IJCTA, 10(07), 2017, pp. 19-26

Flexural Strength of Homogeneous Timber Beams Retrofitted with Prestressed CFRP Sheets

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Abstract : There are varieties of ways to retrofit timber structures. However, some methods induce the appearance changes. In this research prestressed carbon fiber reinforced polymer (CFRP) sheets were used to strengthen timber beams. Experimental research was carried out through ten timber beams which divided into two groups according to their mechanical properties. In each group, one beam without strengthening was used as reference sample. One was strengthened with CFRP sheets. Two were strengthened by prestressed CFRP sheets with different prestressing force. One beam with existing damage at mid-span was repaired and strengthened by prestressed CFRP sheets. The results showed that, the bearing capacity of timber beams strengthened by prestressed CFRP sheets with the prestressing force of 10% tensile strength of CFRP increased 49.5% to 132%. With the prestressing force of 20% tensile strength of CFRP, the bearing capacity increased 95.4% to 150%. The stiffness and ductility of strengthened beams were also improved. For damaged beams, after being strengthened by prestressed CFRP sheets with the prestressing force of 10% tensile strength of CFRP, the flexural performance of it could be restored to the state close to the undamaged state.
Keywords : Prestressed CFRP sheets, Timber beams, Flexural performance, Damaged beams.

1. INTRODUCTION

Timber structure is the main structural form of traditional Thai architectures. Many temples, pagodas, bridges and residents are in use of timber structure. Due to the long-term environmental effects, the beams in ancient architectures were suffered with the reducing of bearing capacity or cracking destruction. Many conventional repair methods, such as adding hoop reinforcement, pasting steel plate, bolts anchorage, under supported steel tension rod, and clapped or lift connection reinforcement, sometimes have great impact on the appearance of members so that the original style of the ancient buildings can't be maintained in the maximum. And more, the iron pieces used as reinforcement are easy to rust. Slight mistakes in repair operation are easy to cause new damages to the members.

Fiber reinforced polymer (FRP) are now widely used for strengthening structures due to its high strength, good geometric plasticity, light weight and corrosion resistance. Several scientific research and engineering practices in recent years have proved that, FRP can be used to retrofit timber beams. There are good adhesion between wood and FRP material, which leads to work together well [1]-[4]. Recently, since the method of using prestressed FRP has been successfully applied on concrete structures[5], ,[6], there are many researchers try to use prestressed FRP on timber structures in order to achieve better strengthening effect by more fully using of the high strength of FRP. In the year 2002 Brunner [7] carried out the experimental study for glulam beams strengthened with prestressed FRP. The results showed that, the maximum strengthening ratio of about 2.3 to 2.8 for glulam beams can be attained when the amount

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of FRP is about 1.2%. In order to prevent the delamination between the FRP sheets and wood beams, Brunner et al.[8], [9] also proposed a special device to bond the prestressed laminate to the timber in stages starting from the center of the beam. There was no delamination. Lindyberg [10] took the analysis by using the nonlinear model, which estimated that the load bearing capacity of naked glulam beams could be double with 3.3% prestressed FRP sheets. Chen Jiade, Wang Feng et al. [11], [12] deduced the formula to calculate the maximum initial prestressing force for FRP sheets used to retrofit timber beams.

In the research discussed above, prestressing force was achieved though Pre-flexure method, in which prestressing force was applied to the beam by using the strain difference between the top and the bottom surface of the timber beam since the bending deformation caused by outside loading. By this method, the prestressing force applied is limited. Moreover, there are still few reports about using prestressed FRP sheets on homogeneous wood beams, especially the beams with square cross section or the damaged beams. So in this paper six timber beams strengthened with prestressed CFRP sheets, including two damaged beams, was tested and analyzed. The special designed equipment was also introduced, by which the FRP sheets can be stretched directly without any damage.

2. EXPERIMENTAL PROCEDURE

A. Materials

In this experiment, the same batch of teak wood, the commonly used hardwood for building constructions in Thailand, was used. For group 1, the compressive strength perpendicular to grain is 8.52 MPa, the compressive strength parallel to grain is 13.43 MPa, the static bending strength is 57.6 MPa, and the tensile strength perpendicular to grain is 3.74Mpa. For group 2, the compressive strength perpendicular to grain is 7.1 MPa, the compressive strength parallel to grain is 10.3 MPa, the static bending strength is 54.8 MPa, and the tensile strength perpendicular to grain is 3.72 MPa. The CFRP sheets used is the type SCB Brace CF 300, with the design thickness of 0.166 mm, the fiber tensile strength of 4,900 MPa, the fiber tensile elastic modulus of 230 GPa and the elongation at break of 2.1%. The adhesive used is Concresive 1001 LPL, with the tensile strength >24 MPa, the tensile elongation of 2.5% and the slant shear bond strength of 35 MPa.

B. Sample Beams

Since for the ancient architectures in Thailand the square section wooden beams are common used, so in this experiment sample beams were designed to be with 100mm square cross section, 1200mm long span and 900 mm clear span. There are five beams in each group. The detail of total ten timber beams are listed in Table I. In order to simulate the existing damages in sample beam B8 and B9, at first the wood in semicircular area in radius of 5 cm was dredged near the tensile side at mid-span of the beam, then block of the same wood was fill in the gap by strong adhesive, as shown in the Fig.1.

Figure 1: Simulation for damaged timber beams

Table 1
Detail of the timber beam samples

Group	*Name*	*Sample status*	*Strengthening scheme*	*Prestressing force*
Group 1	B2	No damage	No strengthening	No
	B6	No damage	CFRP	No
	B8	damaged	Prestressed CFRP	10% of the tensile strength of the CFRP sheet = 9761 N
	B11	No damage	Prestressed CFRP	10% of tensile strength = 9761 N
	B13	No damage	Prestressed CFRP	20% of tensile strength = 19521 N
Group 2	B3	No damage	No strengthening	No
	B4	No damage	CFRP	No
	B9	damaged	Prestressed CFRP	10% of tensile strength = 9761 N
	B12	No damage	Prestressed CFRP	10% of tensile strength = 9761 N
	B14	No damage	Prestressed CFRP	20% of tensile strength = 19521 N

C. Strengthening Method and Test Set-up

For sample beams strengthened with non-prestressed CFRP sheets, 100 mm wide unidirectional CFRP sheet was struck on the bottom surface of the beam along the span, and CFRP sheets were also laterally reinforced in the shear zone to prevent adhesion and shear failure. For sample beams strengthened with prestressed CFRP sheets, the process is shown in Fig. 2. By using a specially designed tensioning device, 120 mm wide CFRP sheet was anchored with the device at one end and stretched longitudinally at the other end until the tensile force reached to determined value. Then the bottom surface of beam and the top surface of CFRP sheet under tension was brushed with adhesive resin and pasted together. Then CFRP sheets were laterally pasted in the 250mm wide shear zone. Heavy objects are placed on the beams to ensure adequate bonding between CFRP sheet and timber beam. After the resin is hardened to meet the requirements, CFRP sheet was cut at two ends and the prestressing force began to act on timber beams.

Figure 2: Process of timber beam strengthened by prestressing CFRP sheets

Load applied by hydraulic jack was distributed though steel beams to achieve two point loading. LVDT was placed at mid-span of the beam to measure the deflection. Meanwhile, strain gauges were placed along the depth of beam and also on the bottom surface at mid-span to measure the strain developments in the respective positions. Fig. 3 shows the detail of test set-up.

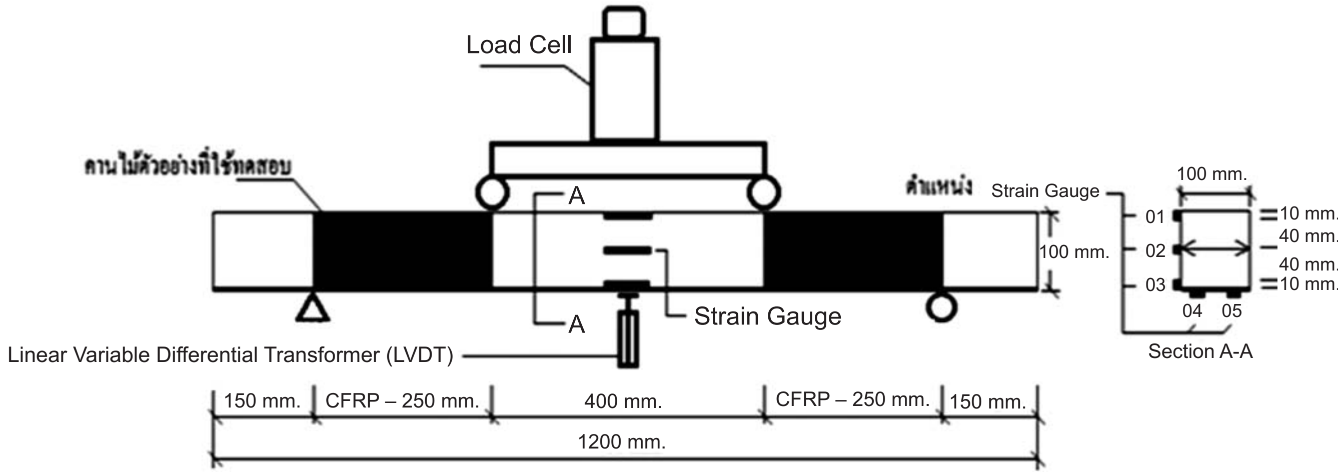


Figure 3: Geometry and test set-up details for flexural test beams

3. RESULTS ANALYSIS

A. Failure Modes

Fig. 4 shows the failure pattern of each sample beams. It can be seen that, the deformations of reference beams B2 and B3 were small. Brittle failure occurred in very short time after cracks appeared. For CFRP reinforced beams, especially for prestressed CFRP reinforced beams, there were large deformations in the failure, which is 1.35 to 2.18 times of the maximum deformation of reference beams. The cracks were very wide and the beams were finally destroyed due to being pulled off of the wood fibers at tension zone. For damaged beams B8 and B9, crack mainly appeared in the existing damaged zone.

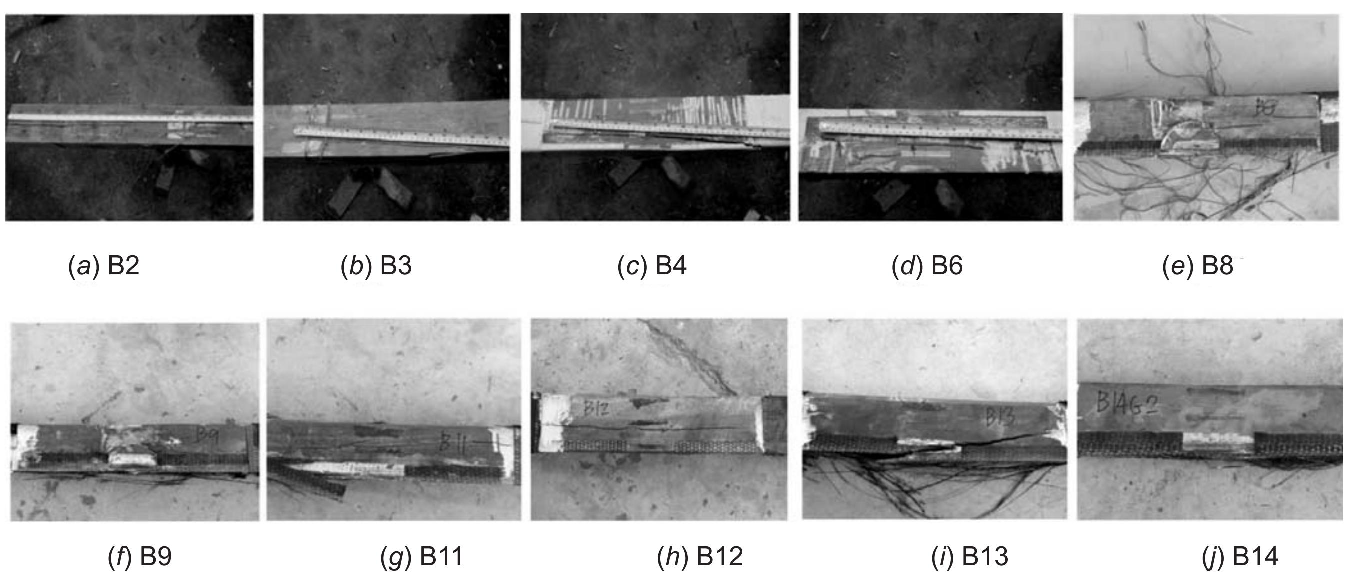
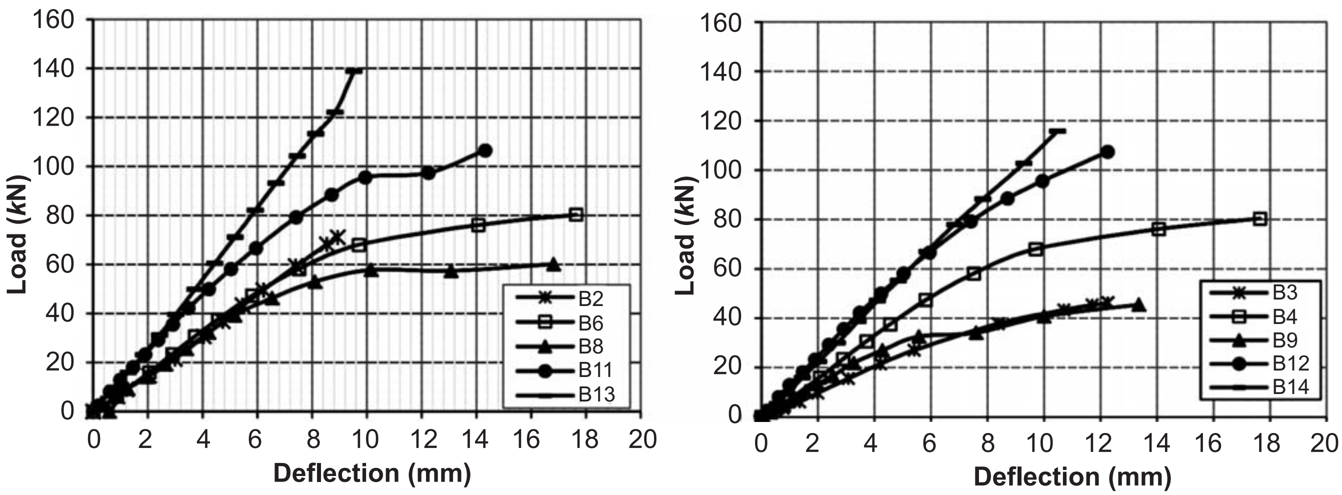


Figure 4: Failure modes of sample beams

B. Bending Moment and Deflection

By comparing the test results of B11, B13 and B2 in group 1 (Fig. 5 *a*), it can be seen that, the bearing capacity of beam strengthened by prestressed CFRP sheets with prestressing force of 10% or 20% of tensile strength was increased by 49.8% or 95.4%. For maximum deflection of timber beam set by the timber structure design specifications, which should not exceed 1/180 of the span, the corresponding load resisted by B11 and B13 were increased 45.4% and 70% respectively, when compared with B2. The stiffness of beam was also improved significantly after prestressed CFRP strengthening. With the increase of prestressing force, the effect was more obvious. For beams in group 2 (Figure 5.*b*), due to the relatively lower compressive strength of wood, the effect of prestressed CFRP reinforcement is more obvious. The maximum load resisted by B12 and B14 were 132% and 150%, correspondingly, more than that of B2. The bearing load corresponding to 1/180 of span were 127% and 127% %, correspondingly, more than that of B2. The increase of prestressing force lead to no obvious improvement of the bearing capacity and the stiffness of beam. Instead, non-prestressed CFRP sheets strengthening resulted in more significant improvement on the bearing capacity and the stiffness for the beams made of wood with lower compressive strength. It can be seen from the both groups, after being strengthened by prestressed CFRP sheets with prestressing force of 10% of tensile strength, the flexural performance of damaged beam could be restored to the state close to the undamaged state.



(*a*) Group 1 (*a*) Group 2

Figure 5: Load versus deflection curves of tested beams

C. Strain and Stress

As an example, Fig. 6 shows the strain distributions at the mid-span cross-section of each beam in group 1. It can be seen that, the strain development with load increase for each beam was in line with the plane section assumption. The position of neutral axis for beam with prestressed CFRP sheets strengthening moved downward continuously with the load increasing, which is due to the effective participation in carrying tension of CFRP sheets, thereby permitting the increase of plastic deformation region for compressed part of the section which leads to the increase of the bearing capacity of the beam. For damaged beam B8, the strain at the damaged area were significantly larger at the later loading stage, which indicated that the failure occurred at the existing damaged area. Figure 7 shows the changes of strain at each measuring point with the load. The strains measured by two strain gauge 04 and 05 on the carbon fiber sheet at bottom surface of each beam developed rapidly, which indicated that CFRP sheet helped to carry most part of the tensile force.

4. CONCLUSIONS

Through the experiment on timber beams strengthened with prestressed CFRP sheets, the flexural performance of tested beams, such as bearing capacity, deflection, strain distribution and development, were studied in detail. Some conclusions were summarized here:

1. The bearing capacity of timber beams strengthened by prestressed CFRP sheets with the prestressing force of 10% tensile strength of CFRP increased 49.5% to 132%. With the prestressing force of 20% tensile strength of CFRP, the bearing capacity increased 95.4% to 150%.
2. For wood with relatively higher mechanical properties, with the increase of prestressing force, the strengthening effect was more obvious. However for wood with relatively lower mechanical

properties, the increase of prestressing force lead to no obvious improvement of the bearing capacity and the stiffness of beam.

3. The stiffness and ductility of timber beams after prestressed CFRP strengthening were also improved significantly. For maximum deflection of timber beam, 1/180 of the span, the corresponding load resisted by timber beams after prestressed CFRP strengthening were increased 45.4% to 127% .
4. For damaged beams, after being strengthened by prestressed CFRP sheets with the prestressing force of 10% tensile strength of CFRP, the flexural performance of it could be restored to the state close to the undamaged state.

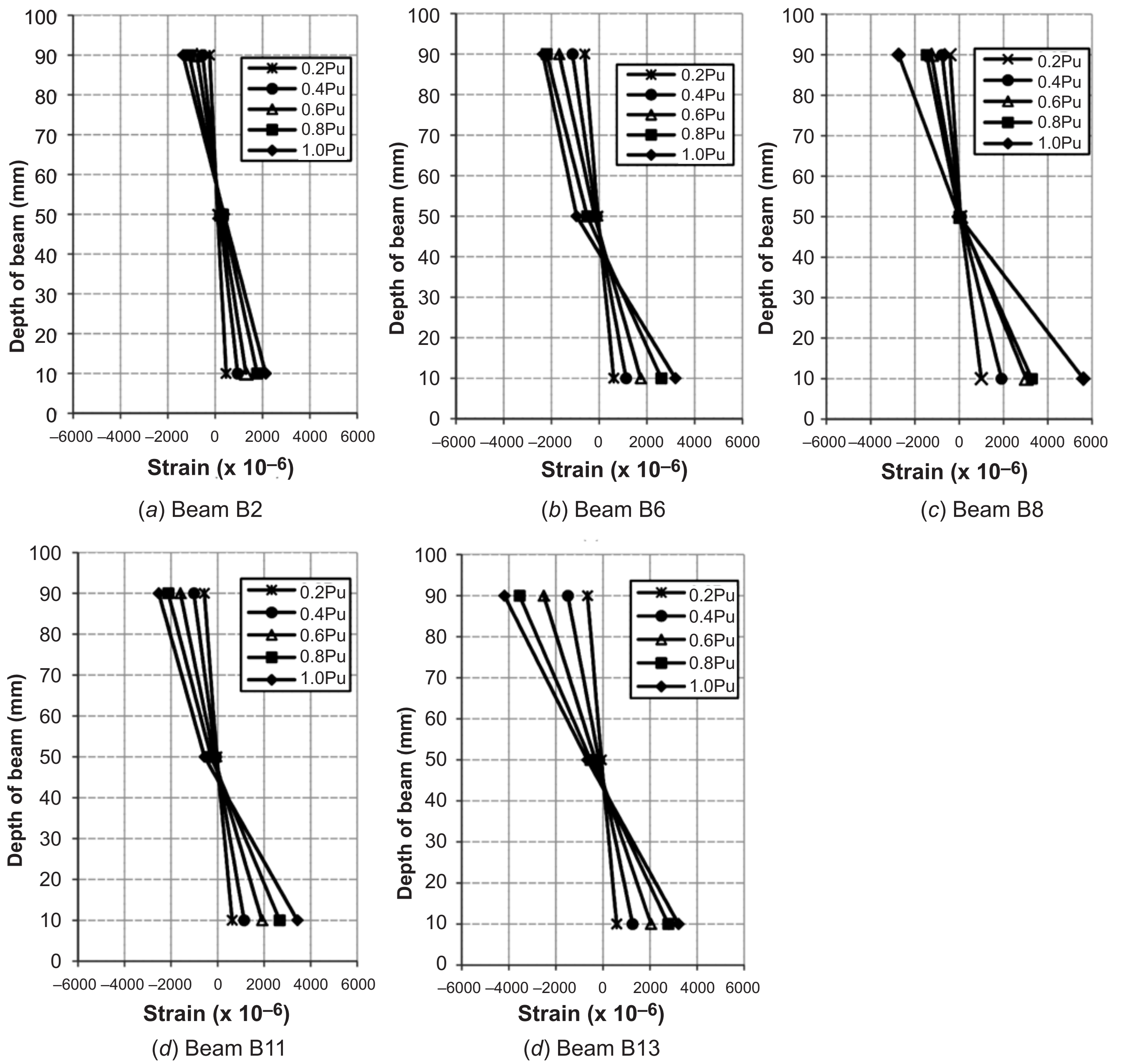


Figure 6: Strain distributions at cross section of each beams in group 1

5. ACKNOWLEDGMENT

The financial support from the RMUTT Annual Government Statement of Expenditure in 2016 is greatly appreciated.

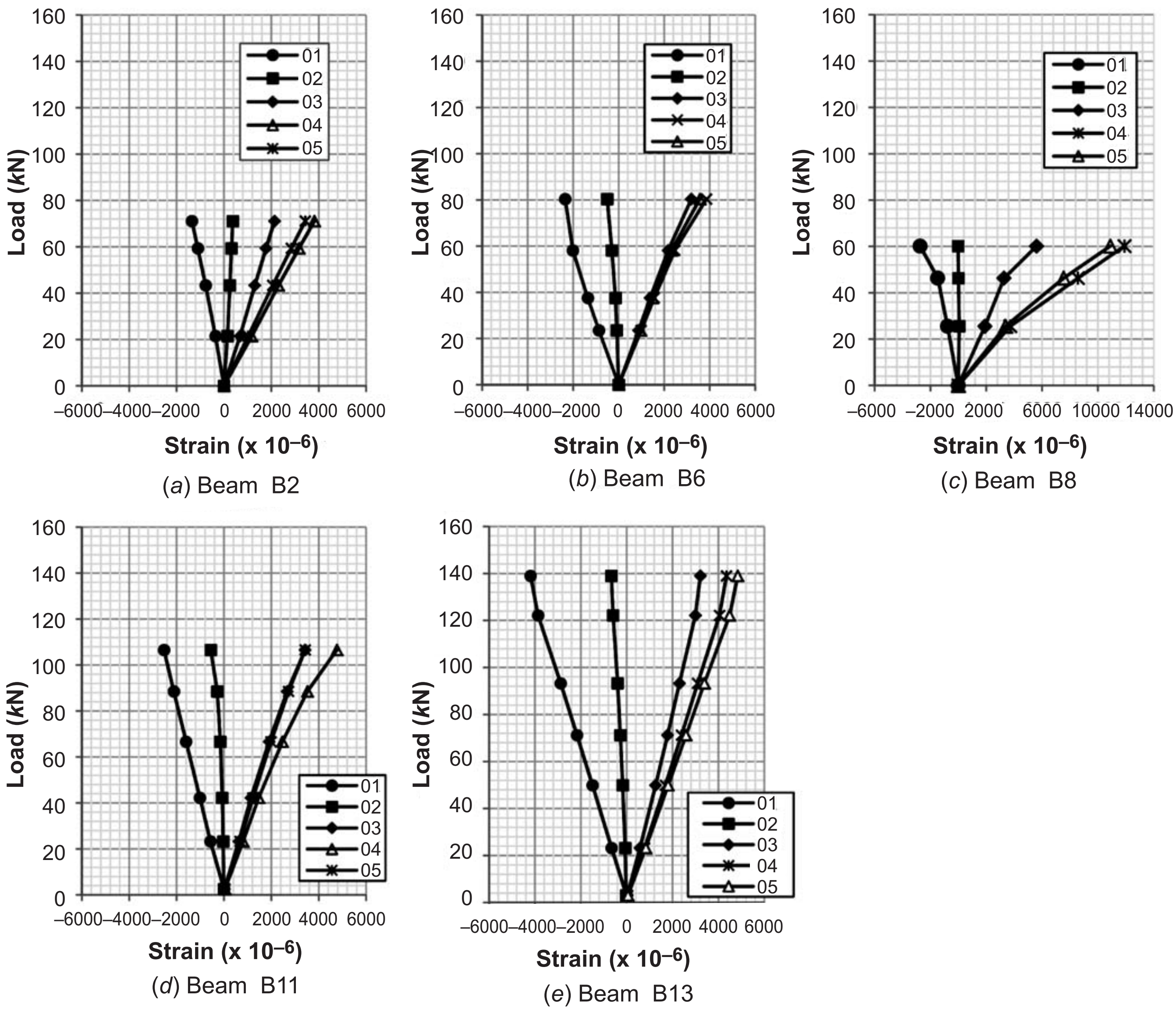


Figure 7: Strain development of each beams in group 1

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