Strength loss or safety factors? Some basic principles that ought to define tree hazard assessment

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Paul Muir - Arboricultural Consultant

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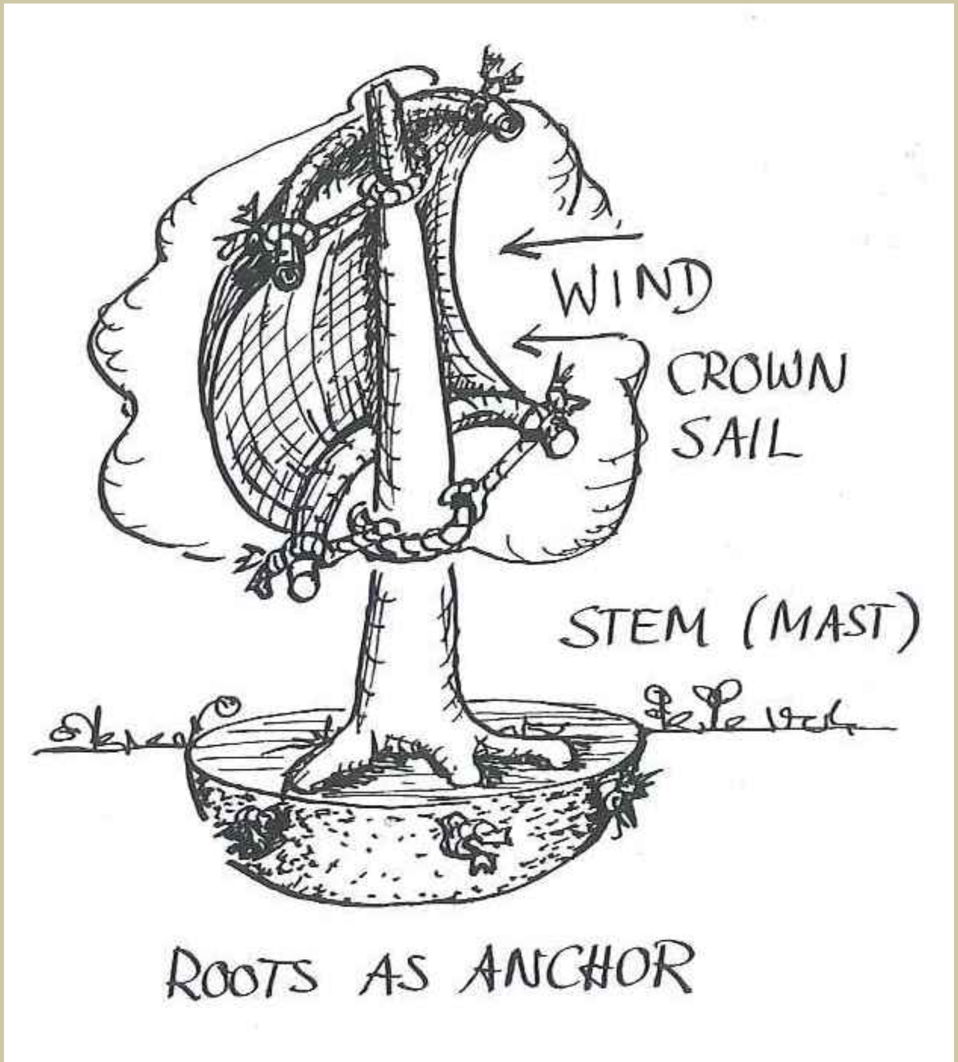
Bending / Overturning Moment

Safety Factors and Strength Loss

Section Modulus

Load – Sail Area and Moment



Mattheck and Breloer (1994) The Body Language of Trees

Crown Size and Shape

SAIL AREA

Wind Speed

WIND PRESSURE

Tree Height

LEVER ARM

MOMENT

Moments

Moment = 9kN x 10m

Total Moment = 90kNm

Moments

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Moment = 1kN x 11m

Total Moment = 33kNm

Moments

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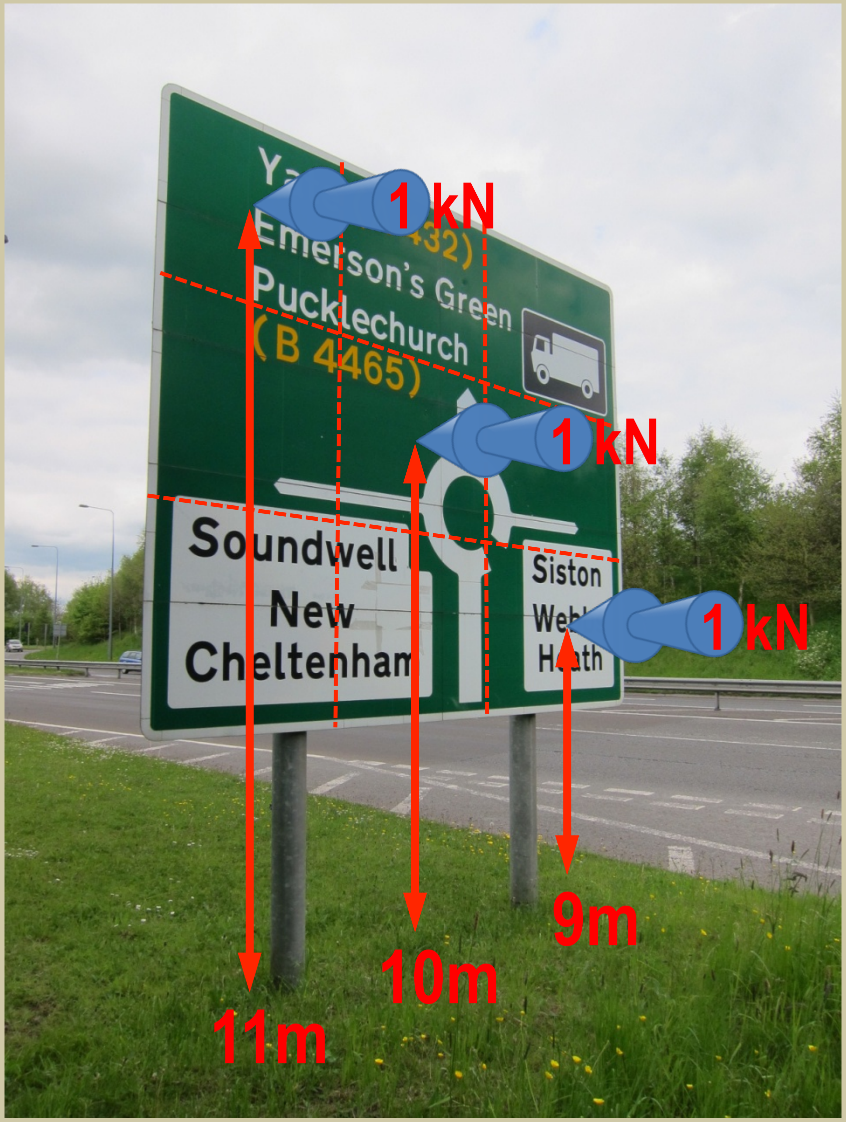


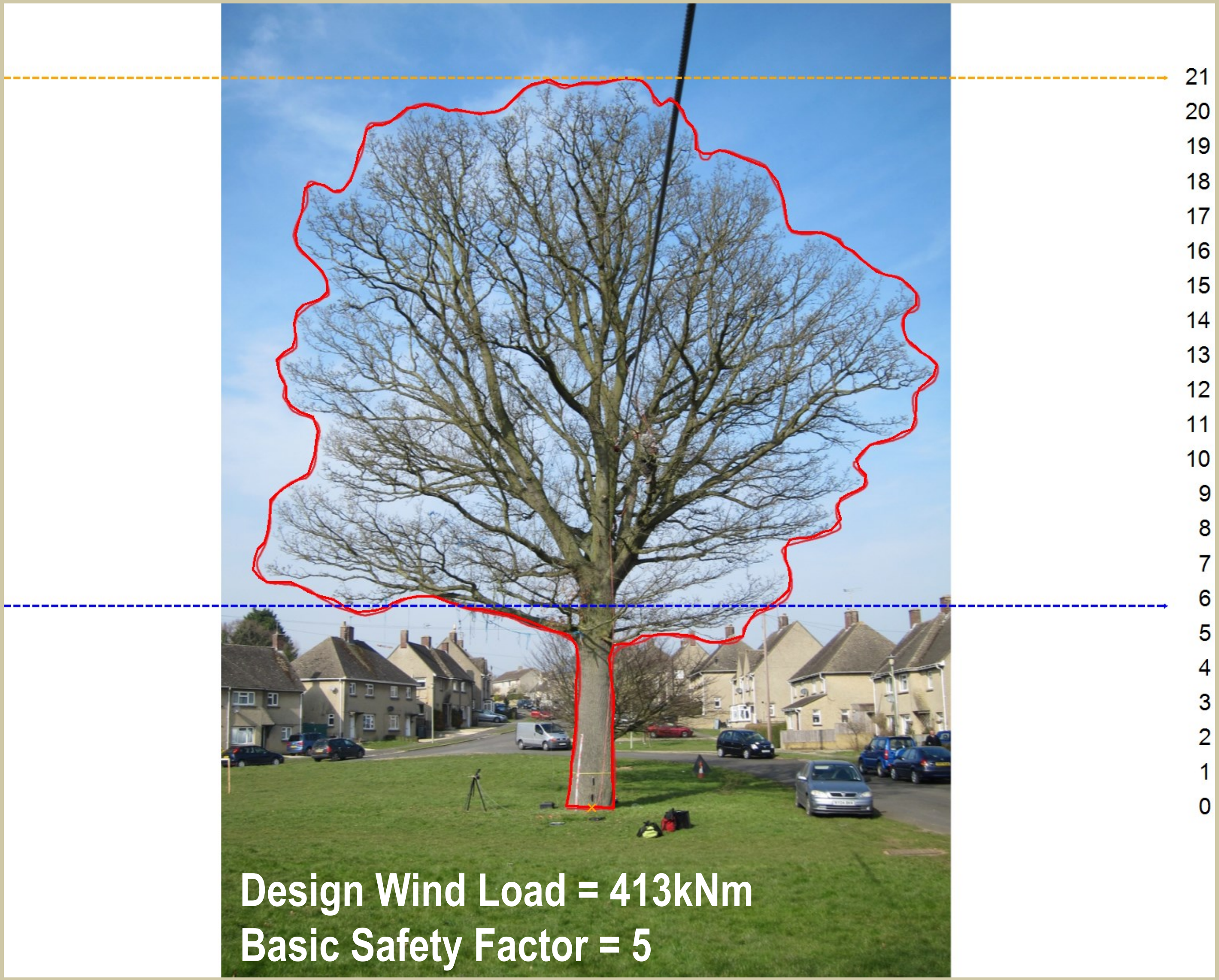
Moment = 33kNm

Moment = 30kNm

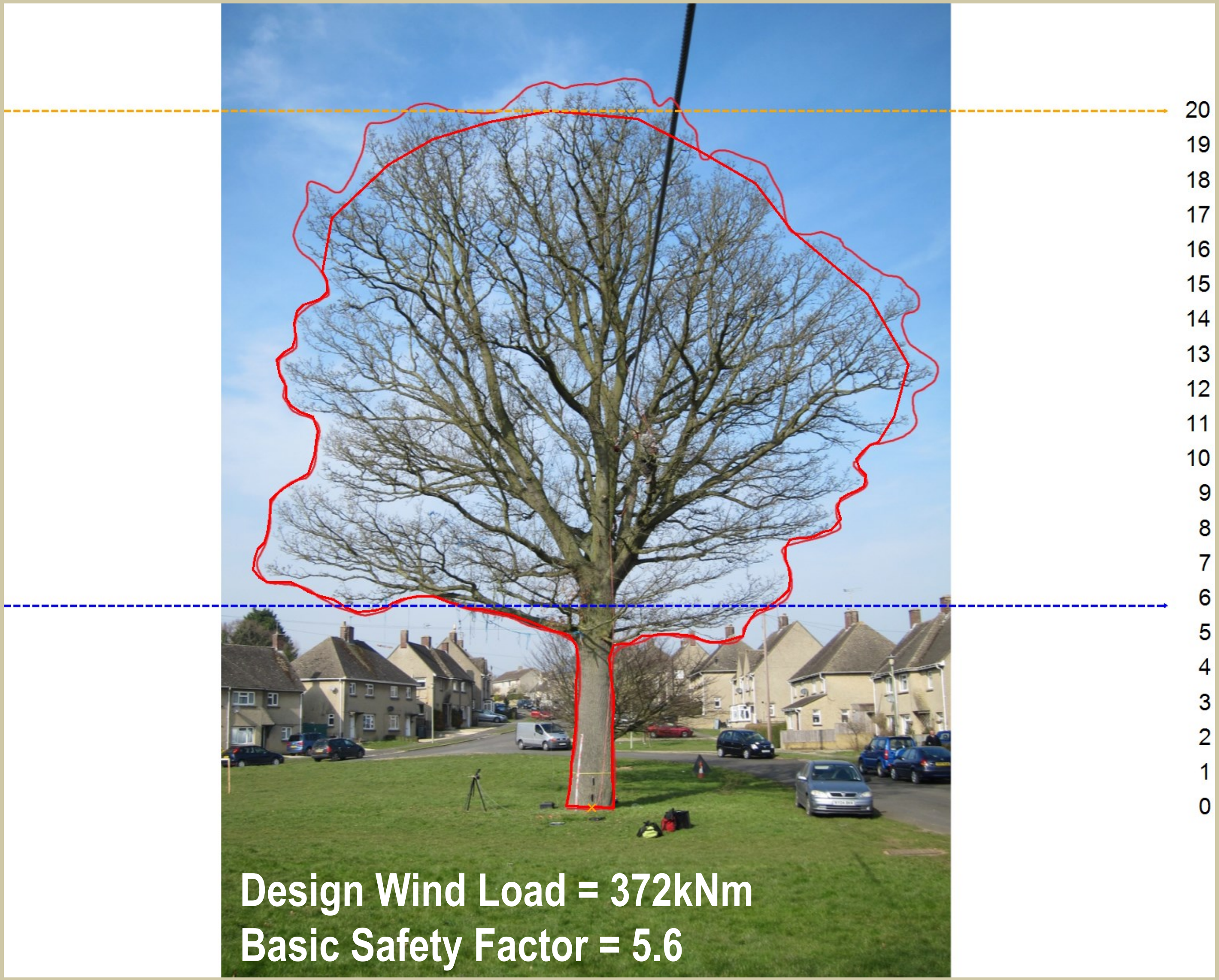
Moment = 27kNm

Total Moment = 90kNm

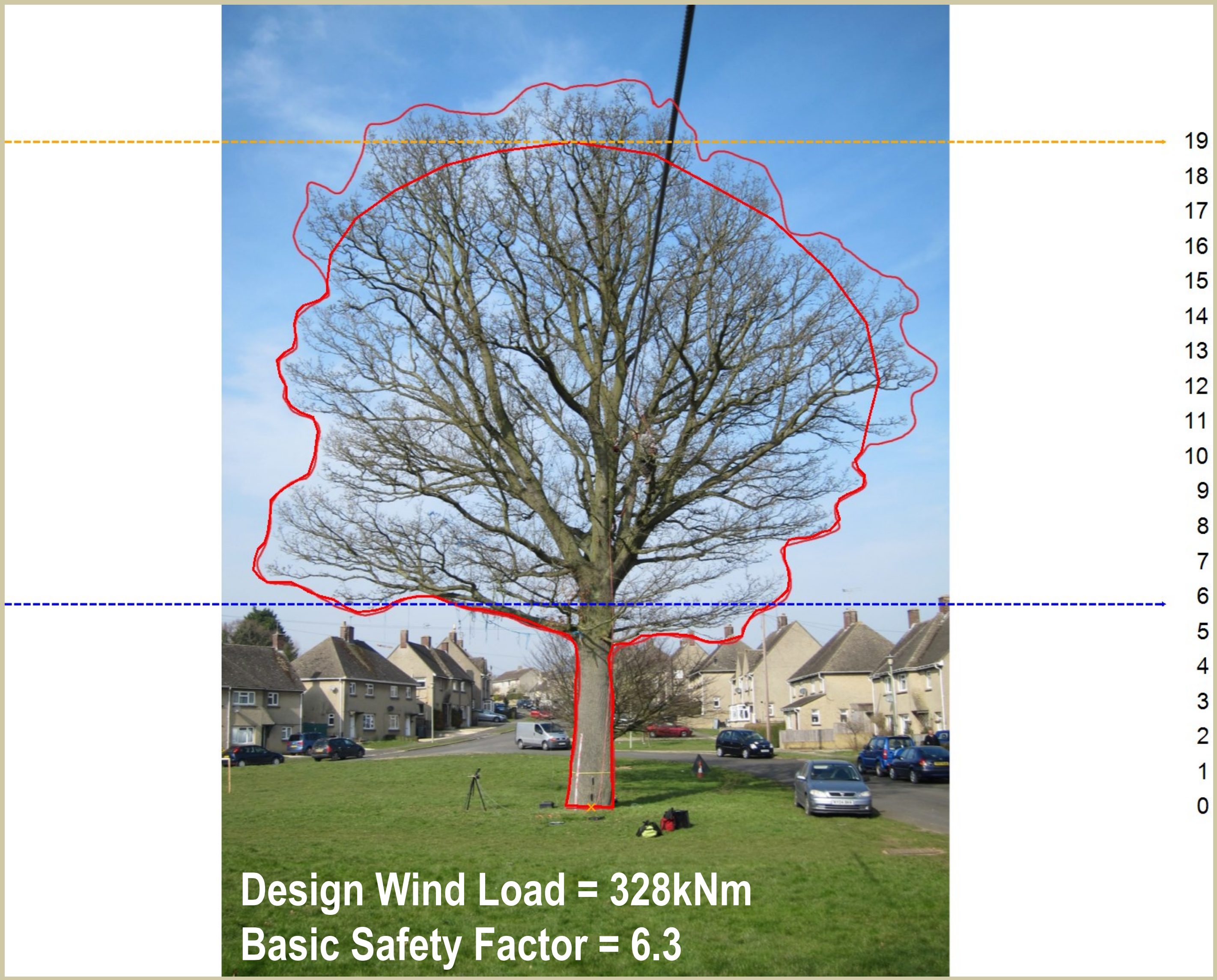
Crown Reduction



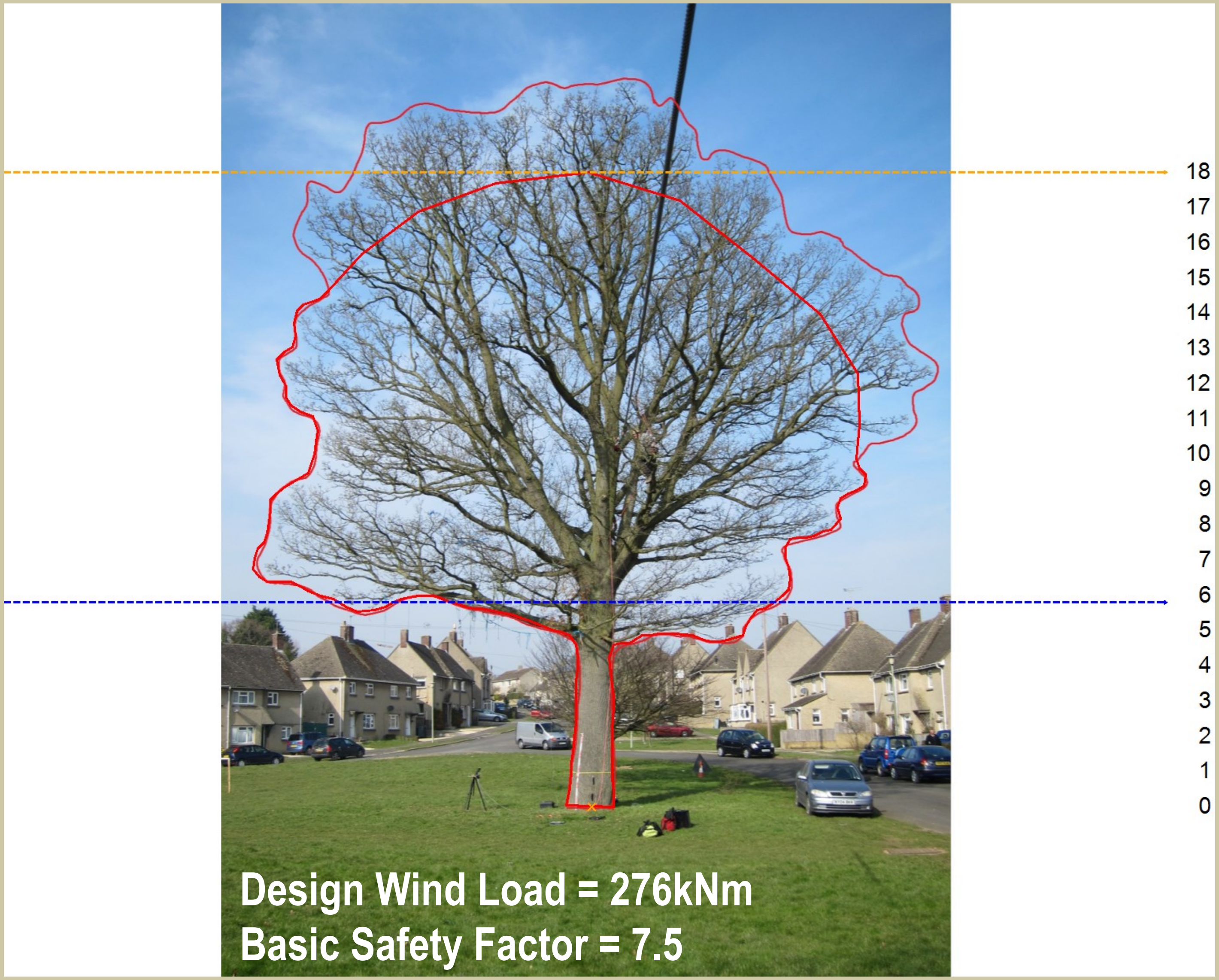
Crown Reduction



Crown Reduction



Crown Reduction



Crown Reduction

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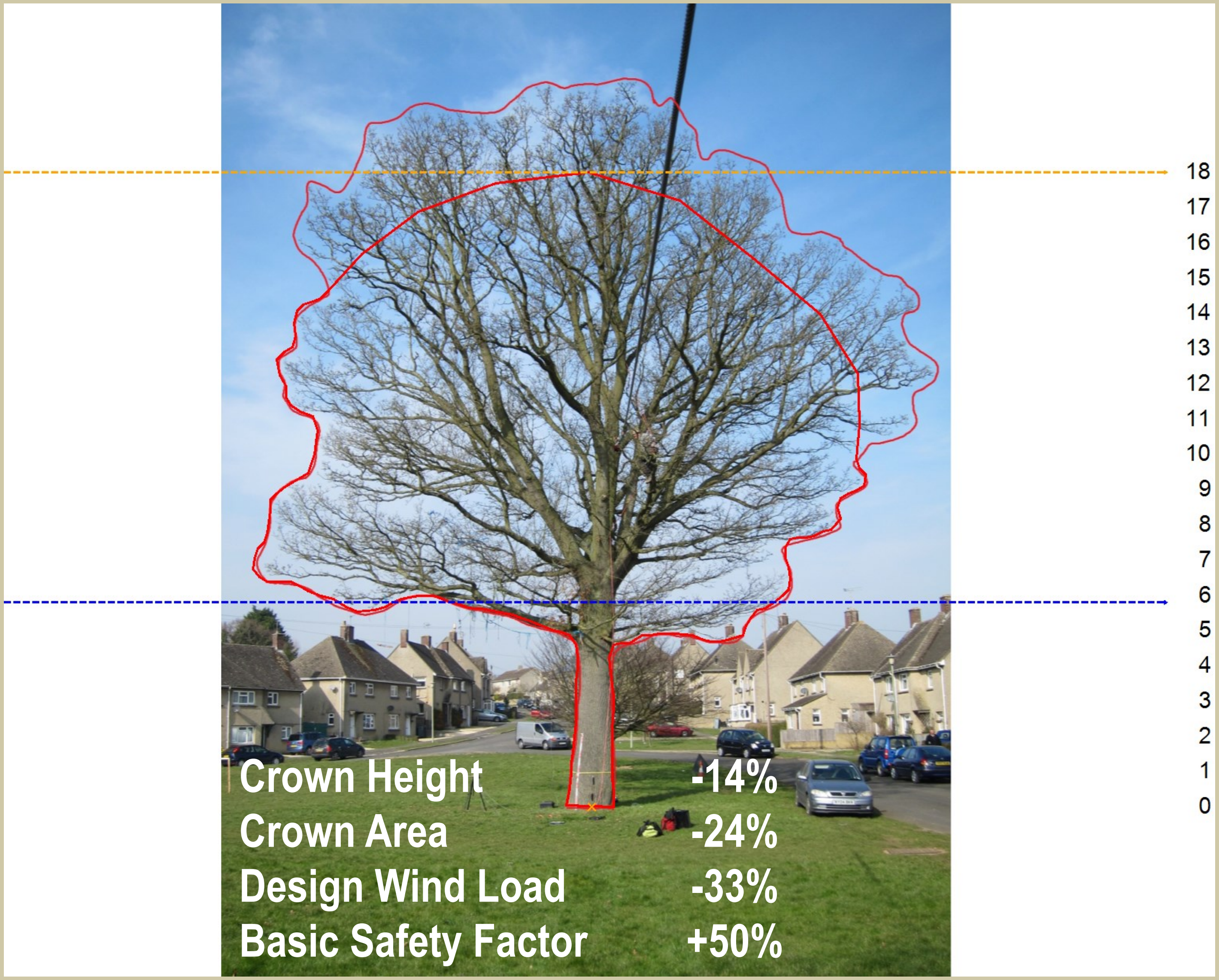


Wind Speed and Wind Profile

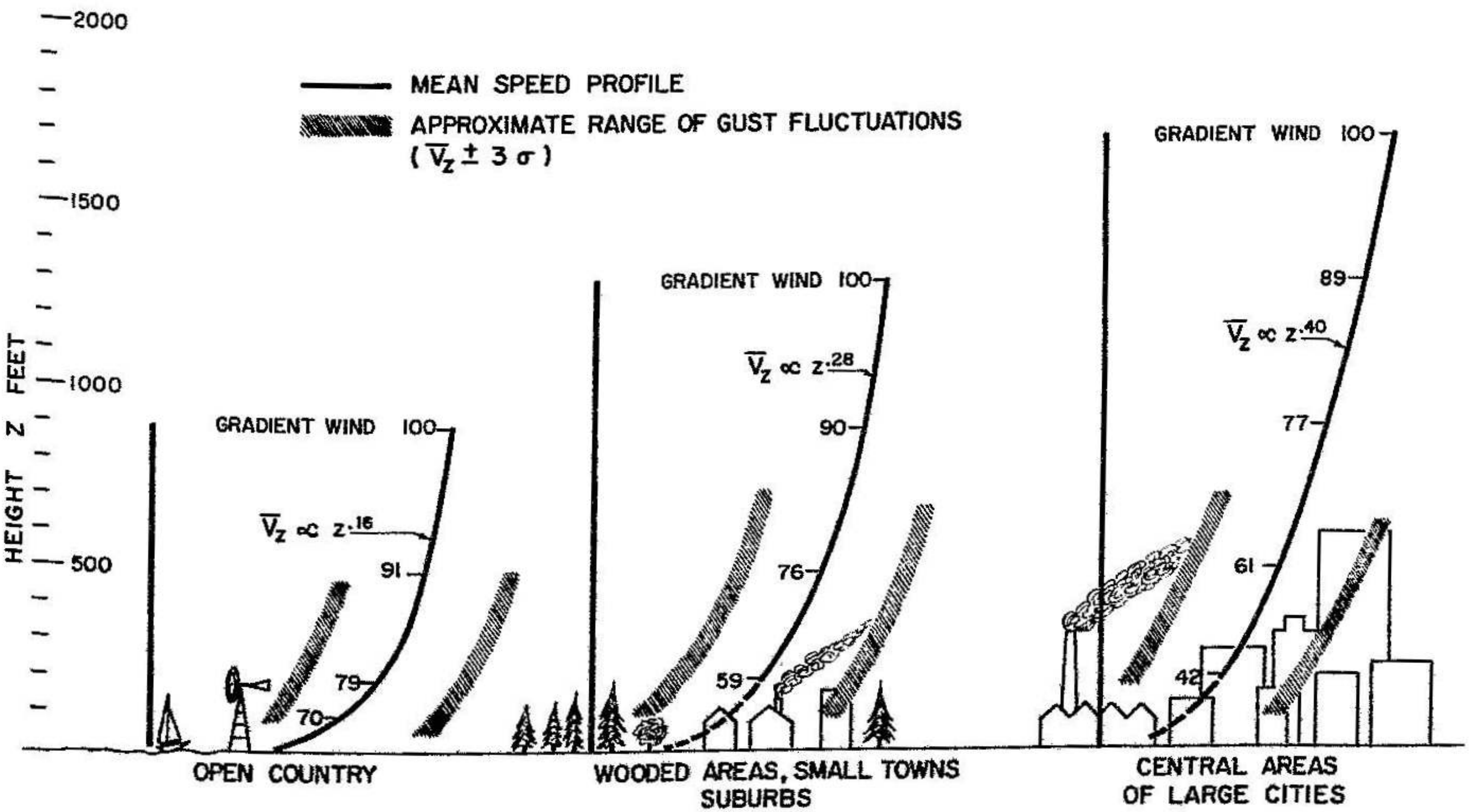


FIG. 2.—MEAN WIND VELOCITY OVER LEVEL TERRAINS OF DIFFERING ROUGHNESS

Davenport (1967)

Higher wind speeds

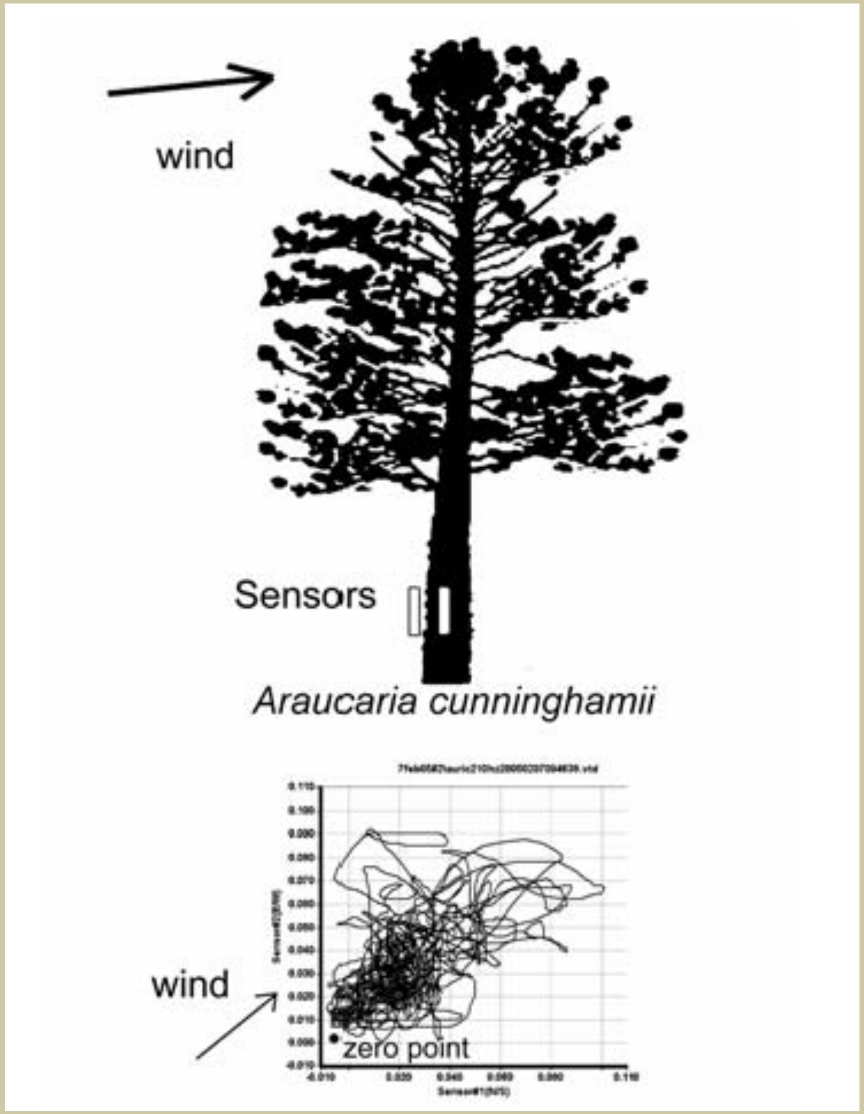
Greater wind pressure

Longer lever

Larger moment

Load Centre

Tree Dynamic Loads



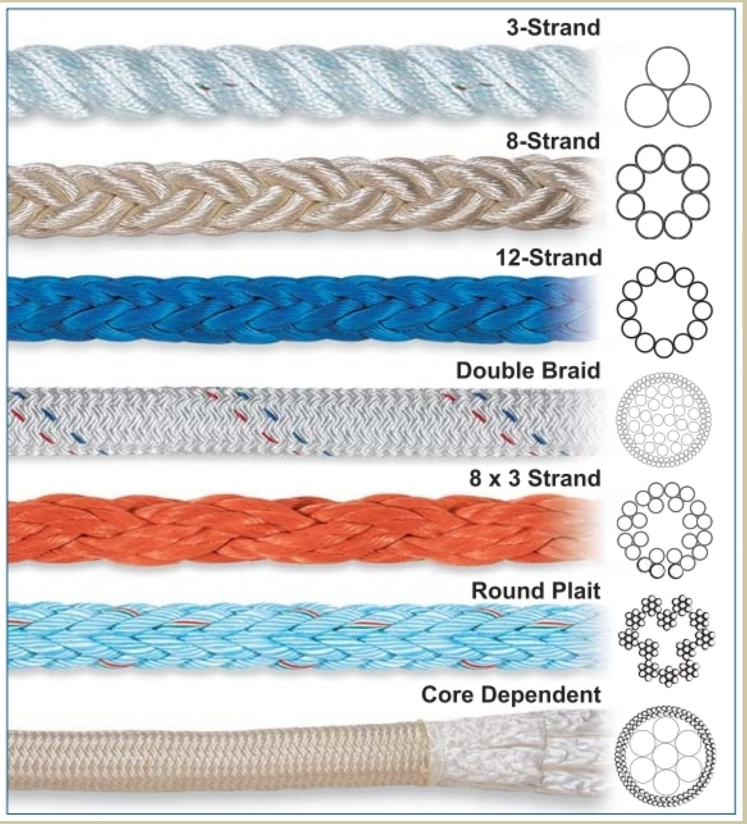
James (2008) Tree Stability and Wind Storms in Urban Parks

Safety Factors

1 ton WLL

1 ton load

Safety Factor = 1



20 ton WLL

80% damaged

1 ton load

Safety Factor = 4

Beech – *Meripilus giganteus*

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Beech – *Meripilus giganteus*

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Wind Load Analysis analogous to DIN 1055-4

Project

Project Name	202 Newbridge Road
Project Number	B321
Test Date	18/06/2012

Site — **Tree Number** T1

202 Newbridge Road
Bath
BA1 3LF , UK
Altitude a. sea level 23 m

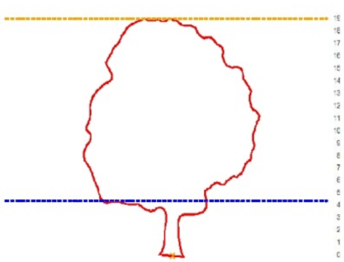
Tree Data

Tree Species	Fagus Sylvatica	
Stem circumference	345	cm
Stem Diameter ‖	98	cm
in 1m height ⊥	115	cm
Bark Thickness	2	cm
Tree Height	**19**	**m**

Applied Material Properties

as for	Fagus sylvatica	
Source	Stuttgart	
Compressive Strength	22.5	MPa
Modulus of Elasticity	8500	MPa
Limit of Elasticity	0.26	%
Green Density	1.05	g/cm³

Crown Outline



Load Direction SE/140°

Surface Area Analysis

Crown Base	4.4	m
Effective Height	13.2	m
Total Surface Area	206	m²
Crown Eccentricity	0.36	m

Applied Structural Parameters

Drag Factor	0.25	
Natural Frequency	0.6	Hz
Damping Decrement	0.5	
Form Factor for Dead Weight	0.8	

Applied Site Parameters

Windzone	GB 21	
Speed of Applied Design Wind Speed	22	m/s
Air Density	1.29	kg/m³
Roughness Catagory	Suburb	
Exponent for Wind Profile	0.22	
Proximity Factor for Effects in Near Ground Wind Flow	1.2	
Factor for Crown Exposure	1.00	

Results

Wind Load Analysis

Mean Wind Pressure	14.4	kN
Gust Reaction Factor	2.56	
Load Centre	11.1	m
Torsion Moment	13	kNm
Design Wind Load	**412**	**kNm**

Tree Static Analysis

Dead Weight Tree	13.1	t
Critical Degree of Hollowness	93	%
Critical Residual Wall Thickness	4	cm
Assuming an Uncompromised Residual Wall		
Basic Safety Factor	**5.2**	

General

Comments

Calculated Tipping Stability according to Pull Test

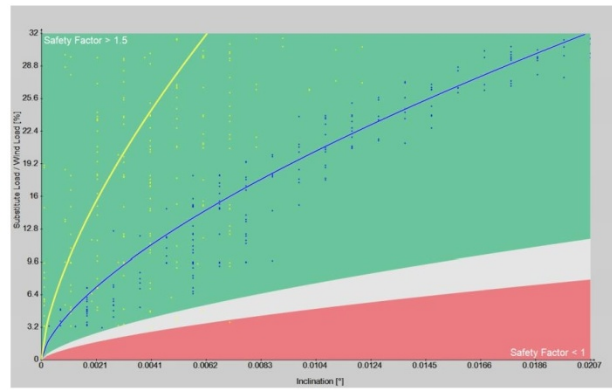
Tree Data

Project	202 Newbridge Road	**Tree Number**	**T1**
Tree Species	Fagus Sylvatica	Date	18/06/2012

Setup Pulling Test

Height of the Stem Anchor	7.3 m	**Measurement No.**	**1**
Rope Angle	10.3 °	Load Direction	SE/140°

Graphic Display (test data and best fit to tipping curve)



Inclinometer Measurement		80	81
Position		x-axis/NEE	x-axis/N
Tipping Stability (based on Generalized Tipping Curve)			
Safety Factor		**4.07**	**8.86**
Control Value	in		
Standard Deviation	%	2.63	11.26
Substitute Load	%	31.6	31.6
Load Direction at Inclinometer		x-Axis	x-Axis

General for Pull Test

Consultant	Paul Muir
Witness / Assistant	Jim Walker

Measurement Comments

Lucombe oak

Quercus x *hispanica* 'Lucombeana'

Hybrid between
Quercus cerris (Turkey oak)
Quercus suber (Cork oak)

Hybrid originated in 1765
This tree up to 187 years old
One of the first planted in the UK

Local civic society described the tree with:

"a magnificent and irreplaceable component of the town's landscape"


Poulton (2008)

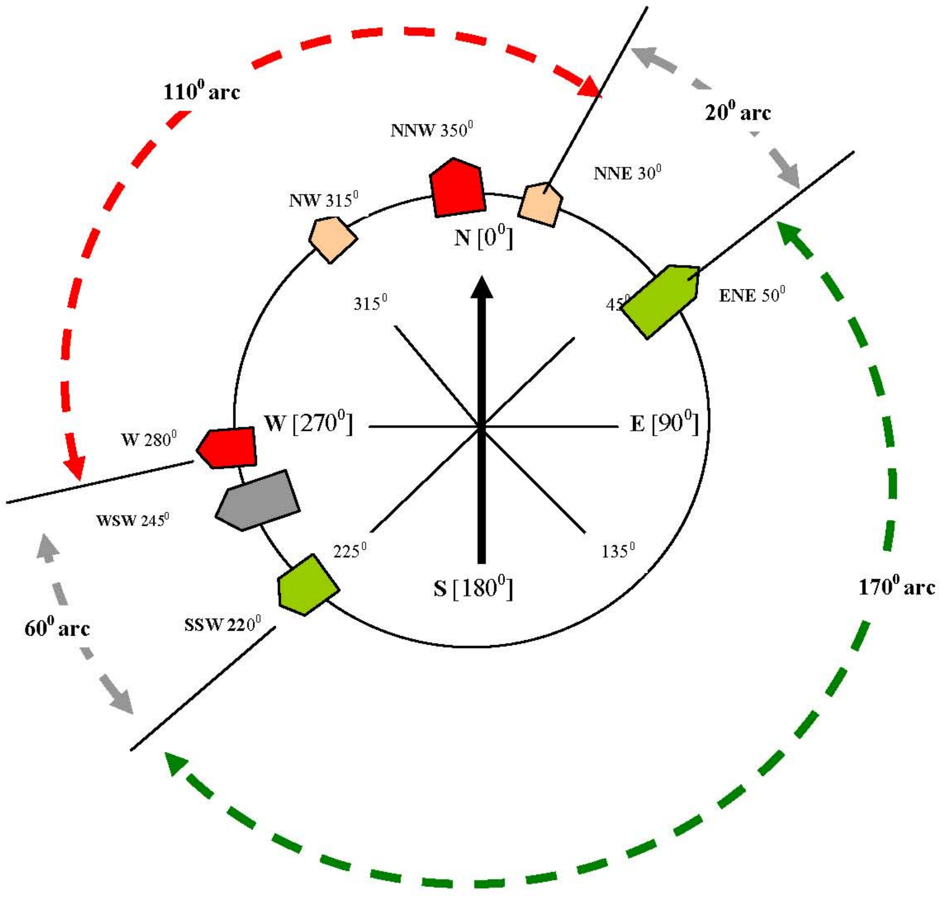

Phillips (2008)

Phillips (2008)

Phillips (2008)


JCB

Lucombe oak



Key:

No decay: **Sound** (live buttress)	(green)
Slight decay. **Sound intermediate** (sound live buttress)	(grey)
Some decay: **Intermediate** (some reduced structure)	(peach)
Extensive decay: **No structure**	(red)

Phillips (2008)


SAVE
OUR
OAK

Lucombe oak

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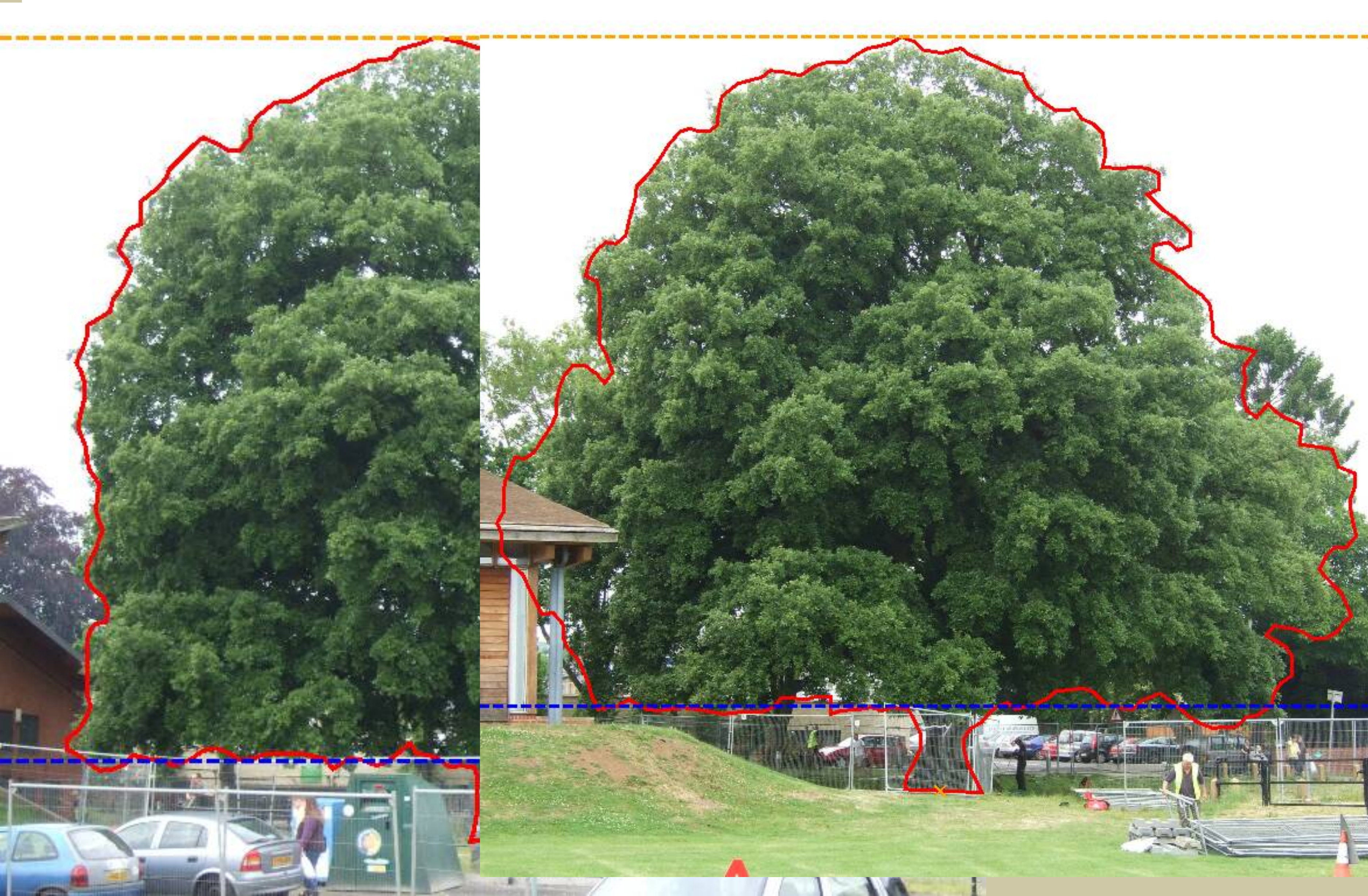

Lucombe oak

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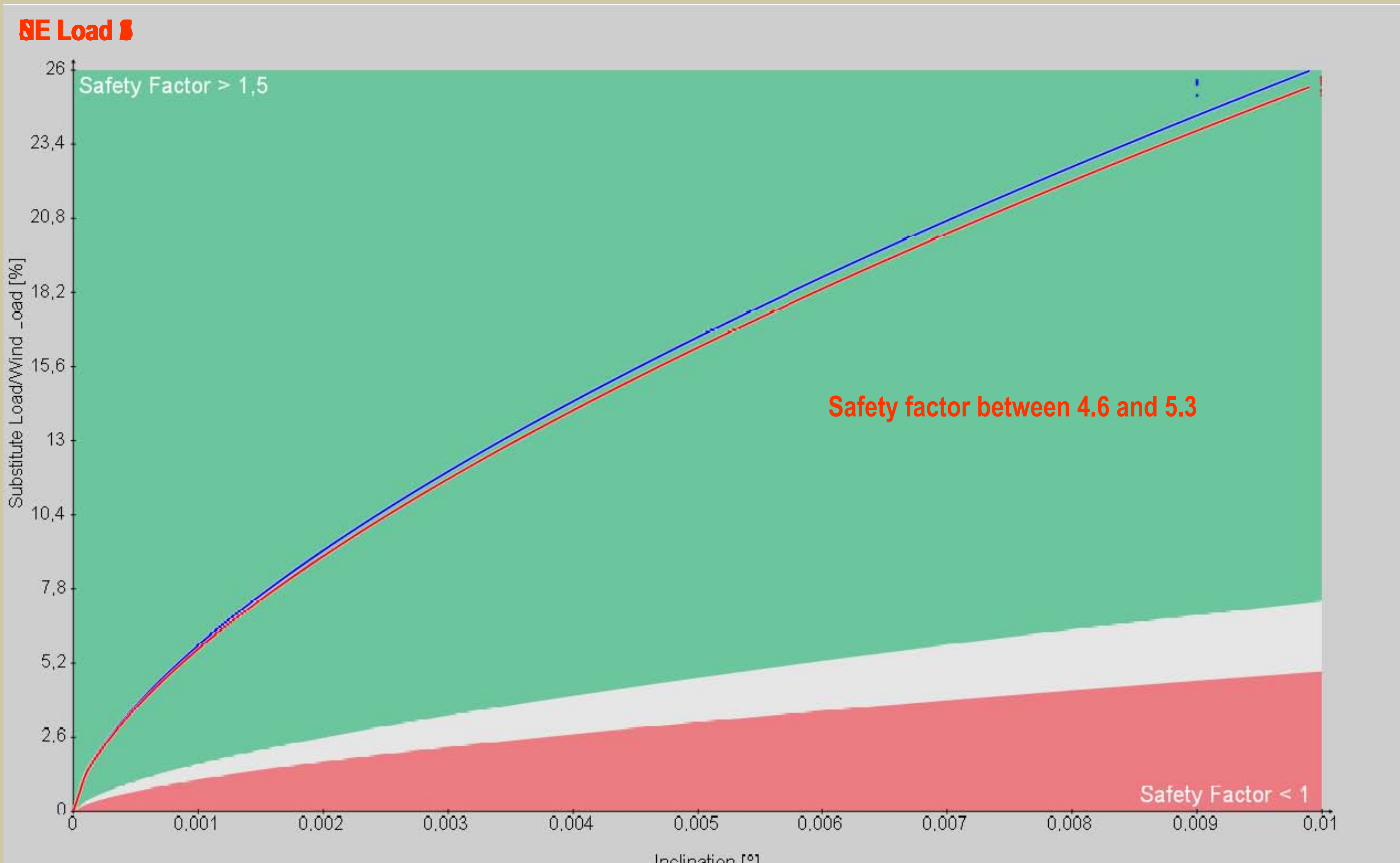

Lucombe oak

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Calculated Fracture Stability according to Pull Test

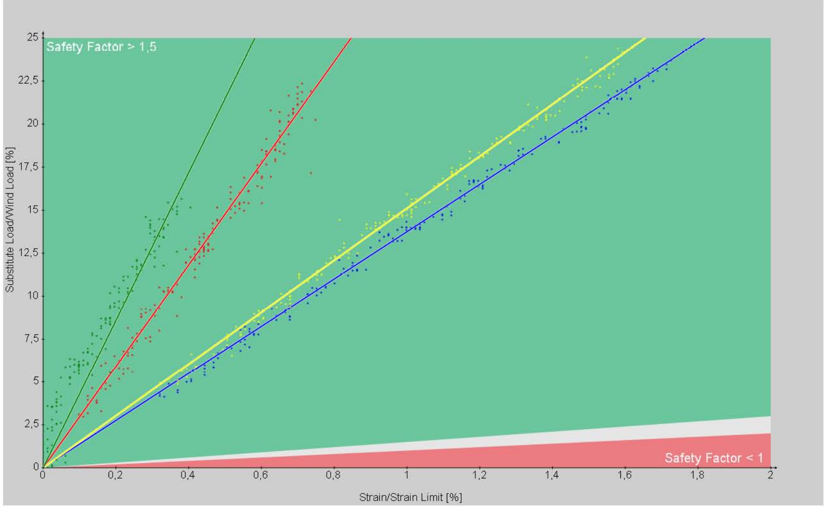
Tree Data

Project	Crewkerne	**Tree Number**	**1**
Tree Species	Lucombe Oak	Date	25.06.2009

Setup Pulling Test

Height of the Stem Anchor	12,5 m	**Measurement No.**	**1**
Rope Angle	16 °	Load Direction	SE

Graphic Display (test data and best linear fit)



Elastometer Measurement	in	90	91	92	93
Measurement Height	**m**	**1,55**	**0,8**	**0,4**	**0,25**
Position		compr	compr	tens	tens
Stem Diameter 1	cm	170	195	220	265
Stem Diameter 2	cm	170	195	220	265
Bark Thickness (1m)	cm	5	5	5	5

Breaking Stability (derived from the gradient of the best linear fit)

Safety Factor		**13,75**	**15,11**	**29,54**	**42,95**

Calculated Fracture Stability according to Pull Test

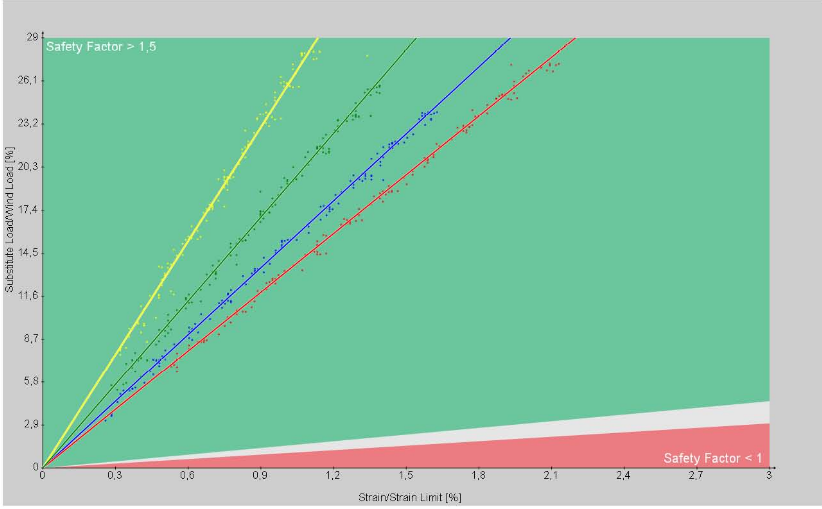
Tree Data

Project	Crewkerne	**Tree Number**	**1**
Tree Species	Lucombe Oak	Date	25.06.2009

Setup Pulling Test

Height of the Stem Anchor	14,1 m	**Measurement No.**	**6**
Rope Angle	19,5 °	Load Direction	NE

Graphic Display (test data and best linear fit)



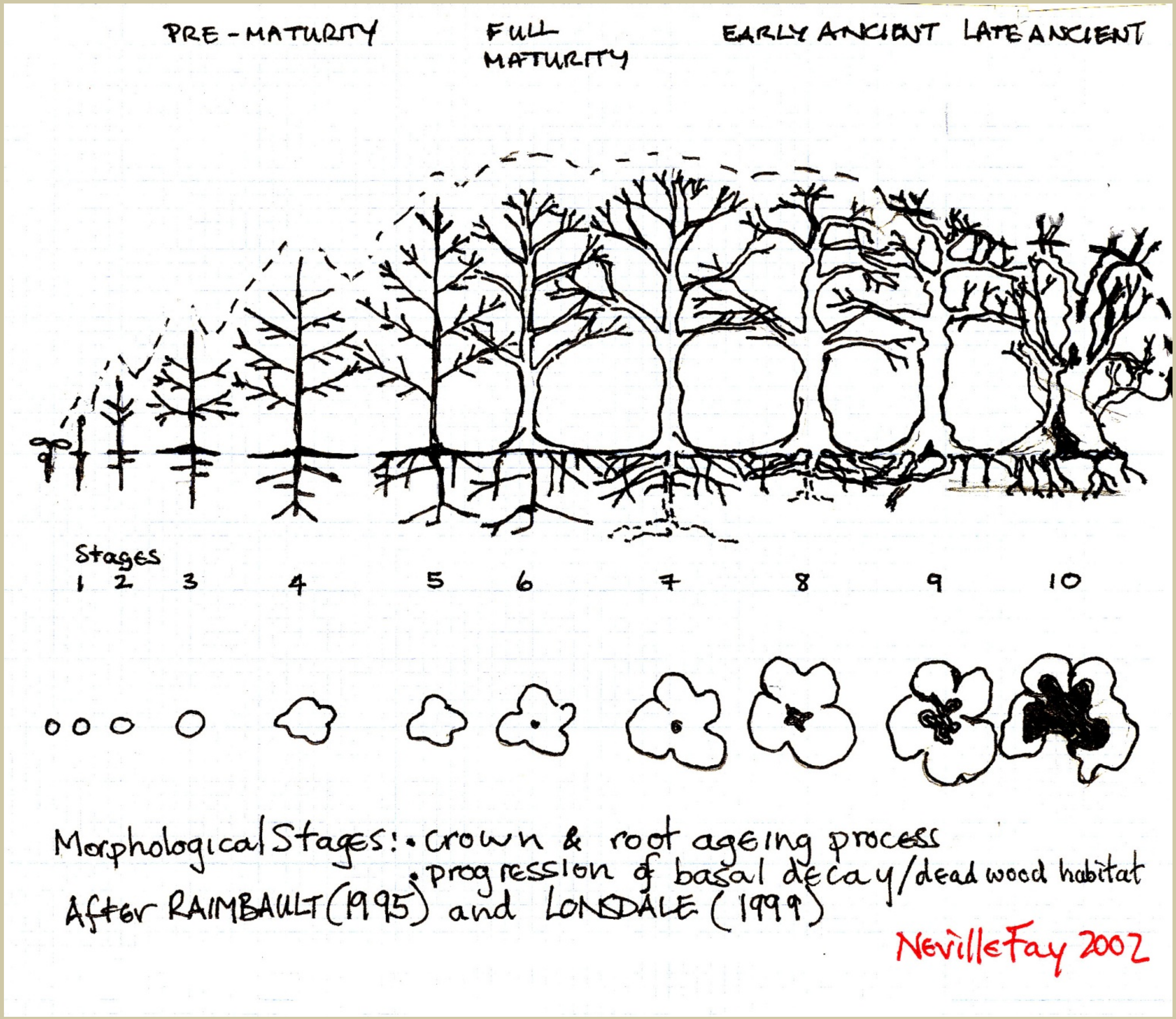
Elastometer Measurement	in	90	91	92	93
Measurement Height	**m**	**1,72**	**0,25**	**1,55**	**0,72**
Position		tens	tens	compr	compr
Stem Diameter 1	cm	150	225	160	200
Stem Diameter 2	cm	150	225	160	200
Bark Thickness (1m)	cm	5	5	5	5

Breaking Stability (derived from the gradient of the best linear fit)

Safety Factor		**15,02**	**25,54**	**13,19**	**18,81**


Van Wassenaer (2009)

Morphological Life Stages of the Tree



Earlyjematture

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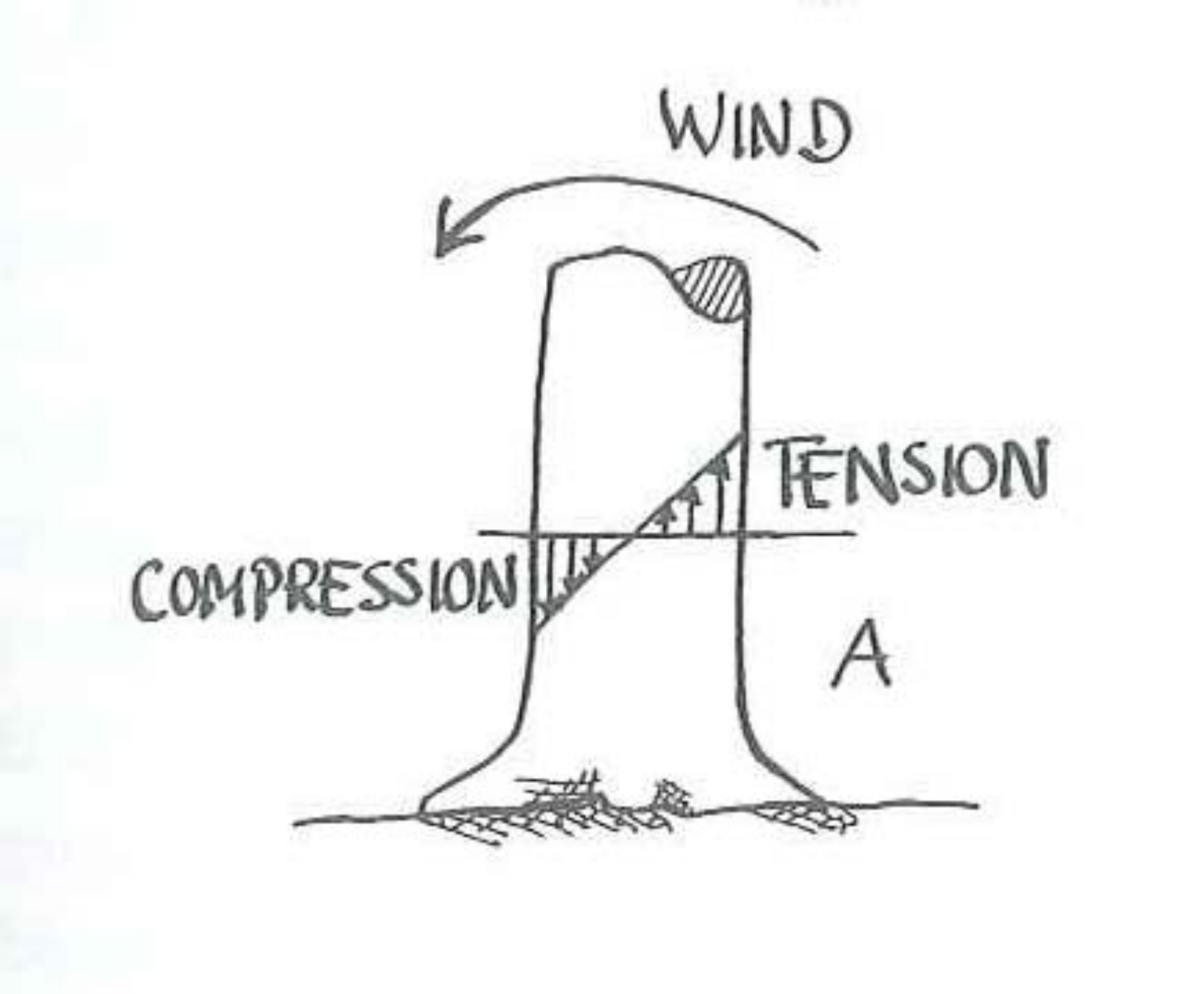
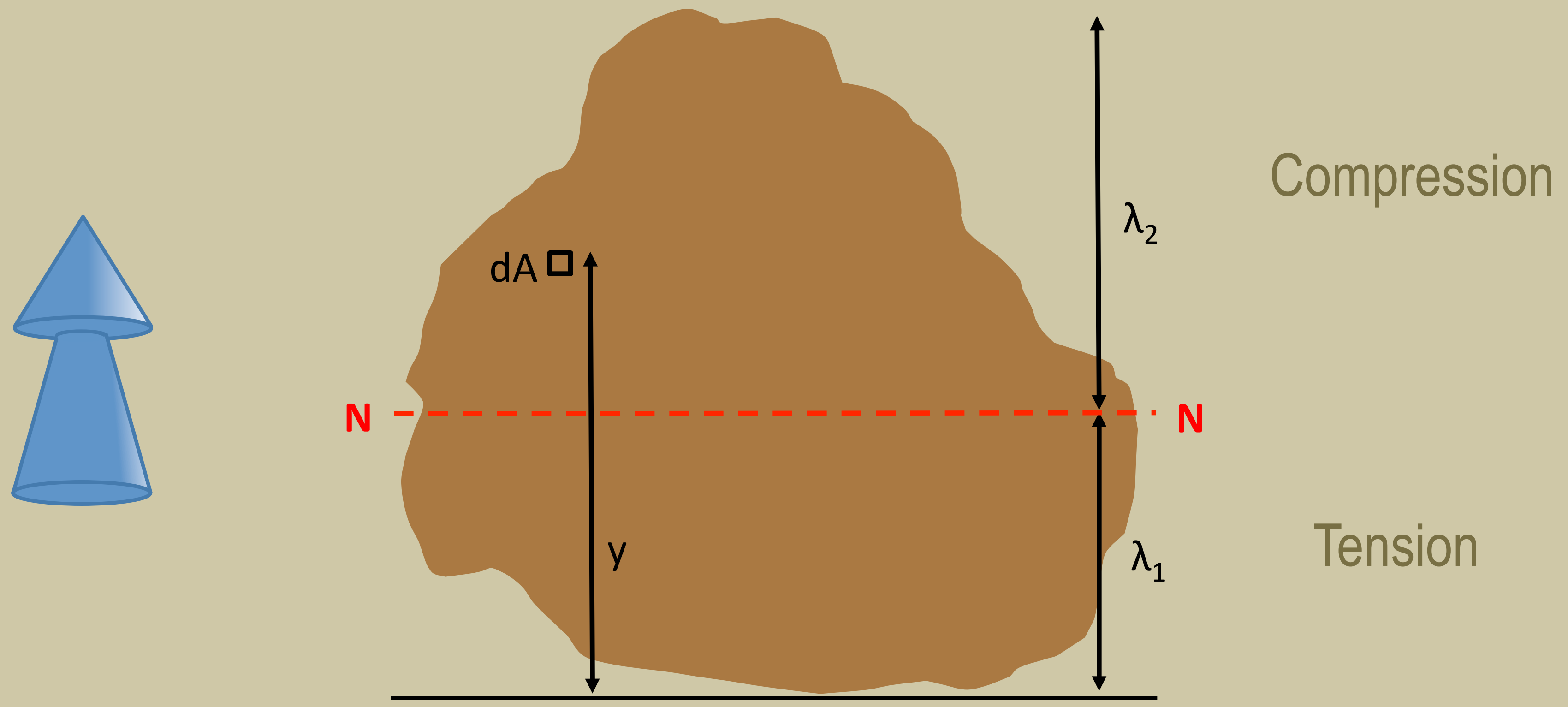
Stem Form – Section Modulus



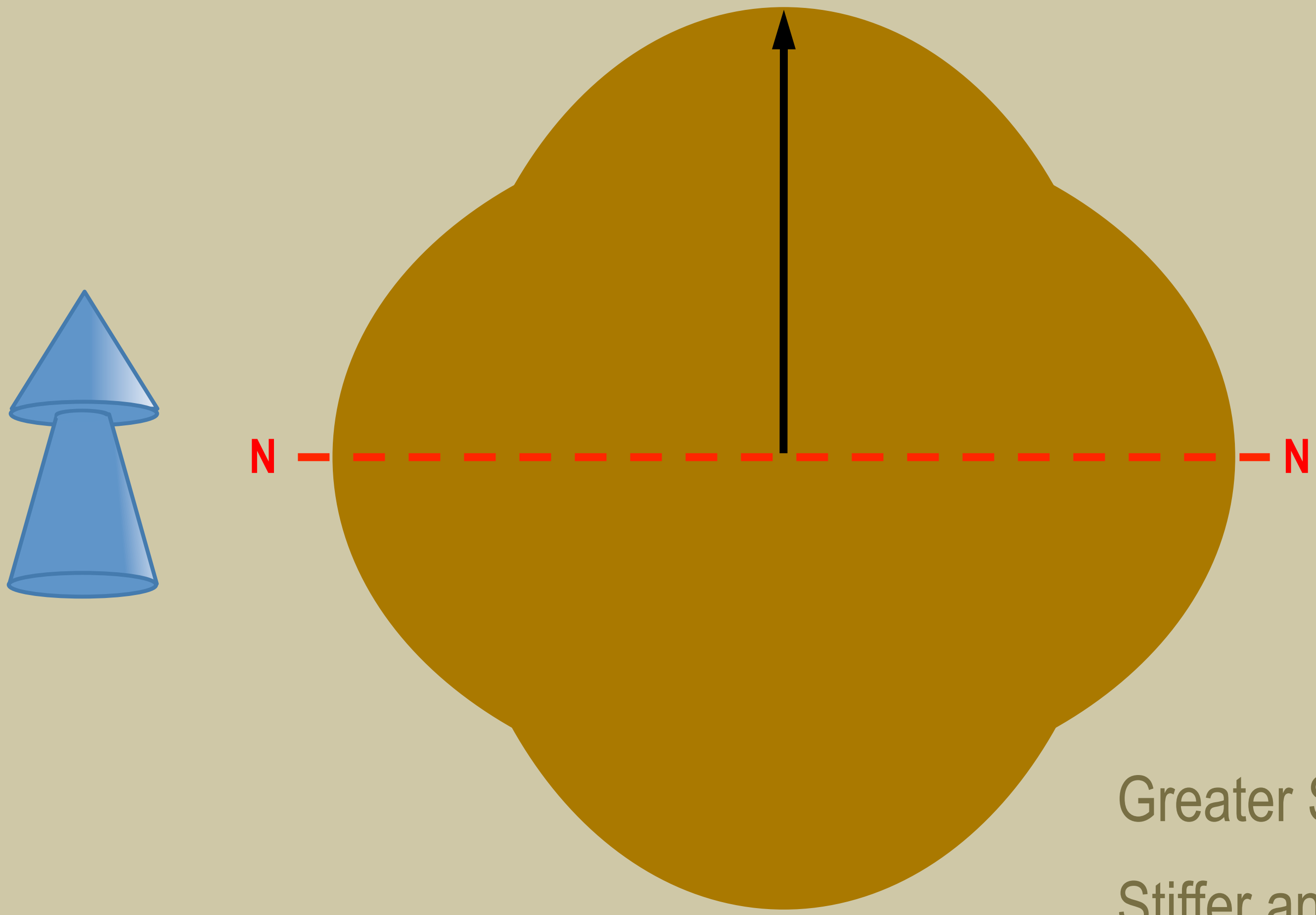
Mattheck and Breloer (1994) The Body Language of Trees

Stem Form – Section Modulus



Section Modulus (Z) represents the geometrical load bearing capacity for a cross section in bending – assuming uniform material properties

Stem Form – Section Modulus



Greater Section Modulus

Stiffer and Stronger

Growth Patterns

Stem Form – Section Modulus

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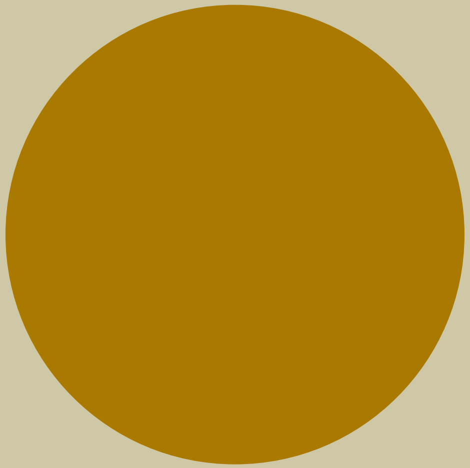


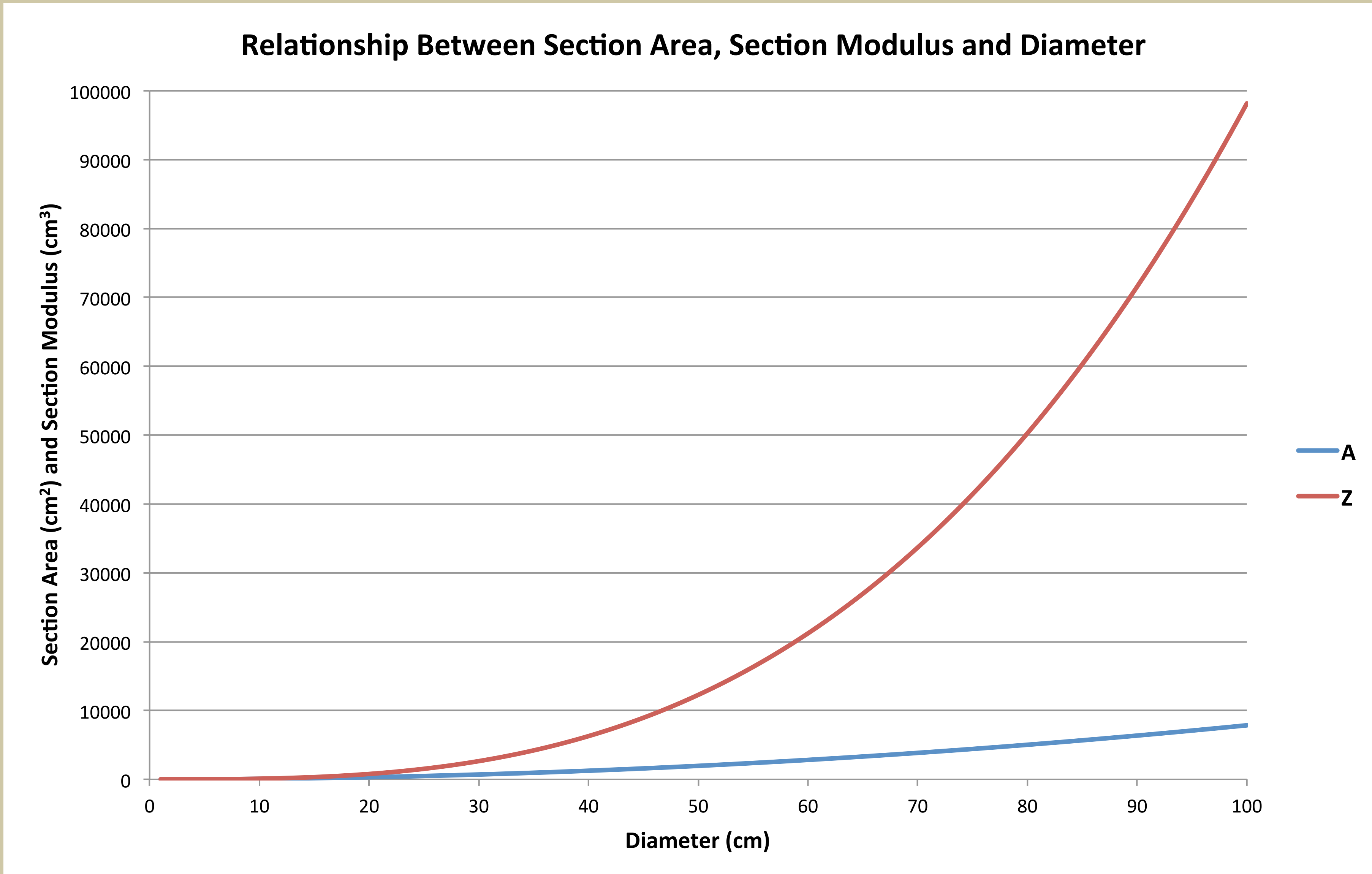
Cross Section Area $A = (\pi/2)\ d^2$

Section Modulus $Z = (\pi\ /\ 32)\ d^3$

Stem Form – Section Modulus

Stem Diameter	Cross-sectional Area	Section Modulus
50cm	1,963cm^2	12,226cm^3
100cm	7,850cm^2	98,125cm^3
200cm	31,400cm^2	785,000cm^3
Factor 2	Factor 4	Factor 8

Stem Form – Section Modulus



Stem Form – Section Modulus

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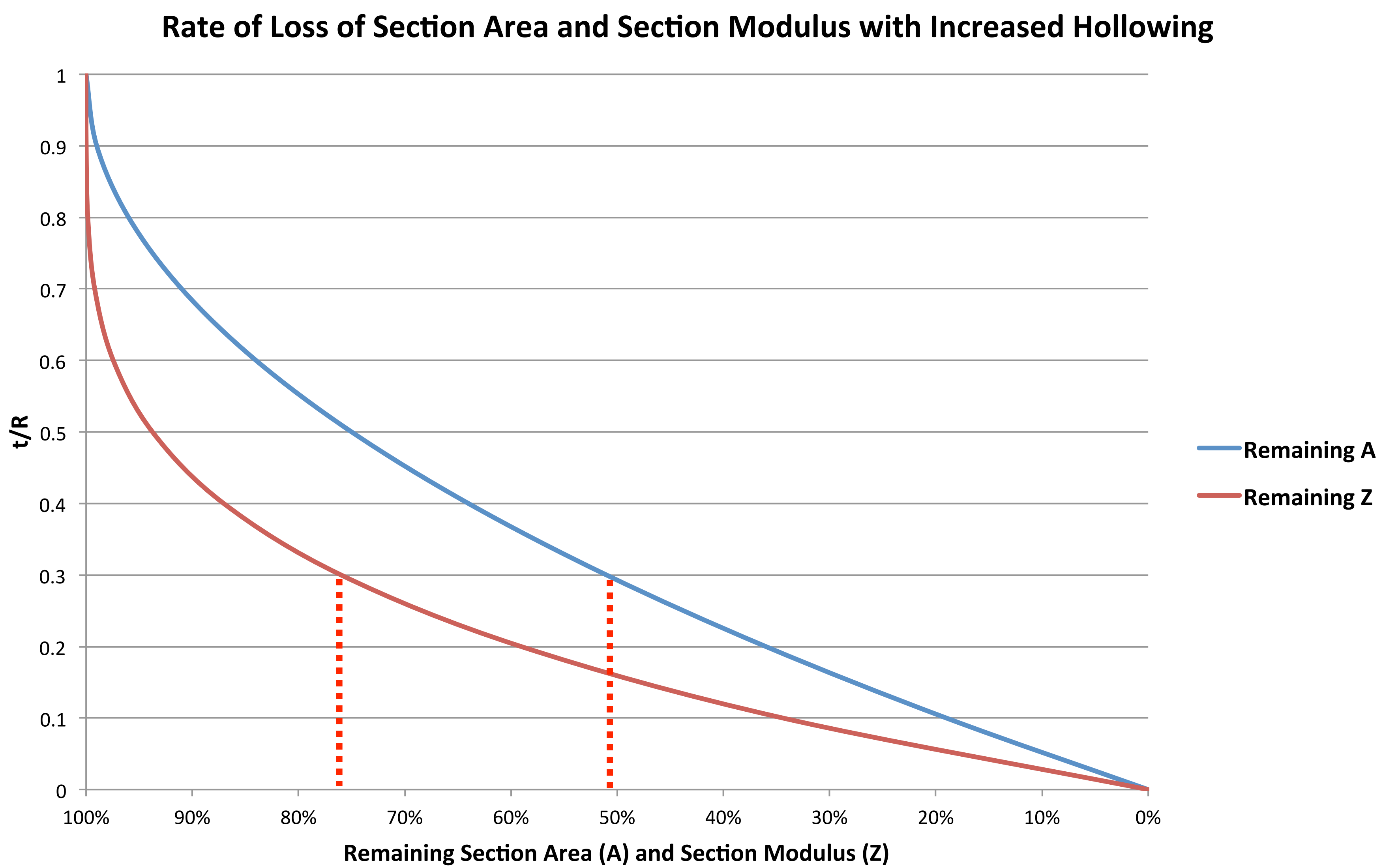

Stem Form – Section Modulus

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There is an increasing mechanical advantage derived from an increase in stem diameter

Trees with larger stem diameters can carry proportionally greater loads

Trees with larger stem diameters have greater safety factors for a given wind load

Trees with larger stem diameters can afford more decay and thinner residual walls for a given wind load

Stem Form – Section Modulus

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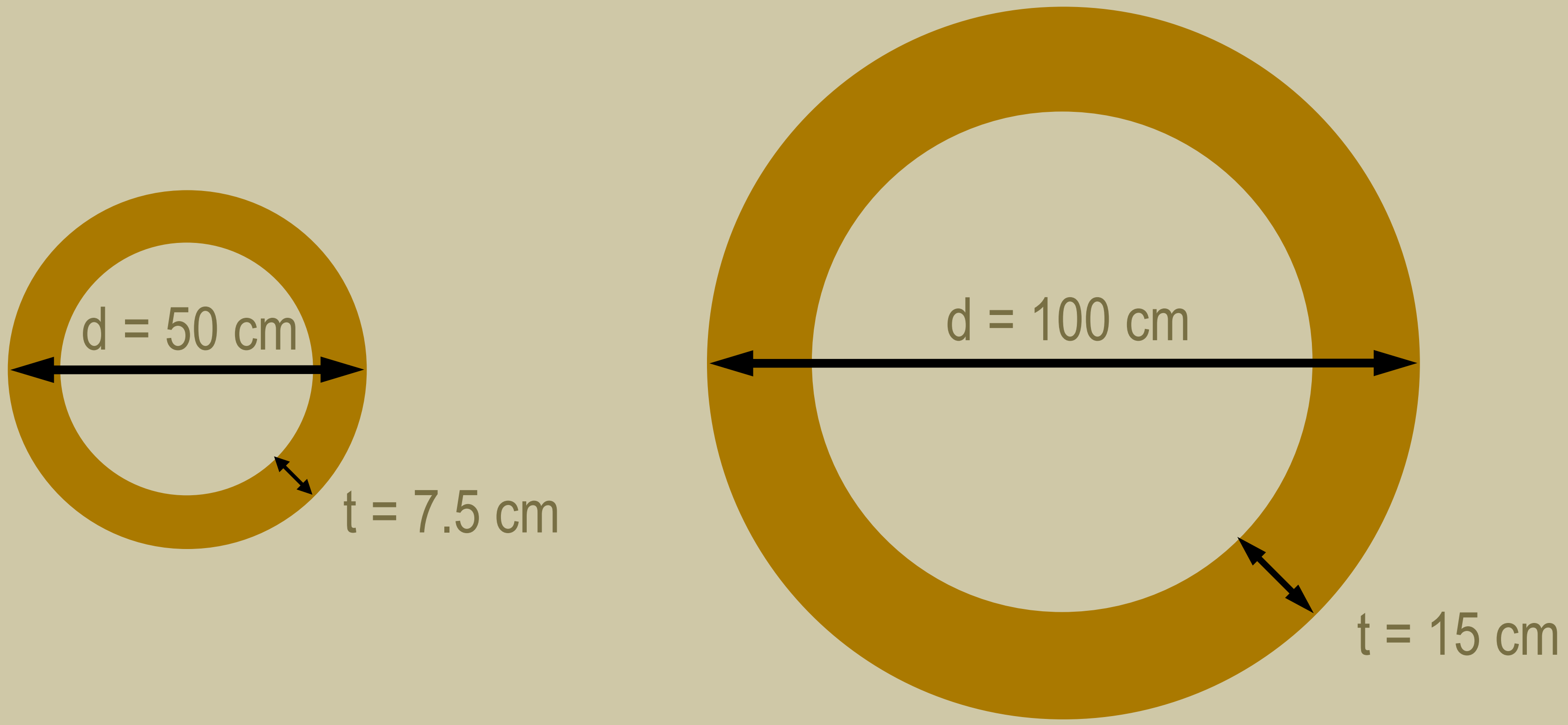

$A = 1{,}000\ cm^2$

$Z = 9{,}325\ cm^3$

$A = 4{,}000\ cm^2$

$Z = 74{,}600\ cm^3$

Stem Form – Section Modulus

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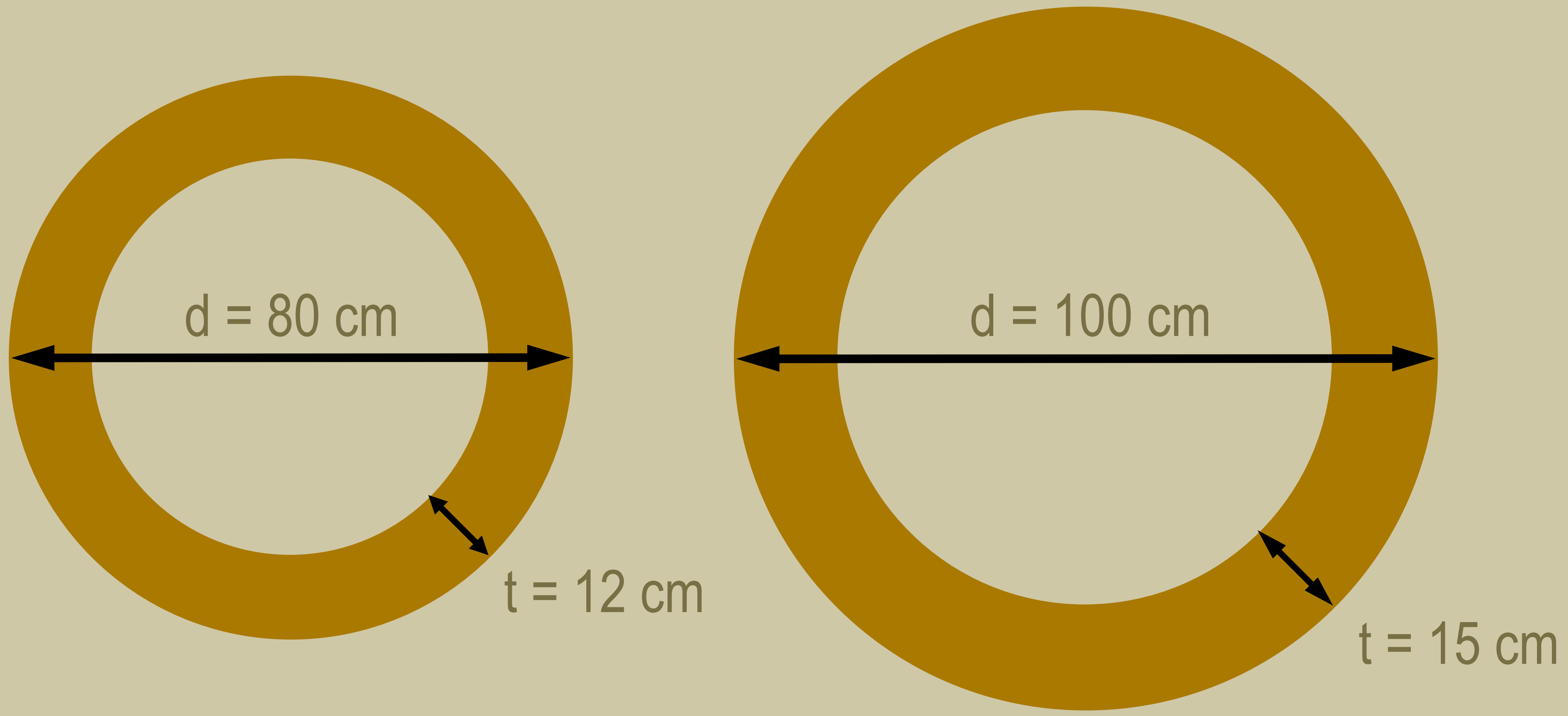


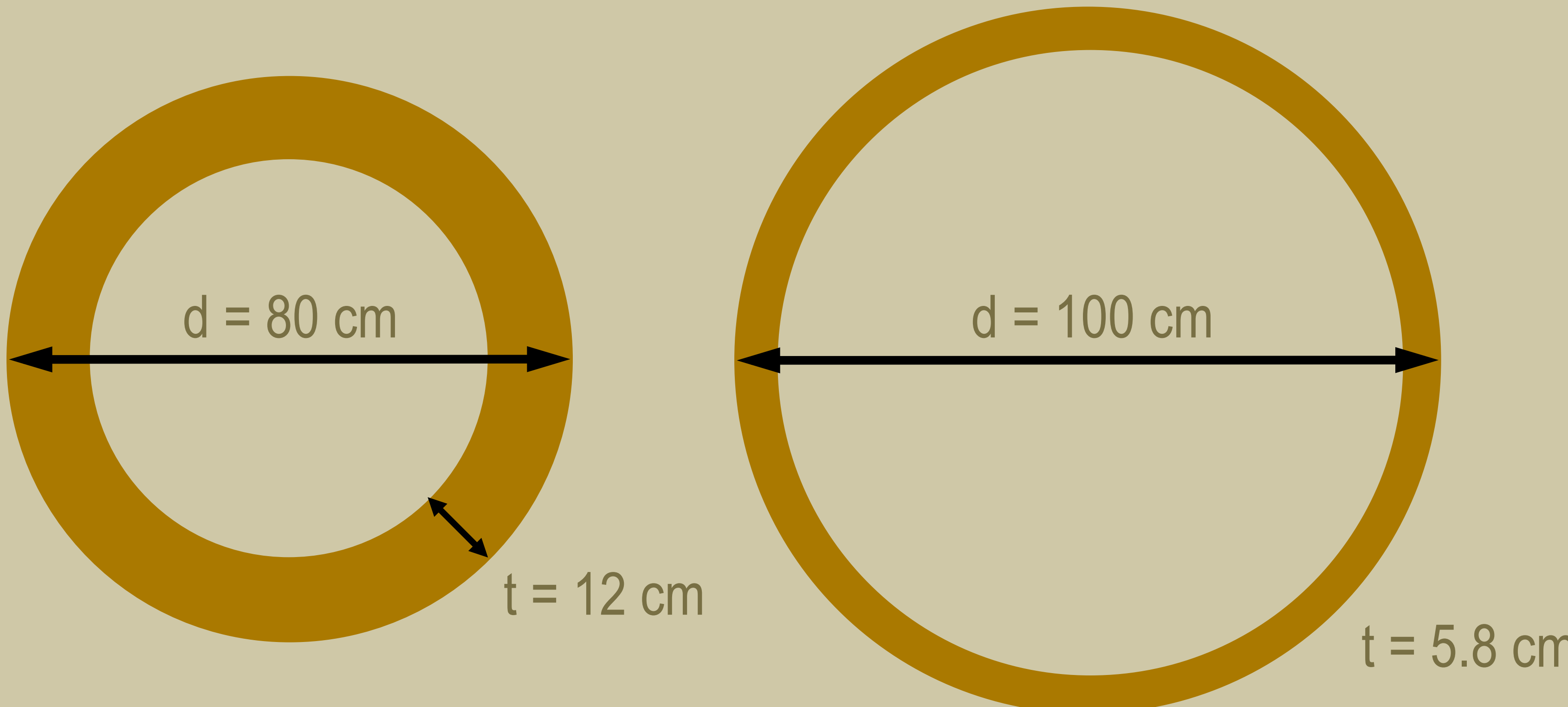
A = 2,560 cm^2

Z = 38,200 cm^3

A = 4,000 cm^2

Z = 74,600 cm^3

Stem Form – Section Modulus



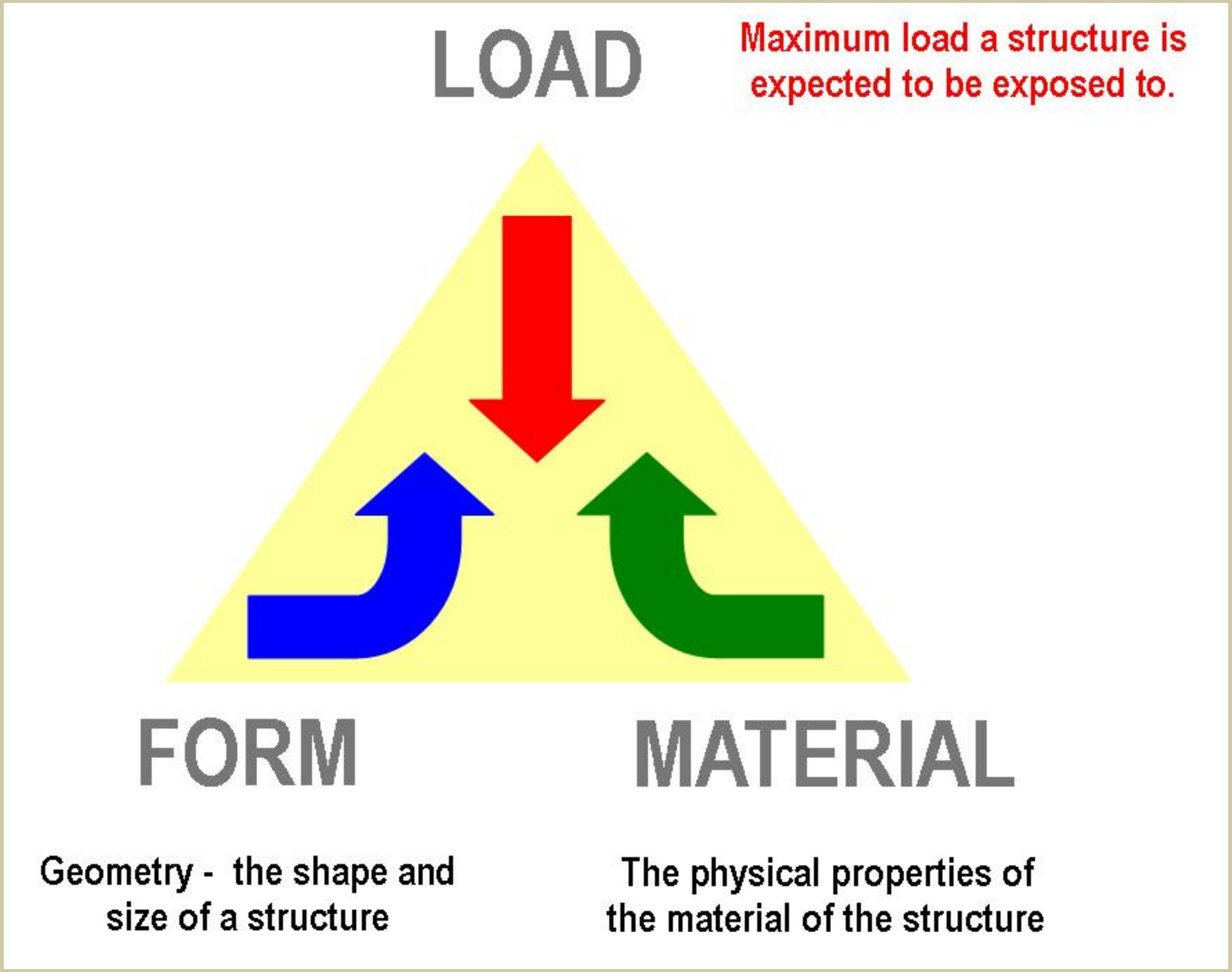
$A = 2{,}560\ cm^2$

$Z = 38{,}200\ cm^3$

$A = 1{,}716\ cm^2$

$Z = 38{,}200\ cm^3$

The Triangle of Statics



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t/R – A Useful Failure Criteria?

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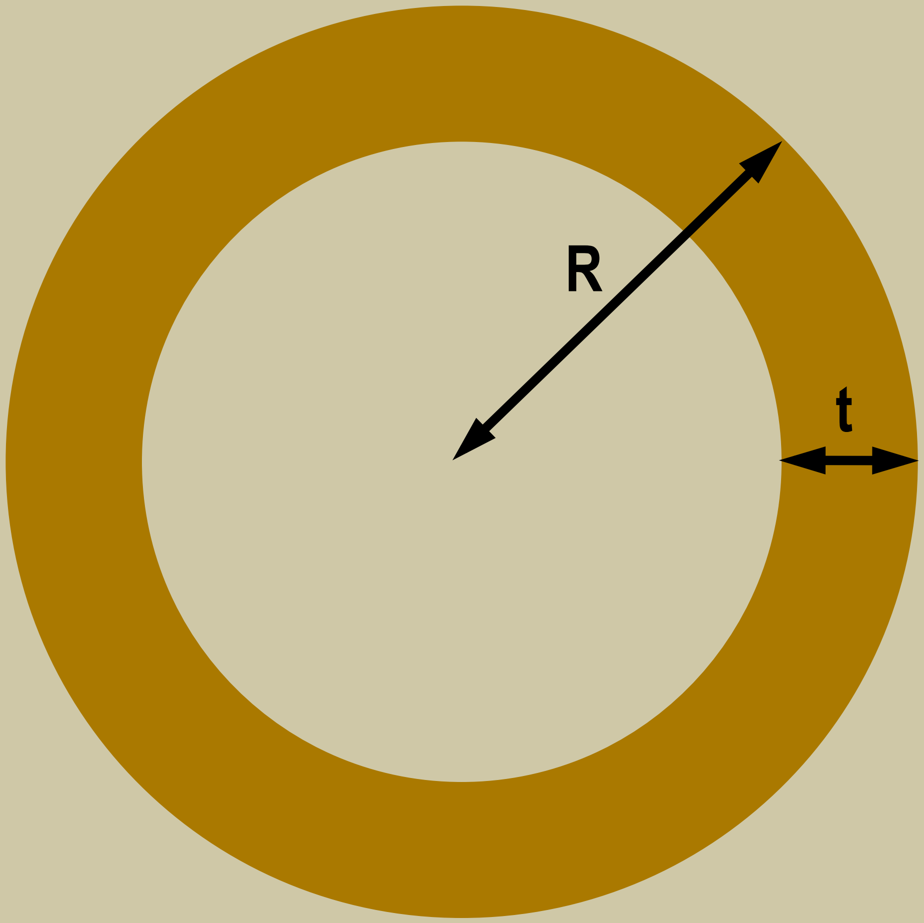
70% Hollow



t/R = 0.3

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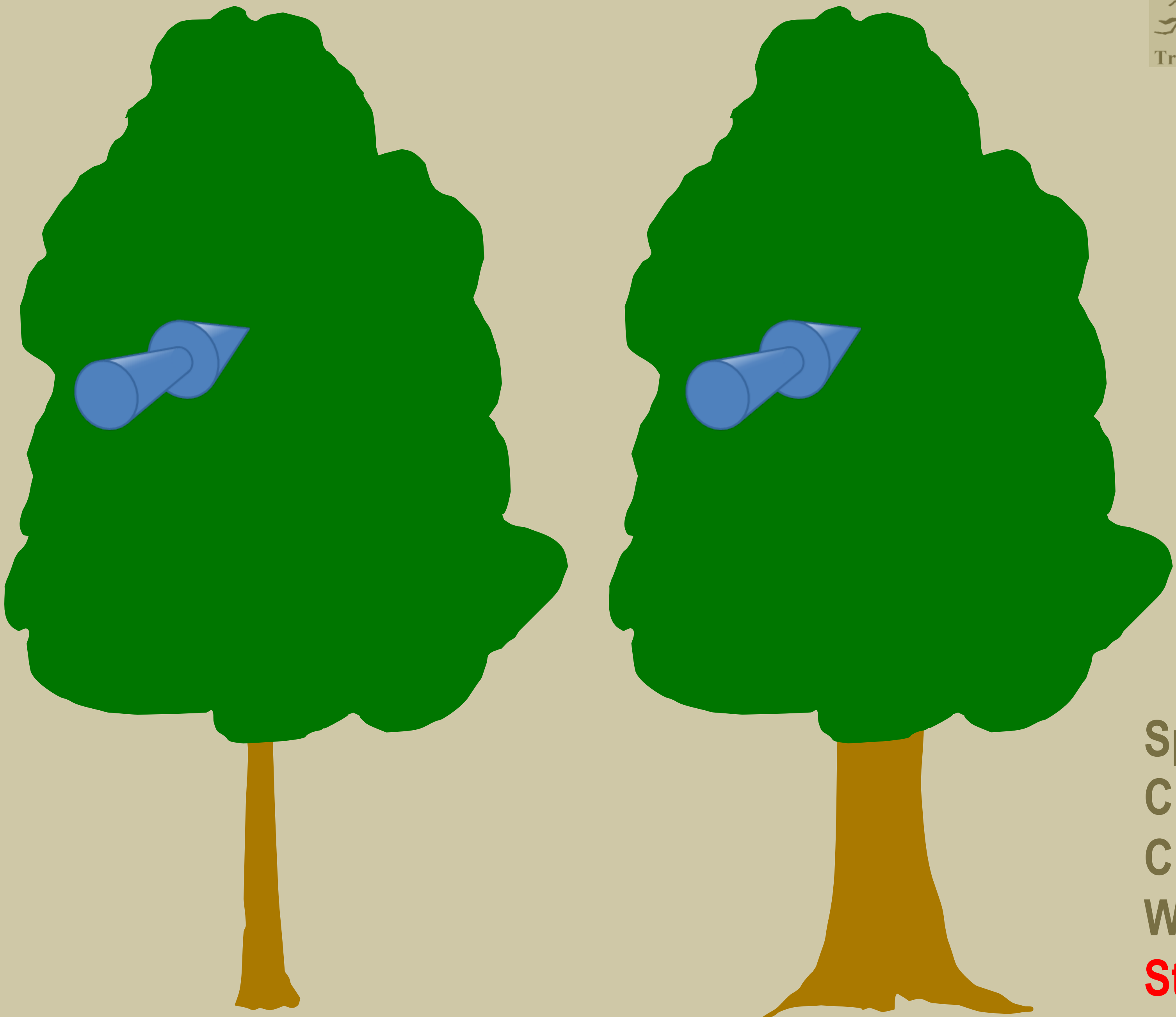

Species

Crown Height

Crown Spread

Wind Speed

Stem Ø

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Species

Crown Height

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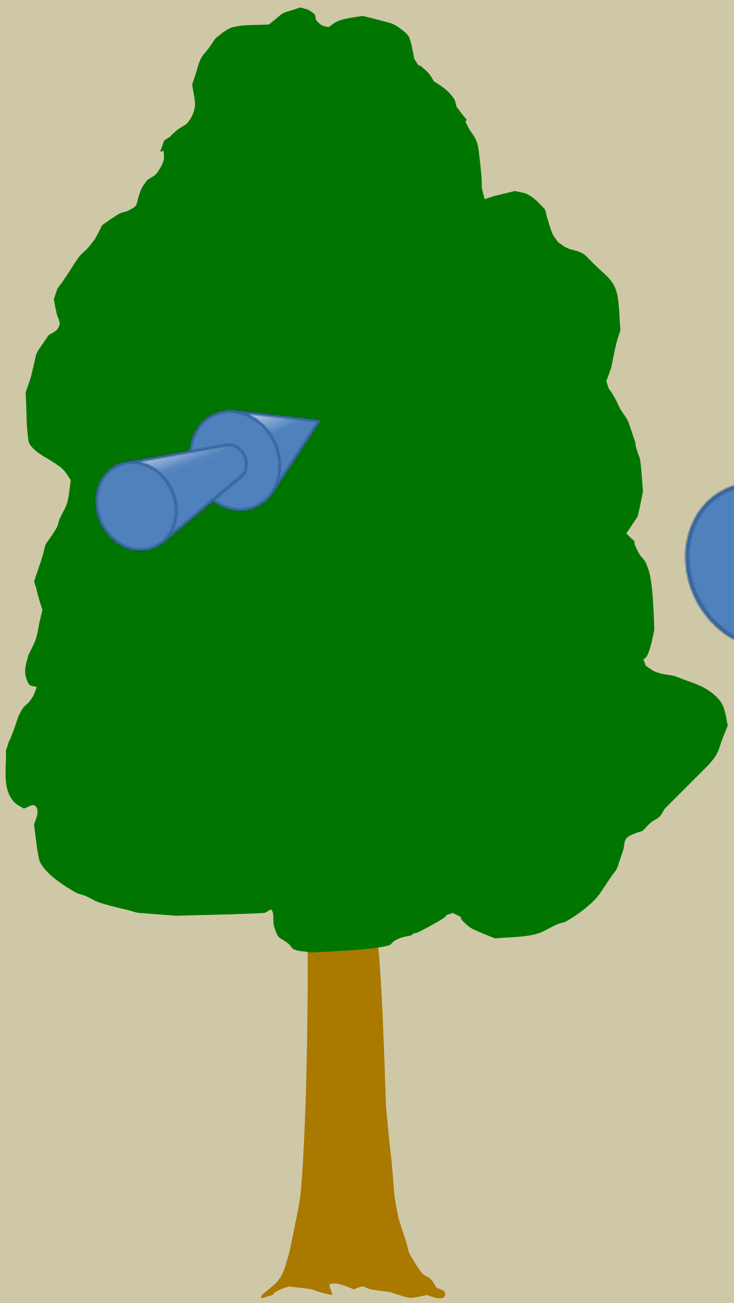

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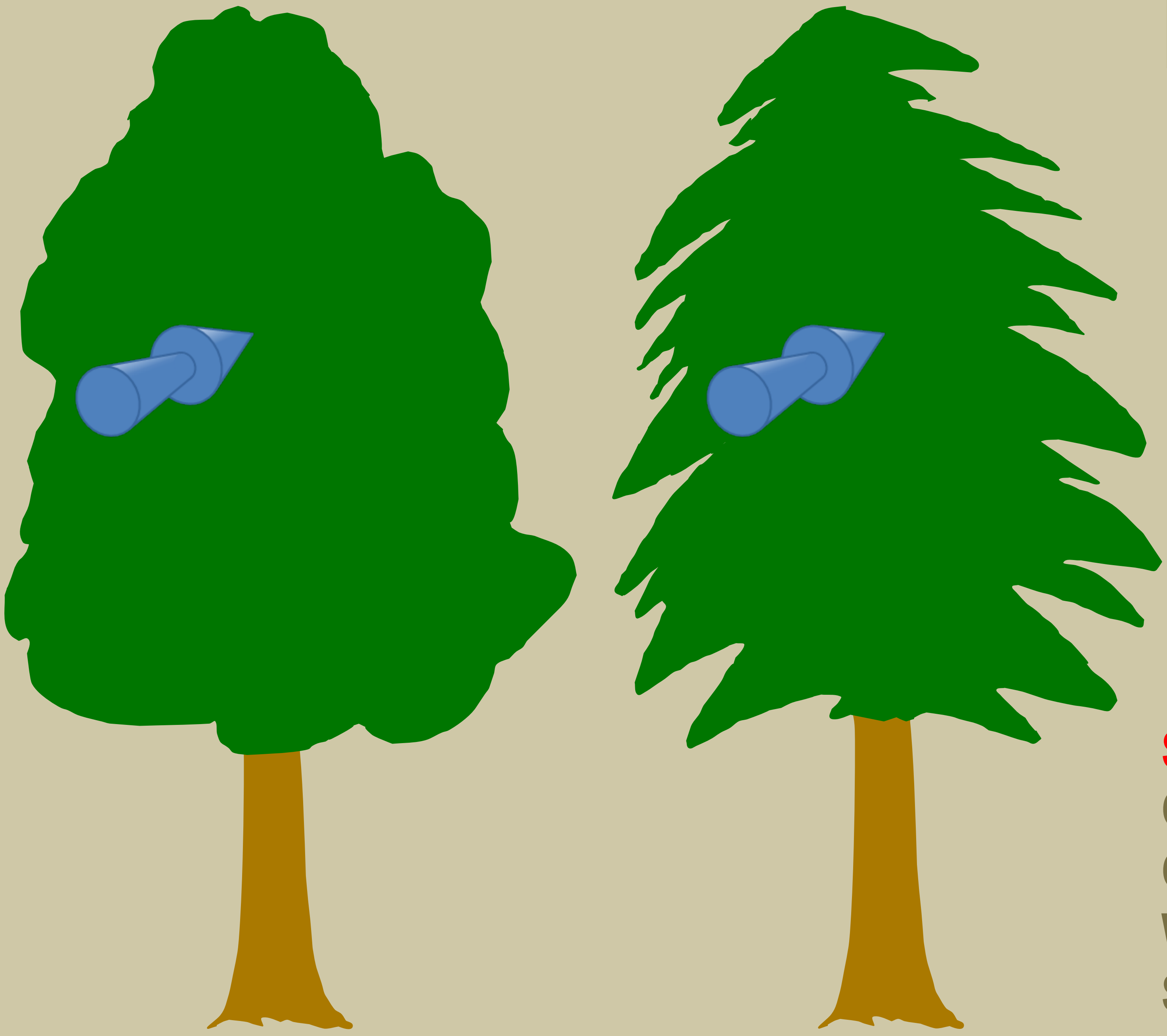
Species

Crown Height

Crown Spread

Wind Speed

Stem Ø



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Species

Crown Height

Crown Spread

Wind Speed

Stem Ø

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