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Slope Stability Assessment in Highway Embankments: A Comprehensive Study on Incorporating C&D Waste as Fill Material

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Abstract

The present study aims to assess the utility of construction and demolition (C&D) waste, specifically recycled concrete aggregates (RCA) and recycled brick aggregates (RBA), as fill materials in highway embankments. The assessment of slope stability is crucial in determining the suitability of any material for embankment fill. GeoStudio software is employed in this study for slope stability assessment of 12 models with LS, RCA, RBA, and their blends as embankment fill materials. The embankment configuration is designed to represent a six-lane highway (carriageway width = 13 m, adhering to IRC: 36 standards), featuring varying slope elevations (3 m, 6 m, and 9 m) and diverse horizontal to vertical slope ratios (H:V = 2:1, 1:1, 1:2, and 1:3). The Morgenstern-Price method is employed to analyze slope stability and determine factor of safety (FOS) values. The study highlights the impact of slope heights, slope ratios, and fill materials (RCA, RBA, LS, and their blends) on FOS values in embankment models. Incorporating RCA or RBA in LS significantly boosts embankment FOS, exceeding stability expectations beyond 45˚ slope angles, potentially reducing costs and required area in construction projects. The incorporation of RCA/RBA into LS increases the FOS values to a range of 1.38 to 5.91, indicating very stable slopes for highway embankments. Based on the findings, replacing LS with RCA or RBA in embankment fill can enhance environmental sustainability and economic efficiency. However, these slope stability results apply specifically to C&D waste with similar composition, grain size, geotechnical properties, and embankment conditions.

1. Introduction

Slope instability is a pervasive concern in both natural landscapes and engineered structures, captivating the attention of researchers and professionals alike. The precarious nature of slopes, whether natural or man-made, is influenced by a multitude of factors such as the quality of fill material, precipitation, fluctuating groundwater levels, and alterations in stress conditions [1-3]. Even seemingly stable natural slopes can experience failure due to changes in geometry, external forces, or diminished shear strength. The primary objective of slope stability analyses is to facilitate the secure and cost-effective design of excavations, embankments, and earth dams [4-8].

Previous investigations into Finite Element (FE) slope stability analysis, juxtaposed with the stress-strain method, have explored diverse facets, including the impact of free surfaces on slope and dam stability [9-12]. The consensus among researchers is that the FE method proves reliable and resilient in calculating the slope factor of safety [13-15]. It satisfies the requirements for efficient computer-aided analysis, suggesting its potency as a substitute for conventional limit equilibrium methods.

Mishal and Khayyun [16] delved into stability analysis using GeoStudio 2007 software, considering soil parameters, water depth, coefficient of permeability, and seepage rate to

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predict the critical factor of safety against slope failure. Their empirical equation simplifies the analysis of the factor of safety for similar dam geometries and materials. Dewedree and Jusoh [17] focused on slope stability by analyzing the Factor of Safety (FOS) with soil nail inclination angle as a variable, determining optimal angles for improved stability using SLOPE/W software. Their Genting Highlands case study underscored the significant impact of soil nail inclination on slope stability.

Nalgire et al. [18] utilized various finite slope stability methods with Geo-Slope software to assess dump slope stability at an open-cast mine, identifying failures resulting from improper dump geometry. Malik and Karim [19] concentrated on slope stability and seepage analysis of Haditha Dam in Iraq, using Geo-Studio software to evaluate design feature effects and factor of safety values under different water levels. Tan et al. [20] explored seepage within slopes under changing rainfall conditions and its impact on slope stability using Geo-Studio finite element software, emphasizing the mechanical response of unsaturated soil slopes and the stability impact of seepage. Al-Homoud et al. [21] conducted a comparative study on slope stability methods and mitigation design for a highway embankment landslide, focusing on the potential for deep-seated sliding. Kumar et al. [22] conducted a slope stability analysis and proposed mitigation measures for specific landslide sites along NH-205 in Himachal Pradesh, India. Subramanian et al. [23] conducted a detailed assessment of soil slope stability in regions experiencing seasonal cold climates. Their study focused on evaluating the unique challenges posed by freeze-thaw cycles and their impact on soil properties, providing insights into effective approaches for managing soil slopes in these environments.

Given the growing interest in sustainable construction and Construction & Demolition (C&D) waste management, this study seeks to comprehensively analyze the slope stability of embankments using C&D waste as fill material through GeoStudio software. Understanding and assessing slope stability is crucial for ensuring the safety and longevity of such structures, particularly within the context of sustainable waste management [24-29]. Despite some limited insights offered by previous studies [30-33], this research aims to fill the gap by exploring the slope stability of embankments, specifically employing C&D waste, utilizing GeoStudio software to simulate and analyze the stability of a highway embankment model, taking into account the unique properties and characteristics of C&D waste as fill material.

The current research aims to address a notable research gap by evaluating the efficacy of incorporating recycled C&D waste materials, specifically Recycled Concrete Aggregate (RCA) and Recycled Brick Aggregate (RBA), in the partial or full replacement of locally available sandy soil (LS) as fill material for embankments and earthen structures. The importance of slope-stability analysis is underscored for any unconventional material intended for use in embankments or earthen structures, as emphasized in IRC: 75 [34].

In this study, the trial version of GeoStudio software is employed to conduct slope-stability assessments on analytical embankment models constructed using recycled C&D waste materials individually and in combination with LS. Leveraging the capabilities of GeoStudio Software, a robust geotechnical analysis tool, the research aims to model and analyze the behavior of slopes containing these recycled materials. Various limit equilibrium methods have been developed in past to assess slope stability, starting with Fellenius [35], who introduced the Ordinary or Swedish method focused on circular slip surfaces. Bishop [4] improved this with a nonlinear FOS equation, and Janbu [36] offered the Generalized Procedure of Slices (GPS). Morgenstern-Price [37], Spencer [38], and Sarma [39] further advanced the field with different interslice force assumptions. The Morgenstern-Price method is chosen in present study due to its thorough consideration of critical factors, flexible failure surface shapes, and broad applicability, making it superior to other simplified methods like Bishop’s and those assuming circular failure surfaces such as Janbu's or Spencer's.

Through comprehensive analysis and simulations, the study endeavors to offer valuable insights into the slope stability characteristics of recycled C&D waste materials. The ultimate goal is to contribute to sustainable engineering practices by promoting the effective utilization of recycled materials in construction projects while ensuring safety and stability in geotechnical applications. This research aspires to fill a critical gap in understanding the slope stability of embankments constructed with recycled C&D waste materials, thereby advancing knowledge in the field and facilitating the adoption of environmentally friendly practices in construction.

2. Materials and Methods

The present study examined the slope stability within the framework of a 6-lane highway embankment model. The model is meticulously crafted and undergoes thorough analysis using the GeoStudio software. The fill material for the embankment model comprises two types of C&D waste materials: RCA and RBA. Additionally, LS is also incorporated as part of the fill material. Concrete and brick masonry residues are sourced from a nearby disposal area, and sandy soil is obtained from a foundation excavation site within Jaipur city. These materials are then processed at a local crushing facility. Figure 1 depicts representative samples of the processed C&D waste aggregates and the gathered sandy soil. Furthermore, Figure 2 illustrates the particle size distribution (PSD) plots of RCA, RBA, and LS. Figures 1 and 2 are derived from the component study [40] conducted as part of this research. The PSD plots reveal that RCA and RBA categorized as well-graded gravels (GW), while LS falls into the poorly graded sand (SP) category.

(a) (b) (c)

Figure 1. (a) Recycled concrete aggregates (RCA); (b) Recycled brick aggregates (RBA); (c) Locally available sandy soil (LS) [40]

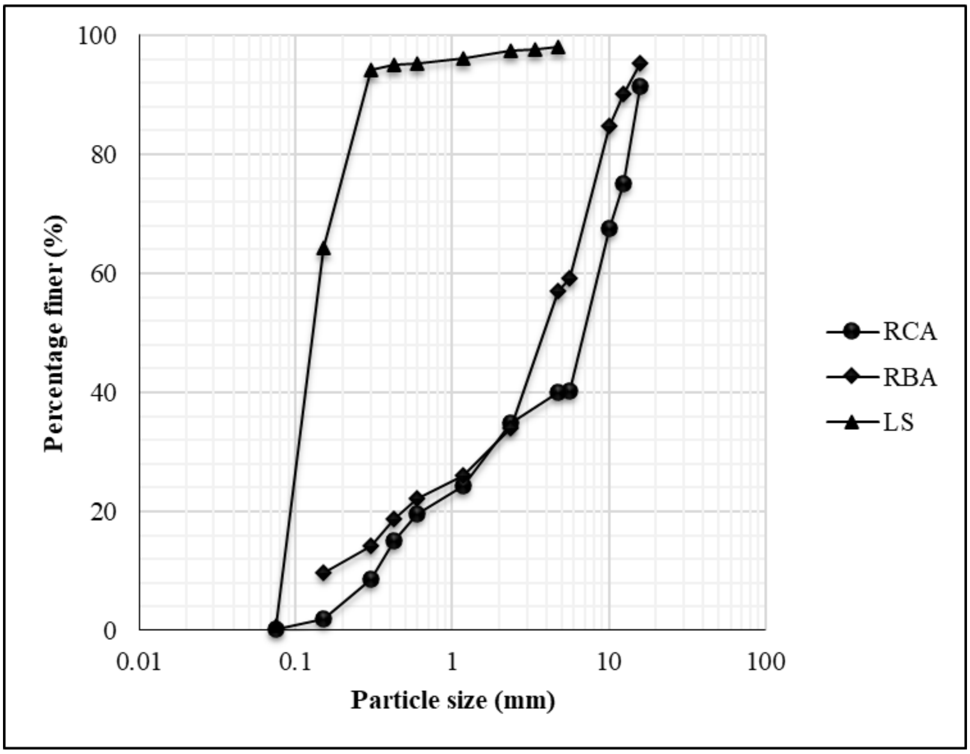

Figure 2. Particle size distribution plots of RCA, RBA, and LS [40]

In the context of this slope stability analysis, a total of twelve distinct combinations of fill materials are scrutinized, encompassing various blends of RCA and RBA with LS, as detailed in Table 1.

Table 1. Descriptions of embankment slope models analyzed in present study by GeoStudio

Sr. No.	Slope Models	Notations	Description
1	Slope Model 1	**SM1**	100% LS as embankment fill material
2	Slope Model 2	**SM2**	100% RCA as embankment fill material
3	Slope Model 3	**SM3**	100% RBA as embankment fill material
4	Slope Model 4	**SM4**	Blend (25% RCA + 75% LS) as embankment fill material
5	Slope Model 5	**SM5**	Blend (50% RCA + 50% LS) as embankment fill material
6	Slope Model 6	**SM6**	Blend (75% RCA + 25% LS) as embankment fill material
7	Slope Model 7	**SM7**	Blend (25% RBA + 75% LS) as embankment fill material
8	Slope Model 8	**SM8**	Blend (50% RBA + 50% LS) as embankment fill material
9	Slope Model 9	**SM9**	Blend (75% RBA + 25% LS) as embankment fill material
10	Slope Model 10	**SM10**	Blend (75% RCA + 25% RBA) as embankment fill material
11	Slope Model 11	**SM11**	Blend (50% RCA + 50% RBA) as embankment fill material
12	Slope Model 12	**SM12**	Blend (25% RCA + 75% RBA) as embankment fill material

The GeoStudio software for designing and analyzing embankment slope stability requires several input parameters, including model geometry, fill material properties, and loading conditions. The embankment is designed to simulate a 6-lane highway (carriageway = 13 m, following IRC: 36) [41], featuring varying slope heights (3 m, 6 m, and 9 m) and different horizontal-to-vertical slope ratios (H:V = 2:1, 1:1, 1:2, and 1:3). An external traffic load (live load) of 24 kN/m^2 is applied to the embankment carriageway as per IRC: 75 [34]. The analysis considers both seismic and non-seismic conditions, with earthquake factors (horizontal = 0.096, vertical = 0.048) introduced in the slope-stability analysis following IS: 1893 (Part I) [42].

The design of embankment models also incorporates essential factors such as shear strength properties (c and Φ) and compaction characteristics (dry unit weight , γ_d) of the fill materials. The input characteristics for fill materials, including the angle of internal friction and cohesion intercept, are directly derived from the component study [43], which employed the large-scale direct shear test to assess the shear strength characteristics of RCA, RBA, LS, and their blends. The dry unit weight is selected at 95% of the maximum dry density (MDD) [41], determined through the modified Proctor test. Table 2 outlines the geotechnical properties of the fill materials used in the slope-stability analysis. The study examines how variations in fill materials and embankment geometry (slope height and slope ratio) influence the slope stability of a highway embankment. The seismic effects are also considered in the design and analysis of embankments. Figure 3 illustrates the schematic diagram of GeoStudio-based embankment model designed and analyzed in this study.

Table 2. Geotechnical characteristics of fill materials employed in GeoStudio model simulation

Sr. No.	Fill Material	Dry unit weight (γ_d) (95% of MDD) (kN/m^3)	Cohesion intercept (c) (kPa)	Angle of internal friction (Φ) (degree)
1	**100 RCA**	18.43	61	71
2	**75RCA-25RBA**	18.34	63	68
3	**50RCA-50RBA**	18.62	60	64
4	**25RCA-75RBA**	18.91	50	55
5	**100RBA**	19.32	56	68
6	**75RCA-25LS**	17.96	40	67
7	**50RCA-50LS**	17.20	23	57
8	**25RCA-75LS**	17.01	16	49
9	**100LS**	16.63	13	39
10	**75RBA-25LS**	18.34	32	62
11	**50RBA-50LS**	17.48	26	56
12	**25RBA-75LS**	17.29	17	53

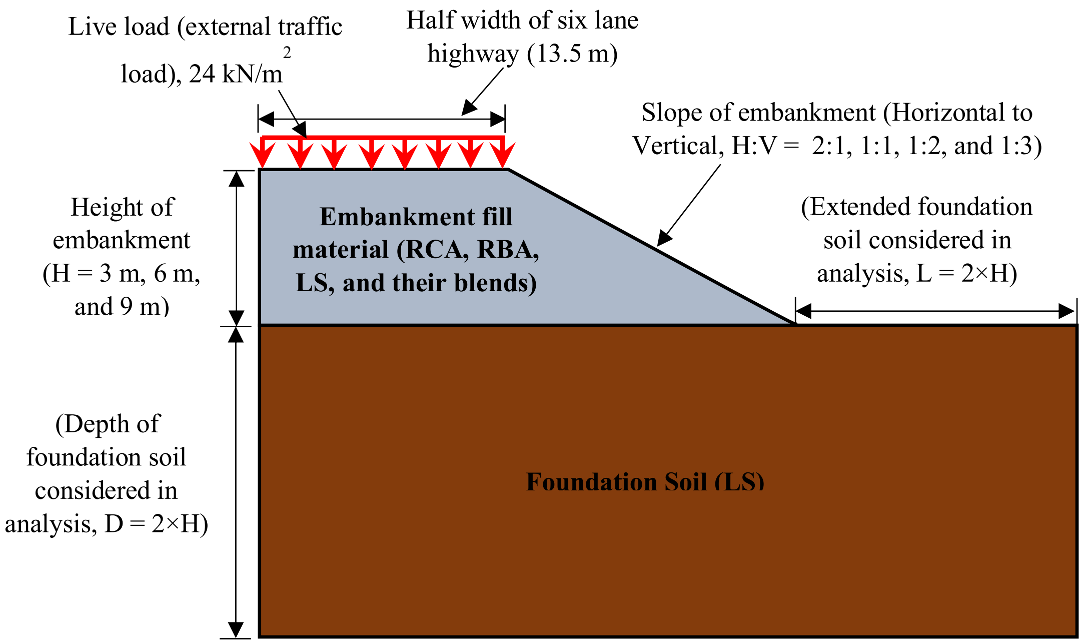

Figure 3. Schematic diagram of GeoStudio-based embankment model designed and analyzed in this study

The robustness and accuracy of the Morgenstern-Price method in assessing slope stability have been validated through extensive research and practical applications, affirming its superiority in slope stability analysis. This method incorporates equilibrium considerations in both the normal and tangential directions, encompassing both force and moment equilibrium for each slice along slip surfaces, whether circular or non-circular. The Morgenstern-Price method is employed in the current investigation to analyze slope stability and establish FOS values. Figure 4 illustrates the schematic flow chart representing the slope stability analysis employed in this stu

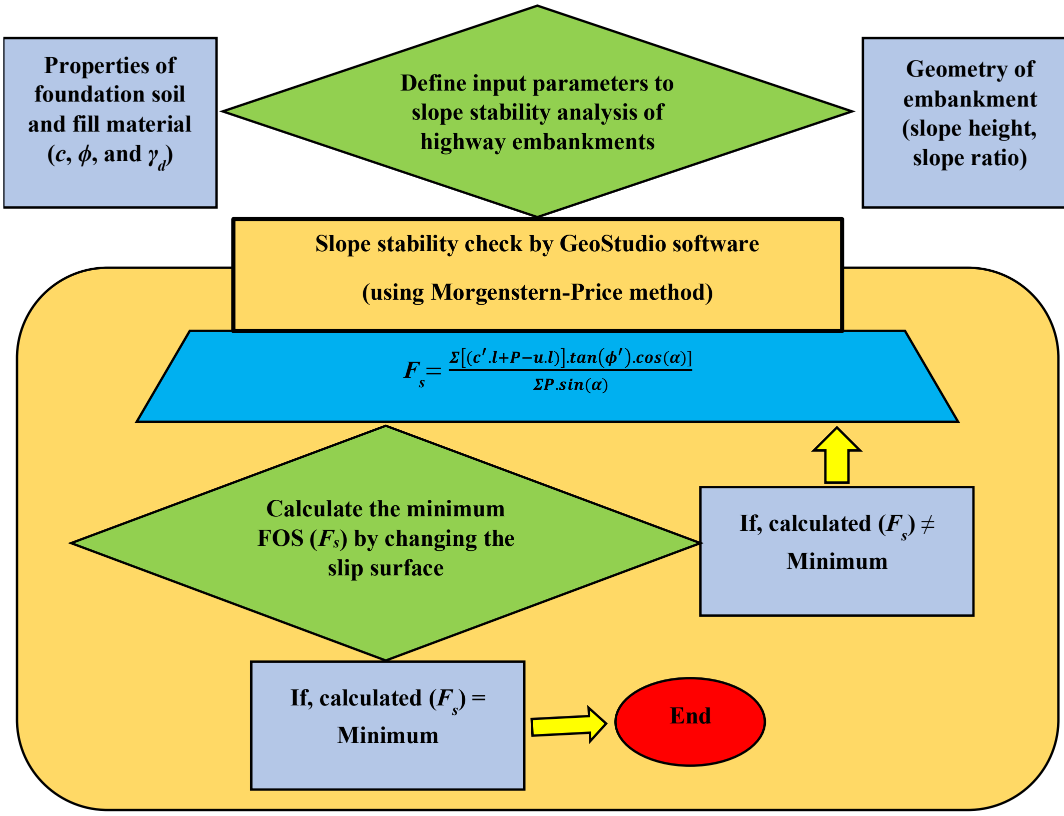

Figure 4. Flowchart outlining the process of slope stability analysis conducted with GeoStudio software, employing the Morgenstern-Price method

The present study utilizes generalized assumptions and models to assess stability, instead of conducting detailed site-specific analyses and precise numerical simulations. This conceptual approach offers broader applicability and initial insights but may need further refinement for precise implementation.

3. Results and Discussion

The evaluation of FOS unfolds under two specific scenarios: one accounts for the impact of earthquakes on embankment stability, while the other excludes earthquake effects. This dual-pronged approach is employed to comprehensively understand the embankment's stability performance under normal conditions and seismic events. The decision to simulate earthquake conditions is rooted in a deliberate consideration of the local context, focusing particularly on the seismic activity prevalent in the Rajasthan region of India. Given the acknowledged seismic activity in this area, a thorough assessment of how seismic events might impact embankment stability is deemed essential. By integrating these earthquake conditions, the analysis offers a more realistic depiction of potential challenges and risks. The FOS (F_s) results from these model analyses are detailed in Table 3, while Figure 5 visually represents the observed FOS values of the analyzed embankment models. Figures 6, 7, and 8 illustrate the influence of slope heights, slope ratios, and fill materials (RCA, RBA, LS, and their blends) on the FOS values of the embankment models.

Table 3. FOS values for slope of embankment models determined through GeoStudio simulation

Embankment height (m)	Slope ratio (H:V)	Slope angle (Degree)	Earthquake (EQ) condition	Material Combination											
				100LS	25RCA-75LS	50RCA-50LS	75RCA-25LS	100RCA	25RBA-75LS	50RBA-50LS	75RBA-25LS	100RBA	75RCA-25RBA	50RCA-50RBA	25RCA-75RBA
				FOS (Fs)											
3	2:1	27	Without EQ	4.11	4.50	4.98	5.63	5.91	4.65	4.99	5.33	5.67	5.89	5.71	5.32
			With EQ	3.29	3.59	3.94	4.42	4.61	3.70	3.94	4.14	4.46	4.61	4.47	4.14
	1:1	45	Without EQ	3.11	3.80	4.28	4.87	5.24	3.94	4.31	4.53	4.98	5.19	4.99	4.57
			With EQ	2.61	3.17	3.57	3.99	4.22	3.31	3.59	3.75	4.07	4.22	4.08	3.79
	1:2	63	Without EQ	2.72	3.38	3.96	4.60	4.83	3.56	3.97	4.22	4.67	4.84	4.72	4.29
			With EQ	2.35	2.92	3.37	3.84	4.07	3.06	3.38	3.56	3.93	4.06	3.95	3.62
	1:3	72	Without EQ	2.24	2.97	3.86	4.49	4.71	3.23	3.87	4.14	4.56	4.73	4.60	4.21
			With EQ	1.88	2.41	3.30	3.81	4.00	2.63	3.31	3.51	3.88	4.02	3.90	3.58
6	2:1	27	Without EQ	3.20	3.68	4.22	4.72	5.03	3.88	4.20	4.38	4.77	4.96	4.74	4.33
			With EQ	2.59	2.96	3.35	3.73	3.94	3.10	3.33	3.51	3.77	3.90	3.75	3.48
	1:1	45	Without EQ	2.26	2.87	3.36	3.94	4.20	3.06	3.36	3.64	3.99	4.15	3.98	3.63
			With EQ	2.23	2.45	2.84	3.32	3.51	2.60	2.83	3.08	3.36	3.48	3.35	3.05
	1:2	63	Without EQ	1.97	2.54	3.03	3.65	3.88	2.75	3.03	3.28	3.70	3.84	3.69	3.26
			With EQ	1.74	2.25	2.64	3.13	3.31	2.41	2.65	2.84	3.17	3.28	3.16	2.84
	1:3	72	Without EQ	1.39	1.83	2.52	3.56	3.82	2.03	2.60	3.18	3.62	3.76	3.59	3.22
			With EQ	1.25	1.62	2.24	3.06	3.27	1.77	2.36	2.82	3.12	3.24	3.10	2.82
9	2:1	27	Without EQ	2.66	3.22	3.68	4.30	4.57	3.44	3.66	3.93	4.34	4.48	4.27	3.81
			With EQ	2.18	2.63	3.00	3.43	3.60	2.80	2.98	3.17	3.46	3.55	3.41	3.10
	1:1	45	Without EQ	1.85	2.39	2.90	3.51	3.73	2.60	2.88	3.20	3.54	3.66	3.50	3.09
			With EQ	1.63	2.08	2.50	2.97	3.14	2.26	2.49	2.74	3.00	3.09	2.97	2.66
	1:2	63	Without EQ	1.20	1.59	2.19	3.27	3.50	1.76	2.23	2.76	3.32	3.38	3.27	2.84
			With EQ	1.07	1.43	1.95	2.82	3.02	1.61	1.99	2.45	2.85	2.94	2.82	2.49
	1:3	72	Without EQ	1.05	1.43	1.91	3.04	3.48	1.57	1.96	2.41	3.27	3.43	3.20	2.57
			With EQ	0.94	1.38	1.73	2.72	2.98	1.52	1.77	2.16	2.84	2.93	2.78	2.32

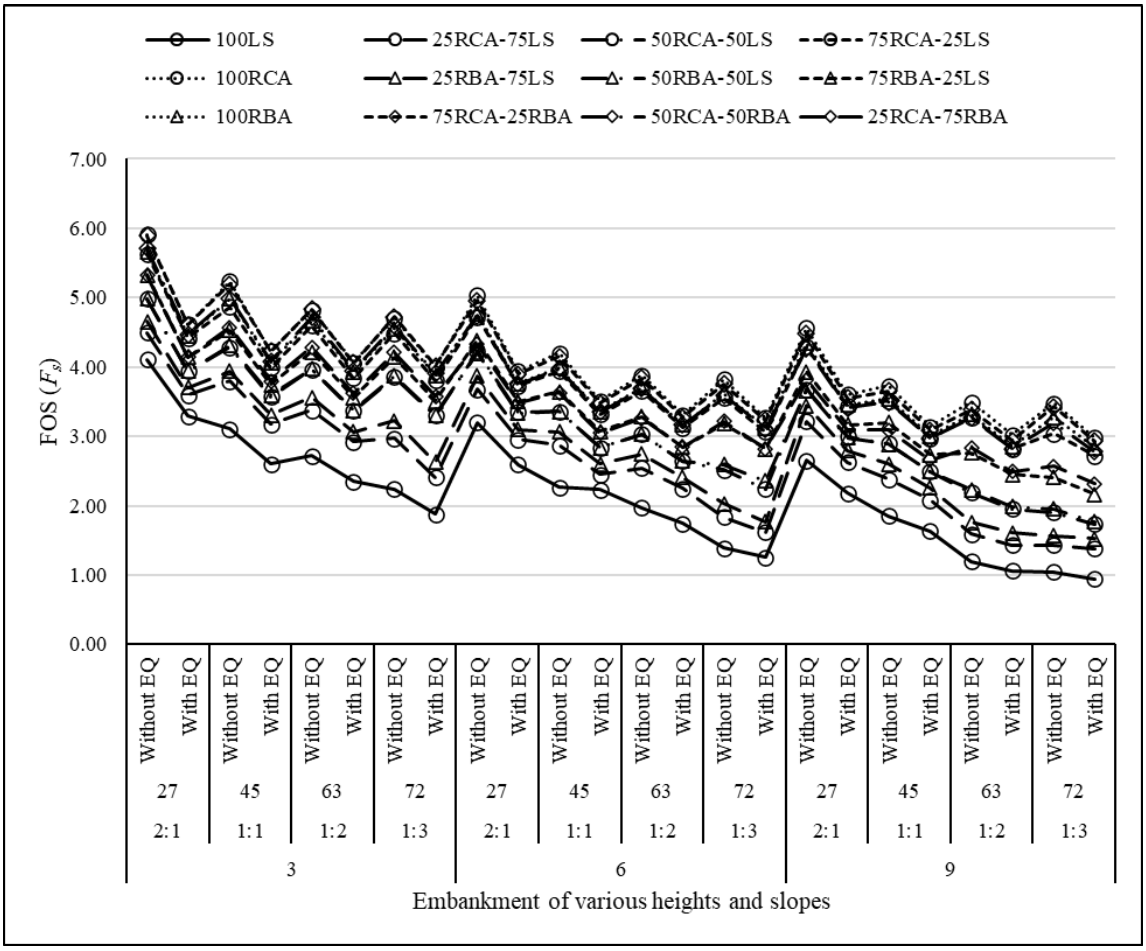

Figure 5. Observed FOS values for slope of embankment models

The observed FOS values for embankment models vary based on factors such as embankment height, slope ratios (slope angles), earthquake conditions, and material combinations. It is evident that FOS values decrease in the presence of earthquake conditions compared to scenarios without earthquakes, in line with expectations, as seismic events can significantly impact embankment stability. These FOS reductions emphasize the potential threat that seismic effects pose to embankment stability, underscoring the need for careful consideration in design and analysis.

Furthermore, FOS values exhibit dependence on material combinations, slope ratios, and embankment height. Notably, a higher proportion of RCA in the material combination tends to result in higher FOS values. Additionally, steeper slope ratios (e.g., 1:1 and 1:2) lead to lower FOS values, highlighting the sensitivity of stability to slope geometry. Similar results have been observed in previous studies with different materials used as fill in embankments. For instance, modified expansive soil containing 16% coconut shell ash demonstrated stability as a road embankment material based on FOS values [44]. Embankments incorporating coarse pond ash were found to be stable, showing no permanent deformations under the earthquake scenarios considered [45]. Additionally, it was discovered that plastic waste-treated clay could serve as embankment fill when reinforced with geogrid [46]. Furthermore, a mixture of soil, extracellular polymeric substances, and fly ash was identified as a viable alternative for lightweight fill materials in embankments [47]. Table 4 outlines the minimum required FOS for high embankments as per IRC: 75 [34].

Table 4. Minimum required FOS for high embankments as per IRC: 75 [34]

Earthquake condition	Without EQ	With EQ
Minimum required FOS	1.4	1.1

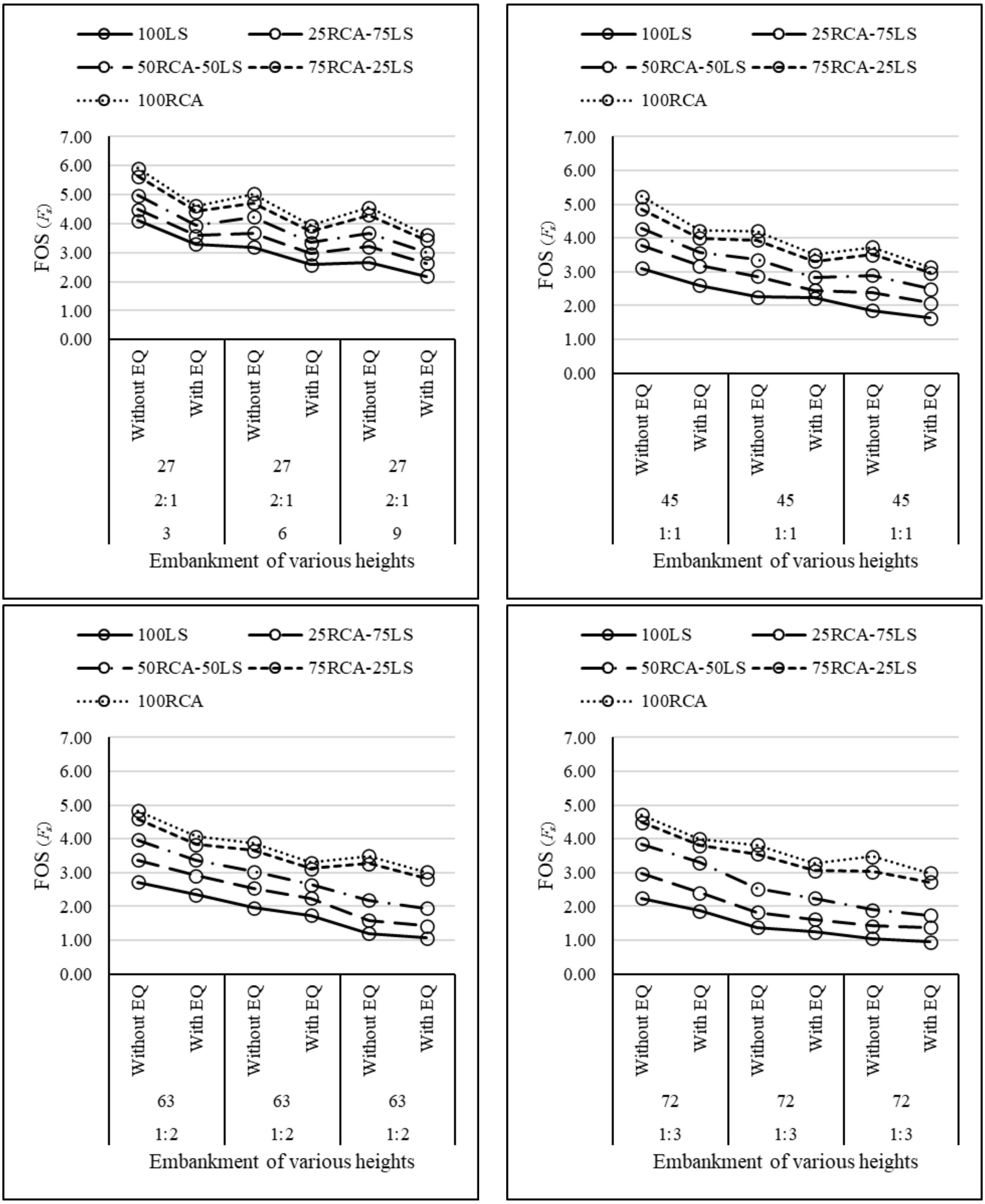

Figure 6. Influence of slope heights, slope ratios, and fill materials (RCA, LS, and their blends) on FOS values of embankment models

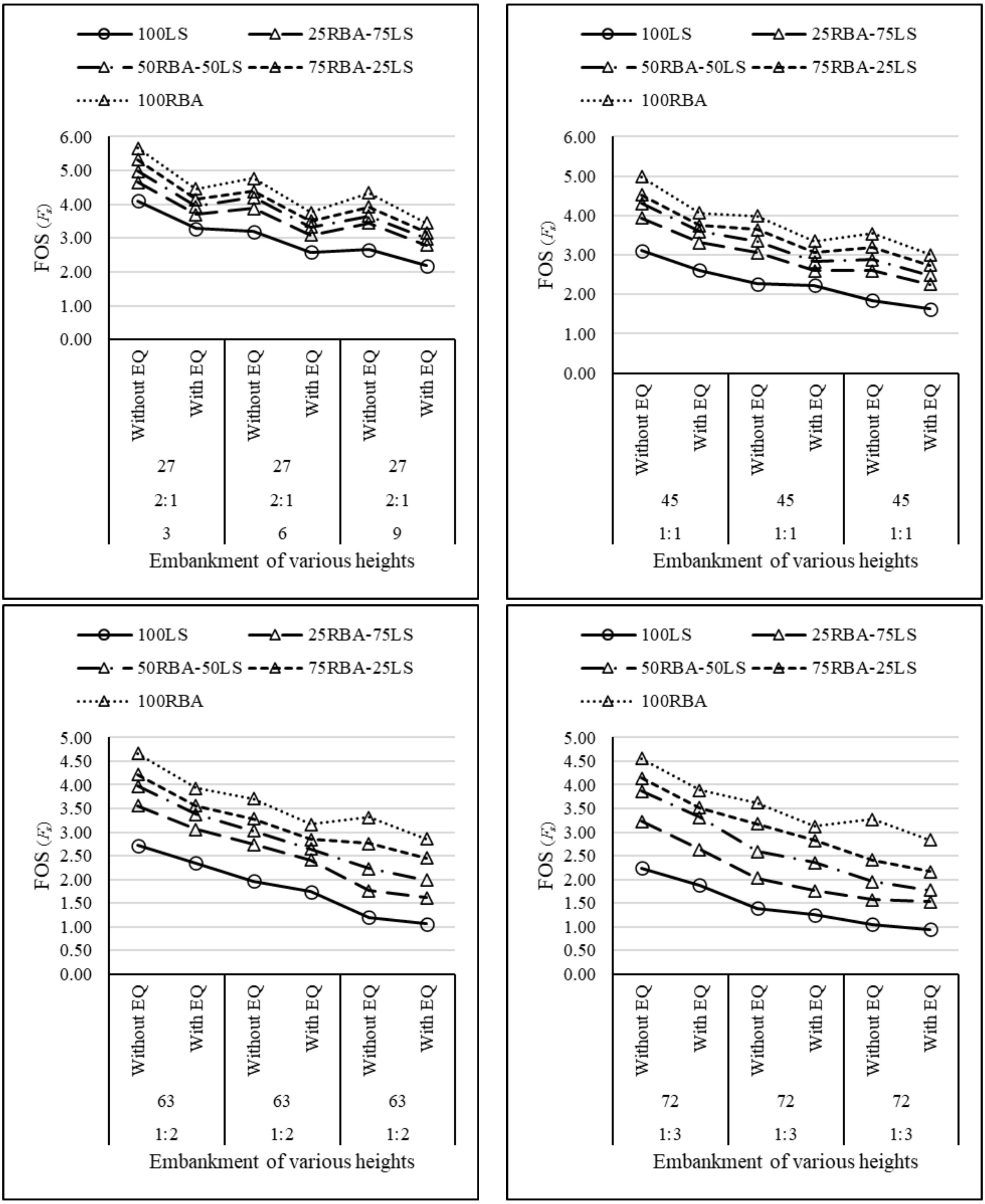

Figure 7. Influence of slope heights, slope ratios, and fill materials (RBA, LS, and their blends) on FOS values of embankment models

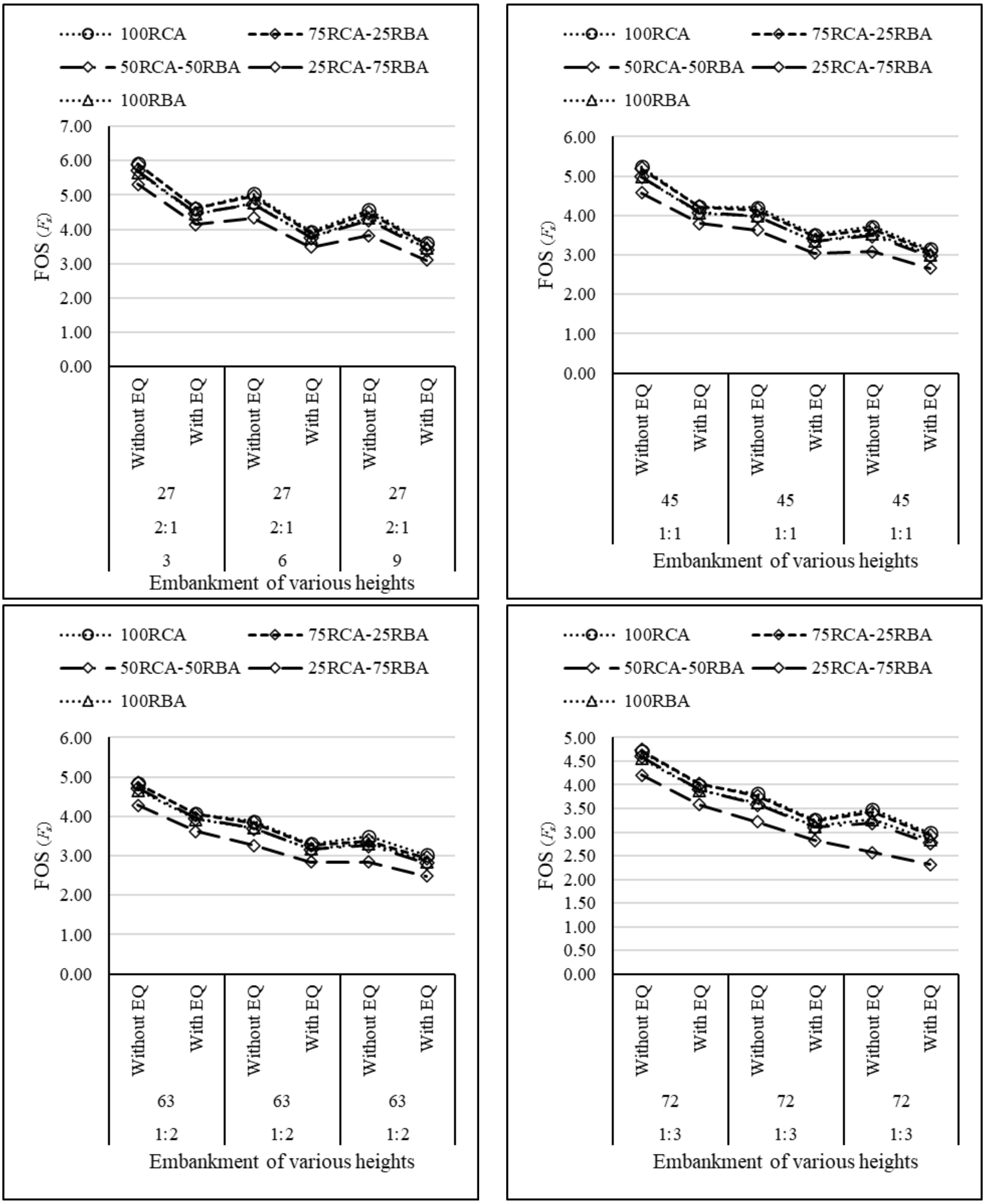

Figure 8. Influence of slope heights, slope ratios, and fill materials (RCA, RBA, and their blends) on FOS values of embankment models

IRC: 75 [34] recommends a maximum allowable slope ratio (H:V = 2:1, i.e., slope angle = 27˚) for high embankments. When comparing the observed FOS values with the minimum acceptable FOS limits, it becomes apparent that embankments using 100LS as fill material maintain stability up to a slope angle of 45˚. Moreover, the inclusion of RCA or RBA in LS extends the embankment slope stability up to a slope angle of 72˚. This implies that integrating RCA or RBA in LS has the potential to decrease the required base width of the embankment's slope triangle due to the increased safe slope angle. Such a reduction may directly influence the necessary build-up volume of the embankment and subsequently impact construction costs. Table 5 and Figure 9 present a detailed analysis illustrating the influence of the enhanced safe slope angle on the required build-up volume of the embankment and overall construction costs.

Table 5. Possible impact of slope angle on embankment build-up volume and construction expenses

Embankment height (m)	Embankment top width (m)	Slope ratio (H:V)	Slope angle (Degree)	Base of slope triangle (m)	Height of slope triangle (m)	Area of slope triangle (m^2)	Area reduction (%)	Total build-up area of Embankment (m^2)	Embankment construction area reduction in total (%) [indirectly construction cost reduction]
3	13	2:1	27	6	3	9	0	48	0
		1:1	45	3	3	4.5	50	43.5	9
		1:2	63	1.5	3	2.25	75	41.25	14
		1:3	72	1	3	1.5	83	40.5	16
6		2:1	27	12	6	36	0	114	0
		1:1	45	6	6	18	50	96	16
		1:2	63	3	6	9	75	87	24
		1:3	72	2	6	6	83	84	26
9		2:1	27	18	9	81	0	198	0
		1:1	45	9	9	40.5	50	157.5	20
		1:2	63	4.5	9	20.25	75	137.25	31
		1:3	72	3	9	13.5	83	130.5	34

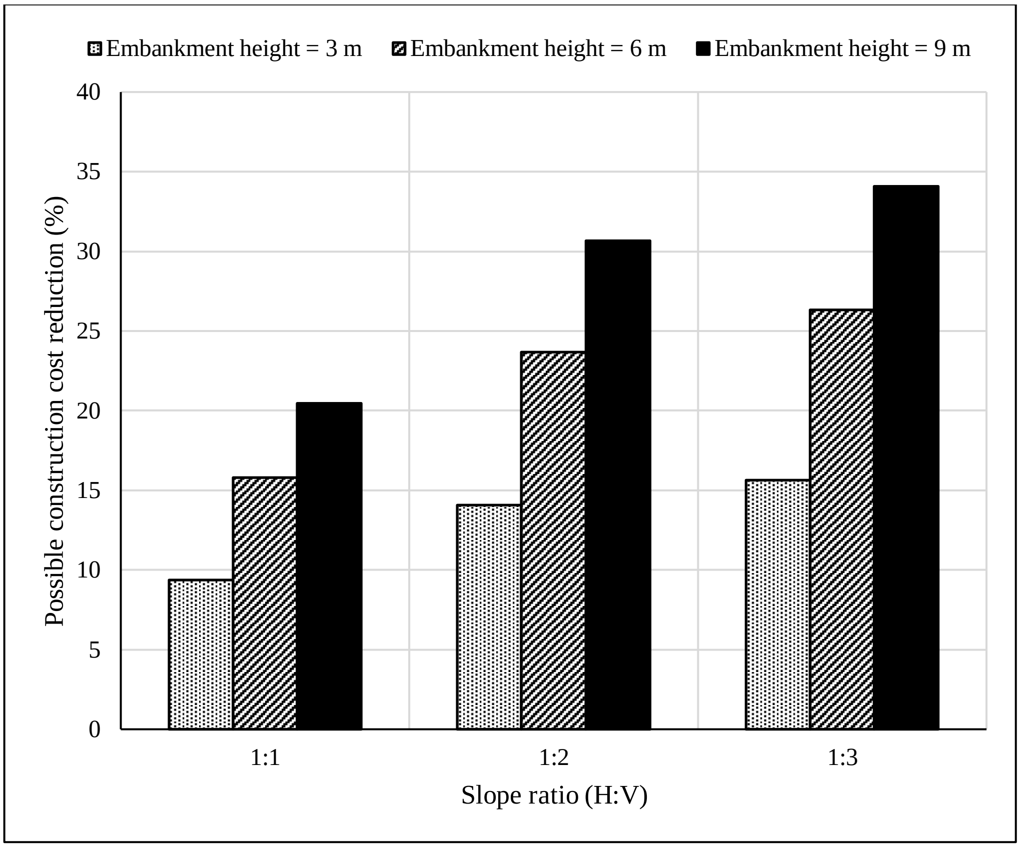

Figure 9. Possible embankment construction cost reduction due to incorporation of RCA/RBA in LS as fill material

The calculation of the stability number (*SN*) plays a pivotal role in evaluating slope stability. By utilizing mathematical models and examining factors such as fill material properties, slope geometry, and external forces, the stability number provides a quantitative understanding of potential risks related to slope failure or instability. This numerical value is crucial for engineers and geotechnical experts, enabling them to make informed decisions and design strategies to enhance slope stability, ensuring the safety of structures and environments. In the current investigation, *SN* values are computed using the formula proposed by Baker [48], incorporating fill material properties, embankment geometry, and observed FOS values. Figures 10 and 11 visually represent the *SN* values of the analyzed embankment models.

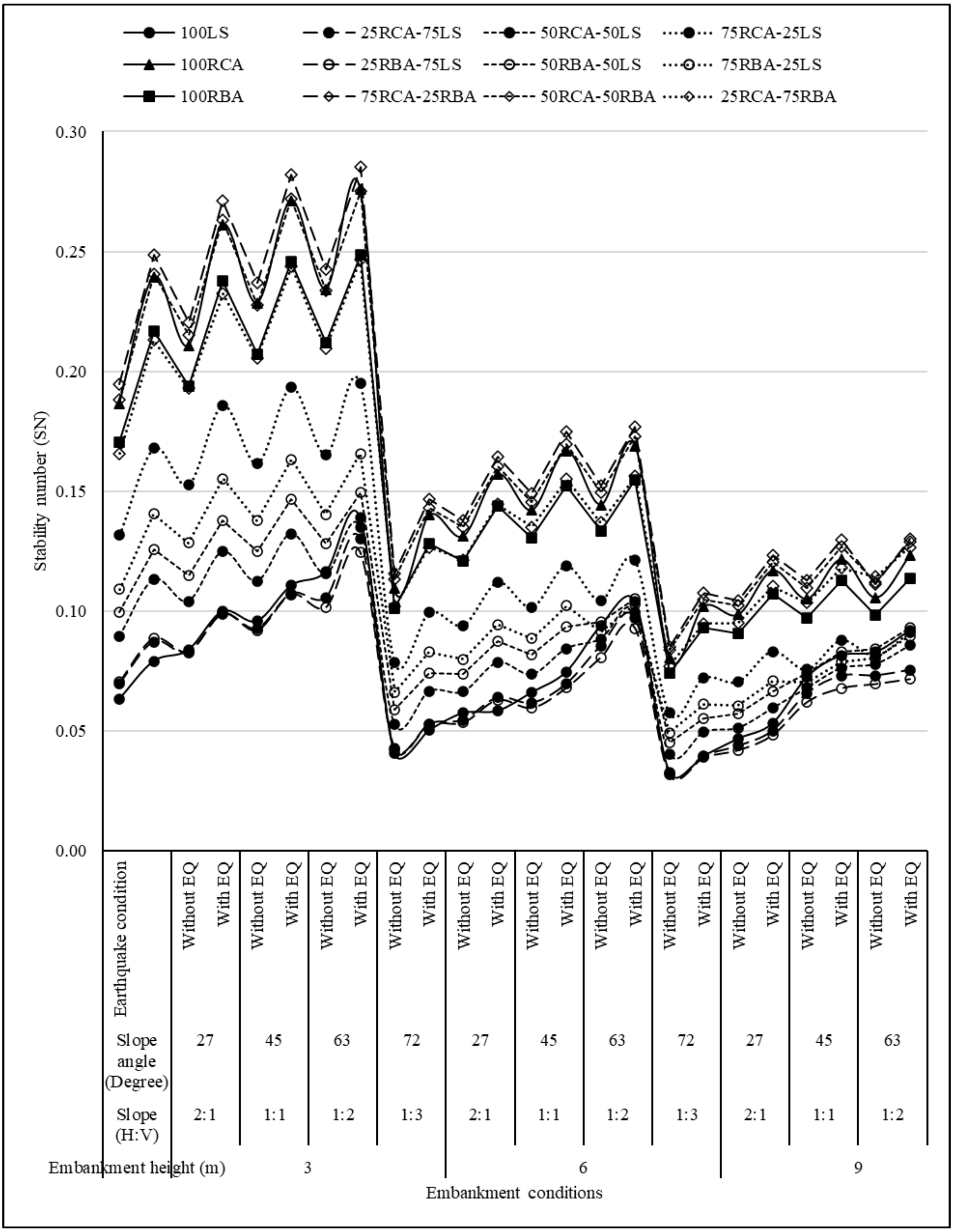

Figure 10. Determined stability number (*SN*) values for slope of embankment models

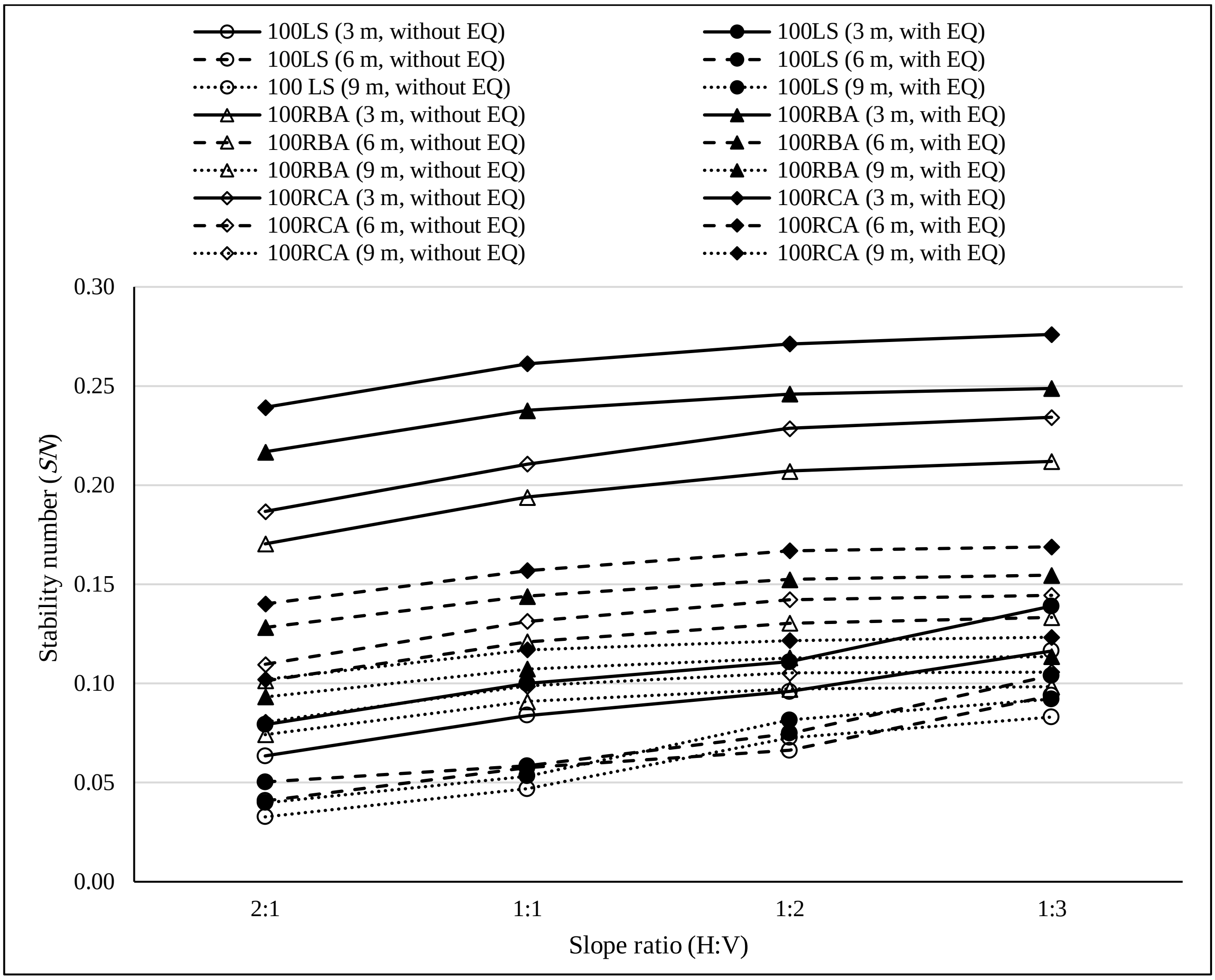

Figure 11. Determined stability number (*SN*) values for slope of embankment models (fill material; 100LS, 100RCA, and 100RBA)

Figures 10 and 11 reveal a clear pattern in the stability number values. Particularly, RCA, RBA, and their blends (RCA-RBA) demonstrate higher stability numbers, contrasting with the lower values associated with LS. The incorporation of RCA and RBA into LS seems to raise stability numbers, as evidenced by the RCA-LS and RBA-LS blends. A decrease in stability numbers is noticeable with increasing embankment height, while stability numbers show a slight increase with slope angle. Additionally, a subtle reduction in stability numbers is observed during earthquake conditions.

4. Conclusions

Following an in-depth analysis of slope stability using software model techniques, wherein model geometry, fill material properties, and loading conditions are systematically varied, the following conclusions can be derived:

- The introduction of earthquake conditions noticeably decreases the FOS values for the embankment models, underscoring the substantial threat that seismic events pose to embankment stability. This emphasizes the imperative need for meticulous consideration of seismic effects in the design and analysis of embankments.
- The composition of fill materials significantly impacts the FOS, with higher proportions of RCA or RBA resulting in increased FOS values. Incorporating RCA or RBA into LS raises FOS values to a range of 1.38 to 5.91, indicating highly stable slopes for highway embankments. A 25% RCA or RBA content in LS ensures slope stability, with FOS values approaching or exceeding 1.4.
- Slope ratios, indicated by slope angles, greatly affect FOS values. Steeper slopes lead to lower FOS values, highlighting the sensitivity of stability to slope geometry. Adding RCA or RBA to LS substantially increases the FOS of embankments, achieving stability even beyond slope angles of 45˚.

- Comparison of observed FOS values with the minimum required FOS, as per IRC: 75 guidelines, reveals that embankments employing the material combinations explored in the present study can maintain stability up to specific slope angles. This information is vital for optimizing embankment designs while ensuring stability and cost-effectiveness.
- Incorporating RCA or RBA in the embankment fill can potentially extend the safe slope angle, potentially reducing the required base width of the embankment's slope triangle. This reduction can directly impact the necessary build-up volume of the embankment and, consequently, influence construction costs.
- As a future scope, further research can focus on various types of C&D waste and their blends with problematic soils using different slope stability approaches. Additionally, the potential integration of geosynthetics with C&D waste warrants exploration.
- The slope stability results from this study are not universally applicable to all C&D waste types, as their composition can vary by source. Consequently, these findings are only relevant for waste materials with similar composition, grain size, geotechnical properties, embankment geometry & boundary conditions.

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ارزیابی پایداری شیب در خاکریزهای بزرگراه: مطالعه جامع در مورد ترکیب زباله‌های C&D به عنوان مواد پر

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چکیده:

هدف مطالعه حاضر ارزیابی کاربرد ضایعات ساخت و ساز و تخریب (C&D)، به طور خاص سنگدانه‌های بتن بازیافتی (RCA) و سنگدانه‌های آجری بازیافتی (RBA)، به عنوان مواد پرکننده در خاکریزهای بزرگراه است. ارزیابی پایداری شیب در تعیین مناسب بودن هر ماده برای پر کردن خاکریز بسیار مهم است. نرم‌افزار GeoStudio در این مطالعه برای ارزیابی پایداری شیب ۱۲ مدل با LS، RCA، RBA و ترکیبات آنها به عنوان مواد پرکننده خاکریز استفاده شده است. پیکربندی خاکریز به گونه‌ای طراحی شده است که یک بزرگراه شش خطه را نشان دهد (عرض کالسکه = ۱۳ متر، مطابق با استانداردهای IRC: 36)، دارای شیب های مختلف ارتفاع (۳ متر، ۶ متر، و ۹ متر) و نسبت‌های شیب افقی به عمودی متنوع (H:V = 2:1، ۱:۱، ۱:۲، و ۱:۳). روش Morgenstern-Price برای تجزیه و تحلیل پایداری شیب و تعیین مقادیر فاکتور ایمنی (FOS) استفاده می‌شود. این مطالعه تأثیر ارتفاع شیب، نسبت شیب، و مواد پرکننده (RCA، RBA، LS و ترکیبات آنها) را بر مقادیر FOS در مدل‌های خاکریزی برجسته می‌کند. گنجاندن RCA یا RBA در LS به طور قابل توجهی FOS خاکریز را تقویت می‌کند، از انتظارات پایداری فراتر از زوایای شیب ۴۵ درجه فراتر می‌رود و به طور بالقوه هزینه‌ها و مساحت مورد نیاز در پروژه‌های ساختمانی را کاهش می‌دهد. ادغام RCA/RBA در LS مقادیر FOS را به محدوده ۱.۳۸ تا ۵.۹۱ افزایش می‌دهد که نشان دهنده شیب‌های بسیار پایدار برای خاکریزهای بزرگراه است. بر اساس یافته‌ها، جایگزینی LS با RCA یا RBA در پر کردن خاکریز می‌تواند پایداری محیطی و کارایی اقتصادی را افزایش دهد. با این حال، این نتایج پایداری شیب به طور خاص برای زباله های C&D با ترکیب، اندازه دانه، خواص ژئوتکنیکی و شرایط خاکریزی مشابه اعمال می‌شود.

کلمات کلیدی: پایداری شیب، خاکریزهای بزرگراه، ضایعات C&D، مواد پرکننده، ضریب ایمنی.