SIRT

Strategic Integrated Research in Timber

Edinburgh Napier UNIVERSITY

Grading structural timber

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Edinburgh Napier University

The Queen's Anniversary Prizes

For Higher and Further Education

2015

Variation of properties

- From species to species
- Within species / species group
  - Between countries
  - Within countries
  - Within a forest
  - Within a stand
  - Between trees in a stand
  - Between boards from a tree

∴ Use grading to get characteristic properties for design & ensure safety

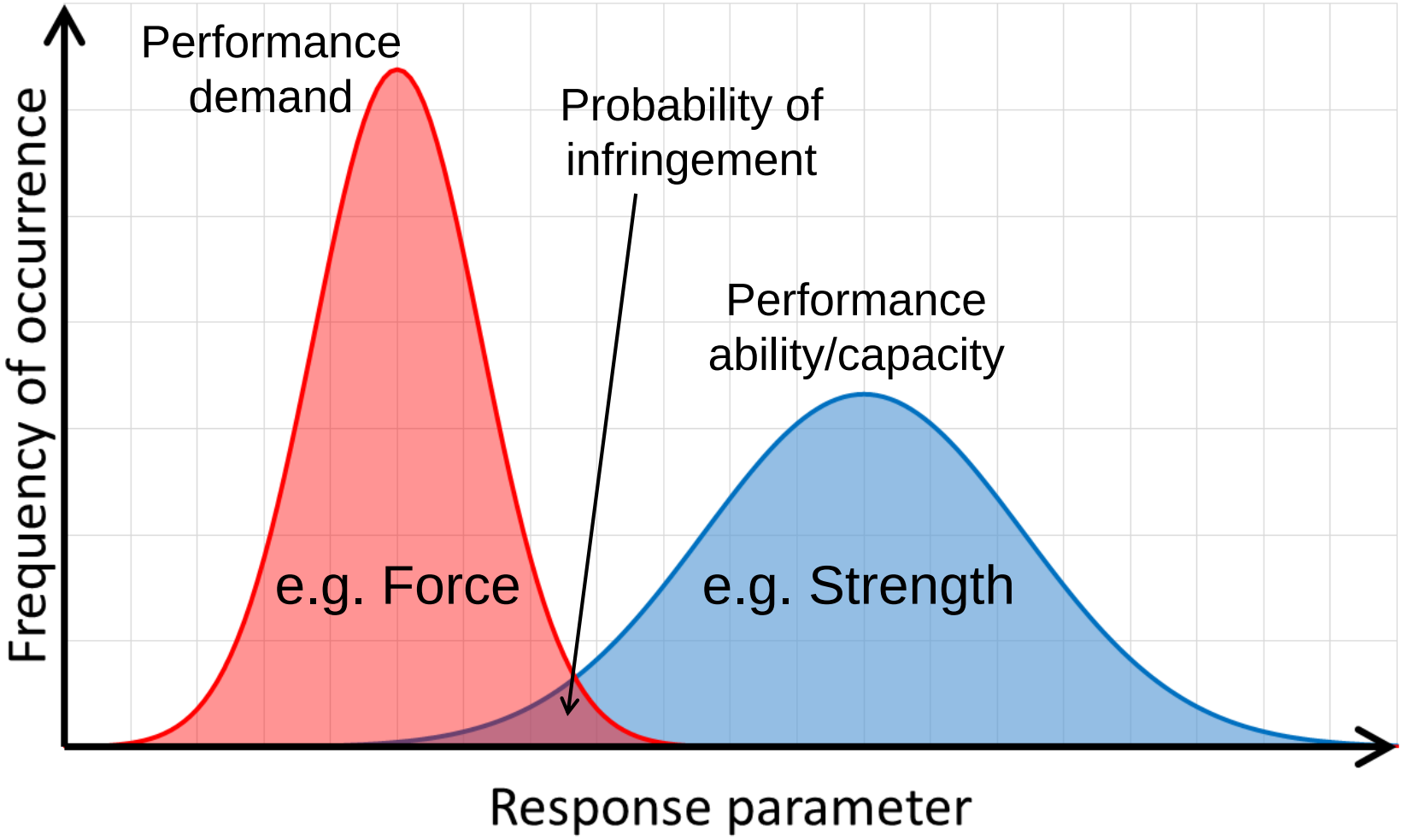
For a fuller description of grading in Europe see:
Ridley-Ellis, D., Stapel, P., and Baño, V.: Strength grading of sawn timber in Europe: an explanation for engineers and researchers. *European Journal of Wood and Wood Products*, 74(3): 291-306, 2016.

Structural engineering design

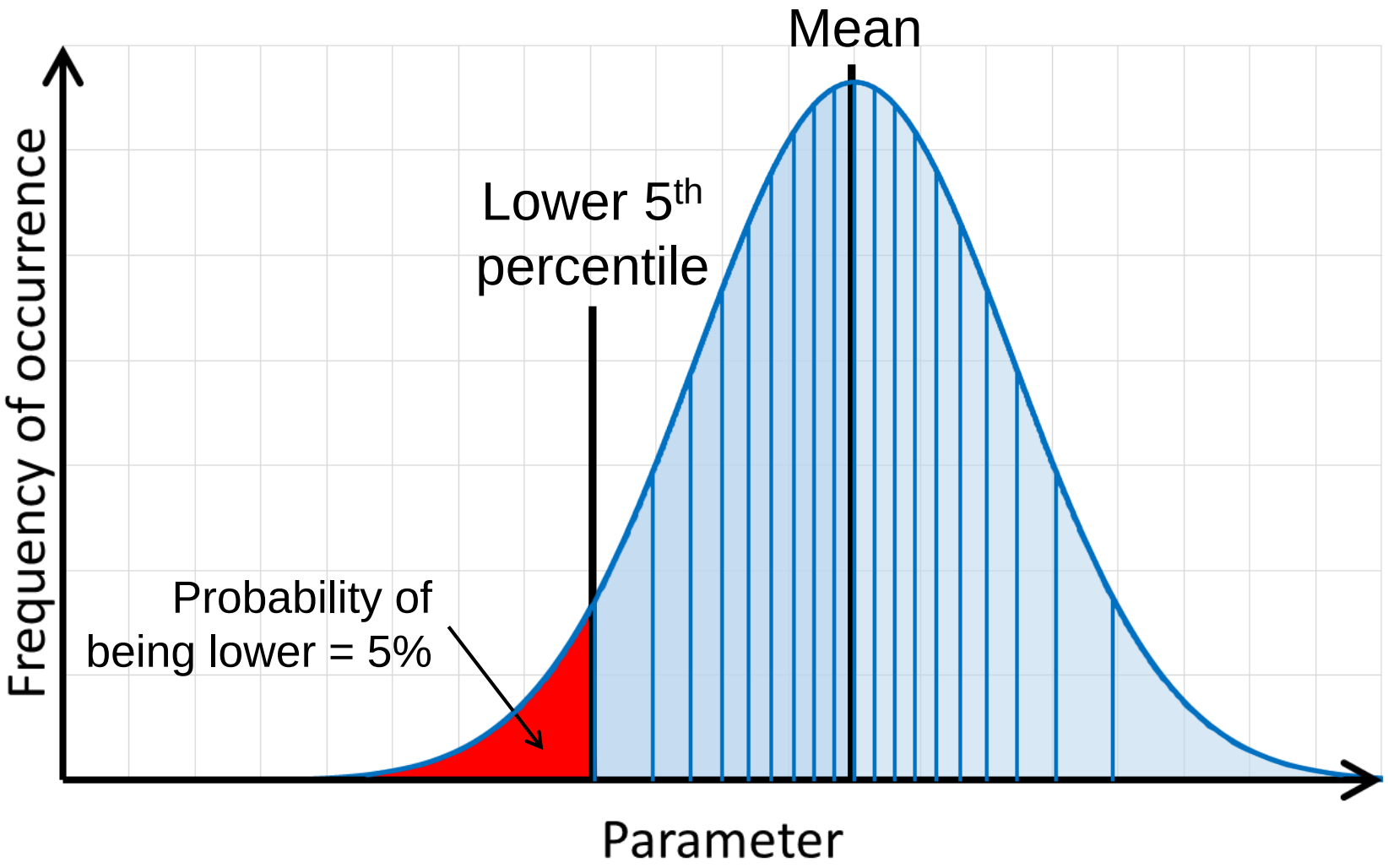
- About buildings
  - Staying safe
  - Staying fit for use
- Dealing with uncertainty
  - Of material
  - Of the actions on a structure
  - Of analysis and construction
- <u>True irrespective of the material</u>

  (There is always some uncertainty)

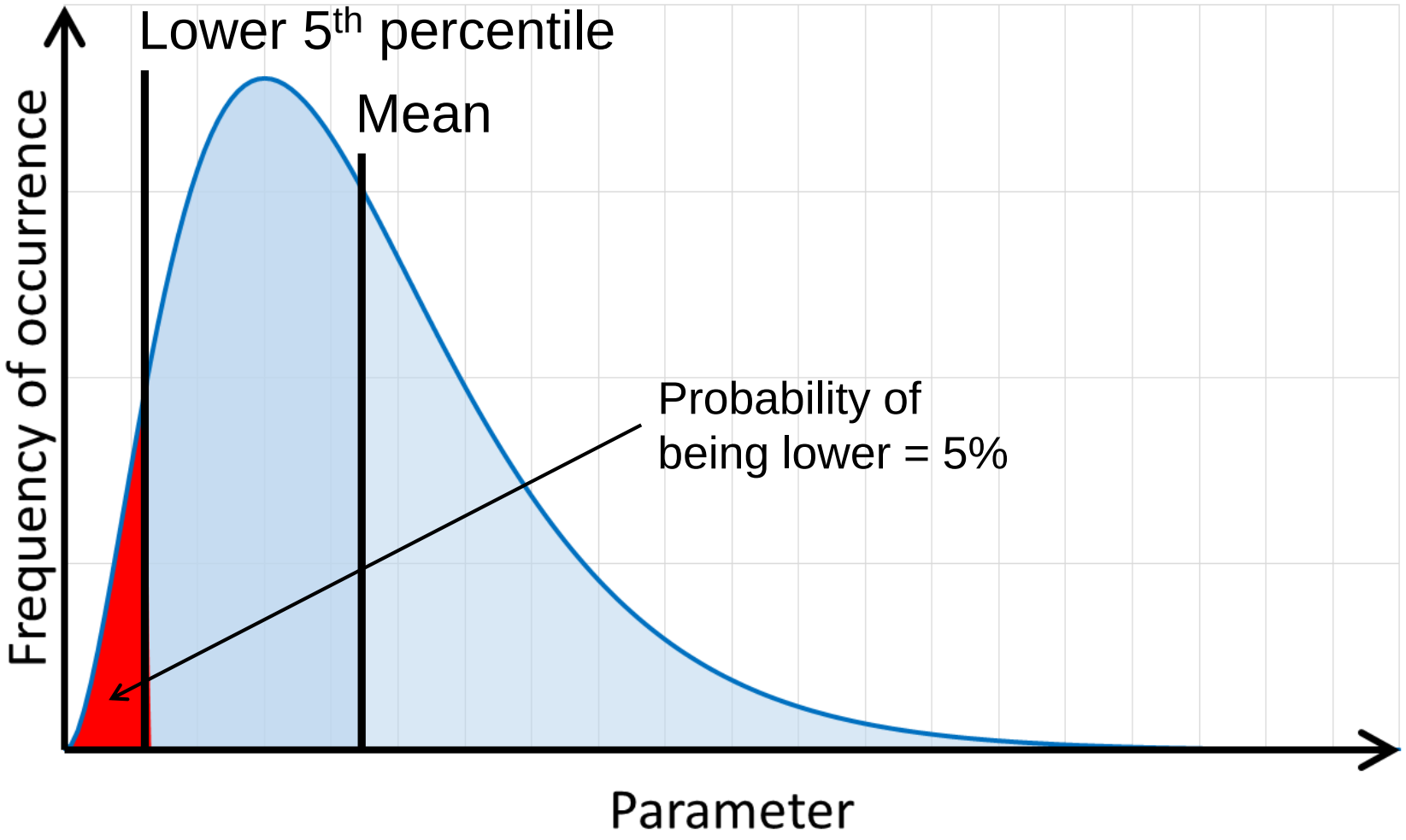
Dealing with uncertainty



Characteristic values



Characteristic values



Grade-determining properties

(definition of a strength class: EN 384 for EN 14081)

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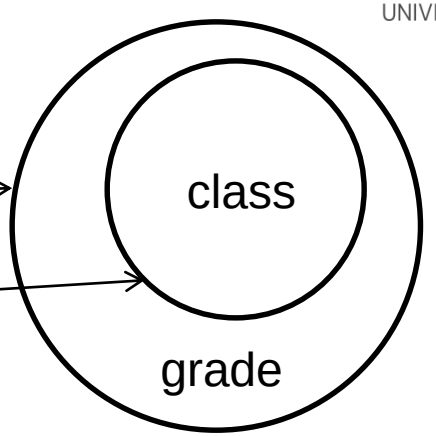
- Strength
  - Bending or tension strength
  - Characteristic is the 5th percentile
- Stiffness
  - Bending or tension stiffness
  - Characteristic is the mean
- Density
  - Used for indirect measure of strength / fire resistance (this is not density for dead weight)
  - Characteristic is the 5th percentile

Critical property

- To comply with the grade, characteristic values must be met (at least*)
- For a species and grade combination usually one property is limiting
  - Strength
  - Stiffness
  - Density
- So strength grading isn't *always* about predicting strength

* subject to adjustments

Grades and classes



- Strength grade
- Strength class
  - Has numerical properties
- Timber grades are assigned to a class
- EN 338 lists strength classes
  - C bending classes for softwoods (now also hardwoods)
  - D bending classes for hardwoods
  - T tension classes for softwoods
- These are not the only strength classes
- & just convenience – DoP what matters

Strength grades (or classes)

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e.g. EN 338:2016

'Softwood' based on edgewise bending

	Class	C14	C16	C18	C20	C22	C24	C27	
Strength properties in N/mm²									
Bending	$f_{m,,k}$	14	**16**	**18**	20	22	**24**	27	
Tension parallel	$f_{t,0,k}$	7,2	**8,5**	**10**	11,5	13	**14,5**	16,5	
Tension perpendicular	$f_{t,90,k}$	0,4	**0,4**	**0,4**	0,4	0,4	**0,4**	0,4	**0**
Compression parallel	$f_{c,0,k}$	16	**17**	**18**	19	20	**21**	22	**24**
Compression perpendicular	$f_{c,90,k}$	2,0	**2,2**	**2,2**	2,3	2,4	**2,5**	2,5	**2,7**
Shear	$f_{v,k}$	3,0	**3,2**	**3,4**	3,6	3,8	**4,0**	4,0	**4,(**
Stiffness properties in kN/mm²									
Mean modulus of elasticity parallel bending	$E_{m,0,mean}$	7,0	**8,0**	**9,0**	9,5	10,0	**11,0**	11,5	**1**
5 percentile modulus of elasticity parallel bending	$E_{m,0,k}$	4,7	**5,4**	**6,0**	6,4	6,7	**7,4**	7,7	
Mean modulus of elasticity perpendicular	$E_{m,90,mean}$	0,23	**0,27**	**0,30**	0,32	0,33	**0,37**	0,38	
Mean shear modulus	G_{mean}	0,44	**0,50**	**0,56**	0,59	0,63	**0,69**	0,72	
Density in kg/m³									
5 percentile density	ρ_k	290	**310**	**320**	330	340	**350**	36	
Mean density	ρ_{mean}	350	**370**	**380**	400	410	**420**	4	

Secondary properties

Softwood bending strength classes (as in EN 384:2016)

- Based on bending strength
  - Tension strength parallel to grain
  - Compression strength parallel to grain
  - Shear strength (up to C24, thereafter fixed)
- Based on bending stiffness
  - 5th percentile stiffness parallel to grain
  - Stiffness perpendicular to grain
  - Shear modulus
- Based on density
  - Compression strength perpendicular to grain
  - Mean density
- Fixed value (applies to all strength classes)
  - Tension strength perpendicular to grain

For tension grades, the primary property is tension strength (the type of testing, and bending strength is a secondary property)

Must work for all species
∴ conservative values
(esp. for hardwoods)

By the way…

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The definition of strength classes can (and does) change

EN338:2016 compared to 2009 version

	Softwood											
	C14	**C16**	**C18**	C20	C22	**C24**	C27	**C30**	C35	C40	C45	C50
Strength												
Bending	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Tension parallel	-10%	-15%	-9%	-4%	0%	4%	3%	6%	7%	8%	11%	12%
Tension perpendicular	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Compression parallel	0%	0%	0%	0%	0%	0%	0%	4%	0%	4%	7%	3%
Compression perpendicular	0%	0%	0%	0%	0%	0%	-4%	0%	-4%	-3%	-6%	-6%
Shear	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Stiffness												
Mean MoE parallel	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
5% MoE parallel	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%
Mean MoE perpendicular	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mean G	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Density												
5% density	0%	0%	0%	0%	0%	0%	-3%	0%	-3%	-5%	-7%	-7%
Mean density	0%	0%	0%	3%	0%	0%	-4%	0%	-2%	-4%	-6%	-5%

Not just secondary properties – grade determining property requirements can also change

How do we predict strength?

- Can only be measured destructively
- But strength is correlated with:
  - Stiffness
  - Density
  - Knots
  - Grain e.g. ring width
    - Rate of tree growth & radial position
  - Species
  - Origin

How do we predict stiffness?

- Stiffness can be measured non-destructively
  - Mechanical bending (within elastic range)
  - Dynamic stiffness (vibration or time of flight)
- It is also correlated with
  - Density
  - Knots
  - Grain e.g. ring width
    - Rate of tree growth & radial position
  - Species
  - Origin

How do we predict density?

- Density can be measured non-destructively
  - By weighing and measuring dimensions
  - Using x-rays (and similar methods)
  - Pin indent
  - But is confounded by moisture content
- It is also correlated with
  - Stiffness
  - Grain e.g. ring width
    - Rate of tree growth & radial position
  - Species
  - Origin

But that's not everything

- "Visual" override
  - Distortion (might be by machine)
  - Fissures
  - Wane (note that genuine wane does not cut the grain)
  - Soft rot and insect damage
  - Knots and slope of grain on any portion that cannot be machine graded (i.e. the ends of the timber for bending type machines)
  - Anything else that causes concern

Grading methods for timber

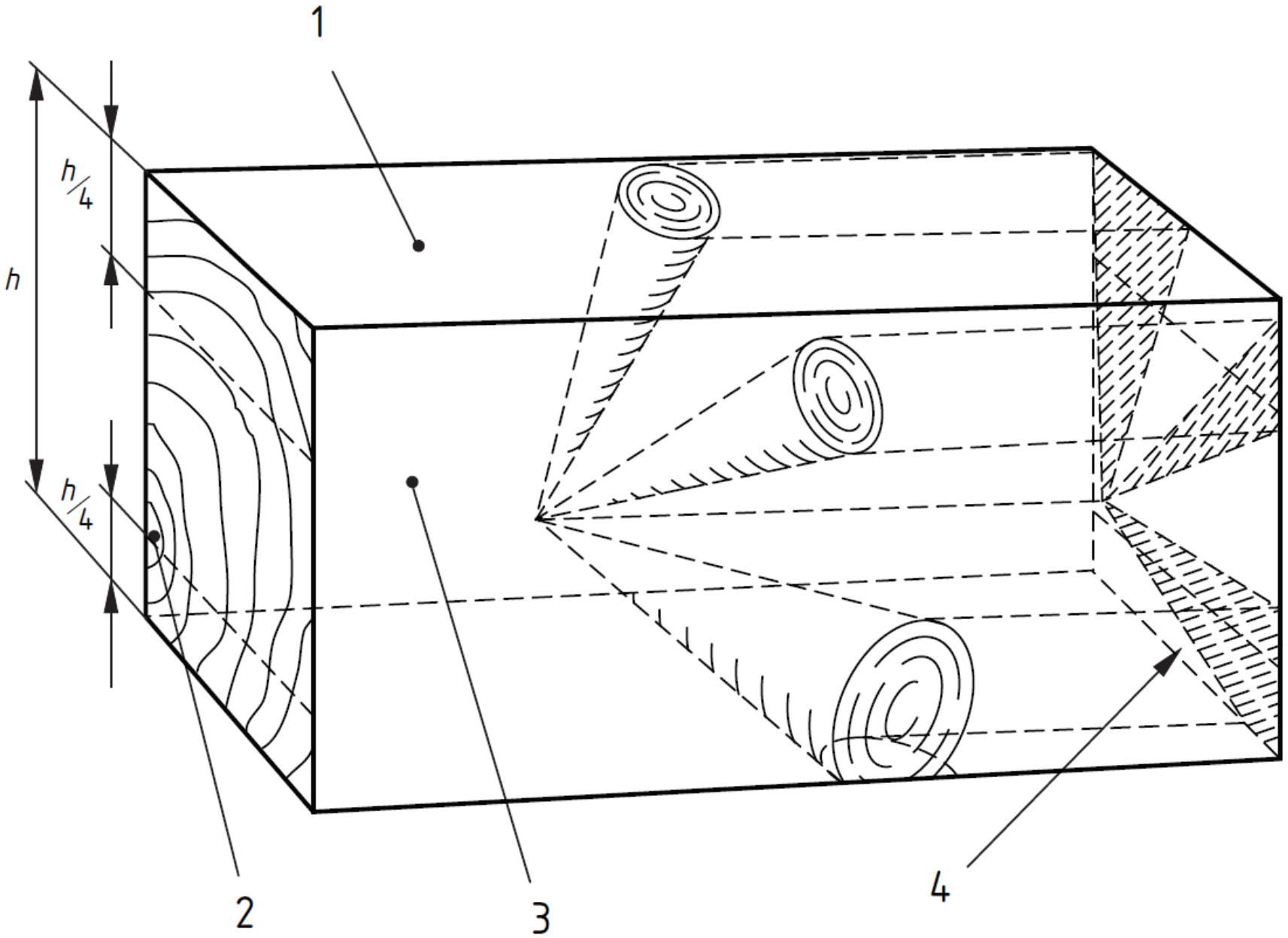
- Visual strength grading
  - (not the same as appearance grading)
- Machine strength grading
  - Machine control
  - Output control

Modern basis = full size testing
Bending type strength classes = bending test
Tension type strength classes = tension test

Visual strength grading

- Manual inspection (can be machine assisted)
- Based only on what we can see (and infer)
- Of limited accuracy…
  …due to the parameters being measured
  …and the human element
  …so assignment to grades is more conservative
- A slow process using trained people
  - But can be assisted…perhaps even done…by machine
- Still very common in Europe even for softwoods

Visual grading



Visual strength grading

- Visually grade
  - e.g. SS, GS (softwoods to BS 4978)
- Assign to strength class based on grading standard, species and origin
  (all three must match)
  - EN 1912
    - e.g. British spruce SS → C18
    - e.g. British spruce GS → C14
  - Somewhere else (not in conflict with EN 1912)
- Based on testing and analysis to EN 384
  - Not supposed to rely on long standing practice any more …need test data

Visual assignments can change

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EN 1912:2004+A4:2010

Strength class	Grading rule publishing country	Grade (see Note 1)	Species commercial Name	Source
D70	UK	HS	Balau	South East Asia
		HS	Greenheart	Guyana
	The Netherlands	A/B	Azobé	West Africa
	UK	HS	Ekki	West Africa
D60	UK	HS	Kapur	South East Asia
		HS	Kempas	South East Asia
D50	UK	HS	Keruing	South East Asia
		HS	Karri	Western Australia
		HS	Opepe	West Africa,
		HS	Merbau	South East Asia
		TH1	American white oak	USA

D70 to D50 (new test data)

EN 1912:2012

with corrigendum August 2013

Strength class	Grading rule publishing country	Grade (see Note 1)	Species commercial Name	Source
D70	The Netherlands	C3 STH	Azobé	West Africa
	UK	HS	Greenheart	Guyana
	UK	HS	Ekki	West Africa
D60	The Netherlands	C3 STH	Cumaru new	Brazil
	UK	HS	Kapur	South East Asia
		HS	Kempas	South East Asia
D50	AC1 *text deleted* AC1			
	UK The Netherlands	HS C3 STH	Balau/Bangkirai	South East Asia
	The Netherlands	C3 STH	Greenheart	Suriname, new

French standard changed, assignments were removed in the corrigendum

Be aware of amendments and corrigenda

Machine strength grading

- Machine grading
  - Relates an ‘indicating parameter’ to the critical grade-determining parameter(s)
  - Better accuracy than visual grading…
    …due to the parameters being measured
    …and the automation
    …so assignment to grade is less conservative
  - Fast but expensive equipment (but getting cheaper)

So how do we machine grade?

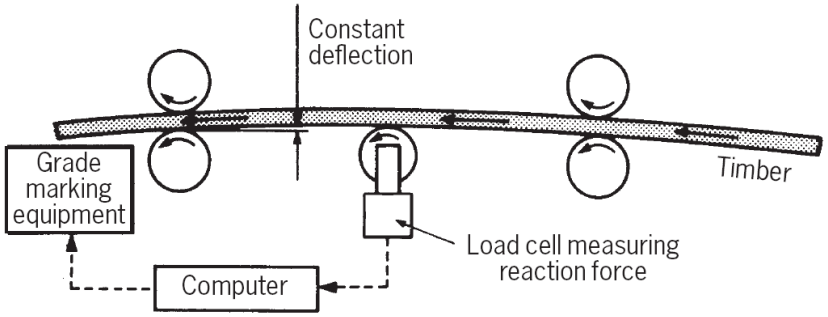
- Now many types of grading machines
  - Bending stiffness
    - Bending about the minor axis
  - Dynamic (acoustic/vibration)
    - Essentially a measure of stiffness
    - May or may not include density
  - X-rays
    - A combination of knots and density
    - Perhaps with optical camera
  - Assessment of slope of grain
  - Mixtures of the above

Bending graders

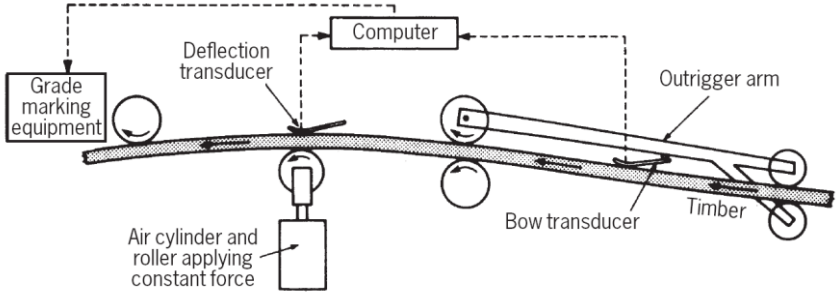
- Measure mechanical stiffness
  - Through application of defined load
  - or defined deflection
  - Minor axis
  - Accounting for pre-existing bow
- Relatively slow (with dynamic errors)
- Limited by cross-section
- Cannot measure the whole piece
- Older technology (hard to link to computers)

Bending graders

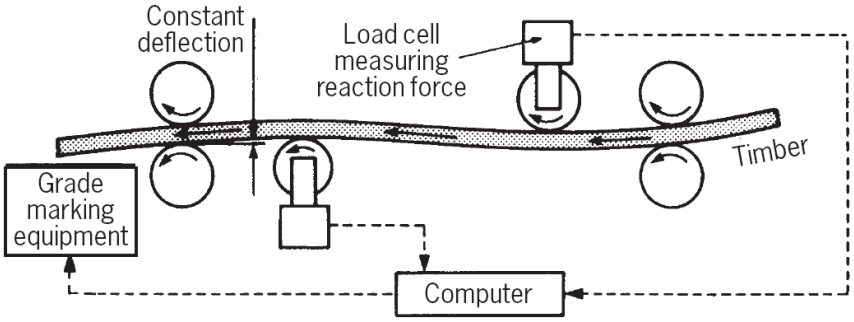
Cook-Bolinder



Computermatic



Timgrader



Figures from BRE Digest 476 “Guide to machine strength grading of timber”

Acoustic graders

- Measure acoustic velocity
  - Through axial or transverse vibration
  - Or time of flight (including ultrasonic)
  - May or may not include density ($MoE_{dyn} = \rho v^2$)
- Fast
- Can be hand-held
- Measure the whole piece
- …but all at once

Acoustic graders

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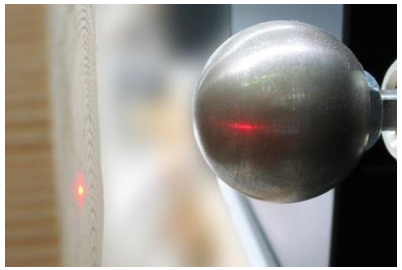
ViSCAN (MiCROTEC)



MTG (Brookhuis)

Precigrader (Dynalyse AB)

Triomatic (CBS-CBT)

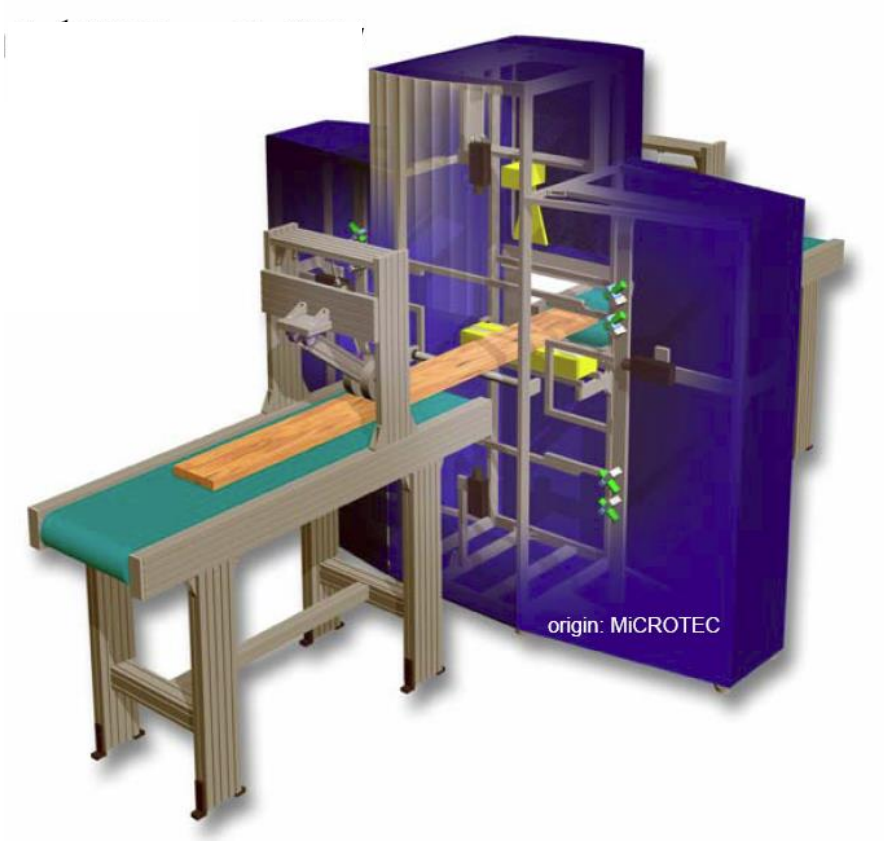
X-ray graders

- Measure
  - Clear wood and average density
  - Knot size and location
- Very fast (and permit board splitting)
- …but big and expensive
- Measure the whole piece
- …and all parts of it individually
- But not great at predicting stiffness

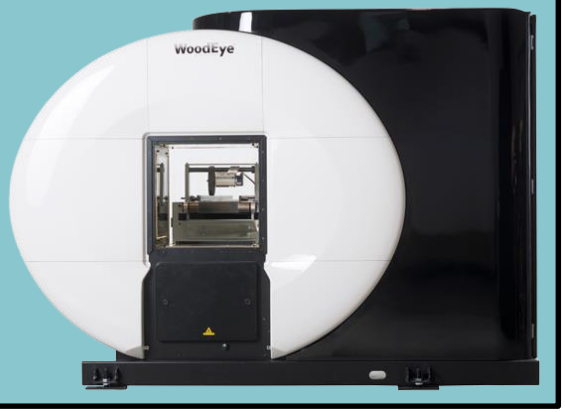
X-ray graders

Clear wood and average density, knot size and location

e.g. GOLDENEYE 702 (MiCROTEC)



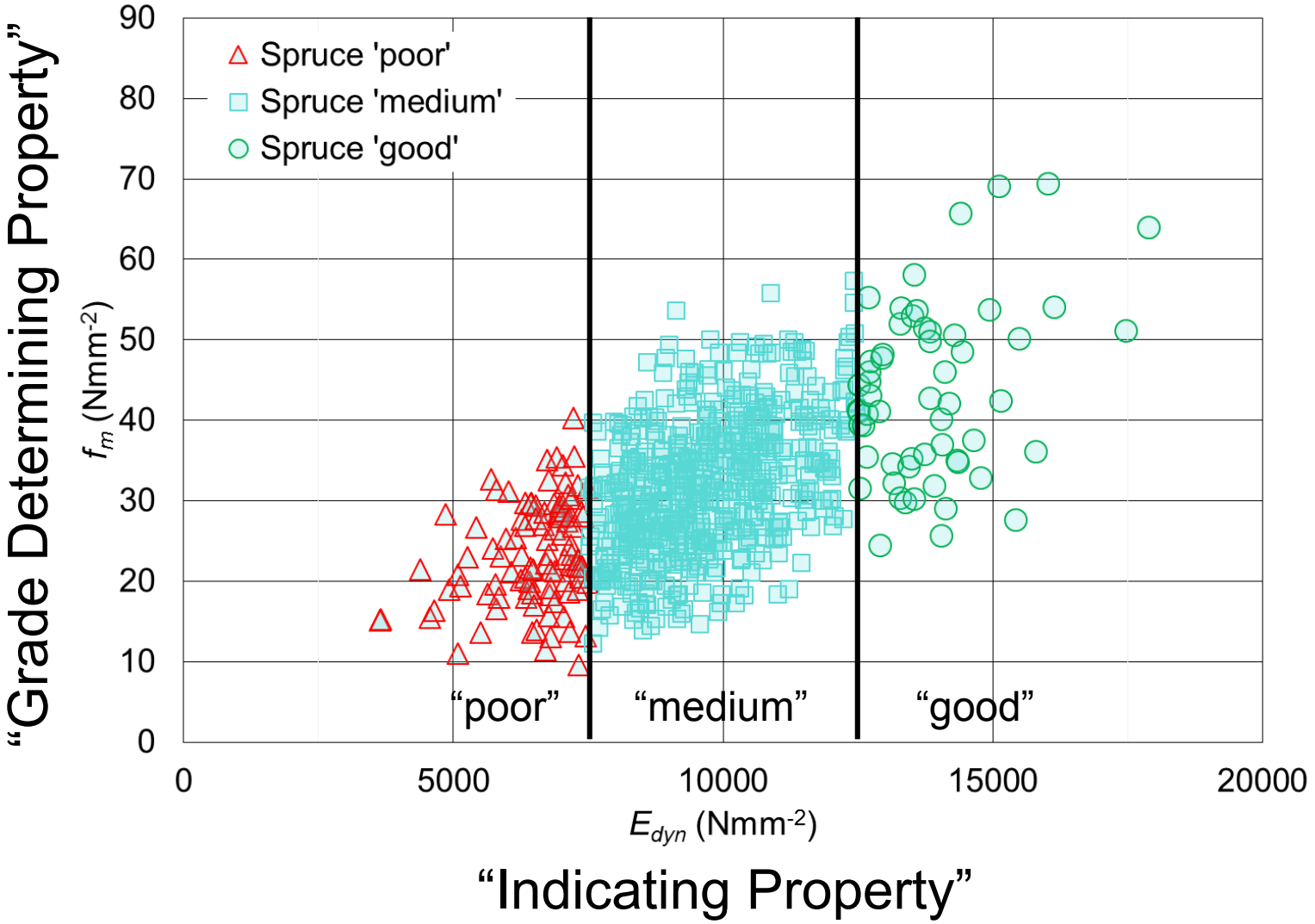
Lately also machines based on grain angle e.g. WoodEye



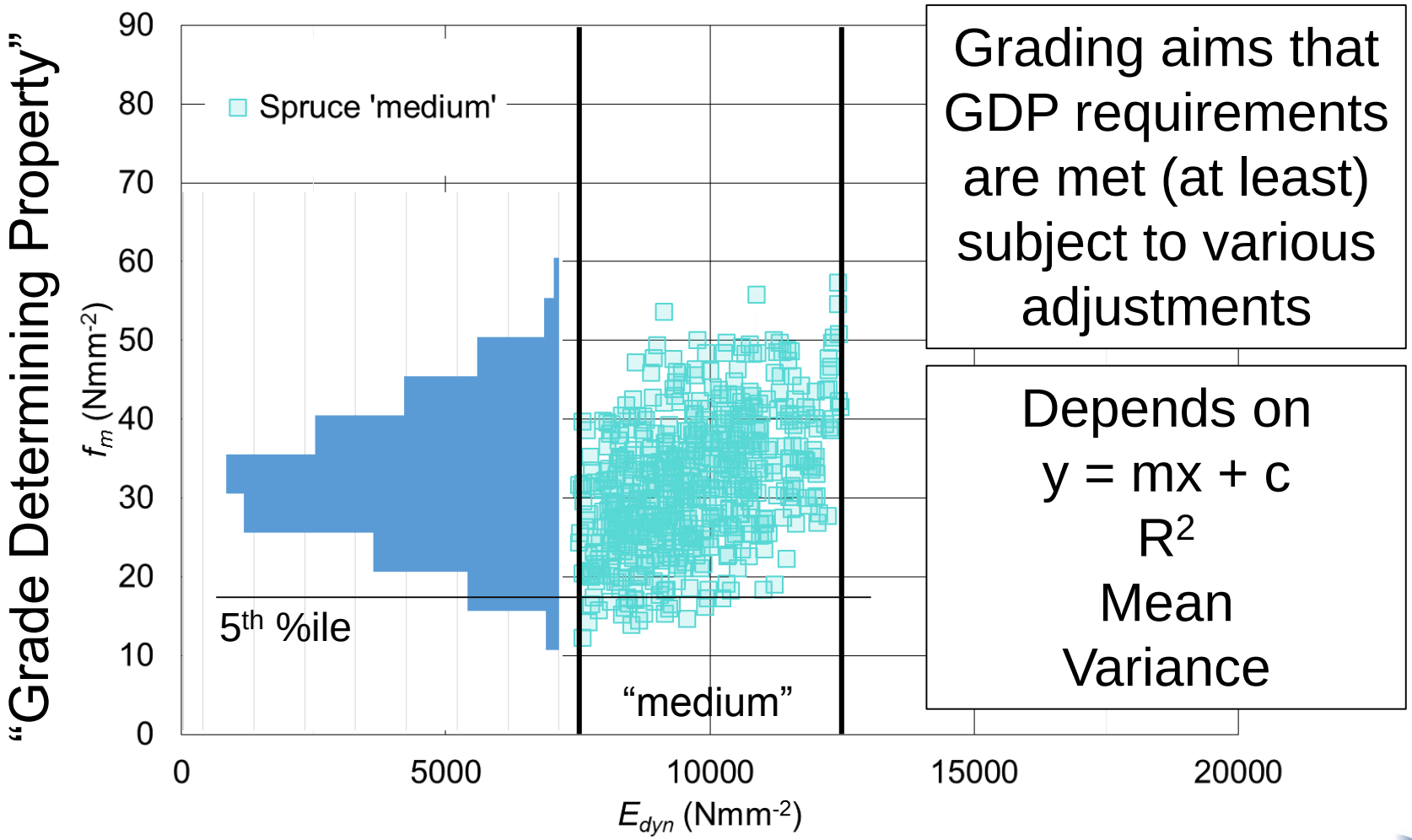
Two types of machine grading

- Output control
  - Periodic testing of output
  - Testing element is costly
  - But adapts the machine settings to optimise yield
  - Idea: some initial testing + continuous testing
- Machine control
  - Can be done without need for testing of output
  - Relies on strict assessment and control of machines
  - No regular fine adjustment of machine settings
  - Idea: large initial testing programme

Grading – IP boundaries



Grading – IP boundaries



Grading aims that GDP requirements are met (at least) subject to various adjustments

Depends on
$y = mx + c$
R^2
Mean
Variance

Means that…

- Grading not about properties of individual pieces
- Often only one of the GDPs is limiting
- Sometimes none of them are
- So quite usual for some properties to exceed what is stated for the strength class
- Especially true of the secondary properties

- Having the same strength class does not make pieces equal! (or even sets of pieces)

UK larch with mtgBATCH 962

(EN14081-2:2010+A1:2012)

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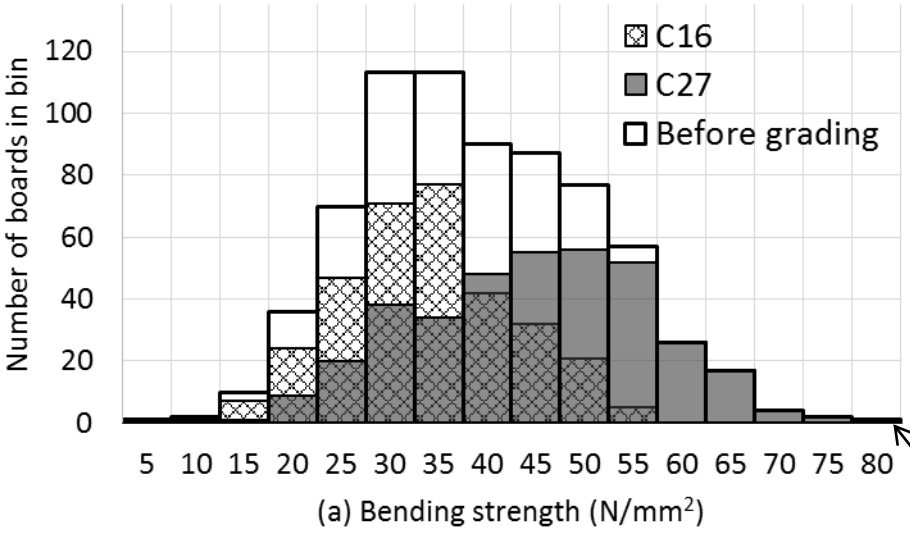
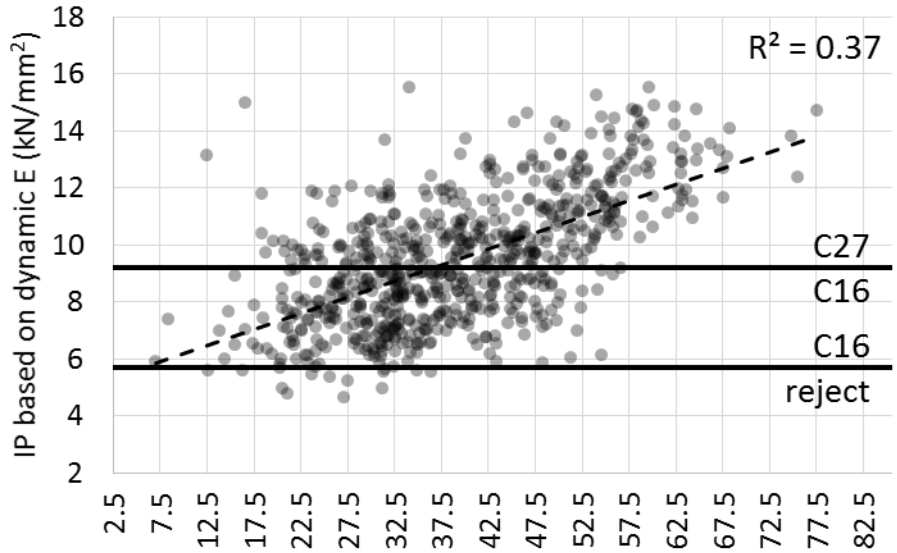


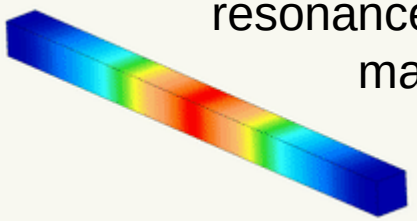


	% of required		
	Bending strength	Bending stiffness	Density
Class	%	%	%
C16	143% ✓	105% ✓	129% ✓
C27	100% ✓	103% ✓	122% ✓

Strength

Note there is still a large variation within the grades – the difference is we now have characteristic values

mtgBATCH is a resonance type machine



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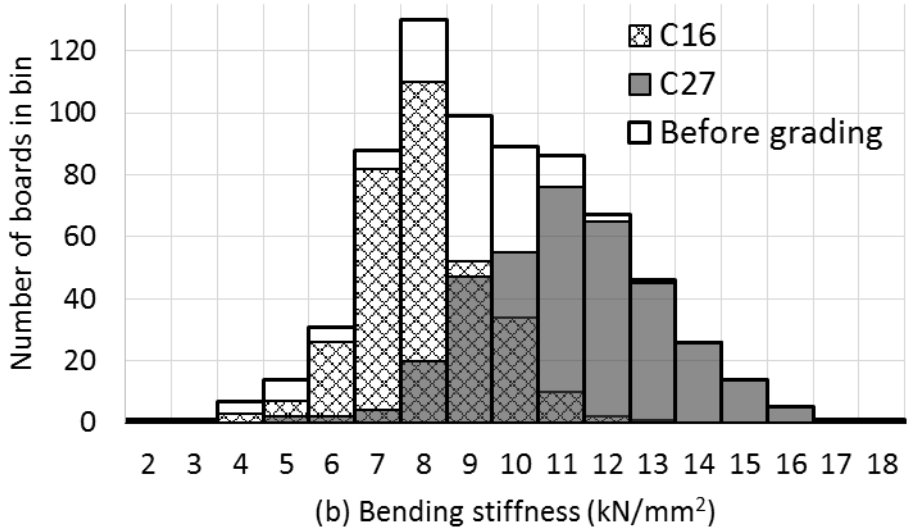

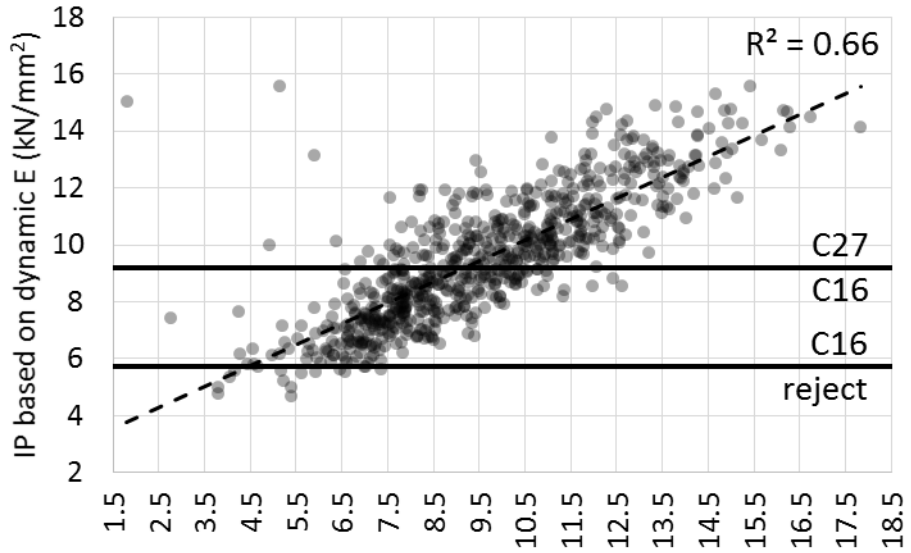

	% of required		
	Bending strength	Bending stiffness	Density
Class	%	%	%
C16	143% ✓	105% ✓	129% ✓
C27	100% ✓	103% ✓	122% ✓

Stiffness

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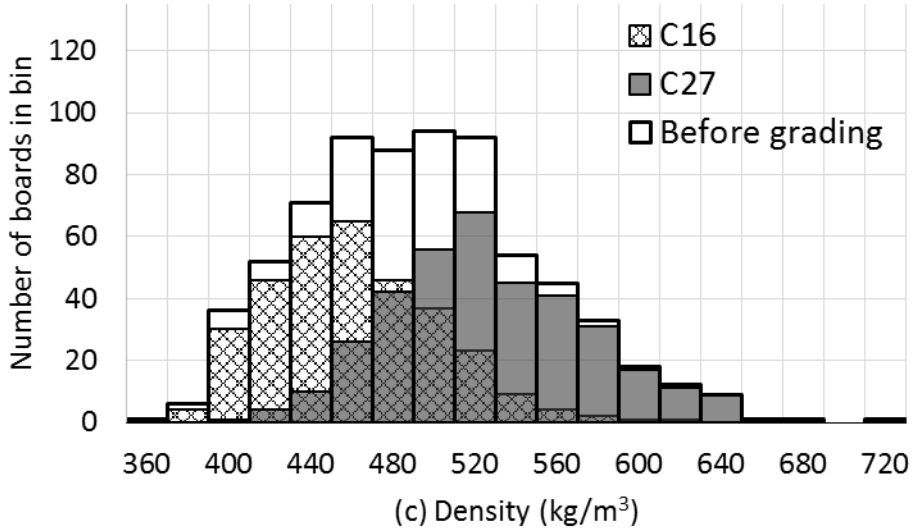
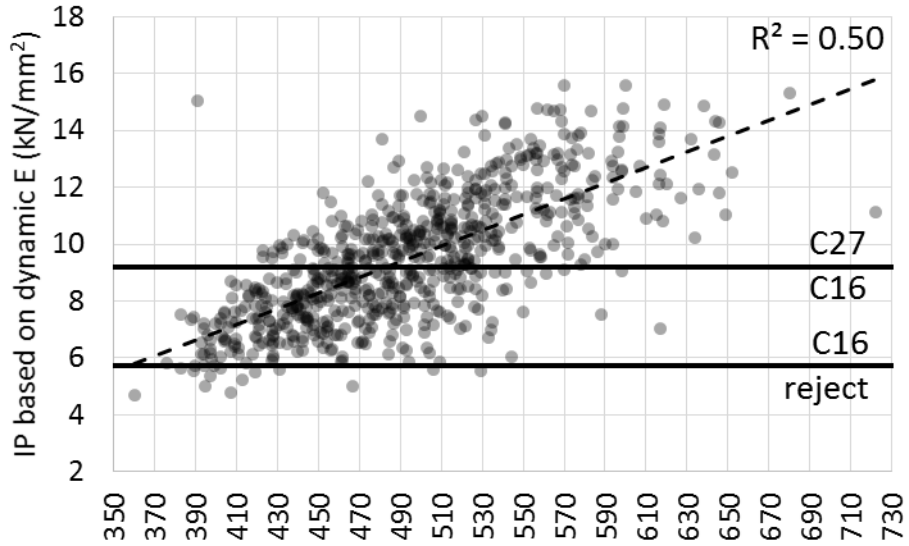
UK larch with mtgBATCH 962

(EN14081-2:2010+A1:2012)





	% of required		
	Bending strength	Bending stiffness	Density
Class	%	%	%
C16	143% ✓	105% ✓	129% ✓
C27	100% ✓	103% ✓	122% ✓

Density

Using E_{dyn} as IP for density because it's not critical. Simpler this way – no point using density from weight (which has $R^2 = 0.85$)

Responsibilities

- The manufacturer assumes the responsibility for the conformity of the construction product with the declared performance in the DoP
- A merchant is considered a manufacturer if they place a product on the market under a company name or trademark or modify it in a way that might affect the DoP

Some quick points

- Not all strength classes are easily available
- There is no need to over specify
- You cannot regrade reject timber (without special consideration)
- Visual grading assignments are not fixed forever
- Strength classes are not fixed forever
- You can make your own strength classes
  - EN 338 is not the definitive list – it is just handy
  - Actually, it is Declaration of Performance (DoP) that matters

Some quick points

- You need to pay attention to
  - Treatments that may affect properties
  - The moisture content
  - Changing the cross-section
- Piece marking (grade stamps) (!!!!!)
  - Be aware of the UK's position (see later)

Regrading timber

- You cannot regrade timber (by machine or visually) if it has already been graded
  - This applies to timber that is rejected
  - And timber already assigned a grade
- Unless the action of the first grading is properly considered
- Because grading works on the population
  - if you remove the better quality timber beforehand you probably won't achieve the required characteristic properties with the same thresholds

Marking

- The new EN 14081-1 allows two methods for visually graded timber
  - Method A “individual piece marking” (grade stamps)
    - Although there are no rules about where the mark can be
  - Method B “package marking” (no mark on the timber)
    - To satisfy small producers
    - UK tried to prevent this (and failed)
- Machine graded timber still needs to be piece marked (method A)

UK position

- The UK mirror committee, BSI B/518, of CEN/TC124/WG2, disagrees with package marking
- Owing to the risk of misidentification and/or loss of identification of strength-graded structural timber which is not individually grade stamped
  - The Construction Products Regulations require the package mark to accompany the timber, but the UK is concerned that this will really happen

UK position

- Method A is expected
  - Furthermore, the grade stamp must be stamped clearly and indelibly at least once on a face or edge and at least 600mm from the end of the piece
- If there is no stamp (method B) the UK National Annex to EN 1995-1-1 applies an increased partial safety factor (γ_m = 2.0 rather than 1.3)
- The only exception is when the grade stamp is omitted for aesthetic reasons
  - Only where it is requested by a specific customer in respect of a specific project
- (Intention to put this in National Annex to EN 14081-1)

Some other changes

- Dry-graded timber – change of meaning
  - Means, specifically, checked for fissures and distortion at a moisture content of no more than 20%
  - Grading might have been done green
  - Not the same thing as moisture content specification
  - No direct correspondence with service class

Summary

- Two types of timber grading
  - Visual
  - Machine (machine control and output control)
- About building safety
- Based on mathematics of uncertainty
- …and test data
- Grading does not operate on a piece by piece basis
- Grading is not proof-loading

Summary

- Strength classes are convenient
  - But not every class listed in EN338 can be obtained
  - & EN338 is not all strength classes
  - & not the only way …DOP is what matters
- Be aware of revisions to standards
  - Properties of strength classes
  - Visual grading assignments
- UK's special position on piece marking

Advantage of usual grades

- When placing timber on the general market
- Familiar
- Design can be done before timber obtained
- Easier for more general visual grading assignments and machine settings
- Don’t need to know specific end use when grading
- But…this is at the expense of properties
  (although this often doesn’t matter much in practice)

But strength classes not the only way - they are just a convenience

Situations for different thinking

- Grading of in-situ timber
  - Think about predicting the properties of actual pieces
  - Even if describing collective properties of several timbers, there is little reason to limit the description to EN 338 strength classes
- Grading timber for a specific building
  - (When the timber is known before the design)
  - Not placing on general market (so why discard properties?)
  - Can even think about sorting pieces for the different components (end use is not unknown)

Situations for different thinking

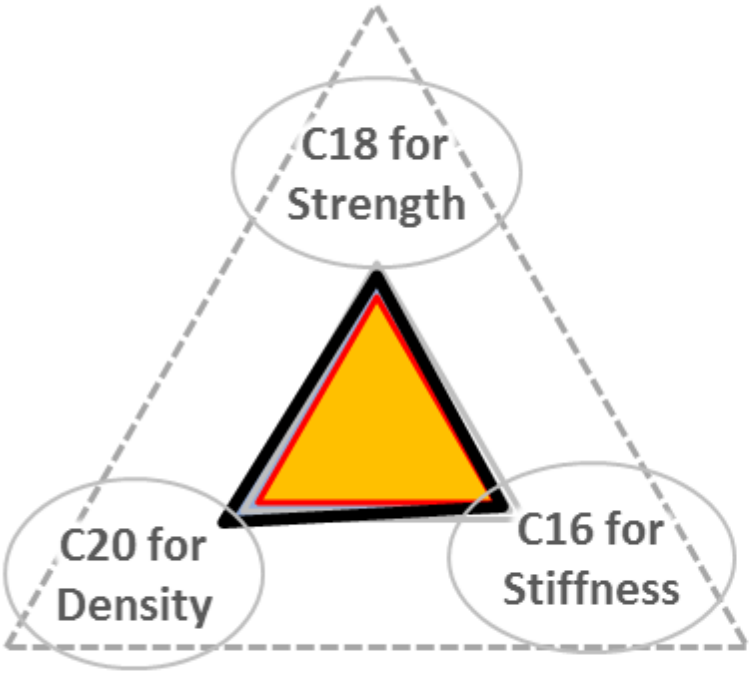
- Grading timber by a fabricator
  - E.g. timber framer, glulam manufacturer
  - Not placing on general market (so why discard properties?)
  - Can fit to resource
  - Can fit to application
  - Can fit design more closely to actual properties
  - Mass production ∴ discarding potential more of a problem
- Grading by a sawmill for certain market
  - Market may accept a different strength class
- Grading by a sawmill for general market
  - Still some things that can be done

Things you can do

- Don't use EN 14081 (if you don't have to)
- Don't use an EN 338 strength class
  - Direct declaration of properties (easier for visual grading)
  - Define your own strength class that works better
  - Use a different standard strength class (e.g. TR26)
- Use an EN 338 strength class
  - Directly declare secondary properties (based on tests)
  - Note that hardwoods can now be graded to C-classes

Simple e.g. British spruce

- Usually want near 100% yield
- ∴ Grading C16/reject
- Typical market is studs
  - where bending stiffness is not as important as the strength



But grading to C16 means discarding strength and density because of relatively low stiffness!

"C16+"

C16+ is a user defined UK grade for studs. Its primary characteristic values are:

$f_{m,k}$ = 18.5 N/mm²

$E_{0,mean}$ = 8000 N/mm²

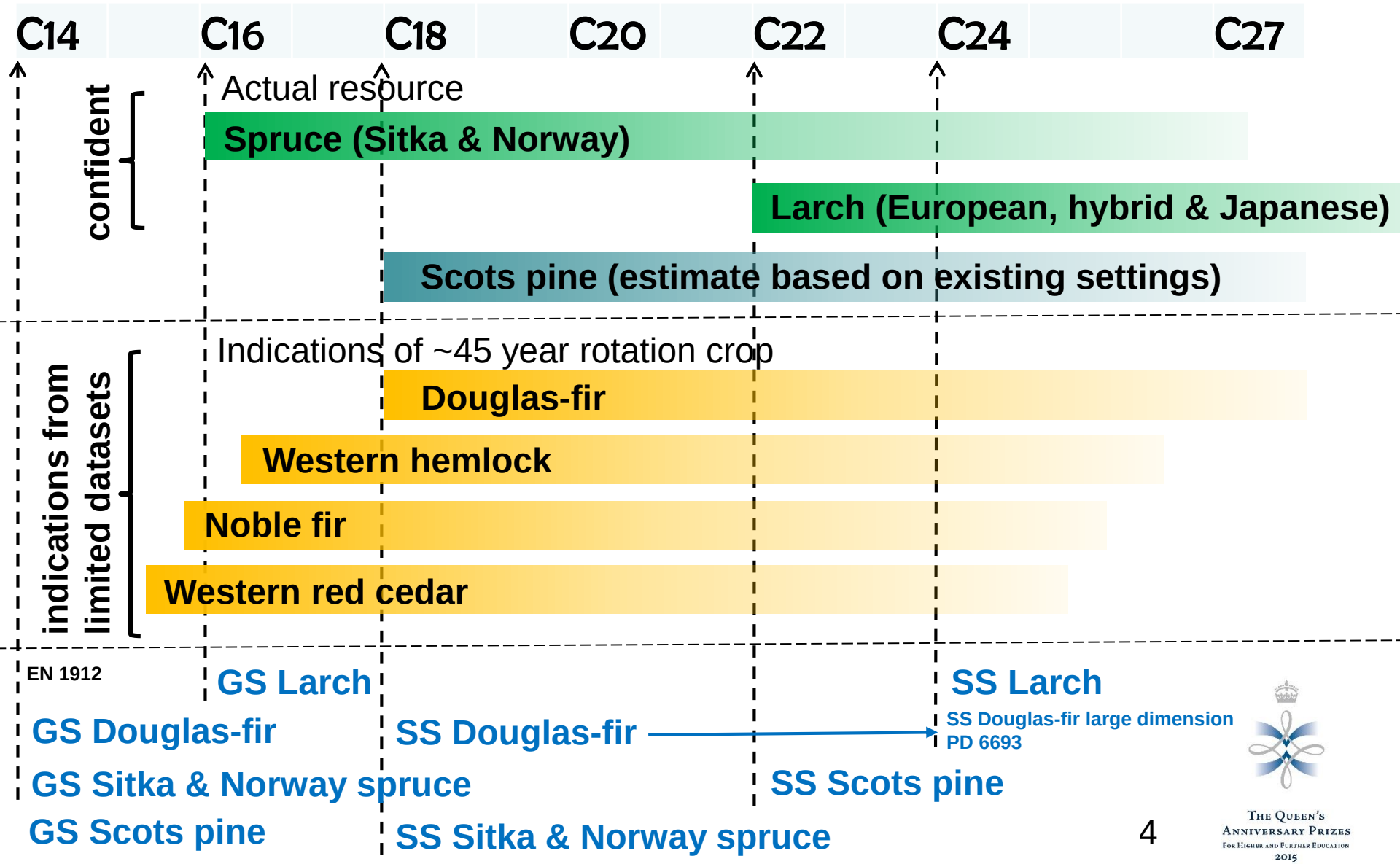
ρ_k = 330 kg/m³

Would be fine if treated as C16

Other characteristic values can be calculated from the equations given in EN 384.

(Strength > C18, and density of C20)

UK-grown timber - potential



UK-grown timber