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To Evaluate the Safe and Economical RCC Multistory Building W.R.T Shape and Analysis Method in all Seismic Zones of Pakistan

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ABSTRACT

The impact of earthquake forces on structural stability is critical, especially in high seismic zones. This research examines how different geometric configurations of buildings respond to seismic forces across various seismic zones in Pakistan. The primary goal is to identify a safe and economical design by considering building geometry and seismic analysis methods. The study focuses on a 12-storey building, including a basement, ground floor, and ten stories, with three geometric shapes: rectangular, circular, and triangular. Each shape maintains approximately equal total covered areas and spans. Two seismic analysis methods are employed: the Static Equivalent Method for static analysis and the Response Spectrum Analysis per UBC97 Code for dynamic analysis. These methods help assess key parameters such as storey displacement, storey drift, moment, shear, and base shear to determine the safest and most cost-effective designs. The study reveals that different building geometries have varying performance levels under seismic forces. Rectangular structures typically provide more straightforward construction and cost estimation, while circular and triangular shapes might offer enhanced stability and reduced seismic impact due to their symmetrical properties. Cost estimations are integral to the analysis, ensuring that the final designs are not only structurally sound but also economically viable. The research concludes with recommendations for the optimal geometric design and analysis methods for 12-storey buildings in various seismic zones of Pakistan, balancing safety, performance, and cost-effectiveness. This comprehensive approach aids in developing resilient infrastructure capable of withstanding seismic events, thereby enhancing structural safety and sustainability.

KEYWORDS: Seismic analysis, economical design, static equivalent method, response spectrum analysis.

1 INTRODUCTION

The escalating population and diminishing horizontal land space, particularly in urban areas, have spurred the construction of high-rise buildings as a sustainable solution to meet growing housing and infrastructure demands. Despite the advantages of maximizing land utilization, the intricate and costly

process of constructing such structures requires careful consideration of various elements, including potential natural disasters like earthquakes, flooding, and wind. Designing a structure to minimize earthquake damage is economically challenging, given the unpredictable nature of seismic events. To address cost concerns and diverse aesthetic preferences, buildings of different shapes and sizes are common. However, these varied structures can be more susceptible to seismic forces.

This research focuses on the impact of building shape on structural performance during earthquakes, comparing three shapes (rectangular, triangular, and circular) using Computer-Aided Design (CAD). The study aims to provide a relative comparison based on different zones of Pakistan's building codes, shedding light on the effects of building shape variations on seismic resistance.

2 PROBLEM STATEMENT

1. To assess the structural response and vulnerability of these buildings under seismic loads, consider the dynamic characteristics and earthquake hazard levels specific to each zone.
2. The analysis will involve evaluating the structural integrity, stability, and deformation patterns of the buildings to determine their seismic resistance and potential failure modes.
3. The study aims to provide insights into the structural design requirements and guidelines for high-rise buildings in different geometries across various seismic zones in Pakistan, with the ultimate objective of increasing their seismic safety and resilience.

3 AIM AND OBJECTIVES

Find the economic structure with respect to shape and cost impact in all seismic zones of Pakistan.

Objectives

1. Compare the top joint displacement of all the shapes in all seismic zones.
2. Compare storey drift of all the shapes in all zones.
3. Compare moments of all the shapes in all zones.
4. Compare the shear of shapes in all seismic zones.
5. Compare base shear shapes in all seismic zones.
6. Cost analysis of shapes in all seismic zones.

4 LITERATURE REVIEW

Various studies highlight design considerations: rectangular buildings excel in strength, while circular structures are better for lateral loads, energy efficiency, and acoustics [1]. Seismic analysis of G+10 RC buildings favors regular structures in terms of key parameters [2][5]. Wind effects on high-rises reveal observations in displacement and drift values [3]. Recommendations for high-rise design include increasing concrete grade and cross-sectional area for safety [4]. Ductility-based design for irregular RCC buildings considers mass and stiffness irregularities [6]. Comparisons of earthquake loading techniques show increased base shear in higher seismic zones [7]. Dynamic responses of RCC high-rises highlight aftershock impacts [8]. Effects of earthquake loading on multi-story structures reveal higher moments and displacements in dynamic analysis [9]. Analysis of tall buildings underscores the superiority of response spectrum methods [10]. Seismic acceleration's impact on construction cost suggests limited effects with modern seismic codes [11]. Consideration of

parameters like storey drift, displacement, moment, base shear, and shear is crucial for designing safe and economical buildings based on geometry.

5 METHODOLOGY

5.1 Building Modeling:

Considered three geometrical shapes (rectangular, triangular, circular) for G+12 RCC structures in all seismic zones of Pakistan, totaling 30 buildings.

Model Specification:

- G+12 multi-story commercial building analyzed in ETAB. Basic parameters include:
- Number of stories: G+12
- Shape: Rectangular, Circular, and Triangular
- Construction: RCC frame structure
- Beam: 12”X18”, Column: 24”X24”, Slab: 8”
- Concrete: FC5000psi, Steel Grade 60
- Raft: 27”, Concrete slab: 4000psi, Raft: 3000psi

5.2 ETAB Modeling:
Modeled buildings of each shape in ETAB for analysis.
Load Pattern:
Considered floor finishing load, partition wall load, roof live load, and dead loads. Project details include 1 basement, 1 ground floor, and 10 residential stories.
Seismic Load:
Applied seismic loads (EQX, EQY, ECC) to vertical elements based on building codes and standards.
Analysis:
Performed Response Spectrum and Equivalent Static Analysis for all shapes. Evaluated parameters such as story drift, displacement, base shear, shear, and moment.
Cost Estimation:
Conducted cost estimation post-analysis, considering resource, labor, material, equipment costs, overhead expenses, and other factors. The analysis findings inform final recommendations for construction and operation costs.

6 RESULTS AND DISCUSSIONS

Graphical Representation of Results and Discussion

6.1 Rectangular Building

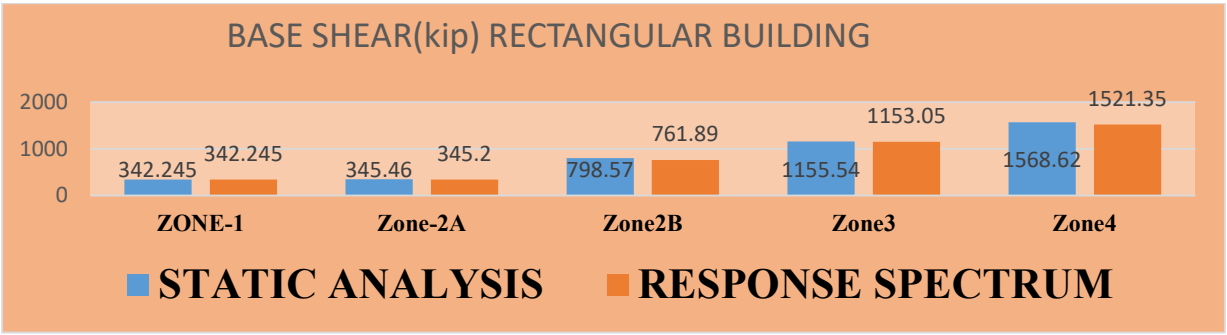

Figure 1: Base Shear results rectangular building

In figure1 base shear value is increasing according zone severity i-e (Z1=0.075 < Z2A = 0.15< Z2B = 0.2<Z3= 0.3<Z4 = 0.4) m/s2 that is according to zone severity and is correct but the results are same in Z1 and Z2 why because we know RSA and ESA are different in their approach, they can produce similar results when the structure behaves linearly elastically under seismic loads but Z2B ,Z3 and Z4 static results are greater than RSA because the response spectrum method is an approximate analysis technique and its accuracy may vary depending on the specific features of the ground motion and the structure being analyzed .It is possible that for certain scenarios, response spectrum method may not capture all the nuances of the structural response accurately.

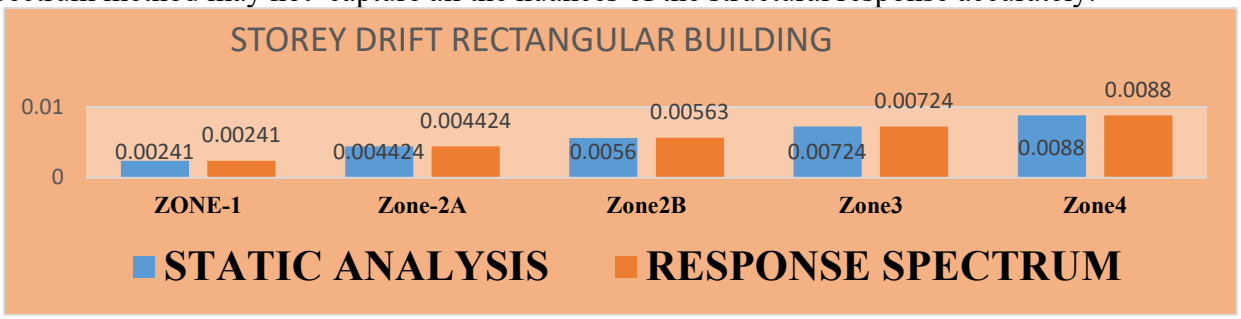

Figure 2: Storey Drift results rectangular building

In this figure 2 story drift is increasing w.r.t zones in sequence because severity is increasing (Z1<Z2A<Z2B<Z3<Z4) and results are same form both methods because they can produce similar results when the structure behaves linearly elastically under seismic loads, the structure predominantly responds in a single mode of vibration due to which results of RSA and ESA come closer.

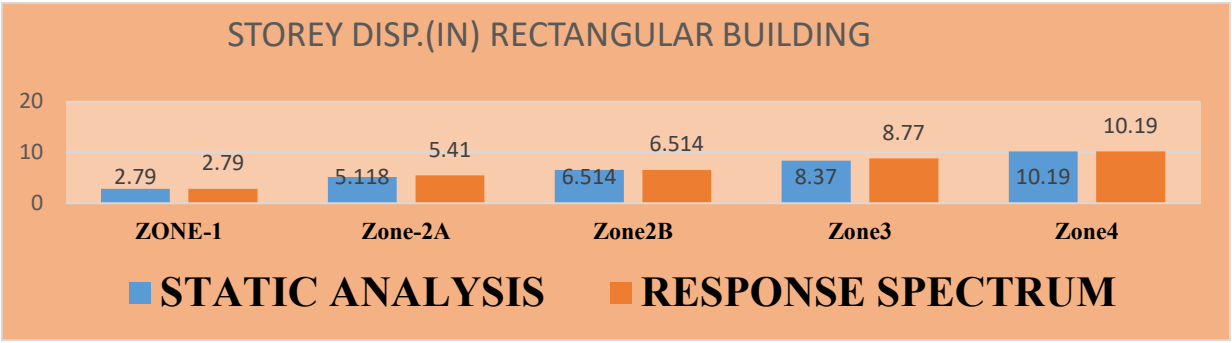

Figure 3: Storey Displacement results rectangular building

As shown in figure 3 the values of storey drift are increasing according to zone severity which is reasonable. And the values from both analysis methods are same because they can produce similar results when the structure behaves linearly elastically under seismic loads, the structure mostly responds in a single mode of vibration due to which results of RSA and ESA come closer.

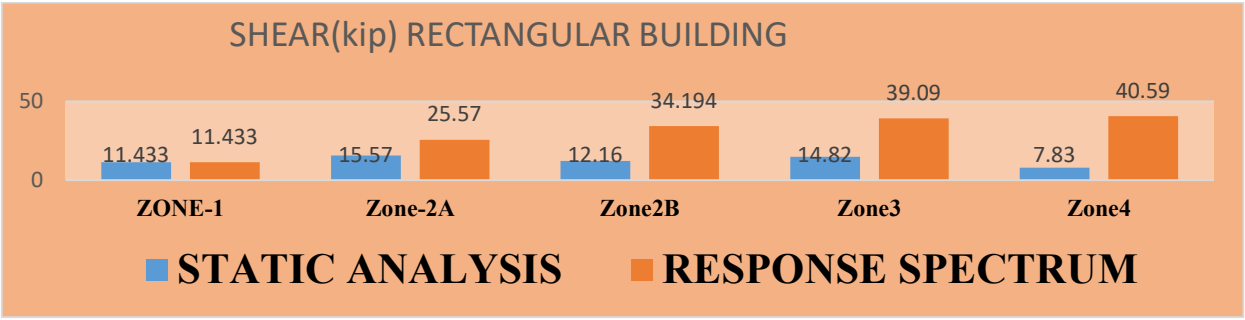

Figure 4: Shear results rectangular building

In this figure 4 values are also increasing according to this sequence (Z1<ZA<Z2B<Z4<Z3) here all zones values are according to sequence and that is reasonable, but RSA analysis that eater then static the reason is that because response spectrum analysis is a dynamic analysis that takes into account the dynamic characteristics of the structure and the input ground motion while static does not consider dynamic response.

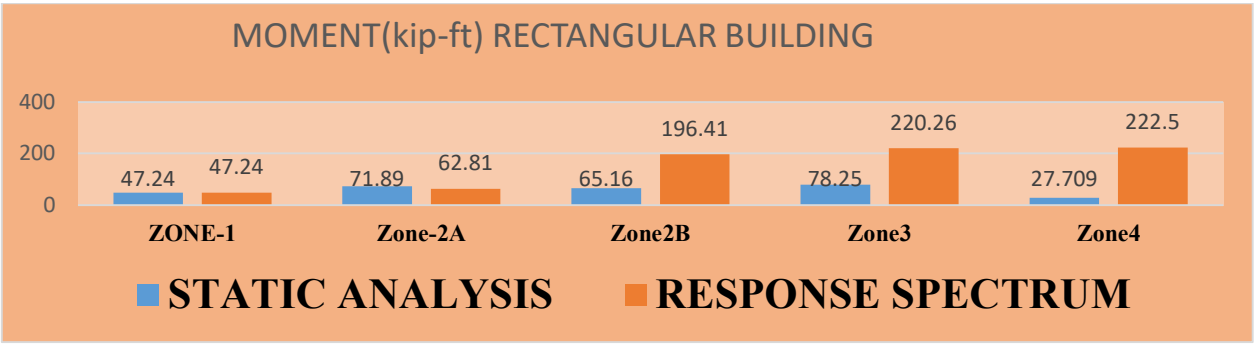

Figure 5: Moment results rectangular building

According to UBC97 zone 4= 0.4m/s2 severity of earthquake acceleration in figure 5 is more then zone3= 0.3 m/s2 similarly all the zones sequence(Z1<Z2<Z3<Z4) so the results are according to UBC97 define accelerations and are correct. But here static analysis gave safer result compare to RSA because static analysis is a simplified approach it doesn't consider the dynamic characteristics of the earthquake.so mostly static analysis results less then RSA, but in zone 1results from both methods are same because they can produce similar results when the structure behaves linearly elastically under seismic loads, the structure predominantly responds in a single mode of vibration due to which results of RSA and ESA come closer.

6.2 Circular building

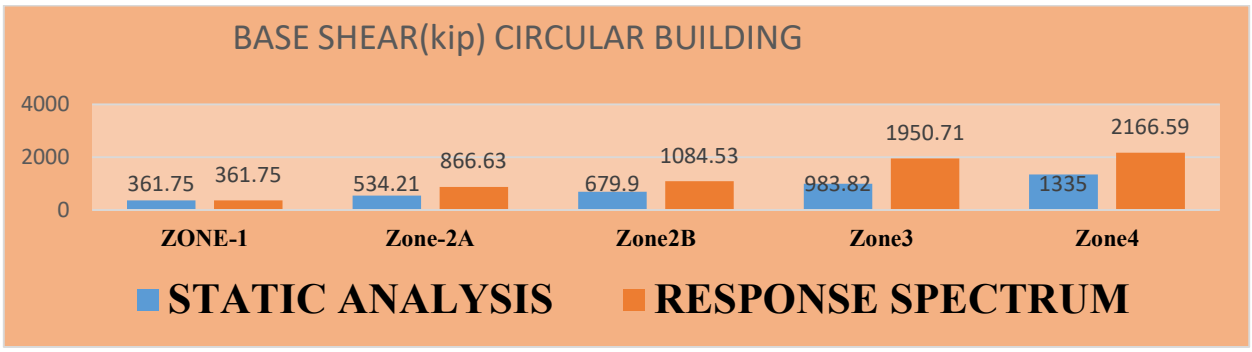

Figure 6: Base shear resultscircular building

In figure 6 the results are according to zone severity but static analysis give safer result then RSA because response spectrum analysis is a dynamic analysis that takes into account the dynamic characteristics of the structure and the input ground motion while static does not consider dynamic response ,but in zone 1 both analysis methods give same results because they can produce similar results when the structure behaves linearly elastically under seismic loads, the structure mainly responds in a single mode of vibration due to which results of RSA and ESA come closer.

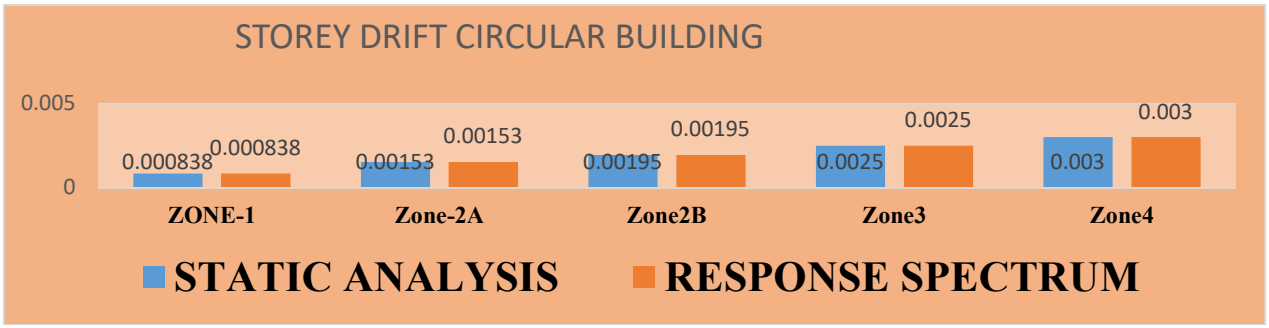

Figure 7: Storey Drift results circular building

Results are according to zone earthquake acceleration in figure 7 and here results from both methods are same, RSA and ESA are different in their approach, they can produce similar results when the structure behaves linearly elastically under seismic loads.

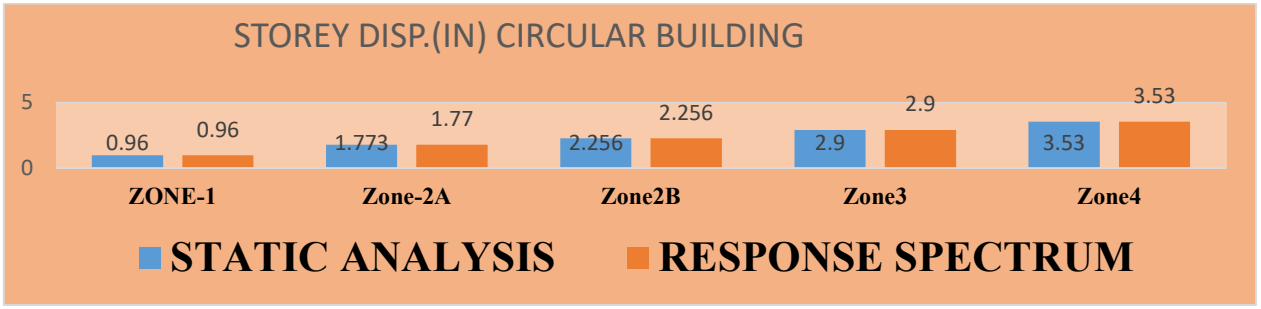

Figure 8: Storey Displacement results circular building

In this figure 8 results are according to the severity of seismic zones but again the results are same from both the methods, they can produce similar results when the structure behaves linearly elastically under seismic loads and the structure predominantly responds in a single mode of vibration sue to which results of RSA and ESA come closer.

The results are according to the increase in earthquake acceleration in figure 9 but Static results are on safer side more than RSA because response spectrum analysis is a dynamic analysis that considers the dynamic characteristics of the structure and the input ground motion while static does not consider dynamic response and because RSA accounts for the interaction btw different modes of vibration in the structure. It considers multiple modes and their contributions to the overall response. This can lead to additional force demands that are not captured by ESA.

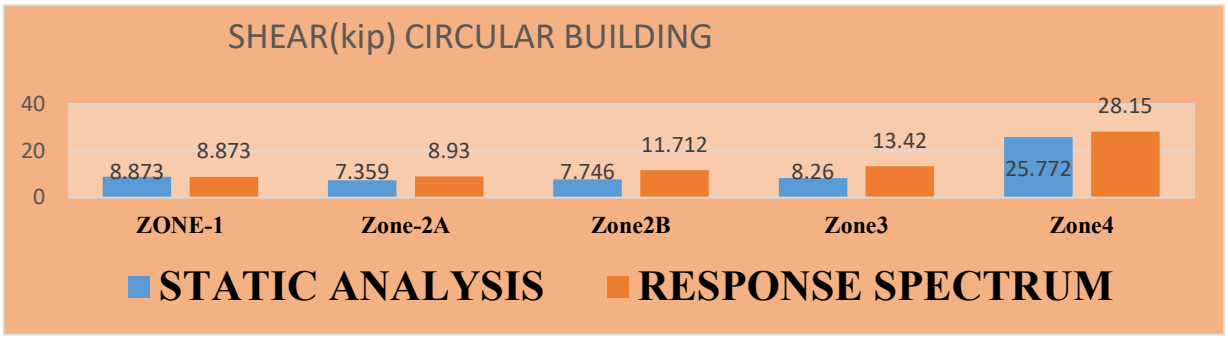

Figure 9: Shear results circular building

In Figure 10, results increase with earthquake acceleration, which is reasonable. Static analysis provides safer results than RSA, as static doesn't consider dynamic responses. However, for complex structures, RSA is more significant than ESA, covering a broad range of building characteristics under seismic loads. In Z1 and Z4, both methods yield the same results, as they converge when structures behave linearly elastically, predominantly responding in a single mode of vibration.

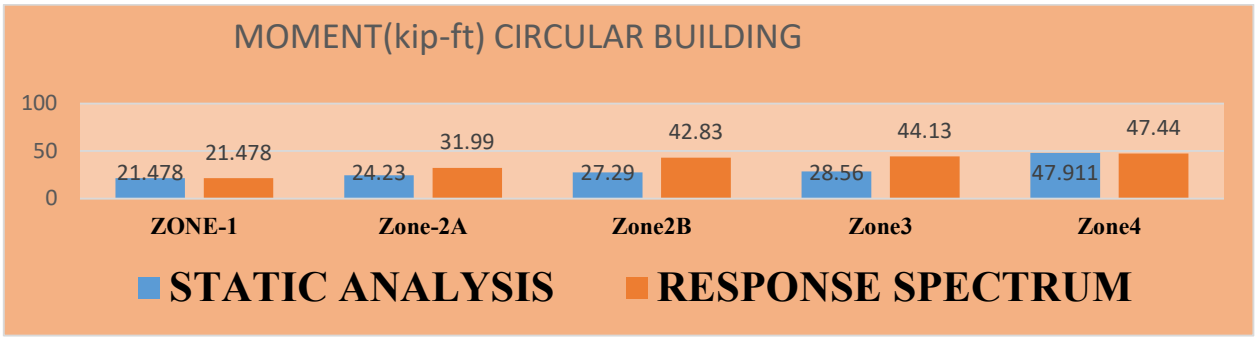

Figure 10: Moment results circular building

6.3 **Triangular building**

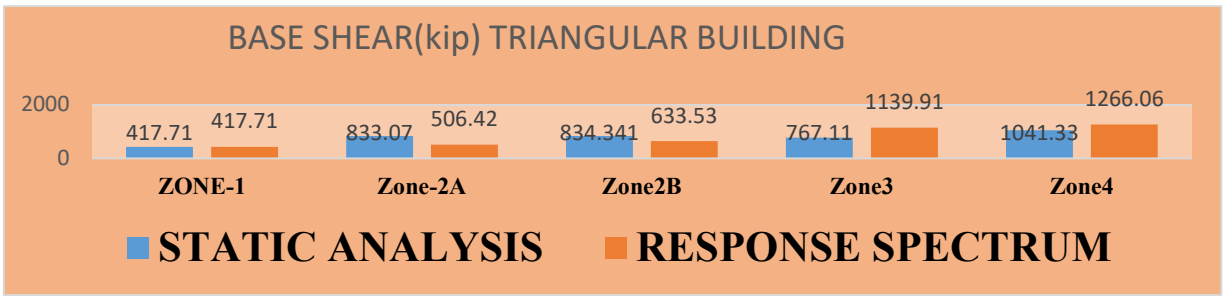

Figure 11 Base Shear results triangular building

In Figure 11, values increase with zone severity. In Z1, RSA and ESA are the same because they yield similar results under linear elastic behavior. Zones 2A and 2B show greater static values due to the approximate nature of the response spectrum method. In Zones 3 and 4, RSA surpasses static values as it considers dynamic characteristics and ground motion. RSA is especially significant for complex structures, covering a broader range of building characteristics under seismic loads compared to ESA.

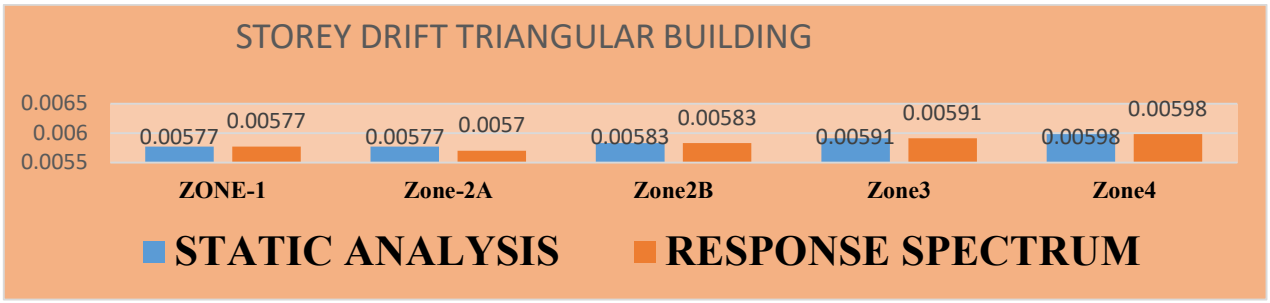

Figure 12: Storey Drift results triangular building

In Figure 12, storey drift values increase sequentially (Z1 < Z2 < Z3 < Z4). In Zone 3, RSA is lower than static analysis as RSA considers dynamic structure behavior and interaction between vibration modes, capturing additional force demands. In other zones, both RSA and ESA yield similar results when structures behave linearly elastically under seismic loads, responding predominantly in a single vibration mode.

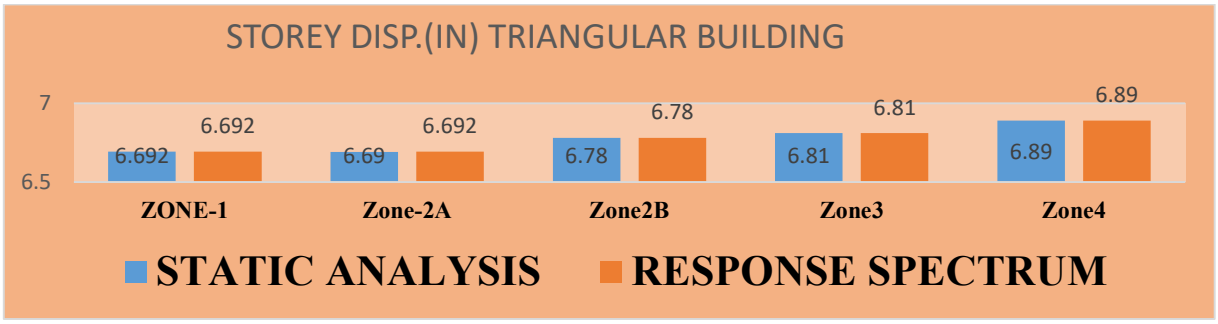

Figure 13: Storey Displacement results (triangular building)

In this figure 13 storey displacement increases with zone severity and is reasonable but result from RSA and ESA are same because they can produce similar results when the structure behaves linearly elastically under seismic loads and the structure predominantly responds in a single mode of vibration due to which results of RSA and ESA come closer.

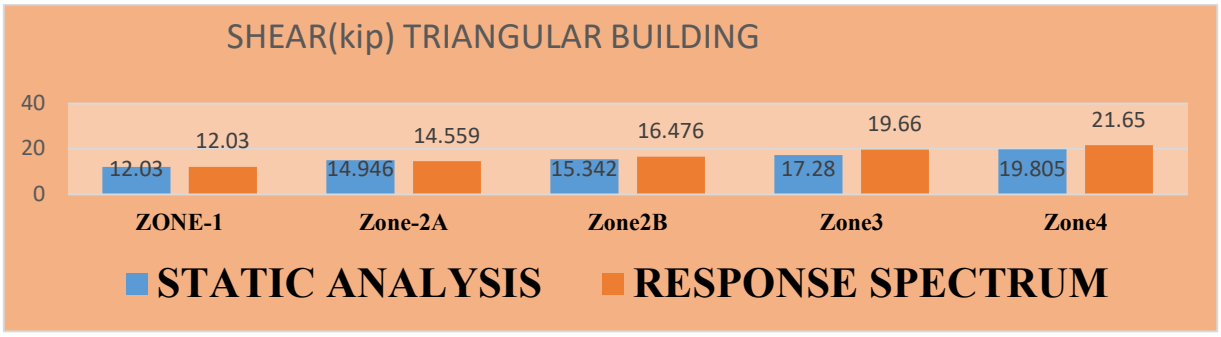

Figure 14: Shear results triangular building

Values in Figure 14 increase with zone severity. RSA surpasses ESA overall because it considers dynamic structure behavior, accounting for interactions between vibration modes. However, in Zone 2A, ESA exceeds RSA due to the approximate nature of the response spectrum method. In Zone 1, both methods yield similar results when structures behave linearly elastically and predominantly respond in a single vibration mode.

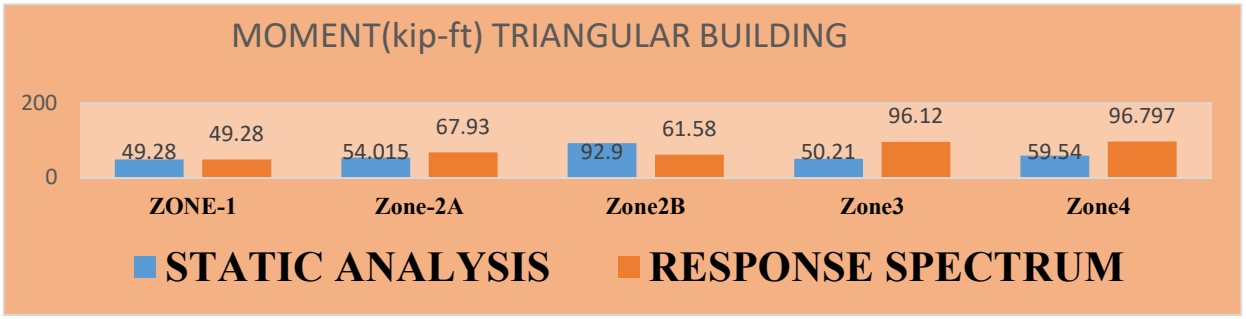

Figure 15: Moment results triangular building

In Figure 15, RSA values increase with severity due to dynamic considerations, surpassing ESA values. However, in Zone 2B, static ESA values may exceed dynamic RSA values, as the response spectrum method's accuracy varies based on ground motion and structural characteristics, potentially missing nuances in certain scenarios.

6.4 Discussion on Results

Discussion w.r.t Analysis Methods (Response Spectrum and Static Analysis)

ZONE-1

1. Rectangular building Base shear, story drift, story displacement, moment and shear, RSA (Response spectrum analysis gives less values (more suitable values**)** compared to ESA (equivalent static analysis).
2. Circular building Base shear, story drift, story displacement, moment and shear, RSA and ESA both give same results, safer results**.**
3. Triangular building Base shear, story drift, story displacement, moment, and shear, both RSA and ESA give safer results and same results.

ZONE-2A

1. Rectangular building Base shear, story drift, story displacement, moment and shear, ESA gives better results than RSA.
2. Circular building Base shear, story drift, story displacement, moment and shear, ESA gives better result than RSA**.**
3. Triangular building Base shear, story drift, story displacement, moment and shear**,** RSA gives better result than ESA.

ZONE-2B

1. Rectangular building Base shear, story drift, story displacement, moment and shear, ESA and RSA results are same**.**
2. Circular building Base shear, story drift, story displacement, moment and shear, ESA gives better result than RSA.
3. Triangular building Base shear, story drift, story displacement, moment and shear**,** RSA gives better result than ESA**.**

ZONE-3

1. Rectangular building Base shear, story drift, story displacement, moment and shear, ESA gives better results than RSA.
2. Circular building Base shear, story drift, story displacement, moment and shear, ESA gives better result than RSA.
3. Triangular building Base shear, story drift, story displacement, moment and shear**,** RSA gives better result than ESA.

ZONE-4

1. Rectangular building Base shear, story drift, story displacement, moment and shear, ESA gives better results than RSA.
2. Circular building Base shear, story drift, story displacement, moment and shear, ESA gives better result than RSA.
3. Triangular building Base shear, story drift, story displacement, moment and shear**,** ESA gives better result than ESA.

6.5 Discussion on performance of geometry of building in all five zones.

1. Based on design parameters, the shapes of structure preferable in Zone 1 and 2A (circular> rectangular >triangular) while zone 2B and 3 and 4 (circular>triangular>rectangular) according to analysis method.
2. As a result, circular shape of structures are preferable in all on the behalf of analysis method. They showed high stability in all seismic zones of Pakistan.
3. Final recommendation will be after cost analysis of structures.

7 BUDGETING AND COSTING

All the rates are used according to MES rates Pakistan.

All results of cost estimation are in tabular form

Table 1: Cost estimation of buildings using MES rates

BUILDING SHAPE	COL+BEAM CONCRETE 5000PSI (CUM)	CONCRETE SLAB+RAFT 3000PSI (CUM)	MES RATES (5000PSI) CONCRETE	MES RATES (3000 Psi) concrete	COST OF TOTAL CONCRETE (Rs)	TOTAL STEEL (KG)	MES RATES OF STEEL (KG)	COST OF STEEL (Rs)	TOTAL COST OF BUILDING CONCRETE+STEEL IN (Rs)
Rectangular	1337.79	5693.45	16864	13547	114136705.5	41923.33	154	6456208.68	120592913.3
Circular	2508.98	5693.45	16864	13547	133888495.9	45970.08	154	7079392.32	140967888.2
Triangular	2486.43	5693.45	16864	13547	133514958.1	45728.214	154	7042144.95	140557103.1

After estimation process it is resulted in table 1 that the most economical building in all three shape with same covered area and dimensions is rectangular then triangular then circular building comes.

The sequence is (**rectangular > circular> triangular**) building with respect to cost.

8 CONCLUSIONS

It is concluded that in each zone ,zone 1 with earthquake acceleration factor 0.075 m/s which is very low compare to other zones and zone 2A having earthquake acceleration factor 0.15, zone 2B earthquake acceleration factor is 0.2 m/s and in zone 3 earthquake acceleration factor is 0.3 m/s and in zone 4 earthquake acceleration factor is 0.4 so according to design strength of building the sequence is (circular building> triangular building> rectangular building) with respect to analysis methods in all seismic zones but with respect cost analysis of these three building circular ,rectangular and triangular building the sequence w.r.t most economical

is (rectangular >triangular>circular) building so in zone 1,zone 2A,2B there earthquake acceleration factor is in moderate range so we recommended rectangular shape of building its have safe results in these zones and it is most economical building and in zone 3 and zone 4 we recommended safety over cost because these zone having high severity w.r.t earthquake so we recommended circular building because circular building showed high stability and most safer results in all seismic zones of Pakistan.

9 RECOMMENDATIONS AND FUTURE PROSPECTS

In zone 1,zone 2A,2B there earthquake acceleration factor is in moderate range so we recommended rectangular shape of building it's have safe results in these zones and it is most economical building in all three shapes of building (circular, triangular and rectangular) and in zone 3 and zone 4 we recommended safety over cost because these zone having high severity w.r.t earthquake so we recommended circular building because circular building showed high stability and most safer results in all seismic zones of Pakistan.
And in future this research will be helpful in selecting the most economical and most stable building shape in all seismic zones of Pakistan.

REFERANCES

1. Mishra, Sustainability analysis of circular building over rectangular building , p. 6, 2019. http://iosrjen.org/Papers/Conf.19010-2019/Volume-1/1.%2001-06.pdf
2. V. Kumar, and R. Rao.V, Comparative study on regular and irregular structures using equivalent static and response spectrum methods, no. 8, p. 9, Jan. 2017, https://www.researchgate.net/publication/314441697_Comparative_study_on_regular_irregular_structures_using_equivalent_static_and_response_spectrum_methods
3. A. Gottala, and K. Kishore, Comparative study of static and dynamic siesmic analysis of a multistoried building , vol. Issue 01, no. 2, p. 12, July 2015. http://www.ijste.org/articles/IJSTEV2I1059.pdf
4. G. G. Kakpure, and D. Mundhada, Comparative study of static and dynamic siesmic analysis of multistoried Rcc building by ETAB, vol. Issue 5, no. 7, p. 6, May 2017.
5. C. Zhai, Z. Zheng, and L. Xie, Siesmic analysis of a rcc building under mainshock-aftershock siesmic sequences, p. 10, 2015. http://www.kresttechnology.com/krest-academic-projects/krest-mtech-projects/Civil/Civil%20M.tech%20Projects%202017%20-2018/1.%20Simulation%20Projects/BASE%20PAPERS/27.Comparative%20Study%20of%20Static%20and%20Dynamic%20Seismic%20Analysis%20of.pdf
6. R. Kanukuntla, Response spectrum analysis of a multistoried rc building , vol. Issue 5, no. 4, p. 9, May 2022. https://www.irjmets.com/uploadedfiles/paper//issue_5_may_2022/22450/final/fin_irjmets1652006879.pdf
7. Anshumn. S, Dipendu Bhunia, Bhavin Rmjiyani (2011), "Solution of shear wall location in Multi-storey building." International Journal of Civil Engineering Vol. 9, No.2Pages 493-506. https://pdf4pro.com/cdn/solution-of-shear-wall-location-in-multi-storey-building-44c361.pdf

8. S. D. Gupta, and K. H. Kanak, Structural Analysis of a High-Rise Building under Strong Winds Using ETABS, vol. 3, p. 9, 2020., https://www.academia.edu/102192759/Structural_Analysis_of_a_High_Rise_Building_under_Strong_Winds_Using_ETABS
9. Bansal, Himanshu, and Gagandeep . Siesmic Analysis and Design of Vertically Irregular RC Building Frames, vol. 3, 2014, p. 7., https://www.ijsr.net/archive/v3i8/MDIwMTUyMjE=.pdf
10. Bhure, Nitesh, and Rashmi Sakalle. Analysis of an RCC Irregularly Building under Dynamic Loading., vol. 4, 2021, p. 8., https://www.academia.edu/81964404/Analysis_of_an_RCC_Irregular_Building_under_Dynamic_Loading?uc-sb-sw=67741220
11. K. Raju, and M. Shereef, Analysis and design of Rc Tall building subjected to Wind and Earthquake loads, p. 9, Dec. 2013, https://www.researchgate.net/publication/269252967_Analysis_and_Design_of_RC_Tall_Building_Subjected_to_Wind_and_Earthquake_Loads