Precast Bamboo Reinforced Furniture Elements using Self Compacting Concrete

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Abstract. Public furniture in India are designed based on ergonomics standards derived from the international standards proving a significant hurdle in comfort for the users. We propose to tackle this by conducting ergonomic studies of true users. This study aims to check the viability of using an eco-friendly composite as street furniture, i.e., Park Bench. Additionally, owing to the increasing negative impact steel manufacturing has on the environment, the furniture is designed using a Bamboo-SCC composite. The objective of the study is to use bamboo as reinforcement in SCC to make furniture. The furniture is made using self-compacting concrete to ensure greater stability of the bamboo reinforcement and further to increase the durability of the benches. The final product is analysed based on deflection tests, cost-benefit analysis, and embodied energy savings. It was concluded that in areas where bamboo is readily available, this project can be implemented as a more energy-efficient and low-cost option.

1. Introduction
Street-furnishing at public places creates a sense of identity when properly designed and integrated. They are generally looked at as places where one can comfortably sit, eat, rest, and meet people. Street-furniture is important for the elderly who have very minimal mobility and people with kids. The benches and tables at parks and squares attract people. Properly designed and placed furniture is socially significant as they are a crowd-puller at public spots. In order to tackle the challenge of human comfort in this project, ergonomic design is used.

Concrete has suitable building properties, such as its capability to take large compressive loads. It is a widely used ingredient in the foundation of infrastructure, readily available, and cheap. The only drawback is that it has low tensile strength. This limits the use of concrete. Overcoming this limitation, we use one of the most popular reinforcing bar (rebar) that is steel. Developing countries that are in need for steel as reinforcement but lack proper means to meet the demand of steel production can opt for a more efficient, maintainable, and extremely resilient building material, i.e., Bamboo. Instead of being dependent on the developed countries which control the global market, bamboo has the potential to replace steel as a low-cost alternative in places it can't be produced.

The tensile strength of bamboo is relatively high and can reach 370 MPa [1]. This makes bamboo an attractive alternative to steel in tensile loading applications. This is due to the fact that the ratio of tensile strength to the specific weight of bamboo is six times greater than that of steel [1].

Studies conducted by Gavami et al., [2] established the durability of bamboo as a reinforcement in concrete, besides improving the bonding of bamboo reinforcing bars. The results of the investigations
show that bamboo can substitute steel satisfactorily. The structural elements developed and studied could be used in many building constructions.

Self-Compacting Concrete (SCC) was developed initially in Japan in the 1980s when contractors were experiencing a severe shortage of skilled manpower. SCC does not require any external vibration; it flows under its own weight and completely fills the forms without segregation or bleeding. For SCC, it is generally necessary to use superplasticisers to obtain mobility and viscosity modifying admixtures or large volume of powder material to eliminate possible segregation. The powdered materials are fly ash, Ground Granulated Blast furnace Slag (GGBS), silica fume, limestone powder [3].

The objective of the study is to use bamboo as reinforcement in SCC to make furniture. Ergonomic studies, Cost-benefit analysis and lab tests were conducted to substantiate the same. The furniture is made using SCC to ensure greater stability of the bamboo reinforcements and further to increase the durability of the benches. The benches were precast as 3 separate slabs, one top slab, and two bottom supports and later assembled. Deflection tests were conducted to ascertain the amount of load that the bench could take, and the benches tested satisfies the design load criteria.

2. Experimental program

The Experimental program was conducted in three phases, mix design of SCC, ergonomic studies, and finally the assembly of the bench.

2.1. Materials

Ordinary Portland cement of 53 grade, conforming to the requirements of IS-12269[4], was used in the study. GGBS used was obtained from M/s JSW, Karnataka, and satisfies the requirements of IS 16714:2018[5].The specific gravity values of the cement and GGBS were 3.14 and 2.91, respectively.

Crushed stone sand was used as fine aggregate, and crushed stone with a maximum size of 10mm was used as coarse aggregate. Commercially available polycarboxylic ether-based Superplasticisers (Glenium sky 8233) was used in this study. Bamboo splits of 9mm width were used as reinforcement. Bamboo splits were treated using dip diffusion method. Commercially available boric and borax solution was used in dip diffusion method[6].

2.2. Mix design of SCC

Guidelines from the standard Japanese method and method proposed by Jagadish Vengala was used to arrive at the mix proportions [7]. Marsh cone test was conducted to arrive at the optimum super plasticiser dosage. Once the SCC mix is designed, the fresh mix is tested for its flowability and passing ability by conducting slump flow, L-box, and V-funnel tests. The test results were compared with the EFNARC guidelines [8].

SCC trial mixes were cast out into 100mm cubes. The specimens were cured and tested at 7, 14, and 28 days. The specimen is removed from the water after specified curing time, and excess water from the surface is wiped out. In order to finalise the design mix of concrete, target strength is a desired input which can also be achieved by resorting to accelerated curing. In the present study, accelerated curing tests were conducted as per IS 9013[9] to arrive at the target strength of concrete.

2.3. Ergonomic studies

First, the potential users of the bench were identified, so that the precast benches could be designed based on the anthropometric dimensions of the potential users. The following flow diagram illustrates the steps followed in arriving at the final dimensions of the bench (Figure 1).

First, the target users were decided based on the location of placing the bench-near the college canteen, thereby making the potential users- teachers, students, workers, gardeners, and outside visitors. The age range of the people using the bench is between 18-65 yrs. A random crowd of 50 women and 50 men were selected from college; this group included all- teachers, students, workers, gardeners, and outside visitors. Dimensions of their shin and their femur were tabulated based on gender. The $25^{th}$, $50^{th}$, and $75^{th}$ percentile of the data were ascertained in a spread sheet.
2.4. Preparation of precast park bench
The next step was to prepare the reinforcements. After the treatment, three slabs were cast out of which one was the top slab, and the other two were bottom support slabs. Bamboo strips were placed at 1.5 inches from the concrete surface, and the strips were staggered to ensure the uniform cross-section of the slab. Binding wire was used to tie the bamboo reinforcement.

SCC is produced and directly poured to the location of concrete placement. Sufficient carpenters, along with the supervisor inspected the behaviour of supports below the slab during the casting. The curing was started immediately after 24 hrs. Curing was done using membrane curing for a minimum period of 7 days. One main slab and two supports were cast. A one-inch deep socket was made along the breadth of the main slab to fix the supports. Two supports were placed, and the main slab was placed above it, gently fixed by the socket provided. The voids were filled in with cement mortar.

2.5. Testing of precast park bench
Once the slab was assembled, its performance was tested. The center line of the slab was located, and a span length of 80cm was taken by taking 40 cm on either side. From the center, an offset of 10cm was taken, and a dial gauge was placed at the bottom of the slab. Loading was done along the span length using uniform hollow blocks of approximately 20kg and sand bags of 40 kg. Deflection was measured, and the behaviour of the bench under loading such as crack formations was observed.

3. Results and discussion

3.1. Mix design and tests on Self Compacting Concrete
Self compacting concrete was designed based on the Japanese method of mix design. Initial trials were made to arrive at final mix proportions. Figure 2 shows the marsh cone test. Table 1 gives the results of the Marsh cone test, which gives the optimum dosage of superplasticiser.
Table 1. Results of marsh cone test.

| Sl. No. | Cement         | Admixture         | W/P ratio | Water (ml) | Optimum Dosage (%) | Avg. Marsh cone time, s |
|---------|----------------|-------------------|-----------|------------|--------------------|------------------------|
| 1       | OPC 53 grade cement | Masterglenium sky 8233 | 0.1       | 1170       | 0.1                | 17.40                  |
| 2       |                |                   | 0.2       | 1570       | 0.2                | 15.20                  |
| 3       |                |                   | 0.3       | 1170       | 0.3                | 11.77                  |
| 4       |                |                   | 0.4       | 1170       | 0.4                | 11.74                  |
| 5       |                |                   | 0.5       | 1170       | 0.5                | 11.71                  |

Trials have been carried out to arrive at the optimum dosage of superplasticiser using Marsh Cone test for the SCC mix of M25 grade. The details of the mix proportions of the SCC mix used for the present study is shown in table 2.

Table 2. Mix proportions of the SCC mix adopted in the study.

| Materials                          | Quantities |
|------------------------------------|------------|
| Coarse aggregates (kg/m³)          | 800        |
| Fine aggregates (kg/m³)            | 1200       |
| Cement (kg/m³)                     | 250        |
| GGBS (kg/m³)                       | 300        |
| Water (litres)                     | 275        |
| W/P ratio                          | 0.5        |
| superplasticiser dosage            | 0.3%       |
| Slump (mm)                         | 650        |

Table 3. Results of fresh Properties of SCC mix.

| Fresh Properties | Range                     | Obtained values |
|------------------|---------------------------|-----------------|
| V-funnel         | EFNARC[3]                 | 8sec            |
| V_{min}          | [6-12] + 3sec             | 11 sec          |
| Slump            | 500 – 700 mm              | 650 mm          |
| L – box = H_{2}/H_{1} | >0.8                   | 0.9             |

Figure 3. Tests conducted for SCC to ascertain fresh properties.

Tests have been conducted to ascertain the fresh properties and check the performance of SCC mix. Figure 3 represents tests conducted for SCC to ascertain fresh properties. The results of the fresh properties are shown in table 3. From table 3 it can be inferred that the filling ability of the SCC mix, which was checked by conducting V funnel and slump flow test satisfies the requirement and the values lie within the range recommended. The passing ability test conducted using the L Box satisfies the requirement, and the values lie within the range recommended.
After casting the concrete specimens, tests have been conducted for specimens after 7, 14 and 28 days. All the tests were conducted as per IS: 516[10]. Table 4 gives the accelerated curing test results and compressive strength results of the mix used in the study.

Table 4. Accelerated curing test results and compressive strength results of mix used in the study.

| Avg. accelerated curing strength $R_a$ (MPa) | Average $R_{28}$ (MPa) | Cube compressive strength $7$ days | $14$ days | $28$ days |
|--------------------------------------------|------------------------|-----------------------------------|----------|----------|
| 18.6                                       | 38.6                   | 27.8                              | 39.4     | 43.5     |

3.2. Design of precast park bench based on ergonomic data

The shin (knee) length and the femur length of target users are collected based on gender. A random crowd of 100 men and women of age group of 18-65 years have been taken. The 25th, 50th, and 75th percentile of the data were ascertained in the excel sheet. Based on the data collected the different percentile ranking and the average is tabulated as below in table 5.

Table 5. Different percentile and average values of anthropometric data in cm.

| Percentile | 50th | 75th | Average of 50th and 75th percentile |
|------------|------|------|------------------------------------|
| Female (femur) | 51.0 | 54.0 | 52.5 |
| Male (femur) | 51.6 | 53.3 | 52.45 |
| Average | 51.3 | 53.65 | 52.5 |

The bench dimensions were decided by taking the average of the 50th and the 75th percentile of both males and females. The final dimensions of the bench were set as follows. Table 6 gives the dimensions of the precast park bench.

Table 6. Dimensions of the precast park bench in cm.

| Length | 152.4 |
|--------|-------|
| Breadth | 52.5 |
| Height of the supports | 45.7 |
| Thickness of the slab | 7.6 |
| Spacing of reinforcement | 7.6 |

3.3. Preparation of precast park bench

Treated bamboo reinforcement was used to make the reinforcement cage (figure 4) and the same was placed in the prepared mould. Bamboo strips were staggered to ensure the uniform cross-section of the slab. SCC is directly poured into the mould as shown in figure 5. Curing was done using membrane curing for a minimum period of 7 days. Figure 6 shows the assembled precast park bench.

Figure 4. Treated bamboo reinforcement cage.
Figure 5. Precast mould while pouring SCC.
Figure 6. Assembled precast park bench.
3.4. Test results of precast park bench

The loads were applied to the precast park bench in increments of load upto a maximum of two and a half times of the design load. Figure 7 shows the precast park bench while testing. Table 7 gives the load increment and corresponding deflection values of the bench.

| Load (kg) | Deflection (mm) |
|-----------|-----------------|
| 0         | 0               |
| 80        | 0.06            |
| 160       | 0.15            |
| 240       | 0.21            |
| 320       | 0.30            |
| 400       | 0.57            |
| 480       | 1.41            |
| 560       | 3.44            |
| 640       | 3.53            |
| 720       | 4.17            |
| 720 @ 24 hrs | 4.38        |

Taking design load as 300kgf, considering 3 people of each 100kgs approximate weight, it can be seen that the load-carrying capacity is almost two and a half times of the design load. Moreover, the load of 750 kgf was left to rest on the bench for one day, and small cracks were seen but deflection remained less than 5mm (Figure 8).

3.5. Embodied Energy

Based on the cost analysis, the precast concrete bench prepared using bamboo reinforcement is 18% low-cost than the bench made using steel reinforcement. In addition to the cost-benefit, the embodied energy of steel is 30MJ/kg, whereas bamboo’s embodied energy is 0.5MJ/kg. The carbon emission from steel is 1.85 tonnes / tonnage of steel, whereas bamboo intakes CO₂ which intern reduces pollution; the greater the CO₂ level faster the growth of bamboo. Also, steel is non-renewable resources after a few decades, the availability of steel decreases, whereas bamboos have faster growth and cost-efficient when compared to steel.

4. Concluding remarks

In this study, the furniture is made using self-compacting concrete to ensure greater stability of the bamboo reinforcements and further to increase the durability of the benches. It is important to design...
the benches based on ergonomics to maintain a correct posture and to increase the comfort level of potential users. Based on the study conducted, it can be seen that concrete furniture elements can be made using bamboo as a reinforcement, and SCC ensures the stability of the reinforcement as there is no vibration required to consolidate the concrete. The permeability of SCC is low, and GGBS as part replacement of cement provides more resistance against chemical attacks moreover, treated bamboo ensures longer life. Precast slabs ensure consistency in quality and reduce errors in design. The performance study conducted on the bench indicates that it can take a load much greater than the design load without significant deflection. The load-carrying capacity of the bench is almost two and a half times of the design load. Based on the cost analysis, the precast concrete bench prepared using bamboo reinforcement is 18% low-cost than the bench made using steel reinforcement.

5. References

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