IARJSET
ISSN (O) 2393-8021, ISSN (P) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Impact Factor 8.066 ⪤ Peer-reviewed & Refereed journal ⪤ Vol. 12, Issue 5, May 2025
DOI: 10.17148/IARJSET.2025.125178

Pullout Behaviour of Reinforced Earth Walls with Cohesive Soil: A Review

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Abstract: Reinforced earth walls constructed with cohesive backfills pose significant challenges due to the low shear strength and poor drainage properties of fine grained soils. This study reviews existing literature on the pullout behavior of geogrid reinforcements in cohesive soils, with a focus on applicability to field conditions in Dakor, Gujarat. Key research findings from laboratory and field studies including the effects of interface friction, drainage enhanced geogrids, lime treated soils, and geosynthetic type are analysed and compared. The case study of a geotechnical investigation conducted at the Dakor site reveals a subsurface profile dominated by silty clays of intermediate plasticity, with shear strength parameters and Atterberg limits comparable to those used in prior research. The review highlights that while cohesive backfills inherently limit interface friction (typically φ = 15–18°), the use of sand layers, high transmissivity geogrids, and compaction improvements can significantly enhance pullout resistance. The study concludes by recommending site specific pullout tests and interface characterization to validate design assumptions and optimize wall stability in the local context. These findings provide a basis for safer, more cost effective design of reinforced earth walls in regions with similar soil conditions.

Keywords: Pullout behavior, reinforced earth walls, cohesive soil, geogrid, interface friction, Dakor, geotechnical investigation, drainage geogrid, lime treated soil.

I. INTRODUCTION

Reinforced earth walls rely on geosynthetic inclusions (e.g. geogrids) to provide tensile strength and improve stability. In fine grained, cohesive backfills (clayey silts or clays), however, low shear strength and poor drainage can critically limit wall performance. As noted by Zornberg and Kang, failures of reinforced soil structures often involve poorly draining clays with low internal friction. In Gujarat, local soils are silty clays of intermediate plasticity that swell and soften under monsoonal moisture. Understanding the pullout behaviour of geogrid in such cohesive soils is therefore essential for safe wall design in the region. Laboratory and field studies have shown that while cohesive soils alone provide limited interface strength, geogrids can mobilize much higher pullout resistance – especially if supplemented by sand layers or drainage. This review examines key findings from relevant studies (Abdi & Arjomand 2011; Altay et al. 2019; Kang et al. 2015; Yang et al. 2012; Hossain et al. 2012) and applies them to site specific soils at Gujarat.

II. LITERATURE REVIEW

Abdi & Arjomand (2011) [1] performed laboratory pullout tests on a clay soil reinforced with geogrid encapsulated in thin sand layers. Their soil was a high plasticity clay (USCS CL) with liquid limit 53%, plasticity index 20% (in situ cohesion ~23.2 kPa, friction φ≈10°. A PET/PVC uniaxial geogrid (mesh type) was embedded at mid depth in a 300×300×200 mm box; thin sand seams surrounded the geogrid. They measured interface shear by pullout and direct shear. The reinforced soil exhibited much higher frictional strength than the clay alone. For example, direct shear on pure clay gave φ≈10° and C≈23 kPa, whereas a clay geogrid interface (with geogrid present) gave φ≈18° and C≈17 kPa. Even more striking, the pullout tests mobilized an apparent interface friction of φ≈65°, with effectively zero cohesion. In other words, the tensile pullout force of the geogrid in sand surrounded clay greatly exceeded the soil's own shear resistance. Abdi and Arjomand concluded that even a 10% area of geogrid solid interfacing with sand could dominate the interface strength (i.e. a "force multiplier" effect). In practice, this suggests that adding localized sand pockets or highly stiff zones around geogrids can dramatically boost pullout strength in clays.

DOI: 10.17148/IARJSET.2025.125178

Altay et al. (2019) [2] report laboratory pullout tests of geogrids in clay. Altay et al. used an internally developed large pullout apparatus and tested a woven polymer geogrid in a compacted clay fill under various normal stresses. They observed that pullout resistance increases with confining pressure, as expected, and that the geogrid stiffness influences behaviour. In particular, stiffer geogrids reached higher pullout loads before large strains developed. The failure mode was predominantly strain softening at the interface. Altay et al. note that the clay geogrid interface shows a hyperbolic stress–strain response and that variations in normal stress changed both peak and residual pullout stress. Although detailed data are not reproduced here, the key takeaway is that for low plasticity clays, higher normal stress (e.g. deeper embedment or surcharge) directly raises pullout capacity, and geogrid stiffness (rib thickness) is a factor in mobilized strength. In terms of Dakor soils, this suggests that overburden pressure and compaction level will significantly affect pullout.

Kang et al. (2015) [3] examined geogrids with and without in plane drainage channels in cohesive soils. They conducted pullout tests in a saturated clay using two geogrids of identical tensile strength: one standard (Paragrid 100/15) and one with drainage (Paradrain 100/15). Under the same normal stress, the draining geogrid (PD) consistently developed higher pullout resistance than the plain geogrid (PG). For example, Kang et al. reported ~15–20% higher peak pullout force for PD vs. PG at comparable displacements. The authors attribute this to the rapid dissipation of pore water pressure along the PD channels, effectively increasing soil stiffness and interface friction. In effect, the PD geogrid allowed local soil near the geogrid to remain drier and stronger under load. The implication is that in poorly draining clays, using a geogrid with engineered drainage can measurably improve pullout performance. This study emphasizes that not just material but geogrid design (porosity, drainage) can affect reinforced soil behaviour.

Yang *et al.* (2012) [4] present a *field case study* of a 6.0 m high geogrid reinforced lime treated cohesive soil wall. In this Chinese highway project, relatively soft clays were stabilized by adding lime and compacting. Two types of high strength geogrids were installed at 0.4–0.6 m vertical spacing. The wall was instrumented with earth pressure cells and strain sensors over 2 years. Yang *et al.* found that the lime treated soil itself carried most of the gravity loading, with the geogrids providing secondary tensile support (i.e. "integrity of the embankment"). Strains in the geogrids (and lateral pressure) remained quite small under normal loading; in fact, the wall behaviour was largely elastic after construction. They noted that meticulous compaction and curing of the lime–clay fill was critical, and that horizontal earth pressures decreased slightly over time as the fill strength increased. In summary, this study implies that in stiffened clays, geogrids help mainly by restraining creep and distributing loads rather than by providing vast additional strength. For Dakor, it suggests that *improving the clay (e.g. mixing lime or using controlled compaction)* could be as important as the geogrid itself. (In Yang's results, geogrid reinforcement *reduced* lateral pressure and deformation compared to unreinforced lime clay, but did not alone prevent movement.)

Hossain *et al.* (2012) [5] investigated *soil–geosynthetic interface behavior* using direct shear tests. They tested one geotextile and three geogrids against three backfills (pure sand, sandy soil, and clayey soil) under various normal stresses. The results show strong influence of soil type. For geogrid–sand interfaces, a pronounced dilative (strain hardening) response was observed: the pullout/shear force increased rapidly with displacement before softening. In contrast, *geogrid–clay* interfaces exhibited only contractive behavior (negative dilatancy): shear stress rose with displacement but did not show hardening loops. Also, all interfaces showed *nonlinear* shear strength vs. normal stress relationships (i.e. a curved envelope rather than a straight line). Specifically, Hossain *et al.* note that for clay and sandy backfills, the stress–strain response was nearly hyperbolic, with no peak beyond the initial hardening. The practical takeaway is that cohesive backfills always tend to soften under shear and give lower friction than granular soils in contact with geogrids. Geogrid design must account for this nonlinearity (e.g. using a hyperbolic interface model) rather than assume constant friction. Hossain's work underlines that Dakor's silty clay backfill will likely be contractive and have limited dilation, so the interface friction angle may be only ~15–18° (similar to the 16° they found) even if the geogrid is strong.

Kang et al. (2014) [6] performed laboratory pullout tests in fine grained (clayey) soils to evaluate geogrids with and without integrated in plane drainage channels. Two geogrid types (same tensile strength) were compared, a conventional extruded geogrid and an identical geogrid equipped with polymeric drainage layers (porous strips). Pullout tests under wet conditions showed that the geogrid with in plane drains mobilized higher pullout resistance than the conventional geogrid across all tests. This confirmed that providing an internal drainage path allows pore pressures to dissipate during pullout, thus increasing effective shear stress along the interface. Their findings support the concept that enhancing geogrid drainage can make poorly draining cohesive soils more viable as backfill. Kang et al.'s data directly tie into pullout behaviour: they quantify how interface drainage boosts pullout capacity in fine soils.

Unnikrishnan et al. (2002) [7] investigated "sandwich" reinforcement schemes in clay, where thin layers of granular soil are placed above and below a geosynthetic.

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

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DOI: 10.17148/IARJSET.2025.125178

They reasoned that since clay–geogrid interfaces are weak, surrounding the reinforcement with small thicknesses of high quality sand would improve stress transfer. Indeed, prior tests by Sreekantiah and Unnikrishnan (1992) (cited in Unnikrishnan et al.) showed a *"significant improvement in the pullout capacity of geogrids embedded in weak soils because of sandwich layers."* Unnikrishnan et al. used triaxial compression (static and cyclic) tests to confirm that reinforcing clay with sand clay sand layers greatly increased strength and deformation resistance under loading. They concluded that using thin sand layers (a "sandwich technique") around the reinforcement improves the soil–geogrid interface properties and mobilizes more of the grid's tensile capacity. This pioneering work establishes that interface modification (granular cushions or drainage) can dramatically affect pullout behaviour in cohesive fills.

Zornberg and Kang (2005) [8] introduced and began to quantify the concept of in plane drainage geogrids. In preliminary pullout experiments, they compared geogrids with identical strength but with versus without integrated drainage channels under wet, fine grained backfill. Their ongoing tests showed a clear beneficial effect: geogrids with lateral drainage mobilized higher pullout loads than conventional grids, effectively allowing the use of otherwise low permeability soils. Zornberg and Kang's conference report emphasizes that providing a path for pore water to escape along the geogrid can increase pullout capacity, a theme later confirmed by Kang et al. (2014). This work is directly relevant to pullout behavior in cohesive soils, as it demonstrates that geogrid design (e.g. adding drainage features) can mitigate pore pressure buildup during pullout and enhance interface resistance.

III. RESULTS

- Case Study: Mechanically Reinforced Earth Retaining wall at G.S.R.T.C. Dakor Bus Station.

The Dakor bus station site is underlain by silty clay fills to about 10 m. A hand auger borehole log shows that the top 0–2.5 m is miscellaneous fill, underlain by 2.5–4.0 m of yellowish silty clay (Intermediate Plasticity) and 4.0–10.0 m of dark brown silty clay (Intermediate Plasticity). Laboratory tests confirm these are CI type clays (clay of intermediate plasticity) with moderate water content. For example, one sample (4.50–4.95 m depth) had liquid limit ≈42%, plastic limit ≈22% (PI≈20%) with specific gravity 2.58. Another (7.50–7.95 m) had LL≈61%, PL≈40% (PI≈21%). All samples were classified CI and had field dry densities ~1.5 g/cm³. Direct shear tests on remoulded specimens gave small cohesion (c≈0.10–0.15 T/m²) and internal friction φ≈15–16°. (By comparison, Abdi's clay had φ=10° and φ≈18° at interface.) Thus, Dakor's native soils are silty clays with limited strength and modest drainage (CL/CI). The Atterberg data and classification confirm they behave as contractive clays.

Design parameters from the report suggest the fill is suitable as compacted backfill ("brownish silty soil of intermediate plasticity – suitable for back filling. However, the relatively low φ (~15°) implies that an unreinforced wall would require a large safety factor. Indeed, the report's safe bearing capacity calculations are based on these low shear strengths. For our purposes, the critical parameters from the Dakor soils are: moderate liquid limits (40–60%), plasticity index ~20%, dry unit weight ~1.5 t/m³, and φ ~15–16°. These are comparable to the "clayey backfill" cases in the literature.

Table 1. Soil Testing Report of sample collected from G.S.R.T.C Dakor Bus Station Site.

Lab No.	Depth (m)	Grain Size Analysis %				Atterberg Limits %									Shear Parameters		
		Gravel (%)	Sand (%)	Silt (%)	Clay (%)	LL (%)	PL (%)	PI (%)	I.S. Classification	FDD (gm/cc)	FMC (%)	Specific Gravity	Silt Factor	Swelling Pressure	Type	C (kg/cm²)	φ (Deg)
2541/Soil/1/1	4.50 to 4.95	0	35	65		42	22	20	CI	1.52	9.7	2.58	--	--	DS	0.15	13.5
2541/Soil/1/2	7.50 to 7.95	2	37	61		40	22	18	CI	1.56	13.1	2.59	--	--	DS	0.1	16
2541/Soil/1/3	10.0 to 10.40	1	42	57		38	30	8	CI	--	--	--	--	--	--	--	--

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The literature findings must be interpreted in light of Dakor's soils. Abdi & Arjomand's dramatic increase in interface strength occurred because a sand layer surrounded the geogrid; on site, we cannot easily insert continuous sand seams into the wall. However, we can mimic their benefit by using well graded compacted layers or sand bedding around reinforcement to improve bond. Kang et al. showed that incorporating drainage channels can increase pullout by ~15–20% even in clays. This suggests that using geogrids designed for internal drainage (or wrapping geogrids with geotextile filters) could improve the Dakor wall performance by letting excess pore water escape. Altay's work implies that the higher the confinement (deeper embedment or surcharge), the greater the pullout; thus, a deeper reinforcement embedment may be required to mobilize sufficient pullout in Dakor's soils.

Conversely, Hossain et al. highlight that clay backfills exhibit only contractive response (no dilation), yielding relatively low interface angles. For Dakor's clays, this means even a stiff, rough geogrid may only achieve $\varphi \approx 15–18°$ at best. If the wall is saturated (monsoon season), effective friction could be even lower. The Yang field case further suggests that improving the clay strength (e.g. with lime or cement mixing) can drastically alter behavior; in that case geogrids primarily served to hold the mass together rather than carry bulk load. For Dakor, if lime stabilization or cement column walls are not feasible, we must rely on geogrid reinforcement alone.

Given these uncertainties, laboratory pullout tests on Dakor soil are recommended before final design. Specifically, a series of pullout box tests should be performed on the actual silty clay from Dakor using the proposed geogrid type(s). These tests should vary normal stress (to simulate wall height), water content (to capture seasonal extremes), and geogrid arrangement (e.g. with/without sand sublayer or geotextile). This would yield a calibrated pullout curve (pullout resistance vs. displacement) under conditions representative of the site. From this data, one could derive an interface law (e.g. the nonlinear hyperbolic relation of Hossain et al.) for design. It would also show whether drainage geogrids or sand layers are cost effective – for example, does the geogrid give a significantly higher resistance in Dakor clay as Kang reported? Without such tests, design would either have to rely on conservative assumptions (low φ) or on extrapolating far from the known data.

This review indicates that reinforced earth walls in cohesive Dakor soils can achieve much higher pullout strength than the soil alone, but only with proper reinforcement detailing. Key findings are: (1) Standard clay interfaces are weak: the Dakor silty clay has $\varphi \approx 15°$ and will exhibit contractive shear behavior. (2) Enhanced configurations help: introducing thin sand layers or "draining" geogrid designs can raise pullout capacity substantially (as Abdi and Kang showed. (3) Engineering the soil matters: lime or cement treatment could stiffen the clay and reduce reliance on geogrid strength (Yang et al.) (4) Nonlinear interface models should be used since shear strength vs. normal stress is not linear (Hossain et al.).

Table 2. Properties of Geogrid

Type	Ultimate Strength	Durability Factor	Installation Damage Factor	Creep Factor	Coverage Ratio	Friction Angle Along Geogrids	Ci	F*=Ci* tan (ø)	α
1.00	80.00	1.15	1.04	1.45	0.20	26.56	0.80	0.23	0.80
2.00	60.00	1.15	1.02	1.45	0.20	26.56	0.80	0.23	0.80
3.00	40.00	1.15	1.02	1.45	0.20	26.56	0.80	0.23	0.80

Table 2 presents the technical specifications of three different types of geogrids supplied by Techfab India, which were used in the current study. Each geogrid type is characterized by its ultimate tensile strength, durability, installation damage factor, creep factor, and interaction parameters with soil.

- Ultimate Strength varies between 40 kN/m to 80 kN/m, indicating their tensile capacity.
- Durability Factor is consistent across all types at 1.15, representing the reduction in strength due to long-term environmental effects.
- Installation Damage Factor ranges slightly from 1.02 to 1.04, accounting for damage incurred during construction activities.
- Creep Factor is constant at 1.45, reflecting the long-term deformation under sustained loading.
- Coverage Ratio of 0.20 indicates the area ratio of geogrid coverage within the reinforced soil mass.

These parameters are crucial in designing geogrid-reinforced soil structures, influencing both internal stability and interaction with surrounding soils.

DOI: 10.17148/IARJSET.2025.125178

Using on site cohesive soil instead of imported granular fill yields huge savings. Imported quarry fill costs ~₹300/m³ (≈₹300,000 per 1000 m³). Local excavated clay has almost zero material charge i.e., only excavation/compaction Labour (say ₹20–50/m³) so 1000 m³ costs on the order of ₹20,000–50,000. This is roughly an 80–85% saving (~₹250,000) on 1000 m³, before considering haulage or material quality differences.

- Imported fill: ₹300/m³; 1000 m³ ≈ ₹300,000.
- Local cohesive fill: ≈₹20–50/m³ (labour only); 1000 m³ ≈ ₹20,000–50,000.
- Cost savings: on the order of ₹250,000 per 1000 m³ (~80–85% less).

IV. SUMMARY

The design utilizes eight layers of Techfab India geogrids placed at various depths ranging from 0.30 m to 5.80 m from the top of the wall. The tensile strengths adopted are 40 kN/m (top 3 layers), 60 kN/m (middle 2 layers), and 80 kN/m (bottom 3 layers), corresponding to increasing overburden pressure and structural demand with depth.

The pullout factor of safety (FOS) rises with depth, starting from 2.03 at 0.30 m and increasing up to 4.58 at 4.30 m, then stabilizing between 3.81 and 4.42 for deeper layers. This trend reflects the beneficial effect of greater confining pressure and higher tensile strength geogrids in deeper zones. Minimum embedment lengths (Le min) are maintained or exceeded in all layers, ensuring adequate anchorage.

Key observations:

- Higher overburden pressures and greater geogrid strengths at deeper layers result in significantly higher pullout resistance.
- The design meets or exceeds the required safety margin (FOS > 2) for all layers, confirming the wall's structural adequacy under pullout conditions.
- Provided embedment lengths (Le) and reinforcement lengths (Lr) satisfy the minimum requirements for each layer, ensuring sufficient coverage and mobilization of resistance.

This layer specific analysis confirms that the geogrid layout is optimized for strength distribution and soil interaction, particularly in a cohesive backfill context where pullout behavior is sensitive to depth and confinement.

V. CONCLUSION

This case study confirms that geogrid reinforcement renders locally available cohesive soil a technically and economically viable backfill for a 6–7 m high retaining wall. The calculated pullout FOS values (all above 2.0) indicate adequate safety margins; even the lowest values at the wall edges exceed standard design criteria. Structurally, the reinforcement engages a sufficient soil wedge to resist pullout. From an economic standpoint, substituting costly granular fill with native soil achieves substantial savings (on the order of 20–30% of wall cost) without compromising performance. These results align with published case histories and guidelines: a well monitored 7.5 m wall with cohesive backfill performed successfully, and experts note that fine grained “marginal” fills can be used in reinforced walls if adequate drainage is provided.

In summary, the reinforced wall design at Dakor demonstrates that reinforcement of a cohesive, high fines backfill is both safe and cost effective. By properly spacing geogrid layers and ensuring drainage, the inherent drawbacks of the silty clay (low φ, high plasticity) are mitigated. The analysis supports adopting local cohesive soil with geosynthetic reinforcement as a sustainable approach for retaining structures, consistent with the literature. Future implementations should still incorporate internal drainage and routine inspection, but the data strongly suggest that this method can achieve structural stability comparable to conventional designs at much lower cost.

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