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Evaluation of shear constant of timber glulam composite with photogrammetric approach

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Abstract

Shear constant of timber glulam materials plays an important role in structural modelling, such as lateral torsional buckling of the glulam beam, floor vibration and stabilities of long span glulam girders. In normal design approach, a fraction of the modulus of elasticity (MOE) from the bending test is adopted. However, recent research (Zhang 2011; Khokhar 2010; Khokhar 2009) have indicated there is little evidence of the strong correlation between the Shear Constant and MOE. A torsional test method has also been proposed in which inclinometers are employed to measure the rotation of the specimens. Although, inclinometer is convenient on measuring the surface rotation, but the size of the sensor has also limited the measure only to the level of average rotation of the area covered by the sensor rather than the accurate rotation at a given location thus it is not possible to measure the shear strain distribution along the height of the cross-sections which is essential to understand the torsional behaviour of the glulam beams. The development of new techniques to measure the rotation for a smaller area is very important on determining the shear constant with torsion test method. In this paper, the photogrammetric technique has been developed for the torsion test method to evaluate the shear constant of glulam beams. The initial results show an improved accuracy and more detailed shear displacement has been captured.

Keywords: Shear constant; Timber Glulam composite; Torsion test method; Photogrammetric method; Stereovision.

1 Introduction

The shear modulus (G) is a fundamental mechanical property of wood that is used in the design of timber and engineered wood products. Timber material has relatively low shear stiffness. Shear deformation contributes a more significant portion of flexural deflection. The shear modulus is critical when designing for lateral-torsional stability of joists (EN 1995-1-1:2004) and G is also significant in designing serviceability of wood-joist floors (Fochi, 1982), and is an important input for setting up analytical and finite element models (Chui 2002; Jiang 2004).

Shear block and bending tests (ASTM 1996; EN 408: 2003) are the two most common approaches to evaluate the shear modulus of timber and glulam materials. However, both methods have also been found difficult to evaluate the shear stiffness of structural-size battens. The shear block is made of clear wood and not possible to reflect influence of defects in structural-size samples (Keenen 1974; Soltis 1994). The bending test creates a combination flexural and shear stresses leads to difficulties in obtaining the true value of shear stiffness (Vafai 1973; Riyanto 1998). Recently, torsion test has been adopted by more and more researchers (Zhang 2011; Khokhar 2010; Khokhar 2009; Gupta 2002; Gupta 2005; Hindman 2005; NDS 2001) to evaluate the shear modulus of structural-size timber and glulam beams. Because of the state of pure shear created in a torsion test, the method has been proved to have more advantages for measuring the shear modulus value of timber and glulam beams (Hindman 2005; NDS 2001).

In a torsion test, measuring the rotations of the samples effectively at various locations is the key of evaluating the shear modulus and its variations. Inclinometer is one of the most commonly used instruments for measuring the rotation of the samples. However, the size of the device and the nature of the surface contact measuring have prevented inclinometers to be used in measuring more details of the shear deformation which is important to help us to understand why there is a very weak correlation has been found between the MOE and G for timber and glulam beams. To overcome this difficulty, the authors propose the photogrammetry method to measure the surface rotation of the samples. With this new approach, the rotations of any point on the sample surface in the field of view (FOV) can be measured from the photos taken by two cameras simultaneously.

Based on this method, an experimental study was conducted to validate the accuracy of photogrammetric technique using a special target plate. The rotation of the target plate was recorded by the cameras and compare with the measurements from the inclinometers. A good agreement has been observed from two methods. In order to investigate more details of the rotation of cross-section in the glulam beams, 5 elliptical target points are painted on the surface of the testing samples under the calibration plate (see the setup on Figure 1). Detailed surface rotations are profiled and compared with the overall average rotation measured from the calibration plate and inclinometers. It can be seen that result from photogrammetric method not only shows strong agreement with result from inclinometers but also gives more details on the surface deformation which will give us a better understanding of the components of the shear deformation and strain.

Figure 1. Experiment setup, location of calibration plate and target points

2 Stereo Vision technique for displacement measurement

The proposed photogrammetric approach is based on Stereo Vision with which displacements of the samples is measured in 3D. Stereo Vision, or Binocular Vision, is the process of recovering the 3D scene from a pair of stereo images taken from slightly different positions. From a pair of stereo images, it is possible to reconstruct the 3D coordinates of a physical point by triangulation. If the target point has a unique texture or special mark, the movement of this point can be traced using pattern recognition algorithms so that the displacements and surface strains of the samples can be calculated accordingly. The procedure of Stereo Vision measurement includes: stereo camera calibration, stereo-matching, 3D reconstructions and 3D displacement and rotation measurement.

2.1 Stereo camera calibration

Camera calibration can be described as the process of determining the intrinsic and extrinsic parameters of the cameras. The intrinsic parameters describe the geometric and optical characteristics of lens and cameras while the extrinsic parameters describe the position and orientation of the cameras in the global coordinate system. Stereo camera calibration involves determining the intrinsic parameters of each camera and the relative position and orientation among the cameras. Using these calibration data, by triangulating each pixel and its correspondence, the 3D coordinate at that pixel can be computed.

In this research, two Basler Pilot piA2400-17gm cameras are used, based on the stereo camera calibration. Two mega pixel lenses with 25mm fixed focal length are used to acquire images of the object simultaneously. Calibration plate is used as reference object during the calibration. Images of the plate from each camera are taken simultaneously. In every image, the border of the calibration plate and the position of the circles are determined and to be used to compute the calibration parameters of the cameras. The calibration parameters are used to calculate the 3-D position of any point from its stereo projections by triangulation.

2.2 Stereo-match, 3D reconstruction and displacement/rotation measurement

After the calibration, the camera parameters, positions and orientations are determined. To measure the position and the movement of a target point on a sample, the positions of this point in each camera's view have to be detected (detect conjugate pairs). It has been an extremely challenging research problem known as the correspondence or stereo-matching in image processing. In this research, a calibration plate and elliptical marks were used to improve the accuracy and speed of stereo-match. A combined edge detection and grey scale threshold method is employed. After the conjugate pairs are detected on the images from each camera, a triangulation technique is used to reconstruct the 3D coordinates from the image sequences captured by the cameras. Measuring displacement or rotation at any location on an object is realized through the 3D tracking of purposed placed target points and calibration plates attached to the samples. These targets need to be visible on every frame of the acquired image sequences.

2.3 Software development

The image processing of the proposed photogrammetric approach is computational intensive work. It requires an automated software package to process the massive acquired image data in each test. A tailor-made toolbox was developed for tracking the rotation and displacement of the sample in a torsion test. In this research a software package was developed (Figure 2(b)) based on Visual Basic and Halcon Application Programming Interface (API). In order to compare the photogrammetric result with the inclinometer measurement, the sequence of two data has to be synchronised in sample system. Another software package (Figure 2(a)) was developed to recode and synchronise the sensor outputs with the camera system. Since the I/O interface for the inclinometer is RS232 serial port and the camera I/O port are industrial leading GigE Ethernet interface, so the real time data recording and processing is possible to be carried out on one computer.

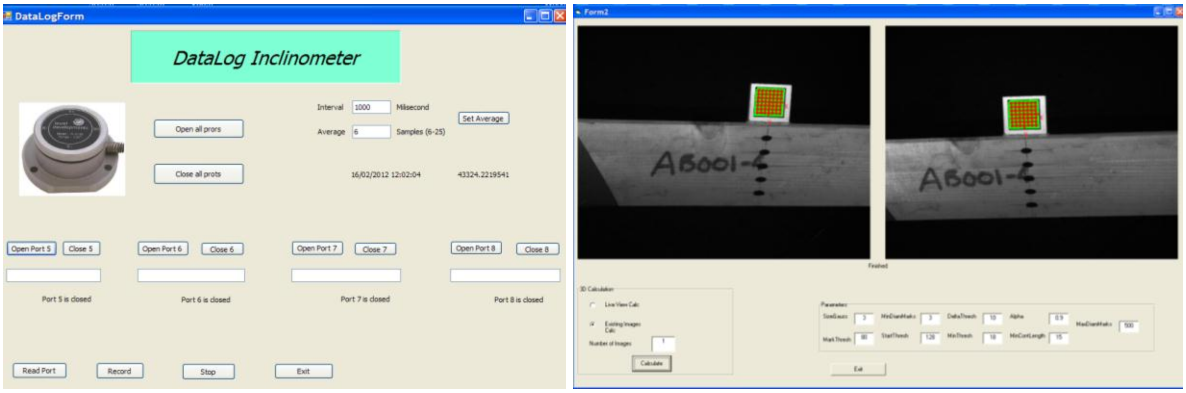

Figure 2. (a) Datalog system for inclinometer (b) Photogrammetric software for torsional tests

3 Test setup

Tests were undertaken on glulam timber with nominal cross sectional dimensions of 95×45 mm. The schematic diagram for test setup is shown in Figure 3. The timber glulam beams are graded to C24 strength class. The test samples were cut into 2.0 m length. Prior to the torsional tests, four point bending tests and acoustic tests are carried out to measure the modulus of elasticity in bending and the dynamic modulus of elasticity from acoustic measurement. However, for sake of briefness, the relationship of MOE and G will not be discussed in this paper.

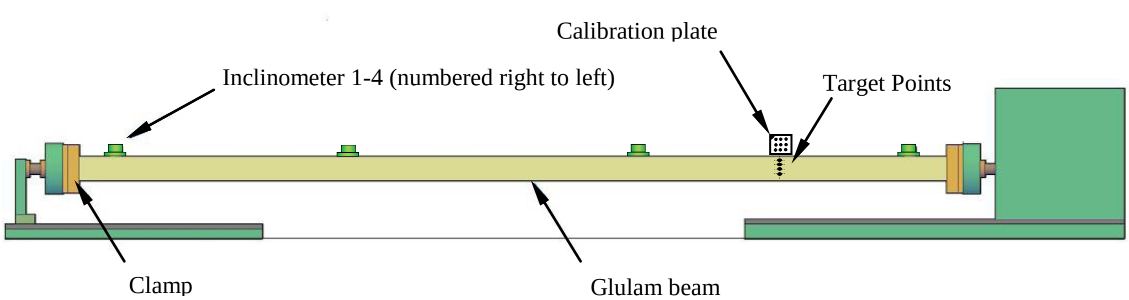

Figure 3 Schematic diagram for test setup timber joist

Each sample was mounted in a testing machine with 1 kN-m torsional capacity. Special clamps are designed to hold different size of the rectangular timber samples with a moveable cleat. To measure the rotation of the glulam beam during the test, 4 inclinometers were attached to the upper surface of each sample to record the longitudinal variation in G. Two end inclinometers were mounted 200 mm from the clamps to avoid possible end effects arising from the attaching clamps. All Inclinometers were mounted at 500 mm apart from each other. Since it is sensible to measure and compare a section which rotates more, so the right most section which is connected to the rotating end was chosen to be monitored. At the middle of this section, a calibration plate is glued to the top surface. Under the calibration plate, 5 elliptical target points are marked 15mm center to center to give a traceable marks on the sample surface. The calibration plate is precisely printed with predefined geometric shape, which not only can calibrate the FOV but also can be used to measure the sample rotation by attaching it to the sample surface. It gives a better measure of the movements with this tailor-made target. However, because of the size of the plate and the nature of the contact measurement, it is not possible to measure the rotation of the samples into more details. To measure the rotation of the long side of the cross-section, 5 elliptical target points are employed as shown in Figure 1.

The target plate is used to calibrate the FOV, and to give accurate average top surface rotation of the sample. The result will be compared with the two measurement from the inclinometers adjacent to it. The 5 elliptical target points under the calibration plate will provide details of surface movement, from which the rigid body movement, detailed displacement and average rotation will be distilled.

The two cameras are setup around 1.5m away from the sample. Two LED flood illuminators are used to overwhelm the influence of the natural and indoor lighting. To avoid the over-exposure and quality being reduced, the lenses are set to small aperture with increased field of depth (FOD) so that more details in wider area can be captured.

4 Test results

4.1 Comparison of the inclinometer and photogrammetric measurement

The accuracy of the photogrammetry method is greatly influenced by cameras, lighting, algorithms of the calibration, and algorithms of the 3D reconstruction. To validate the accuracy of our system, the rotation of the calibration plate is captured by two cameras and compare with the average readings from the two inclinometers next to the plate. The samples is loaded at a speed of 8°/min. The comparison of the results from the inclinometers and the photogrammetric approach are shown in Figure 4 and 5 from which a good agreement between these two methods can be observed.

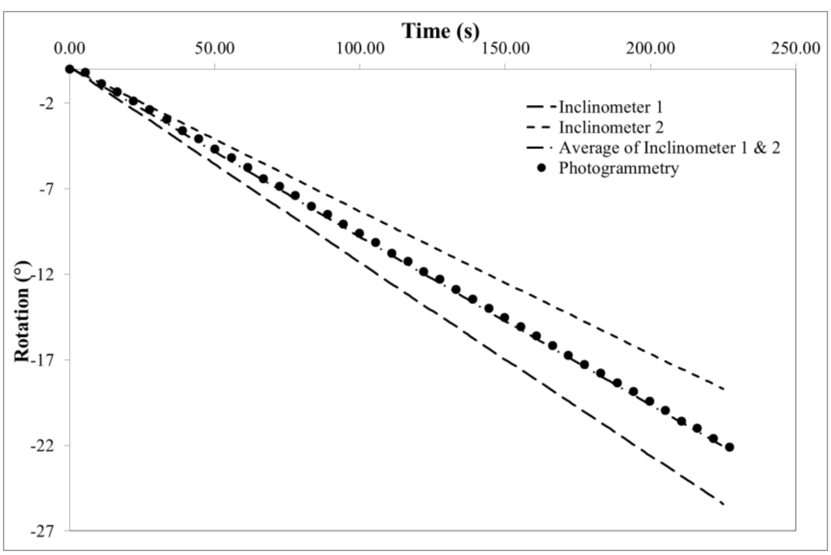

Figure 4 Comparison of the inclinometer and photogrammetric measurement for Sample 1

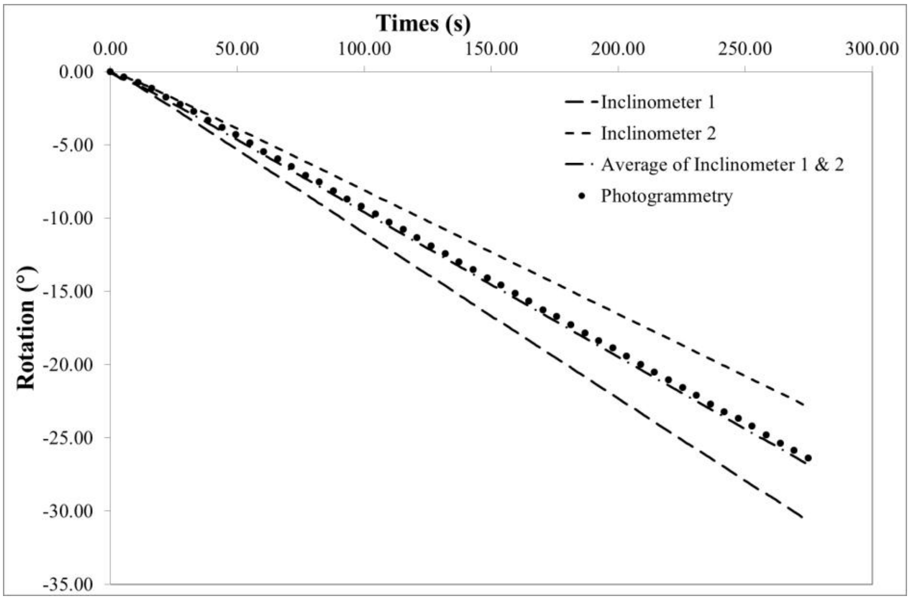

Figure 5 Comparison of the inclinometer and photogrammetric measurement for Sample 2

4.2 Shear deformation along the long edge of the cross-section

The ability of monitoring and measuring any target points inside of the FOV has become the most attractive feature for researchers to apply the photogrammetric method in the their experimental research especially when it is not feasible to use conventional sensors. In this research, the photogrammetric method is also employed to measure the displacement along the long side of the cross-section. Figure 6 shows the displacement of the longer edge of the cross-section under the calibration plate. The displacement is measured every 50 seconds. Although under the Saint-Venant's torsion theory, there should not have a cross-sectional distortion within x-y plane. However it can be seen that significant warping in x-y plane has been observed even under a relatively low torque at the 50^{th} second, so it has non-negligible effects on the shear strain and shear stress for timber materials in torsion.

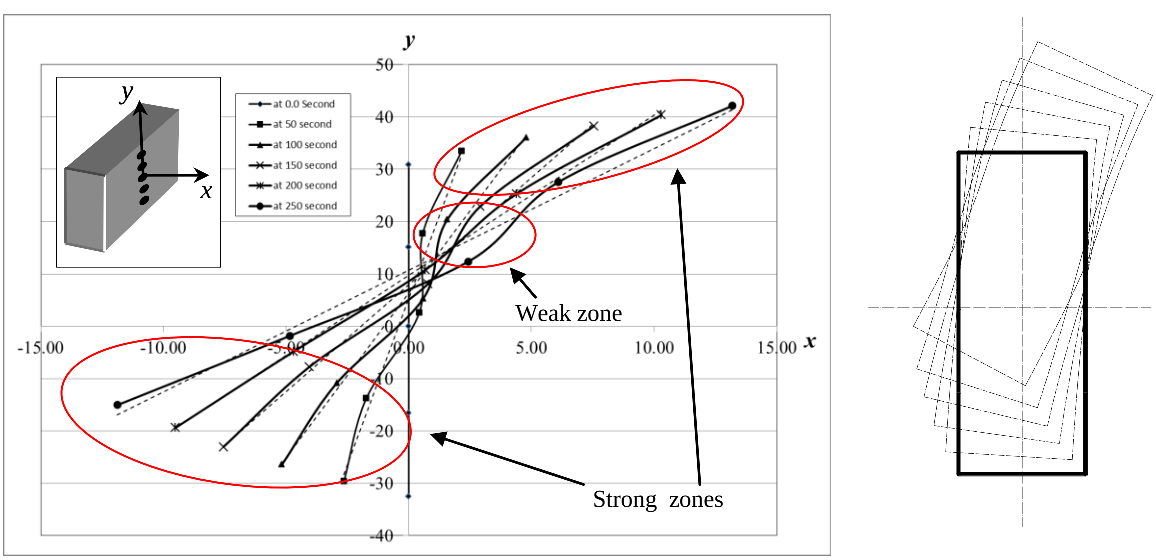

Figure 6 (a) Displacement of longer side of the cross-section (b) Original and deformed cross-section

From the displacement shown in Figure 6 (a), two different zones can be easily recognized with different gradients of increase in displacement, i.e. weak zone with larger increase than the strong one.

In a torsion test, the inclinometers are normally mounted on the short side of the cross-section. Considered the non-linear displacement observed along the long side of the cross-section, it is important to understand the difference between the rotation of the long and short side of the cross-section. To calculate the average rotation of long side, an average is taken for the long side as indicated by the dash line in Figure 6 (a). From the average displacements, the rotations of the long side can be calculated. Figure 7 shows the comparison of the average rotations of long (from photogrammetric method) and short side (from inclinometers). Although small difference is observed while a noticeable agreement is also indicating the measurement of short side with inclinometers is acceptable in structural member level. This is also supported by a scaled sketch of the original and deformed shape of cross-section shown in figure 6(b). However, it may not be a good approach to investigate the shear strain/stress distribution of glulam beams. A more sophisticated technique such as photogrammetric method should be considered.

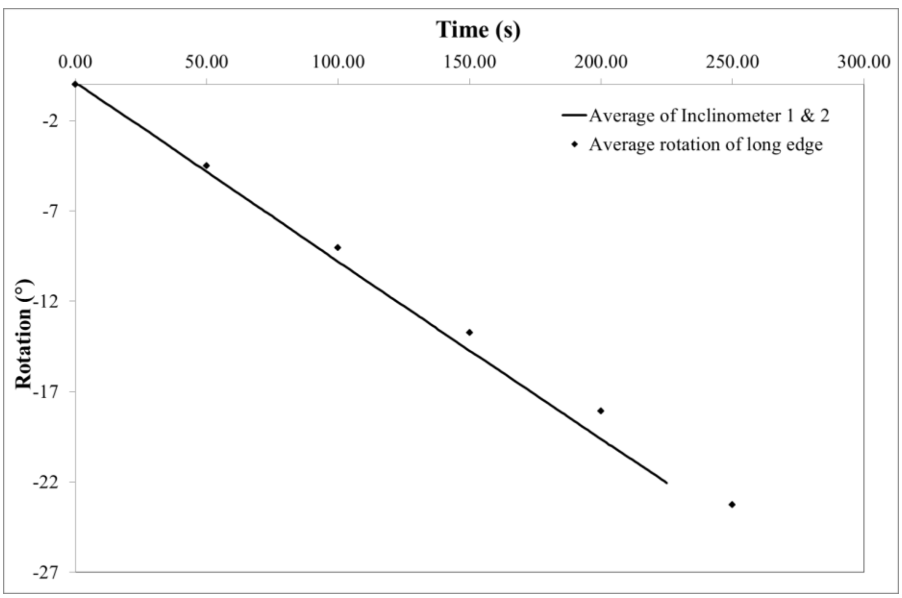

Figure 7 Comparison of rotation of the short side and long side

5 Conclusion

In this paper, a new photogrammetric method has been employed to investigate the torsional behaviours of timber glulam beams. To validate the accuracy of this method, a comparison study has been carried out between the photogrammetric method and the method of using conventional inclinometer sensors. A calibration plate is used as the tracing target for the photogrammetric method at this stage. Good agree has been found between these two measuring systems. After confirming the accuracy of the proposed method, a further study on the shear displacement at cross-sectional level is carried out by tracking and measuring the displacement of 5 elliptical target points pre-painted on the sample surface. Significant non-linearity has been found from the measurement of the shear displacements along the long side of the cross-section. However, the average rotation shows clear agreements with the inclinometer readings.

References

ZHANG, H., MOHAMED, A. AND XIAO Z., 2011. Evaluation of the shear constant of a timber beam using photogrammetric approach. *The 13th International Conference on Civil, Structural and Environmental Engineering Computing, 2011, Crete, Greece.*

KHOKHAR A. M., ZHANG H., RIDLEY-ELLIS D. AND MOORE J. 2010. The shear strength, and failure modes, of timber joists obtained from the torsion test method, *The 11th World Conference on Timber Engineering, 2010, Riva Del Garda, Italy.*

KHOKHAR A. M, ZHANG H. AND RIDLEY-ELLIS D. 2009. Shear strength of timber joists obtained from torsion tests. *WG meetings COST Action E53-Quality Control for Wood and Wood Products, 2009, Lisbon, Portugal.*

EN 1995-1-1 : 2004. *Eurocode: Design of Timber structures – Part 1-1: General – common rules and rules for building", European Committee for Standardization.* Brussels: European Committee for Standardization.

FOSCHI R. O., 1982. Structural analysis of wood floor system. *ASCE Journal of Structural Engineering*, 108(7), 1557-1574.

CHUI Y. H., 2002. Application of ribbed-Plate theory of predict vibrational serviceability of timber floor systems", *The 7th World Conference on Timber Engineering, 2002, Selangor, Malaysia.*

JIANG L., HU L.J. AND CHUI Y. H., 2004. A finite element model for wood-based floor structures with lateral reinforcement. *ASCE Journal of Structural Engineering*, 130(7),1097-1107.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM), 1952. *Standards methods of testing small clear specimens of timber", ASTM D 143-94, Vol 04, Serial Designation, Conshohocken*, PA, USA.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM), 1996. *Standard Methods of Static Test of Lumber in Structural Size", ASTM D 198-94, Vol 04.10 Wood, West Conshohocken*, PA, USA.

EN 408 : 2003, *Timber structures-structural timber and glued laminated timber- determination of some physical and mechanical properties perpendicular to the grain*. Brussels: European Committee for Standardization.

KEENEN F. J., 1974. Shear strength of wood beams, *Forest Products Journal*, 24(9), 63-70.

SOLTIS L. A. AND RAMMER D. R., 1994. Shear strength of un-checked glued-laminated beams. *Forest Products Society*, 44(01), 51-57.

VAFAI A. AND PINUS G., 1973. Torsional and bending behaviour of wood beams. *ASCE Journal of Structural Engineering*, 99(6), 1205-1221.

RIYANTO D. S. AND GUPTA R., 1998. A comparison of test methods for evaluating shear strength of structural lumber. *Forest Products Journal*, 48(2), 83-90.

GUPTA R., HECK L. R. AND MILLER T. H., 2002. Experimental evaluation of the torsion test for determining shear strength of structural lumber. *Journal of Testing and Evaluation*, 30(4), 283-290.

GUPTA R. AND SILLER T., 2005. Shear strength of structural composite lumber using torsion tests. *Journal of Testing and Evaluation*, 33(2), 110-117.

HINDMAN D., MANBECK H. B. AND JANOWIAK J. J., 2005. Torsional rigidity of rectangular wood composite materials. *Wood and Fiber Science*, 37(2), 283-291.

AMERICAN FOREST AND PAPER ASSOCIATION, 2001. *National Design Specification (NDS) for Wood Construction*, Washington, USA.