Innovative Timber Composites:

Improving wood with other materials

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Summary of shear connector methods for timber - concrete composites

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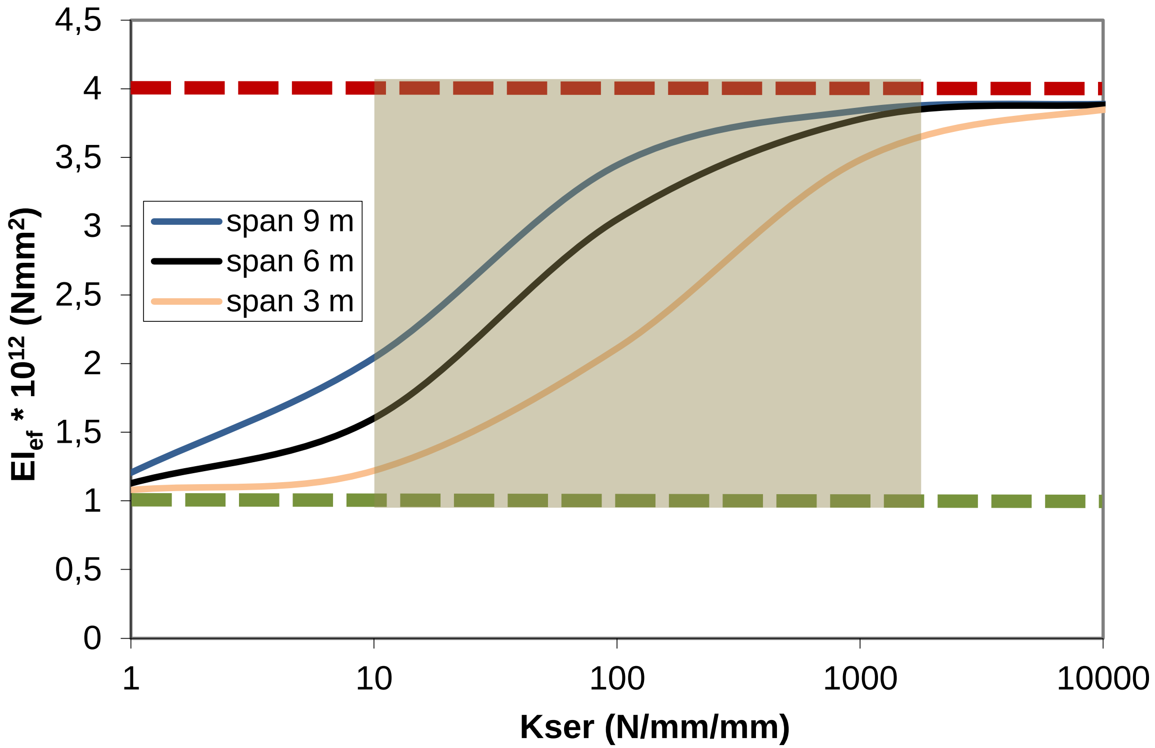
Outline

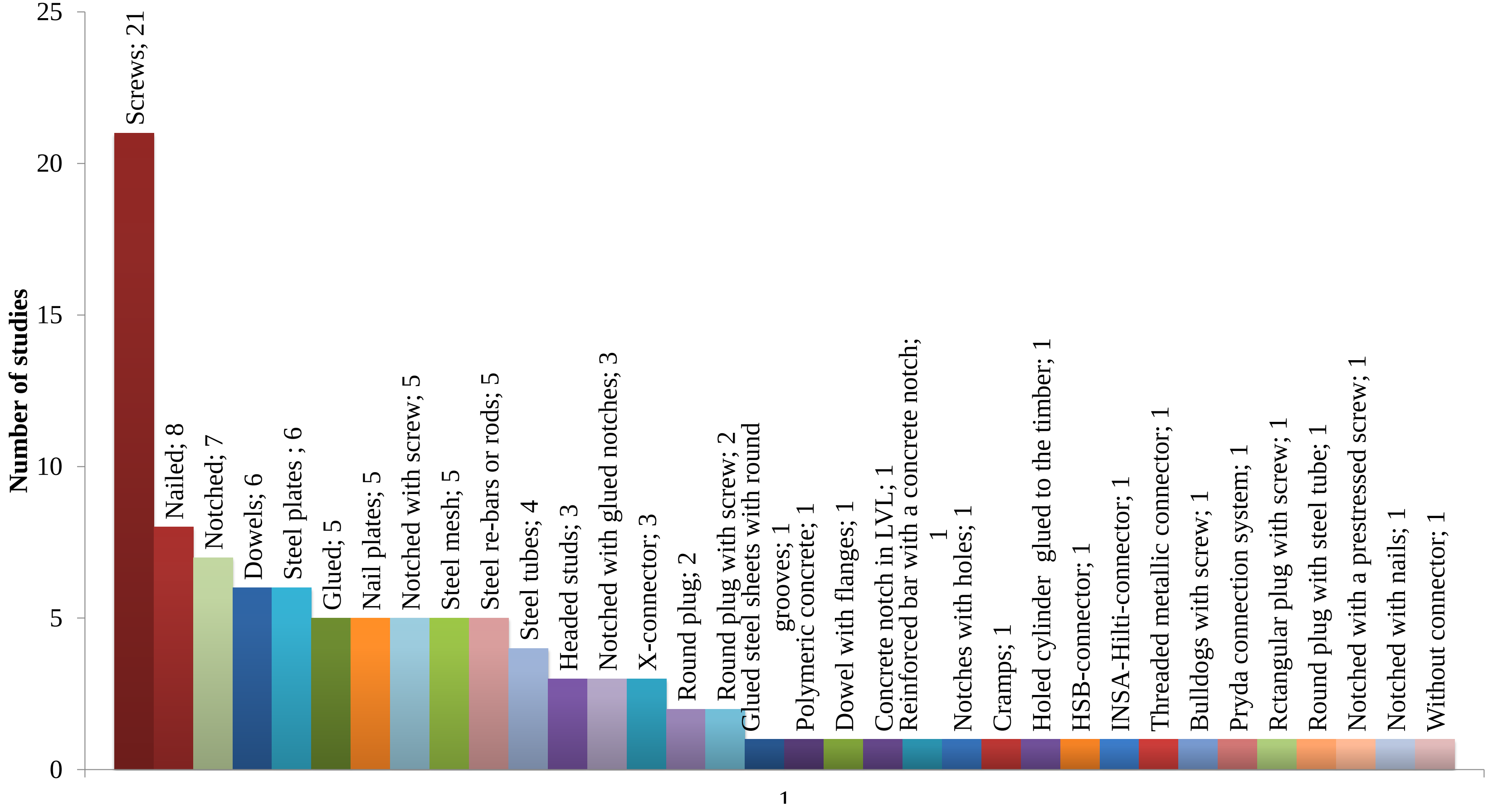
- **Types of timber-concrete connections**
- **Assessment of the connection mechanical properties**
- **Mechanical properties for linear-elastic analysis**
- **Mechanical properties for non-linear analysis**

Types of Timber-Concrete Connections

Importance of the connection

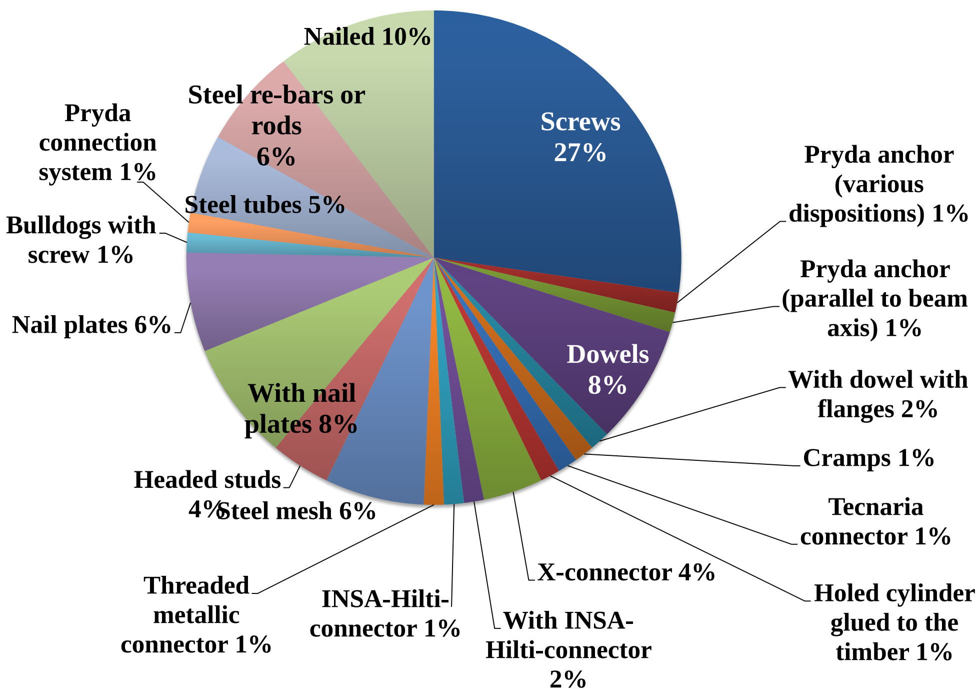


Connection types usually used

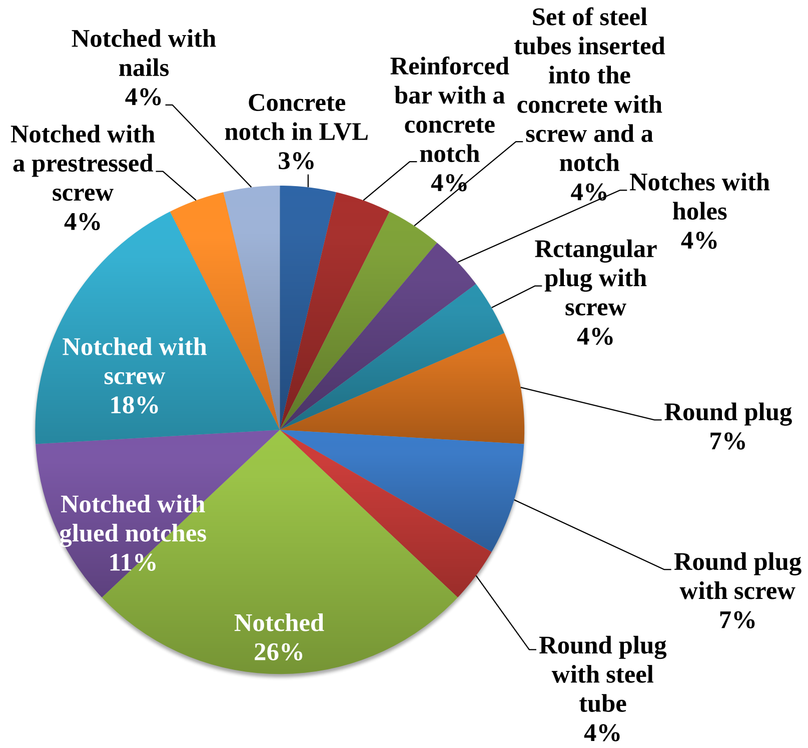


Types of Timber-Concrete Connections

➢ Connections with steel fasteners



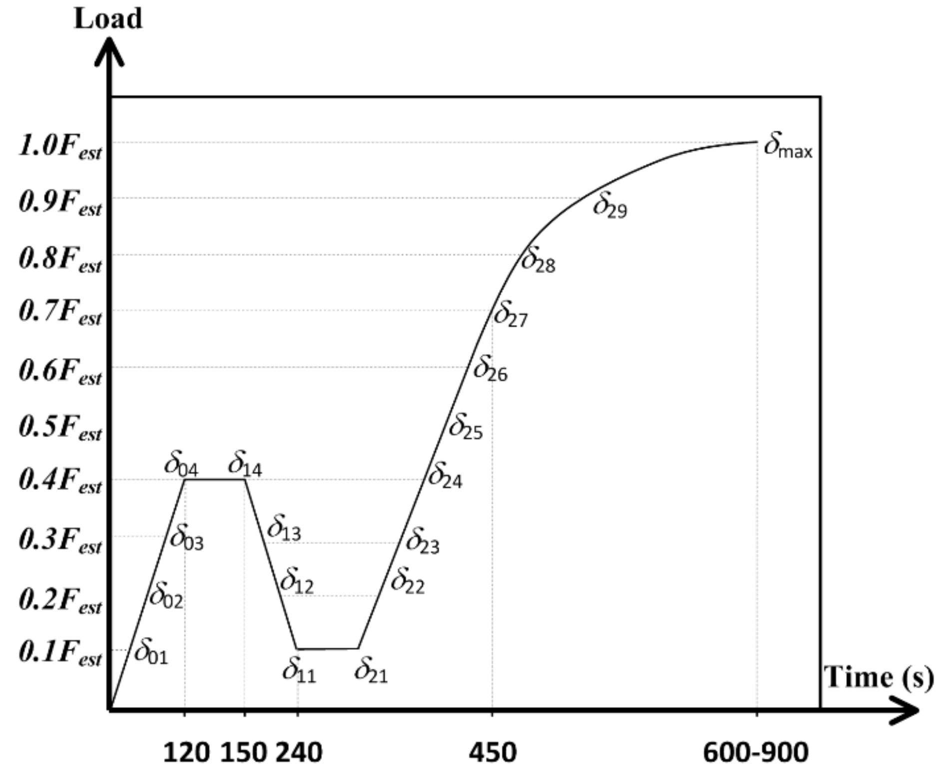
➢Notched connections



Assessment of the connection mechanical properties

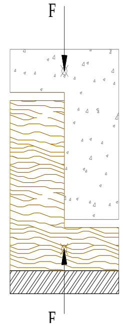
There is no standard for the assessment of timber-concrete connections. Most of times, EN ISO 26891 is followed in this type of test, which gives specific indications for various issues, namely:

- **Loading procedure**
- **Measurements**
- **Test report**
- **Very general indications for dimensions and config.**

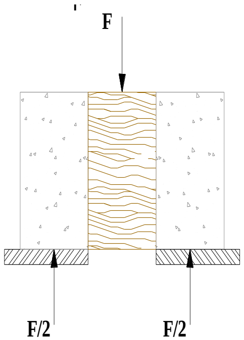


There are three main test configurations used in experimental tests:

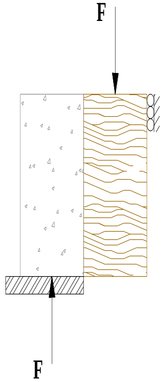
- **Pure shear**



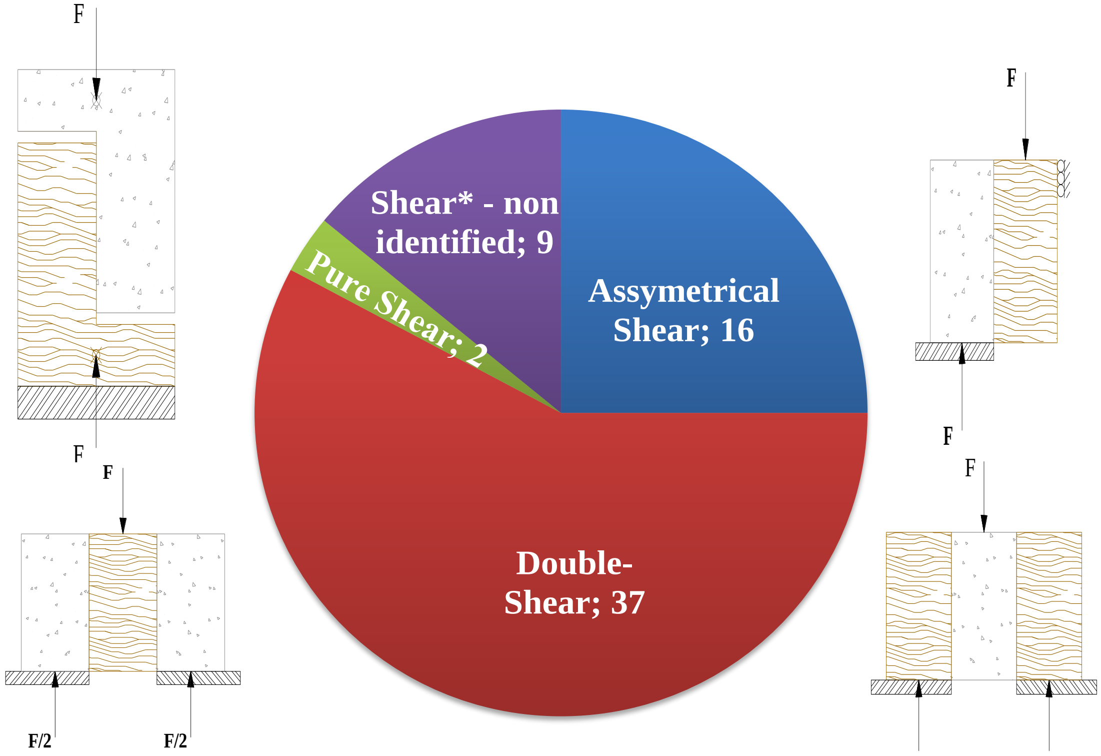
- **Double shear push-out**



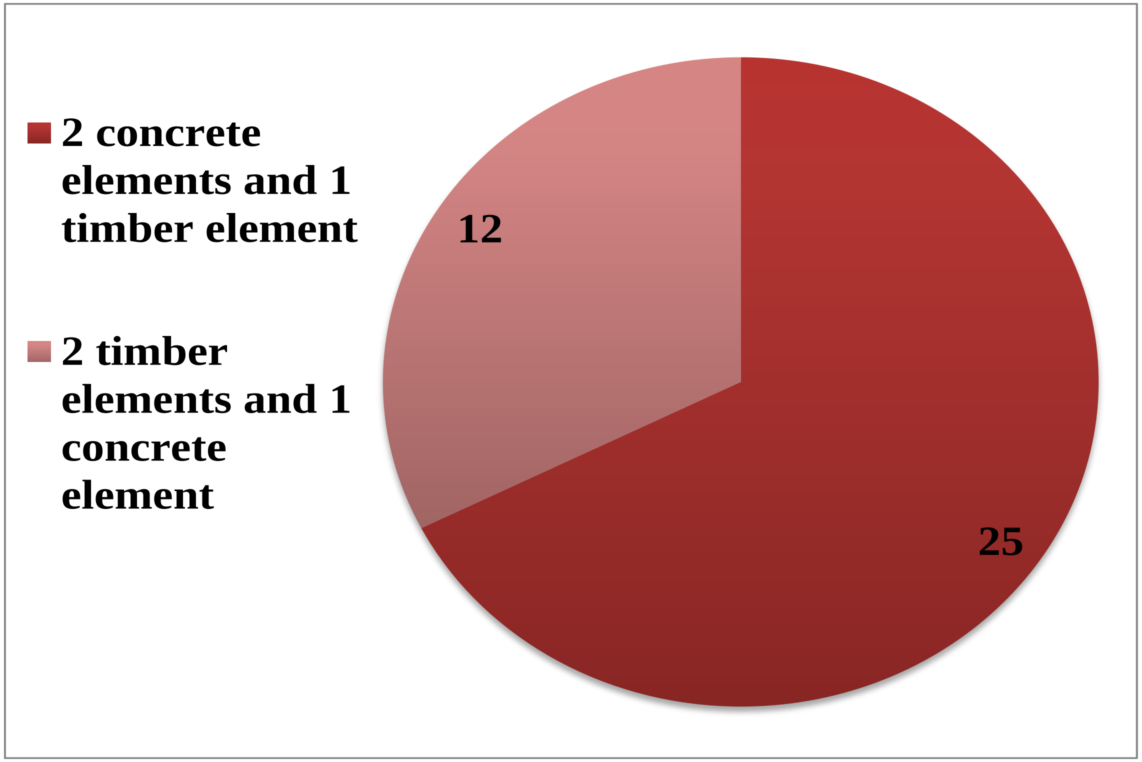
- **Single shear push-out**



Types of test set up most often used

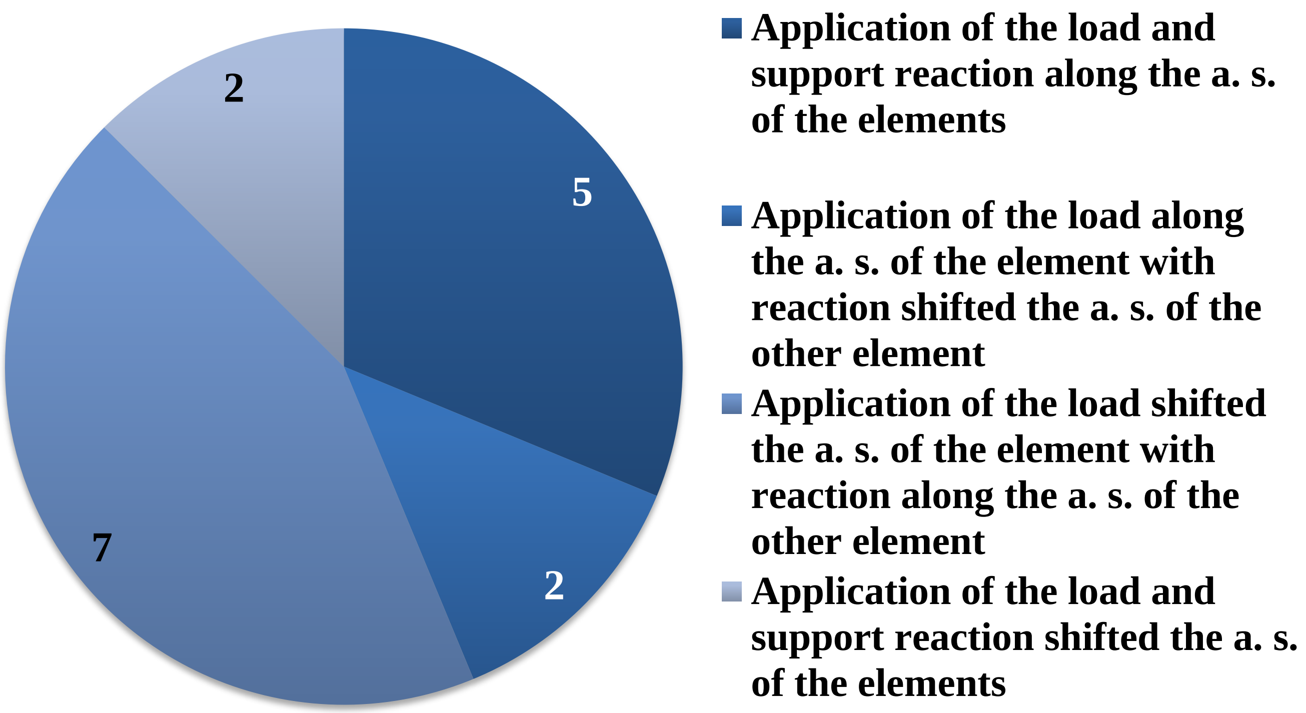


- Types of double shear



Assessment of the connection mechanical properties

➢ **Load application in double shear configurations**



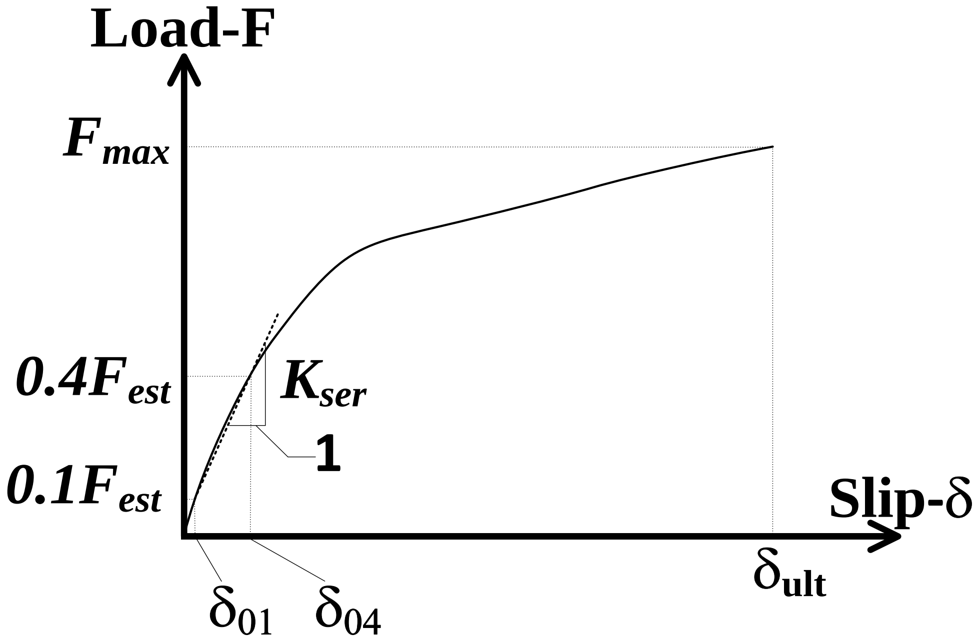
Numerical and experimental results available in Literature show that:

- **The maximum magnitude of the difference using the various test set up is usually lower than 5%**
- **The highest differences shall be expected between the pure shear and the asymmetrical push-out test**

Mechanical properties for linear-elastic analysis

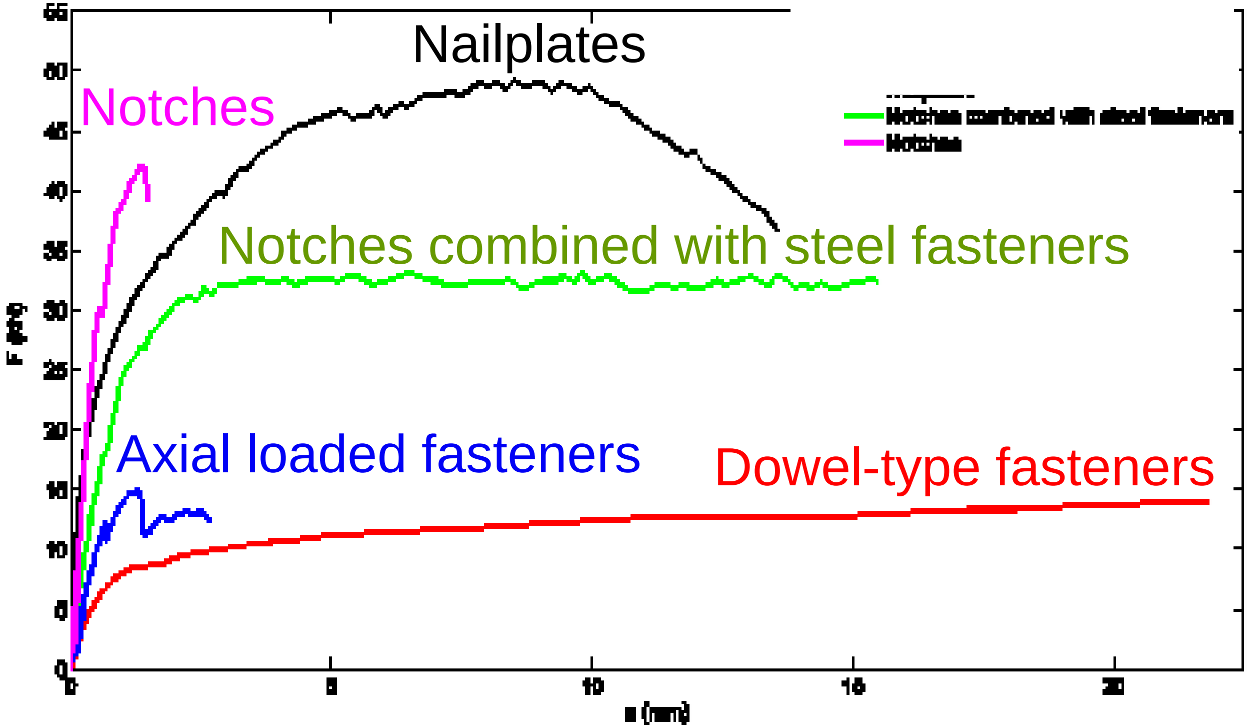
The most used linear elastic model is the one given in Annex B from Eurocode 5. The properties required in the analysis are:

- **Slip modulus – K_{ser} (Stiffness)**
- **Maximum load – F_{max} (Load carrying capacity)**



Mechanical properties for linear-elastic analysis

➢**Types of connection find in literaturegrouped by mechanical behaviour**



Mechanical properties for linear-elastic analysis

➢ **Sample considered in the analysis and outliers (Grubb's test)**

Connection	Nr. tests	Outliers	
		Stiffness	Strength
Dowel-type fasteners	263	3	0
Axially loaded fasteners	438	3	0
Notches	204	2	1
Notches combined with steel fasteners	51	0	0
Nail plates	65	1	0

Mechanical properties for linear-elastic analysis

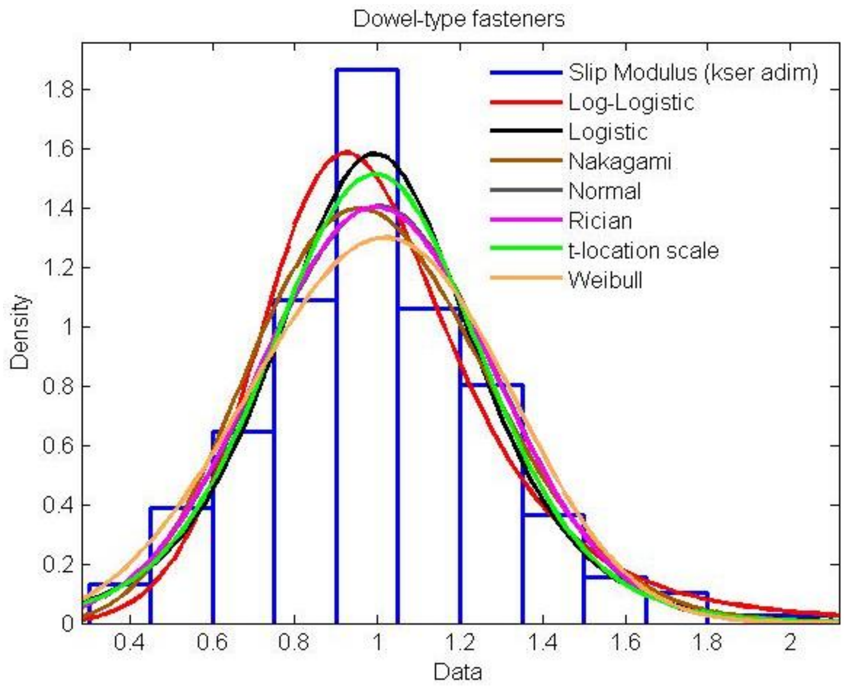
Procedure followed:

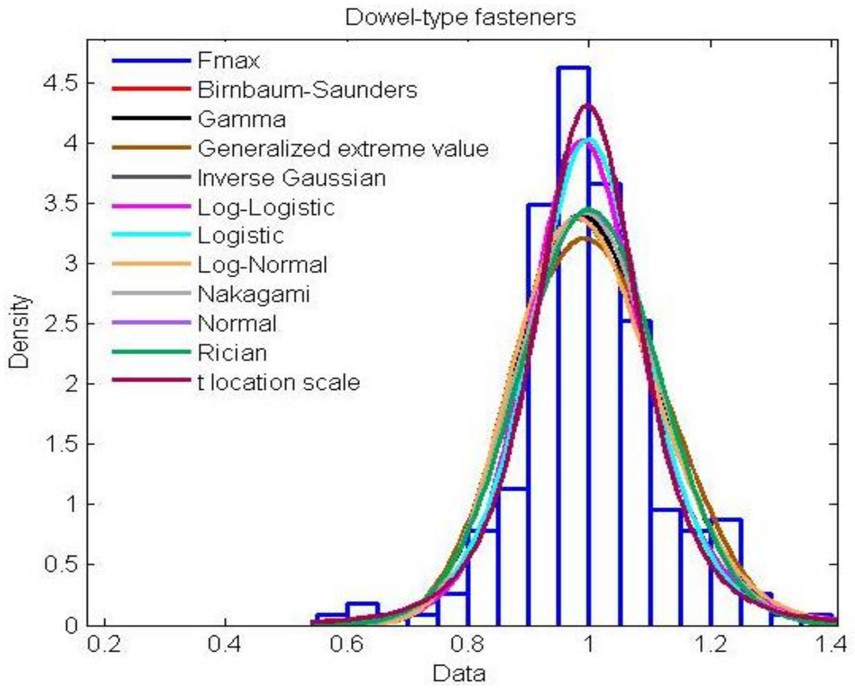
- **The values of the mechanical properties were made dimension less for the maximum from each test series**

- **Outliers were identified and excluded**

- **Different statistical distributions were fitted to the sample**

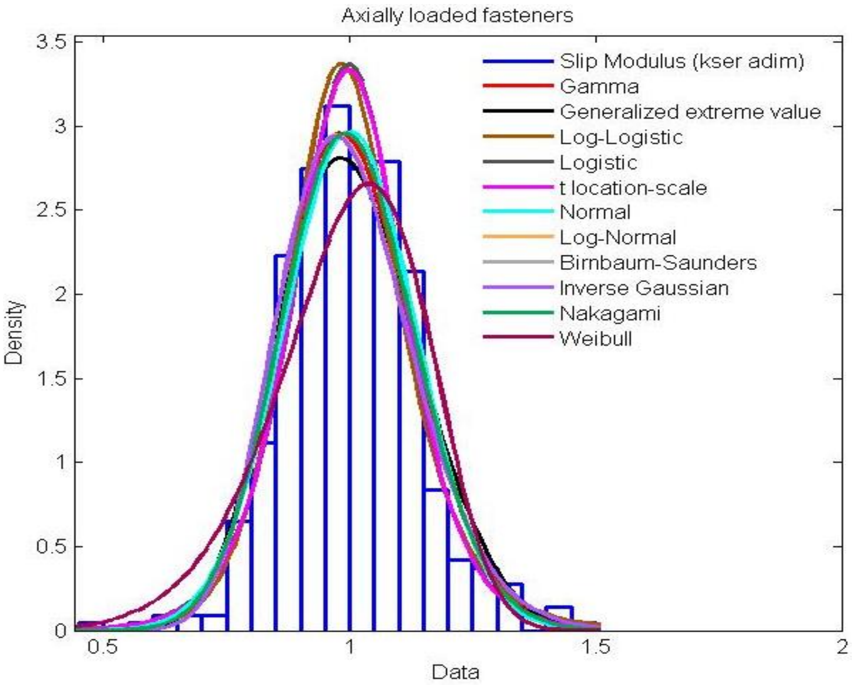
➢ Dowel type fasteners

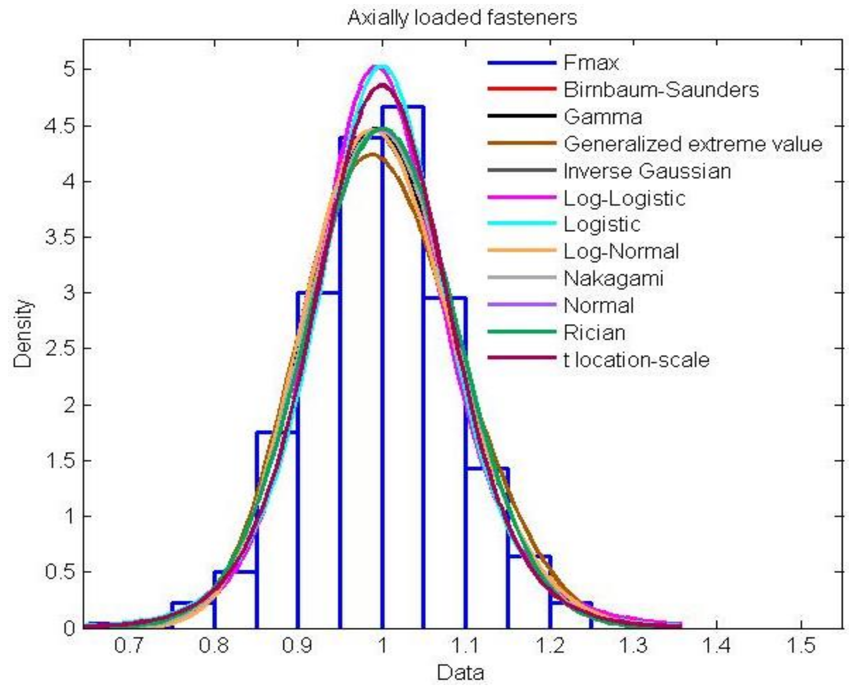




Mechanical properties for linear-elastic analysis

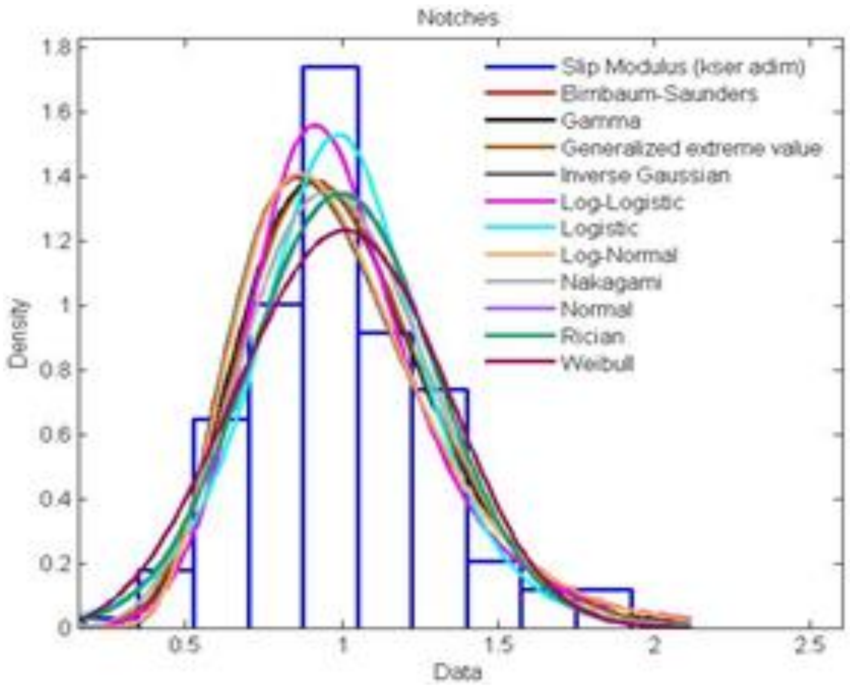
➢Axially loaded fasteners

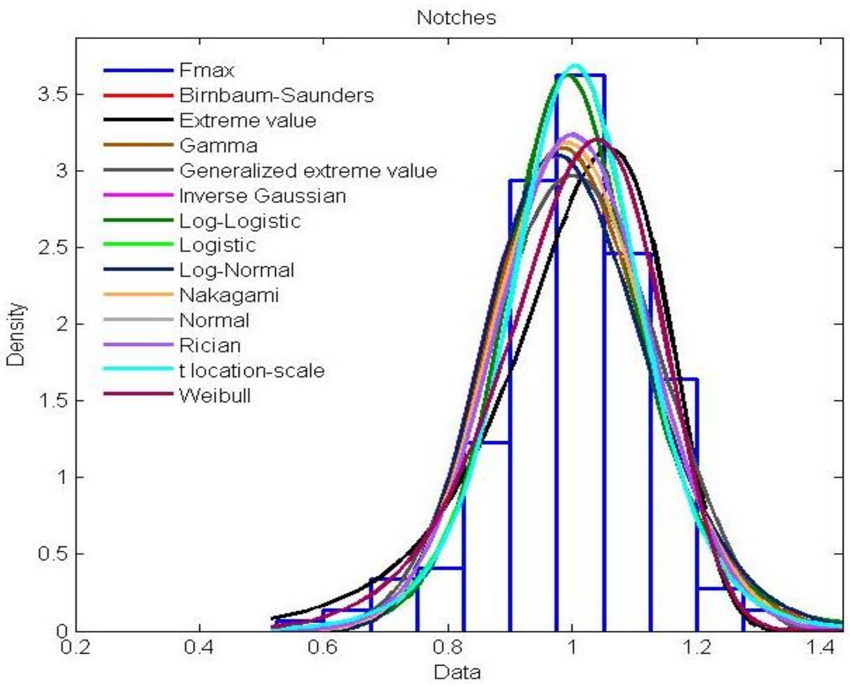




Mechanical properties for linear-elastic analysis

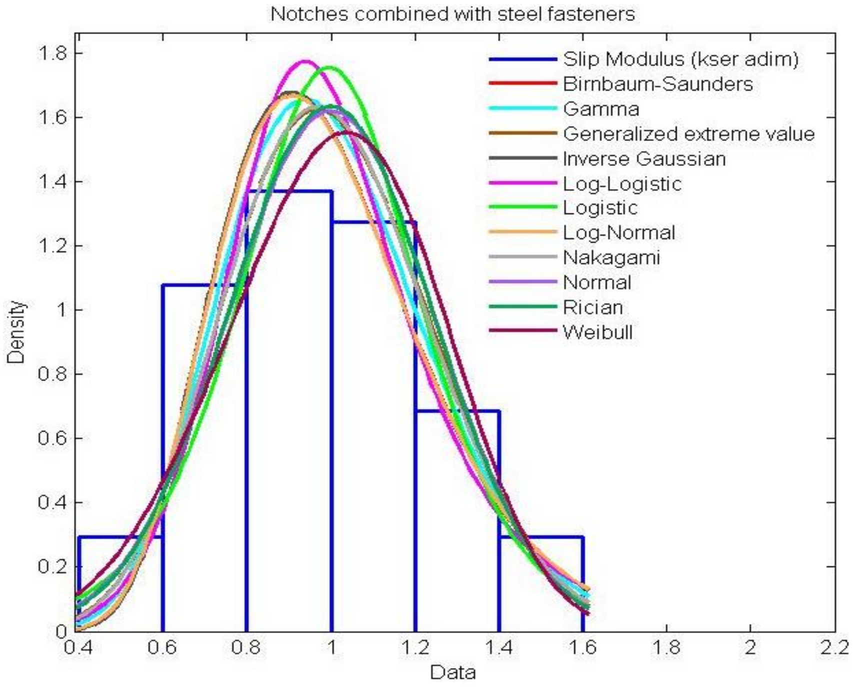
➢Notches

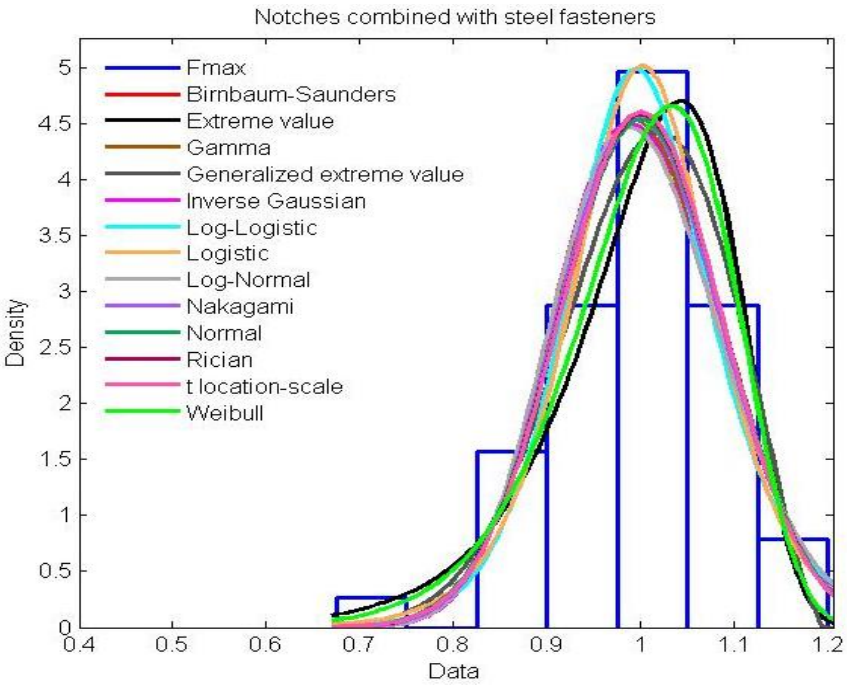




Mechanical properties for linear-elastic analysis

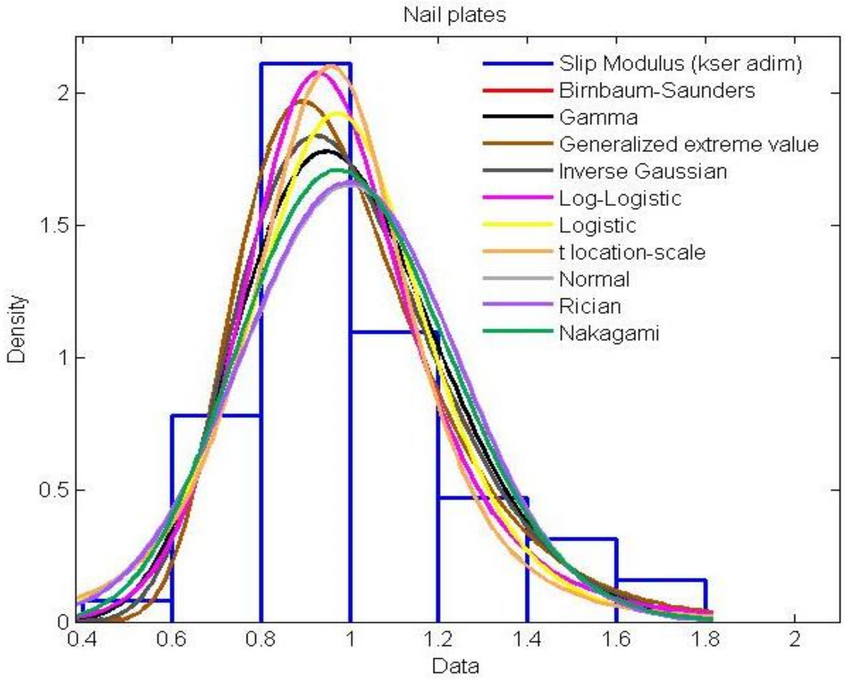
➢Notches combined with steel fasteners

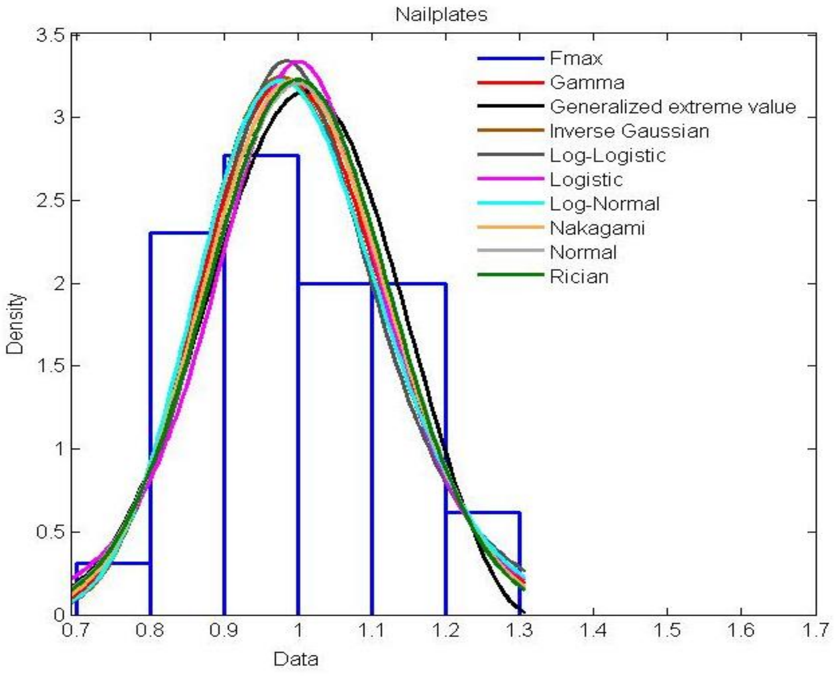




Mechanical properties for linear-elastic analysis

➢**Notches combined with steel fasteners**





Mechanical properties for linear-elastic analysis

- **Global results**

Variable	k_{ser}^{adim}				F_{max}^{adim}			
	s	v (%)	η	κ	s	v(%)	η	κ
Dowel-type fasteners	0.284	28.4	0.36	3.54	0.113	11.3	−0.06	4.52
Axially loaded fasteners	0.140	14.0	0.15	4.08	0.089	8.9	0.09	2.88
Notches	0.296	29.6	0.56	3.83	0.124	12.4	−0.45	3.89
Notches combined with steel fasteners	0.246	24.6	0.19	2.32	0.088	8.8	−0.31	2.92
Nail plates	0.241	24.1	0.98	3.59	0.124	12.4	0.02	1.82

Mechanical properties for linear-elastic analysis

Results

- **The slip modulus showed a high coefficient of variation (between 14% and 30%)**

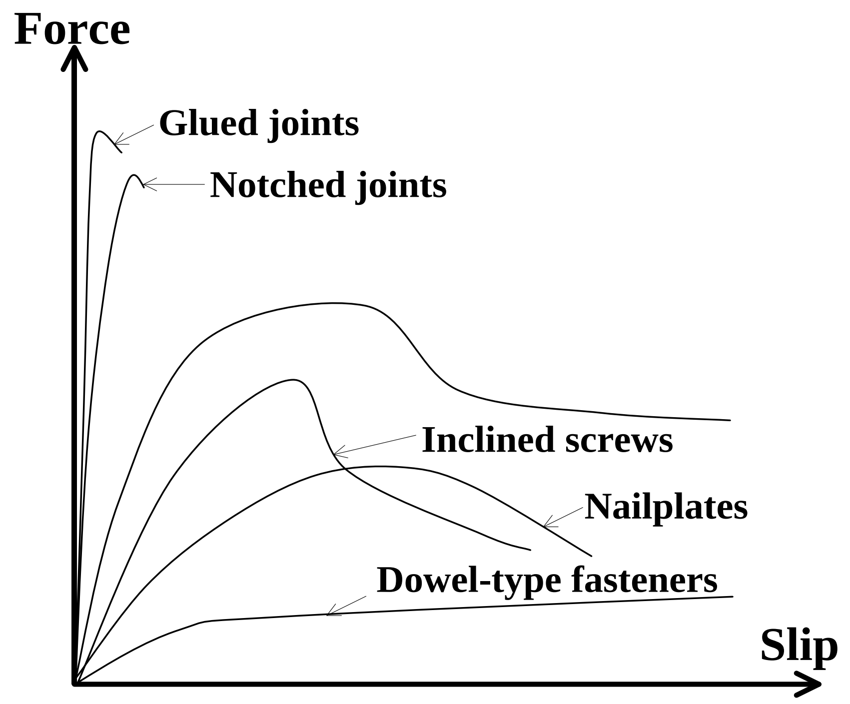
- **Load carrying capacity of the connections showed a lower coefficient of variation (around 10%)**

- **In most cases the normal distribution was identified as the best statistical distribution**

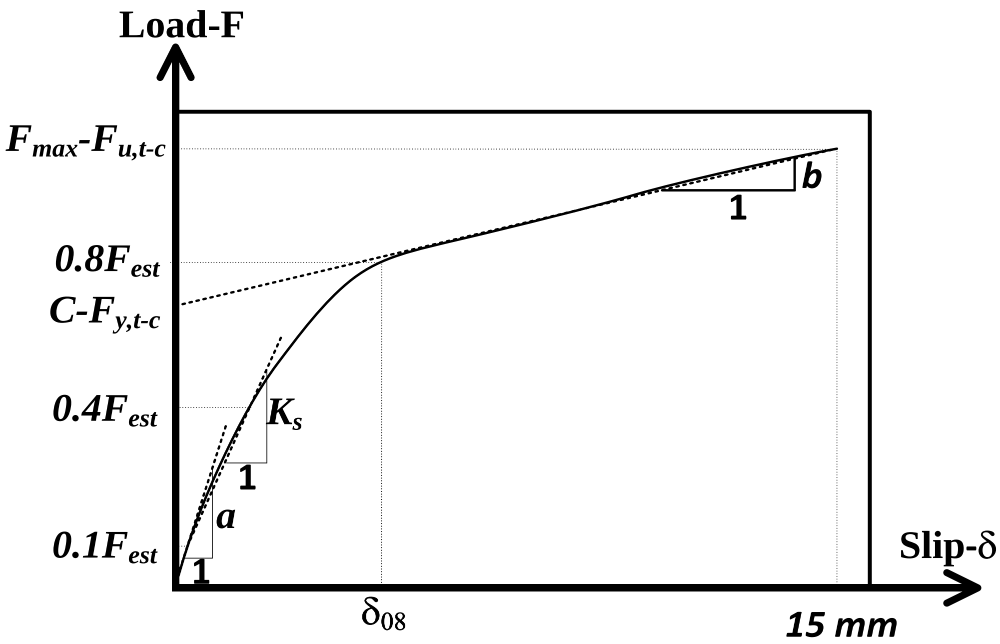
- **The correlation found between these two mechanical properties was low 0.38**

Mechanical properties for non-linear analysis

For non-linear analysis the numerical models are used (e.g. FEM). In this type of analysis the whole load slip curve of the connection is necessary.

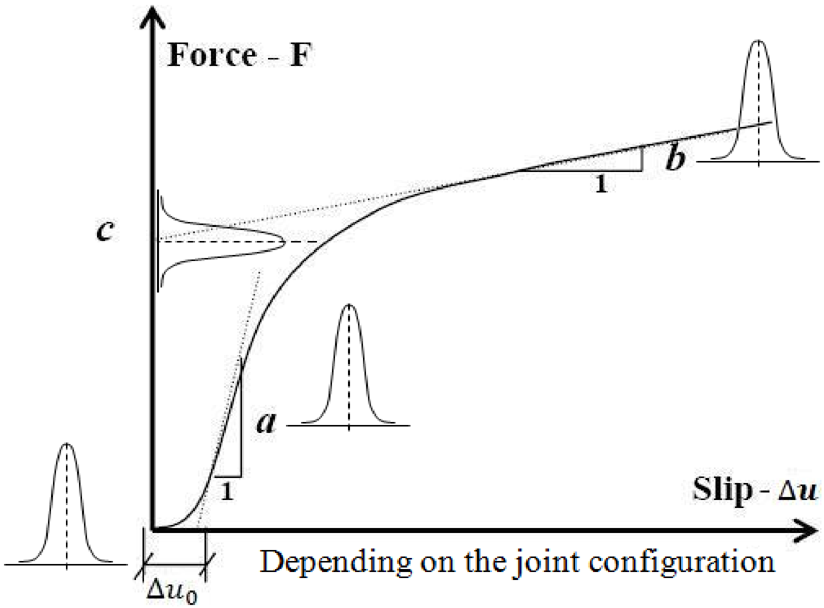


Recent studies show that in some situations accurate descriptions can be obtained based in the linear elastic properties obtained, either from tests or from models.



Descriptive models

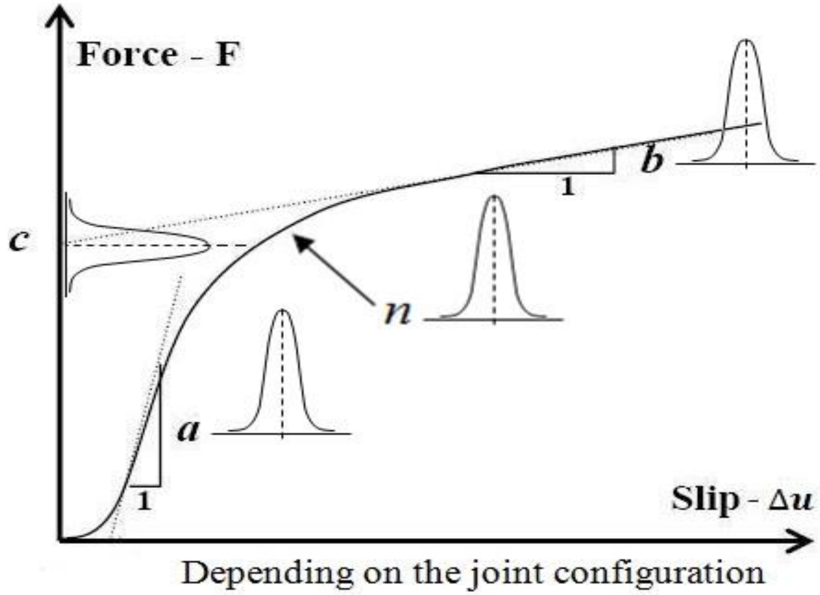
Foschi – 3 parameter – $F = (c + b\Delta u)\left(1 - e^{\frac{-a\Delta u}{c}}\right) \leq F_{max}$



Foschi RO. Load-slip Characteristics of Nails. Wood Science. 1974;7(1):69-76.

Descriptive models

Goldberg-Richard-Abbott-Richard – 4 parameter- $F = \frac{(a-b)\Delta u}{\left[1+\left(\frac{(a-b)}{c}\Delta u\right)^{n}\right]^{\frac{1}{n}}} + b\Delta u \leq F_{max}$

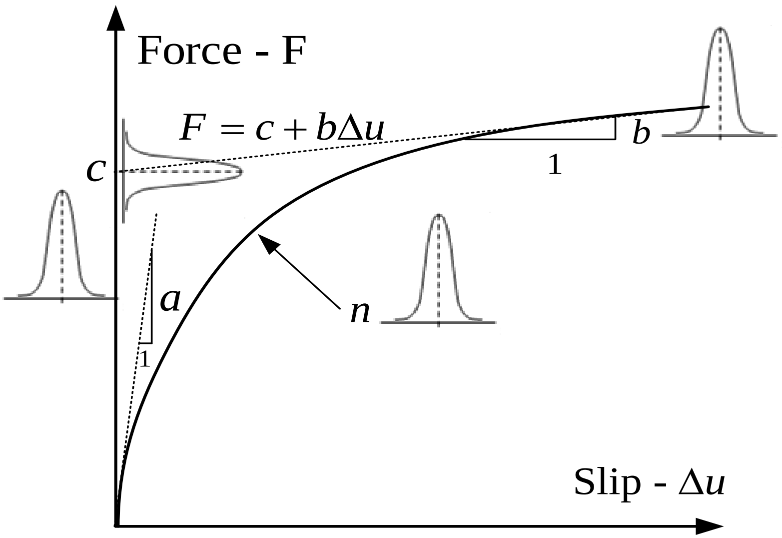


Jaspart JP, Maquoi R. Prediction of the semi-rigid and partial-strength properties of structural joints. Proceedings of the annual Technical Session, SSRC. Lehig, USA1994.

Mechanical properties for non-linear analysis

Descriptive models

Yee-Melchers – 4 parameter - $F = c\left(1 - e^{\frac{-\Delta u(a-b+n\Delta u)}{c}}\right) + b\Delta u \leq F_{max}$



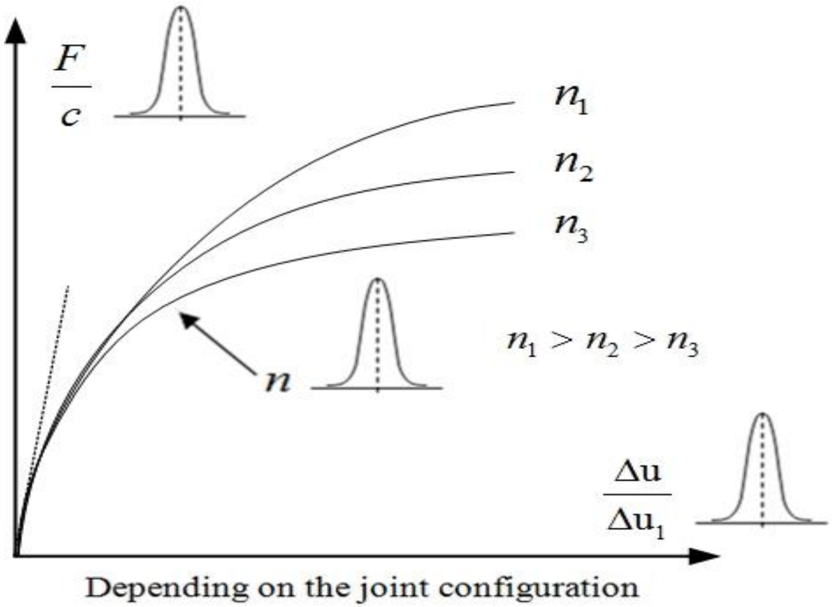
Depending on the joint configuration

Faella C, Piluso, V., Rizzano, G. Structural Steel Semirigid Connections. Theory, Design and

Mechanical properties for non-linear analysis

Descriptive models

Wu and Chen – 3 parameter - $F = c\, n\, ln\left(1 + \frac{1}{n}\frac{\Delta u}{\Delta u_1}\right) \leq F_{max}$

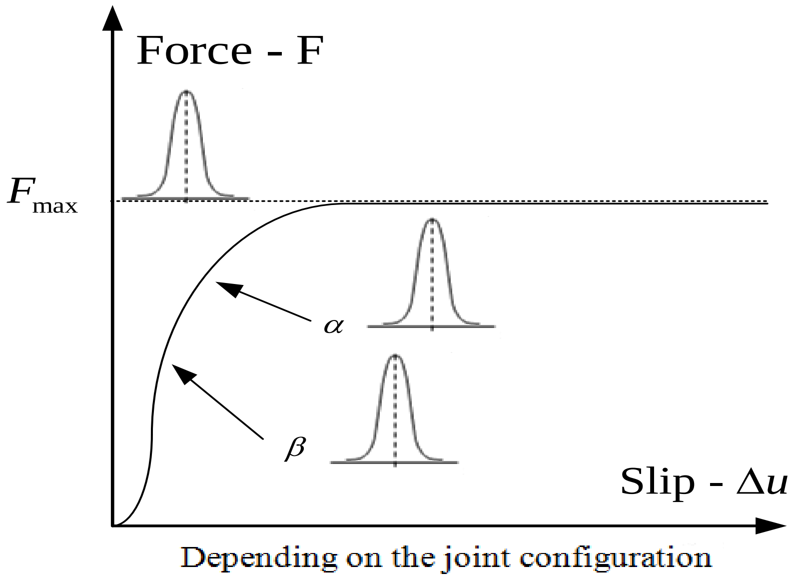


Faella C, Piluso, V., Rizzano, G. Structural Steel Semirigid Connections. Theory, Design and Software. ilustrada ed2000.

Mechanical properties for non-linear analysis

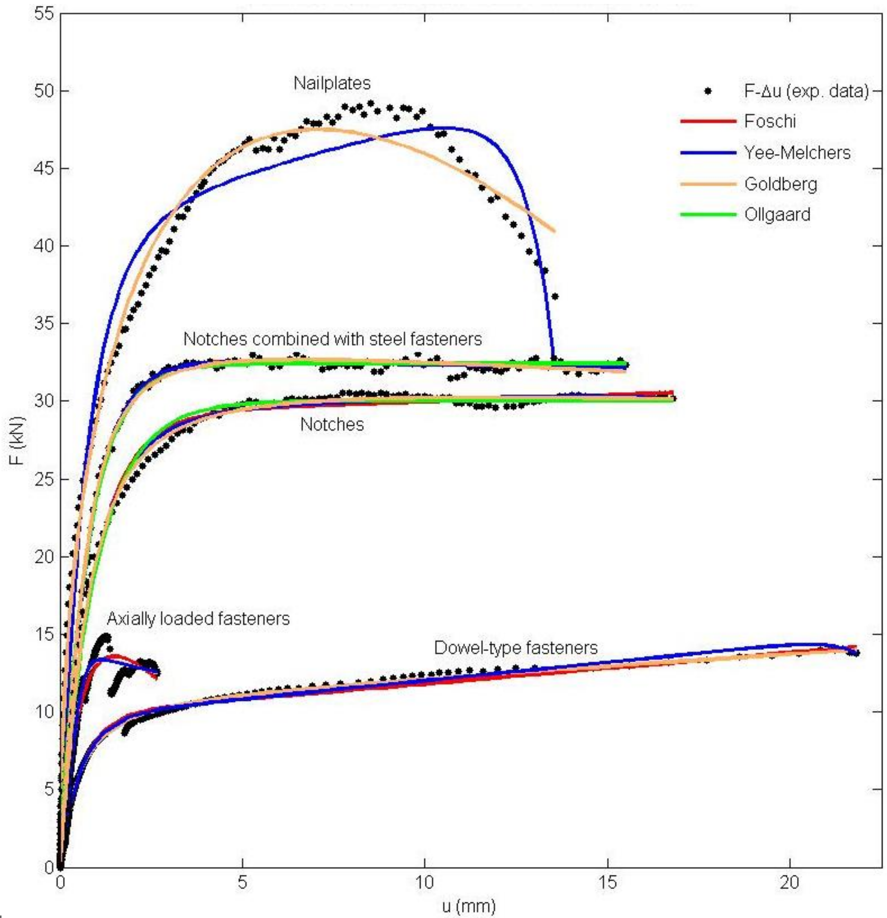
Descriptive models

Ollgaard-Slutter-Fischer – 3 parameter - $F = F_{max}\left(1 - e^{-\beta\Delta u}\right)^{\alpha} \leq F_{max}$



Ollgaard JG, Slutter RG, Fisher JW. Shear Strength of Stud Connectors in Lightweight and Normal-Weight Concrete. Eng J Aisc. 1971;8(2):55-&.

Results – Load slip curves



Results – Correlations between experimental and model data

Connection type	Foschi	GRAR	Yee-Melchers	OSF
Dowel-type fasteners	0.991	0.995	0.993	
Axially loaded fasteners	0.991	0.994	0.989	0.976
Notches	0.989	0.979	0.991	0.970
Notches combined with steel fasteners	0.979	0.996	0.968	0.982
Nail plates		0.997	0.985	

Mechanical properties for non-linear analysis

Conclusions from the analysis

- ➢**The five models proposed could describe the load slip behavior in most of cases (3 exceptions)**

- ➢**High values of coefficient of correlation were obtained for all the descriptive models that could be adjusted**

- ➢**Due to its simplicity and traditional use on timber connections, Foschi's model was the one identified as the best for most of connection types (dowel-type fasteners, axially loaded fasteners, notches and notches combined with steel fasteners)**

- ➢**For the nailplates the Yee-Melcher's model was considered a good solution**

Statistical summaries – Parameters *a* and *c* for Foschi's and Yee-Melcher's models

Numerical summaries	Parameter *a*					Parameter *c*				
	I	II	III	IV	V	I	II	III	IV	V
S-std. Variat.	0,21	0,14	0,32	0,24	0,19	0,07	0,33	0,36	0,10	0,19
η-coef. skew.	0,31	0,20	0,00	-0,01	0,79	0,27	1,09	0,10	-0,20	0,60
κ-coef.kurt.	3,41	3,59	4,82	2,07	3,28	3,43	5,52	5,06	2,95	3,16

I – Dowel-type fastener
II – Axially loaded fastener
III – Notches
IV – Notches combined with steel fasteners
V – Nailplates

Mechanical properties for non-linear analysis

Statistical analysis

- **The best fittings, for most of parameters were obtained either with normal or log-normal distributions**
- **A high level of symmetry was obtained in most of the histograms (coefficient of skewness close to 0)**
- **High values were obtained for the coefficient of variation**

Thank you very much for your attention