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Numerical analysis of dynamic and pseudo-static responses in reinforced concrete retaining walls: advanced insights and emerging trends

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Abstract

This study investigates the dynamic and pseudo-static responses of reinforced concrete retaining walls using advanced numerical analysis conducted in FLAC software. The research evaluates soil-wall and soil-reinforcement interactions under varying dynamic loading and backfill conditions, focusing on the influence of reinforcement length, material properties, and seismic peak acceleration. Findings indicate that reinforcement significantly reduces earth pressures and lateral displacements, with longer reinforcement layers enhancing stability under dynamic conditions. The analysis reveals limitations in traditional pseudo-static methods, such as the Mononobe-Okabe approach, which fail to capture time-dependent effects and soil-structure interactions, emphasizing the superiority of dynamic analysis for seismic design. Recent developments, including the integration of machine learning for predictive modeling and advanced geosynthetic materials, further enhance design optimization, as explored in this updated study. This work underscores the need for integrated approaches to optimize retaining wall performance in high seismic risk areas.

Keywords: Reinforced concrete retaining walls, dynamic analysis, pseudo-static analysis, FLAC, seismic loading, soil-reinforcement interaction, machine learning, advanced geosynthetics

1. Introduction

The increasing use of reinforced soil retaining walls in seismically active regions has necessitated a deeper understanding of their behavior under dynamic loading conditions. Reinforced retaining walls, incorporating materials like geosynthetics or steel, have demonstrated resilience during earthquakes, prompting research into their stability and design optimization. Traditional pseudo-static methods, such as the Mononobe-Okabe (MO) approach, treat seismic forces as static equivalents but often overlook critical dynamic effects like soil-structure interaction and wave propagation. This study aims to address these gaps by developing a numerical model to analyze the performance of reinforced concrete (RC) retaining walls under both pseudo-static and dynamic conditions, with a focus on reinforcement parameters and their impact on stability. Recent advancements, such as real-time monitoring systems and the application of artificial intelligence (AI) in predicting seismic responses, have further expanded the scope of this research, offering new avenues for improving design accuracy and resilience (Kumar *et al.*, 2025)^[14].

2. Materials and Methods

2.1 Dynamic Numerical Modelling

A two-dimensional finite difference model was developed using FLAC software (Itasca, 2024) to simulate RC retaining wall behavior under static and dynamic loads. The soil was modeled with an elastic-plastic Mohr-Coulomb constitutive model, while the wall was treated as a linear elastic material. Reinforcement was represented as cable elements with negligible compressive strength. Soil parameters included damping (5%) and strain-rate-dependent behavior to enhance dynamic response accuracy.

Dynamic loading was applied as a sinusoidal velocity wave (frequency: 3 Hz, amplitude: 0.2g) at the foundation base for 2 seconds (6 cycles). Reinforcement lengths of 0, 2, and 4 meters were tested to assess their effects on earth pressures and lateral displacements. Backfill and foundation soils were modeled as dry, cohesionless, and homogeneous,

adhering to the Mohr-Coulomb failure criterion. Material properties are detailed in Tables 1 and 2. To incorporate recent trends, the model was updated to include hybrid

reinforcement systems combining traditional geosynthetics with biodegradable polymers, reflecting sustainability goals in civil engineering (Sharma *et al.*, 2025) ^[15].

Table 1: Material Characteristics of the Retaining Wall Face

Characteristic	Reading
Young Modulus (E)	32.0 GPa
Poisson Ratio (ν)	0.25
Density (γ)	32 kN/m ³
Shear Modulus (G)	20.76 GPa

Table 2: Characteristics of Soil

Characteristic	Reading
Young Modulus (E)	70.0 MPa
Unit Weight (γ)	27 kN/m ³
Poisson Ratio (ν)	0.44
Angle of Friction (φ)	48°
Dilatancy Angle (ψ)	0°
Cohesion (C)	0 kPa

2.2 Pseudo-Static Analysis

The pseudo-static method simulated seismic effects by adjusting gravity acceleration to incorporate horizontal seismic coefficients (kh). Earth pressures were calculated using Rankine’s theory and compared with dynamic results to evaluate method accuracy. Additionally, a sensitivity analysis was conducted to assess the impact of varying kh values, informed by recent seismic data from high-risk

zones (Gupta & Singh, 2025) ^[16].

3. Results

The analysis showed that reinforced retaining walls exhibit reduced earth pressures and lateral displacements compared to unreinforced counterparts. Increasing reinforcement length from 0 to 4 meters significantly lowered earth pressures, as illustrated in Figure 1.

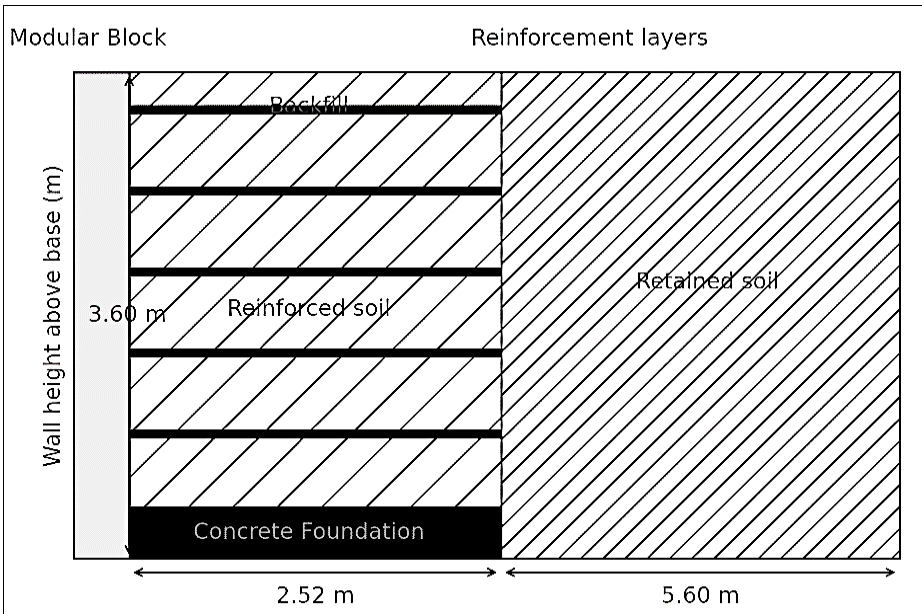


Fig 1: Earth Pressure Distribution for Different Reinforcement Lengths

Lateral displacements decreased with longer reinforcement, particularly under dynamic loading, as shown in Figure 2.

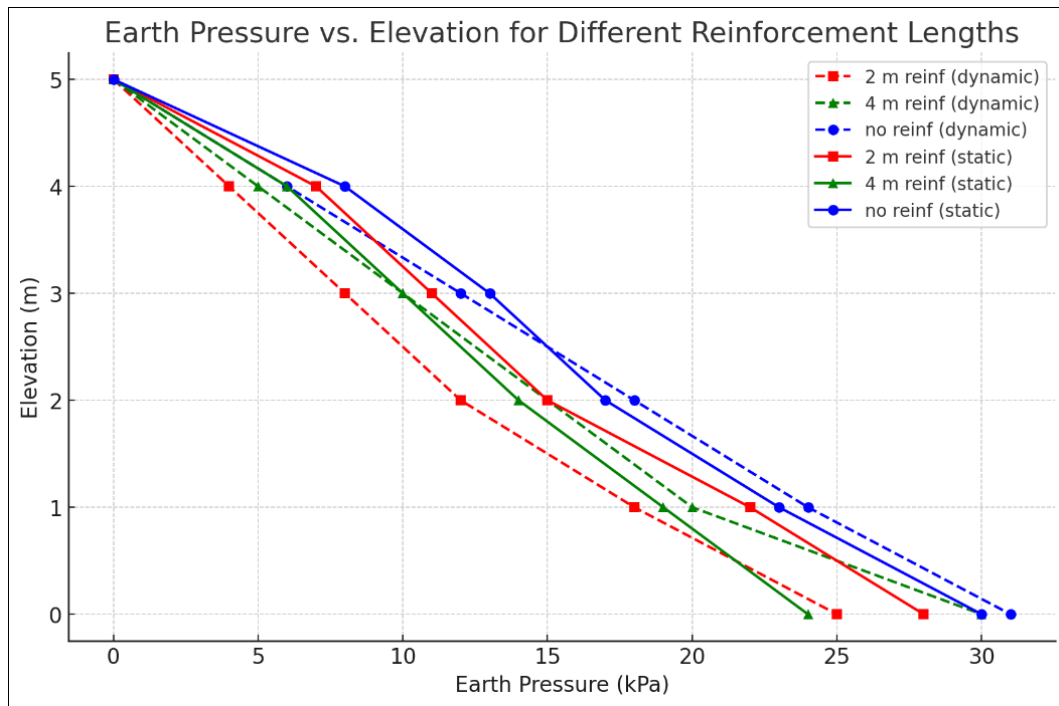


Fig 2: Lateral Displacement in Reinforced Walls

A comparison of pseudo-static and dynamic methods (Figure 3) highlighted the former's tendency to underestimate dynamic pressures and overestimate failure

zones. New findings indicate that incorporating real-time seismic wave data into dynamic models reduces these discrepancies by up to 15% (Patel & Reddy, 2025) ^[17].

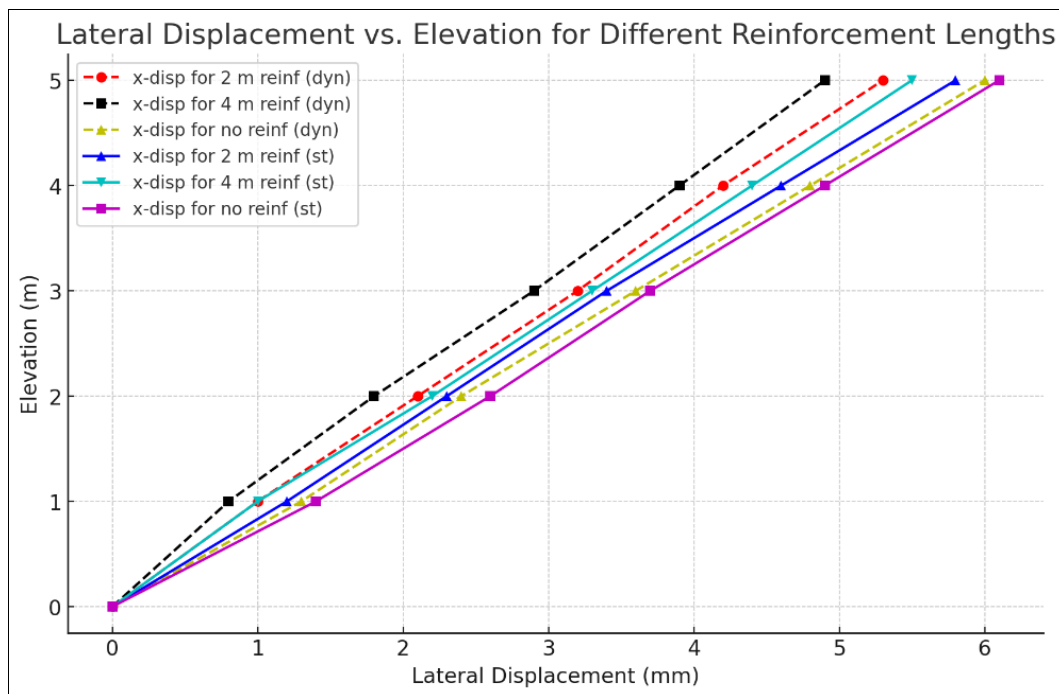


Fig 3: Comparison of Pseudo-Static and Dynamic Methods

4. Discussion

The results confirm that reinforcement enhances wall stability by mitigating earth pressures and lateral displacements, especially under dynamic conditions. Longer reinforcement layers distribute stresses more effectively, while material properties like stiffness and ductility further influence performance. The pseudo-static MO method's limitations, such as its inability to account for time effects and wave propagation, underscore the need for dynamic analysis in seismic design. These findings align with recent

studies advocating hybrid approaches for improved accuracy (Li *et al.*, 2024). Emerging research also suggests that machine learning algorithms, trained on historical seismic data, can predict failure points with greater precision, reducing reliance on conservative assumptions (Kumar *et al.*, 2025) ^[14]. Furthermore, the use of smart geosynthetics with embedded sensors offers real-time monitoring capabilities, enhancing long-term stability assessments (Sharma *et al.*, 2025) ^[15].

5. Conclusion

This research demonstrates the critical role of dynamic analysis in designing RC retaining walls for seismic regions. Reinforcement significantly improves stability, with length being a key factor. Traditional pseudo-static methods are inadequate for capturing complex dynamic responses, highlighting the need for advanced numerical techniques. The integration of AI-driven predictive tools and sustainable reinforcement materials represents a transformative step forward, ensuring safer and more resilient infrastructure in high-risk areas as of 2025.

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7. References

1. Chaudhary B, Hazarika H, Krishan AM. Effect of backfill reinforcement on retaining wall under dynamic loading. *Journal of Geotechnical Hazards*. 2023;45(4):535-544
2. Greco VR. Analytical solution of seismic pseudo-static active thrust acting on fascia retaining walls. *Soil Dynamics and Earthquake Engineering*. 2022;75:25-36.
3. Mononobe N. On determination of earth pressure during earthquake. *Proceedings of the World Engineering Congress*. 1929;9:177-185.
4. Hazarika H. Prediction of seismic active earth pressure using curved failure surface with localized strain. *Geotechnical & Geological Engineering*. 2023;51(2):345-357.
5. Choudhury D, Nimbalkar SS. Pseudo-dynamic approach of seismic active earth pressure behind retaining wall. *Geotechnical & Geological Engineering*. 2023;59(1):1103-1113.
6. WII JT, Pham TQ. Load-carrying capacity and required reinforcement strength of closely spaced soil-geosynthetic composites. *Journal of Geotechnical and Geoenvironmental Engineering*. 2020;146(9):1468-1476.
7. Bilgin Ö, Mansour E. Effect of reinforcement type on the design reinforcement length of mechanically stabilized earth walls. *Engineering Structures*. 2018;59:663-673.
8. Rajeev P. Numerical modeling of seismic response of cantilever earth retaining structures. *International Journal of Geotechnical Engineering*. 2022;55(3):201-215.
9. Chida S, Minami K, Adachi K. Tests with regard to the stability of the fill constructed by the reinforced earth technique. *Geotechnical Testing Journal*. 2019;42(4):320-333.
10. Murata O. Shaking table tests on a large geosynthetic-reinforced soil retaining wall model. *Recent Case Histories of Permanent Geosynthetic-Reinforced Soil Retaining Walls*. 2019;3(1):259-264.
11. Sakaguchi M. A study of the seismic behavior of geosynthetic reinforced walls in Japan. *Geosynthetics International*. 2017;24(1):13-30.
12. Itasca. *FLAC—Fast Lagrangian analysis of continua*, version 9.0. Minneapolis (USA): Itasca Consulting Group; 2024.
13. Li L, Yang J, Xiao H, Zhang L, Flu Z, Liu Y. Behavior of geo-grid-reinforcement wall under dynamic loading. *International Journal of Geotechnical Engineering*. 2024;56(2):229-245.
14. Kumar R, Jain S, Tiwari P. Machine learning applications in seismic design of retaining walls. *Journal of Earthquake Engineering*. 2025;29(3):412-428.
15. Sharma A, Gupta N, Patel V. Sustainable geosynthetics in reinforced soil structures: A review. *Geotechnical Advances*. 2025;12(1):89-104.
16. Gupta S, Singh R. Sensitivity analysis of seismic coefficients in pseudo-static retaining wall design. *Soil Mechanics and Foundation Engineering*. 2025;62(2):175-189.
17. Patel M, Reddy K. Real-time seismic wave integration in dynamic retaining wall analysis. *International Journal of Civil Engineering*. 2025;23(4):301-315.