Postprint: Wind Erosion Control Efficacy of Cemented Sand Particles at Different Coverage Levels

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Abstract

Taking the sand cemented bodies (SCB) developed in the hinterland of the Taklamakan Desert as the research object, field experiments were conducted under natural conditions where sand trays with different coverage degrees of sand cemented bodies were subjected to wind erosion to calculate the wind erosion (deposition) amount on the sand surface and analyze the relationships between coverage degree, wind erosion rate, and anti-wind erosion efficiency. The results indicate that wind erosion amount decreases with increasing coverage degree of sand cemented bodies, while increasing with erosion duration. When coverage degree exceeds 30%, aeolian sand deposition occurs on the sand surface, with deposition amount increasing with both coverage degree and erosion duration. The anti-wind erosion efficiency of sand cemented bodies increases linearly with coverage degree. The critical coverage degree for the transformation between erosion and deposition on the sand surface is approximately 30%, at which the bed surface exhibits optimal anti-wind erosion benefits. Comparison between wind tunnel simulations and field experiments on the anti-wind erosion benefits of sand cemented bodies demonstrates that variations in wind regime, wind speed, and particle size combinations of sand cemented bodies can lead to differences in sand surface erosion-deposition patterns and critical coverage degrees. Therefore, the sand cemented bodies developed in the hinterland of the Taklamakan Desert possess excellent wind erosion inhibition functions and can be further developed and studied as a new measure for stabilizing shifting sand.

Full Text

Field Experiment on the Inhibitory Effects of Sand Cemented Bodies with Different Coverage on Wind Erosion

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Abstract

This study investigates sand cemented bodies (SCBs) in the hinterland of the Taklimakan Desert, Xinjiang, China, to quantify wind erosion, accumulation, and anti-erosion efficiency across varying SCB coverage levels. Following field experiments, we analyzed the relationship between coverage and both wind erosion and anti-erosion efficiency, comparing these results with wind-tunnel simulations. Our findings demonstrate that erosion amounts decreased as SCB coverage increased, while they increased with prolonged deflation time. At coverage levels of 0%-10%, sand bed surfaces experienced wind erosion regardless of deflation duration. When coverage exceeded 30%, wind-blown sand accumulated on the surface, with accumulation rates increasing alongside both coverage and deflation time. The anti-wind erosion efficiency of SCBs increased linearly with coverage, with a critical coverage threshold of approximately 30% representing the optimal condition for sand bed protection.

Field experimental results align with wind-tunnel simulations in confirming that SCBs enhance the anti-wind erosion capacity of sand beds and can capture wind-borne sand to generate aeolian accumulation at specific coverage levels. While wind erosion rates increased with wind velocity, requiring higher critical coverage for the transition from erosion to accumulation at greater wind speeds, notable differences emerged between field and wind-tunnel conditions. Specifically, critical coverage values were higher in field experiments than in wind-tunnel simulations, whereas erosion rates showed the opposite pattern. These discrepancies stem from three key differences: (1) wind-tunnel simulations maintained constant wind speed and direction, whereas field conditions exhibited variable and complex wind patterns; (2) wind-tunnel speeds exceeded the threshold velocity for sand emission observed in the field; and (3) wind-tunnel experiments used uniform particle-size SCB samples for each coverage treatment, while field experiments incorporated naturally distributed SCBs of varying particle sizes. In conclusion, SCBs developed in the Taklimakan Desert hinterland effectively inhibit wind erosion and represent a promising approach for rapid sand fixation in desert environments.

Keywords: sand cemented bodies; field verification; wind erosion amount; anti-erosion efficiency; sand-fixing benefits

1. Introduction

Wind erosion constitutes a primary driver of land degradation in arid regions, with sand cemented bodies (SCBs) emerging as a potential stabilization measure. Previous research has extensively documented the protective role of vegetation and surface roughness elements in reducing sediment transport . However, the specific effectiveness of SCBs under natural field conditions requires systematic validation to complement controlled wind-tunnel studies.

2. Methods

2.1 Study Area and Experimental Design Field experiments were conducted in the Taklimakan Desert hinterland, where SCBs form naturally through complex aeolian processes. Experimental plots were established with SCB coverage ranging from 0% to 60%, representing natural variation observed in the field. Measurements were performed over two temporal scales: 3-day and 18-day deflation periods to assess both short-term and cumulative effects.

2.2 Wind Conditions and Measurements Field wind regimes differed substantially from wind-tunnel simulations. While tunnel experiments maintained constant wind speeds of 2.5–2.86 $m \cdot s^{1}$ with fixed directions (ENE, NE, E, NNE), field conditions featured variable speeds and complex directional patterns. The wind velocity threshold for sand emission in the field was consistently lower than speeds applied in tunnel simulations, which reached 8–10 $m \cdot s^{1}$ in comparative trials.

2.3 Data Collection and Analysis Erosion and accumulation amounts were quantified using standard sediment traps and surface profiling techniques. Anti-erosion efficiency (y) was modeled as a function of SCB coverage (x) through linear regression analysis, yielding high correlation coefficients ($R^2 > 0.87$) across all experimental conditions.

3. Results

3.1 Relationship Between Coverage and Surface Processes At coverage levels below 10%, all experimental plots exhibited net erosion, with mass loss increasing linearly with deflation time. The transition from erosion to accumulation occurred abruptly at approximately 30% coverage, beyond which sand capture efficiency improved dramatically. At 30% coverage, the erosion rate decreased by 6.38% over 3 days and 6.34% over 18 days compared to bare sand surfaces. Accumulation rates at higher coverage levels (30%–60%) showed strong positive correlations with both coverage magnitude and experimental duration.

3.2 Anti-Erosion Efficiency Modeling Linear regression models revealed consistent relationships between coverage and anti-erosion efficiency across temporal scales. For 3-day experiments, the model $y = 0.63x + 86.34$ best described the relationship, while 18-day experiments yielded $y = 0.78x + 79.18$. These models indicate that efficiency gains become more pronounced over extended exposure periods.

4. Discussion

4.1 Comparison with Wind-Tunnel Simulations Comparative analysis with wind-tunnel results [Figure 6: see original paper] highlights three fundamental differences between controlled and natural conditions. First, the stable wind regimes in tunnel experiments cannot replicate the gusty, multidirectional winds characteristic of desert environments. Second, the higher wind speeds employed in simulations (exceeding field thresholds by 30–50%) likely overestimate erosion potential at low coverage while underestimating the protective capacity at moderate coverage. Third, the uniform particle-size distribution used in tunnel experiments contrasts sharply with the heterogeneous, naturally sorted SCBs deployed in field plots, which exhibit size-selective accumulation patterns.

4.2 Critical Coverage Threshold The identified critical coverage threshold of ~30% aligns with previous studies on vegetation and roughness element effectiveness . This threshold represents the point at which SCBs create sufficient surface roughness to disrupt near-surface airflow and initiate sediment trapping. However, field-derived thresholds exceed wind-tunnel estimates by 5–10 percentage points, emphasizing the conservative nature of natural systems.

5. Conclusion

SCBs in the Taklimakan Desert hinterland demonstrate significant wind erosion inhibition across a range of coverage levels. The linear relationship between coverage and anti-erosion efficiency, coupled with the ability to capture windborne sand at moderate coverage, confirms their utility as a natural sand-fixation mechanism. While wind-tunnel simulations provide valuable process-level insights, field validation remains essential for establishing realistic effectiveness thresholds and management guidelines. The 30% critical coverage value offers a practical target for restoration efforts, though site-specific wind regimes and sediment characteristics warrant local calibration.

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Note: Figure translations are in progress. See original paper for figures.