DETERIORATION OF UNTREATED BAMBOO AND COIR YARN IN EXPOSED STRUCTURES

by
S.R. de S. Chandrakeerthy

Abstract

Untreated bamboo and coir yarn are rapidly decaying materials which are widely used in Sri Lanka for temporary structures by the construction industry. The need to use these structures for a longer period of time and the current trend of greater reuse, require a thorough understanding of the deterioration characteristics of these materials with time of exposure. However, the required information is not available for the local materials and hence a study on deterioration characteristics of bamboo, coir yarn and their joints was considered valuable.

The study consisted of a field survey to elucidate the current practices adopted by local users of bamboo and coir yarn for structural purposes, and an experimental study, at various exposures up to 360 days, on (i) compressive stress, tensile stress and flexural stress of bamboo; (ii) breaking strength of coir yarn; (iii) compressive strength of vertical/vertical coir yarn joint in a bamboo scaffold; and (iv) visual appearance.

The investigation resulted in providing guidance on selection of bamboo and coir yarn for structural applications, the design process to be adopted for these rapidly decaying structures, and the maintenance of these structures to extend the initially anticipated service life.

1.0 Introduction

In Sri Lanka, most common structural engineering applications of bamboo are in scaffolding construction and formwork construction. Although there are ten native species and twenty introduced species of bamboo in Sri Lanka[1], the yellow variety Bambusa vulgaris (Kaha Una) is the most widely available. It is this species that is used commonly for the above structural applications.

A bamboo shoot completes its upward growth within a period of four to eight weeks. Once the maximum height is attained, strengthening of the culm takes place during the subsequent 2 to 3 years by polymerisation to get the appropriate cellulose and lignin molecules[12]. The culm never increases in height, thickness or diameter after its initial growth in height is completed. Generally a bamboo of age 2 years, 5 years and 8 years can be classified as immature, mature and overmature respectively. A living bamboo can grow for 10 to 12 years[13]. Bamboos are suitable for structural engineering applications because of their higher strength to weight ratio, resilience, economy, and hollow cylindrical shape with protruding nodes to prevent local buckling.

The coir yarn used for bamboo scaffolds[2] is commonly known as scaffold-coir yarn (palanchi lanu). This variety is stronger, thicker and closely twisted than normal coir yarn. It is generally specified[3] by breaking strength (maximum force in a tensile test), runnage (length per unit mass), scorage (number of strands that could be laid very close to each other without overlapping in a length of one metre), and twist (number of turns per metre of the yarn). However, these properties are not normally measured, and buyer selects the coir yarn by visual inspection based on diameter, closeness of twist, strength, absence of coir dust, mass and moisture content. Scaffold-coir yarn considered to be satisfactory, locally, may have diameter varying from 3.5 to 6.0mm, tensile strength of at least 0.25 KN, a very close twist, mass of a hank (lanu kerella) varying from 70 to 130g, and a very low moisture content.

Durability of bamboo is affected by splitting caused by drying shrinkage, as well as insect attack and fungal attack. It depends on climatic conditions and the environment. When in contact with soil and atmosphere, untreated mature bamboo has an average life[8,9] 1 to 3 years, while under cover an average life 4 to 7 years is possible which can go up to 10-15 years if exposed to fumes of burning fuel. However, in marine water, life expectancy is as low as 6 months[9] due to marine borer attack. In contrast, an immature bamboo may not last more than 6-9 months even under cover. Durability of the bottom portion of the culm is higher than elsewhere in the culm.

Prof. S.R. de S. Chandrakeerthy, *BSc(Eng)Hons, PhD, AMIE(SL),Head of the Division of Structural and Construction Engineering, Dept. of Civil Engineering, University of Moratuwa.*

Methods of preservative treatment of bamboo are available[1,4], but they are not used in Sri Lanka for bamboo utilised for structural purposes. As it is difficult to prevent splitting in exposed structures due to drying shrinkage with passage of time, full benefits of preservative treatment are unlikely to be realised for bamboo used structurally, because of poor structural performance of split bamboo culms.

Long term performance of coir yarn is affected by : drying shrinkage; creep; weathering by wetting, drying and ultra-violet light; termite attack; loss of friction; chemical action leading to hydrolysis of carbohydrates; and wear and tear. Preservative or other treatments are not normally applied to coir yarn, although it is used under severe exposure such as by toddy tappers for the ladder rungs tied to coconut trees. Instead coir yarn is replaced or strengthened by; additional new windings as joint loosens or decay proceeds.

Bamboo scaffoldings have been used in the past for construction and maintenance work of tall buildings in Sri Lanka. In addition to satisfying strength and deformation requirements, durability of scaffolds is a major concern due to longer duration of service required from those temporary structures which may be sometimes more than six months. Even in shorter bamboo scaffolds and in formwork structures utilising bamboo posts, the current trend of maximum reuse requires a thorough understanding of durability characteristics. Further, bamboos have more consistent properties than wood because defects such as slope of grain and knots do not occur, but decay by termites, powder post beetles, fungi and splitting have a much greater influence[9]. More importantly, as bamboo and coir yarn are unlikely to be subjected to preservative treatment in Sri Lanka due to cost implications, the rate of strength reduction with time is an essential information to ensure continued safety of these structures by strengthening or replacement.

Some information on proportioning and layout of bamboo scaffolds[2,5] and on bamboo posts in formwork structures[6] is available. However, no such information is available on deterioration characteristics of untreated bamboo or coir yarn in exposed structures. Hence this study is directed to provide the above required information.

2.0 Objectives

The main objectives of this study are: (a) to determine the present practice of selection of materials as well as replacing or strengthening deteriorated bamboo and coir yarn in scaffolding/shuttering work; (b) to determine percentage strength reduction, and variation of physical features (colour change, splitting, fungal attack and borer holes, whichever is applicable) of above materials with passage of time in exposed structures; (c) to formulate a viable design approach for these rapidly decaying materials; and (d) to recommend when and how to replace or strengthen deteriorated elements.

3.0 Field Survey

A field survey was conducted using a questionnaire to elucidate the current practices adopted by local users of bamboo and coir yarn for structural purposes. Seventy-seven respondents were drawn from civil engineers, technicians, minor supervisors, carpenters and masons. Those not fluent in English were interviewed and the questionnaire was filled on their behalf. The conclusions are drawn from views expressed by the respondents. Although these views may reflect current practices, whether those reported include all the current practices cannot be guaranteed. Detailed results are presented only when it was possible to do so in condensed form.

The main findings were :

(a) The survey reflected the practices in Western, North-Western, Sabaragamuwa and Southern Provinces as respondents were mainly drawn from them;

(b) The composition of the respondents consisted of 22.1% civil engineers, 9.1% technicians, 10.4% minor supervisors, 26.0% carpenters and 32.5% masons;

(c) In the selection of bamboo for felling the characteristics ranging from most used to least used were: wilting of leaves (77.9% of responses), brownish yellow rather than bright yellow colour (68.8%), interior culms of a bamboo clump (67.5%), appearance of dead or live twigs from each node (63.6%), diameter greater than 63mm (61.0%), and age about 5 years when known (50.6%);

(d) In the selection of bamboo for purchase from a timber trader, the most used to least used characteristics were: base diameter range of 63-88 mm (87.0%), freedom from cuts across the grain (85.7%), freedom from longitudinal splits completely rupturing the shell wall (84.4%), brownish yellow but not with a faded appearance (80.5%), freedom from bud scars at nodes to ensure bamboo is not immature (77.9%), base thickness range of 5-15mm (70.1%), not out of straight by more than one diameter in every 2.0m (63.6%), freedom from chipped areas that remove the polished bamboo skin containing silica[12] (62.3%), length range of 8.0-13.0m (61.0%), heavier mass among similar specimens (48.4%), bamboo[7] not dead (either due to flowering (30-60 years) or injury to culm or dying culm, identified by dull greyish colour, lightness in weight and brittleness) (29.9%), and freedom from any objectionable crack[7] defined by a separation of fibres in the longitudinal direction which extends beyond 3mm into the depth of the skin of a bamboo and beyond a node (28.6%);

(e) In the selection of coir yarn for purchase, the most used to least used characteristics were: closely twisted rather than loosely twisted (88.3%), diameter range 3.5-6.0 mm(75.3%), absence of excessive coir dust (74.0%), relatively strong and less extensible (70.1%), unfaded but not grey in colour (68.8%), low moisture content (59.7%), and heavier mass among similar specimens (30.0%);

(f) The most used to least used characteristics considered to decide when bamboo requires replacement in a scaffolding or shuttering were: longitudinal split in bamboo with more than 1.0mm opening (76.6%), very dull faced yellow colour but not grey (75.3%), increasing deflections (or local distortions at stress concentrations) (70.1%), a period of 4-6 months of exposure (68.8%), and appearance of patches of grey fungus (42.9%);

(g) The most used to least used characteristics considered to decide when coir yarn requires replacement were: slipping of coir yarn joint under load due to loosening of joint (67.5%), time of exposure of 4-5 months (64.9%), greyish-brown to grey colour (50.6%), and development of frequent creaking sounds due to extension of coir yarn with load application (49.4%);

(h) Methods adopted for strengthening of deteriorated bamboo in scaffoldings (Figure 3) were: Putlog - replacement with new bamboo (100.0%) or reducing load by inserting new putlogs between old members (0%), Ledger - replacement with new bamboo (80.5%) or reducing span by inserting new standards between old standards (68.8%), Standard - Insertion of a new standard to replace the old standard (71.4%) or insertion of a new standard between two old standards to reduce the load on standards (70.1%), Bracing - Insertion of a new bracing to replace the old bracing (97.4%) or insertion of a new bracing by the side of the old bracing (79.2%);

(i) Method adopted for strengthening of deteriorated bamboo props in a formwork system was to insert additional bamboo props into the system (100%) or insert new members to replace of (0%); and

(j) Methods adopted for strengthening of deteriorated coir yarn joints in a scaffolding were: winding new coir yarn and jointing over old (88.3%), replacement of old coir yarn with new coir yarn (77.9%), and unwinding and retightening of old coir yarn (41.6% of responses).

4.0 Experimental Study

4.1 Test Programme

The test programme was directed to investigate how normal exposure to wetting and drying adversely influences certain key physical and mechanical properties of untreated bamboo, coir yarn and coir yarn joints in bamboo. The important physical and mechanical properties that require closer scrutiny were considered to be: (i) compressive stress, tensile stress and flexural stress of bamboo; (ii) breaking strength of coir yarn; (iii) compressive strength of vertical/vertical coir yarn joint in a bamboo scaffold; and (iv) visual appearance.

The properties in (i) above were selected as they will influence performance of a scaffold or formwork system employing bamboo. Breaking strength of coir yarn was selected as it directly influences performance of coir yarn joints and since scorage, runnage and twist are not expected to change due to decay. Vertical/vertical coir yarn joint was selected as it is a critical joint which does not allow development of frictional resistance of all its windings as part of the joint slackens under load (see Figure 1) with no physical interlock. Finally, visual appearance was selected hoping that it will allow formulation of guidelines for deciding replacement/ strengthening times of the constituent elements of a structure under prolonged exposure.

Each of the selected properties was determined at certain time intervals. The first group of tests were done at 0 days where bamboo or coir yarn or their joints were tested 4 weeks after felling of bamboo or manufacture of coir yarn to ensure that material is well seasoned[7,8]. As scaffoldings or formwork systems are known to have been used without any repair for 60 days, subsequent tests were carried out in intervals not exceeding 60 days.

The exposure times of various groups of tests were 0, 60, 90, 120, 150, 180, 240, 300 and 360 days. The upper limit of 360 days was considered adequate since maximum time of exposure before repair does not appear to exceed 240 days, and since typical conditions of sun, rain and wind can be accommodated within a year.

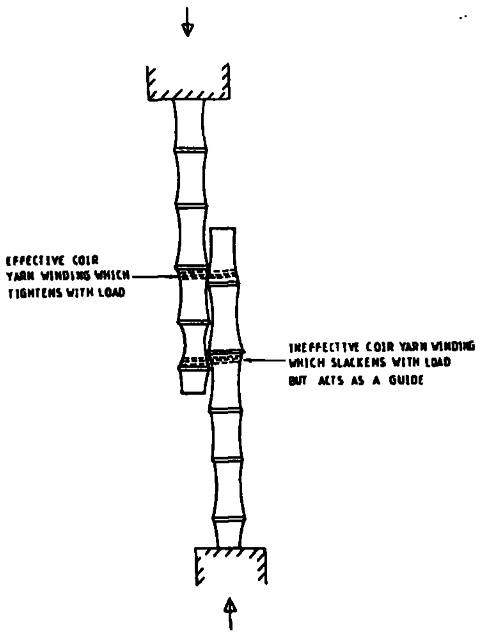

Figure 1 - Vertical to Vertical Joint in a Bamboo Scaffold

Table 1 - Factors used for Derivation of Design Values

Item	Property	Exclusion limit	Statistical factor for the exclusion limit (K)	Reduction factor (F)
Bamboo	Bending Mean modulus of elasticity Minimum modulus of elasticity Compression Tension	5 in 100 -- 5 in 100 5 in 100 5 in 100	1.645 --- 1.645 1.645 1.645	2.25 1.00 1.00 1.40 2.25
Coir Yarn	Breaking strength	5 in 100	1.645	2.25
Vertical to vertical bamboo and coir yarn joint	Compression	5 in 100	1.645	2.25

Although bamboo, coir yarn and their joints are exposed in vertical, horizontal or inclined positions in an actual structure, the most critical exposure was considered to take place when they are placed horizontal about 225mm above ground in the North-South direction subject to direct action of sun, wind and rain. Accordingly all the specimens were exposed in the above manner till removal for testing after the respective period of exposure.

Compressive stress, tensile stress and flexural stress of bamboo are affected by the species, age, growth condition, specific gravity, moisture content, node spacing, position along the culm, initial curvature, diameter, thickness, modulus of elasticity, duration of loading, seasoning and durability defects. The species was kept fixed at Bambusa vulgaris as it is most widely used and age was kept within the range 4-6 years by selecting only matured bamboo (brownish-yellow, free of bud scars at nodes, higher density, and free of splits or damages). This was very easy as traders give freedom of selection of bamboo to the buyers. Three growth conditions were considered by selecting bamboo from three traders each one supplying from three different sources, and the sources were the banks of Kelani ganga, Kalu ganga and Bolgoda Lake. Specific gravity, moisture content, node spacing, thickness and modulus of elasticity were measured for each specimen. Position along the culm was considered by taking two specimens from each culm covering bottom as well as top part of the culm. Initial curvature was isolated from this study by rejecting any bamboo out of straight by more than one diameter in every 2.0m, similar to IS 10145[7]. Variation of diameter was considered by conducting tests on three sizes of bamboo, small (63mm $\leqslant$ d < 72mm), Average (72mm $\leqslant$ d < 88mm) and large (d $\geqslant$ 88mm) classified in accordance with Samarasinghe[2]. Different durations of loadings were not considered and only short term loading was considered. If other loading conditions are required, BS 5268[11] factors can be used. Only well seasoned bamboos (period 4-6 weeks after felling) were used for this study. Influence of durability defects[23,24] was considered by testing bamboo at various periods of exposure. In the case of compressive stress, slenderness ratio is an important variable. As slenderness ratio cannot be varied in a regular manner, it was measured for each compression test specimen. Compression test and flexural test used whole bamboos of length 1.5m and 2.4m (span 2.1m) respectively. Tensile test used bamboo strips 10mm x thickness in cross-section with a gauge length of 125mm and overall length of 200 mm with gripping ends 25mm wide. Although dimensions were different, to satisfy those of bamboo elements in a scaffolding, test methods were held as far as possible similar to those in IS 6874[10] and IS 8242[14].

Breaking strength of coir yarn is affected by type of coir yarn (defined by runnage, scorage and twist) and moisture content. The type of coir yarn used was scaffolding coir yarn of lowest acceptable quality and moisture content of each specimen was measured. Specimen size of the coir yarn was 500mm and the test method complied with SLS 513[3].

Strength of vertical/vertical coir yarn joint in bamboo is affected by variables that affect bamboo and those that affect coir yarn as described earlier. In addition, it is affected by number of coir yarn attachments, initial tightening and number of hanks of coir yarn per attachment. Selection of bamboo and coir yarn were done as for tests on bamboo and coir yarn so that influence of unimportant variables can be eliminated while highlighting the influence of important variables. Number of coir yarn attachments used was two (Figure 1) so that one coir yarn attachment can be critically loaded. Initial tightening was controlled so that joints were hand tightened by applying the largest force that can be applied to coir yarn by hand, as both excessive or insufficient tightening will adversely effect the joint performance. A hank of coir yarn per attachment was used as this was the quantity found to be adequate for a vertical/vertical joint[15]. Specimen was formed by jointing two bamboo culms about 1.0m long each as shown in Figure 1. It was loaded in compression till failure noting the load-slip behaviour of the joint.

Visual appearance is affected by the period of exposure and initial conditions of bamboo and coir yarn. Details of period of exposure as well as location and layout of exposure site were as described earlier. Properly seasoned fresh bamboo and coir yarn were selected for the study so that initial conditions of the materials will neither exaggerate nor hide the typical likely visual appearance. Characteristics observed were colour, insect attack, splitting and fungal attack.

One test group representing a particular period of exposure consisted of the following: (a) Compression tests on 18 specimens of 1.5m long bamboo covering three growth conditions, three sizes and top and bottom of each culm[16]; (b) Tension tests on 18 specimens of 200mm long bamboo strips as above; (c) Flexure tests on 18 specimens of 2.4m long bamboo as above; (d) Tension tests on 18 specimens of 500mm long coir yarn selected for the experimental program; and (e) Vertical/vertical coir yarn joints in bamboo on 18 specimens made of 1.0m long bamboo pairs covering various conditions as above.

4.2 Experimental Results and Analysis:

4.2.1 Results and Their Reduction :

Approximately half the test programme[17,18] was conducted for one year and the remainder was conducted at a subsequent year. Climatic conditions of these two years adequately simulated the typical weather in Sri Lanka with periods of bright sun to overcast sky, heavy rain to dry weather, and gusty winds to gentle breezes.

Measurements of specific gravity of bamboo in this study ranged from 0.51 to 0.87 with the mean value of 0.65. These compared well with those reported by Jayanthi Manel[1] (0.47 - 0.74), Siopongco[16] (0.46 - 0.72), Raitt[13] (0.76 to 0.96) and Janssen[12,19,20] (0.6 - 0.9). All the test results were reduced to the mean value of specific gravity assuming each mechanical property is directly proportional to the specific gravity.

Moisture content of bamboo ranged from 12.41% to 188.0%. In specimens where moisture content fell below the fibre saturation point of 30%, measured value of a mechanical property was adjusted to a moisture content of 30% by the relationship $\log_e S = \log_e S_p + k(M_p - M)$ where S in the property at the moisture content M while S_p and M_p are the property and the moisture content at the fibre saturation point, k (see Table 2) being a constant. No adjustment was made to a mechanical property above fibre saturation point as variation of that property with moisture content above fibre saturation point is insignificant.

The design value of any mechanical property was obtained by first adjusting the measured values to the mean specific gravity of all test specimens. Next those values were adjusted to those at fibre saturation point using respective moisture content values, since green or wet values are required for exposed structures. Finally design value was obtained by the application of $f = (f_m - KS)/F$ where f = the required design value; f_m = mean of that property; K = statistical constant; S = standard deviation of that property and F = reduction factor. Values of K and F are given in Table 1. K allows for an exclusion limit[11] of 5% while F is the conventional factor of safety[11,27,28] which allows for small variations of moisture content, duration of loading, extent of loading, sectional properties and construction tolerances. Statistical information on design stresses are given in Table 5.

In the compression test on bamboo, slenderness ratio could not be held constant, although length was kept constant, as sectional properties of bamboo vary. Slenderness ratio varied from 54.0 to 109.8 and the mean value was 61.9. Measured values of ultimate compressive stress were adjusted to this mean slenderness ratio using the Euler's theory that buckling stress is inversely proportional to the square of the slenderness ratio. Thereafter specific gravity and moisture content adjustments were made and design values obtained statistically as described above. The design compressive stress values are shown in Table 2, and initial value with no exposure compared well with those reported by Siopongco et al[16] (7.845) and Janssen[19] (6.6). There was no significant correlation between the parameter, node spacing/diameter, and buckling stress.

Design tensile stress, flexural stress and modulus of elasticity of bamboo, breaking strength of coir yarn and design load of vertical/vertical joint were computed by applying specific gravity correction, moisture content correction and statistical data reduction process described earlier. Respective results are shown in Table 2.

Design tensile stress of bamboo with no exposure compared well with those reported by Siopongco et al[16] (29.42) and Janssen[9,19] (20).

Design flexural stress of bamboo with no exposure compared well with those reported by Siopongco et al[16] (9.81) and Janssen[19,20] (12.2). There was no significant correlation between the parameter, node spacing/diameter, and flexural stress.

Modulus of elasticity with no exposure compared well with those reported by Samarasinghe[2] (15200), Siopongco et al[16] (5590 to 21180) and Janssen[19,20] (20000). There was no significant correlation between the parameter, node spacing/diameter, and modulus of elasticity. Modulus of elasticity was measured in flexure with minimum and mean values given in Tables 2 and 5 respectively.

In the case of vertical/vertical bamboo coir yarn joint, there was no significant correlation between the parameter, ratio of diameters of two bamboo verticals, and the design load of the joint.

Results of observations of visual appearance of bamboo subject to exposure are shown in Table 3. Clear signs of decay after 180 days of exposure can be seen with the appearance of yellowish-grey colour, 11-25 insect holes per metre, few 1.0mm wide splits, and fungi at few locations. The probable strength reduction or deformation increase is also worked out from Figure 2 and presented in Table 3 for application when bamboo is being reused for a new structure.

4.2.2 Design Process and Service Life

Structural design process is normally applied to materials that are either naturally durable or made durable by some treatment. As untreated bamboo and

Table 2 - Variation of Design Values of Various Properties with Exposure

Period of exposure (days)	Design compressive stress of bamboo (N/mm^2)	Design tensile stress of bamboo (N/mm^2)	Design flexural stress of bamboo (N/mm^2)	Modulus of elasticity (E) of bamboo (N/mm^2) x 10^3	1/E (mm^2/N) x 10^{-5}	Design breaking strength of coir yarn (kN)*	Design load of vertical / vertical joint (kN)
0	12.28	29.29	17.82	11.79	8.462	0.164	2.07
60	10.35	25.10	15.29	11.54	8.666	0.142	2.03
90	9.15	23.11	14.45	11.11	9.001	0.129	1.99
120	8.19	21.72	13.61	10.83	9.234	0.120	1.95
150	7.22	20.[illegible]2	12.77	10.24	9.766	0.115	1.88
180	6.26	19.33	12.21	9.58	10.438	0.106	1.81
240	5.06	17.93	11.08	8.12	12.315	0.102	1.58
300	4.57	16.94	10.24	7.06	14.164	0.100	1.41
360	4.33	15.94	10.10	6.23	16.051	0.098	0.86
k for m.c. correction	0.02795	0.01072	0.02349	0.00891	----	0.02348	0.01267

* Usually expressed as a force (3)

Table 3 - Deterioration Indicators at Various Periods of Exposure

Period of exposure (days)	Colour	Insect attack	Splitting	Fungal attack	Percentage strength reduction (or 1/E increase) from Figure 2 (%)
0	Brownish-yellow to yellow	No	No	No	0.0
60	Faded yellow	No	No	No	18.3
90	Dull faded yellow	No	No	No	27.5
120	Very dull faded yellow	0-5 holes per meter	Few* 0.1mm wide splits	No	37.7
150	Yellowish-grey	6-10 holes per metre	Few up to 0.5mm wide splits	Fungi at few places (up to 10% of surface)	45.8
180	Yellowish-grey	11-25 holes per metre	Few up to 1.0mm wide splits	Fungi at few places (up to 25% of surface)	55.0
240	Grey	26-50 holes per metre	Numerous** splits up to 1.0mm wide	Moderate fungal attack (up to 45% of surface)	66.7
300	Grey	51-100 holes per metre	Few splits 1.1-2.5mm wide and numerous splits up to 1.0mm wide	Moderate fungal attack (up to 70% of surface)	78.3
360	Grey	More than 100 holes per metre	Numerous splits up to 2.5mm wide	Considerable fungal attack (More than 70% of surface)	90.0

* Few - a split every five or more internodes
** Numerous - a split in every four or less internodes

Table 4 - Percentage Changes in Various Properties with Exposure

Period of exposure (days)	Decrease in Percentage					Increase in Percentage
	Design compressive stress of bamboo (%)	Design tensile stress of bamboo (%)	Design flexural stress of bamboo (%)	Design breaking strength of coir yarn (%)	Design load of vertical /vertical joint (%)	I/E (%)
0	0	0	0	0	0	0
60	15.72	14.31	14.20	13.41	1.93	2.17
90	25.49	21.10	18.91	21.34	3.86	6.12
120	33.31	25.84	23.63	26.83	5.80	8.88
150	41.21	30.62	28.34	29.88	9.18	15.14
180	49.02	34.00	31.48	35.37	12.56	23.06
240	58.79	38.78	37.82	37.80	23.67	45.19
300	62.79	42.16	42.54	39.02	31.88	66.99
360	64.74	45.58	43.32	40.24	58.45	89.24

Table 5 - Statistical Information of Design Values Given in Table 2

Period of exposure (days)	Design compressive stress of bamboo (N/mm^2)		Design tensile stress of bamboo (N/mm^2)		Design flexural stress of bamboo (N/mm^2)		Modulus of elasticity of bamboo (N/mm^2) x 10^3		Design breaking strength of coir Yarn (kN)		Design load of vertical to vertical (kN)	
	M*	S**	M	S	M	S	M	S	M	S	M	S
0	25.01	4.75	91.49	15.55	58.32	11.08	16.37	2.78	0.537	0.102	6.94	1.30
60	19.67	3.15	86.28	18.12	48.87	8.80	16.39	2.95	0.476	0.095	6.64	1.26
90	18.63	3.54	77.49	15.50	45.13	7.67	16.16	3.07	0.443	0.093	6.67	1.33
120	17.09	3.42	71.09	13.51	46.78	9.82	16.14	3.23	0.402	0.080	6.38	1.21
150	13.42	2.01	64.95	11.69	40.82	7.35	14.55	2.62	0.376	0.072	6.46	1.36
180	12.17	2.07	63.27	12.02	39.96	7.59	13.30	2.26	0.364	0.077	5.92	1.13
240	10.06	1.81	57.31	10.32	37.15	7.43	11.54	2.08	0.342	0.068	5.30	1.06
300	8.49	1.27	55.44	10.53	31.98	5.44	10.27	1.95	0.327	0.062	4.85	1.02
360	8.42	1.43	53.45	10.69	33.87	6.77	9.06	1.72	0.337	0.071	2.96	0.62

* M = Arithmatical mean of the property

**S = Standard deviation of the property coir yarn, which are not durable, are used for structural applications, the usual theories cannot be directly applied, and strength reduction and deformation increase with exposure should be identified and accounted for. This practice is already applied for steel scaffolds[25,26] where a reduction factor (15%) is used for old scaffold tubes to allow for corrosion, in comparison to 'as new' tubes.

Table 2 gives the measured strength reductions with time of various strength parameters required for the design of bamboo scaffolds and bamboo formwork, while Table 4 expresses the above values as percentage strength reductions with respect to the corresponding strength value at the commencement of exposure.

Modulus of elasticity unlike strength does not directly control behaviour except through the deformations developed. The most important deformation, deflection of a flexural member, is directly proportional to the parameter "1/E' and hence "1/E" and percentage changes of "1/E" were computed and presented in Tables 2 and 4. For easy interpretation as well as development of a simple lower bound enveloping curve, both the percentage reductions (strength parameters) and percentage increases (1/E) are presented together in Figure 2. The equation of the simplest enveloping curve was found to be: (a) $p = (55d/180)$ for $O < d < 180$; and (b) $p = [(35d/180) + 20]$ for $180 < d < 360$ where p = most unfavourable percentage increase or decrease of the variable; and d = duration of the exposure in days. Materials can be utilised more economically if values are read out from each curve of figure 2 to develop the critical percentage decrease or increase to be used for a given duration.

For the structural design of a rapidly deteriorating structure two approaches are possible. One approach is to apply a higher factor of safety than the usual so that in effect design stresses (or parameters) relate to that allowable after a certain degree of decay of the structure. The other approach is to develop design stresses (or parameters) with the usual factor of safety for the structure at the commencement of the exposure and let the designer use a percentage reduction (percentage increase in the case of 1/E) of the above values depending on the period of service life (time of exposure before replacement or strengthening) anticipated for the structure. The latter approach is recommended for the following reasons :- (i) Whatever design method used will depend on the anticipated service life of the structure and in the case of temporary bamboo structures it is better to let the structural designer decide it depending on the particular situation rather than specifying a general time period for the service life for all structures; (ii) This method using percentage reduction in strength is being successfully applied for nailed joints in non-durable timber[21]; (iii) This method allows the use of very deteriorated structures by applying appropriate strength reduction (or 1/E increase) factors giving rise to optimum use of a given bamboo structure; (iv) Reuse of bamboo even after some periods of storage in a sheltered environment can be easily accommodated in the design process; (v) Method of strengthening a bamboo structure after anticipated service life can be used on a logical basis by harnessing the residual strength of deteriorated bamboo; and (vi) This method is already used for steel scaffolds.

Anticipated service life[22] should be decided by the designer depending on the actual period of service required from the structure, or the proposed replacement time of the structure, or the proposed strengthening time of the structure. Once the service life in known, period of exposure is taken as the service life and strength reduction (or 1/E increase) factor can be obtained for design from the Figure 2.

Reuse potential of bamboo can be harnessed by using the Table 3. Bamboo earmarked for reuse should be inspected for deterioration indicators of Table 3 and, using that table, most conservative value of the equivalent exposure period assessed. Anticipated service life of the structure to be erected should be added to the previous equivalent exposure period to obtain the required exposure period. Finally, strength reduction (or 1/E increase) factor is obtained from Figure 2 for the above required exposure period.

Recommended method is illustrated by the examples that follow.

Example 1: Determine the strength reduction (or 1/E increase) factor for a bamboo scaffold whose anticipated service life is 120 days.
From Figure 2, $p = (55 \times 120)/180 = 36.67\%$

Example 2: Due to unavoidable circumstances the above scaffold (Example 1) has to be used for a further period of 120 days, by replacing all ledgers, and by reducing loads on putlogs, verticals and braces by attaching new members between old members. Determine the strength reduction (or 1/E increase) factor for the old bamboos.

New period of exposure for old bamboos = 120 + 120 = 240 days
From Figure 2, $p = [(35 \times 240)/180] + 20 = 66.67\%$

Example 3: A stock of bamboos is to be reused. The worst condition of each deterioration indicator in that stock was found to be : faded yellow colour; No insect attack; Few 0.1m wide splits; and no fungal attack. Determine strength reduction (or 1/E

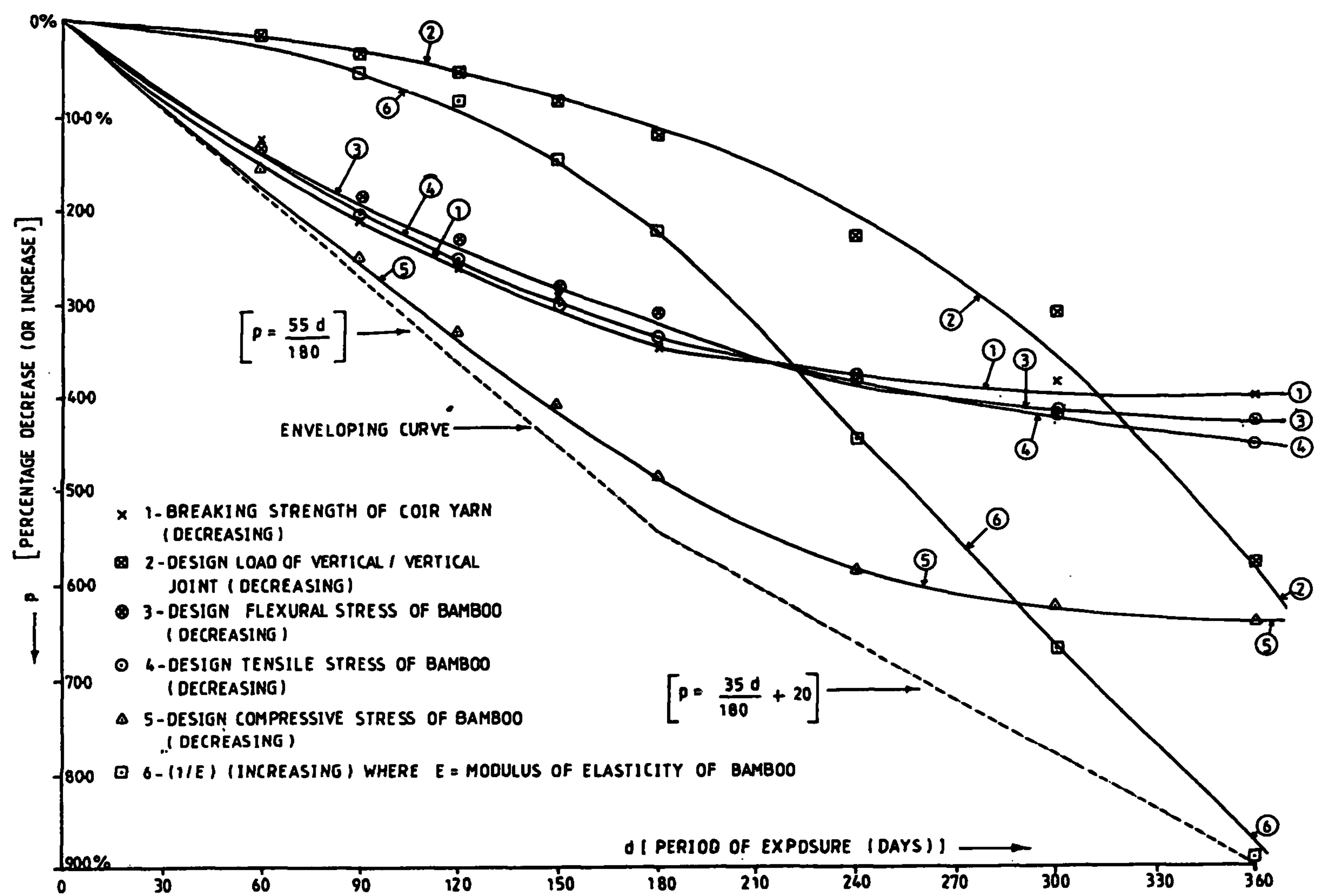

Figure 2 - Variation of Percentage Strength Deduction (or Deformation Increase) with Exposure

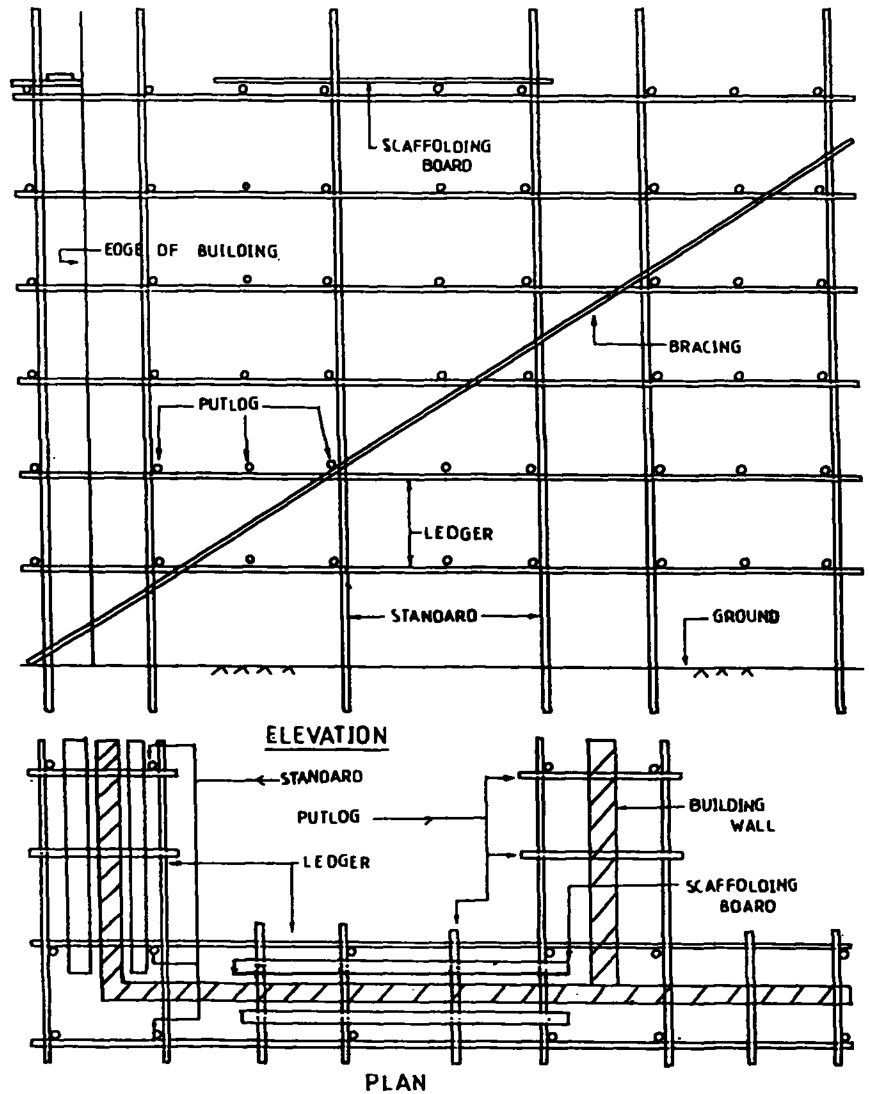

Figure 3 - Platform Type Bamboo Scaffolding

increase) factor to be used if the anticipated service life of the new structure is 90 days.

From Table 3, equivalent period of previous exposure of bamboo to be reused is 120 days. Required exposure period of the bamboo is 210 days (=120+90).
From Figure 2, p = (35 x 210/180) + 20 = 60.83%

4.2.3 Replacement / Strengthening methods

There are two methods currently in use to extend the service life of a bamboo structure. One method is to replace old elements of the structure with new bamboos and new coir yarn in a step by step manner starting from verticals and proceeding level by level upwards so that entire structure is not dismantled at any intermediate stage. This is possible as a bamboo culm generally curves in one plane making it possible to fix it in any given plane. Bamboos with double curvature are suited for putlogs only. The other method is to reduce the load of old elements by fixing new bamboo element in the vicinity of old members and winding new coir yarn joints over the old. This latter method is difficult to use efficiently as reduction of load of old members and using new elements at their optimum capacity are often difficult to attain simultaneously. Also as stiffness of old and new are different, exact manner of loadsharing is difficult to ascertain. Hence this method can best be used by a trial and error approach. Hence only the former method is recommended.

5.0 Conclusions

The following conclusions are made from this study: (a) In purchasing bamboo, the characteristics to be ensured are: outside base diameter not less than 63mm, freedom from cuts across the grain, freedom from longitudinal splits that rupture the entire shell wall, brownish-yellow colour, freedom from bud scars at the nodes, base wall thickness not less than 5mm, out of straightness not exceeding one base diameter in every 2.0m length, freedom from chippings that remove polished bamboo skin, length not less than 8.0m, heavier mass among similar specimens, freedom from shattering when dropped to the ground, and freedom from shallow cracks that extend beyond a node; (b) In purchasing coir yarn, the characteristics to be ensured are: a close twist, diameter 3.5 - 6.0mm, absence of excessive coir dust, high strength, low extensibility, unfaded colour, low moisture content, and heavier mass among similar specimens; (c) Recommended design process is based on prediction of strength reduction (or 1/E increase) factor for various exposure times; (d) Design process recommended can ensure optimum use of rapidly decaying bamboo and coir yarn as well as accommodating reuse of old bamboo in new structures; and (e) The best way to extend service life of a bamboo structure is to replace old elements with new bamboo and new coir yarn, stage by stage, without dismantling the entire structure at any intermediate stage.

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