Developments in Structural Design Standards with Bamboo

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Origin of codes/standards

- Codes? Standards?
- Codes and standards for bamboo (Gatóo *et al*. 2014)

Country	Code	Standard
China		JG/T 199: Testing method for physical and mechanical properties of bamboo used in building (PRC MoC, 2007)
Colombia	*Reglamento Colombiano de Construcción Sismoresistente* – chapter G12 Estructuras de Guadua (Guadua structures) (ICONTEC, 2010)	NTC 5407: Uniones de Estructuras con *Guadua angustifolia* Kunth (Structural unions with *Guadua angustifolia* Kunth) (ICONTEC, 2006) NTC 5525: Métodos de Ensayo para Determinar las Propiedades Físicas y Mecánicas de la *Guadua angustifolia* Kunth (Methods and tests to determine the physical and mechanical properties of *Guadua angustifolia* Kunth) (ICONTEC, 2007)
Ecuador	*Norma Ecuatoriana de la Construcción* – chapter 17 Utilización de la Guadua Angustifolia Kunth en la Construcción (Use of *Guadua angustifolia* Kunth in construction) (INEN, 2011)	INEN 42: Bamboo Caña Guadua (bamboo cane Guadua) (INEN, 1976)
India	*National Building Code of India*, section 3 Timber and bamboo: 3B (BIS, 2010)	IS 6874: Method of tests for round bamboos (BIS, 2008) IS 15912: Structural design using bamboo – code of practice (BIS, 2012)
Peru	Reglamento Nacional de Edificaciones, Section III. Code E100 – Diseño y Construcción con Bamboo (ICG 2012)	
USA		ASTM D5456: Standard specification for evaluation of structural composite lumber products (ASTM, 2013)
International		ISO 22156: Bamboo – structural design (ISO, 2004a) ISO 22157-1 Bamboo – determination of physical and mechanical properties – part 1: requirements (ISO, 2004b) ISO 22157-2: Bamboo – determination of physical and mechanical properties – part 2: laboratory manual (ISO, 2004c)

Table 1. Existing structural bamboo standards and codes

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Origin of codes/standards

Timeline:

- 1824 – invention of Portland Cement
- 1830 – invention of the I-beam
- 1856 – development of the Bessemer process (steel)
- 1857 – first rolled steel rails
- 1880s – First iron and steel-frame high-rise buildings
- 1890s – first Reinforced Concrete (RC) frame buildings
- c1925 – welding of steel

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Origin of codes/standards

- 1892 - Francois Hennebique patented a form of RC
- High quality control on site
- Sold licences for system
- 1899 - >3,000 projects used the system
- 1909 - ≈ 20,000 projects & 62 offices worldwide
- Many other contractors had their own system
- Eventually RC codes/standards emerged
- These broke the monopoly
- It allowed authorities to check designs for safety

Origin of codes/standards

- Standards provide a consensus about best practice
- Codes/Standards collected three types of information:
  - *“Properties of materials, including the quality of their manufacture;*
  - *the various loads that building structures should be designed to carry;*
  - *codes of design practice that provided suitable methods for designing the various structural elements of buildings – columns, beams, floors and shear walls – and the connections between them.”(Addis, 2007)*
- Committees of code writers typically consist of representatives of:
  - Product manufacturers,
  - Structural designers,
  - Researchers

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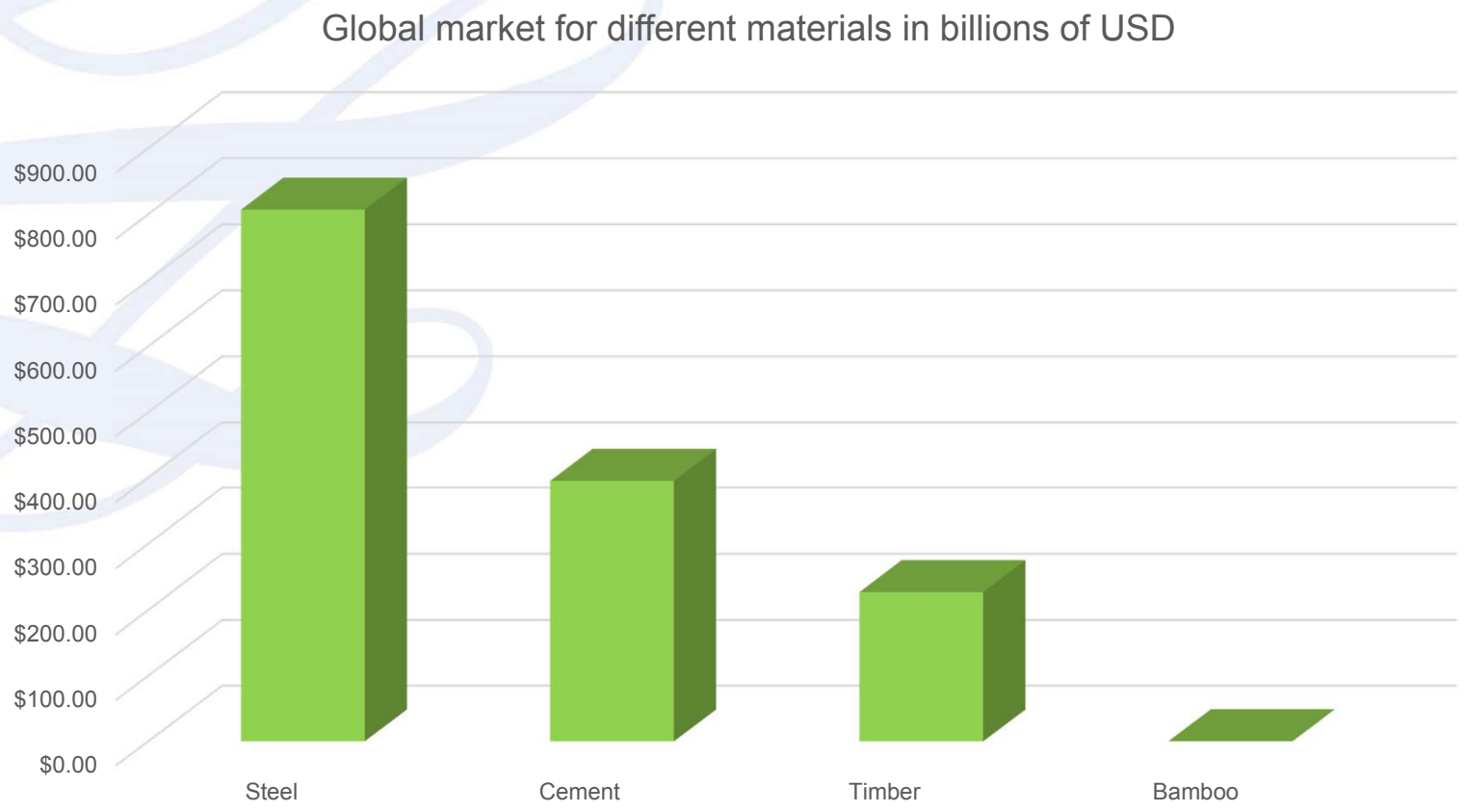
Development of codes and standards is a slow and lengthy process, it requires a compromise between the parties and needs to be underpinned by extensive experimental research, which is expensive.



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Code and standard development of bamboo: a brief history

Design code/standard	Year	Country	Species included	Mechanical properties	Derivation of design values	Beams	Columns	Connections / joints	Shear walls	Grading
AC 162	2000	Calif., USA	0	✗	✓	✗	✗	✗	✗	✗
NSR-98	2002	Colombia	1	✗	✗	✗	✓ (simple)	✗ (Details)	✓	Some
ISO 22156:2004	2004	International	0	✗	✓	✗	✗	✗ (Test)	✗	✗
NBC	2004	India	20 & 16	✓ (few)	✗	✗	✗	✗ (Details)	✗	Some
NSR-10	2010	Colombia	1	✓	✓	✓	✓	✓	✓	Some
E.100	2012	Peru	1	✓	✗	✓	✓	✗ (Details)	✗ (Details)	Some
Andean Standard	2015	International	1	✗	✗	✓ (simple)	✓ (simple)	✗ (Details)	✓	Some
NEC – SE – GUADÚA	2016	Ecuador	1	✓	✗	✓	✓	✗ (Details)	✗ (Details)	Some
	2017	México	3							

Engineered ‘Bahareque’

Onto a bamboo frame apply bamboo strips or mesh

Apply a cement mortar render onto mesh or strips

Images: Webb (2015)

Universidad de los Andes

Engineered ‘bahareque’ school

Engineered ‘bahareque’ school

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Bahareque in the Philippines

Engineered ‘bahareque’ has been adopted in Colombia, Peru, Ecuador, Mexico, Costa Rica and The Philippines.

Current developments within ISO and INBAR Task Force

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ISO Technical Committee 165 Working Group 12

- In September 2013, At the annual meeting of TC 165 ‘Timber Structures’ the development of bamboo standards was reactivated.
- Working Group 12 – ‘Structural Use of Bamboo’ of ISO TC 165 was created.
- Members across: Colombia, Ecuador, Ethiopia, Indonesia, Malaysia, China, UK, Germany, Australia and USA.

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31ST ANNUAL MEETING OF ISO TC165 TIMBER STRUCTURES

4-8 September, 2017 in Vienna

INBAR Task Force

- In 2015, INBAR launched the Bamboo Construction Task Force.
- The Task Force "*coordinates the activities of international research institutes and commercial companies interested in the structural uses of bamboo*"
- It does so by linking individuals who are experts in the field.
- The intention is to pool and coordinate the isolated and disparate efforts occurring throughout the world.

Delegates at 'Bamboo in the Urban Environment' Symposium at Pittsburgh, USA, 2016

INBAR Task Force

- Amongst the objectives of the Task Force are:
- *“Help drive and refine the development of new international standards on the structural uses of bamboo and review and update existing international standards…”*

Delegates at ‘Bamboo in the Urban Environment’ Symposium at Bogor, Indonesia, 2017

INBAR Task Force members

Task Force Coordinator:		
Liu Kewei	Coordinator of Global Bamboo Construction Programme at INBAR	
Task Force Chair:		
David Trujillo	Coventry University	UK
Andrew Lawrence	Arup	UK
Arjan Van Der Vegte	Moso	The Netherlands
Andry Widyowijatnoko	Intistut Teknologi Bangdun	Indonesia
Bhavna Sharma	University of Bath	UK
Denamo Addissie	Addis Abada University	Ethiopia
Edwin Zea Escamilla	ETH Zurich	Switzerland
Greg Smith	University of British Columbia	Canada
Haitao Li	Nanjing Forestry Univeristy	China
Hector Archila Santos	Amphibia BASE	UK
Juan Francisco Correal Daza	Universidad de los Andes	Colombia
Kent Harries	University of Pittsburgh	USA
Luis Felipe López	Base Bahay	The Philippines
Martin Tam	Able Mart Limited	Hong Kong
Mateo Gutierrez Gonzalez	Univeristy of Queensland	Australia
Mauricio Cardenas Laverde	Politécnico de Milano	Italy
Michael Ramage	Univeristy of Cambridge	UK
Nripal Adhikary	ABARI	Nepal
Ramesh Chaturvedi	Retired	India
Rodolfo Lorenzo	UCL	UK
Romildo D. Toledo Filho	Universidad Federal do Rio de Janeiro	Brazil
Sebastian Kaminski	Arup	UK
Verónica María Correa Giraldo	Kaltia / Bambuterra	México
Xu Qingfeng	Shangai Research Institute of Building Sciences	China
Yann Barnet	Universidad de San Martín	Peru

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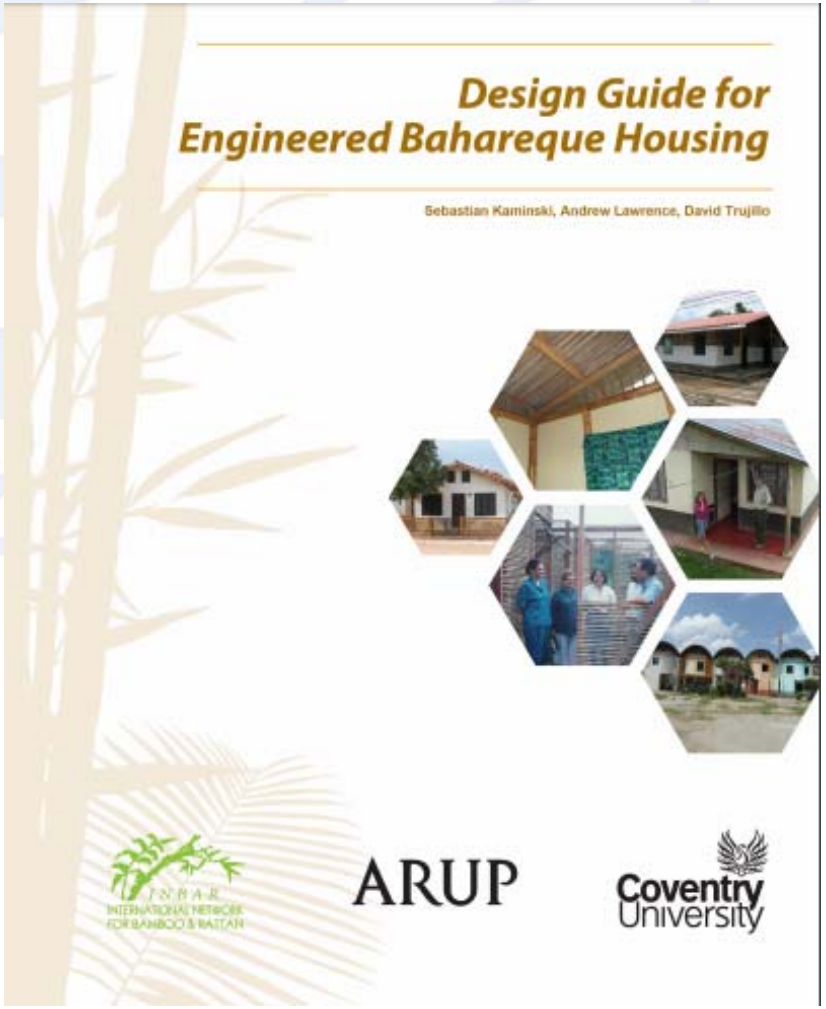
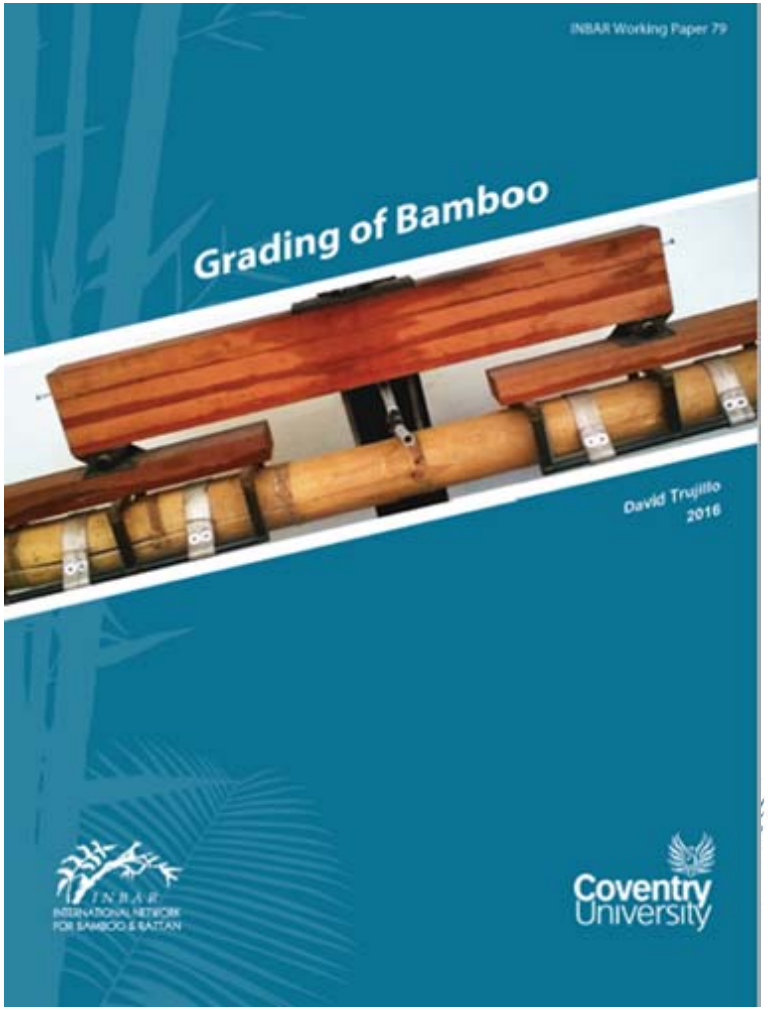
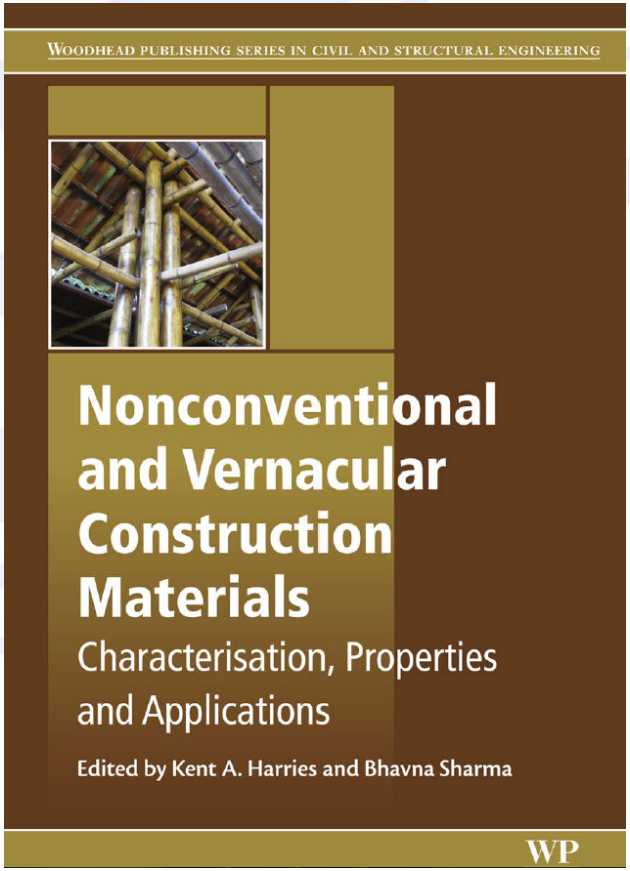
INBAR Task Force publications





INBAR Task Force collaborations



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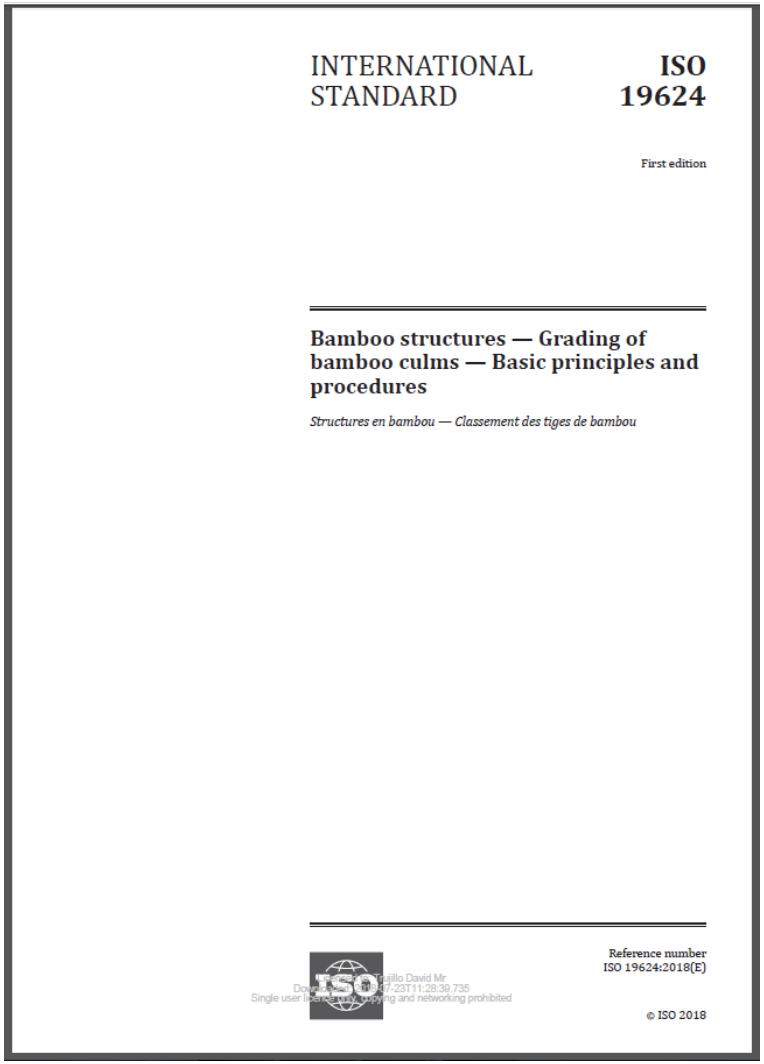
ISO 19624 Bamboo structures — Grading of bamboo culms — Basic principles and procedures

- Grading is:
- *"(…) the process of sorting every piece of bamboo in a sample into grades according to defined selection criteria. The criteria identify dimensional, visual, geometric, mechanical and/or physical properties that reflect the bamboo's mechanical strength or structural capacity and may affect the utility of the product."*

CARACTERIZACIÓN DE BAMBÚES
a través de métodos no destructivos
Proyecto de Investigación Regional
INBAR . Universidad de Conventry . Universidad Nacional de Colombia . ESPE Ecuador


INTERNATIONAL STANDARD **ISO 19624**

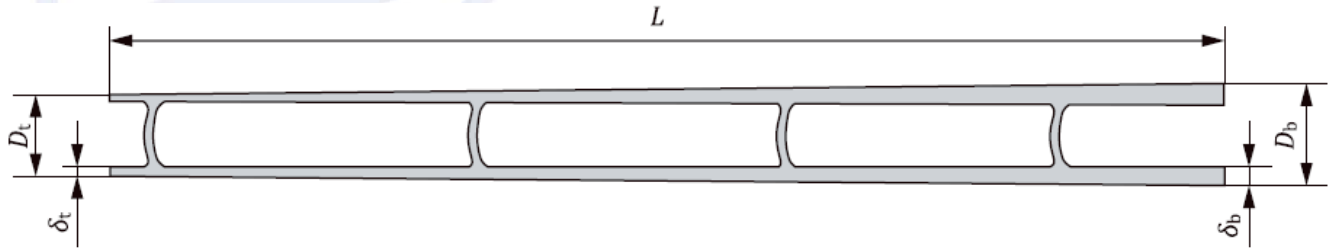
First edition

Bamboo structures — Grading of bamboo culms — Basic principles and procedures

Structures en bambou — Classement des tiges de bambou

Reference number
ISO 19624:2018(E)

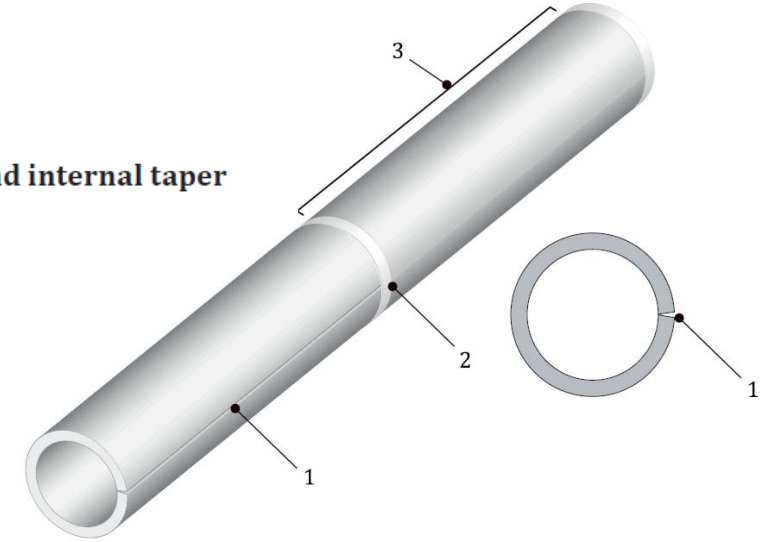
Contents



Key

D_b	diameter at the base of the piece
D_t	diameter at the top of the piece
L	length of the piece
δ_b	wall thickness at the base of the piece
δ_t	wall thickness at the top of the piece

Figure 3 — Longitudinal section of bamboo culm showing external and internal taper



Key

1	fissure
2	node
3	internode

Figure 1 — Manifestation of fissure on surface of culm and cross-section through fissure

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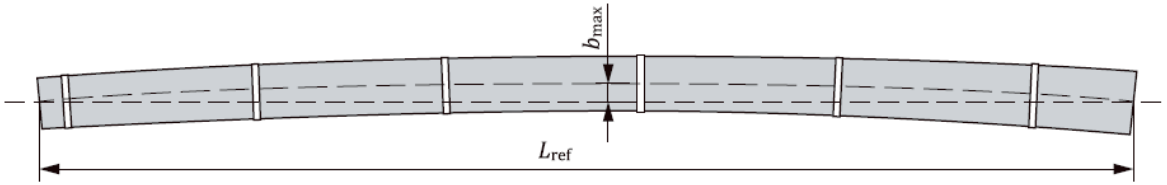


Key

b_{max} maximum perpendicular distance from the centre of the culm section to the chord drawn from the centres of either end of the piece

L_{ref} reference length of the piece

Figure 4 — Elevation of a bamboo culm showing bow

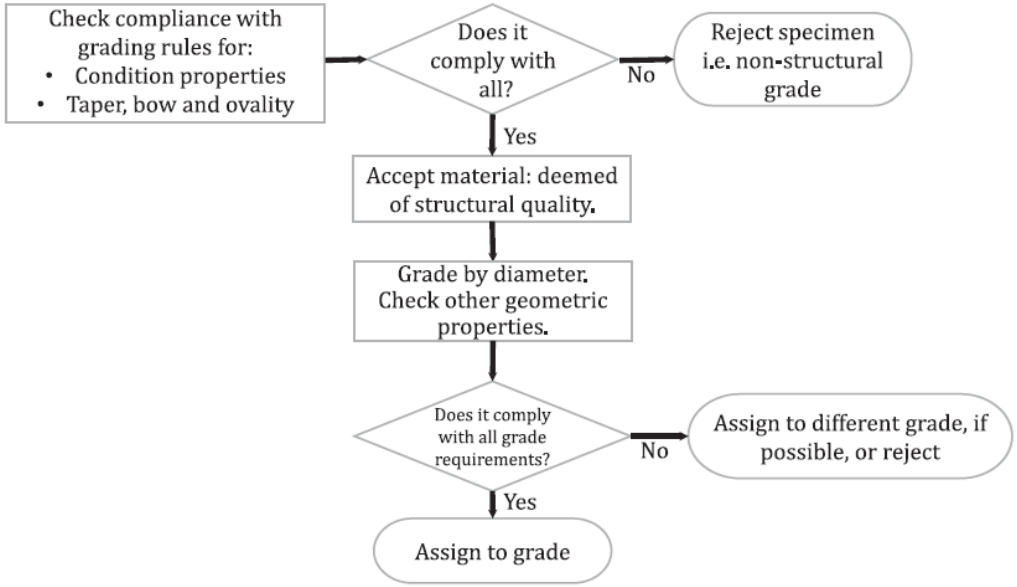
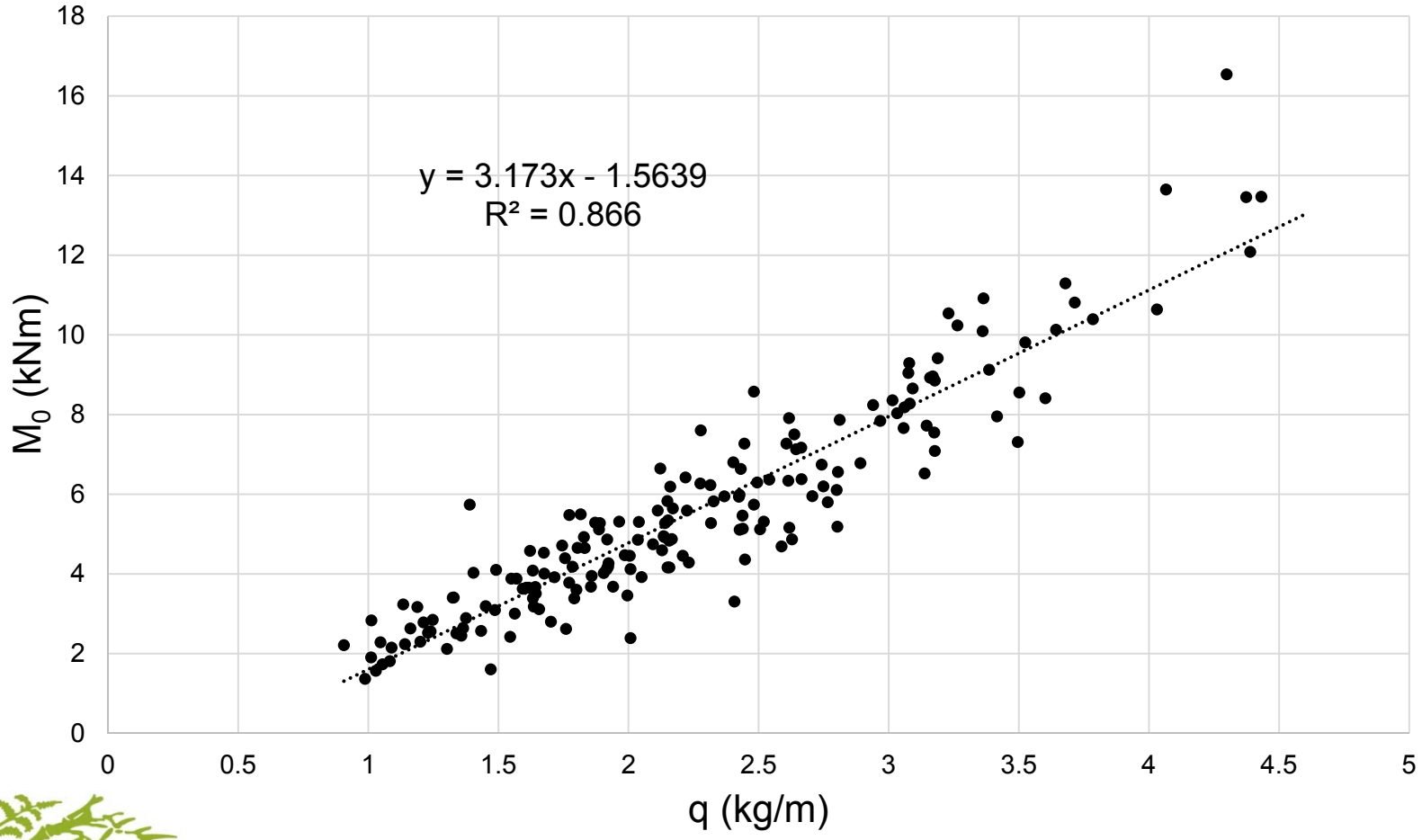


Figure A.1 — Grading of bamboo culms by external diameter

Ways to improve grading: Linear mass

(image not in standard)



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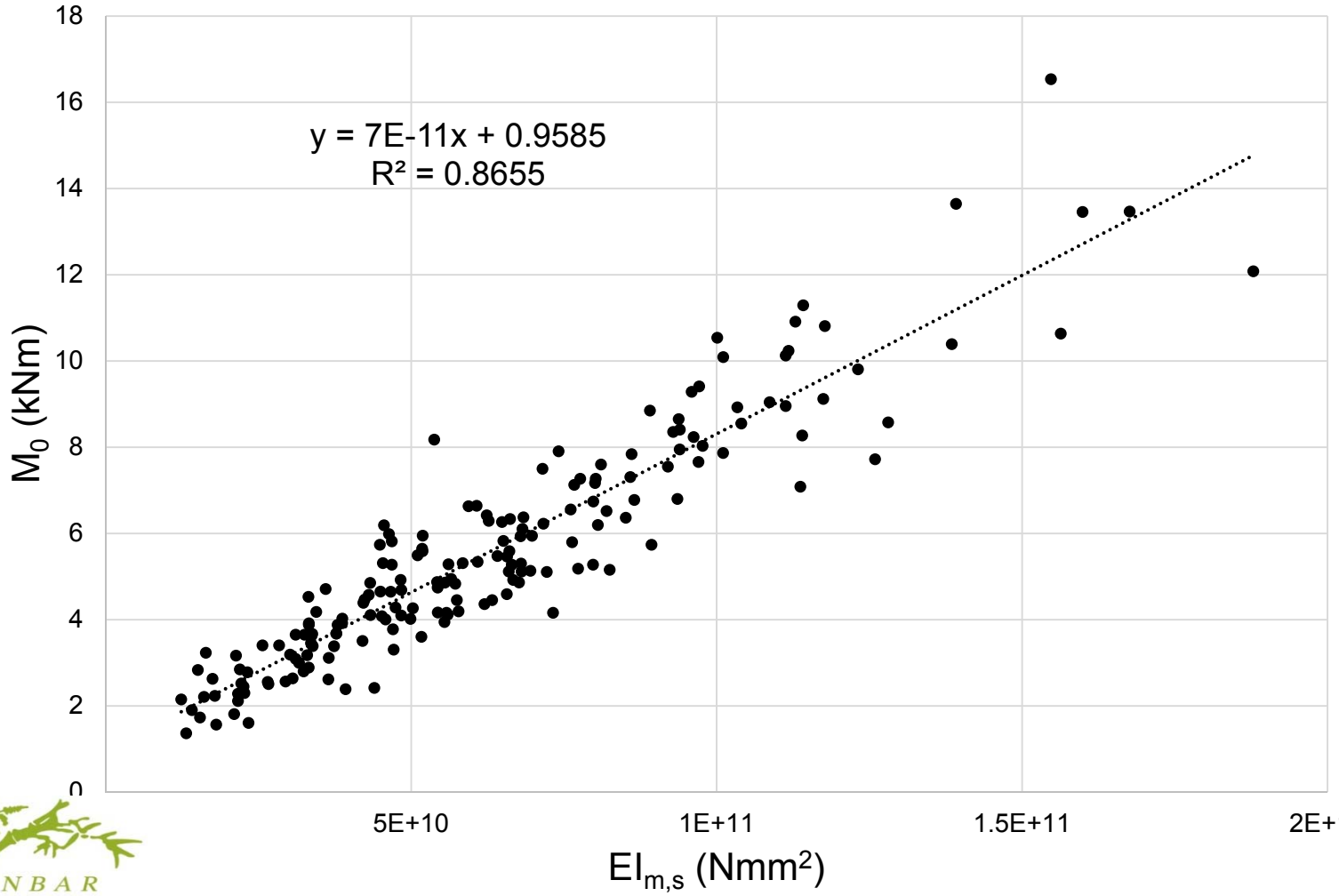
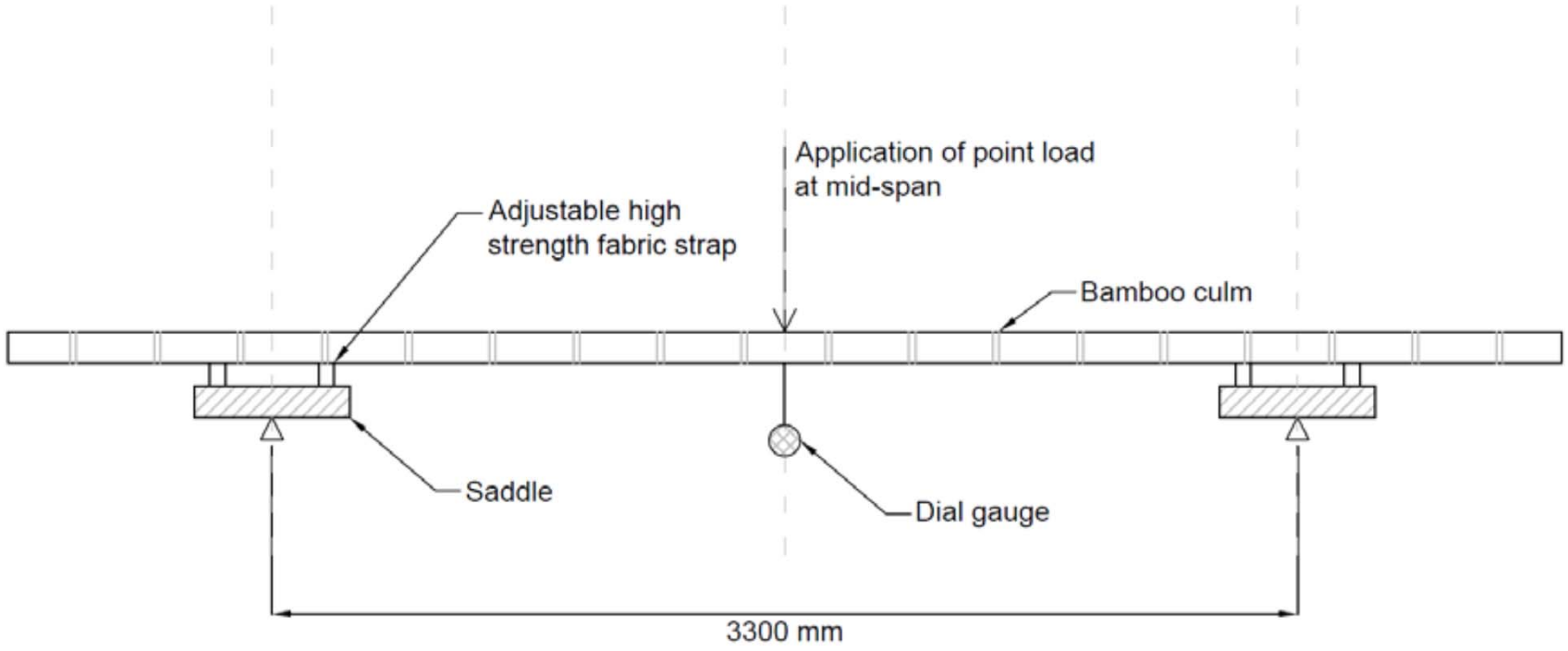
Ways to improve grading: flexural stiffness

(image not in standard)



Low-cost measurement of flexural stiffness (EI)



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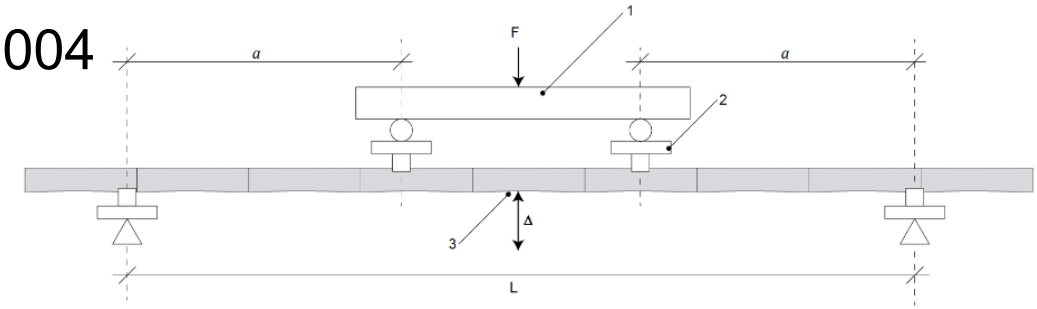
ISO 22157 Bamboo structures — Determination of physical and mechanical properties of bamboo culms — Test methods

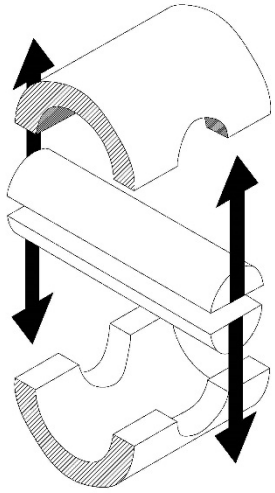
- Replaces ISO 22157-1:2004
- Removes ISO 22157-2:2004
- Removes shrinkage test
- Incorporates two tests
- Clarifies other tests

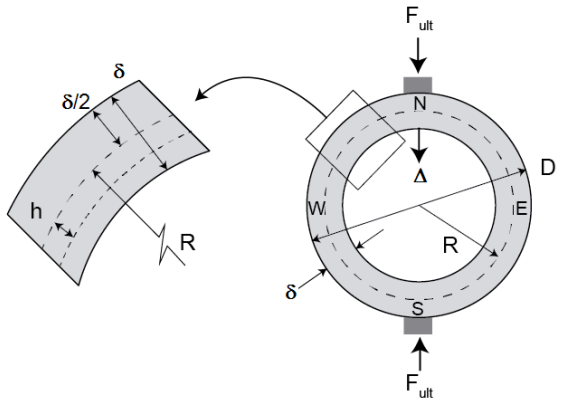


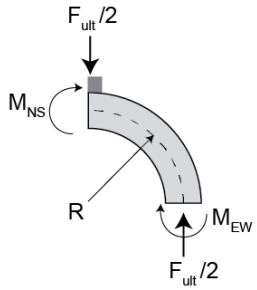
ISO 22157 Bamboo structures — Determination of physical and mechanical properties of bamboo culms — Test methods

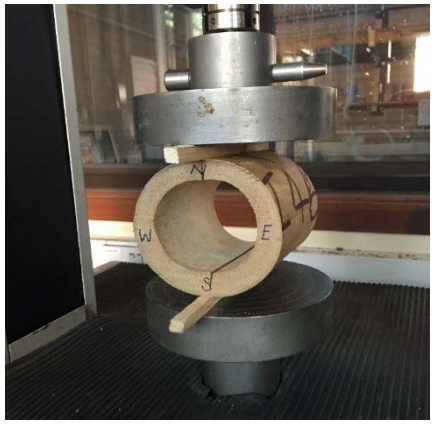
Two new tests:

- Tension perpendicular to fibres
- Bending perpendicular to fibres









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ISO 22156 Bamboo – Structural Design

- Update to ISO 22156:2004
- Due 2022
- Objectives:
  - To be the most comprehensive and modern structural design standard for bamboo in the world,
  - Push bamboo engineering forward and try to close the gap between bamboo and the other materials,
  - To draw from experience and expertise from across the globe,
  - Serve as the template for all other bamboo codes.

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ISO 22156 Bamboo – Structural Design

Features:

- Methods of design:
  - Allowable Stress Design
  - Load and Resistance Factor Design (Limit State)
- Approaches:
  - On the basis of stresses (as a material)
  - On the basis of capacities (as a product)
- Allows:
  - Experience from previous generations
  - Design by testing

Bamboo specific considerations:

- Susceptibility to splitting
- Durability & preservation
- Redundancy of members
- Maintenance, Inspectability and Replacement

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ISO 22156 Bamboo – Structural Design

Includes:

- Design of
  - Beams
  - Columns (Ylinen)
  - Tension member
- Principles for the design of:
  - Connections
  - Trusses
  - Shear walls
- Provides methods to derive design values
- Does not contain mechanical properties

- Provides guidance about how to model,
- Includes Seismic Force Reduction Factor for Bamboo Structures
  - Most R = 1.25
  - Bahareque R = 2
- For connections gives:
  - Design philosophy
  - Requires thought for yield loads, elastic stiffness and ductility.
  - Robustness against splitting

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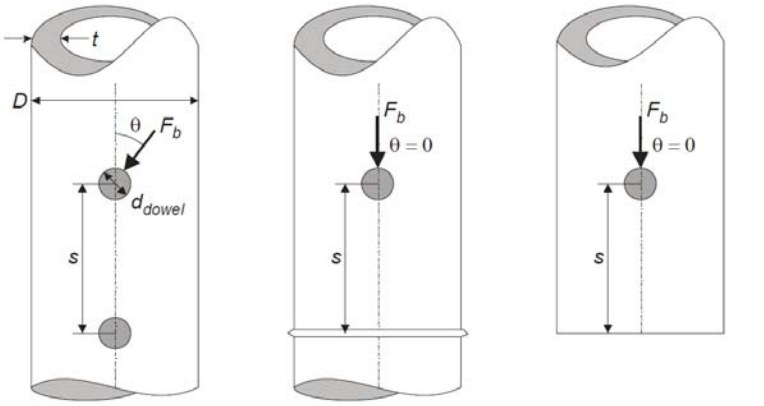
ISO 22156 Bamboo – Structural Design

Links to other ISO standards:

- ISO 12122 for characteristic values,
- ISO 19624 for grading,
- ISO 22157 for testing,
- ISO 21581 for testing of shear walls,
- ISO 16670 for connection testing,
- ISO TR 21141 for analysis of connection tests,

It proposes a way to design certain types of dowel connections



a) *s* determined between adjacent dowels

b) *s* determined to nearest node

c) *s* determined to end of culm; this detail is not recommended (see **10.6**)

Figure 10.1 Geometry of dowel connection

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ISO/NP 23478 – Bamboo structures — Glued laminated bamboo — Test methods for determination of physical and mechanical properties

- Since 2015 the TF has deliberated about standards for Engineered Bamboo Products (EBPs), as these could potentially enter the structural market.
- First step is knowing how to test them.
- The first product to be studied is ‘glued laminated bamboo’

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Other standardization work

- In 2015, ISO TC 296 Bamboo and Rattan was created
- Structural aspects remain under TC 165, because of the importance that the committee understands structural safety.

Standard and/or project under the direct responsibility of ISO/TC 296 Secretariat (5)

ISO/CD 21625 [Under development]
Terminology of bamboo products

ISO/WD 21626 [Under development]
Bamboo charcoal

ISO/WD 21629 [Under development]
Bamboo floorings

ISO/WD 23066 [Under development]
Terminology of Rattan Materials and Products

ISO/AWI 23067 [Under development]
Grading System for Rattan: Guidelines and Classification

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Final thoughts

- Development of standards/codes is a process that requires a lot of experimental backing, as well as expertise.
- There are very few structural engineers in the world who have experience and knowledge about bamboo.
- There are no large funders. So we need to be efficient.
- We need to pool expertise and resources, as well as coordinate experimentation.

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An invitation

- Please use the standards we have developed, develop them further, criticise them,
- Please join our work in developing the other two standards.
- Many thanks.
- Any questions?

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