Part II: User's Manual

BAMBOO
TEST-KIT-IN-A-BACK PACK

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Translations by: Janine Vieira, Tianqiao Liu & Richard Moran

INBAR Technical Report No.36

About INBAR Technical Reports

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Acknowledgements

This project was funded by the Watkins Haggart Structural Engineering Laboratory (WHSEL) at the University of Pittsburgh. Student support was provided by the Mascaro Center for Sustainable Innova- tion (MCSI) at the University of Pittsburgh through a United States National Science Foundation (NSF) International Research Experience for Students (IRES) Programme award (IIA-1031392). The project was undertaken in the summer of 2013 by University of Pittsburgh Undergraduate Students Rebecca Glucksman, Eric Belski, Andrew Beck and Steve Marusic. The authors acknowledge the support of Prof. Khosrow Ghavami at the Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio) and Charles 'Scooter' Hager and Jennifer Gottron in the WHSEL.

Key words

Full-culm bamboo, material test, compression, shear, bending

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ISBN: 978-92-95098-82-4 (Online)

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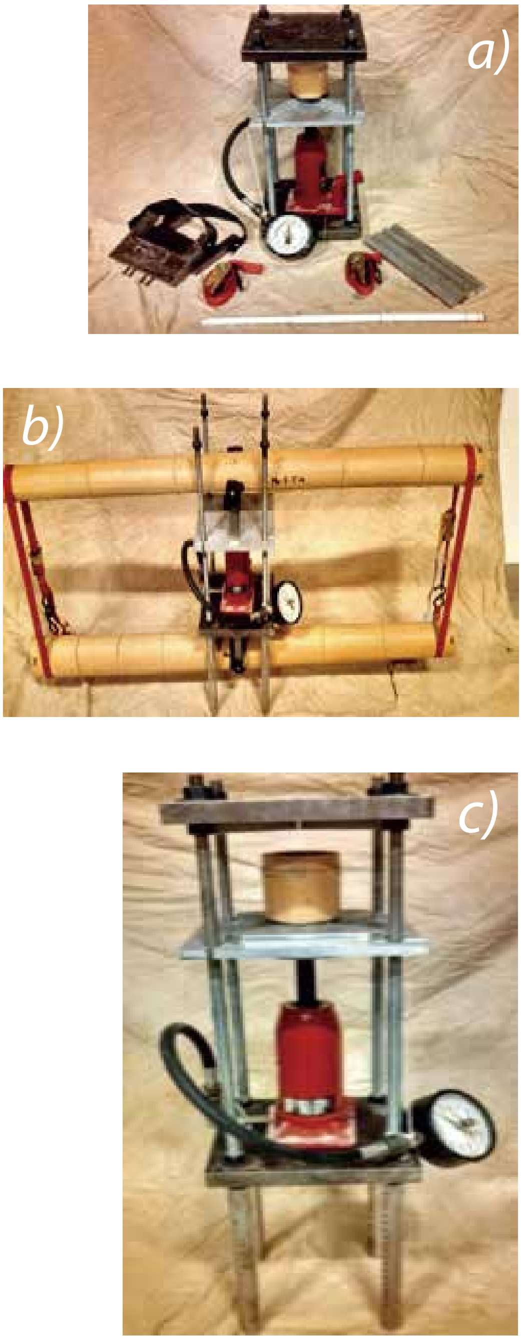


The 'kit' (Figure 1), intended for rapid in-the-field assessment of bamboo mechanical and material properties, is designed to be an inexpensive, robust, portable test apparatus that may be carried, assembled, operated and maintained by a single technician. Presently the kit supports:

1. Full-culm compression (ISO 22157-1);
2. Longitudinal shear ('bowtie' test; ISO 22157-1);
3. Edge bearing (Sharma et al. 2012);
4. Culm flexural tests (modified from ISO 22157-1 by Richard 2013).

This manual documents the fabrication of a kit having a capacity of 72 kN (8 tons force). Figures 2 and 3 provide drawings documenting the fabrication of the kit prototype.

Figure 1: Prototype test-kit-in-a-backpack.

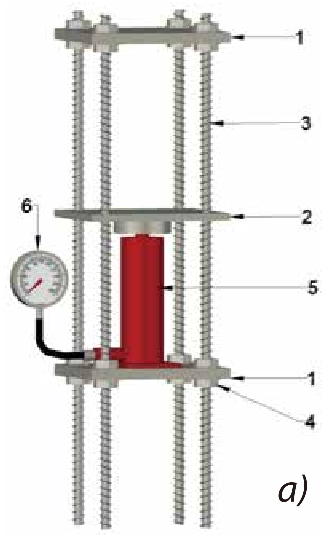
a) Test kit (white pump handle is 600 mm (24 in.)

b) Set-up for longitudinal shear

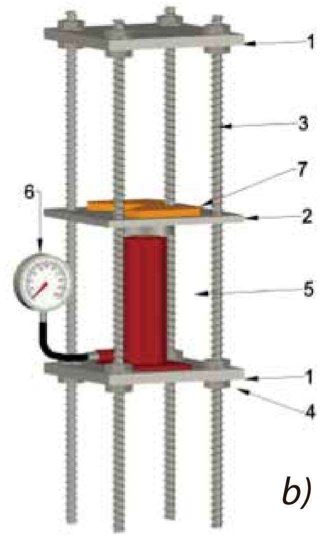
c) Set-up for short culm flexure test

The reaction plates (part #1 in Fig. 2) are fixed in place on the threaded rods (part #3) using nuts and washers (part #4). The loading plate (part #2) moves freely; guided by the rods. The threaded base of the hydraulic cylinder (part #5) is bolted to the lower reaction plate. The 'bowtie' loading plates (part #7), flexure saddles (part #8) or any spacer plates required are provided with threaded holes and subsequently bolted to the loading plate and upper reaction plate. Concentric circles are scribed onto the loading and reaction plates to help to centre specimens over the hydraulic cylinder.

The extension of the threaded rods below the lower reaction plate may be used as 'legs', raising the unit off the ground. In order to protect the threads, pipe sleeves, slightly longer than the threaded rod extensions, are slipped over the rods (these are seen in Fig. 1).



Assembly



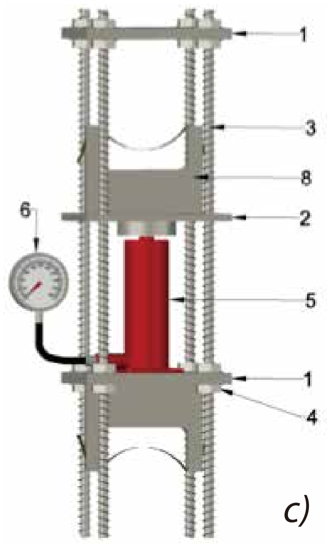


Figure 2: Prototype test kit assemblies.

a) Assembly for compression and edge bearing tests
b) Assembly for longitudinal shear test
c) Assembly for flexure test

1. 254 x 254 x19 mm fixed reaction plates (2 required; see Fig 3a)
2. 254 x 254 x 12.7 mm moving load plate (see Fig 3b)
3. 16 mm x 1000 mm long threaded rod (4 required)
4. nut and washer assemblies for rods (16 required)
5. 72 kN hydraulic cylinder (bottle jack)
6. high precision pressure gauge
7. 'bowtie' plates (two sets; see Fig 3c)
8. flexure test saddles (two required; see Fig. 3d)

Test Kit Pressure Gage and Force Conversion

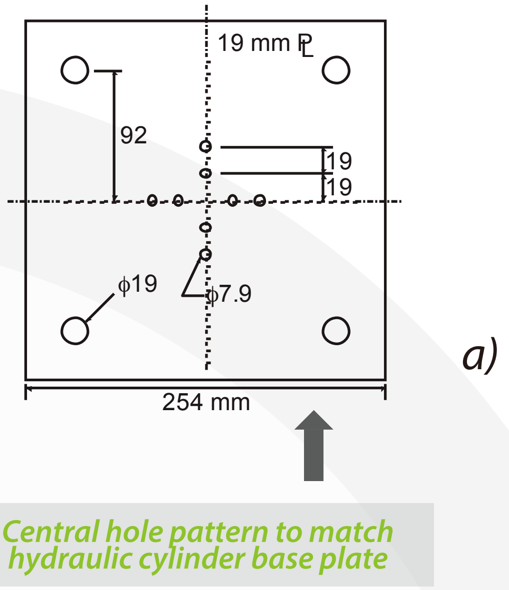
The hydraulic cylinder must be fitted with a pressure transducer. In the prototype, a precision dial-type pressure gage having a peak needle is used (part #6). The force applied by the cylinder is equal to the product of the indicated pressure and the cross sectional area of the cylinder used. There may be some degree of friction loss in the cylinder associated with seal friction or binding of the cylinder; this should be minimized and can be accoun- ted for if an alternate means of calibration is available.

Example

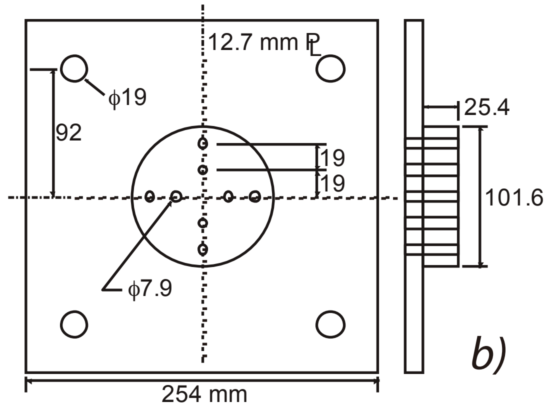
For the prototype kit, the cylinder has a manufacturer-reported diameter of d_j = 38.1 mm (1.5 in.) giving an area of $A_j = \pi d_j^{\,2}/4$ = 1140 mm^2 (1.77 in^2). Calibration using an external load cell resulted in calibration factor of 1090 mm^2 (1.69 in^2), indicating friction losses on the order of 4.5% (a reasonable value for the bottle jack used). The applied load (*P*) for any test is therefore:

P(N) = 1090 x (gage pressure in MPa)

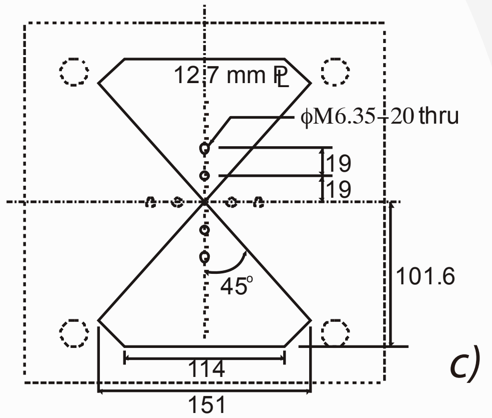
P(lbf) = 1.69 x (gage pressure in psi)



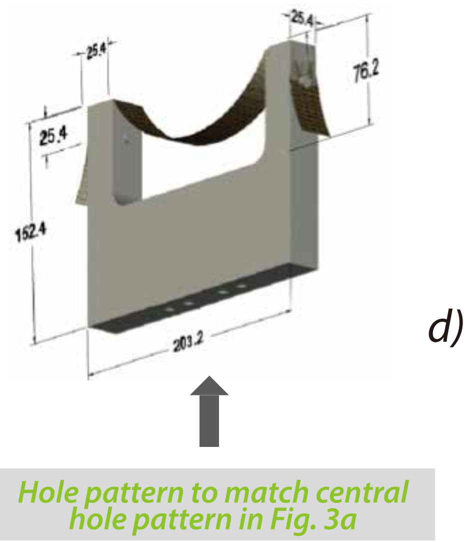
a) Fixed reaction plates (2 assemblies; part #1)



b) Moving load plate (part #2)



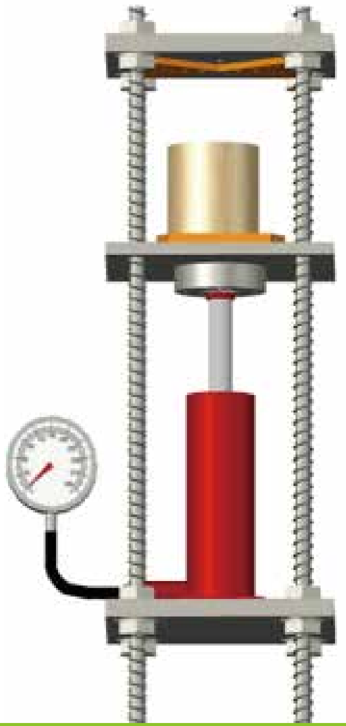
c) 'Bowtie' plates (2 assemblies; part #7)



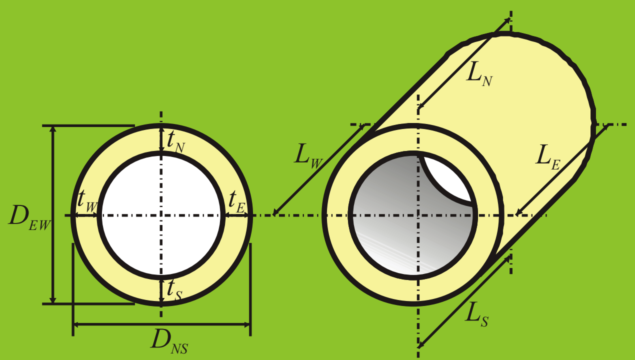
d) Fiexure saddles (2 assemblies; part #8)

Figure 3: Prototype test kit plate details

Test Methods



Bamboo Specimen Geometry



$D = (D_{NS} + D_{EW})/2$

$t = (t_N + t_S + t_E + t_W)/4$

$L = (L_N + L_S + L_E + L_W)/4$

$A_{culm} = (\pi/4)(D^2 - (D - 2t)^2)$

$I_{culm} = (\pi/64)(D^4 - (D - 2t)^4)$

$R = 0.5(D - t)$

The following measured dimensions are obtained from the test specimens:

- D = culm outside diameter taken as average of two orthogonal measurements at any section
- t = culm wall thickness taken as average of four quadrant measurements at any section
- L = length of culm specimen taken as average of four quadrant measurements

The following geometric properties are calculated:

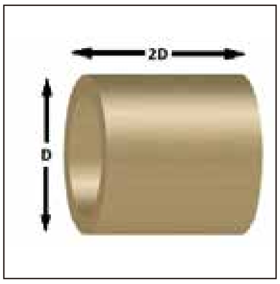
- A_{culm} = net cross section area of culm
- I_{culm} = moment of inertia of net culm section
- R = radius of culm measured to centre line of culm wall

Additionally,

- P = load applied by the test kit corresponding to specimen failure

Concentric Compression Test

Assemble test kit as shown.



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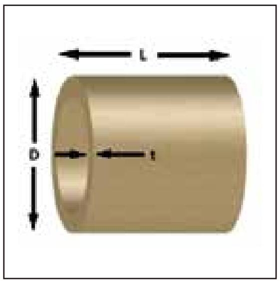

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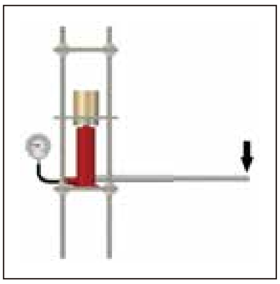

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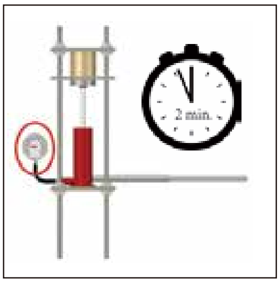

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1. Cut specimen length such that $L \leq 2D$. Specimen ends should be smooth, parallel and at right angles to culm axis. Specimens should not include nodes. Specimens containing nodes are expected to exhibit lower capacities.

2. Obtain dimensions *D, t* and *L* of culm specimen. Calculate the culm area:

$$A_{culm} = (\pi/4)\,(D^2 - (D - 2t)^2)$$

3. Centre culm specimen above hydraulic cylinder on loading plate.

4. Bring culm into contact with upper reaction plate.

5. Begin test, loading specimen at a rate that results in failure in approximately two minutes (an initial test may be required to calibrate this rate).

6. Record the ultimate load achieved *P.*

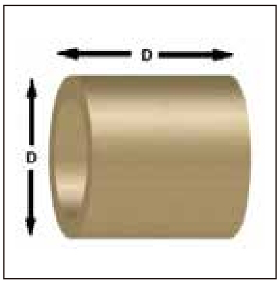
7. Calculate the ultimate compressive stress

$$\sigma_c = P/A_{culm}$$

Report the following:
- measured dimensions *D, t* and *L*
- ultimate load observed *P*
- calculated values A_{culm} and σ_c
- stress versus strain curve and calculated value of E_c if recorded

Longitudinal Shear ('Bowtie') Test

Assemble test kit as shown including the bow-tie plates; ensure that the bow-tie plates are oriented in opposite directions on each plate.



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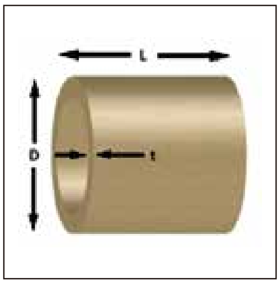

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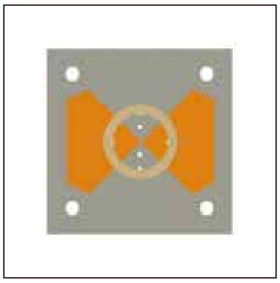

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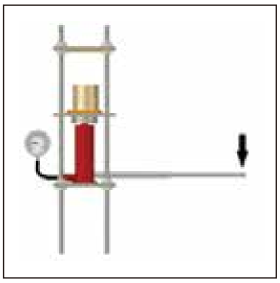

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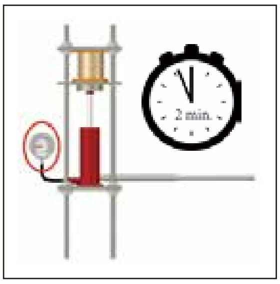

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1. Cut specimen length such that $L = D$. Specimen ends should be smooth, parallel and at right angles to culm axis. Specimens should not include nodes. Specimens containing nodes are expected to exhibit higher capacities.

2. Obtain dimensions D, t and L of culm specimen.

3. Centre culm specimen above hydraulic cylinder on bow-tie loading plate.

4. Bring culm into contact with upper reaction plate.

5. Begin test, loading specimen at a rate that results in failure in approximately two minutes (an initial test may be required to calibrate this rate).

6. Record the ultimate load achieved P.

   Record the number of failure planes observed n.

7. Calculate the shear stress:

$$\tau_L = P / 4Lt$$

   If $n < 4$, note this indicating that the calculated shear stress is a lower-bound value for the specimen.

Report the following:

- measured dimensions D, t and L
- ultimate load observed P and number of failure planes observed n
- calculated value τ_L

Edge Bearing Test

1. Cut specimen length such that $L \approx D$. Specimens must not include nodes.

2. Obtain dimensions D, t and L of culm specimen.

3. Place small flat and thin softwood or neoprene loading shim on loading plate centred over hydraulic cylinder.

4. Centre culm specimen above hydraulic cylinder such that the culm longitudinal axis is aligned along the shim.

5. Place second shim along top of specimen parallel to lower shim (aligned along the culm longitudinal axis).

6. Bring culm-shim assembly into contact with upper reaction plate.

7. Begin test, loading specimen at a rate that results in failure in approximately two minutes (an initial test may be required to calibrate this rate).

8. Record the ultimate load achieved P.

9. Calculate longitudinal moments at quadrants:

$$M_{NS} = \left(\frac{PR}{\pi}\right)\left(1 - \frac{t^2}{12R^2}\right) \qquad M_{EW} = \left(\frac{PR}{\pi}\right)\left(1 - \frac{t^2}{12R^2}\right) - \frac{PR}{2}$$

10. Calculate the transverse through-wall modulus of rupture:

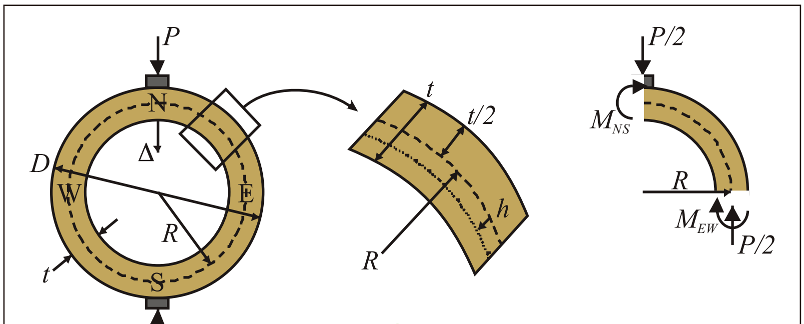
$$f_{rNS} = M_{NS}\frac{12\left(t/2 + h\right)}{Lt^3} \qquad f_{rEW} = M_{EW}\frac{12\left(t/2 + h\right)}{Lt^3} - \frac{P}{2Lt}$$

in which: $h = R - t \Big/ ln\left(\frac{2R}{t} + 1 \Big/ \frac{2R}{t} - 1\right)$

11. If vertical deflection (Δ) was measured, the apparent transverse tangent modulus of elasticity is calculated as:

$$E_{\varphi} \approx \frac{3PD^3}{2Lt^3\Delta}\left(\frac{\pi k_1}{4} - \frac{2k_2^2}{\pi}\right)$$

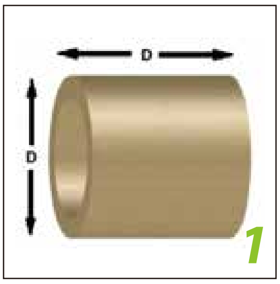
in which: $k_1 \approx 1 + \frac{7.6t^2}{D^2}$ and $k_2 = 1 - \frac{t^2}{3D^2}$



9-11

Assemble test kit as shown.

Report the following:
- measured dimensions D, t and L
- ultimate load observed P
- calculated values M_{NS}, M_{EW}, f_{rNS}, f_{rEW} and E_{φ}



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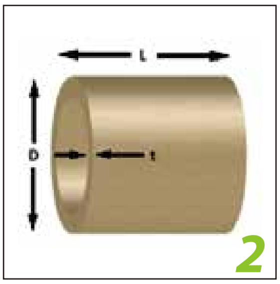

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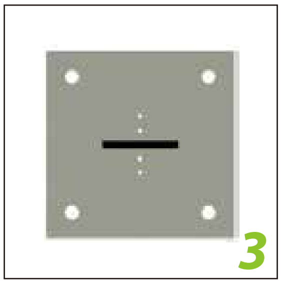

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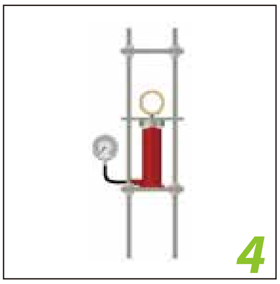

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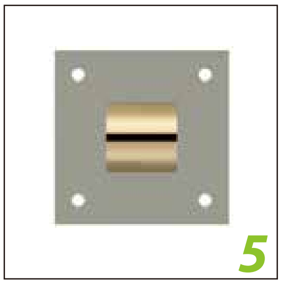

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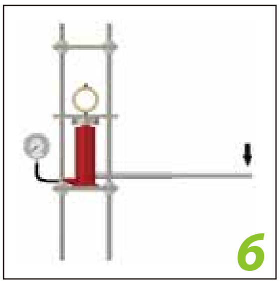

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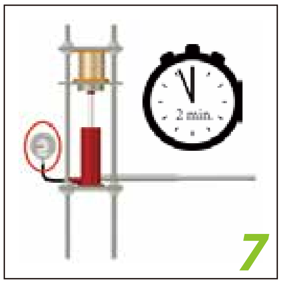

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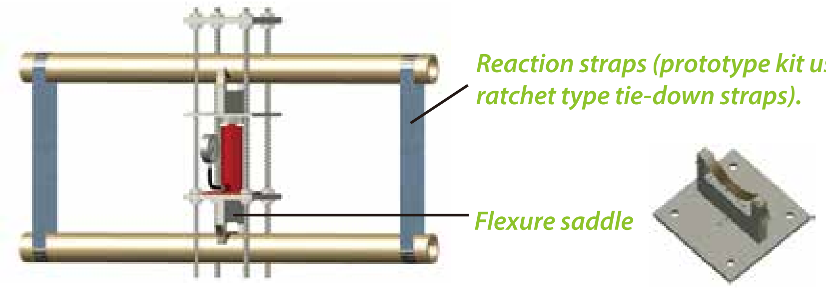
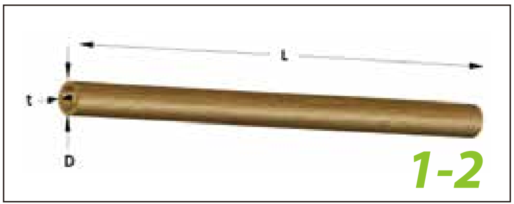
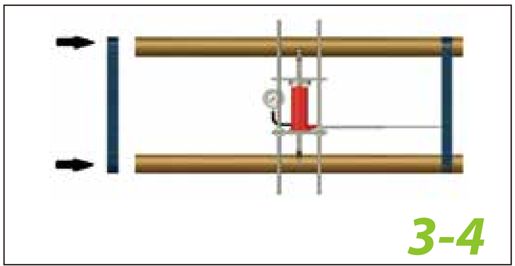
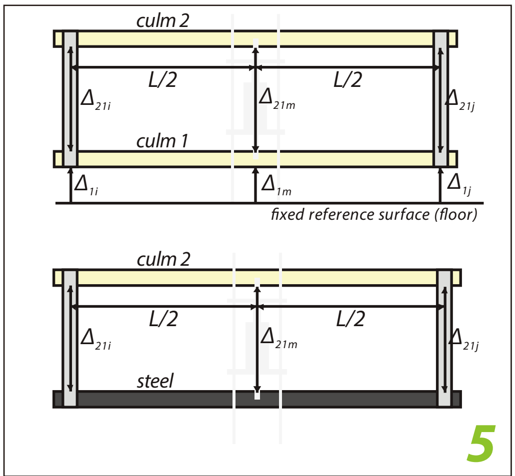
Assemble test kit as shown with the flexure saddles on the loading plate and base reaction plate. Two sets of reaction straps (ratchet-type tie down straps work well) and two similar culms are placed into the kit as shown. Alternatively, one culm may be replaced with a steel pipe (or similar) to provide the required reaction, minimise compliance and provide a means of calculating deflection of part of the self-reacting system.

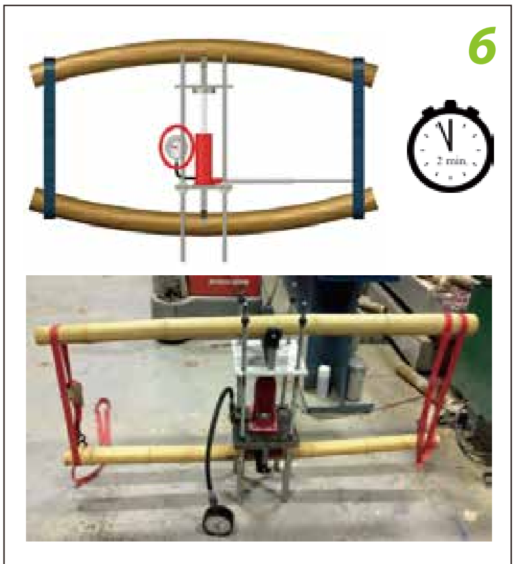
Flexure Test











1. Cut specimen length to the desired length L. To be consistent with ISO 22157, $L > 20D$ although this is not a requirement provided test results are only compared with other results sing the same L/D ratio.

2. Obtain dimensions D, t and L of culm specimen. Calculate I_{culm}:

$$I_{culm} = (\pi / 64)\,(D^4 - (D - 2t)^4)$$

3. Centre the culms on the flexure saddles and place the straps around the ends of the culms at equal distances from the saddle (i.e: the saddle is located at the mid lengthof the culms).

4. Extend the hydraulic piston until the culms are snug against the straps and the culms are parallel; adjust the strap lengths until the culms are parallel keeping the straps equidistant from the saddle.

5. Measure the tested length of the culm L, as the distance between the centrelines of each strap; verify that the flexure test saddle is located at $L/2$.

Methods for calculating individual culm displacements.

a) two self-reacting bamboo culms

midspan displacement of culm 1: $\Delta_1 = 0.5\,(\Delta_{1i} + \Delta_{1j}) - \Delta_{1m}$

midspan displacement of culm 2: $\Delta_2 = \Delta_{21m} - 0.5\,(\Delta_{21i} + \Delta_{21j}) - \Delta_1$

b) use of known reaction member (steel or other)

midspan displacement of steel: $\Delta_1 = PL^3 / 48\, E_{steel}\, I_{steel}$

midspan displacement of culm 2: $\Delta_2 = \Delta_{21m} - 0.5\,(\Delta_{21i} + \Delta_{21j}) - \Delta_1$

6. Begin test, loading specimen at a rate that results in failure in approximately two minutes (an initial test may be required to calibrate this rate).

7. Record the ultimate load achieved P, corresponding to the failure of the first culm to failure.

8. Calculate the apparent ultimate flexural stress:

$$\sigma_f = PLD / 8\, I_{culm}$$

9. If net culm deflection at midspan (Δ) was measured, the apparent flexural modulus of elasticity is calculated

$$E_a = PL^3 / 48 \Delta I_{culm}$$

Report the following:

- measured dimensions D, t and L
- ultimate load observed P
- calculated value σ_f
- method of determining Δ if measured
- calculated value E_a if applicable

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INBAR
INTERNATIONAL NETWORK
FOR BAMBOO & RATTAN

INBAR is an intergovernmental organization established in 1997 by Treaty deposited with the United Nations and hosted in Bejing, China. It is the only Intergovernmental Organization headquartered in China. INBAR currently has 41 Member States, comprising most of the bamboo and rattan resource countries from the Global South. Since its creation two decades ago, INBAR has run projects and programmes in over 20 countries, and provided capacity building and awareness raising on the productive use of bamboo and rattan in over 80 countries. Today, INBAR's global programme is coordinated from its secretariat in Beijing, and put into action through country and regional offices in China, Ecuador, Ethiopia, India and Ghana. INBAR fields an international team of professionals, expert in bamboo and rattan, forestry and natural resource management, ecosystem services, socio-economics, capacity building and knowledge sharing.

The University of Pittsburgh (Pitt) is a Carnegie Research I institution located in Western Pennsylvania. Founded in 1787, Pitt is home to 35,000 students and over 5000 faculty. The Swanson School of Engineering is also a partner, with Sichuan University in Chengdu China, in the Sichuan University - Pittsburgh Institute, an innovative education and research partnership. The bamboo materials research program at the Watkins Haggart Structural Engineering Laboratory was initiated in 2005 and is the preeminent facility for such research in North America. The primary objective of the bamboo research programme at Pitt is to establish the framework and tools required to evaluate the material and mechanical properties of full-culm bamboo. This seminal research objective is aimed at establishing the standardization of the material – placing it on the same footing as timber as a conventional building material. The bamboo research programme has established collaborations in the UK, Brazil, China, Colombia, India and Indonesia.

Producer & Designer: Liu Kewei