Flexural conduct of FRP fortified solid wood composite pillars

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ABSTRACT: *An exploratory examination was directed to contemplate the primary presentation of solid lumber composite bars gave situation of semi-unbending connectors of different arrangements and solidness. Eleven solid lumber composite pillars and one solid steel composite bar were tried in three-point flexure test. The development of the bar web and the kind of shear connector were the essential boundaries of examination. The possibility of boosting the flexural execution of these pillars when wrapping their networks with GFRP overlays was inspected. Correlation of the flexural conduct of the favorable to presented composite solid wood radiates with that of both of post-focused on shafts utilizing outer steel longitudinal poles and a solid steel composite pillar was additionally assessed. Test outcomes indicated that ver-tical glulam wood web is better than both even glulam and monstrous square lumber networks in provid-ing higher solidness and burden conveying limit and bigger strength. Additionally, dovetail shear connector improved with inclusion of a steel dowel at the focal point of the score confers a full composite activity among cement and wood web. Utilization of GFRP covers wrapping along the full range of lumber web is an exceptionally viable strategy to exploit the utilization of improved dovetail shear connector. The conduct of the proposed solid lumber composite shaft was tantamount to that of the solid steel web pillar.*
KEYWORDS: *Shear connector;Timber;Glulam;Composite;Wrapping*

I. INTRODUCTION

Reinforced concrete, steel or timber are those traditional mate- rials used in the manufacture of structures as they verify the requests of the serviceability limit state and the ultimate limit state concepts. Since concrete is inherently a durable material, it is a ubiquitous material, which has a long history in buildings, highways, dams, sidewalks, and even artworks. The Romans invented cement based concrete more than 2000 years ago and used the material to build architectural masterpieces such as the Pantheon [1]. Steel is the material of choice for commercial or industrial truss construction because it is strong, readily available, easily fabricated, and not excessively costly. Timber is one of the earliest construction materials, and the structural use of woodand wood-based materials continues to steadily increase. It is becoming recognized as a highly attractive structural materialforlarge-scale building projects throughout the world. The orthotropic nature of the timber imparts unique and independent mechanical properties in the directions of three mutually perpendicular axes: longitudinal, radial, and tangential.

Thetechniquetoassociatethesematerialsasacompositestruc- ture has great importance in the direction to search better exploitation of the mechanical properties of each one of these materials.Theuseofcompositesenhancessomefavorablepropertiessuchasstiffness,strength,toughness,an dstraincapacity. On the other hand, it reduces som unfavorable properties such as water absorption, permeability to gases and liquids, weight, and manufacturing costs, installment and maintenance [2–4]. In this constructive technique, the following associations are possible: timber-concrete,steel-concreteortimber-steel,thusmakingpossi- ble, to exceed some inherent limitations of each one of these materials.

These systems, timber-concrete composites are the easiest and most prospective ones in the construction sector. The most common shape of these composites is concrete deck associated with timber web to form composite T-section beam. The timber providesthetensilestrengthfortheconcreteworkingincompression.Inbuildingdesignsuchasystemofferspe rformanceandconstructionbenefits.Technicalcommitteereport[5]statedthatsuchsystemshavebeenusedin bridgeconstructionsworldwide.

II. RESEARCHES SIGNIFICANCE

The program has investigated the structural performance of timber-concrete beams enhanced with systemsofsemirigidconnectorsofvariousconfigurationsandstiffness.Themainobjectiveofthestudywastoe xaminethefeasibilityofenhancingtheflexu- ral performance of these beams when wrapped with GFRP lami- nates. The evaluation depended on the values of the load carryingcapacity, thecorrespondinglong

itudinalstrain,themid- span deflection and the shear deformations between the timber web and the concreteflange.

Thescopeoftheexperimentalprogramwasplannedtoinvesti- gate the continuity of the wrapping system along the span of the beam. Comparison studies were included in this research. Post-stressingofbeamsusingexternalsteellongitudinalrodswasused forthefirstcomparisonwithFRPwrappedbeams.Theothercom-   parisonwascarriedoutusingsteel-concretecompositebeam.The   outputofthisstudywillopenupnewpossibilitiesfortheconstruc-tionofhighlyefficienttimber-concretebeams.Additionalcostsav- ings are also envisaged by reducing the cross-sectional area required for the same designload.

III. EXPERIMENTALSTUDY

Asascopeoftheexperimentalprogramtoinvestigatethestruc- tural behavior of the tested specimens, 11 timber-concrete beams and 1 steel-concrete beam were prepared for testing. The study wasaccomplishedthroughthreestagesinwhichstageI,consistedofthreebeams,investigateddifferentcompo sitionsoftimberweb.Choosingtheverticalglulamweb(asanoutputofstageI),stageII,consistedofsixbeams,h andledthetypeofshearconnectoraswell as the use of FRP wraps to the timber web. Stage III, consisted of three beams, was implemented to study the effect of external stressingappliedtotheverticalglulamwebandthemassivetimberweb.Anotherobjectiveofthisstagewasthe monitoringofthe overall efficiency of using timber-concrete composite beams as goodalternativesforsteel-concreteones.Beyondtheresearchpro- gram proposed, the materials used in the construction of these structural elements were characterized and described in this section.

1.1. Materials

Cement:Portlandcementcomplyingwith[17]wasusedinthe currentresearch.

Aggregate: Crushed dolomite stone, 16 mm maximum nominal size, was used as coarse aggregate. Natural silicate sand was used as fine aggregate. The aggregates used complied with [18].

Water: Tap water was used as mixing water.

Timber:Pine timber commercially available was procured for the entire experimental study from single source. The timber wasmachinedtothedesireddimensionsusingelectricalsaws.

FRP System: The FRP system used in the current work consists of bi-directional E-glass woven fabric laminates and polyester resin as an impregnation resin. The system is provided by Sika-Egypt Company. The properties of the glass fibers used based on the product data sheet of the supplier are shown in Table 1.

1.2. Testspecimens

The timber-concrete ''T" beams, of span 1.10 m between sup- ports, were constituted of the web in pine timber (7.5 cm15 cm) and the cross-section of the flange in concrete (30 cm6 cm). The steel-concretebeam,ofthesamespanandflange,waspreparedby replacing the timber web with standard steel I-beam web (IPE 100).Thelongitudinalreinforcementoftheflangeforallspecimens wasfive8 mmdiameter barswhilethestirrupswere6mmdiam- eter bars every 140 mm. Typical cross section of test beams is shown in Fig.1.

The designed slump of concrete used for the flange was 50 mm. Test cubes were cured in water before testing at the ages of 7 and 28 days. The average compressive strength of the tested cubes after 28 days was 29 MPa. The study was fulfilled through three stages asfollows:

Stage I: Three beams were prepared for this stage to study the efficiency of three different compositions of the timber web, namely, vertical glulam, horizontal glulam and massive timber. Hooked steel stud was implemented in this stage as a shear con- nector at intervals of 10 cm along the span of the beam. The details ofbeamsusedinthisstageareshowninFig.2.

StageII:AsanoutputofstageI,verticalglulamwebwaschosen for completing other stages of the study. The parameters of studyin this stage included the type of shear connector as well as encas- ing the timber web with either discrete or continuous FRP lami- nates. The shear connectors investigated were hooked steel stud,steel mesh and interlocking dovetail. The timber web was wrapped with three layers of U-shape FRP fabrics. Discrete and continuouswrapping were adopted for the timber web for each shear connec- tor. The details of beams used in this stage are shown in Fig. 3 that includes a cutout view for the steel mesh shearconnector.

Stage III: Post-stressing of the timber web in thelongitudinal direction by means of mechanical torque using 16 mm bars with nuts was applied on two beams, one with vertical glulam web and another with massive timber web. Hooked steel stud was theshearconnectorused.Additionalthirdbeamwasprepared to evaluatethecost-savingaspectofusingtimber-concretecompos- ite beams. In this beam, standard steel beam IPE 100

replaced the timber web and hooked steel dowels of diameter 12 mm was

Table 1 Properties of glass fiber fabric.

Fiber orientation	Bi-directional
Weight	600 g/m²
Effective thickness (mm)	0.12
Fabric width (mm)	1000
Tensile strength of fibers (MPa)	1264
Tensile E-modules of fiber (MPa)	57,630
Elongation at break %	2.14
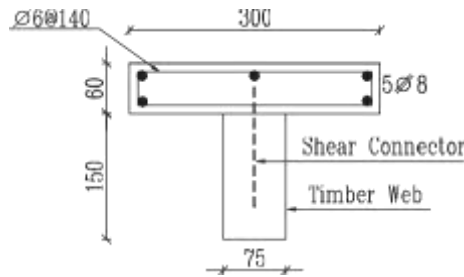
welded to the upper flange of the I-beam. The details of beams used in this stage are shown in Fig. 4.

1.3. Testing

The beams are tested using the third point load over a simply supported span with length of 1100 mm. The load was applied gradually till failure. During the loading, observations and mea- surements included: crack pattern; strain in the longitudinal direc- tion on the surface of the concrete flange and the timber web; central deflection, and the failure modes. Longitudinal deforma- tions were measured using micro-measurement electrical resis- tance gages designed for bonding to concrete while dial gages of sensitivity 0.002 mm were used for recording the central deflec- tion. Dial gages were also installed on the concrete top surface direct lyoverthe supports to record any settlement of the supports during testing. Fig. 5 shows the test setup featuring one of the test specimens ready for attaching the instrumentation and applying the load.

IV. RESULTS AND DISCUSSION

The results of the experimental program are presented and dis-cussed in this section. The load-strain curves for test columns are shown in Figs. 6–8 and the ultimate carrying capacity is shown in Fig. 9.

Fig. 6 illustrates the load-deflection curves for the three test specimens investigated in stage I. It is shown from the graph that the vertical glulam web imparts the test specimen the higher stiff- ness and load carrying capacity and the larger toughness compared to both horizontal glulam web and massive block web. The dis- continuounity of natural defects of wood specially cracks and knots in vertical glulam web minimized the weakness points in the web and improved the overall performance of the beam compared to that made of massive piece of wood. Moreover, the strong adhesive used to bind vertical laminates of timber through two continuous
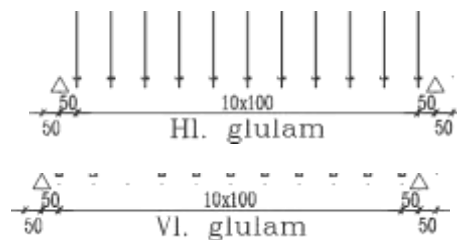
planes along the entire span of the beam provided additional rein- forcing elements to resist tensile stresses and shear transfer. The recorded failure loads for the test specimens were 7.2, 6.5 and

6.4 tons for vertical glulam, horizontal glulam and massive block webs, respectively. The holes ex ecuted through the horizontal lay- ers of adhesives in horizontal glulam web to fasten the shear con- nectors limited the functional efficiency of these reinforcing layers. Besides, the shear stresses transferred through horizontal planes of adhesive contributed in limiting the load carrying capacity of hor- izontal glulam.

Fig. 7shows the load-deflection curves for the test specimens for stage II proposed to study the effect of type of shear connector as well as the role of FRP wrapping. The almost linear performance of the two beams enhanced with steel mesh shear connector sup- ported the observation of shear failure at the interface between the concrete and the shear connector. The slip at the concrete-steel mesh interface led to partial composite action between concrete and timber and to increased bending deflections. Neither the FRP layers wrapping the full section of the timber web nor the concrete flange in compression zone boosted the load carrying capacity of the two beams because of this shape of failure. Concisely, beams manufactured using steel mesh shear connector showed marginal decrease in load carrying capacity and stiffness compared to other beamsmadewithdovetailorhookedsteelshearconnectors.

On the other hand, beams provided with enhanced dovetail shear connector exhibited superior behavior in flexure in view of load carrying capacity, stiffness, toughness and ductility. This con- clusion was verified in an experimental study on notched wood- concrete composite beams [16]. The attribution of this enhanced performance is a result of different reasons. First is the transfer of the shear forces between the timber and concrete over as large an area as possible. Other reasons include the swelling of timber when the moist concrete is cast in addition to grasping the timber with the shrinking concrete. The element responsible for the enhanced ductility of these beams was the steel dowels provided atthecentersofthedovetailgrooves.

The performance of beams made with hooked steel shear con- nectors was intermediate between those of dovetail and steel mesh shear connectors. The relative small area of timber acting torestrain the shear dowel and the concentrated loads that result limited the capability of hooked steel shear connectors of obtaining full composite action and developing the shear transfer seen withdovetailconnectors.

Generally, wrapping the timber web with FRP laminates increases the structural stiffness of the beam and thus results in a smaller deflection at all load levels (complying with [19]. It was obvious that continuous wrapping along the whole span of the beam increased the resistance to shear flow and minimized the tendency to generate stress concentrations at transition zonesas in the case of dis- continuous FRP wraps. The continuousFRP
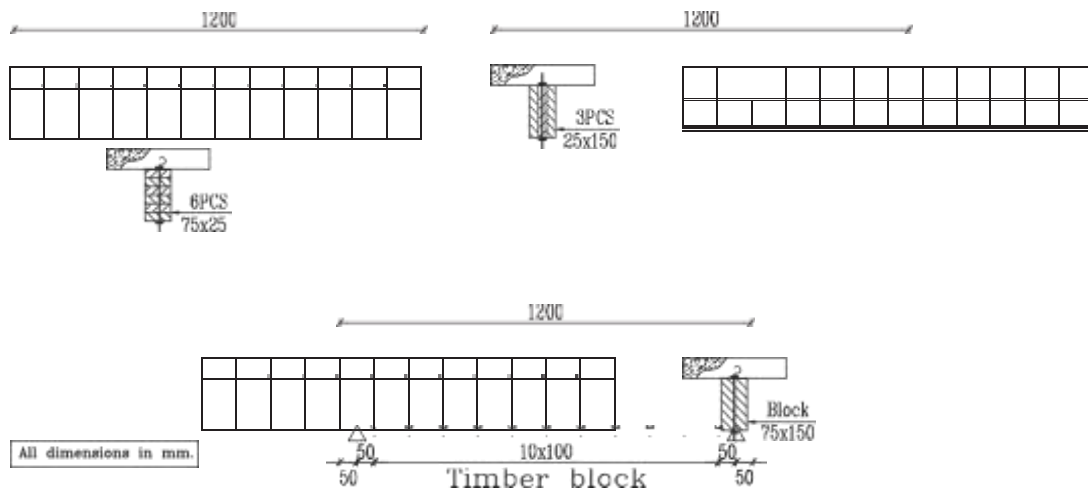
Fig. 2. Details of test beams in stage I.
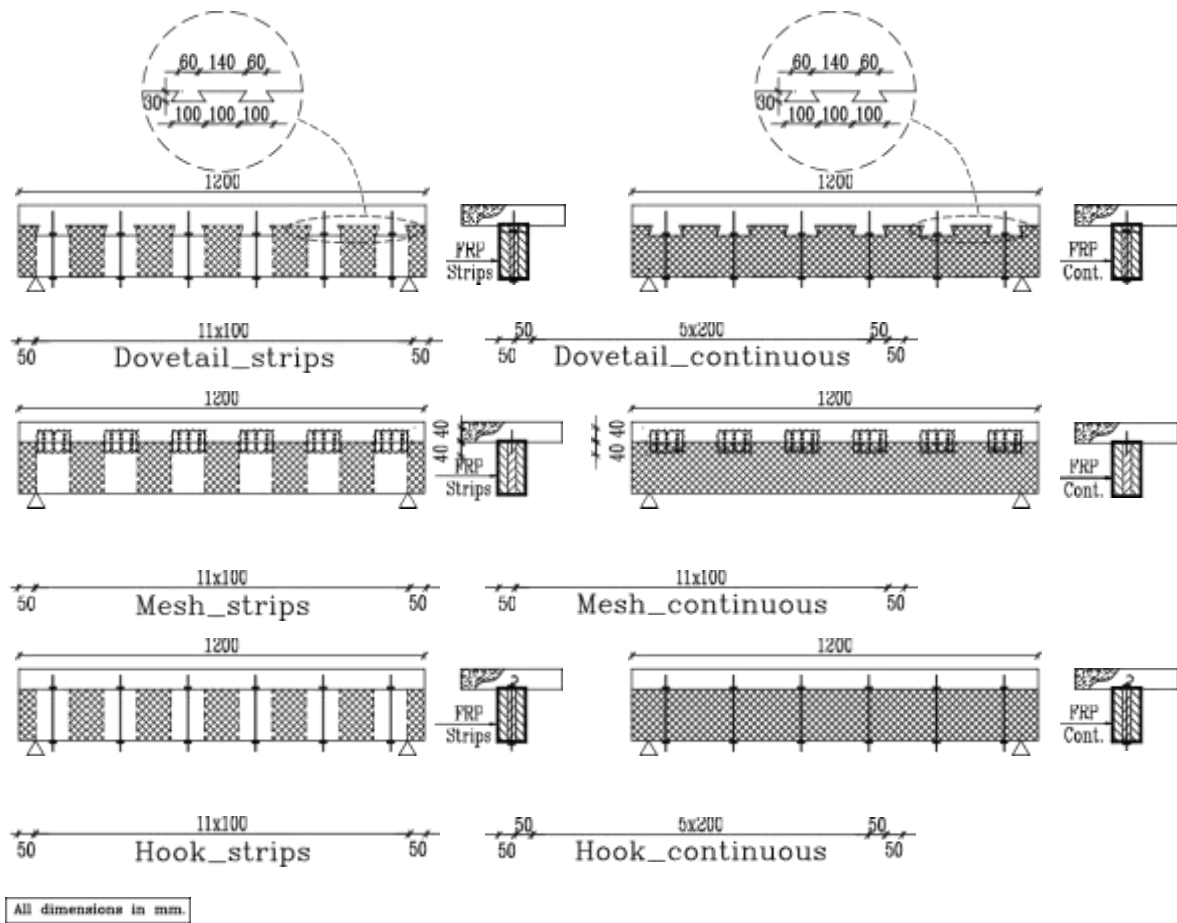
Fig. 3. Details of test beams in stageII.

Fig. 4. Details of test beams in stage III.
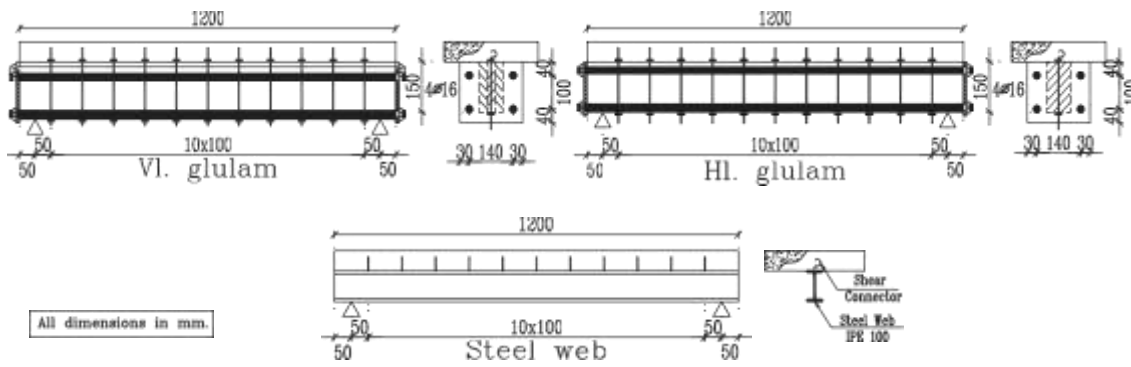
Table 2

Dovetail-continuous	3.110	Dovetail-strips	2.830
Hook-continuous	1.715	Hook-strips	1.572
Mesh-continuous	1.384	Mesh-strips	1.275

Ductility index for test beams of stage II.
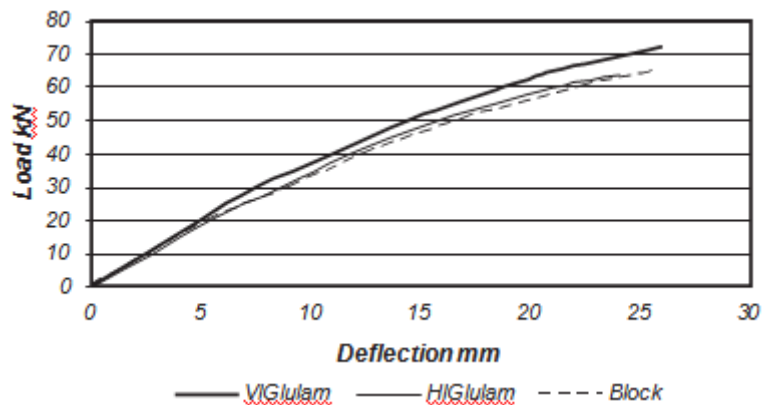

Fig. 5. Test set up for beams.

Fig. 6. Load-deflection curves for test beams in stage I.

The bearing stresses between concrete and timber developed in dovetail grooves and the deformability of timber with no apparent failures in these locations strongly enhanced the ductile behavior of beams with this shear connector compared with others. The ductility capability shown by these beams provides very effective composite action and also prevents total structuralcollapse.

To evaluate the success of the beam made with enhanced dove- tail shear connector and wrapped with continuous FRP laminates, Fig. 8 illustrates a the behavior of this beam along with three stiff- ened web beams. The webs of these three beams were post- stressed vertical glulam, post-stressed massive timber and stan- dard steel beam IPE 100. It was clear that the behavior of dovetail beam is comparable to the concrete-steel composite beam except that the later one experienced large deformations near failure due to the out of plane buckling of the steel web (Fig. 9). By consid- ering the advantageous use of timber compared with steel in view of the total weight and environmental impacts, this proposed enhanced dovetail shear connector is highly recommended for use in flexural compositeelements.
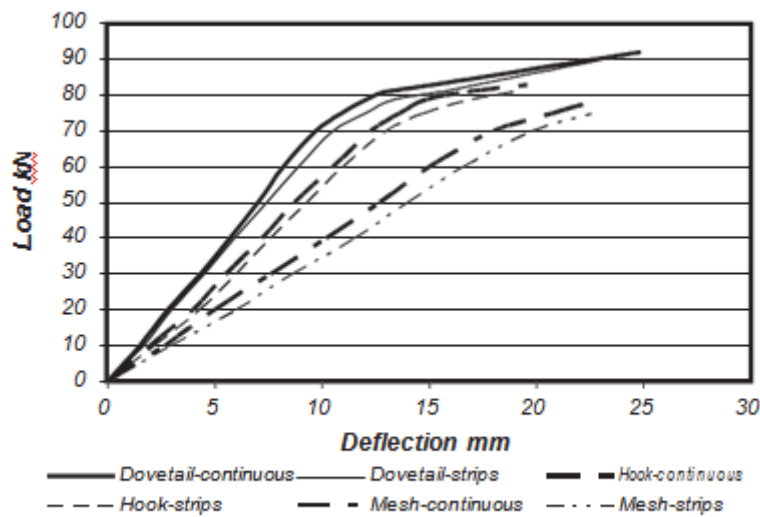

Fig. 7. Load-deflection curves for test beams in stage II.

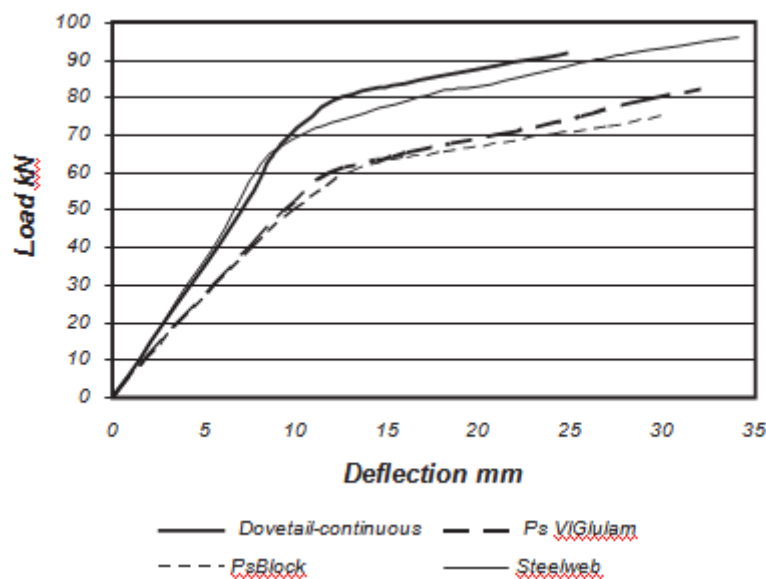**Fig. 7.** Load-deflection curves for test beams in stage II.

Fig. 8. Load-deflection curves for test beams in stage III.

wraps in beams with steel mesh shear connector limited the slip- page between the shear connector and the timber web and hence exhibited a marginal improvement in performance over dis- continuous ones.

Theductilebehavioroftestbeamsisexpressedbytheductility index**1**,definedbyNaamanandJeong[20],as:

1¼0:5ðE_{tol}**=**E_{el}**Þ1Þ**

where E_{tol} and E_{el} are total energy and elastic energy, respectively, computed under load-deflection curve. The curves wereapproxi-
mated to smaller engineering shapes for ease of calculating the areasundercurve.The computedvaluesof**1**areshowninTable2.

Fig. 9. Failure mode of concrete-steel composite beam.

Contrarily, the behavior of the two externally post-stressed beams was inferior to other beams. However, using the external longitudinal stressing bolts did increase the load carrying capacity of the beams with only 15% compared with the corresponding beams tested in stage I. The surplus strength of these beams maybe attributed to the increased resistance to shear flow through tim- berlayers.

V. CONCLUSIONS

The following summarizes the findings of this investigation:

1. Thepresentstudyshowsthatverticalglulamtimberwebcanbe successfullyusedforthemanufactureofconcrete-timbercom-posite beams since it contributes in providing higher stiffness and load carrying capacity and larger toughness compared to both horizontal glulam web and massive block timberweb.

2. Dovetail shear connector enhanced with insertion of a steel dowel at the middle of the groove is the superior shear connec- tor, among different types investigated in this study, to impart a full composite action between concrete and timber web in beams. It strongly enhances the load carrying capacity, stiffness, toughness andductility.

3. Use of GFRP laminates wrapping along the full span of timber web in composite beams is a highly effective method to take advantage of the use of enhanced dovetail shearconnector.

4. The success of FRP laminates wrapping for timer webs con- nected to concrete flange by enhanced dovetail shear connector was emphasized by obtaining a comparable behavior of the manufactured beam with that of concrete-steelweb beams.

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