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PERFORMANCE OF BAMBOO- AND GLASS-FIBRE-REINFORCED CONCRETE SLAB SUBJECTED TO STATIC AND CYCLIC LOADS

OBNAŠANJE PREIZKUŠANCEV IZDELANIH IZ BETONA OJAČANEGA S STEKLENIMI IN BAMBUSOVIMI VLAKNI, IZPOSTAVLJENEGA STATIČNIM IN DINAMIČNIM OBREMENITVAM

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In the construction field, mild steel is using as reinforcement in concrete, which can easily corrode and destroy the environment. So, the construction industries are focusing on alternate materials like natural and synthetic fibres for sustainability. In this study bamboo, glass-fibre bars were used as reinforcement and compared with a normal reinforced concrete slab subject to static and cyclic incremental loading conditions. According to this, the experimental studies were carried out on 9 slab elements of size 600 mm × 450 mm with different forms of reinforcement. The slab elements' deflection, deformation, load-carrying capacity, stress, strain, crack patterns, stiffness and energy absorption were determined and compared. The ultimate load-carrying capacity of elements like conventional, GFRP and bamboo are 28.90 kN, 29.31 kN and 5.50 kN respectively; similarly, deflection 12.70 mm, 13.50 mm and 8.60 mm were found under static load. In the same way, the ultimate load-carrying capacities of the elements are 24.23 kN, 25.00 kN and 6.80 kN under cyclic loading conditions; deflections of 10.10 mm, 13.50 mm and 3.60 mm, respectively, on conventional, GFRP and bamboo elements. From the test results the stress, strain, energy absorptions were calculated and compared and the energy absorption of bamboo was 9.38% less than conventional and GFRP was 22.49 % higher than conventional elements. The study proved that GFRP material has a significant impact than conventional and bamboo elements and the bamboo reinforcement can be used in light-loading conditions.

Keywords: GFRP bar, bamboo, static load, cyclic load

Za gradbene konstrukcije se običajno uporablja malolegirano konstrukcijsko jeklo, ki lahko rjavi in uničuje okolico ter kot ojačitvena faza ojačan cementni beton. Zato so se v industriji gradbenih konstrukcij začeli ozirati po alternativnih novih trajnostnih materialih kot so na primer naravna in umetna vlakna. V tem članku avtorji opisujejo študijo za katero so uporabili vzorce betona ojačanih z bambusovimi in steklenimi vlakni ter jih primerjali z normalno ojačanim betonom. Iz izbranih materialov so izdelali preizkušance in jih testirali pod statičnimi in dinamičnimi obremenitvami. V ta namen so uporabili devet (9) oz. 3 krat po 3 preizkušance enakih dimenzij (600 × 450 × 50 mm) z različnimi ojačitvami. Vse vzorce so skrbno pregledali, jih analizirali in primerjali med seboj glede na stanje poškodb, nosilnost, deformacijo v odvisnosti od obremenitve, končno deformacijo, potek razpok, togost in absorpcijo energije. Ugotovljene vrednosti končne kvazi statične obremenitve pri porušitvi so bile naslednje: konvencionalni beton 28,9 kN, GFRP beton 29,31 kN in z bambusom ojačan beton 5,5 kN. Podobno so bile ugotovljene vrednost za upogib 12,7, 13,5 in 8,6 mm. V primeru dinamičnih obremenitev so dobili naslednje vrednosti za nosilnost 24,23 kN, 25,00 kN in 6.80 kN ter za upogib 10,1 mm, 13,5 mm in 3,6 mm. Iz rezultatov testiranja napetosti, deformacije in izračunov energije absorpcije je jasno razvidno da ima konvencionalni beton za 9,38 % manjšo nosilnost kot GFRP beton. Z bambusovimi vlakni ojačani vzorci betona pa so imeli nosilnost, ki je bila manjša kar za 22, 49 % v primerjavi z vzorci iz konvencionalnega betona. Ta študija je pokazala, da imajo polimerna vlakna uporabljena v GFRP betonu pomemben pozitiven vpliv na njegove mehanske lastnosti v primerjavi z ojačitvijo uporabljeno pri konvencionalnem betonu, ali betonu ojačanem z bambusovimi vlakni. Od tod sledi, da se beton ojačan z bambusom lahko uporablja le za mesta, kjer so obremenitve precej manjše.

Ključne besede: preizkušanci iz betona ojačanega s polimernimi vlakni (GFRP), bambus, statična in ciklična obremenitev

1 INTRODUCTION

Natural and artificial fibre-reinforced-polymer (FRP) bars are increasingly being used as an alternative to conventional steel bars for the reinforcement of concrete structures. This is because FRP bars offer several advantages over steel bars, including high strength-to-weight ratio, excellent corrosion resistance, and electromagnetic neutrality. This research investigates the strength, stiffness, crack propagation, and durability of steel-fiber-reinforced-concrete (SFRC) wall-slab joints under cyclic loading conditions.[1] The research focuses on the performance of repaired reinforced concrete slabs under static and cyclic loading. The results can be used to guide the design and implementation of repairs for reinforced concrete slabs subjected to a variety of load conditions.[2] The research examines the static and cyclic properties of structural lightweight concrete at cryogenic temperatures. The findings may shed light on how light-

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Table 1: Properties of Building Materials

Description of materials	Specific gravity	Initial setting time	Final setting time	Fineness modulus	Water absorption	Yield strength of reinforcement
Cement	3.14	30 min	360 min	…..	…..	…..
Fine Aggregate	2.66	…..	…..	2.64	0.54%	…..
Coarse Aggregate	2.70	…..	…..	6.80	0.50%	…..
Fe 415 Mild Steel	…..	…..	…..	…..	…..	472 N/mm^2
Bamboo	…..	…..	…..	…..	…..	195 N/mm^2
Glass Fibre Rod	…..	…..	…..	…..	…..	526 N/mm^2

weight concrete behaves in a cryogenic environment.[3] The study investigates factors like strength, stiffness, crack resistance, and durability to better understand the effectiveness of glass-fiber-reinforced-polymer (GFRP) dowels in jointed concrete pavements, taking into account their performance under various load conditions.[4] The research involves an experimental evaluation of bamboo-reinforced concrete slab panels and the effectiveness of using bamboo as a reinforcement material in concrete slabs, potentially contributing to sustainable construction practices.[5] The research focuses on the feasibility and effectiveness of using bamboo reinforcement in concrete masonry shear walls, potentially offering sustainable and resilient alternatives in construction.[6] The research investigates the bond performance of the bamboo-steel interface after cyclic loading. It aims to assess factors such as bond strength, durability, and potential degradation of the interface between bamboo and steel under repeated loading.[7] The research examines the flexural behavior of untreated, plain, bamboo-reinforced concrete beams under four-point loading and determines the strength, stiffness, and deformation characteristics of these beams.[8] The research focuses on the fatigue performance of sea-sand concrete slabs reinforced with basalt-fiber-reinforced polymer (BFRP) bars.[9] The research employs nonlinear finite-element analysis to predict the cyclic behavior of ultra-high-performance concrete (UHPC) shear walls reinforced with both fiber-reinforced polymer (FRP) and steel bars. It aims to assess factors such as strength, stiffness, and energy dissipation under cyclic loading conditions.[10] The research investigates reinforced concrete slabs that are strengthened with externally bonded carbon-fiber-reinforced polymer (CFRP) strips under long-term environmental exposure and sustained loading conditions.[11] The research focuses on the behavior of one-way concrete slabs reinforced with carbon-fiber-reinforced polymer (CFRP) grid reinforcements, evaluating factors such as strength, stiffness, crack resistance, and the load-carrying capacity of these slabs.[12]

2 OBJECTIVE AND SCOPE OF THE RESEARCH

From a literature survey it is observed that the studies on the performance of natural, synthetic-fibre-reinforced slabs subjected to static and cyclic loads are limited. So, the aim of study is to restore the absence through this experiment. The aims of th work are given below.

- To study the behaviour of conventional, bamboo, glass-fibre-reinforced slabs under static loads
- To study the behaviour of conventional, bamboo, glass-fibre-reinforced slabs under cyclic loads
- To study the failure pattern of slabs under static and cyclic loads
- To compare the conventional, bamboo and glass-fibre-reinforced slabs' behaviour.

3 MATERIALS AND METHODS

3.1 Materials

For this experiment, the locally available building materials like cement, fine aggregate, coarse aggregate, water, bamboo, glass-fibre and mild-steel bars were collected and used with relevant Indian Standard (IS) codes recommendation. Ordinary Portland Cement (OPC) 53 grade, Coarse aggregate (CA) 20 mm, river sand used as fine aggregate (FA), potable water, Fe 500–8 mm and 12 mm diameter rods are the main ingredients, those were tested as per IS Codes 8112-1989,[13] 383-1970,[14] 456–2000,[15] 1786-1985,[16] respectively, and the results were tabulated in **Table 1**. Glass-fibre rods'[17] properties were collected from the manufacturer's data sheet from literatures and tabulated in Table 1. Experimental works were initially carried out from cube, cylinder and prism specimens as per IS code 516-1959,[18] with M30-grade designed concrete,[19] also analyzed and confirmed the characteristic strength results and then main tests were carried out on the reinforced slabs.

3.2 Experimental Investigation

The main aim of the research study was to test the RCC slabs with different forms of reinforcement and compare the performance and behaviours. From **Table 2**, the experiment slabs were 3 conventional, 3 bamboo-reinforced slabs and 3 glass-fibre-reinforced slabs were cast with 600 mm length, 450 mm breadth and 50 mm thick in the same area of reinforcement the practice is shown in **Figure 1**. After 28 d curing, the elements were tested in the 50-kN capacity loading frame. In addition, stain and dial gauges were fixed at the middle span for observing the deflection and deformation of the elements during loading.

Table 2: Testing details of the elements

Description of Element	Size in mm	Reinforcement In mm^2		Nos. Element used for Testing	First crack accrue in kN		Mean ultimate strength in kN	
		Main	Distributor		Static	Cyclic	Static	Cyclic
Conventional slab	600 × 450 × 50	201.06	301.60	3	18.80	15.75	28.90	24.23
Bamboo-reinforced slab		201.06	301.60	3	3.30	4.15	5.50	6.80
Glass-Fire-Reinforced slab		201.06	301.60	3	19.75	16.90	29.31	25.00

Figure 1: Element testing set up and cracks pattern under static load

Then static compressive load is applied to the centre of the slab with a simply supported condition at a rate of 20 kN/min in 2 kN intervals up to the ultimate load-carrying capacity of the slabs for the conventional and glass-fibre-rod slabs; similarly a 0.5-kN-interval series up to the ultimate load-carrying capacity for the bamboo-reinforced slab. For every 2 kN loading interval the strain, dial gauge readings were observed and failure pattern also studied under static load. Similarly, the cyclic loads were applied as incremental loading; that is 0 kN to 2.5 kN applied and observe the readings then release the load from 2.5 kN to 0 kN, again applied the load 0 kN to 5 kN then release the load 5 kN to 0 kN, again applied the load 0 kN to 7.5 kN then released processes up to ultimate load-carrying capacity for conventional and glass-fibre-reinforced slabs; similarly, the cyclic load was applied at 0.5 kN intervals for the bamboo-reinforced slab. A data-acquisition system is used to record the load, strain, and deflection data at regular intervals during the test.

The control system is used to control the loading frame and to apply the cyclic load according to the predetermined load range and number of cycles. Besides, from the test results the stress, strain, stiffness, energy absorptions were calculated, tabulated in **Table 2** and cracks pattern were shown in **Figure 1** and compared.

4 RESULTS AND DISCUSSIONS

4.1 RC Slabs Experimental Test Subjected to Static Loads

In this study, the behaviour of RC slabs with different form of reinforcements was observed subject to the static load. The glass-fibre-reinforced slabs performed well in vertical compression static loading by enchasing the load-carrying capacity, resistance to deformation and deflection than conventional and bamboo slabs. Comparisons are as follows. **Figure 2** shows that the conventional slab carries an ultimate mean load of 28.90 kN with corresponding displacement 12.7 mm. The bamboo-reinforced slab carries an ultimate load of 5.5 kN with corresponding displacement of 8.6 mm, it is shown in **Figure 3**. The glass-fibre-reinforced slab carries an ultimate load of 29.310 kN with a corresponding displacement of 19.8 mm; it is shown in **Figure 4**. **Figures 2** to **4** show the load vs. vertical displacement of elements subjected to static loads. From the test results, the stress, strain and stiffness were calculated, i.e., 0.963 N/mm^2, 0.0000352 and 2275.591 N/mm, respectively, for the conventional slab.

Similarly, the stress, strain and stiffness is 0.183 N/mm^2, 0.0000067 and 647.059 N/mm respectively for the bamboo-reinforced slab. Likewise, the stress, strain and stiffness is 0.997 N/mm^2, 0.0000357 N/mm and 1480.303 N/mm, respectively, for the glass-fibre-reinforced slab. **Figure 1** shows the crack

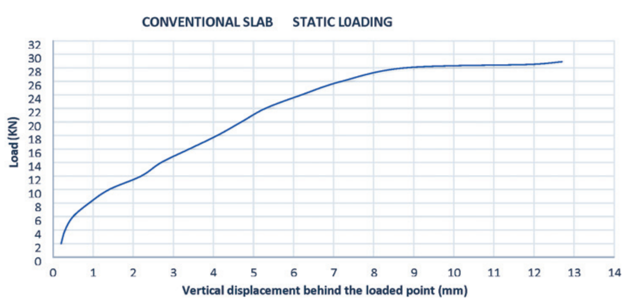

Figure 2: Vertical displacement of conventional slab under static vertical load

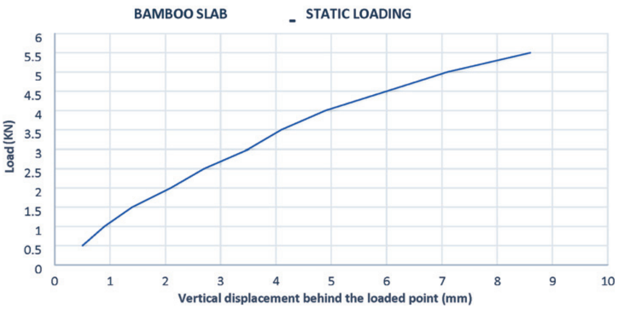

Figure 3: Vertical displacement of bamboo-reinforced slab under static vertical load

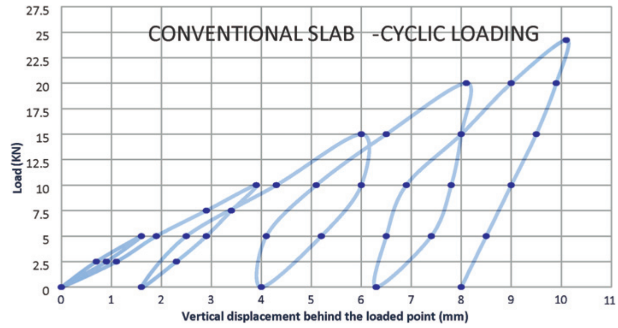

Figure 5: Vertical displacement of conventional slab under cyclic vertical load

patterns of the slabs, with all slabs failing in the middle of the span along to the breadth of slab because the maximum bending moment and deflection are occurred at center of a simply supported span.

Because of the glass-fibre rod having excellent mechanical properties, such as high tensile strength, light weight, strong corrosion resistance, strong materials bonding, strong design ability and strong magnetic waves permeability compared to the mild steel and bamboo. From these calculations the bamboo-reinforced slab's performance is less than the glass-fibre-rod slab and the conventional. The conventional slab's performance is better than bamboo-reinforced slab because Fe 415 steel was used as a reinforcement in this slab. The Fe 415 steel has outstanding mechanical properties, like a high yield strength, good ductility, and better elongation than bamboo. But the bamboo-reinforced slab can be used in the precast slab, light weight structures, pavements, cover slabs, pathway, partitions, sill slab, fin wall and nominal reinforcement areas. In addition the bamboo is free from corrosion, heat and electric conductivity, pollution and has lower cost than mild steel.

4.2 RC Slabs Subjected to Cyclic Vertical Loads

The loading setup and the support conditions for cyclic loading were maintained similar to that of the static loading. A load with an increment of 2.50 kN for each cycle was applied at a constant rate of 140 kg/cm^2 per minute manually (as per IS 516 1959) and then released to the 'no load' condition after reaching the peak load of the cycle. The conventional slab attained an ultimate load-carrying capacity of 24.23 kN with a corresponding displacement of 10.1 mm under the action of incremental loads. Similarly, the glass-fibre-reinforced slab carried an ultimate load of 25.0 kN with corresponding displacement of 13.5 mm. Likewise the bamboo-reinforced slab was loaded with 0.5 kN intervals from the same producer; the bamboo slab withstood an ultimate load-carrying capacity of 6.80 kN with a corresponding displacement of 3.60 mm. During every cycle of loading the deformation, deflection, cracks pattern were observed; from these results the stress, strain, stiffness, stiffness degradation, energy dissipation and cumulative energy dissipation are calculated and tabulated in **Table 3**. **Figure 7** shows that ultimate load vs displacement curve for the conventional slab; from this curve the energy dissipation and cumulative energy dissipation are arrived at with the help of AutoCAD software.

From Table 3, the ultimate stiffness, stiffness degradation, energy dissipation and cumulative energy dissipation of the conventional slab are 2399 N/mm, 23.23 %, 36153 N-mm and 118403 N-mm respectively. From **Figure 6** and **Table 3**, the ultimate stiffness, stiffness degradation, energy dissipation and cumulative energy dissipation of the bamboo reinforced slab is 1889 N/mm, 33.89 %, 5780 N-mm and 11379 N-mm, respectively. From **Figure 7** and **Table 3**, the ultimate stiffness, stiffness degradation, energy dissipation and cumulative energy dissipation of the glass-fibre-reinforced slab is 1851 N/mm, 48.15 %, 75000 N-mm and 152750 N-mm, respectively.

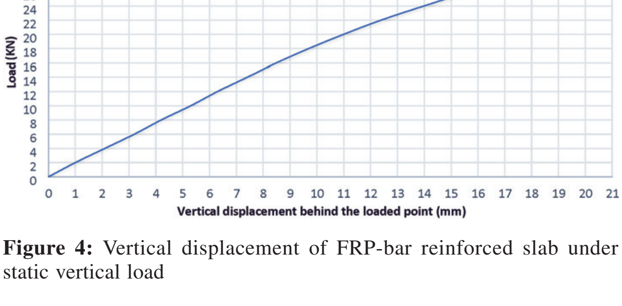

Figure 4: Vertical displacement of FRP-bar reinforced slab under static vertical load

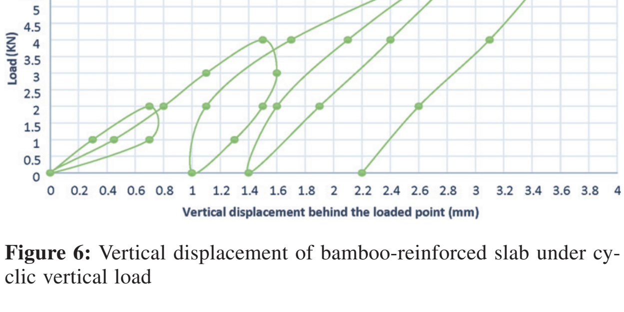

Figure 6: Vertical displacement of bamboo-reinforced slab under cyclic vertical load

The test results proved that the glass-fibre-reinforced slab has 1.03 times and 3.67 times more strength than the conventional and the bamboo-reinforced slab, respectively. Because the glass-fibre rod has a high tensile strength, the fatigue strength, dimensional stability, high heat resistance, good thermal conductivity, great fire and chemical resistance, dielectric permeability and great durability.

These properties are inducing the load-carrying capacity, energy dissipation and cumulative energy dissipation capacity of the glass-fibre-reinforced slab. Besides bamboo enhancing the stiffness up to glass-fibre rod level; moreover it had 26 % higher stiffness than the conventional slab. But, the bamboo-reinforced slab had more stiffness than the conventional slab because the bamboo has a high Young's modulus, stiffness.

Table 3: Stiffness degradation and energy dissipation of elements

CONVENTIONAL						
Cycle Number	Peak Load in kN	Displacement in mm	Stiffness in kN/mm	Stiffness Degradation in %	Energy Dissipation in kN-mm	Cumulative Energy Dissipation in kN-mm
1	2.5000	0.500	5.000	.....	.....	.....
2	5.000	1.600	3.125	37.50	0.500	0.500
3	7.500	2.75	2.727	45.46	5.820	6.320
4	10.000	3.900	2.564	48.72	8.000	14.320
5	12.500	4.900	2.55	49.00	10.950	25.270
6	15.000	6.000	2.469	50.62	28.000	53.270
7	17.500	7.100	2.464	50.72	38.650	91.920
8	20.000	8.200	2.439	51.22	45.750	137.67
9	22.500	9.300	2.419	51.62	40.952	178.622
10	24.230	10.100	2.399	52.02	36.154	214.776
BAMBOO						
1	0.5	0.100	5.000	......	.....	......
2	1.00	0.25	4.000	20.00	0.199	0.199
3	1.50	0.45	3.333	33.40	0.300	0.499
4	2.00	0.70	2.857	42.86	0.399	0.898
5	2.50	0.9	2.77	44.60	0.749	1.647
6	3.00	1.00	3.000	40.00	1.099	2.746
7	3.50	1.30	2.692	46.16	1.449	4.195
8	4.00	1.50	2.666	46.80	1.800	5.995
9	4.50	1.85	2.432	51.36	2.200	8.195
10	5.00	2.150	2.325	53.50	2.600	10.795
11	5.50	2.475	2.222	55.56	3.000	13.795
12	6.00	2.80	2.142	57.16	3.400	17.195
13	6.50	3.05	2.131	57.38	4.887	22.082
14	6.80	3.60	1.888	62.24	5.780	27.862
GLASS-FIBRE-ROD REINFORCEMENT						
1	2.50	0.500	5.000	….	…..	…..
2	5.00	1.400	3.571	28.58	1.500	1.500
3	7.50	2.50	3.000	40.00	5.625	7.125
4	10.00	3.60	2.777	44.60	9.750	16.875
5	12.50	4.80	2.604	47.92	19.125	36.000
6	15.00	6.00	2.500	50.00	28.500	64.500
7	17.50	7.20	2.430	51.40	33.250	97.750
8	20.00	8.40	2.380	52.40	38.000	135.750
9	22.50	10.95	2.054	58.92	56.500	192.250
10	25.00	13.50	1.851	62.98	75.000	267.250

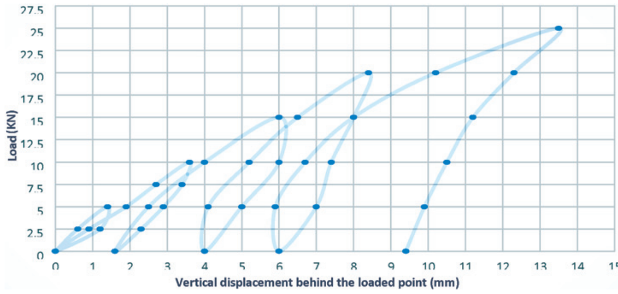

Figure 7: Vertical displacement of fibre-reinforced slab under cyclic vertical load

The stiffness degradation of the slab is 23.23 %, 33.89 % and 48.15 % for the conventional, bamboo- and glass-fibre-reinforced slab, respectively; from this, the conventional slab's performance is less than the bamboo and the glass-fibre slab. The energy-dissipation performance of the glass fibre slab is 2 times more than conventional and 12.95 times more than bamboo slab. Likewise, the conventional slab's energy dissipation is 6.25 times higher than the bamboo slab.

5 CONCLUSIONS

The experimental study was carried out on a conventional slab, a bamboo-reinforced slab and a glass-fibre-reinforced slab. All three slabs were tested under static and cyclic vertical loads. The static results showed that the glass-fibre-bar reinforced slab has a higher load-carrying capacity than the conventional slab. The ultimate load-carrying capacity of the fibre-reinforced slab is 1.12 times and 2.08 times higher than the ultimate load-carrying capacity of the conventional and bamboo slabs, respectively. Similarly, the glass-fibre-reinforced slab's ultimate load-carrying capacity is 1.03 times and 3.67 time more than the conventional and bamboo slabs respectively. The bamboo slab's stiffness is 1.27 times more than the conventional and similar to the glass-fibre slab. From this research study we confirmed that the glass-fibre reinforcement is enhancing the load-carrying capacity, energy dissipation subjected to static and cyclic loading conditions than conventional and bamboo. Bamboo is enhancing the stiffness more than the conventional. Hence, the bamboo reinforcement can used in nominal reinforcement areas, precast slabs, cover slabs, sill slabs, lightweight structures, pavements, pathways, partitions and fin walls, no load RCC structures and elevation drops. From this practice further research study is required for the development of bamboo structural elements under impact load.

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