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Geo-Base Isolation Using Construction and Demolition waste-Tyre Crumb Mixtures: Shake Table Investigation

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Abstract—**Earthquake-induced structural damage can be significantly mitigated through base isolation systems, yet conventional solutions remain cost-prohibitive for developing regions. This study investigates the geo-base isolation potential of Construction & Demolition waste-Tyre crumb Mixtures (CDTM) using 0%, 10%, 20%, 30%, 40%, 50%, and 100% tyre content by weight. Physical properties showed systematic reductions in specific gravity from 2.27 to 1.10, minimum dry unit weight from 13.67 to 4.45 kN/m³, and maximum dry unit weight from 17.49 to 6.99 kN/m³ with increasing tyre content. C&D waste was classified as poorly graded gravel (GP) while tyre crumbs showed SP-equivalent characteristics per IS 1498. Shake table tests at 3 Hz on a 40×40 cm table measured Peak Acceleration Ratio (PAR = PGAframe/PGAbase) and settlement in a 4 cm CDTM layer using a 1-storey aluminium frame model. CDTM 30 (30% tyre content) provided optimum performance with PAR = 0.78, achieving 36% acceleration reduction compared to without base isolation, with acceptable settlement. Excess tyre content above 30% increased PAR due to excessive flexibility. CDTM 30 demonstrates sustainable geo-base isolation using locally available waste materials.**

Index Terms—**Geo-base isolation, Construction and demolition waste, Tyre waste-derived rubber, Shake table test, Seismic response reduction, Sustainable seismic engineering.**

I. INTRODUCTION

Earthquakes pose significant threats to structures worldwide, particularly in seismically active regions where ground motions can amplify structural responses and cause catastrophic failures [1]. Conventional seismic isolation systems using high-damping rubber bearings or lead-rubber bearings effectively reduce structural acceleration but remain cost-prohibitive for widespread adoption, especially in developing countries[2]. Recent research has explored geotechnical seismic isolation systems using sand-rubber mixtures as sustainable alternatives, demonstrating substantial reductions in peak acceleration transmission through viscoelastic damping [3], [4]. However, these studies predominantly utilized clean sand as the base material, limiting practical applicability in regions where natural aggregates are scarce or expensive.

India generates approximately 150 million tonnes of construction and demolition (C&D) waste annually [5].Urban India faces acute C&D waste management challenges with limited recycling infrastructure. Infrastructure barriers including limited processing plants, weak enforcement by urban local bodies, and lack of market demand for recycled aggregates hinder C&D waste utilization [6], [7]. Simultaneously, millions of scrap rubber tyres accumulate in landfills, presenting both environmental hazards and untapped material resources [8]. The geotechnical properties of C&D waste—primarily crushed bricks, concrete, and mortar—offer angular particle morphology suitable for engineering applications, while rubber tyre crumbs provide inherent damping characteristics [9]. Combining these locally available waste materials creates Construction & Demolition waste-Tyre crumb Mixtures (CDTM) with potential as geo-base isolation systems, yet no systematic investigation exists on their seismic performance.

Previous shake table studies identified optimum rubber contents between 20-40% for sand-rubber mixtures, achieving peak acceleration ratio (PAR) reductions of 30-60% compared to rigid bases [10]. However, C&D waste exhibits different particle characteristics—lower specific gravity, poorly graded profiles, and higher angularity—compared to uniform silica sand, potentially altering the damping-stiffness balance critical for isolation effectiveness [11]. The interaction between C&D angular particles and rubber crumbs under dynamic loading remains unexplored, representing a significant research gap.

This study systematically evaluates CDTM mixtures containing 0%, 10%, 20%, 30%, 40%, 50%, and 100% tyre content by weight using gravimetric proportioning. Comprehensive physical characterization established grain size distribution, specific gravity, and minimum/maximum dry unit weights for all mixtures. Shake table tests conducted at 3 Hz input frequency measured PAR (PGA_frame/PGA_base) and settlement in a 1-storey aluminium frame model, identifying the optimum CDTM composition balancing acceleration reduction with acceptable deformation.

II. LITERATURE REVIEW

Conventional base isolation systems employing high-damping rubber bearings, lead-rubber bearings, and friction pendulum systems effectively decouple structures from ground motions, reducing inter-story drifts by 70-80% and floor accelerations by 40-60%[2]. These manufactured isolators achieve this performance through high initial stiffness (k=500-2000 kN/m) transitioning to low post-yield stiffness under displacement, providing both stability and energy dissipation. However, their high material and installation costs limit widespread adoption, particularly in developing countries where seismic risk is high but construction budgets remain constrained [1].

GeoBase isolation systems offer a cost-effective alternative, substituting engineered bearings with thick deformable granular layers (300-600 mm) that dissipate seismic energy through particle re-arrangement, frictional sliding, and viscoelastic damping. Shaking table experiments demonstrate these systems achieve peak acceleration ratio (PAR) reductions from 1.0 (rigid base) to 0.4-0.7 across 0.2-0.5g input motions, comparable to conventional isolators at 10-20% of the cost. The mechanism involves inter-granular shear deformation creating hysteretic loops with equivalent viscous damping ratios of 15-35% [1], [4].

Sand-rubber mixtures represent the most extensively studied geobase material system. Cyclic triaxial tests reveal optimum performance at 20-40% rubber content by volume, where shear modulus (G) reduces from 80 MPa (pure sand) to 30-50 MPa while damping ratio (D) increases from 8% to 25-35% across typical earthquake shear strain amplitudes (10^{-3} to 10^{-1}) . Shaking table studies on 1:4 scale single-story frames confirm PAR values of 0.45 at 0.3g input with 30% rubber, accompanied by manageable residual settlements below 12 mm [3], [10]. Field trials of gravel-rubber layers (200 mm thick) beneath temporary structures validate laboratory performance, showing 40-50% acceleration reductions during moderate shaking [12]. Rubber-soil dynamic properties confirm enhanced damping ratios and shear modulus reduction across 10-50% rubber content ranges through viscoelastic hysteresis mechanisms [13], [14], [15], [16].

Geogrid-reinforced geo-base isolation systems have demonstrated superior seismic protection for low-rise buildings through enhanced lateral confinement and shear energy dissipation. These systems combine recycled materials with geosynthetic reinforcement to achieve optimal stiffness degradation characteristics under cyclic loading [17].

Material scalability challenges arise from aggregate shortages, particularly clean silica sands. India generates approximately 150 million tonnes of construction and demolition (C&D) waste annually, primarily angular crushed concrete and brick exhibiting poorly graded profiles with comparable compaction characteristics to natural gravels. These materials demonstrate California Bearing Ratio (CBR) values of 25-40% and friction angles of 38-45°, positioning them as viable substitutes for seismic isolation applications [18] . C&D waste geotechnical reuse requires standardized processing to address variable aggregate quality and fines content issues [19], [20], [21].

Scrap tire crumbs simultaneously provide superior damping properties, with loss factors exceeding typical synthetic elastomers. Dynamic property tests confirm rubberized granular mixtures maintain adequate stiffness while achieving damping ratios 2-3 times higher than pure granular materials. The synergy between C&D waste's structural stability and tire crumb's energy dissipation capacity suggests Construction & Demolition waste-Tyre crumb Mixtures (CDTM) as sustainable geo-base isolators [22], [23].

Critical research gaps persist regarding CDTM performance under dynamic loading. C&D waste's heterogeneous characteristics may significantly alter the damping-stiffness balance established for uniform sand systems [11] . No systematic shake table investigations exist evaluating C&D waste-tyre crumb interactions across practical rubber content ranges, representing a substantial opportunity for sustainable seismic isolation innovation [24].

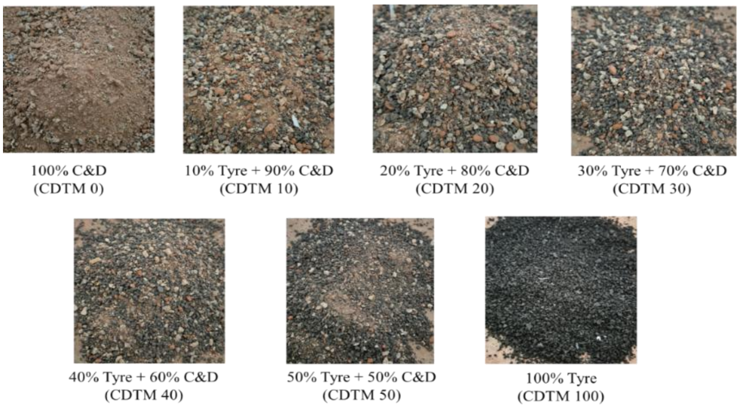
III. METHODOLOGY

Materials

Construction and demolition (C&D) waste, serving as the primary granular component, was collected from an active dumping site in Chinnavedampatti, Coimbatore. The raw material predominantly consisted of fragmented bricks, concrete chunks, mortar fragments, and minor ceramic tiles, reflecting typical demolition debris compositions observed in Indian urban contexts. These were processed through mechanical crushing followed by sieving to isolate particles passing a 4.75 mm sieve, yielding angular granules suitable for dynamic loading applications.

Scrap rubber tyres were procured from a nearby recycling facility, where steel reinforcements and textile fibres were meticulously extracted from heavy-duty truck and lorry casings. Such sources yield higher natural rubber content, conferring enhanced abrasion resistance and longevity relative to passenger vehicle tyres. The cleaned tyre shreds underwent further granulation via industrial shredders, producing angular crumbs uniformly below 4.75 mm.

C&D waste and tyre crumbs were then manually mixed to obtain homogeneous compositions, ensuring uniform distribution through thorough hand blending. The resulting Construction & Demolition waste-Tyre crumb Mixtures (CDTM), designated as CDTM 0 (pure C&D), CDTM 10, CDTM 20, CDTM 30, CDTM 40, CDTM 50 (with tyre content at 0%, 10%, 20%, 30%, 40%, and 50% by dry weight, respectively), and pure tyre (CDTM 100), employed gravimetric proportioning for precise compositional control over volumetric methods. Figure 1 shows the test samples.



100% C&D (CDTM 0)
10% Tyre + 90% C&D (CDTM 10)
20% Tyre + 80% C&D (CDTM 20)
30% Tyre + 70% C&D (CDTM 30)
40% Tyre + 60% C&D (CDTM 40)
50% Tyre + 50% C&D (CDTM 50)
100% Tyre (CDTM 100)

Figure 1 Test Samples

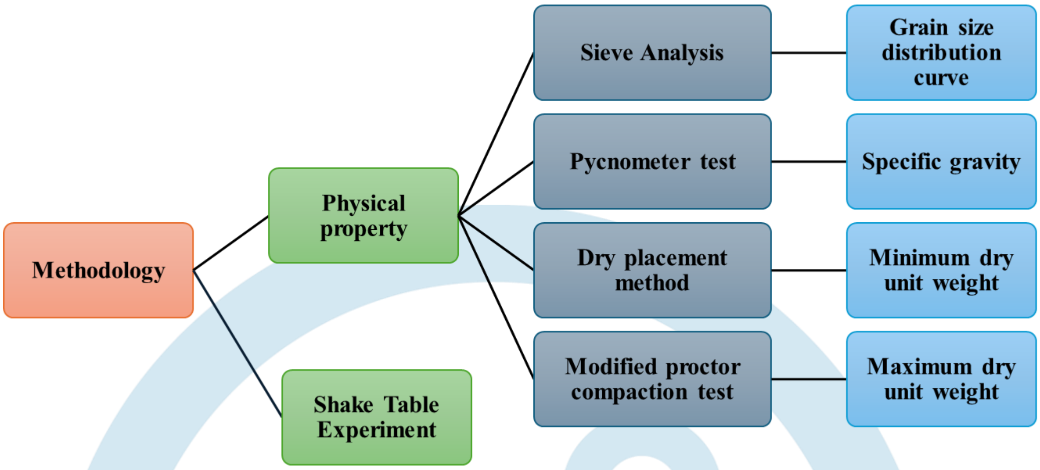


Figure 2 Methodology

Physical Characterisation

Grain size distributions were determined through standard dry sieving following IS 1498 [25], with gradation curves plotted and presented in figure 3. Pure C&D waste exhibited poorly graded gravel (GP) characteristics defined by Cu = 10.65 and Cc = 0.80, typical of crushed demolition debris with limited fines content[26]. In contrast, tyre crumbs—classified as granulated rubber according to ASTM D6270 [27] standards demonstrated poorly graded sand-equivalent (SP) behaviour with Cu = 2.43 and Cc = 1.15, reflecting their relatively uniform particle size distribution dominated by 1-4.75 mm granules.

Specific gravity measurements were performed using the pycnometer method, revealing a marked progressive reduction from 2.27 for pure C&D waste to 1.10 for pure tyre crumbs as rubber content increased across the CDTM series. This systematic decline attributable to rubber's inherently low density underscores the mixtures' transition toward lightweight compositions conducive to seismic energy dissipation[28] .

Minimum and maximum dry unit weights were evaluated following ASTM D4254 [29] and ASTM D4253 [30] standards, respectively, to define the mixtures' achievable density range under dynamic conditions. Results documented in Table 2 indicate consistent reductions with escalating tyre content: minimum dry unit weight decreased from 13.67 kN/m³ (pure C&D) to 4.45 kN/m³ (pure tyre), while maximum dry unit weight fell from 17.49 kN/m³ to 6.99 kN/m³. These trends indicate reduced skeletal density and increased void ratios, promoting the shear deformability required for effective base isolation while preserving sufficient bearing capacity under structural loading [23].

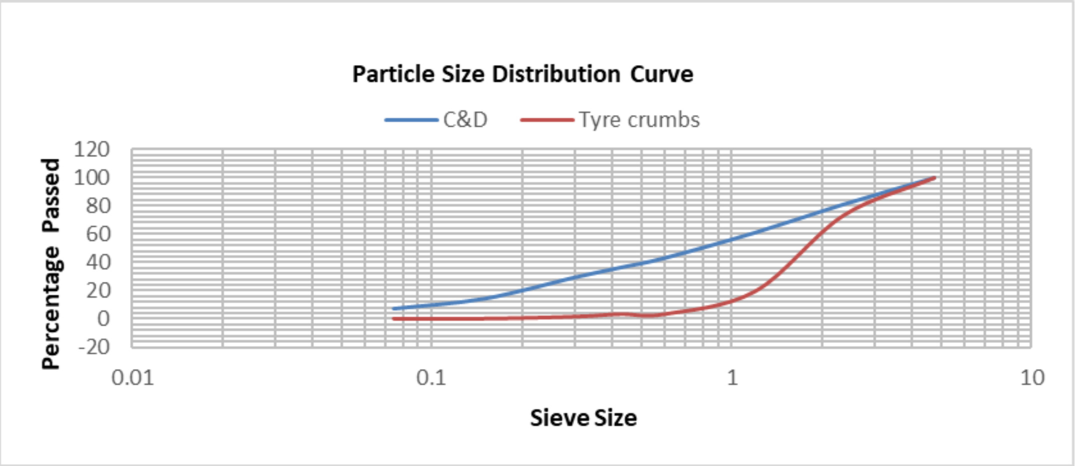


Figure 3 Particle Size Distribution Curve

Table 1 Grain Size Characteristics

Property	C&D	Tyre crumbs
D_{10} (mm)	0.11	0.85
D_{30} (mm)	0.32	1.43
D_{60} (mm)	1.16	2.08
Coefficient of Curvature (C_c)	0.80	1.15
Coefficient of Uniformity (C_u)	10.65	2.43

Table 2 Physical properties of CDTM

CDTM %	Max dry unit weight (KN/m^3)	Min dry unit weight (KN/m^3)	Specific Gravity
CDTM 0	17.49	13.67	2.27
CDTM 10	15.97	11.69	2.04
CDTM 20	14.26	10.54	1.78
CDTM 30	12.87	9.41	1.64
CDTM 40	12.34	9.31	1.49
CDTM 50	10.47	7.51	1.35
CDTM 100	6.99	4.45	1.1

Shake Table experimental setup

The dynamic performance of CDTM mixtures was evaluated using a uniaxial horizontal shake table facility equipped with a 1 HP variable speed motor, capable of controlled sinusoidal excitations. The shaking platform measured 40 cm × 40 cm, featuring a circular mounting plate of 39 cm diameter to ensure stable specimen containment. An acrylic fiberglass container (34 cm × 20 cm × 15 cm depth, open at the top) housed the CDTM samples, filled to a consistent 4 cm thickness to replicate practical geo-base isolation layer dimensions.

A single-storey aluminium frame model (30 cm × 15 cm base, 20 cm height), representative of low-rise structures common in seismic zones, was positioned centrally atop each CDTM layer. The frame's lightweight rigid construction facilitated clear measurement of acceleration transmission. Acceleration monitoring employed two high-sensitivity accelerometers using inbuilt mobile sensors via the phyphox mobile application, with gravity components systematically removed from recordings to isolate horizontal seismic inputs. One sensor was affixed to the frame's top level to capture transmitted structural acceleration (PGA_frame), while the second was mounted on the shake table platform to record input base acceleration (PGA_base), both oriented along the principal X-axis of motion [10].

Settlement measurements utilized three precision rulers strategically placed at the left, center, and right edges of the acrylic container, enabling average deformation calculation to account for potential non-uniform subsidence. This multi-point approach provided reliable quantification of residual settlements post-shaking [1].

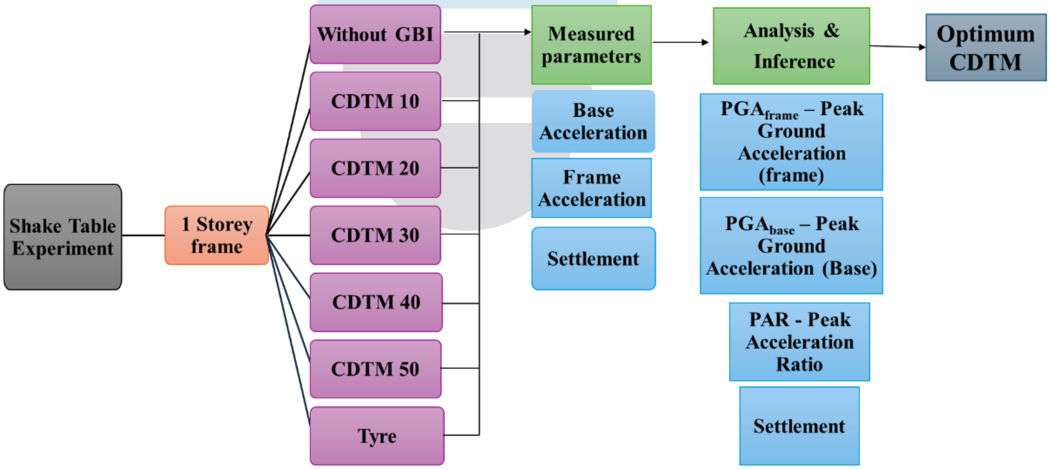


Figure 4 Shake table test methodology

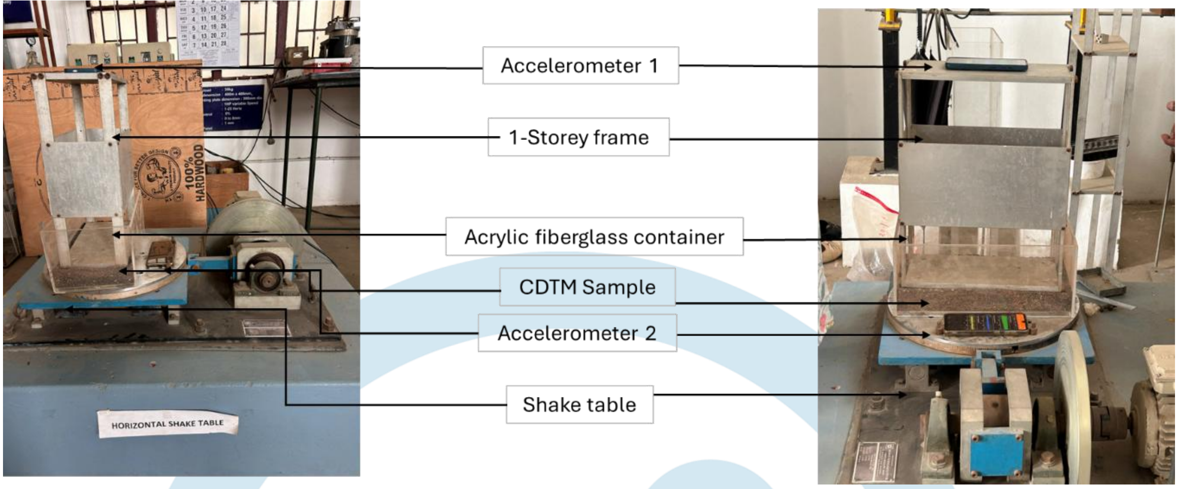


Figure 5 Shake table experimental setup

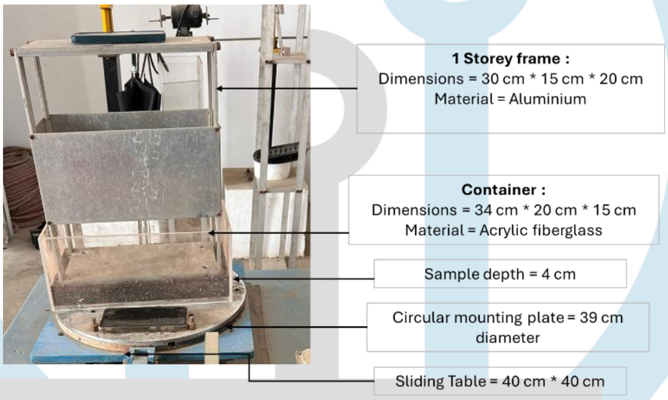


Figure 6 Shake table dimensions

Test Procedure and Data Acquisition

Each CDTM composition (CDTM 0 through CDTM 50, plus CDTM 100) underwent one shake table test, with a rigid base condition (no GBI) tested separately for direct comparison of base isolation effectiveness. Tests applied 3 Hz sinusoidal input frequency sustained for 2 minutes, with acceleration-time histories extracted over representative 10-second windows for analysis.

Raw acceleration signals from phyphox were processed in Excel, where absolute peak values determined PGA_frame and PGA_base for each test. The Peak Acceleration Ratio (PAR = PGA_frame / PGA_base) was calculated as the primary indicator of isolation effectiveness, with values below 1.0 indicating reduced acceleration transmission to the structure. Average settlements, derived from the three ruler readings immediately post-excitation, complemented PAR analysis to assess deformation limits.

Test sequences followed randomized order to eliminate systematic bias, with each container meticulously cleaned and refilled between trials to maintain consistency. This systematic approach enabled comprehensive evaluation of CDTM's seismic isolation potential across the rubber content range [4].

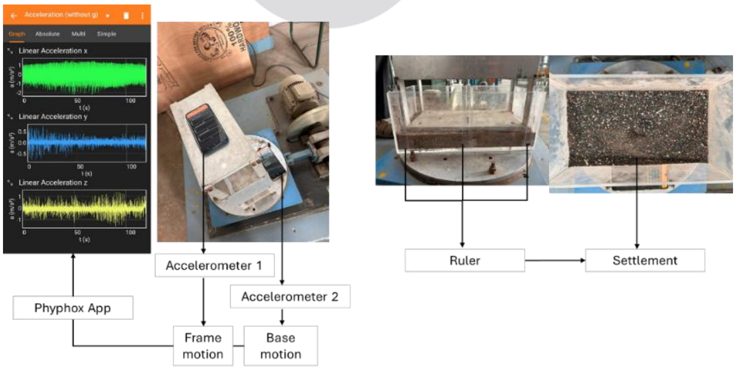


Figure 7 Acceleration and Settlement measurements

IV. RESULTS AND DISCUSSION

Peak Acceleration Ratio (PAR) Analysis

Shake table tests revealed distinct trends in acceleration transmission across CDTM compositions. Figure 8 shows that the rigid base condition (no GBI) exhibited PAR = 1.22, indicating amplification of base motion to the structure—characteristic of direct ground motion transfer without isolation. Pure C&D waste (CDTM 0) reduced this to PAR = 0.99, providing marginal improvement through limited particle re-arrangement under dynamic loading.

Progressive tyre incorporation initially enhanced isolation effectiveness, with PAR decreasing systematically: CDTM 10 (0.96), CDTM 20 (0.88), reaching optimum performance at CDTM 30 (PAR = 0.78)—a 36% reduction relative to the no-GBI condition. This substantial attenuation demonstrates effective motion filtering at moderate rubber content, where viscoelastic damping balances sufficient stiffness to prevent excessive flexibility [10].Beyond 30% tyre content, PAR increased: CDTM 40 (0.94), CDTM 50 (1.08), and CDTM 100 (1.17), approaching rigid base amplification levels. This reversal reflects excessive mixture deformability, where high rubber fractions (>30%) create overly compliant layers that fail to adequately support structural inertia, leading to motion magnification rather than attenuation [31].

Static loading tests on sand-tyre mixtures further validate these PAR trends, demonstrating stable deformation characteristics under service conditions [32].Demolished waste-based friction isolation systems in masonry housing show comparable PAR reductions, particularly effective for low-rise structures in developing regions [33].Shaking table experiments validate these PAR observations, showing significant motion decoupling between soil layers and superstructures [34]. Comprehensive reviews confirm that soil-structure interaction under base isolation consistently reduces PAR across various geotechnical configurations [35].

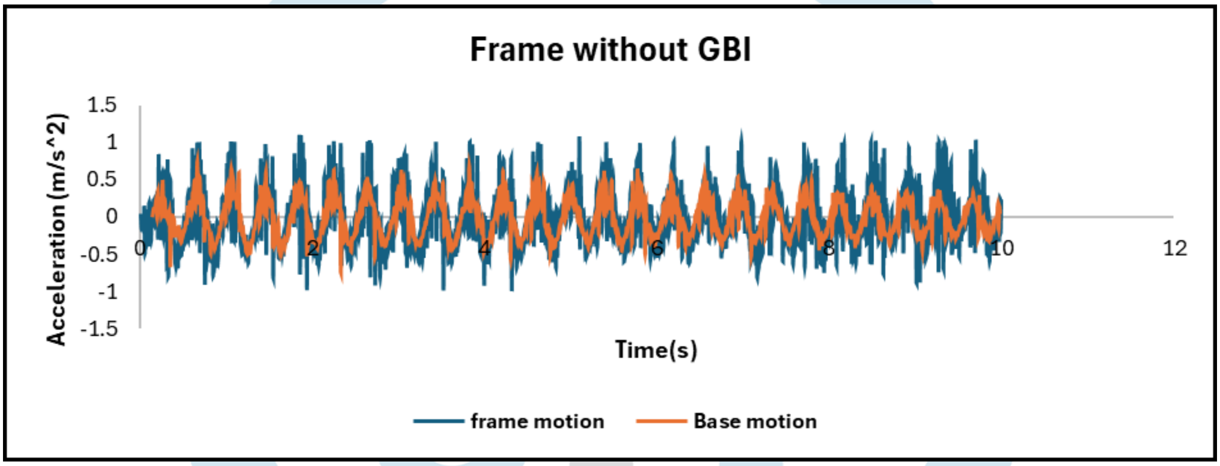


Figure 8.a) Acceleration vs Time graph (without GBI)

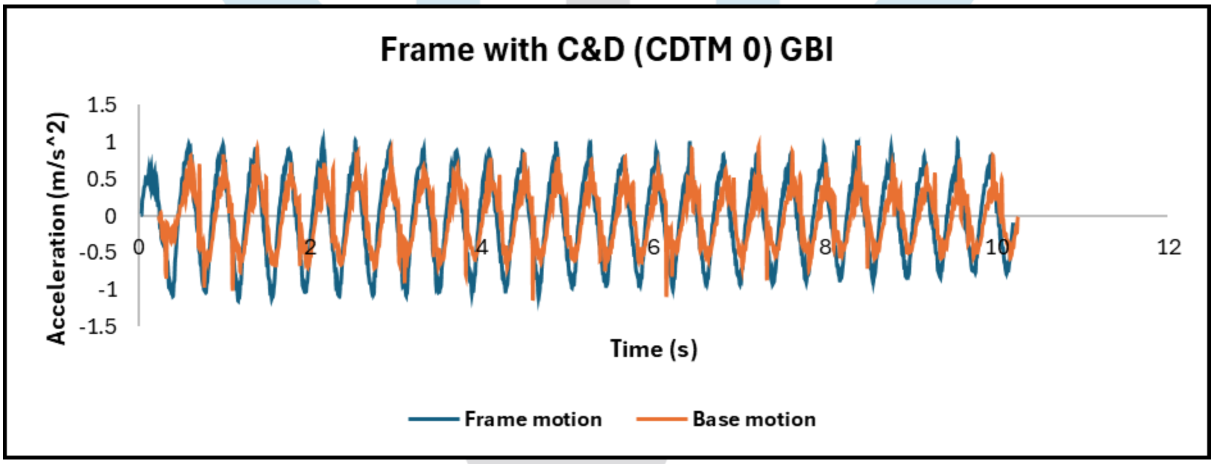


Figure 8.b) Acceleration vs Time graph (C&D)

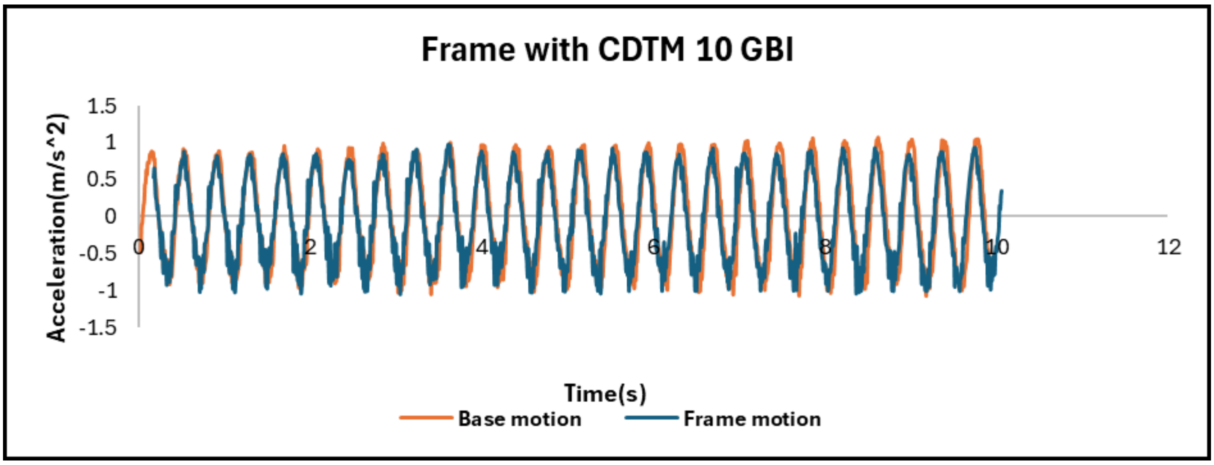


Figure 8.c) Acceleration vs Time graph (CDTM 10)

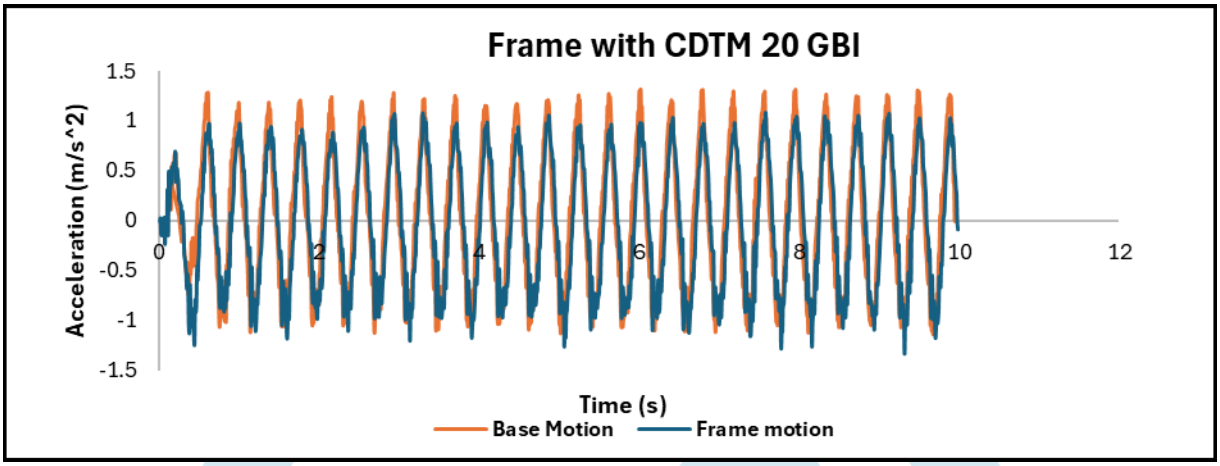


Figure 8.d) Acceleration vs Time graph (CDTM 20)

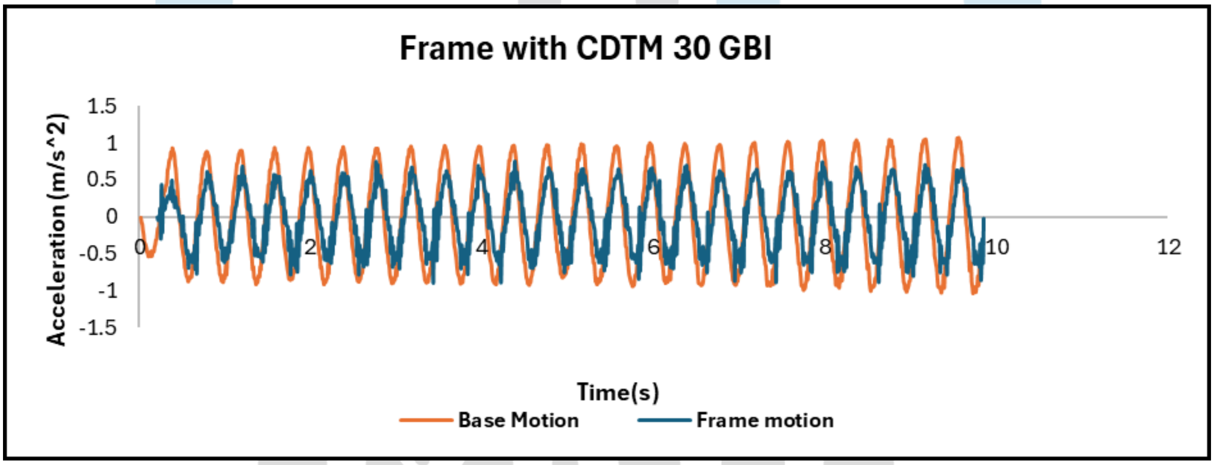


Figure 8.e) Acceleration vs Time graph (CDTM 30)

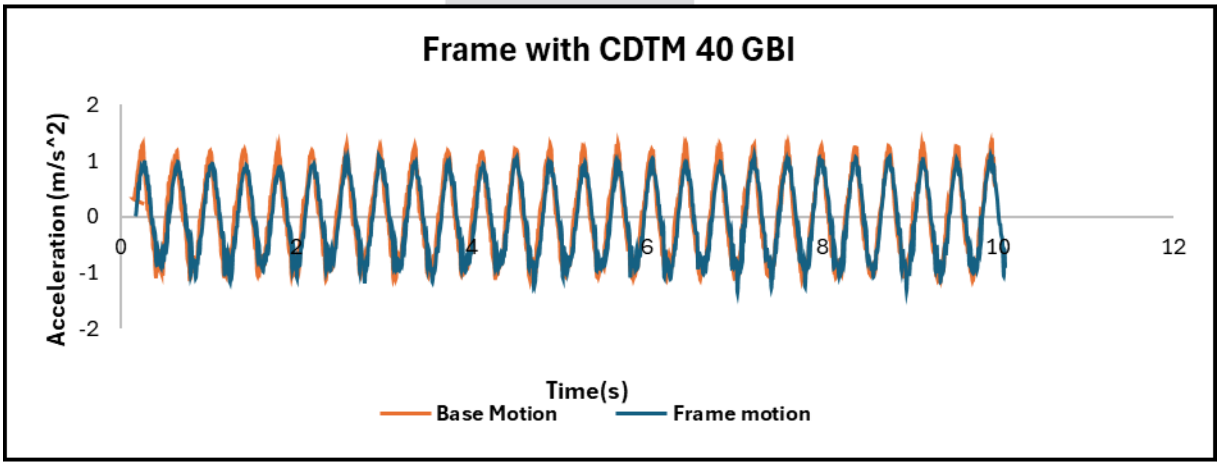


Figure 8.f) Acceleration vs Time graph (CDTM 40)

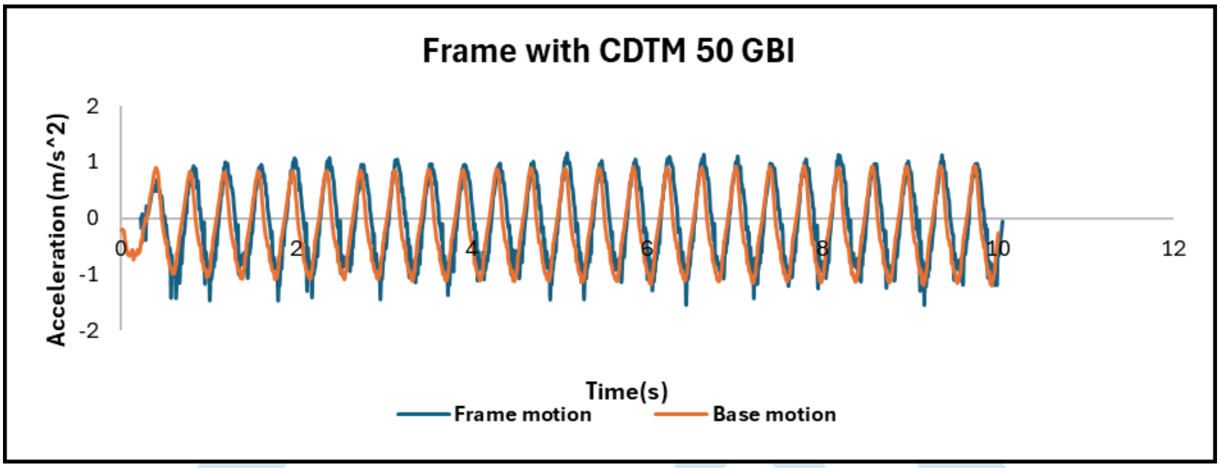


Figure 8.g) Acceleration vs Time graph (CDTM 50)

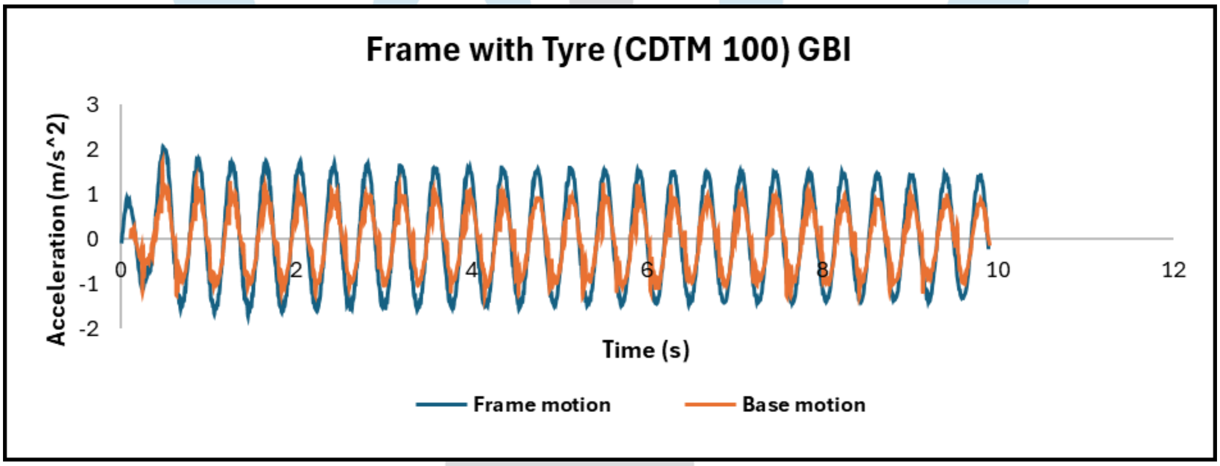


Figure 8.h) Acceleration vs Time graph (CDTM 100)

Settlement response

Settlement measurements, averaged across three container positions, increased monotonically with tyre content (Figure 9). Pure C&D showed minimal deformation (0.5 mm), while CDTM 30 recorded 3 mm—acceptable for serviceability limits in low-rise applications. Higher rubber mixtures exhibited progressively larger settlements: CDTM 40 (5 mm), CDTM 50 (8 mm), and pure tyre (12 mm), correlating with reduced unit weights and increased void potential observed in physical characterization.

The controlled settlement at CDTM 30 (3 mm) validates its practical viability, remaining below typical geotechnical tolerances (10-15 mm for isolation layers) while delivering superior acceleration reduction [4]. Excessive settlements at higher tyre contents (>30%) underscore the importance of balanced mix design to prevent structural distress under prolonged shaking.

Optimum mixture identification

CDTM 30 emerges as the optimal composition, achieving PAR = 0.78 (36% reduction vs. no GBI) with manageable 3 mm settlement. This performance aligns with literature benchmarks for 20-40% rubber-sand mixtures, confirming transferability to C&D-based systems despite angular particle morphology differences [2]. The mechanism involves optimal shear deformation within the isolation layer, where rubber crumbs dissipate energy through hysteresis while C&D aggregates maintain bearing stability—preventing the excessive flexibility observed at higher tyre fractions.

Notably, PAR values exceeding 1.0 in rigid base and high-tyre conditions indicate amplification phenomena typical of resonance or insufficient damping, emphasizing geo-base isolation's critical role in motion mitigation [36]. CDTM 30 demonstrates sustainable seismic protection using locally abundant waste materials, offering >70% cost savings over conventional isolators while addressing India's 150 million tonnes annual C&D waste challenge [26].

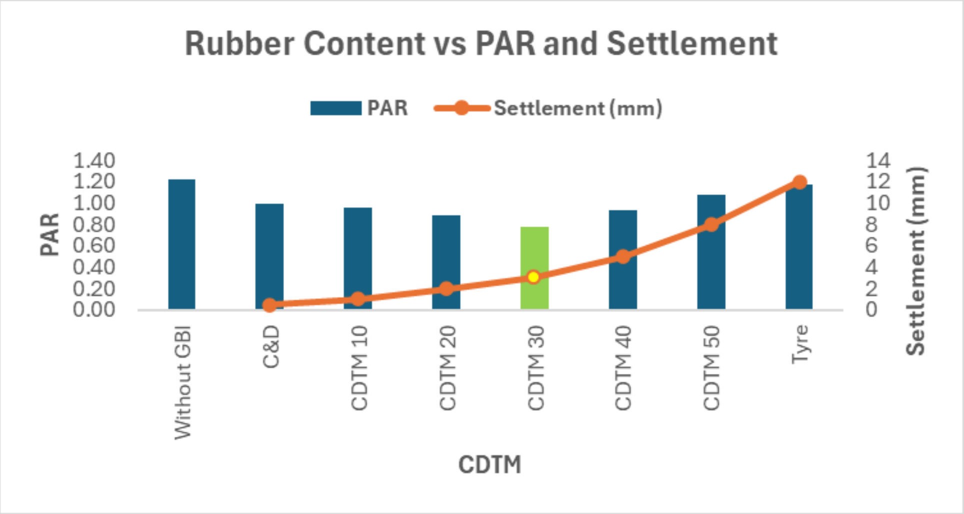


Figure 9. Comparison of PAR and settlement for various CDTM ratios

V. CONCLUSION

This investigation systematically evaluated Construction & Demolition waste-Tyre crumb Mixtures (CDTM) as sustainable geo-base isolation systems through comprehensive physical characterization and 3 Hz shake table testing. CDTM 30, containing 30% tyre crumbs by dry weight, demonstrated optimal performance with PAR = 0.78—achieving 36% acceleration reduction compared to rigid base conditions—while exhibiting acceptable 3 mm settlement within serviceability limits.

Physical properties confirmed the mixtures' evolution from dense, rigid C&D waste toward lightweight, deformable composites with increasing rubber content, enabling effective seismic energy dissipation through controlled shear deformation. The observed PAR minimum at 30% tyre content validates literature findings on optimal rubber-sand ratios while extending applicability to angular C&D aggregates prevalent in developing regions.

CDTM 30 represents a practical, low-cost seismic isolation solution leveraging India's abundant C&D waste (150 million tonnes annually) and scrap tyre resources. Future research should explore cyclic loading, multi-storey frame responses, and field validation to facilitate widespread adoption in seismic Zone III-V regions, advancing sustainable seismic engineering practices.

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