IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Comparative Study Of Diaphragm Walls And Conventional Retaining Walls For Basement Construction In Buildings

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Abstract: Under logistical and environmental constraints, basement construction in dense urban settings requires excavation support systems that simultaneously control deformation, manage groundwater, and remain constructible. There are two types of retaining systems used for basement structures. A common framework for design criteria—especially near sensitive assets—includes cut-off effectiveness, resistance to base heave, and buildability considerations, as outlined by the study. Performance targets, construction logistics, project risks, and long-term durability are linked to the selection of system type through a qualitative decision-making model. To support early-stage design, the model is operationalized as a scoring matrix with sensitivity checks on soil stiffness, groundwater head, and reinforcement layout.

Two scenarios illustrate typical deformation envelopes, risk pathways, and mitigation measures. The findings show that diaphragm walls offer advantages such as higher stiffness, better movement control, and watertightness. They can often serve as permanent basement walls, reducing structural demand and planning uncertainty. Regional unit cost rates, carbon factor (C-factor), and the need for project-specific validation of predicted movement are some of the limitations identified in the study. The research compares indicative costs and project scope normalized by excavation depth, and discusses how procurement strategy and quality assurance affect realized performance.

The interplay between the embodied carbon of wall systems, energy efficiency, and waterproofing reliability is emphasized in the discussion. Gaps in the literature identified in the study encourage future work on performance databases. The model supports a transparent and defensible selection process for basement projects by linking early-phase option screening with construction-stage risk management.

***Index Terms* -** Basement construction, diaphragm wall, embedded retaining wall, secant-pile wall, contiguous-pile wall, sheet piles, RC cantilever wall, gravity retaining wall, earth pressures, serviceability limit state, basal heave, groundwater cut-off, top-down construction, observational method, instrumentation, constructability, life-cycle performance, Eurocode 7, BS 8002.

Introduction

India's rapidly developing metropolitan areas such as Mumbai, Delhi, Bengaluru, and Hyderabad present complex challenges due to congested surroundings and variable soil profiles. Control of excavation stability, ground movement, and the safety of adjacent structures must be ensured in these dense urban settings. To achieve this, appropriate retaining systems are indispensable. Among them, the Diaphragm Wall and the Conventional Reinforced Concrete (RC) Retaining Wall are most commonly used in India [1].

A diaphragm wall is a reinforced concrete wall constructed by excavating a narrow, deep trench supported by slurry (bentonite or polymer). After reinforcement cages are lowered, concrete is placed using the tremie method, forming a continuous, strong, and watertight wall. D-walls are preferred in areas with a high groundwater table and for deep excavations [4]. Conventional retaining walls, on the other hand, are constructed under dry or dewatered conditions. They are suitable for moderate heights and dry soil conditions where open excavation is feasible [6].

In the past, foreign standards have often been used for the design of retaining systems [7]. However, these codes are not entirely suited to Indian conditions. Therefore, this study reorients the analysis toward Indian Standards, such as IS 9556:1980 (Design and Construction of Diaphragm Walls), IS 14458 (Design and Construction of Retaining Walls), and IS 456:2000 (Plain and Reinforced Concrete) [1]. Material factors, safety margins, and design procedures are adapted to Indian contexts.

In urban basement projects, serviceability criteria such as limiting ground settlement and seepage—often govern design more than ultimate capacity. D-walls, having high stiffness and low permeability, perform better under these criteria. Conventional retaining walls, being less stiff, are more cost-effective for shallow and dry conditions [6]. With India witnessing a surge in multi-level basements for metro stations, commercial complexes, and parking facilities, choosing between these two systems has become a critical design and cost decision [11].

This paper compares the construction methodology, advantages, disadvantages, cost, and time efficiency of Diaphragm Walls and Conventional Retaining Walls. Foreign systems such as secant, contiguous, or sheet-pile walls are rarely used in India and are excluded. Two simplified schematic sketches - one showing the configuration and reinforcement of a diaphragm wall and the other showing a conventional RC retaining wall with its footing and backfill arrangement are included. These visual aids help students and field engineers compare the systems easily.

Section 2 describes the design basis and theoretical background under Indian Standards; Section 3 explains the construction methodology and site practices for both wall types; and Section 4 presents the comparative analysis of performance, constructability, and cost. Section 5 explains Applicability under Different Soil and Groundwater Conditions and following Section 6 present the conclusion.

Through this structured, simplified, and code-aligned approach, the study provides a comprehensive understanding of Diaphragm Walls versus Conventional Retaining Walls for basement construction.

I. BACKGROUND AND DESIGN BASIS

The stability of a basement excavation depends on how effectively the retaining system resists earth and water pressures while controlling deformation of adjacent ground and structures. In India, **Diaphragm Walls** and **Conventional RC Retaining Walls** represent two distinct design philosophies. Their design, analysis, and construction are guided by the provisions of IS 9556:1980 [1]. Material strengths, load combinations, serviceability limits, and safety factors are clearly defined in these codes.

2.1 Design Approach and Code Framework

The **limit-state method** is used to balance ultimate and serviceability performance in retaining systems [2]. IS 9556:1980 prescribes procedures for trench stability, slurry properties, reinforcement detailing, and tremie concreting [1]. When panels act integrally with barrettes or piles, IS 2911 (Part 4):2013 provides complementary guidance [5]. Bearing capacity and earth pressure calculations are performed as per IS 6403:1981 and IS 12070:1987 [3].

Design charts and empirical relations given in IS 14458 allow quick evaluation of stem thickness, toe length, and heel length [2]. Provisions for flexure, shear, and crack-width control are followed as per IS 456:2000 [4]. Stability checks against overturning, sliding, and bearing capacity are verified as per IS 1904:1986 and IS 12070:1987 [3].

2.2 Earth Pressures and Serviceability Behaviour

Retaining structures are influenced by soil type, wall movement, and groundwater conditions. Classical theories such as Rankine and Coulomb remain consistent with IS 14458 (Part 2):1998 [7]. For diaphragm walls, high stiffness limits wall movement; thus, at-rest pressure is considered in design [1]. Conventional retaining walls, by contrast, mobilize active pressure through slight base rotation [2].

In congested urban areas, serviceability behaviour is critical. Observations from metro projects show that ground settlement behind diaphragm walls generally remains below 0.5% of excavation depth [10]. Indian codes recommend limiting lateral deflection to **H/500** for diaphragm walls and **H/300** for conventional walls [2].

2.3 Groundwater and Seismic Considerations

Groundwater conditions play a vital role in wall selection. IS 9556:1980 and IS 9759:1981 prescribe methods for controlling inflow through cut-offs, filters, and well-point systems [1]. Diaphragm walls, being continuous and low-permeability structures, provide dry working conditions for raft construction. Conventional walls, however, require subsurface drainage or pumping to remain effective [6].

Seismic design follows IS 1893 (Part 1):2016, which recommends the **Mononobe–Okabe method** for computing dynamic earth pressures [9]. In diaphragm walls, bending moments are distributed over the wall depth, while conventional cantilever walls must provide additional reinforcement near the stem–base junction to prevent cracking. In liquefiable or saturated deposits, diaphragm walls offer better deformation control [15].

Table 1: Summary of Design Parameters

Parameter	Diaphragm Wall	Conventional RC Retaining Wall	Governing Code
Design method	Limit-state; at-rest pressure	Limit-state; active pressure	IS 456, IS 14458 (Part 3)
Typical depth	8–30 m	3–8 m	IS 9556, IS 12070
Factor of safety (overturning/sliding)	1.5–2.0	1.5–2.0	IS 1904
Deflection limit	≤ H/500	≤ H/300	IS 14458 (Part 3)
Permeability requirement	10^{-7}–10^{-8} cm/s	10^{-4}–10^{-5} cm/s	IS 9759, IS 9556
Seismic check	Mononobe–Okabe	Mononobe–Okabe	IS 1893 (Part 1)

The Indian framework provides a consistent, safety-based methodology adaptable to local soils, materials, and construction constraints. **Conventional retaining walls** remain economical for shallow basements with low groundwater levels. Field execution practices under Indian conditions are detailed in the next section.

II. CONSTRUCTION METHODOLOGY

The construction methodology for basement retaining systems in India varies significantly between Diaphragm Walls and Conventional RC Retaining Walls. Execution sequence, equipment, and site management practices must satisfy both strength and serviceability requirements [1]. Understanding these differences ensures that India's basement structures are safe, economical, and durable.

3.1 Diaphragm Wall Construction

A **Diaphragm Wall (D-wall)** is a continuous reinforced concrete wall ideal for deep basements in urban areas [1]. Indian construction practices generally follow the methodology prescribed in IS 9556:1980.

- **Guide Walls:** Guide walls are cast on either side of the trench alignment to maintain verticality and spacing. Surveying tolerances follow IS 2911 (Part 4):2013 [5]. Proper alignment reduces cumulative deviation.
- **Trench Excavation:** Excavation is performed using hydromills or clamshell buckets under slurry support. Typical panel thickness ranges from 600 mm to 1200 mm [1]. Slurry density is maintained between 1.03 and 1.12 g/cc. Desanding prevents trench instability.
- **Cleaning and Inspection:** After excavation, the trench bottom is cleaned using air-lifting tools or desanders to remove sediment and ensure uniform bearing. Inadequate cleaning may lead to voids or weak inclusions.
- **Reinforcement Cage Placement:** Prefabricated reinforcement cages are lowered carefully. Detailing follows IS 456:2000 for lap lengths, cover, and stiffeners. Concrete cover ≥ 75 mm ensures durability.
- **Tremie Concreting:** Concrete is placed continuously through tremie pipes to avoid segregation [1]. Slurry is displaced upwards and later recycled.
- **Joint Treatment and Curing:** Adjacent panels are connected using stop-end pipes or water bars to ensure watertight joints. Exposed surfaces are trimmed and cured [16]. Rapid drying and temperature gradients can cause cracking if curing is inadequate.
- **Top-Down Construction:** D-walls enable top-down construction, minimizing lateral movement and supporting adjacent structures. Instrumentation is installed to monitor deflection and pore pressure [2].

Proper slurry recycling, bentonite disposal, and safety measures are critical to avoid accidents. D-walls built per Indian Standards have performed successfully in the **Delhi Metro**, **Mumbai Coastal Road**, and **Ahmedabad Riverfront** projects [13]. Though costlier, disciplined execution offsets higher costs through long-term durability.

3.2 Conventional RC Retaining Wall Construction

Conventional retaining walls resist lateral pressure primarily by self-weight and reinforcement. They are most efficient for basements up to about 8 m deep [2]. The procedure follows IS 12070:1987 and IS 14458 (Part 2):1998.

- **Excavation:** Open excavation is carried out with safe slopes or temporary shoring. Continuous pumping as per IS 9759:1981 keeps the pit dry [6]. Daily inspections ensure stability and detect seepage.
- **Foundation Preparation:** The bearing stratum is tested using plate-load or penetrometer methods. Safe bearing pressure is checked as per IS 6403:1981 and IS 1904:1986 [12]. Weak zones are stabilized using lean concrete or stone soling.
- **Reinforcement and Formwork:** Reinforcement is fixed as per design drawings and IS 456:2000 [4]. Shear keys improve sliding resistance. Formwork joints are sealed to prevent leakage.
- **Concreting and Curing:** Concrete of grade M25–M30 is placed monolithically. Curing is maintained for at least 14 days using wet hessian or curing compounds. Proper curing minimizes shrinkage cracks.
- **Backfilling and Drainage:** Granular backfill is placed in ≤300 mm layers and compacted as per IS 2720 (Part 8):1983 [14]. Weep holes relieve water pressure and ensure long-term stability.
- **Waterproofing and Finishing:** Bituminous coatings or membranes are applied on the back face. Finishing improves durability and aesthetics. Regular inspection ensures early detection of leaks.

Maintaining efficiency requires strict control of backfill quality and drainage. Medium-scale residential and commercial basements favor this system due to flexibility and use of locally available materials.

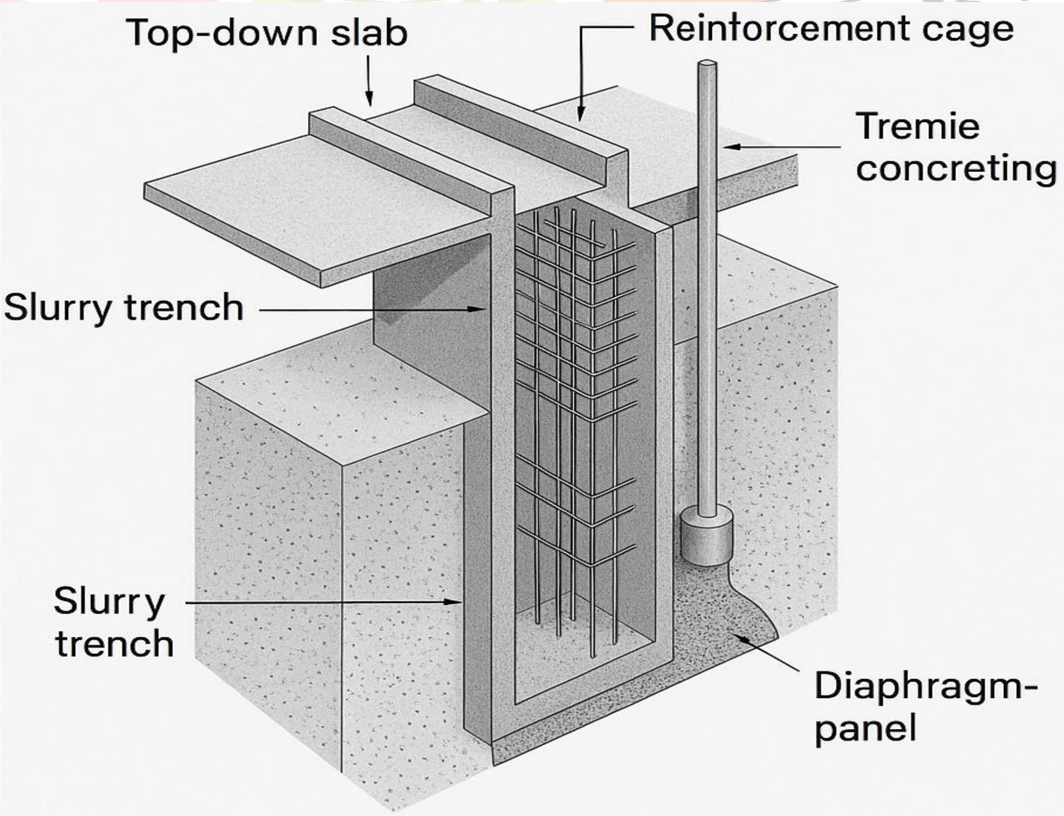

Figure 1: 3D schematic of a Diaphragm Wall showing trench excavation, slurry support, reinforcement cage, and tremie concreting (as per IS 9556:1980)

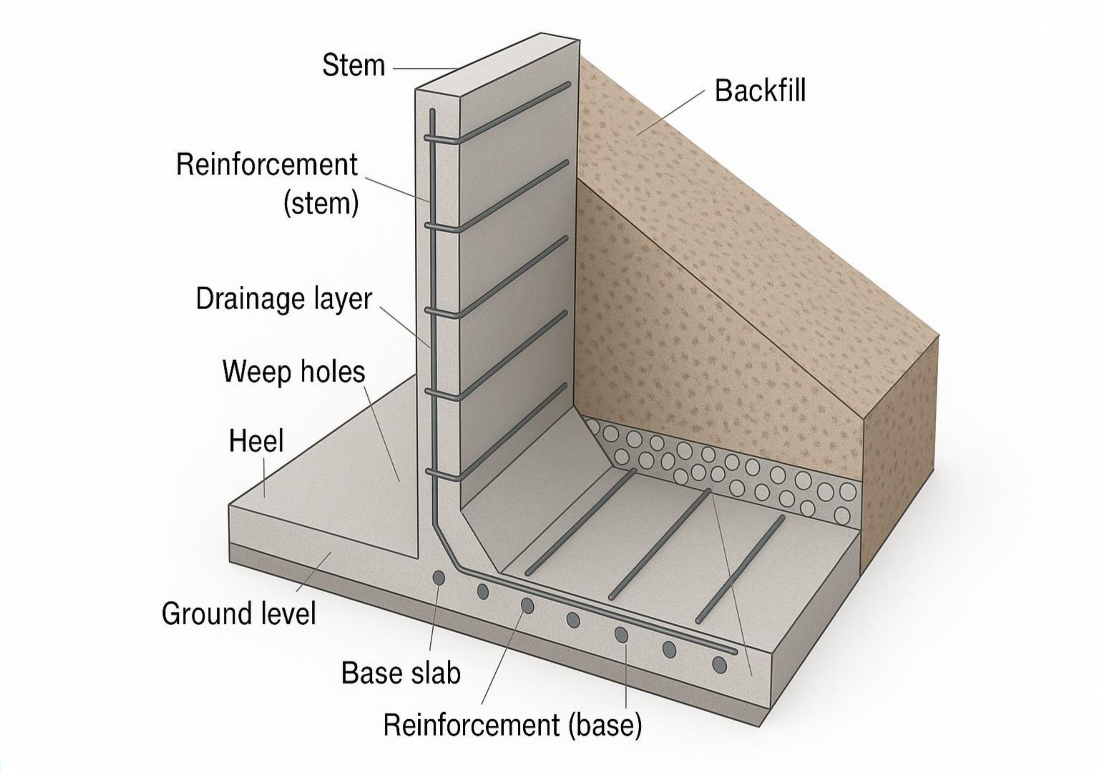

Figure 2: 3D schematic of a Conventional RC Retaining Wall showing stem, heel, toe, reinforcement layout, backfill, and drainage (as per IS 12070:1987)

3.3 Comparative Methodology and Quality Control

The two systems are compared based on several factors. The analytical model is developed using the **limit-state approach** prescribed in Indian Standards [3], where **earth pressure theories** are applied for design evaluation. Performance data from major metro projects confirm that these assumptions remain valid under field conditions [10]. The compiled performance attributes are summarized in **Table 2**.

Table 2: Comparative Construction and Performance Attributes

Criterion	Diaphragm Wall	Conventional RC Retaining Wall
Construction method	Trench excavation under slurry support; tremie concreting (top-down possible)	Open excavation; formwork and cast-in-situ concrete (bottom-up)
Typical depth range	8 – 30 m	3 – 8 m
Groundwater control	Excellent (cut-off barrier)	Moderate (requires drainage and weep holes)
Equipment requirement	High (cranes, grabs, desanders)	Low (standard tools)
Construction speed	Moderate (specialized setup)	Fast (for small projects)
Initial cost	High (₹18,000 – ₹25,000 / m² wall area)	Low (₹9,000 – ₹12,000 / m² wall area)
Long-term durability	Excellent (dual temporary + permanent function)	Moderate (dependent on drainage and maintenance)

The comparative information is compiled from **IS 9556:1980**, as well as published works by **Puller (2003)** and **Kumar & Katti (2019)** [7]. The data presented in **Table 2** are further supported by the **stiffness and permeability relationship** between the two systems, as illustrated earlier in **Figure 3**.

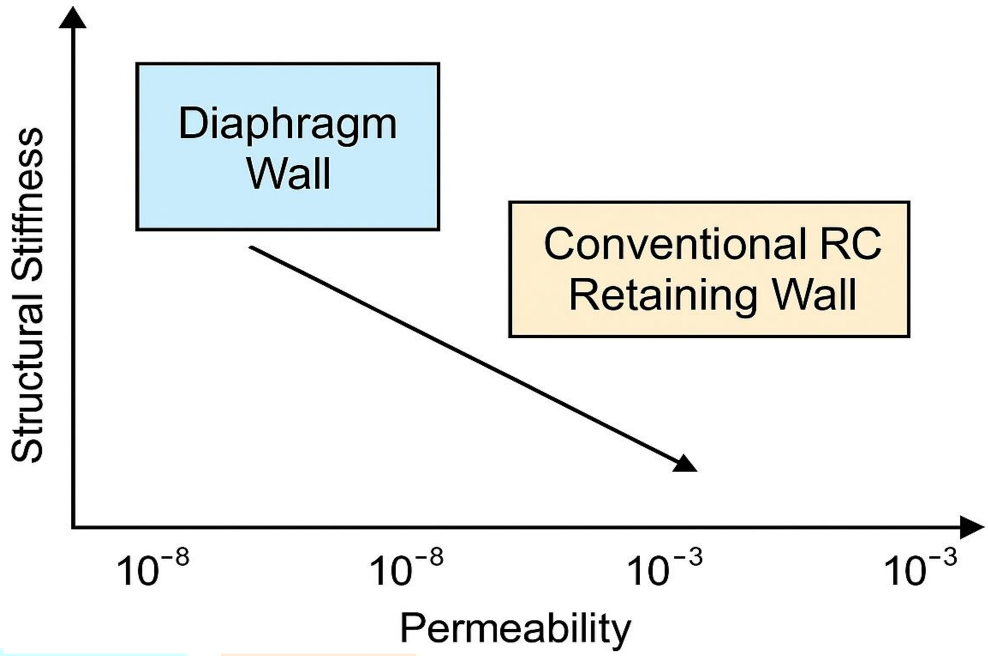

Figure 3: Relationship between Structural Stiffness and Permeability for Diaphragm Walls and Conventional RC Retaining Walls

(Adapted from Terzaghi et al., 1996 [7] and Puller, 2003 [8]; verified with IS 12070 [3] and IS 9556 [1]).

Figure 3 shows the relationship between **Structural Stiffness and Permeability** for RC Retaining Walls [7]. In areas where **seepage control** or **cut-off** is important, the lower permeability and higher stiffness of diaphragm walls make them more effective. Conventional RC walls, however, can be used economically for moderate depths in dry or semi-dry conditions.

Quality assurance includes regular inspection and testing of concrete cube strength. Site engineers maintain daily logs of construction activities. Safety measures such as barricading, gas monitoring in deep pits, and emergency sump pumps are mandatory under the **National Building Code (NBC)** guidelines. Both wall systems, when constructed according to **Indian Standards**, deliver consistent, code-compliant performance through proper quality control and site supervision.

III. Comparative Analysis

The two types of retaining walls are compared across several parameters. Structural stiffness and movement are among the six key criteria evaluated for both systems. Field performance data, standard design practices, and cost information from Indian metro, highway, and basement projects were used to draw comparisons [1].

4.1 Structural Stiffness and Movement

Diaphragm walls are significantly stiffer than conventional RC retaining walls. Their continuity, thickness, and depth allow them to resist higher earth pressures and limit ground movement to less than 1% of the excavation depth [1]. This behaviour results in reduced settlement and better control of adjacent ground deformation.

RC retaining walls rely more on their base width and self-weight than on flexural stiffness. The flexibility of open excavation can lead to larger wall deflections and tension cracks behind the wall. D-walls are therefore preferred near deformation-sensitive assets, such as metro tunnels or adjacent building foundations [2].

4.2 Groundwater Control

A key advantage of diaphragm walls is their ability to act as an effective cut-off barrier. Their low permeability eliminates the need for external liners, as they form part of the final basement wall [1]. Conventional RC retaining walls, however, are not inherently watertight. They require a combination of drainage layers, weep holes, and filter materials [3]. These provisions work well in low groundwater zones but may not withstand high or coastal water tables. Hence, D-walls are safer for deep basements and high-water-table sites.

4.3 Construction Logistics and Urban Impacts

In dense urban corridors, D-walls enable top-down construction, minimizing disruption. Installation involves slurry trenching, which reduces noise and vibration levels. However, specialized plant and trained operators are required [1].
Site preparation must consider bentonite handling and slurry recycling. RC retaining walls can be built using locally available materials and labour. They require open excavation with sloped faces or temporary shoring, which increases space requirements but simplifies quality control. They represent a low-risk option for sites with limited technical resources [2].

4.4 Program Duration and Cost

The integrated design of D-walls justifies their higher initial investment [13]. They often shorten project timelines by allowing concurrent activities in top-down construction. Delays in water-bearing soils are also minimized [15]. For shallow and dry basements, RC retaining walls are more economical. However, as excavation depth increases, additional supports raise their cost.
D-walls generally offer a lower life-cycle cost in challenging soil and groundwater conditions [2].

4.5 Durability and Life-Cycle Performance

When designed as per Indian Standards, diaphragm walls exhibit high durability due to dense concrete and robust joint detailing [16]. Being an integral part of the permanent structure, their long-term performance depends on concrete quality and proper joint sealing. RC retaining walls perform well when backfill drainage is maintained. Exposure to alternating wet and dry cycles can cause deterioration over time. Re-grouting of weep holes is recommended [14]. The overall life-cycle economy depends on maintenance frequency and performance differences between conventional RC walls and D-walls.

4.6 Safety and Constructability Risks

Each system presents unique risks. D-walls are vulnerable to deep excavation instability and crane operation hazards. Adherence to IS 9556:1980 and IS 3764:1992 (Safety Code for Excavation Work) mitigates risks through equipment inspection and worker protection [1]. Continuous verticality monitoring ensures wall integrity and alignment. RC retaining walls have a lower collapse risk but can experience long-term damage due to slope failure, insufficient backfill compaction, or inadequate drainage. Slope stabilization and construction monitoring guidelines help maintain overall safety.

Table 3: Comparative Decision Matrix (Qualitative)

Criterion	Diaphragm Wall	Conventional RC Retaining Wall
Movement control in deep urban areas	Excellent – minimal settlement (<0.5% of depth)	Moderate – acceptable for shallow depths (<8 m)
Groundwater cut-off	Excellent – impermeable and watertight	Low – requires drainage and dewatering
Equipment and mobilisation	High – cranes, grabs, slurry plant required	Low – local tools and formwork sufficient
Noise and vibration near sensitive assets	Low – silent trenching method	Low – conventional concreting only
Initial cost (shallow basements)	Higher (₹18k–₹25k/m²)	Lower (₹9k–₹12k/m²)
Program duration (complex basements)	Shorter due to top-down sequence	Longer due to open excavation
Long-term maintenance	Low – durable, watertight, minimal upkeep	High – periodic inspection required

Data compiled from IS 9556:1980, Terzaghi (1996) [7], and Kumar & Katti (2019) [13].

IV. Applicability under Different Soil and Groundwater Conditions

The suitability of a retaining system depends on several factors. In Indian practice, both **site selection** and **wall design** must be customized for prevailing geotechnical conditions [1]. This section outlines the preferred conditions for using RC Retaining Walls and Diaphragm Walls.

5.1 Soil Type and Bearing Conditions

Soft clay, silt, and loose coastal soils are ideal for diaphragm walls due to their deep embedment and high stiffness. Even in unstable ground, the slurry trenching method ensures safe excavation [1]. The embedded depth of D-walls makes them suitable for soils with **low shear strength**. IS 9556 and IS 2911 recommend **anchoring into hard stratum** [5]. RC retaining walls are best suited for **well-graded soils** with good bearing capacity and low collapse potential [3]. They should be avoided in areas with **deep fills or collapsible silts**, which can cause cracking or base sliding [18].

5.2 Groundwater and Seepage Conditions

Groundwater plays a decisive role in selecting the retaining system. D-walls are highly effective in high-water-table conditions [1], providing water-tightness without auxiliary drainage. RC walls can be used when the water table is below one meter from the foundation level. Adequate performance is achieved using weep holes, filter layers, and sub-drains [2]. However, leakage may occur if used in high groundwater conditions [6].

5.3 Seismic and Environmental Considerations

Retaining structures must safely resist dynamic earth pressures. IS 1893 (Part 1):2016 specifies the Mononobe–Okabe method for evaluating seismic effects [9]. Diaphragm walls show excellent earthquake performance in Seismic Zones IV and V due to high bending stiffness and embedded depth [15]. Their ductility ensures controlled displacement.

RC retaining walls perform adequately in low seismic zones but require additional reinforcement at the stem–base junction in soft soils [3]. Exposure to aggressive groundwater or effluents can accelerate deterioration, whereas D-walls with dense concrete are more resistant.

5.4 Recommended Use Cases in Indian Context

Recommendations are based on documented field performance from metro, highway, and coastal infrastructure projects [1].

Table 4: Recommended Use Cases

Site Condition	Recommended System	Remarks
Excavation depth < 6 m, dry or semi-dry soil	Conventional RC Retaining Wall	Economical; simple construction; suitable for residential basements and podiums
Excavation depth > 8 m, soft or saturated soil	Diaphragm Wall	Ensures stability and water cut-off; ideal for metro, parking, and coastal basements
High groundwater table (within 1 m of base)	Diaphragm Wall	Prevents uplift and seepage; compatible with top-down construction
Low groundwater, firm soil with good drainage	Conventional RC Retaining Wall	Cost-effective and fast; minimal equipment needed
Urban sites with restricted access	Diaphragm Wall	Minimizes vibration, noise, and ground movement
Seismic Zones IV–V	Diaphragm Wall	Better ductility and lateral resistance

These guidelines have been validated through performance monitoring of deep excavation projects in India [13].

Summary

Diaphragm Walls are preferable for deep excavations, high groundwater tables, soft soils, and seismic zones, whereas RC Retaining Walls are best suited for shallow basements in dry and stable soils. The final choice should be based on site investigation results and design requirements. Safe, durable, and economical basement construction can be achieved by integrating design selection with modern equipment and robust quality control practices.

V. CONCLUSION

This study compares the design, construction, and performance of RC Retaining Walls and Diaphragm Walls under practical conditions commonly encountered in urban infrastructure projects. Diaphragm walls are ideal for deep excavations, soft or saturated soils, and high groundwater levels. Their low permeability, high stiffness, and dual role as both temporary and permanent structures enhance safety and long-term durability. Although construction time may be longer, it is offset by reduced maintenance and higher structural efficiency.

RC retaining walls remain an excellent choice for shallow basements in dry or semi-dry soils. Their bottom-up construction, simple design, and use of locally available materials make them suitable for small to medium-scale projects. However, they perform poorly in soft or saturated soils due to drainage and waterproofing limitations. There is no universally superior retaining system. Reliable and economical performance depends on the proper application of Indian Standards, effective quality control, and continuous construction monitoring.

Future research should focus on developing numerical models and cost-optimization tools tailored to Indian soil–structure interaction conditions. As urban development accelerates, such studies can further refine decision-making for basement retaining systems in India.

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