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Seismic Analysis of High Rise Buildings Using Different Codes

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Abstract: **An examination was conducted on a residential building in Egypt consisting of 15 stories to assess its ability to withstand lateral loads. The analysis was then repeated for the same building, but with an increased number of stories, reaching a total of 30 stories. Two different lateral load resisting systems, namely outriggers and bracing systems, were used in the study. The analysis of all the buildings was performed using the ETABS 2015 program, according to the Egyptian, European, and American codes. High-rise buildings in Egypt commonly range from 15 to 30 stories. Consequently, a linear analysis was conducted on the 30-storey building using the Egyptian, European, and American codes, but in a different region and soil type compared to the initial study. The findings indicate that the Egyptian code yields higher values for base shear, maximum displacement, and total weight of the building compared to European and American codes. Furthermore, the lateral load resisting system experienced a significant increase when the building was relocated from a seismic region to a higher seismic region.**

Keywords: **Earthquakes, seismic analysis, Outer Bracing, High rise buildings, Outrigger and Belts system.**

I. INTRODUCTION

In recent times, advanced societies have expressed a strong desire to construct tall buildings as a means to showcase their expertise in civil engineering technology, boost tourism in their respective countries, and increase urban population density through vertical expansion in prime city locations. However, these structures face significant challenges when it comes to lateral loads. Various countries have established codes that outline distinct methods for calculating and analyzing loads on buildings, as well as provisions and limitations for loads and displacements caused by lateral forces. This thesis aims to delve into these codes and explore their details.

High and ultra-high rise buildings employ various lateral load resisting systems to counteract the effects of lateral loads. These systems include frames, shear walls, bracing, and dampers. In Egypt, frames and shear walls are predominantly used as the primary lateral load resisting systems, while other systems are rarely utilized. Consequently, this thesis will focus on conducting a structural analysis of a high-rise building that incorporates lateral load resisting systems other than frames and shear walls. The analysis will be carried out in accordance with different code requirements and provisions.

II. OBJECTIVES AND SCOPE

This thesis employs ETABS (Extended Three-Dimensional Analysis of Building Structures) program to conduct structural analyses on buildings comprising 15 and 30 stories, aiming to achieve the following objectives:

1. The aim is to conduct an examination of the various structural systems employed in the construction of tall buildings.

2. Investigating and presenting the role of frames, shear walls, outriggers, and lateral bracing systems in effectively resisting lateral loads.
3. The linear structural analysis of a chosen case study, which encompasses various configurations and specifications of these systems, will be conducted. This analysis will be carried out in accordance with the Egyptian, European, and American codes.
4. The diverse code requirements used for assessing the lateral loads that affect such structures.
5. The suggested configurations will be compared to the various code limitations regarding lateral deformations.

III. CASE STUDY STRUCTURE

3.1 Case study structure configurations

The focal point of this case study structure is a residential building situated in Cairo, Egypt, comprising a total of 15 stories. The structure encompasses two basement levels, a ground story, the 1st story, eight repeated stories, the 10th story, a roof stories, and upper roof rooms. Figure 1 show the configuration of the case study structure.

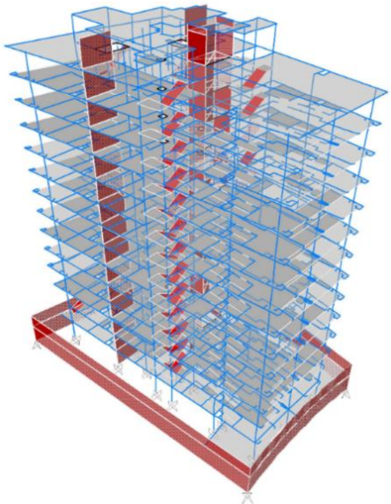

Figure 1: 3D view for the 15 stories structure

3.2 linear analysis for the case study structure

The thesis employs linear analysis using the ETABS program to assess a residential building in Cairo, Egypt, initially with 15 stories and subsequently expanded to 30 stories, adhering to the specifications of the Egyptian code for Loads and Forces 2012 (ECLF 2012), Eurocode 8: Design of structures for earthquake resistance 2004 (Eurocode-8-2004), and American Society of Civil Engineering 2010 (ASCE07-10). The building incorporates a shear wall frame system to withstand lateral loads. The structural design involves two stages: initial design based on vertical loads and a secondary stage introducing lateral loads, ensuring resilience through the shear wall frame system. If insufficient, two additional lateral load resisting systems, outrigger and belt system and bracing system, are incorporated individually or in combination with the shear wall frame system. The outrigger and belt system, made of reinforced concrete, is strategically placed to enhance building stiffness against lateral loads. The bracing system, composed of steel X-bracing, is employed in conjunction with the shear wall frame system, reducing story sway. Composite columns/shear walls are connected to steel bracing through welding and bolts, enhancing overall structural integrity. The outer bracing system, implemented due to bay constraints, involves relocating columns for effective bracing. The trial-and-error approach determines the number of bays and steel sections for the outer bracing, considering lateral loads. Connections between steel bracings involve welding and bolts.

3.2.1 Analysis of Numerical results

The findings regarding the structure's weight, base shear, and maximum displacement are presented through the analysis results.

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3.2.1.1 Weight of case study structures according to the three utilized codes

As the base shear increased, there was a corresponding rise in the volume of lateral load resisting elements, leading to an overall increase in the building's total weight. Among the three codes utilized, the ECLF 2012 code exhibited the highest base shear, followed by the Eurocode-8-2004 code, and the ASCE07-10 code with the smallest base shear. Consequently, the weight hierarchy of the buildings designed according to these codes follows the order of ECLF 2012 > Eurocode-8-2004 > ASCE07-10.

Table 1 illustrates the weight of 15 and 30-storey buildings based on the ECLF 2012, Eurocode-8-2004, and ASCE07-10 codes. In the 30-storey building incorporating an outriggers and belts system, the Egyptian code resulted in a weight approximately 2% and 6% greater than that of Eurocode-8-2004 and ASCE07-10 codes, respectively. Conversely, in the 30-storey building featuring an outer bracing system, the Egyptian code produced a steel bracing weight roughly twice that of the Eurocode-8-2004 code.

Table 1: Structures weight for both 15 and 30 stories in accordance with the ECLF 2012, Eurocode-8-2004, and ASCE07-10 codes

Quantites

Number of Stories	15 Stories	30 Stories		
Structural System		Outriggers System	Outer Bracing System	
Code	R.C Weight (ton)	R.C Weight (ton)	R.C Weight (ton)	Bracing Steel Weight (ton)
ECLF 2012	8006.7	19765.5	18854.38	81.8
Eurocode8-2004	8006.7	19386.34	18853.4	41.77
ASCE07-10	8006.7	18610.57		

3.2.1.2 Maximum base shear results of case study structures according to the three utilized codes

The base shear for all buildings in both the X and Y directions is depicted in Figure 2 and Figure 3, respectively. Notably, in the 15-storey building, the Egyptian code yields a base shear approximately 11% higher than the Eurocode-8-2004 code and 15% higher than the ASCE7-2010 code, reflecting a slight variation. The base shear for the all buildings in the X and Y directions were shown in figure 2 and figure 3 respectively.

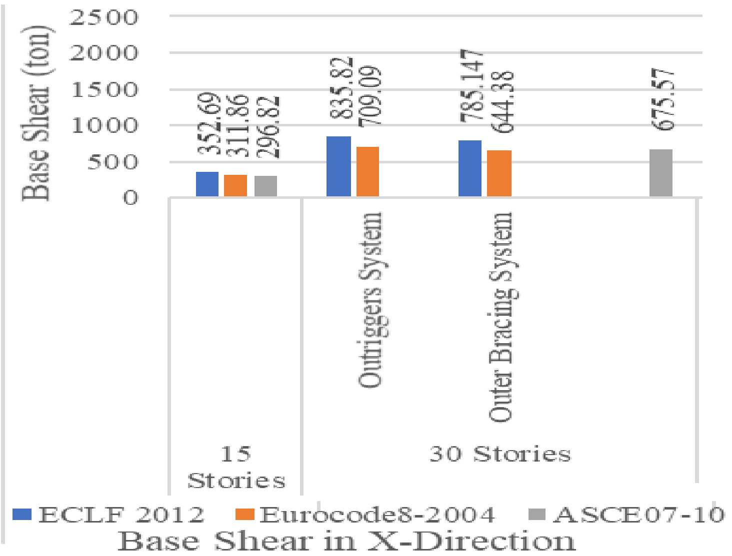

Figure 2: Base shear for both 15 and 30 stories in accordance with the ECLF 2012, Eurocode-8-2004, and ASCE07-10 codes in X-direction

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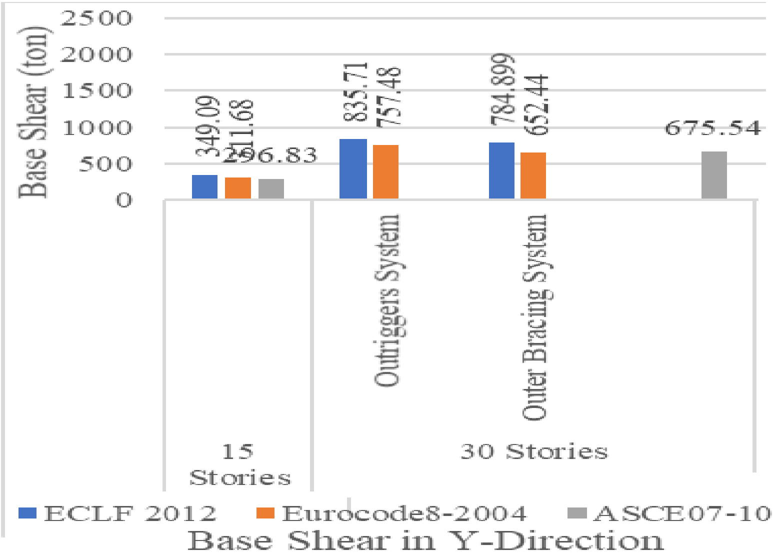

Figure 3: Base shear for both 15 and 30 stories in accordance with the ECLF 2012, Eurocode-8-2004, and ASCE07-10 codes in Y-direction

The Egyptian code yields a base shear that surpasses the Eurocode-8-2004 and ASCE7-2010 codes by around 15% and 19%, respectively, in the 30-storey building incorporating outriggers. Similarly, in the 30-storey building featuring an outer bracing system, the Egyptian code produces a base shear approximately 17% higher than the Eurocode-8-2004 code and 14% higher than the ASCE7-2010 code. Across all three codes, buildings incorporating an outer bracing system exhibit lower base shear forces compared to those incorporating outriggers and belts. This is attributed to the fact that the outer bracing system carries a lower weight than the outriggers and belts system.

3.2.1.3 Maximum story displacement results of case study structures according to the three utilized codes

Figure 4 and figure 5 display maximum displacement of the structures in the X and Y direction respectively.

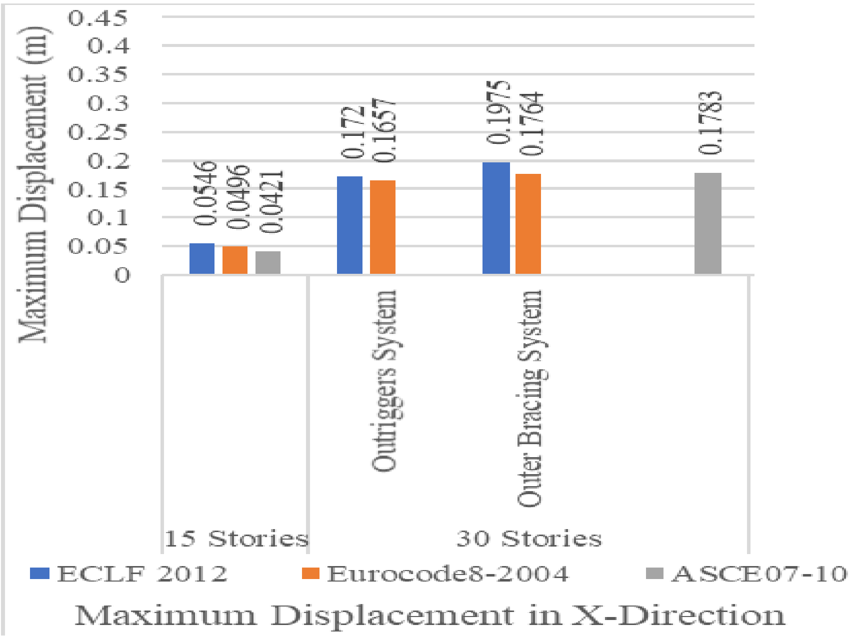

Figure 4: Maximum displacement for both 15 and 30 stories in accordance with the ECLF 2012, Eurocode-8-2004, and ASCE07-10 codes in X-direction

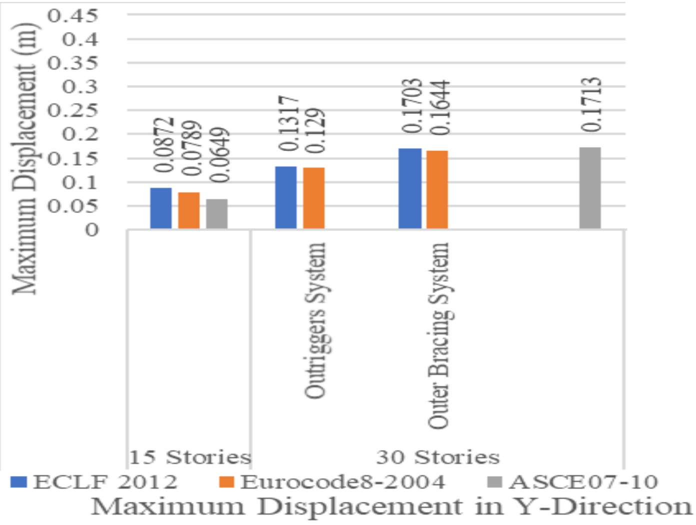

Figure 5: Maximum displacement for both 15 and 30 stories in accordance with the ECLF 2012, Eurocode-8-2004, and ASCE07-10 codes in X-direction

In the 15-storey structure, the maximum displacement according to ECLF 2012 exceeds that of Eurocode-8-2004 and ASCE7-10 by roughly 9% and 23%, respectively. For the 30-storey building incorporating an outrigger and belt system, the maximum displacement under ECLF 2012 is approximately 4% higher than Eurocode-8-2004 and approximately 3% lower than ASCE7-10. Conversely, in the 30-storey building with an outer bracing system, the maximum displacement under ECLF 2012 surpasses that of Eurocode-8-2004 and ASCE7-10 by around 11% and 10%, respectively.

3.3 Linear analysis of the 30 stories structure after changing the region and the soil type

Linear analysis is performed on the case study, considering an increment in the number of building stories to 30. This is done under the assumption that the region has transitioned from the 3rd region to the 4th region, and the soil type has shifted from type C to type D. The analysis is conducted using the same three codes mentioned earlier, resulting in an augmentation of earthquake loads.

3.3.1 Analysis of Numerical results

A comparison was made between the weight, base shear, and maximum displacement of the 30-storey buildings situated in the 3rd region with soil type C and those in the 4th region with soil type D, based on the three codes employed.

3.3.1.1 Weight of case study structures in the 3rd and 4th region according to the three utilized codes

Table 2 shows the weights of 30-story buildings situated in the 3rd and 4th regions, as per the ECLF 2012, Eurocode-8-2004, and ASCE07-10 standards. By shifting the building from the 3rd region to the 4th using outriggers and belts system, the Egyptian and Eurocode-8-2004 indicate an increase of around 5% in weight, while the ASCE7-2010 code shows a roughly 1% increment. For buildings with an outer bracing system, the Egyptian code suggests an approximately 263% higher steel bracing weight, and the Eurocode-8-2004 code suggests around 133% more. Across all scenarios, the ECLF 2012 yields the highest weight, followed by Eurocode-8-2004, and finally, ASCE7-10.

3.3.1.2 Maximum base shear results of case study structures in the 3rd and 4th region according to the three utilized codes

Figure 6 and figure 7 depicts the base shear in X direction and Y direction respectively. Shifting the 30-story building from the 3rd region to the 4th region and altering the soil from type C to type D resulted in an increase in base shear. Specifically, in the Egyptian code, there was an approximately 37% rise, in the Eurocode-8-2004 code, a 21% increase, and in the ASCE7-2010 code, a 13% increase for buildings equipped with outriggers and belts systems. Conversely, for buildings featuring an outer bracing system, the base shear increased by approximately 34%, 35%, and 9% in the Egyptian code, Eurocode-8-2004 code, and ASCE7-2010 code, respectively. Across all three codes, the outer bracing system consistently exhibited the lowest base shear force when compared to the outriggers and belts system.

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Table 2: Structure weight for 30 stories in 3rd region and 4th in accordance with the ECLF 2012, Eurocode-8-2004, and ASCE07-10 codes

Quantites

Number of Stories	30 Stories (3rd Region)			30 Stories (4th Region)		
Structural System	Outriggers System	Outer Bracing System		Outriggers System	Outer Bracing System	
Code	R.C Weight (ton)	R.C Weight (ton)	Bracing Steel Weight (ton)	R.C Weight (ton)	R.C Weight (ton)	Bracing Steel Weight (ton)
ECLF 2012	19765.5	18854.38	81.8	20765.23	18860.97	296.41
Eurocode8-2004	19386.34	18853.4	41.77	20302.43	18855.89	95.93
ASCE07-10	18610.57			18638.75	18852.8	45.72

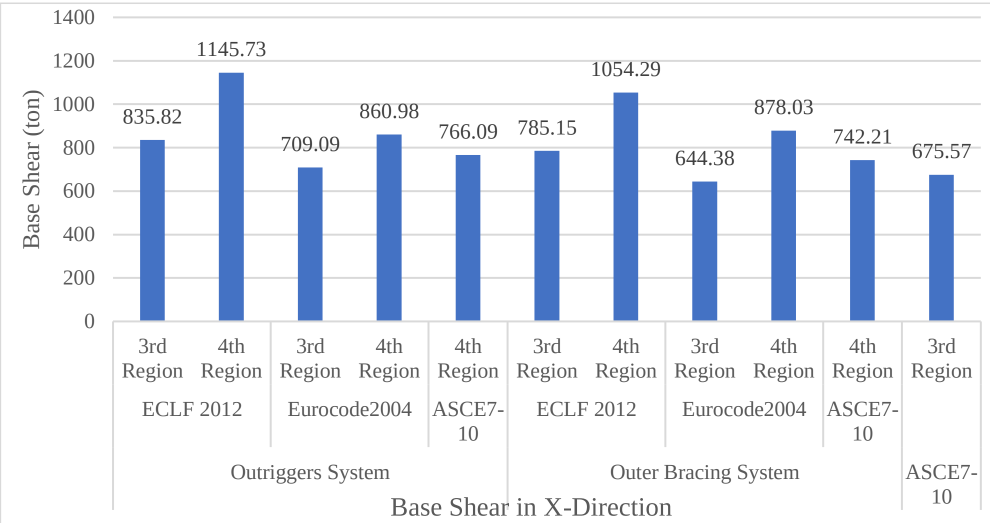

Figure 6: Base shear for 30 stories in 3rd region and 4th region in accordance with the ECLF 2012, Eurocode-8-2004, and ASCE07-10 codes in X-direction

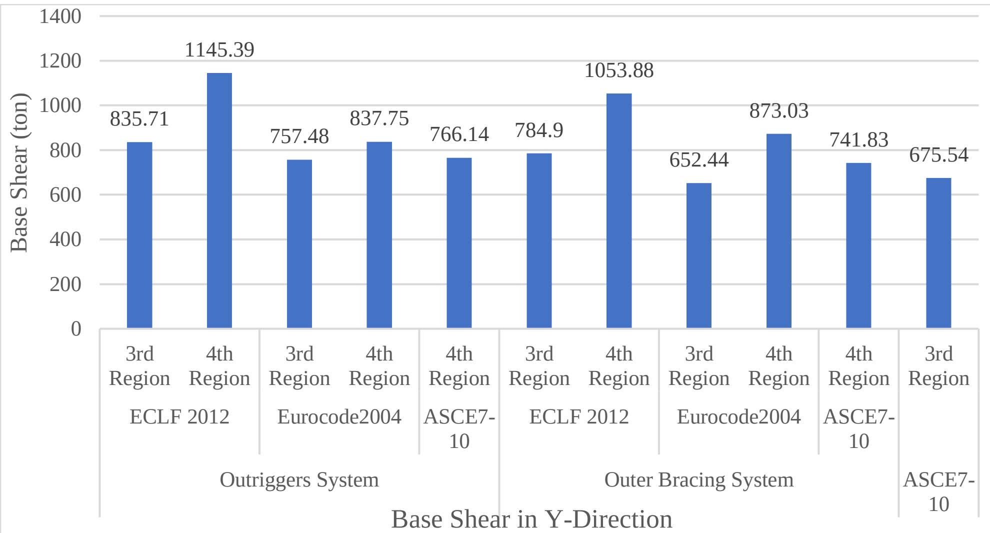

Figure 7: Base shear for 30 stories in 3rd region and 4th region in accordance with the ECLF 2012, Eurocode-8-2004, and ASCE07-10 codes in Y-direction

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3.3.1.3 Maximum story displacement results of case study structures in the 3rd and 4th region according to the three utilized codes

Figure 8 and figure 9 displays the maximum displacement of buildings in the X and Y direction respectively. With the 30-story building transitioning from the 3rd region to the 4th region and the soil evolving from type C to type D, there were notable changes in maximum story displacement. In buildings featuring an outrigger and belt system and designed per the Egyptian code and Eurocode-8-2004 code, there was an approximate reduction of 34% and 4%, respectively. Conversely, for buildings incorporating an outer bracing system, the Egyptian code and Eurocode-8-2004 code revealed an increase in maximum story displacement by approximately 2% and 13%, respectively. Meanwhile, structures designed following the ASCE7-2010 code exhibited an approximate 8% rise in maximum story displacement.

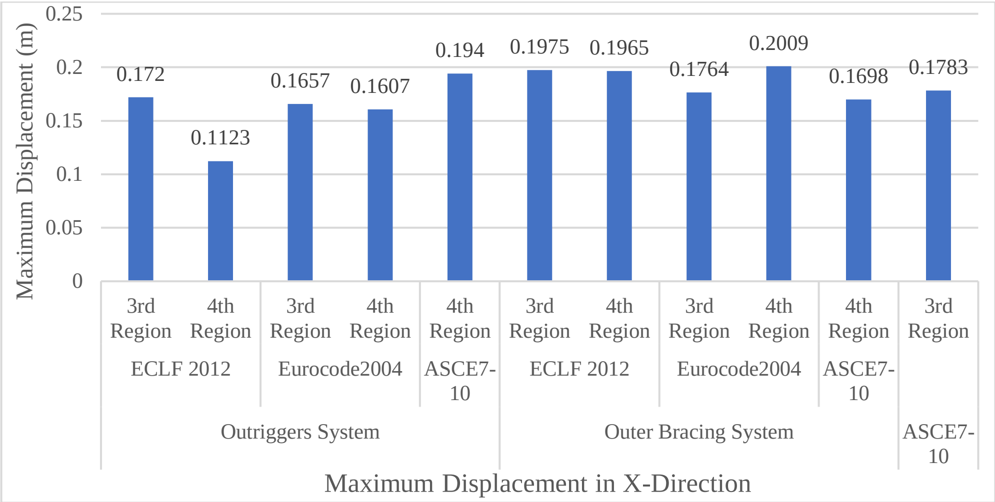

Figure 8: Maximum displacement for 30 stories in 3rd region and 4th region in accordance with the ECLF 2012, Eurocode-8-2004, and ASCE07-10 codes in X-direction

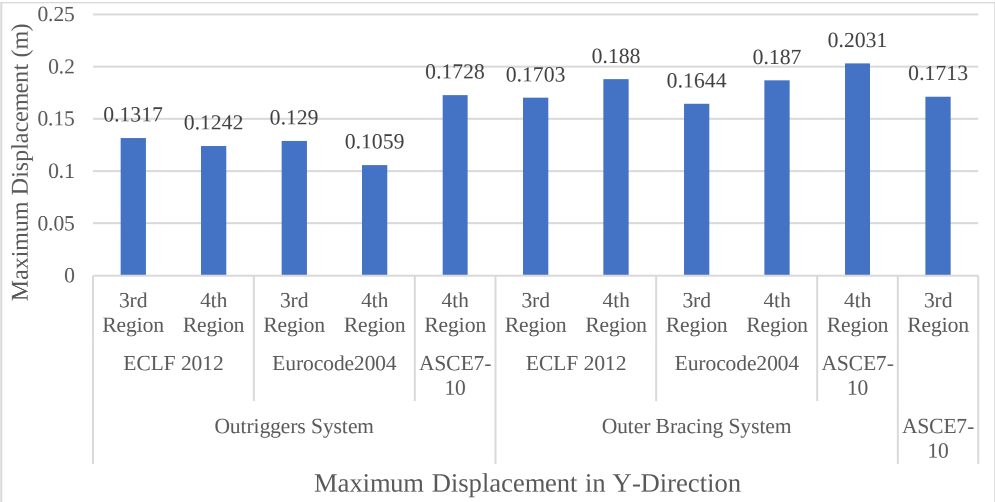

Figure 9: Maximum displacement for 30 stories in 3rd region and 4th region in accordance with the ECLF 2012, Eurocode-8-2004, and ASCE07-10 codes in Y-direction

IV. CONCLUSION

- The base shear and inter-story drift values provided by the Egyptian code surpass those specified in the Eurocode-8-2004 and ASCE7-2010 codes.
- The building weight results are minimized when using the ASCE7-2010 code.

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- The beams within outriggers and belts models exhibit higher bending moments and shear forces compared to those in braced models.
- The Egyptian code attains the maximum displacement, followed by the Eurocode-8-2004 code, and ultimately, the ASCE7-2010 code.
- Shifting the 30-story building from the 3rd region to the 4th region and altering the soil type from C to D leads to the following conclusion: The Egyptian code, Eurocode-8-2004 code, and ASCE7-2010 code show a slight increase in base shear, while the building's weight experiences a significant rise.

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