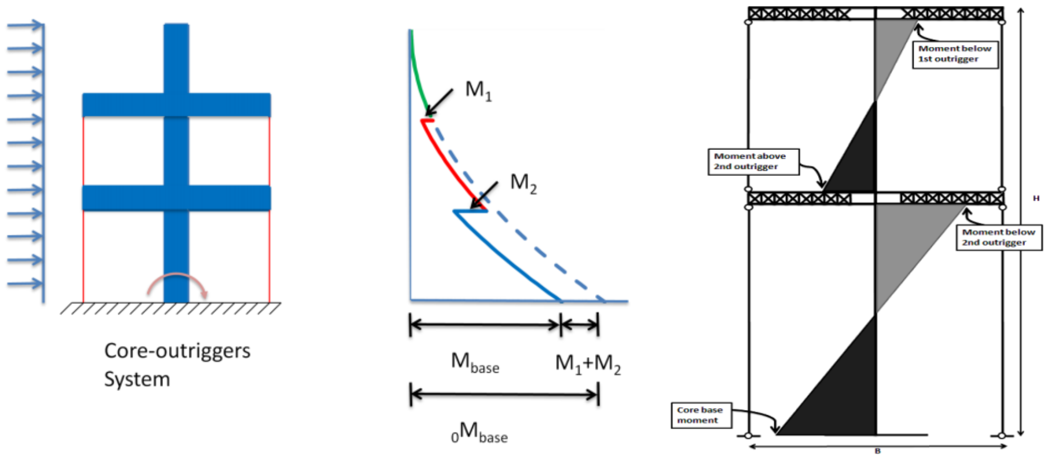

Fig 6. Difference of Moment Diagraph between Ordinary and Outrigger Frame

There are some researchers who do research for outriggers, one reducing drift and optimum locations called Taranth, B.S (2016) **[9]**, and Stafford smith (1994) **[10]**. Some of researchers explain execution of outrigger-braced and offset like smith et al **[11]**. and other gives the development and documented outrigger Ali and Moon **[12]**, for building up to 150 stories. Some showed the effectivness of system with different cases called Wolfgang **[13]**. Lyengar **[14]**, used outrigger with belt truss. Taranth, Jahanshah et al and meleka**[15]**. N. et al **[16]**, showed optimum location of system. Ho. **[17]**, Studied different topology of system with different stiffness and load capacity, but no one illumines the effect of the parameters R-factor to make this system suitable for use. We will try to solve this problem to make high rise building development and make comparison between 2 systems one of them is outrigger and the other is ordinary with core and columns only. Analysis was performed by Etabs software with take all effective parameters like earthquakes and wind loads and made 3D models and compare displacement and drift.

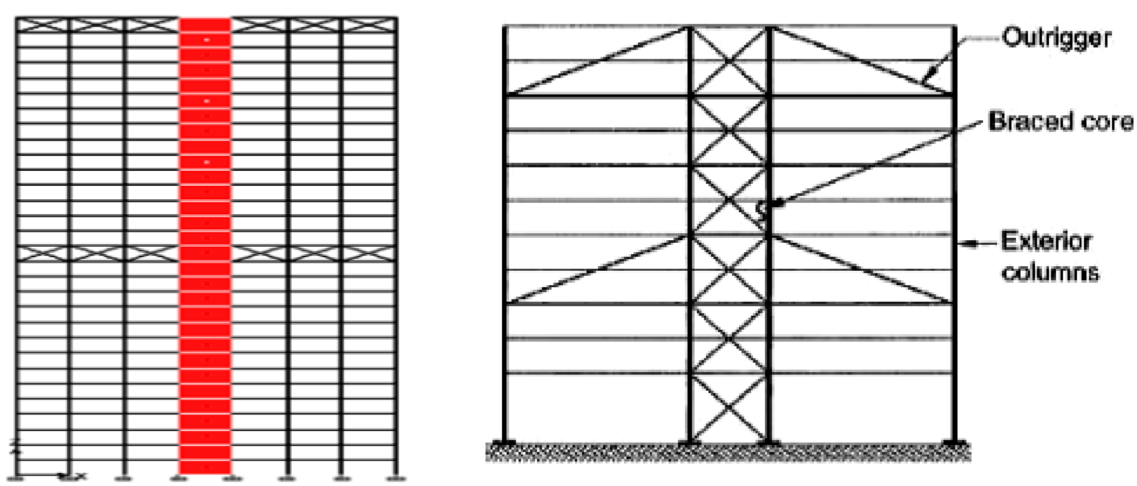

Fig 7. Shape of Outrigger System in Building in Optimum Location

NUMERICAL ANALYSIS

MODEL DESCRIPTION

This study will use commercial 30 stories reinforced concrete structural building **[18]** with area 692m with story height 3.2m, the building consists of central core (Rc core), outrigger element considers as shear walls that ties to exterior column to make core ties with column, column are tied together with belt (marginal beam) as shown in Fig 8 and put outriggers in refuge floor, maintenance floor or emergency floor to use this floors for useful thing. Core dimensions are (20x20) m this designs according ECP201-2012/ECP203-2018 based on loads in table1. materials properties in Table 2. cross-section dimensions for different elements in Table3.

The analysis is performed using ETABS 2016 v16.0.3 11**[19,20,21]** and one modeling shear wall using fiber model and two using ETABS 2019 v19.0.0 11**,** program by modeling shear wall (core) and outrigger elements that ties either outer column as nonlinear multilayer shell (layered shell) using Egyptian Code (ECP Codes) **[22]**, Area of reinforcement column and core is one percent of concrete dimensions. Floors, core, shear walls are modeled in program as shell element with mesh size(0.5x0.5) cm and Outrigger, beams and column are modeled as frame elements using pushover analysis.

pushover analysis **[23]** was carried out for the base-fixed superstructure to examine the yield displacements and succeeding inelastic behavior is a nonlinear technique for estimate seismic structural deformations started with small set of horizontal forces is utilized so as to simulate the results of ground motions, and deformations are calculated. The forces are then multiplied in steps so as to develop a plot of base shear versus deformation. Examination for develop a plot displays the greatest base action that the constructing can resist. And ordinary building is consisting of column, central core and beams as shown in fig.10.

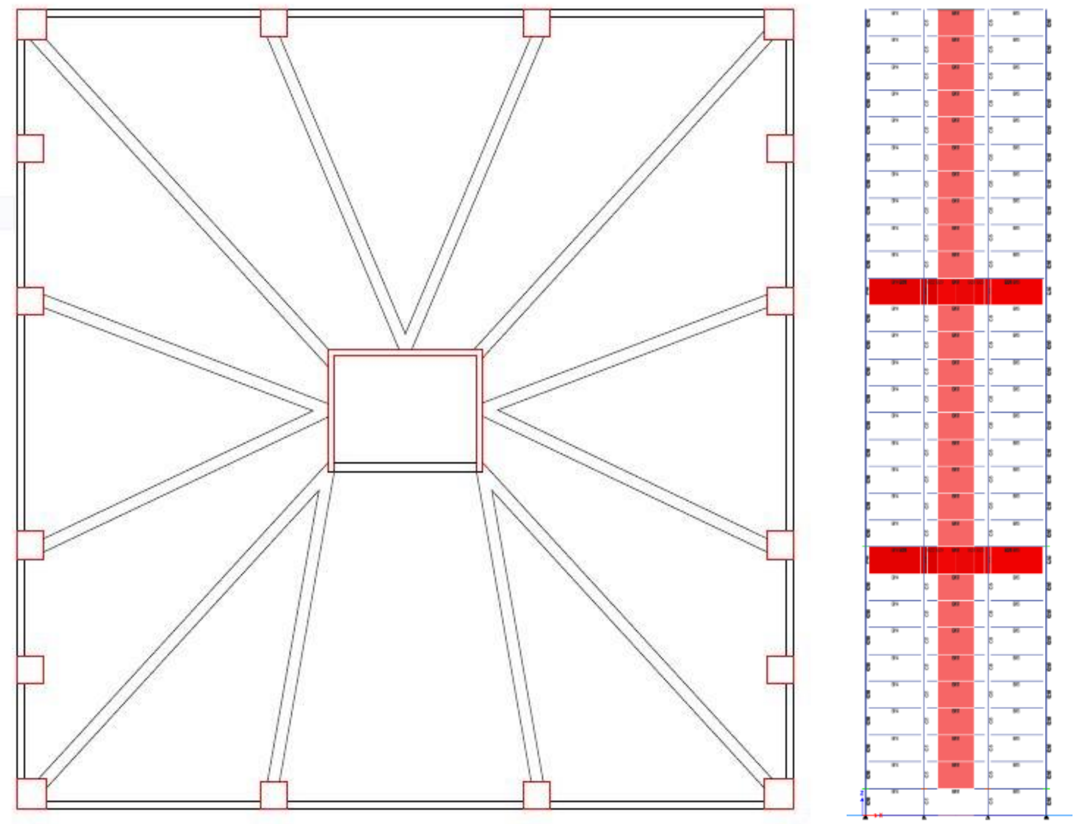

Fig 8. Plan&Vertical Configurations Of Outrigger Of Square Plan Model

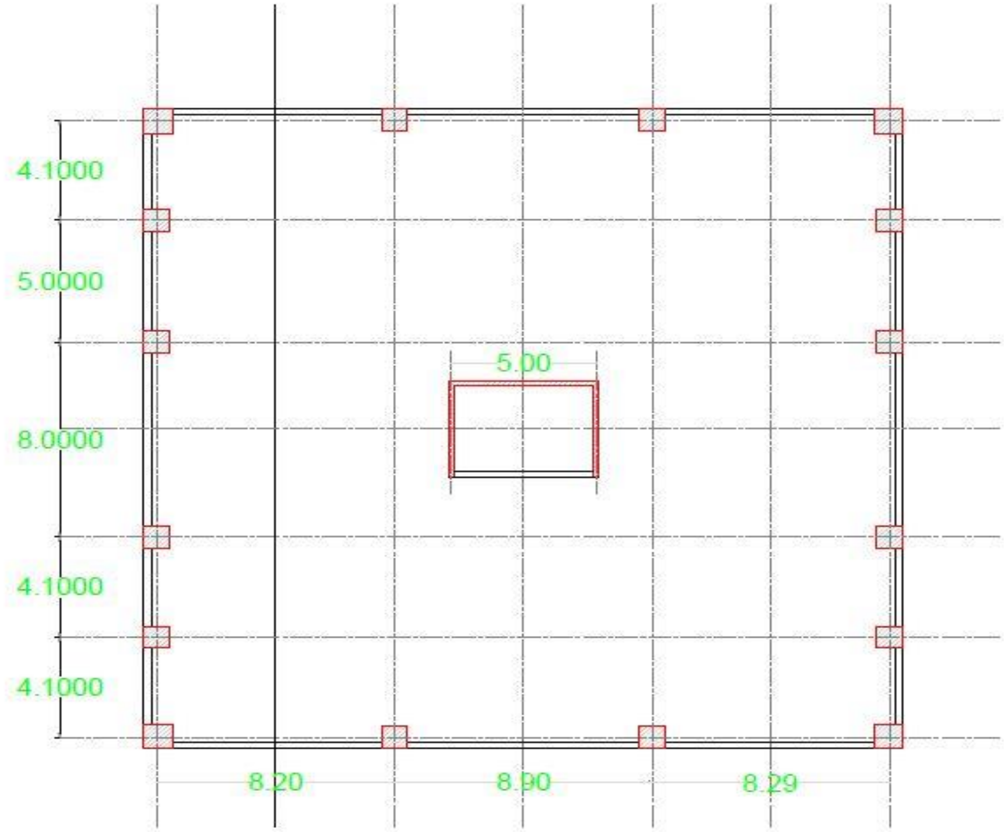

Fig 9. **Plan of typical floor of outrigger building**

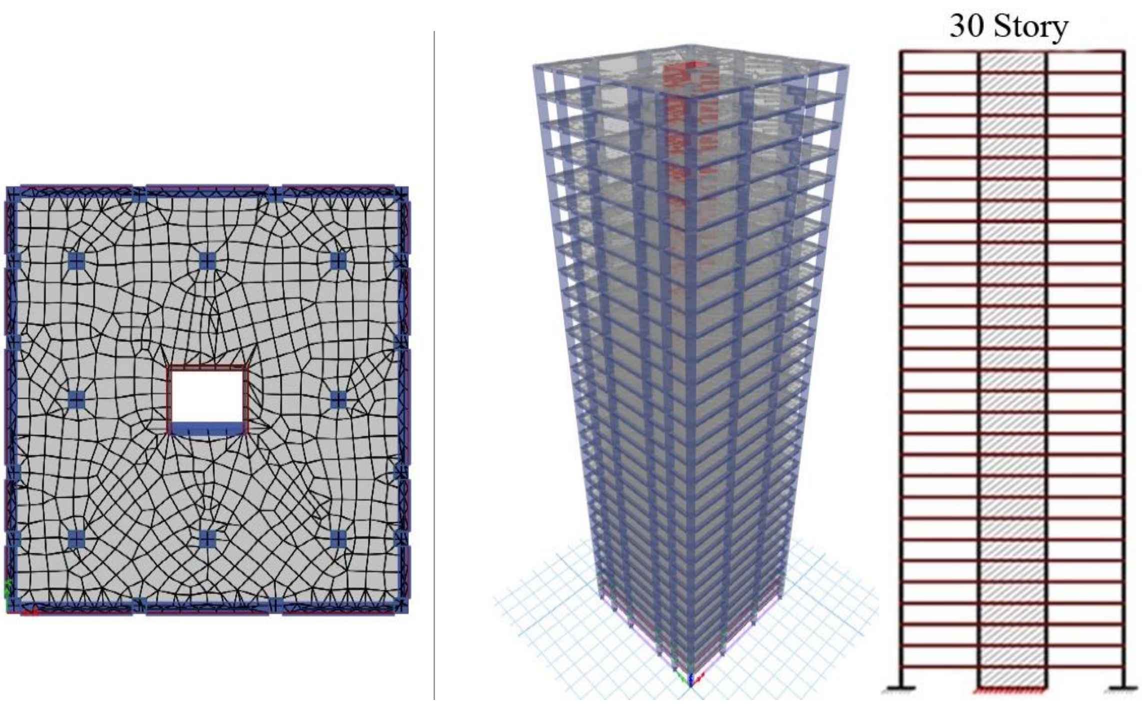

Fig 10. **Plan &Vertical Configurations of 3D Square Plan Model of 0rdinary**

Table 1 loads

Loads	
Thickness	26 cm
OW	6.37 kN/ m^2
Structure own weight	weight per unit volume = 24.50 kN/m^3
Floor cover	1.5 kN/ m^2
Last Floor cover	2.5 kN/ m^2
Outer walls line load	6.0 kN/m
Inner partitions equivalent distributed load	2.0 kN/m^2
Live load	2.5 kN/ m^2 for Residential floors
Live load	5 kN/ m^2 for commercial floors
Wind speed	74.0 mph (33.0 m/s) corresponding to Cairo governorate in Egypt class A
Response spectrum curve	Type 1
Exposure type for soil C	corresponding to exposure type zone 2
Ground acceleration design	0.125g
Damping correction η=1	Impact factor γ=1
R	5.0. Seismic forces are resisted

Table 2 material properties

Material	
Compressive strength f'_c	40 N/mm^2 for walls and column
f'_c	30 N/mm^2 for beams and slabs
Specific weight	24.5 kN/m^3
Modulus of elasticity E_c	$4700\sqrt{f'_c}$ MPa as per ACI 318-08
E_c	$4400\sqrt{f_{cu}}$ MPa as per ECP-203
Poisson's ratio	0.2
Fy	400 N/mm^2 as per ECP-203
Fy stirrups	260N/mm^2 as per ECP-203
Modulus of elasticity E_s	200 kN/mm^2.

Table 3 Cross-sections

Cross-sections			
ID	**story**	**DIM(cm)**	**RFT**
C1	1-10	70X70	20Φ20
	11-20	60X60	16Φ18
	21-30	50X50	12Φ18
C2	1-10	80X80	20Φ25
	11-20	70X70	20Φ20
	21-30	60X60	16Φ20
B1	25X80		
B2	40X100		

Table 3- 1: Columns and beams Sections and reinforcement, ECP.

ID	story	DIM (cm)	VL RFT	Shear RFT
core	**1-30**	20cm	T16@200	T12@200

Table 3-2: Shear wall sections and reinforcement, ECP.

This study used 30 floor building with two Outrigger in their optimum locations **[24]** in one-third at 11th floor and the other in two-third in 21th floor and outrigger used is solid truss as shear walls is (30x30) as shown in fig 10. Fig 11 is the 3D modeling for building outrigger system according to axial and lateral forces.

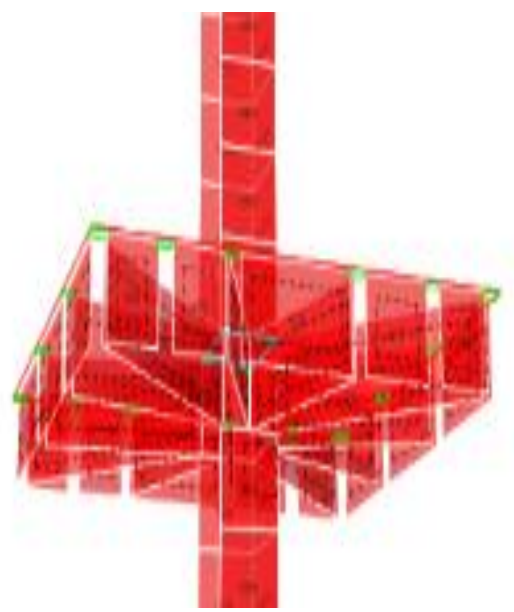

Fig 11. 3D View of Outrigger Shapes in Building

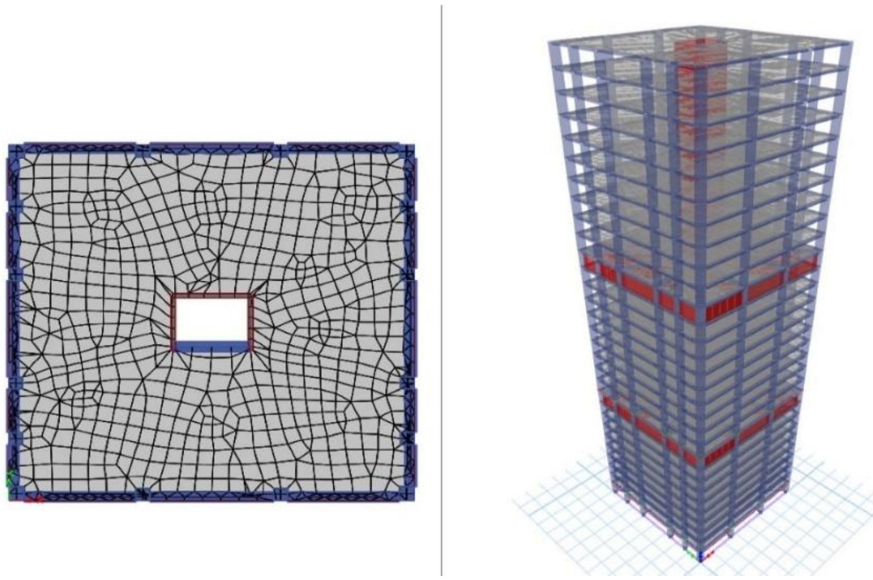

Fig 12. 3D Analysis Model-ETABS with outrigger

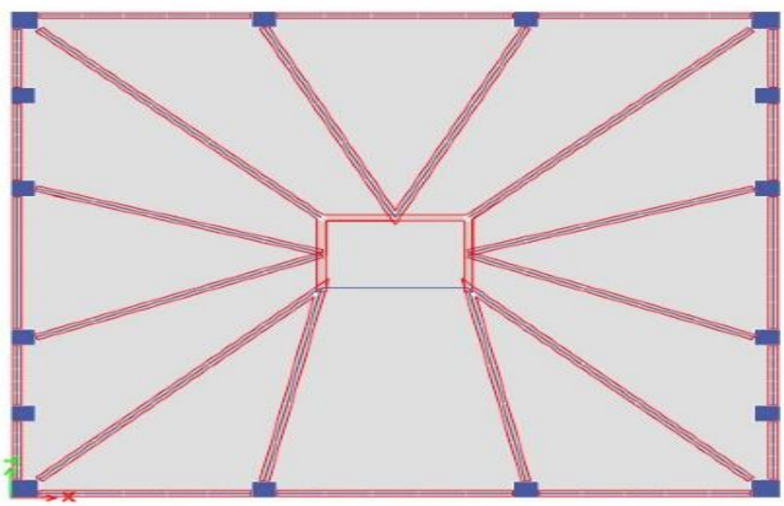

Fig 13. Typical Story with Outrigger

For the models analysis assumptions are the linear elastic range for materials, core is rigid connected to foundations and Outrigger is rigid connect to core and slabs are considered rigid diaphragm.

Analysis, Results and Discussions

The aim in this study to get the resistance earthquake factor R-factor with critical lateral load for Outrigger by ECP and use for this model with 2 Outrigger and Fig 14 gives typical response spectrum for models, Fig 15 show the lateral displacement under earthquakes for Outrigger element, Fig 16 show drift index for outrigger building in x-y directions. Fig 17 show lateral displacement in x-y directions, Fig 18 show drift index for ordinary building for ordinary building according to response spectrum as shown in Fig 13.

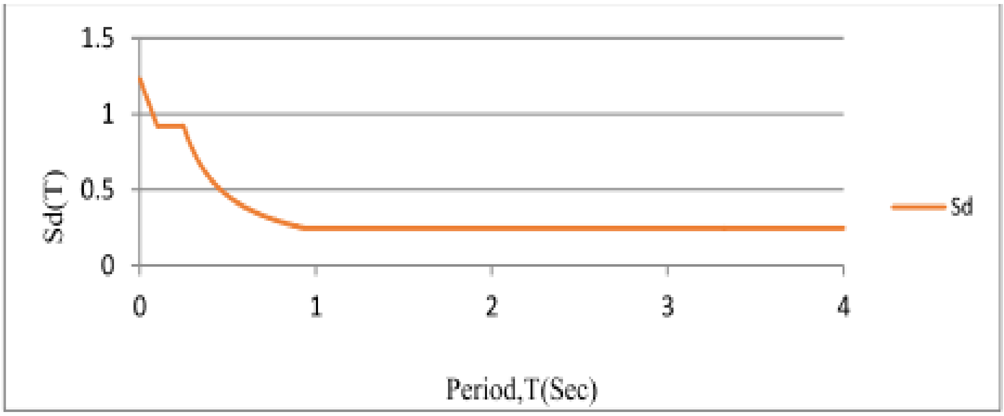

Fig 14. Typical Response Spectrum of Models

The top story displacement and interstory drift **[25]** curves indicate that the min values in X and Y directions are 25.018cm and 0.01156, respectively, and the max values are 16.56cm and 0.00046 as shown in fig 15 and fig 16. The carves show that the displacement and drift are reducing at the outrigger level, which we found at the 10 and 20 story.

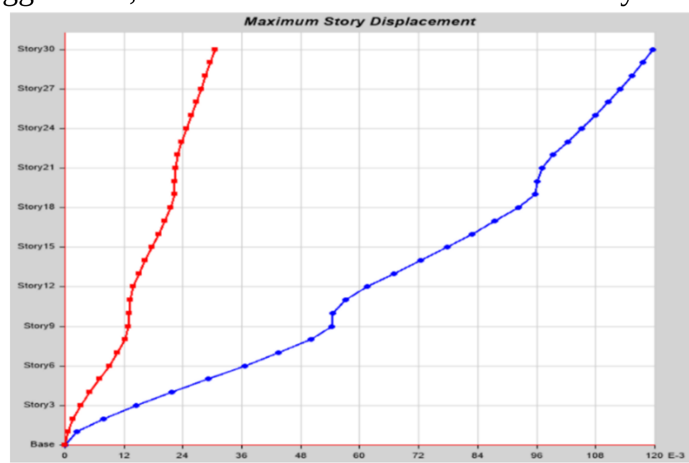

Fig 15. Lateral Displacement of Outrigger Building in 2 Direction

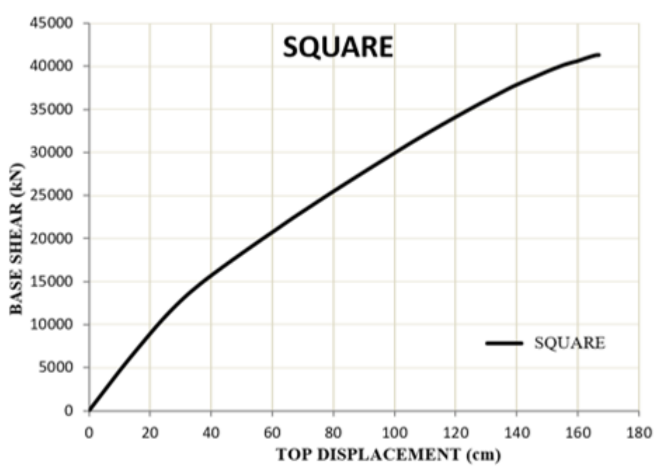

Fig 16. Lateral Displacement of Outrigger Building

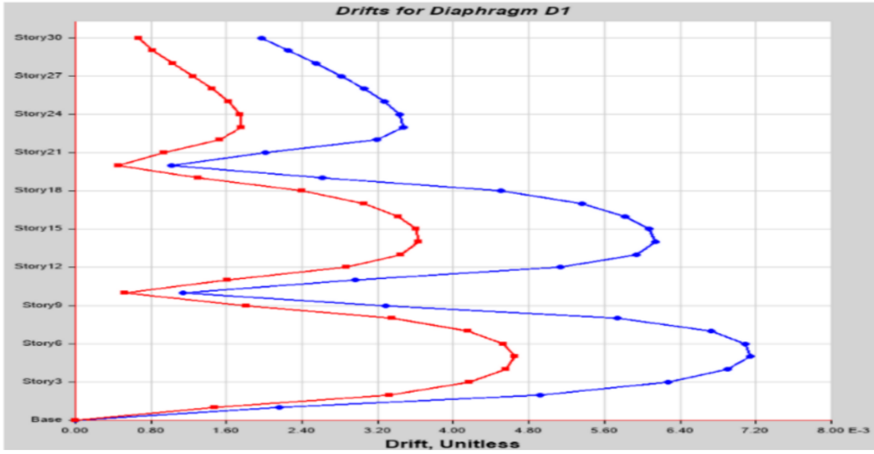

Fig 17. Drift Index of Outrigger Building in 2 Direction

The story displacement and interstory drift curves show that the top story displacement and interstory drift min values in X and Y directions are 35.3cm and.0055 and 10.8cm and 0.00014, respectively as fig 18 and 19. We found displacement rise in ordinary system without Outrigger from 25.027 to 35.35, which carves suggest that displacement and drift are affect with statics systems.

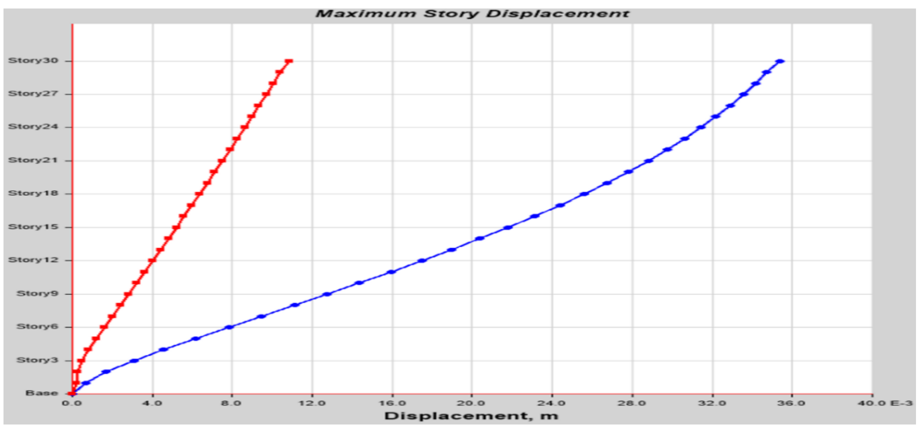

Fig 18. Lateral Displacement of Ordinary Building in 2 Direction

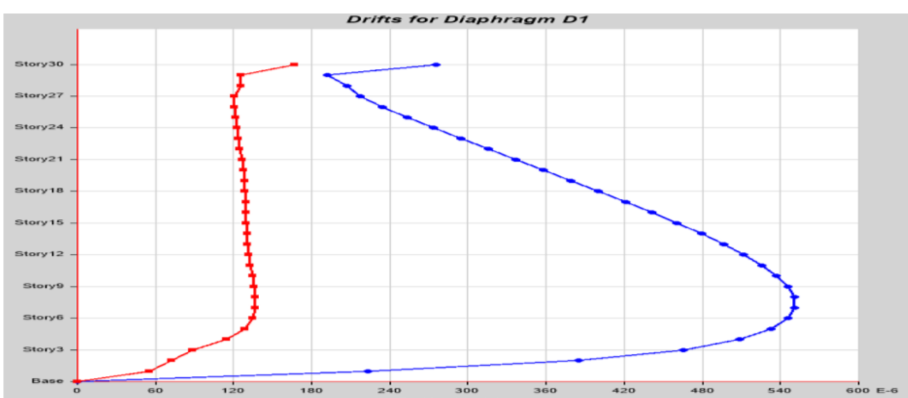

Fig 19. Drift Index of ordinary Building in 2 Direction

Outrigger system is more resistant to earthquakes, in addition to having a safe place and materials, makes it a more secure and cost-effective method and it showed R-factor which is the bigger effective factor in earthquake resistance system.

Table 4: 30 Story Rμ, Rs and R factors, outrigger system.

structural system	Ti (sec)	∆max cm	∆y cm	μ	Rμ	Vy kN	Vd kN	Rs	Rx
Outrigger	3.5	296.181	65.021	4.561	4.561	134821.531	8846.8321	1.53	6.98

Table 5: 30 Story Rμ, Rs and R factors, outrigger system.

structural system	Ti (sec)	∆max cm	∆y cm	μ	Rμ	Vy kN	Vd kN	Rs	Ry
Outrigger	3.64	167.851	4.841	4.841	3.761	11159.6771	8846.8321	1.26	6.1

Table 6: 30 Story Rμ, Rs and R factors, ordinary system.

structural system	Ti (sec)	∆max cm	∆y cm	μ	Rμ	Vy kN	Vd kN	Rs	Rx
ordinary	4.41	125.631	41.431	3.0321	3.0321	11017.531	7654.541	1.44	4.37

Table 7: 30 Story Rμ, Rs and R factors, ordinary system.

structural system	Ti (sec)	∆max cm	∆y cm	μ	Rμ	Vy kN	Vd kN	Rs	Ry
ordinary	4.62	122.631	40.431	43.031	3.031	10218.001	7654.541	1.33	4.03

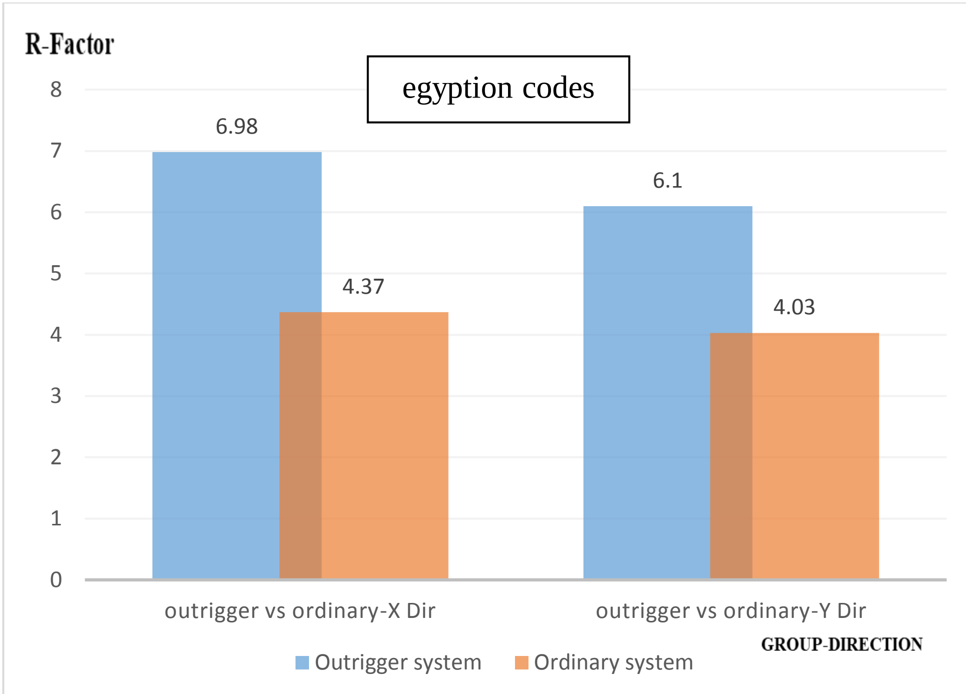

Fig 19. Comporsion Of R- Factor, With ECP-201/ECP-203, In X & Y- Direction

From the previous analysis find R-factor for outrigger system is more effective than ordinary, safe and economic by 38 percent than ordinary system and make lateral displacement and drift index reduce than ordinary system.

CONCLUSIONS:

1. According to Egyptian Codes ECP-201/ECP-203 Data; Using Outrigger is more efficient than ordinary system.
2. According to Table 4&6 Response modification factor R in x direction is highly affected by the building structural system; for 30 story models results by ECP-201/ECP-203; the value of R reduces lateral load by 44.53% than ordinary system.
3. According to Table 5&7 Response modification factor R in y direction is highly affected by the building structural system; for 30 story models results by ECP-201/ECP-203; the value of R reduces lateral load by 41.68% than ordinary system.
4. Resistant factor is highly affected by the building structural system; for 30 story Outrigger models results by Egyptian Codes ECP-201/ECP-203; is more safe by 38.26% vs ordinary system.
5. According to this study Outrigger is more economic and cost less than ordinary system, Outrigger is uses less number of element in building that made it economic.

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