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Feasibility of using bamboo as a potential reinforcement in concrete beams

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Abstract

This paper presents the evaluation of the feasibility to use bamboo as a potential reinforcement in concrete beams. To achieve this objective a series of tensile tests on two types of bamboo (i.e. yellow color and green color) were conducted to obtain their mechanical properties. Also, a series of pull out tests on two types of bamboo were conducted to obtain their bonding behavior in the concrete. To achieve the main objective, four-point bending tests on concrete beams reinforced with bamboo were performed to identify their behavior compared to conventional steel reinforced concrete beams. The test results of this study indicated that the ultimate load carrying capacity of tested bamboo reinforced concrete, on averaging all percent reinforcement, was about 29% of the equivalent reinforced steel concrete beams.

Keywords: bamboo reinforcement, concrete beam, reinforced concrete, flexural behavior

Introduction

Concrete is widely used in many constructions due to its special properties such as economy, readily availability and appropriate material property of high compressive strength. However concrete has very low tensile strength and therefore it is needed to be reinforced to increase the tensile strength of concrete. Habitually steel is used as the reinforcing material in concrete. Comparing with the other structural materials, steel has high tensile strength though it is very costly. Therefore it is only affordable to rich countries and in other countries like Sri Lanka alternative reinforcing materials for concrete is need to be researched. Currently, scientists and engineers are seeking for new substitute for steel as reinforcement. The substitute should be readily available and cheap in price. Hence it is prudent to focus on naturally available materials for countries like Sri Lanka. We can consider the timber as suitable substitute but due to its organic structure, timber will decay rapidly with time and which may results a decline in tensile strength. Considering those reasons scientists and engineers are seeking a new natural structural material and the idea of using bamboo is become high popularity as reinforcement material.

Materials and Methods

Tensile test

For Tensile tests bamboo specimens were prepared by splitting the bamboo typically in 18 mm wide strips of 200 mm in length for both types of bamboo. Those specimens were placed in between the Tenso-meter apparatus and test the tensile strength. The specimens were placed in between the aluminum tabs to avoid slip of the specimen. The specimens were made with the small cross sectional area in the middle to avoid shear failure of the specimen but larger cross sections were used at the ends to hold the specimen tightly.

Bond strength test

The bamboo splits were prepared with suitable length to satisfy the available apparatus and they were 25 mm×10 mm cross sectional area. The open helical spring was made with the diameter of 110 mm using 4 mm mild steel bar. The space of helical was kept about 25 mm. Then the spring was placed in the 150 mm × 150mm × 150mm cubic mould and pours the Grade 25 concrete thin layer of thickness 25 mm. Then the bamboo specimen was placed at center of the mould and concrete was poured while compacting. The specimen was cured until 28 days and pull out test was done.

Beam test

Six bamboo r/f concrete beams and 2 steel r/f concrete beams were cast to check the flexural behavior of bamboo r/f and compare with steel r/f and for this four-point bending tests were conducted. Initially the bamboo reinforcement nets were prepared with the ratio of 1.5 and 2.6 for both types of bamboo types (i.e. yellow and green bamboo) and kept the spacing between bamboo reinforcement strips 25 mm spaces. The bamboo strips were prepared by raw bamboo and those were sized to take cross section of 18 mm×9 mm or available thickness with 1920 mm length. There were three types of reinforcements were prepared for each beams as shown in Table 1. First type was bamboo reinforcement and bamboo stirrups for both types of bamboo. The bamboo strips were kept to dry for reducing the moisture content. The spacing between stirrups was 125mm. The second type was bamboo reinforcement and steel stirrups. 6mm diameter mild steel bar was used as stirrups. Steel stirrups were used to avoid the shear cracks. The third type was prepared by using 1% of steel reinforcement and 1% of bamboo reinforcement. This was used to compare with bamboo reinforcement beam.

Figure 1: Bamboo reinforcement net with bamboo stirrups

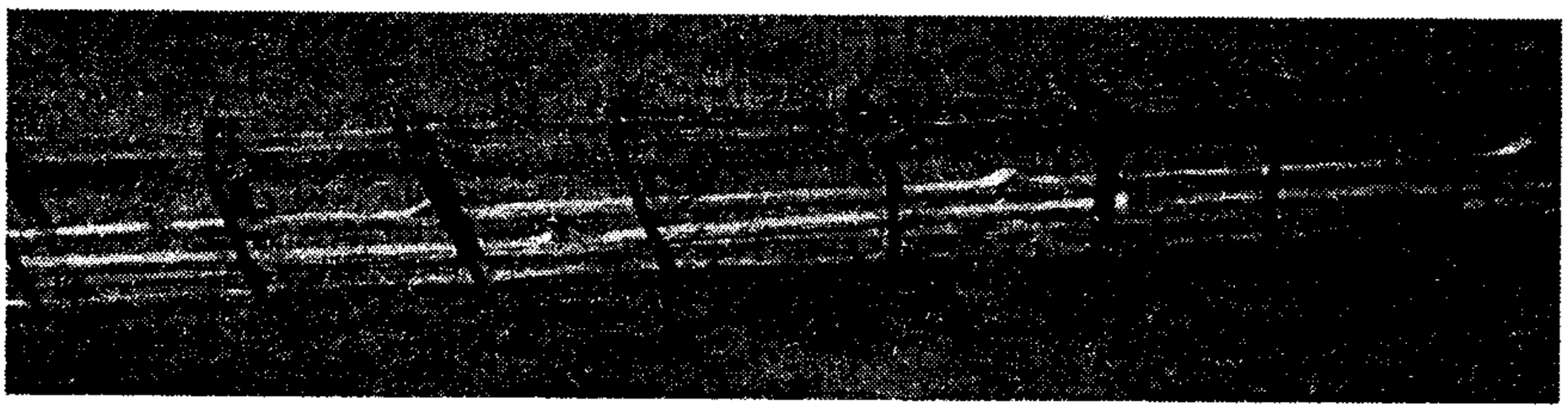


Figure 2: Bamboo reinforcement net with steel stirrups

Table 1: Type of beam preparation

Type of reinforcement	% of Reinforcement
Yellow type bamboo	1.5%
	2.6%
Green type bamboo	1.5%
	2.6%
Yellow with steel stirrup	1.5%
	2.6%
Yellow bamboo + steel	Bamboo 1% and Steel
steel	1%

The beam dimensions were decided based on the available apparatus in the Civil Engineering laboratory. Therefore the size of a beam was 100 mm × 200 mm × 2000 mm. The covering was 15 mm except the bottom face which was 25 mm.

Test setup

Four point bending test was done to check the flexural behavior of concrete beams reinforced by bamboo, steel and their combinations. The load was applied as two points with static loading rate and loading distance as given in Table 2.

Three dial gauges were placed in three places under the beam. Three locations are; center of the beam, quarter way from one end and the other. Then the readings of applied load and deflection were measured until beam failed. The load was applied manually with the constant rate of increment of load approximately 200N/sec.

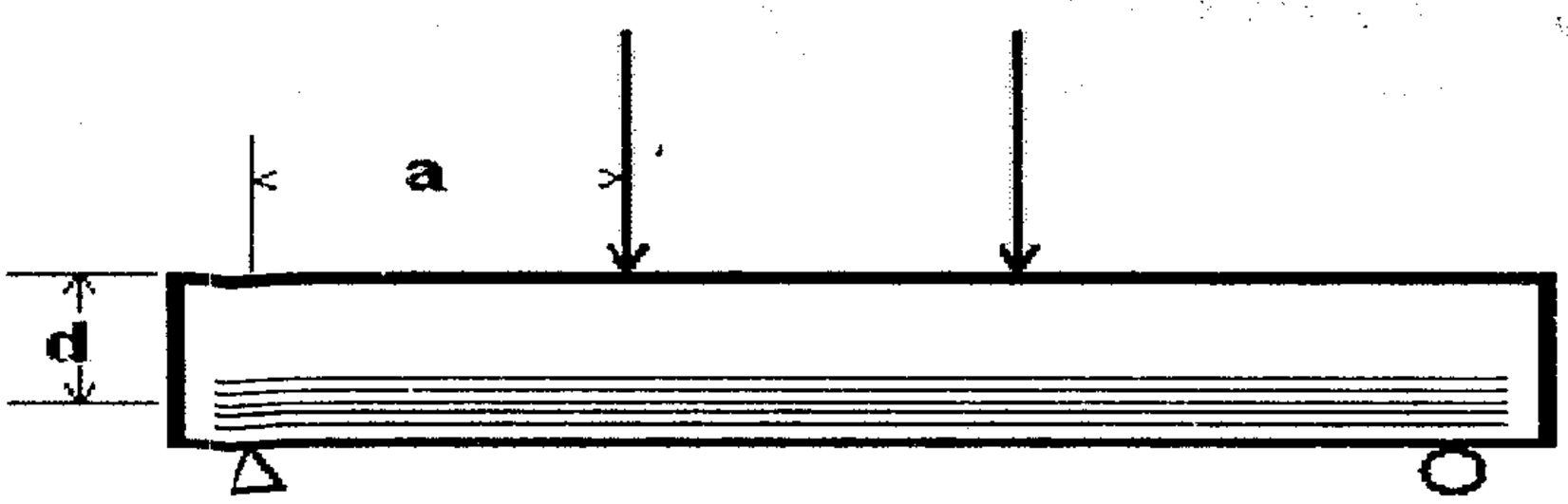


Table 2: Loading distance for beam test

Variables	Test 01	Test 02
% area of r/f	1.5	2.6
a/d ratio	4.5	4.5

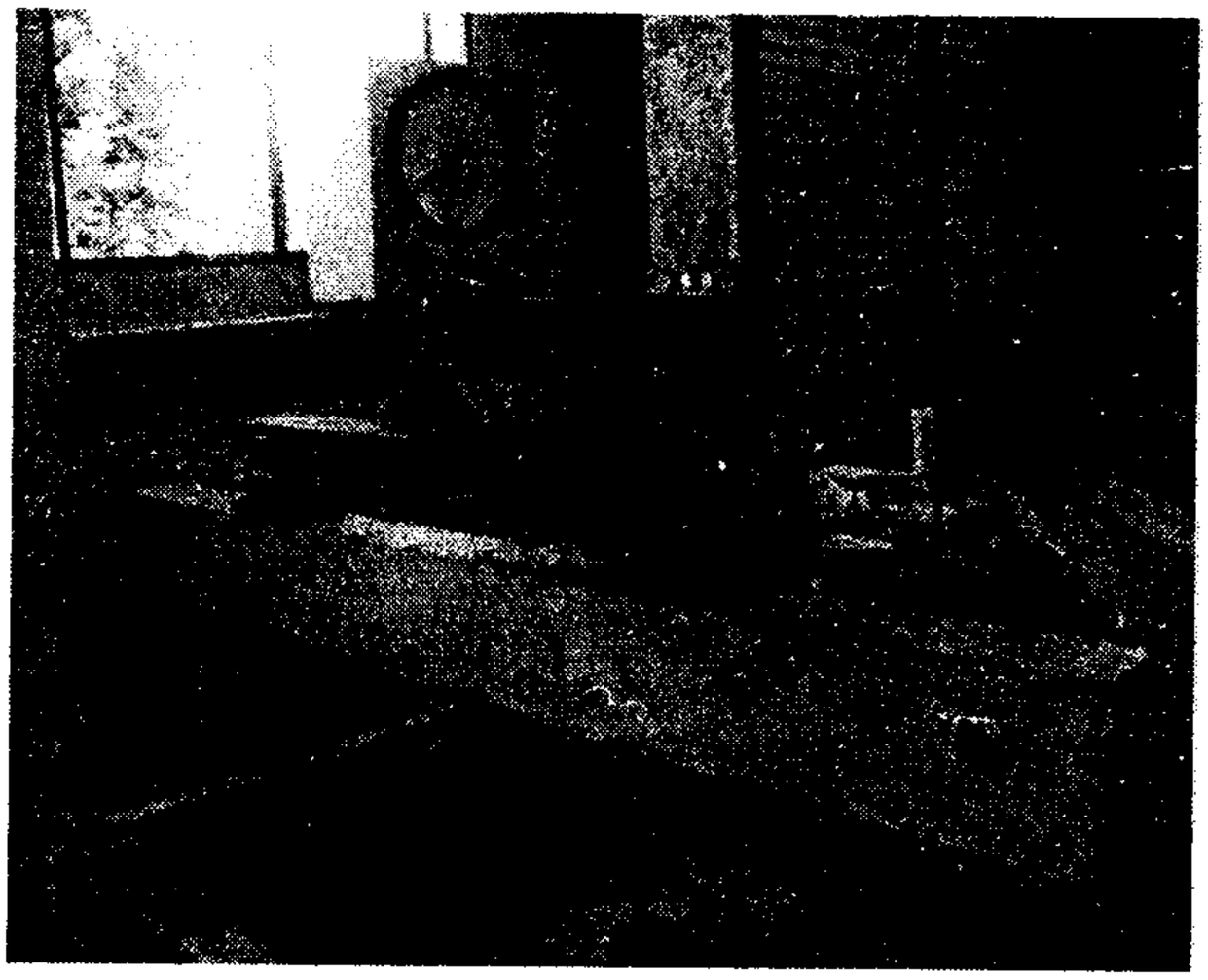


Figure 3: Beam test set-up

Results and Discussion

Tensile test

Generally, samples were failed in one or more of the following ways: (1) node failure; (2) end-tap failure; and (3) failure at the vicinity of the end-tap. In the test, normal chuck of the apparatus could not hold the specimen effectively without slipping. An Aluminium tab was introduced to avoid sudden facture at the ends.

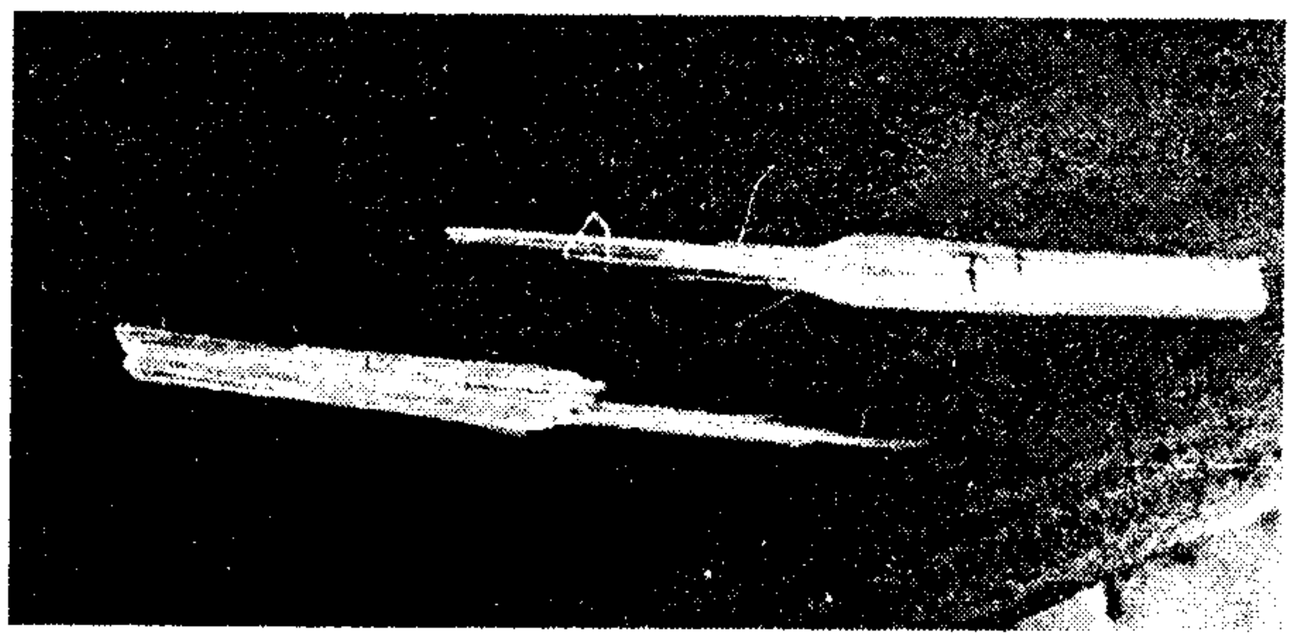
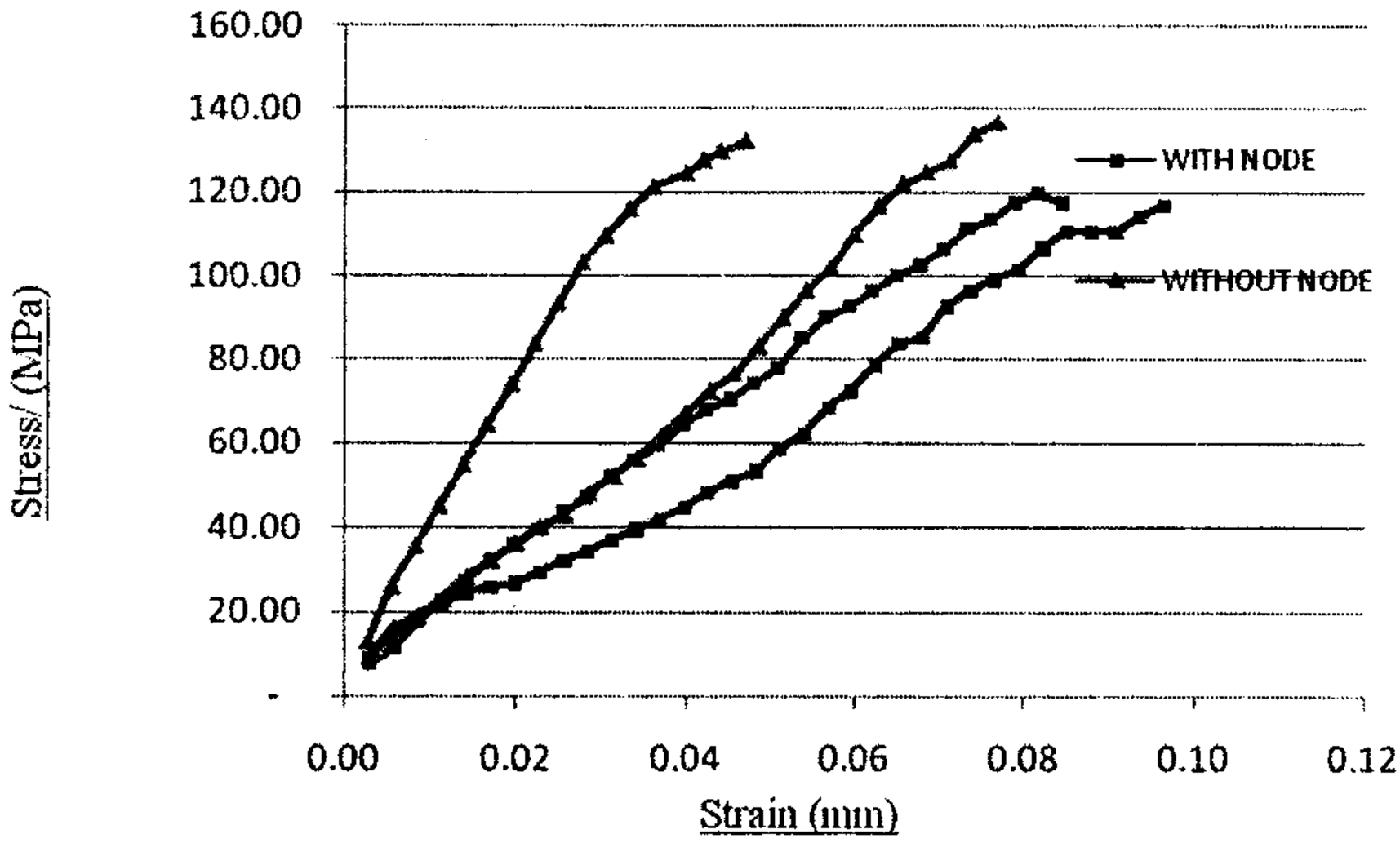


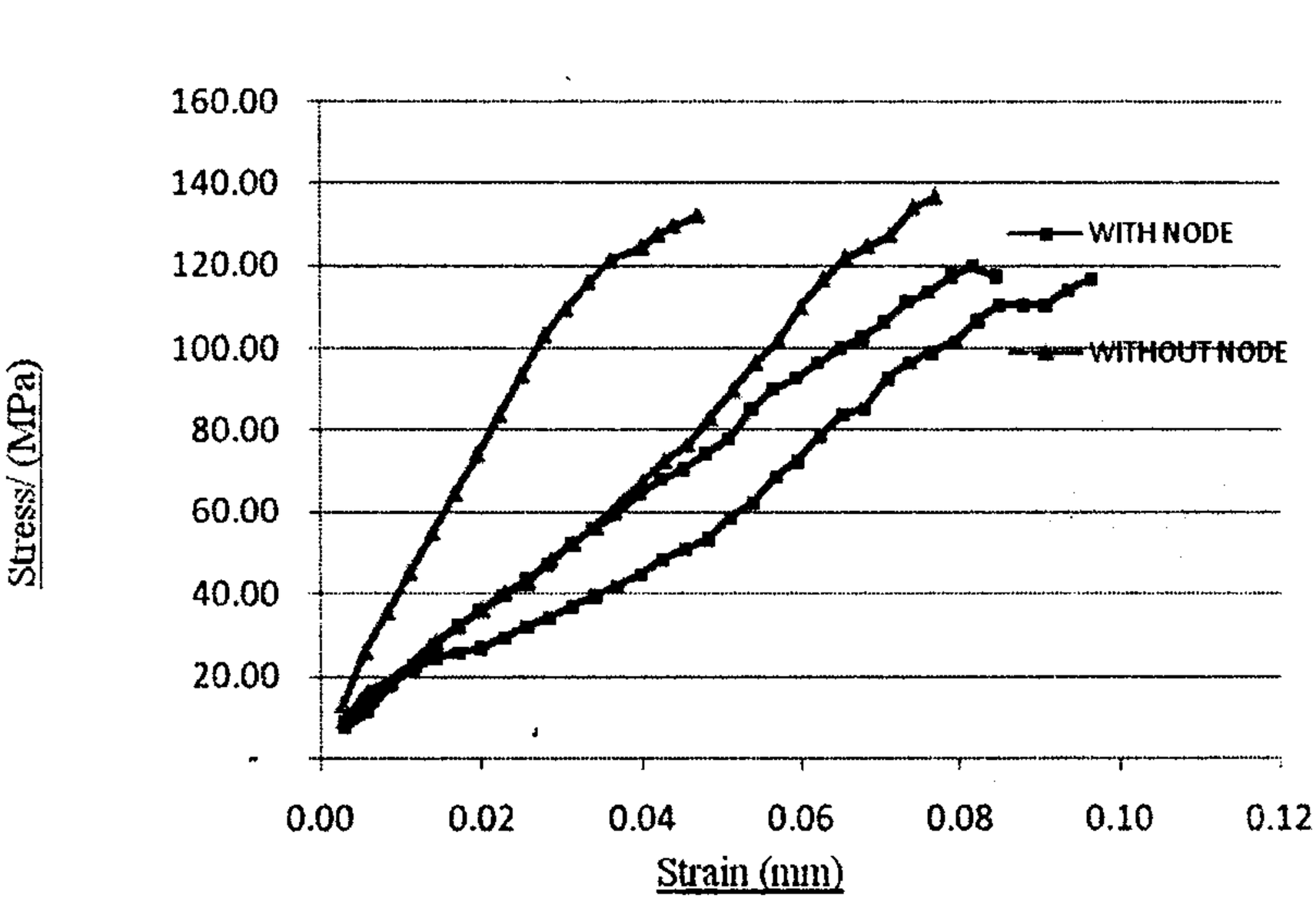
Figure 4: Failure of yellow bamboo without node

Tensile tests of the two bamboo types showed that the specimens with nodes behaved in a less ductile manner with low tensile strength than those without nodes. Failure of yellow bamboo without node is shown in Figure 4.

The Graph 1 and Graph 2 show the stress strain behavior of yellow and green bamboo respectively.



Graph 01: Graph of stress vs. strain of yellow bamboo



Graph 02: Graph of stress vs. strain for green bamboo

In the tests the bamboo with nodes achieved higher capacity than without-node specimen. According to the test result, the maximum failure tensile strength was given by yellow bamboo type without-nod which was 225 N/mm^2.

Bond strength test

Two types of samples; with node and without node were usedto test the bond strength between bamboo and concrete. Figure 6 shows bond failure of pull out test. Numbers of tests were conducted on each type and took the average value of failure load. The results are as shown in Table 3 and the equivalent steel r/f failure force got from the manual calculation.

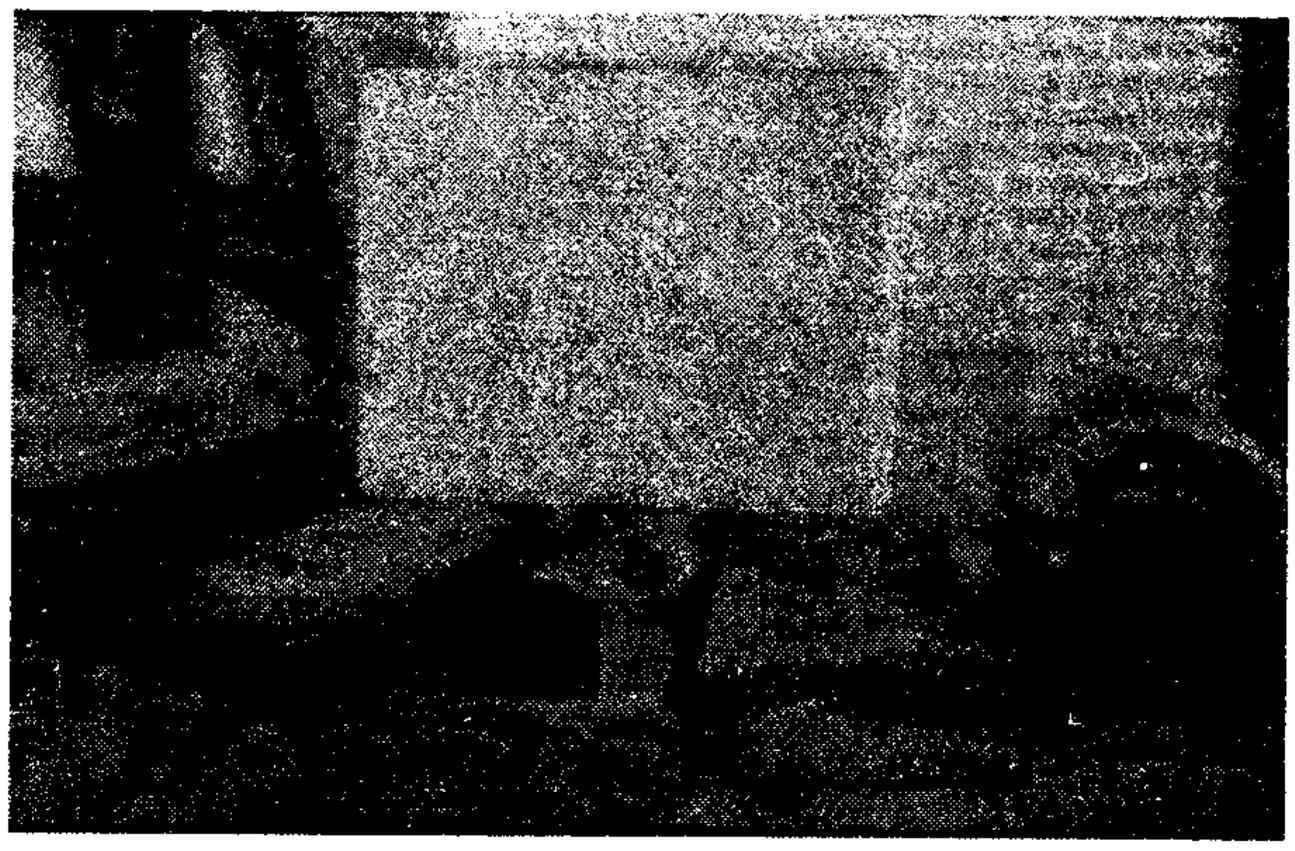


Figure 5: Bond failure of pull out test

Table 3: Failure load of pull out test

Type of bamboo strip	Avg. failure load (KN)	Equivalent steel R/f load	Percentage of failure load of steel
Without	10.98	19.69	55
With Node	12.39	19.69	62

Figure 6: Broken piece of the bamboo r/f concrete beam

The behavior of bamboo in concrete beam without proper bonding between concrete and the bamboo, failed as shown in Figure 6. Therefore it can be seen that bond between concrete and bamboo is considerably week

Beam Test

The beam tests were conducted to check the flexural behavior of bamboo r/f concrete beams. These tests were done on: four bamboo r/f concrete beams with bamboo strips as stirrups, two bamboo r/f concrete beams with steel stirrups, and one beam with the combination of steel and bamboo r/f together where it was ensured same steel ratio in the beam to check their improvement. The test results of the different reinforcement arrangements are described below.

Yellow bamboo r/f concrete beam

First the beam was tested with the design parameters of 4.5 a/d ratio, 1.5 % of reinforcement and loading point 760 mm from end. When the load was increased initial cracked appeared at near to the right side of the beam at the load of 9.32kN. Finally the beam was crushed at right side and shear failure was occurred at the same side at 17.2kN load. Failure pattern is shown in Figure 6.

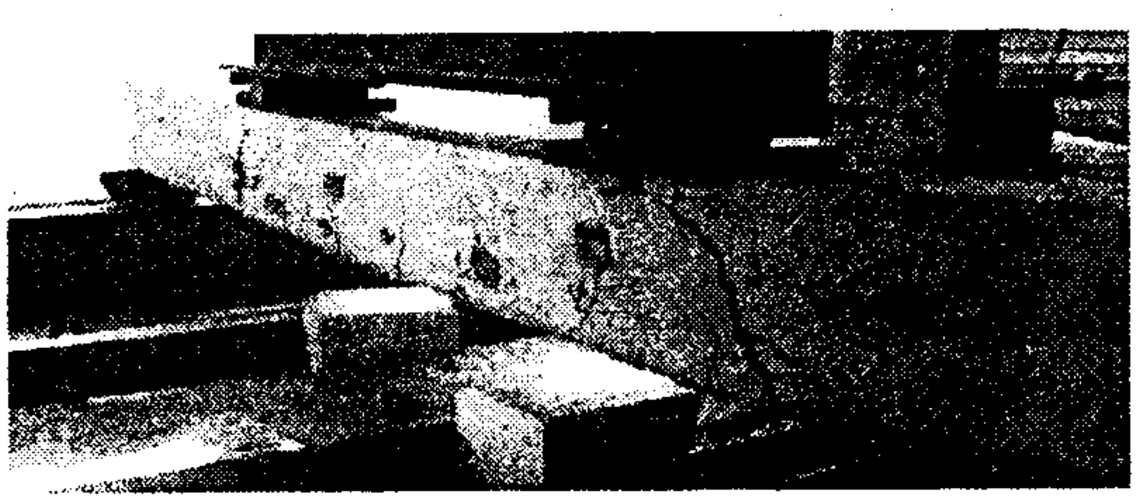


Figure 7: Cracks pattern for 1.5% of yellow bamboo reinforcement beam

The second beam was tested with 4.5 a/d ratio and 2.6% of reinforcement area and the loading point was set at 641 mm from each end. First crack due to bending was appeared at 11.28kN load and final failure load was 25.99kN. All the cracks are shown in the Figure 8.

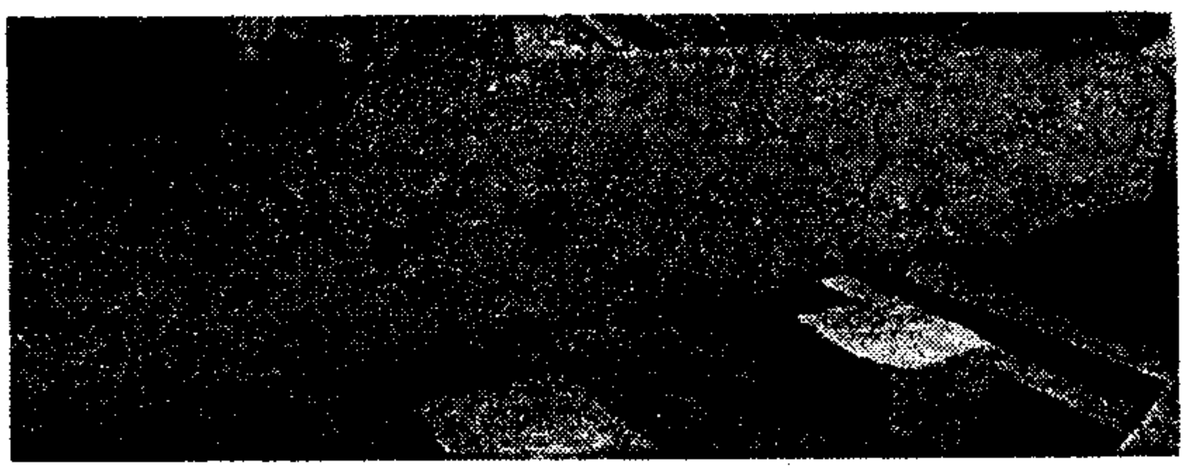


Figure 8: Cracks pattern for 2.6% yellow bamboo reinforcement beam

Yellow bamboo r/f concrete beam

The third test was conducted for green bamboo reinforced beam with 4.5 a/d ratio, and 1.5% reinforcement and loading point was set at 760 mm from each end. The first crack was initiated at 7.484 kN load and the failure load was 14.7 kN. The crack pattern is shown in Figure 9 and failure pattern was identified as shear failure.

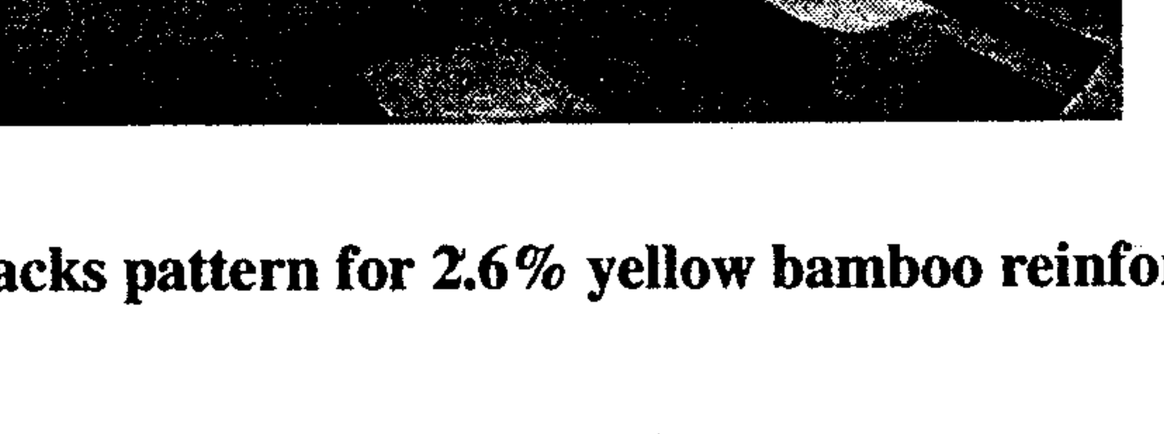


Figure 9: Bamboo reinforcement beam with 1.5% of green bamboo

The fourth test was conducted with 4.5 a/d ratio, 2.6% of reinforcement and 155mm effective depth. In this test the initial crack was appeared very near to the center and the load of 9.3kN. The beam was failed by crushing at right side of the beam of the load of 22 kN. All the cracks locations are shown in Figure 10. The failure mode was not flexure and that was due to bond failure of bamboo reinforcement.

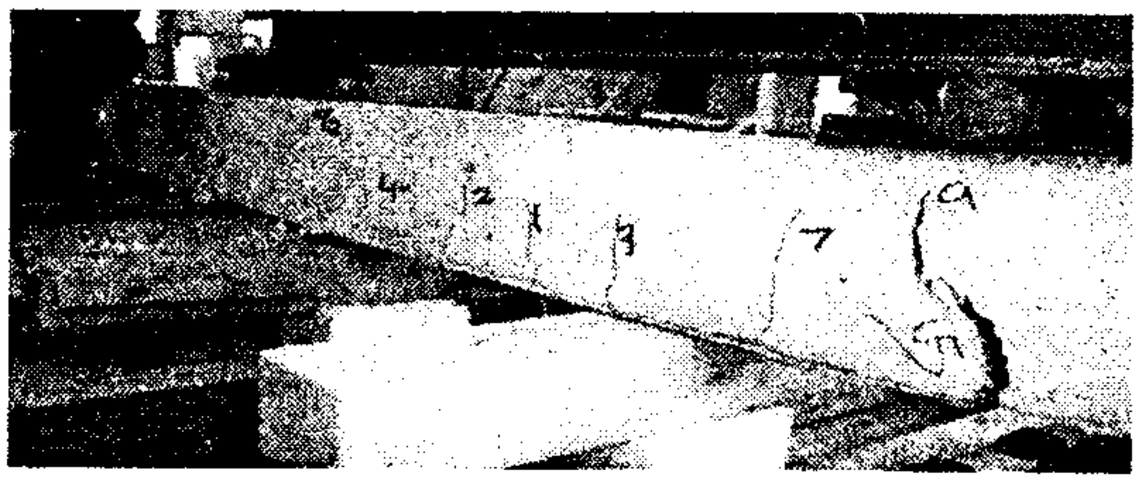
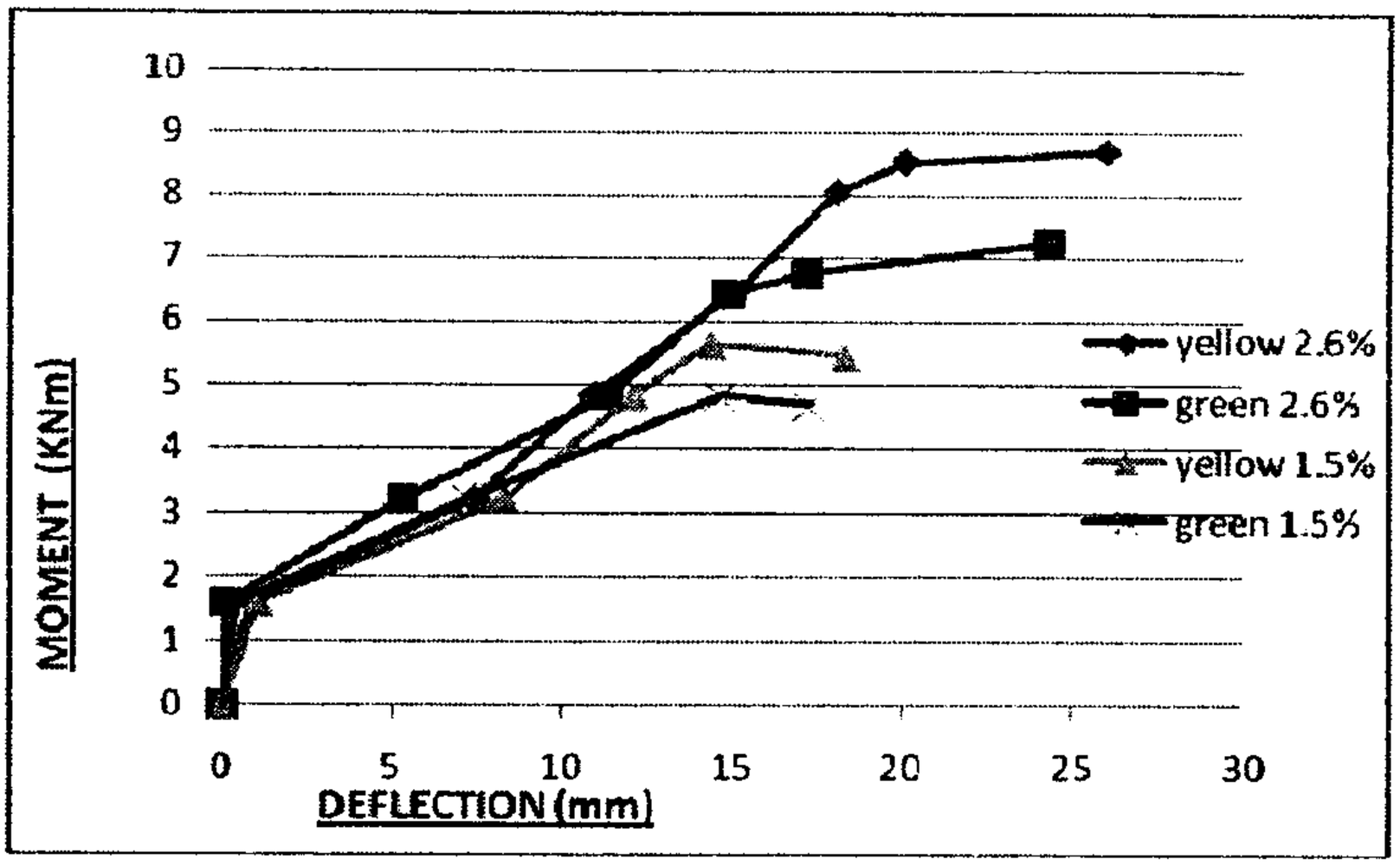


Figure 10: Bamboo reinforcement beam with 2.6% of green bamboo



Graph 03: The graph of moment vs. deflection curves

According to the graph yellow color bamboo shows higher loads at initial crack propagation and load capacity than the green color bamboo type. Deflection also lesser in the yellow types but the bamboo stirrup was not give effective support to avoid the shear failure and it may be due to lack of bonding.

<u>Bamboo reinforcement with steel stirrups</u>

The second type of test was conducted for bamboo reinforcement with steel stirrups. Yellow bamboo was used for this test. The test was targeted to avoid the shear failure of the beam. Two types of tests were conducted and they were; 1.5% and 2.6% of bamboo reinforcement with 4.5 and 5.25 a/d ratios. The first crack of 1.5% of bamboo was at 9.81kN and failed at 19.62kN. For 2.6% of bamboo, initial crack was occurred at 11.52kN and failure load was at 29.43kN. According to the crack pattern there was no any shear failure occurred within the beam. Cracks locations for 1.5% of bamboo are shown in Figure 11.

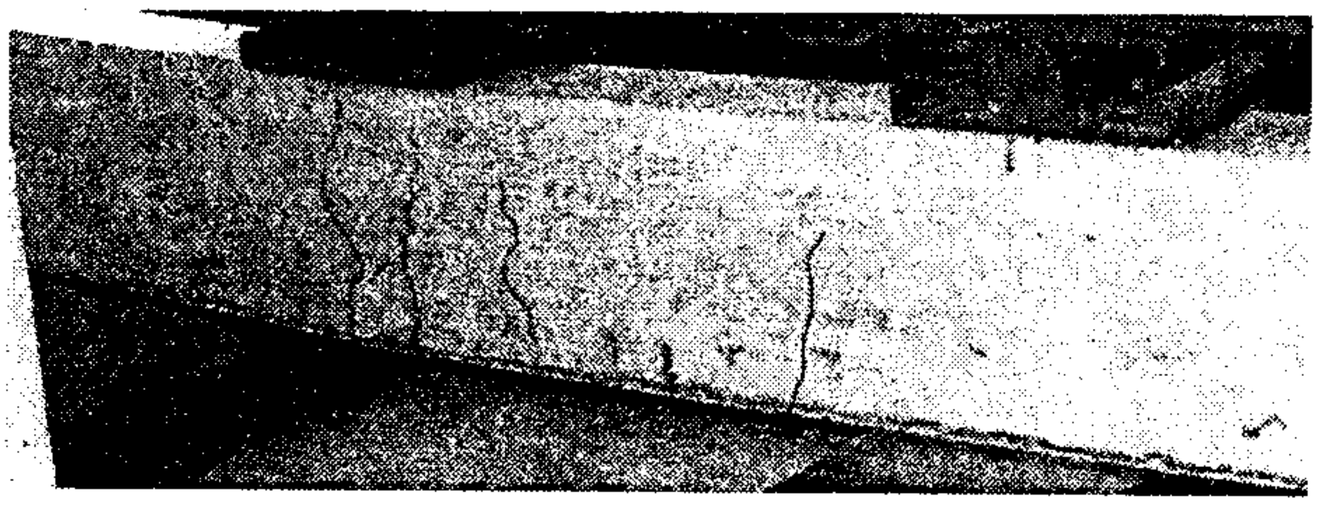
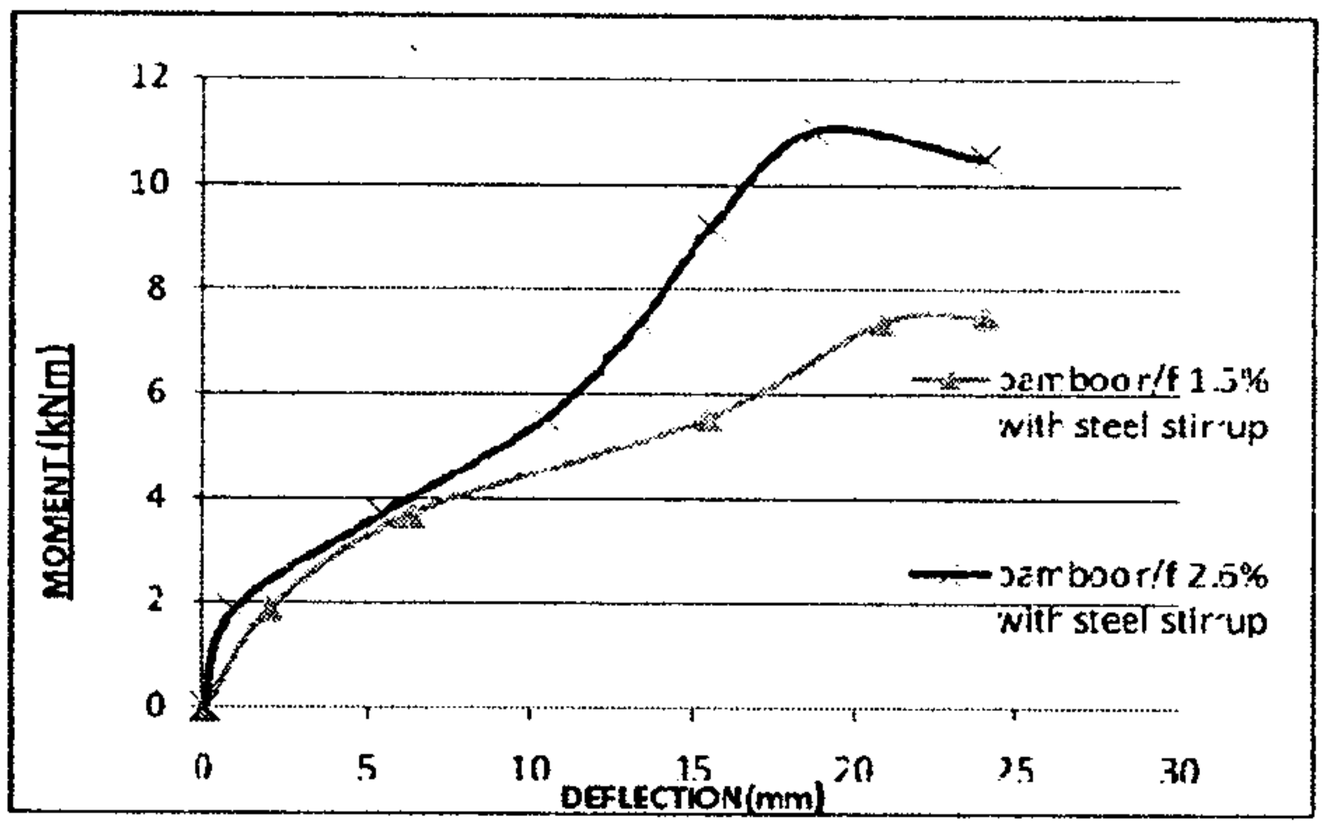
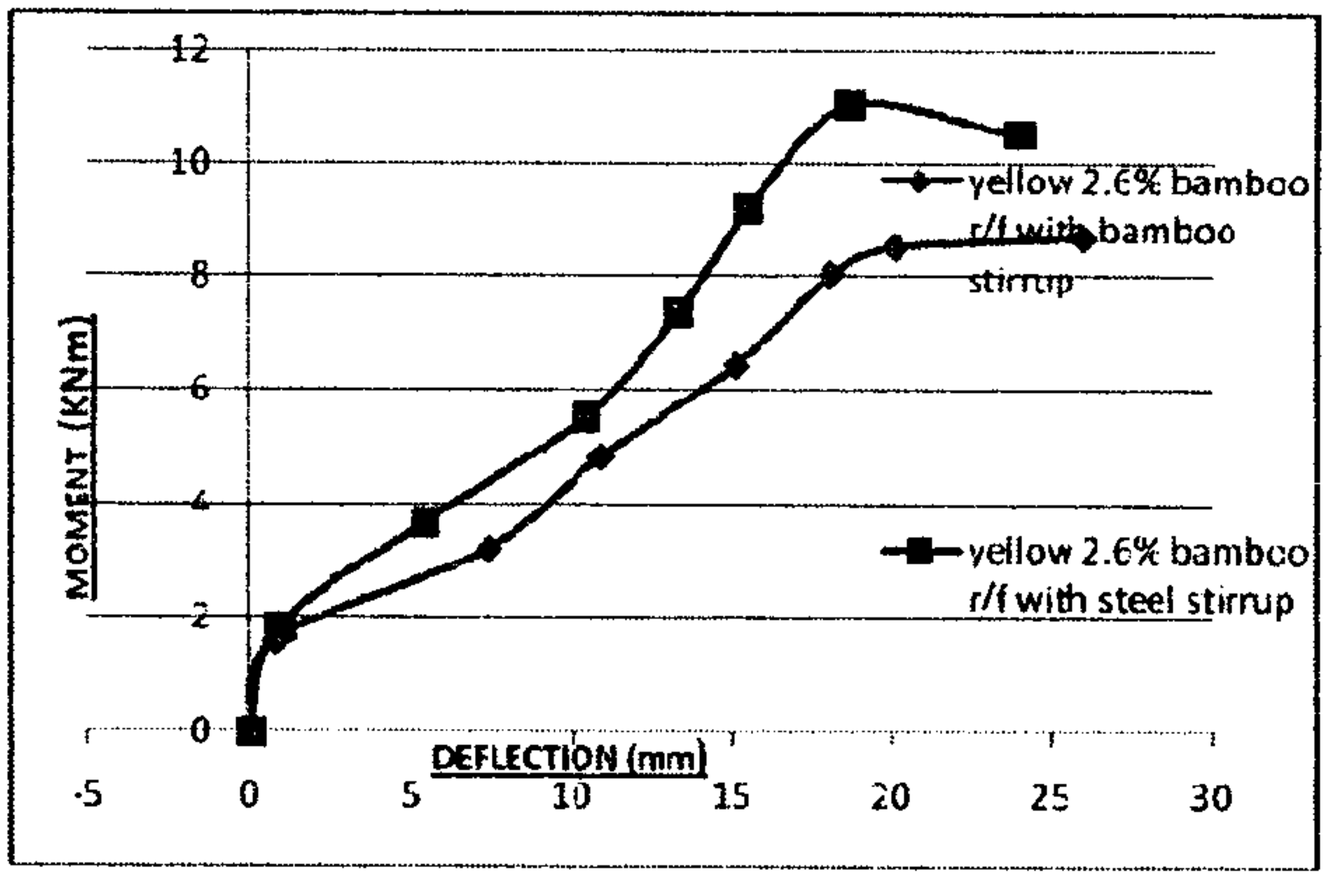


Figure 11: Cracks locations of 1.5% of bamboo with steel stirrups

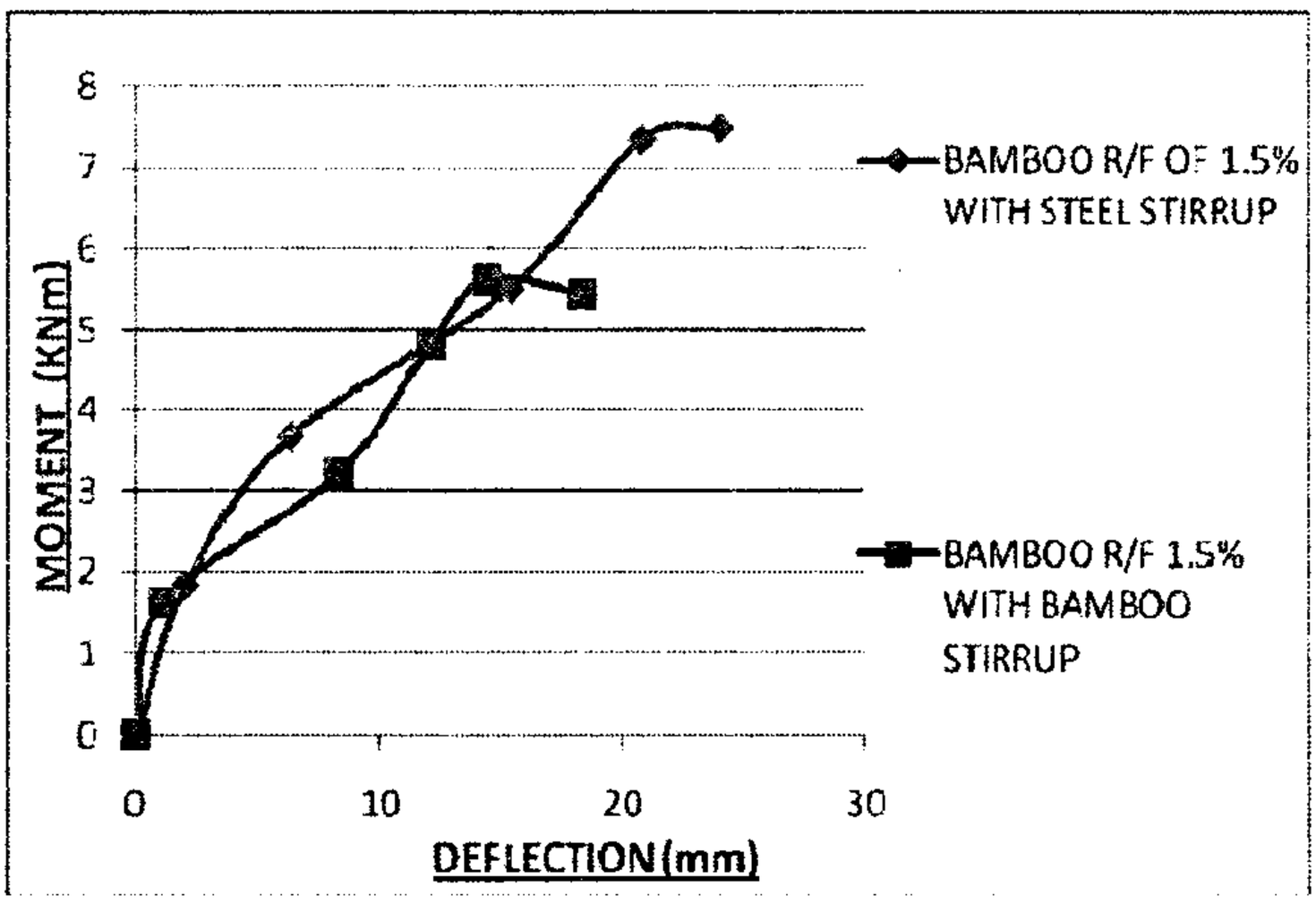
According to the beam test results bamboo steel stirrups not effectively support to the shear failure and bamboo reinforcement beam which have steel stirrup were gave high failure load as Graph 04, 05 and 06. According to the calculation and experimental results as shown in Table 4, the calculation part have done to find the failure load on steel r/f used beam according to BS 8110 part 1 1997, clause 3.4.4.4 Design formulae for rectangular beams so we obtain the steel to bamboo percentage which moment gain from the same amount of bamboo and steel r/f. that ratio was approximately 27% in bamboo stirrup and 39% when steel used for shear link. But each of beams not gave proper steel r/f behaviors.



Graph 04: The graph of moment vs. deflection of center of the beam with 1.5% steel r/f



Graph 05: The graph of moment vs. deflection of center of the beam with 2.6% of bamboo r/f



Graph 06: The graph of moment vs. deflection of center of the beam with 1.5% of bamboo r/f

Table 4: Failure load of pull out test

Bamboo type	Failure Moment (KNm)	Equivalent moment for Steel (KNm)	bamboo/ steel%
Yellow1.5%	5.63	18.98	29.66
green1.5%	4.83	18.98	25.45
Yellow2.6%	8.53	27.15	31.42
Green2.6%	7.24	27.15	26.67
yellow with steel	7.36	18.98	38.78
yellow with steel stirrup	11.04	27.15	40.66
bamboo + steel 1%	26	22.07	117.81

Bamboo with steel r/f and stirrups

In this test used 1% of steel and 1% of bamboo r/f used and test was done and check the failure mechanism and compare the failure behavior of 1% steel used beam. The first crack of combination of bamboo and steel was at 38.259kN and failed at 64.25kN. For 1% of steel r/f beam initial crack was occurred at 39.73kN and failure load was at 58.86kN. According to the crack pattern there was no any shear failure occurred within the beam. Cracks pattern most probably was same for both beams as shown Figure 12.

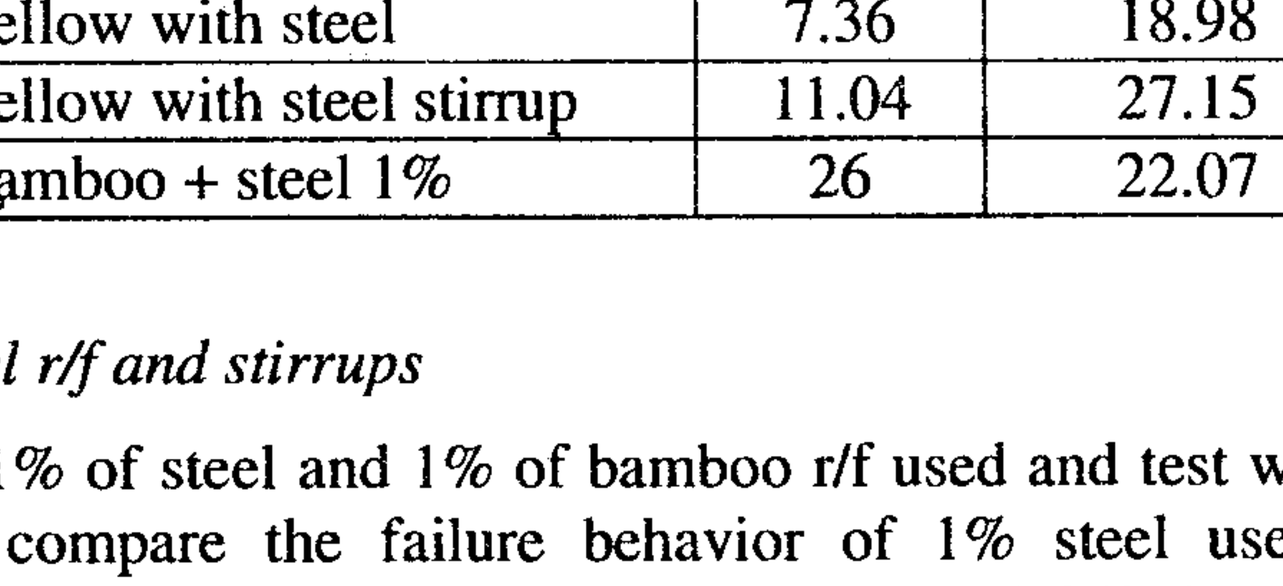
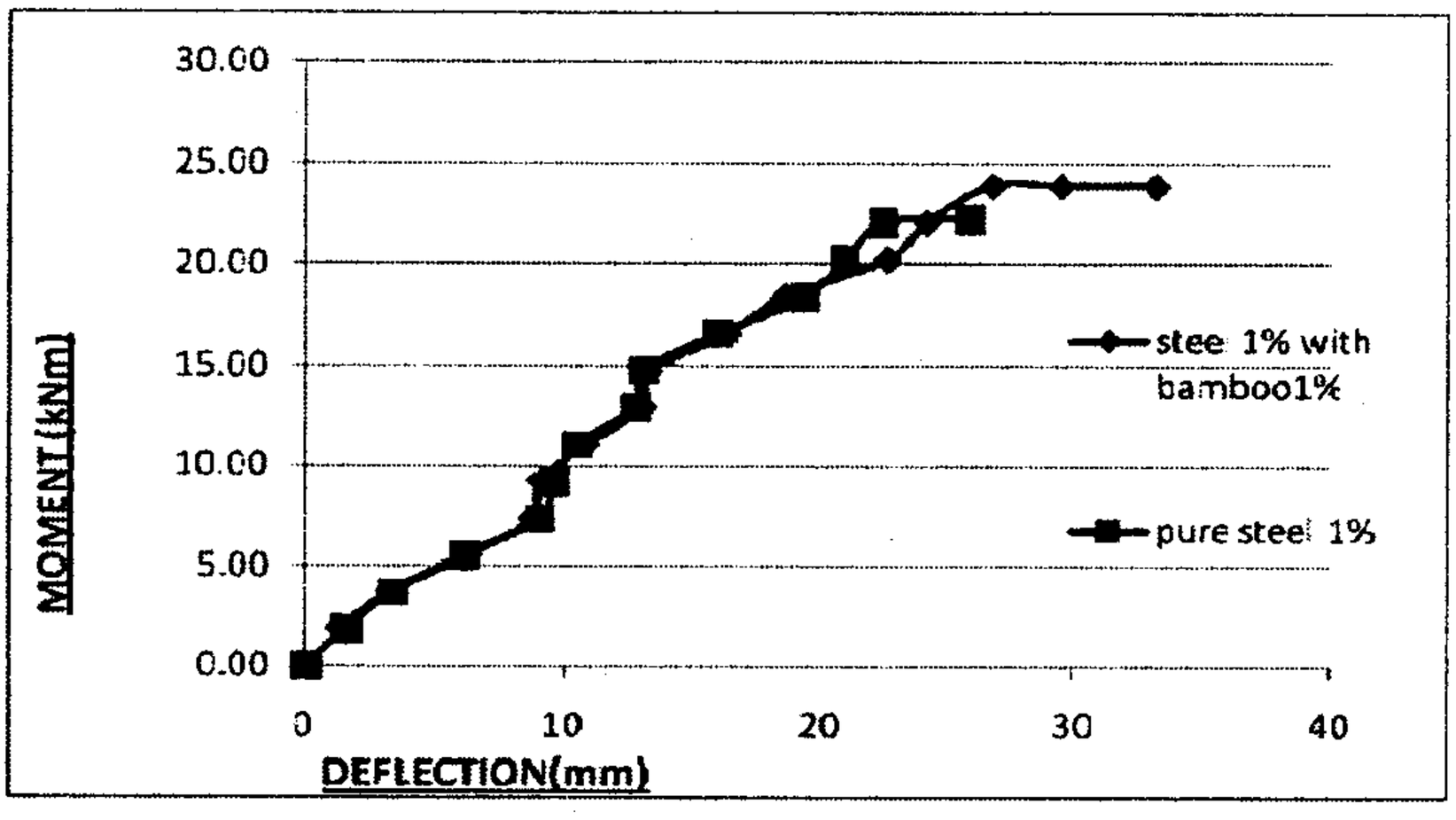


Figure 12: Cracks locations of 1% of bamboo + 1% of steel with steel stirrups

The beams failure moment vs. center deflection of both beams have compare in Graph 7. So the application of bamboo can improve the failure moment with small percentage. Hence can be reduced the cost with small percentage. But it is difficult to develop the beams as fully bamboo r/f used one.



Graph 07: The graph of moment vs. deflection of center of the beam for steel beam and steel with bamboo used beam

Computer Programme

Due to insufficient database from the experimental program, it is difficult to get a clear picture about the behavior of bamboo reinforced beams moment Vs deflection. Therefore finite element model was developed using SAP2000 software. The model was validated by using experimental results.

Using solid element beam was developed and the beam was divided into finite element. The longitudinal reinforcement and shear links were modeled by grouping to finite element, and assign the bamboo properties. Corresponding bamboo properties are shown in Table 5.

Table 5: Mechanical properties of bamboo

Mechanical Property	Value (N/mm2)
Ultimate compressive	150
Ultimate tensile strength	225
Modulus of elasticity E	1.72*104
Poison ratio	0.15

After the modeling apply the testing failure load and check the deflection for the model with test results in Table 6 were obtained.

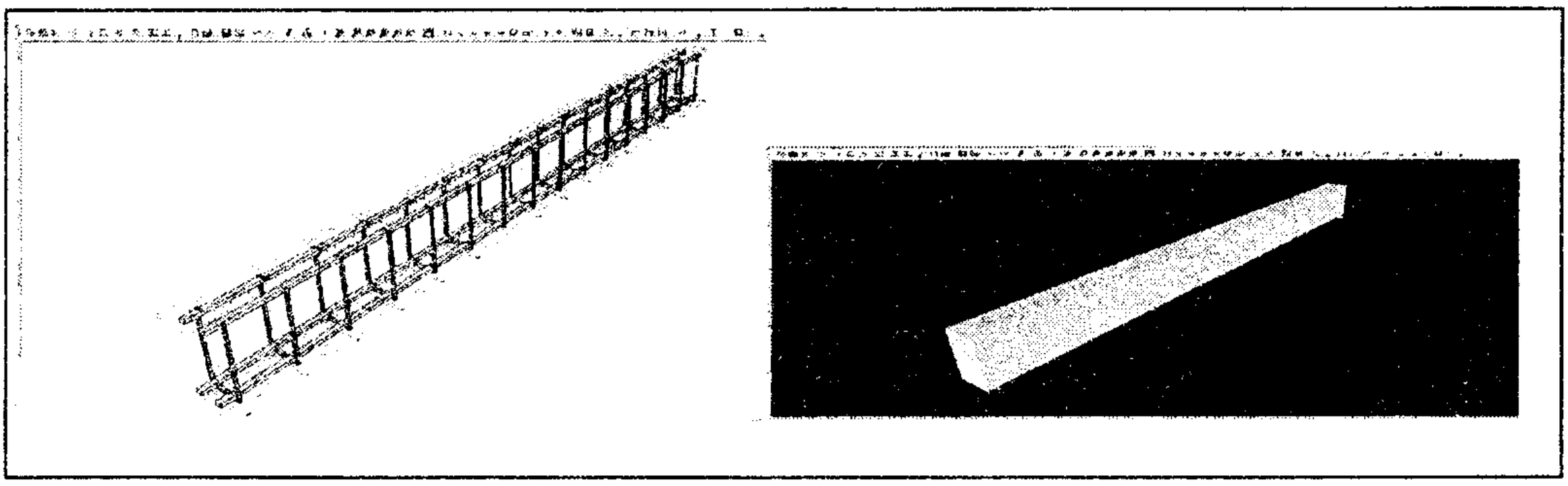
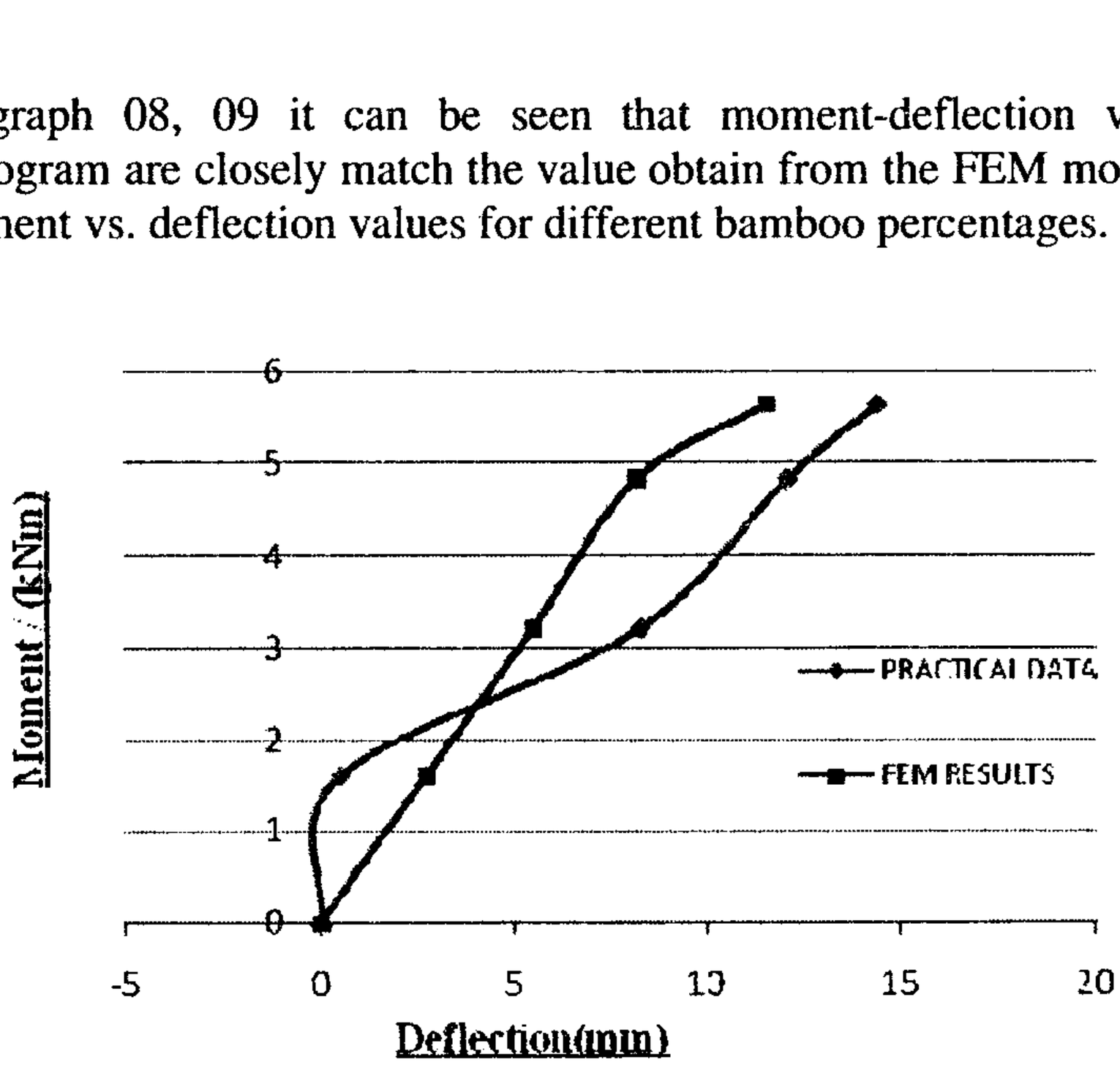


Figure 13: Reinforcement net and solid beam of the FEM

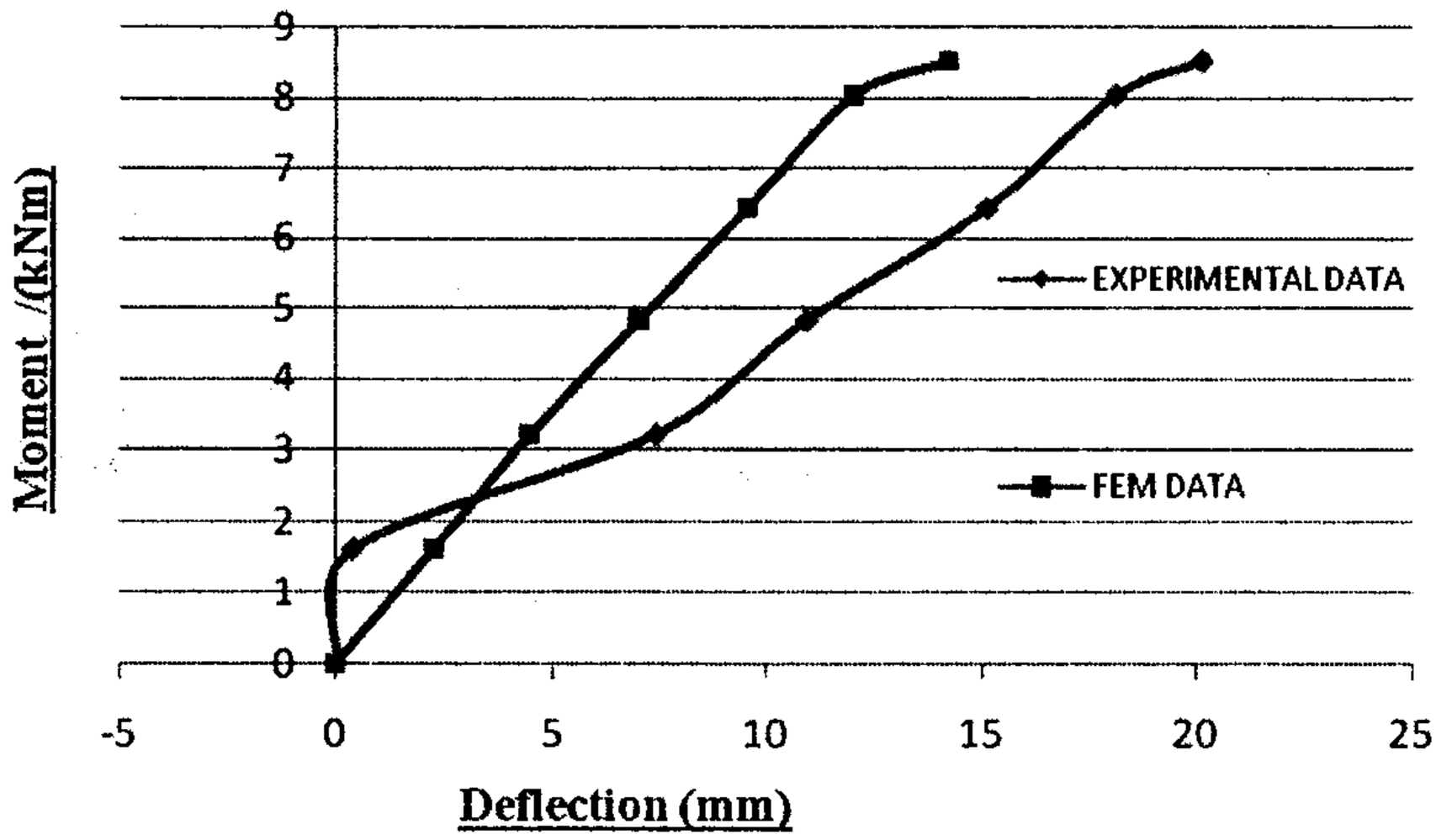
Table 6: Output of the finite element model

Beam	Load (kN)	Stress (MPa)	Deflection (mm)
Bamboo 1.5%	18	96	11.6
Bamboo2.6%	27	115	14.2

According to graph 08, 09 it can be seen that moment-deflection values obtained from experimental program are closely match the value obtain from the FEM model. So with FEM can achieve the moment vs. deflection values for different bamboo percentages.



Graph 08: Comparison of moment vs. deflection for bamboo 1.5%



Graph 09: Comparison of moment vs. deflection for bamboo 2.6%

Conclusion

The following conclusions based on the experiment and analytical results can be made. The tensile strength of yellow bamboo is larger than green bamboo and it is about 200MPa. Generally the failure occurs in the tensile test as; node failure, end tap failure, and failure in the vicinity of the end tap. The bamboo reinforcement beam achieved 29% of failure load of equal steel reinforce beam and that was improved up to 38% when used the steel stirrups. It was shown that a bonding agent can be used to increase the bond strength. The bamboo stirrup cannot be used effective as steel stirrup. Generally bamboo does not show better behavior like steel bars in the concrete beam but it is feasible to use bamboo r/f mixing with steel r/f effectively.

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