Eurocode – EN 1990
Basis of Structural Design

Structural Analysis
and
Design by Testing

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Contents Section 5

for calculation **Appropriate structural models**

predicting structural behaviour at limit state 5.1.1(2)	involving relevant variables 5.1.1(1)	acceptable accuracy 5.1.1(2)	established engineering theory and practice, where necessary verified experimentally

Design assisted by testing

- Design may be based on combination of calculations and tests see Annex D
- The limited number of tests to be considered in the reliability required [5.2(2)]
- Partial factors should be as in EN 1991 - 1999 [5.2(3)]

Modelling

For static or equivalent static actions

Modelling based on appropriate choice of **force-deformation relationship** of [5.1.2] and [5.12(2)]

members	connections	ground	boundary conditions intended

2nd order theory [5.1.2(3)]
when increase of action effects significant
see => EN 1990 - 1999

Indirect actions to be introduced in

linear elastic analysis directly or by equivalent forces	non-linear analysis as imposed deformations

For dynamic actions

Modelling based on [5.13(1)]
- masses
- stiffness
- damping characteristic
- boundary conditions as intended [5.13(2)]
- strengths

for all structural and non-structural members

Contribution of soil modelled by equivalent springs and dash pots [5.1.3(4)]

Where relevant (for wind and seismic actions) actions from modal analysis or where the fundamental mode is relevant from equivalent static forces [5.1.3(5)]

Dynamic actions also expressed as time histories or in the frequency domain to be dealt with by appropriate methods [5.1.3(6)]

Where relevant dynamic analysis also for SLS [5.1.3(7)] see Annex A, EN 1992 - 1999

In case of determination of equivalent static action dynamic parts either included implicitely or by magnification factors

For fire design

Structural fire design analysis based on fire scenarios considering models for [5.1.4(1)]
- temperature evolution in the structure
- mechanical non-linear behaviour of structure at elevated temperature (see EN 1992-1999) [5.1.4(6)] [5.1.4(4)]

Fire exposure as
- nominal fire exposure (5.1.4(3))
- modelled fire exposure

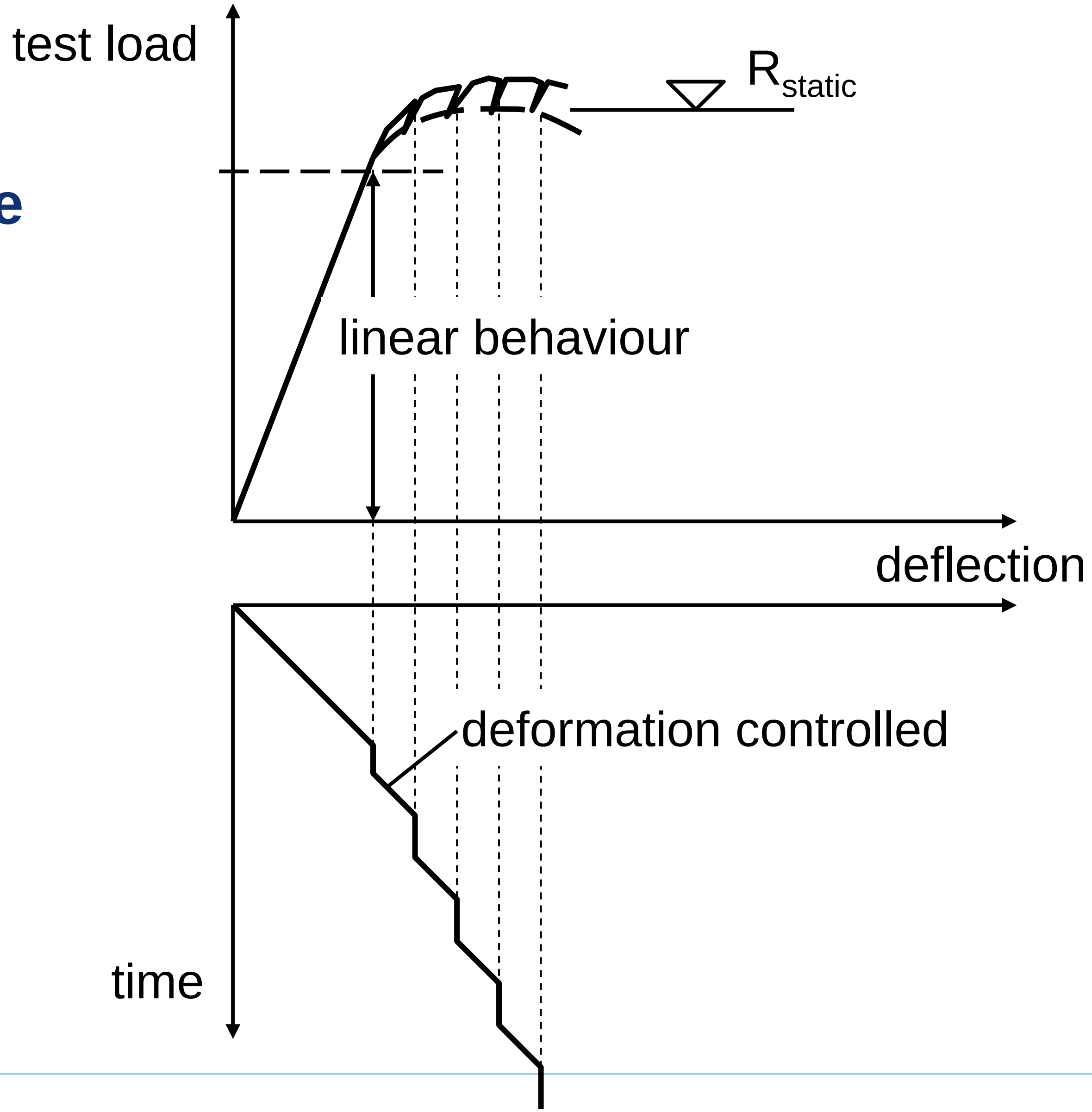
Verification of the required performance by either
- global analysis
- analysis of subassemblies or member analysis

or by tabulated data or test results

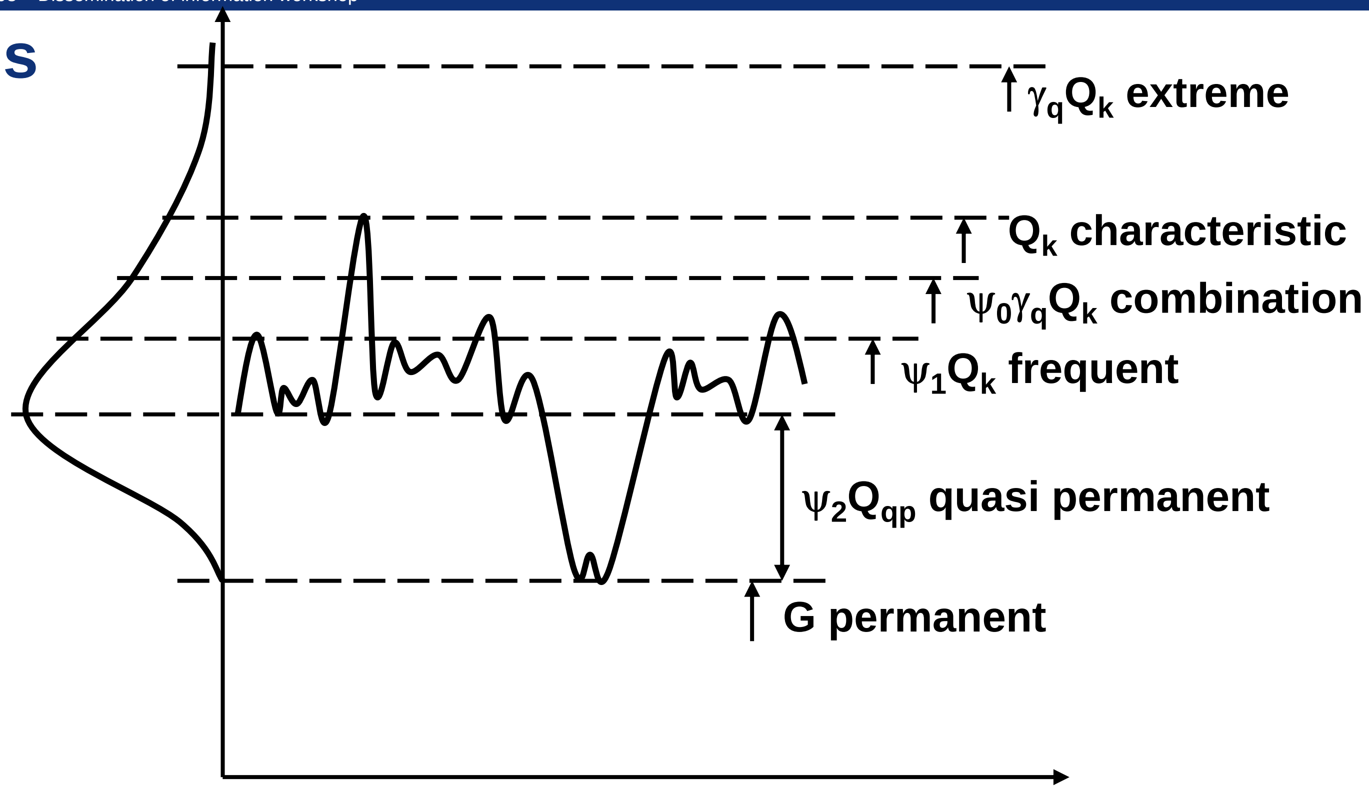
Specific assessment methods within
- uniform or non uniform temperature with cross-section and along members
- analysis of individual members and interaction of members

Basis assumptions for static analysis

Product Resistance



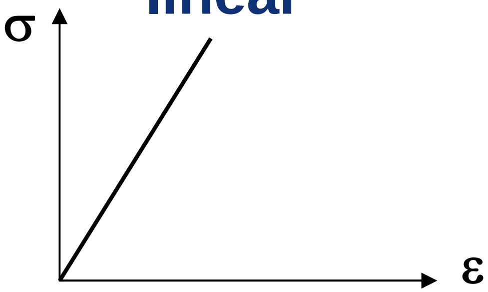
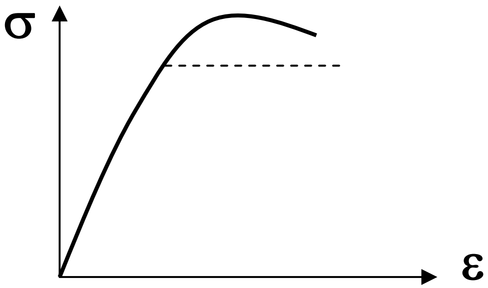
Actions



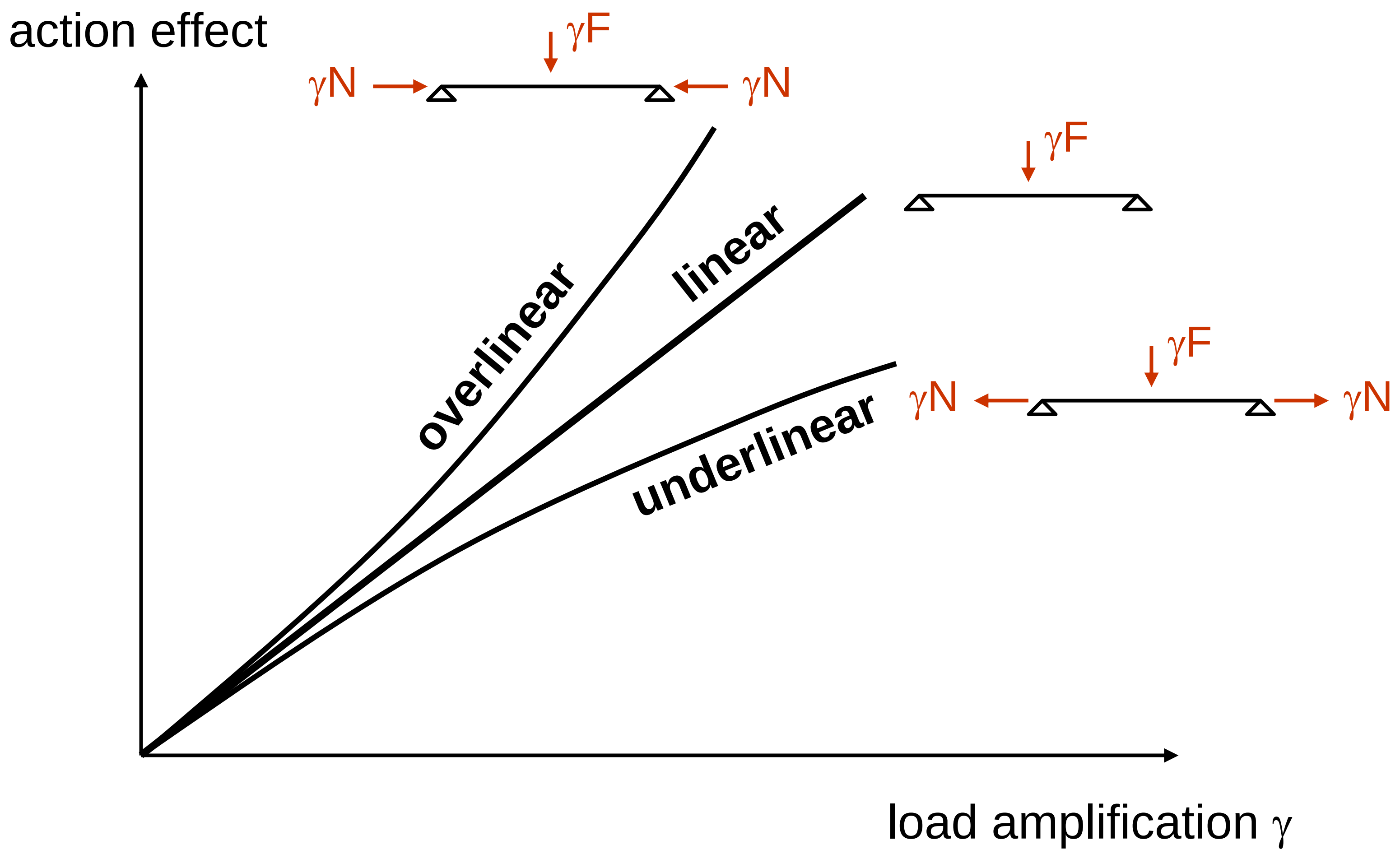
Verification: ULS (static)

$$E_d = E_d\{G + Q\} \le R_d = \frac{R_k}{\gamma_M}$$

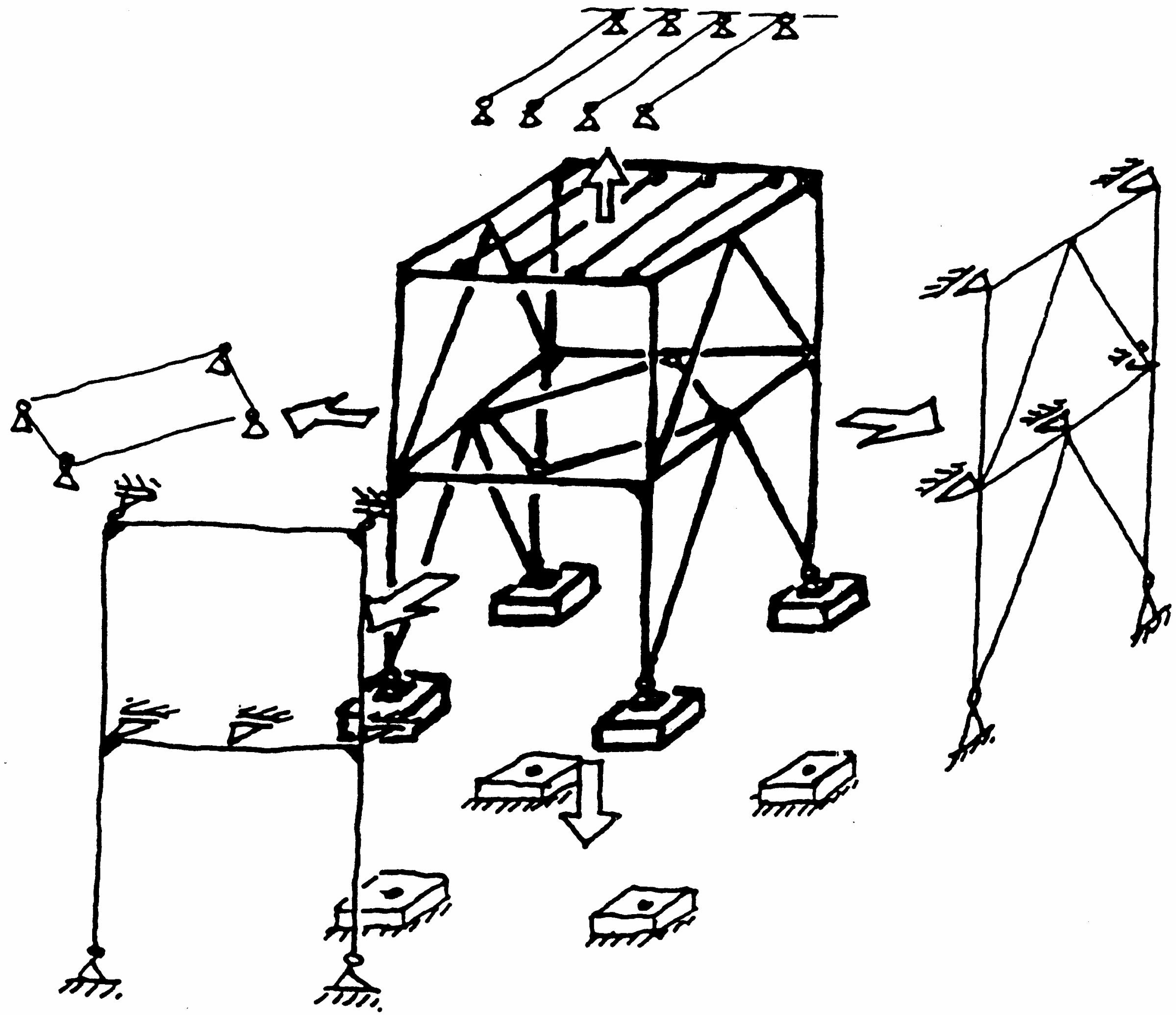
Code for type of static analysis

Material	Geometry		
	linear	non-linear	
			imperfection included
linear 	LA	GNA	GNIA
non-linear 	MNA	GMNA	GMNIA

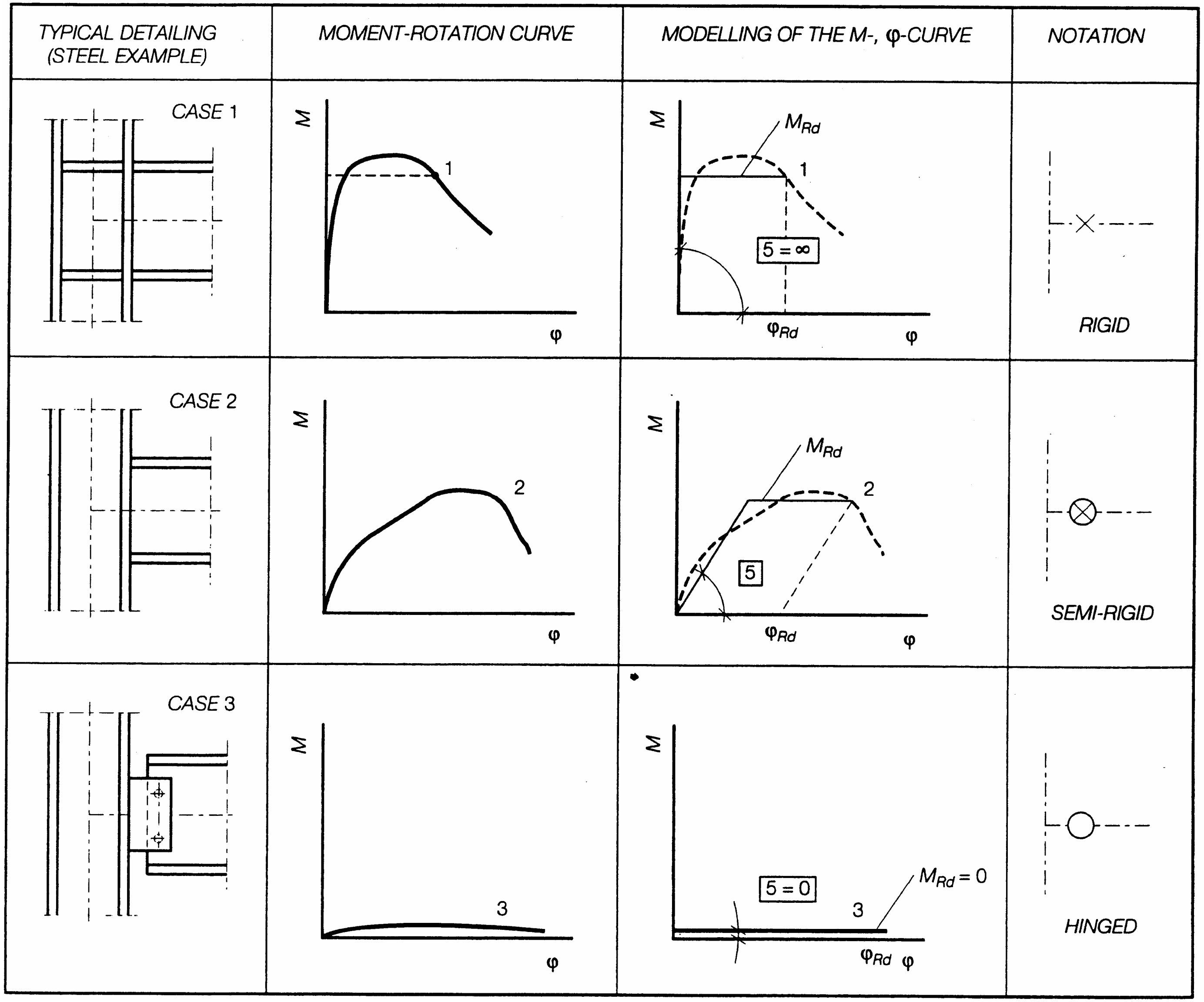
Action effects in static analysis



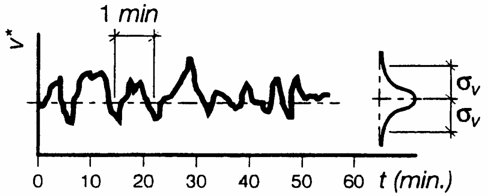
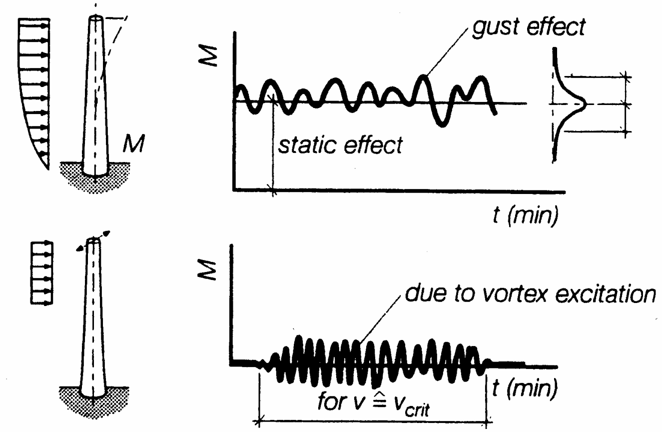
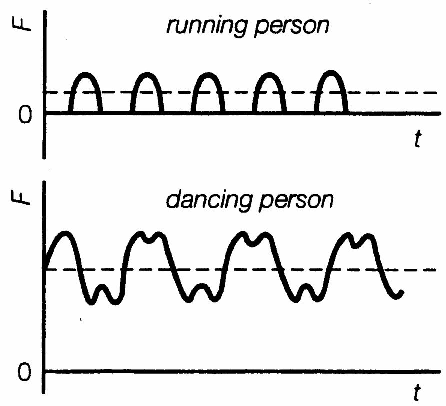
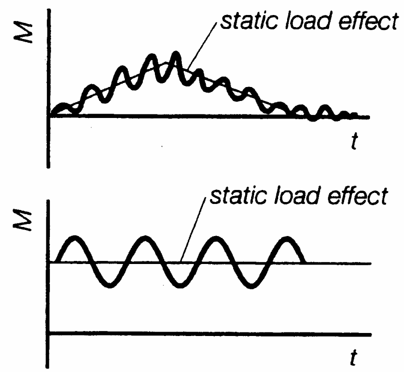
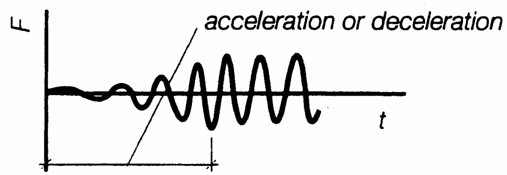
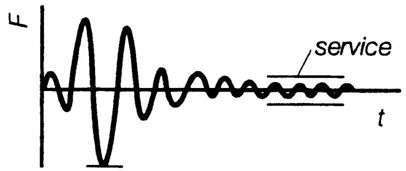
Substructuring for static analsysis



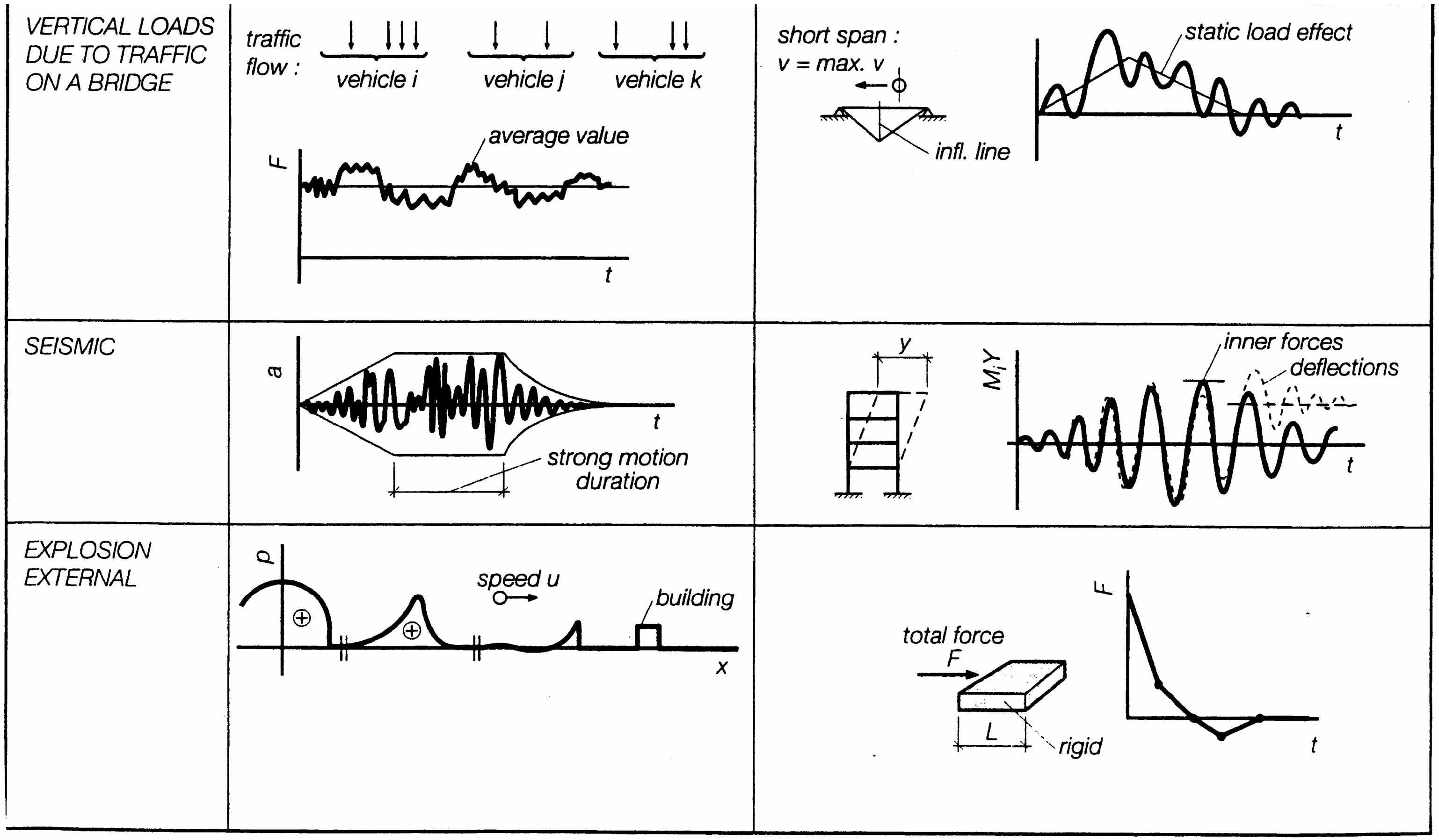
Consideration of stiffness of connections



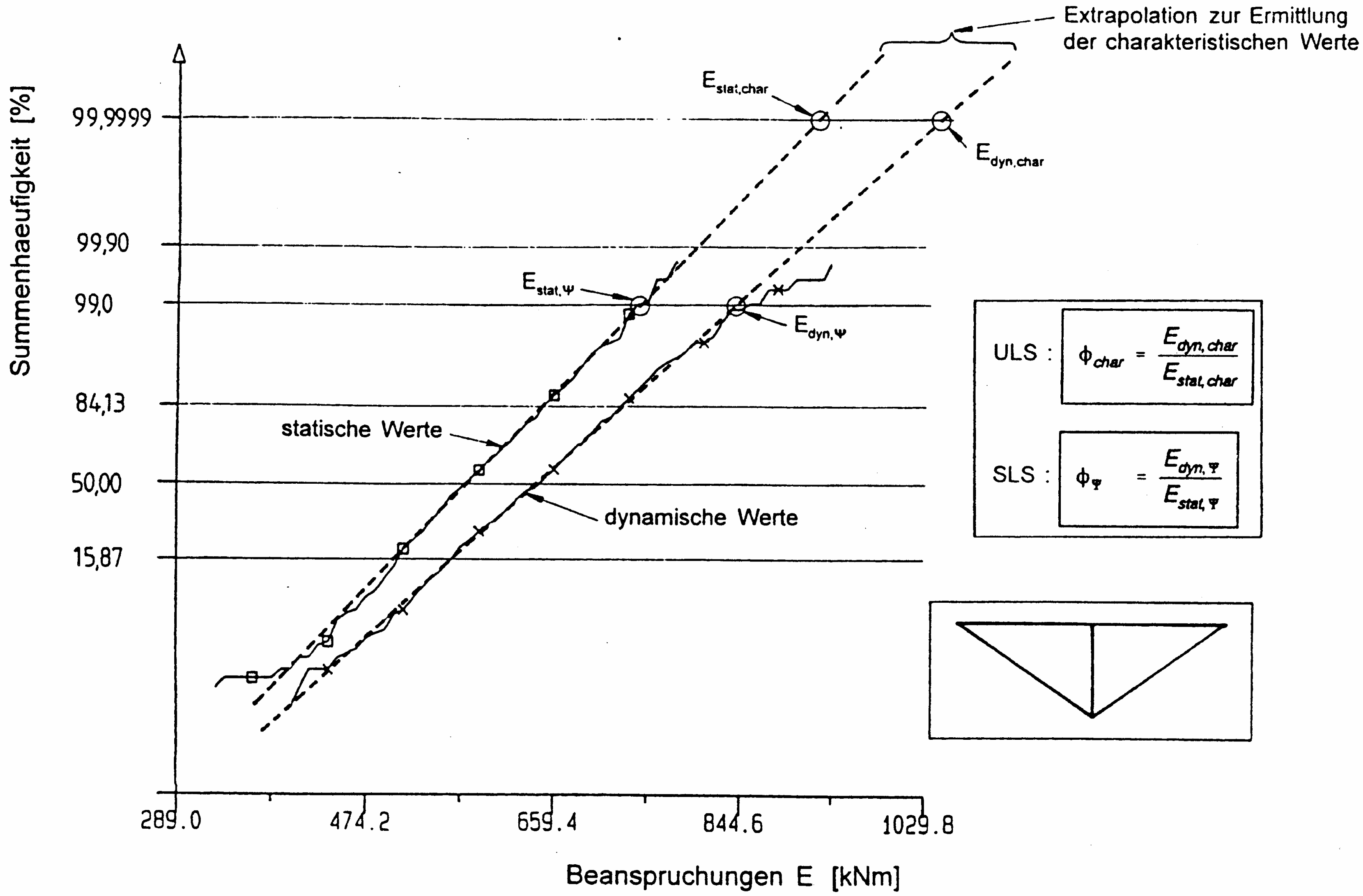
Dynamic actions and response

TYPE OF ACTION	ACTION - TIME HISTORY	TYPICAL STRUCTURAL RESPONSE DEALT WITH IN EC1
WIND	 (*wind speed in 10 m height above NN)	
MOVING PERSONS		
MACHINERY LOADS		

Dynamic actions and response



Static and dynamic actions for traffic loads



Contents Annex D

ANNEX D (INFORMATIVE) **DESIGN ASSISTED BY TESTING**

Contents of Annex D

Types of tests (D3)
a) to determine ultimate resistance or serviceability properties
b) to determine material properties with standardized testing procedures
c) to reduce parameters in load and load effect models
d) to reduce parameters in resistance models
e) to check identity or quality of delivered products
f) to obtain information for execution
g) to check the behaviour of an actual structure

(a)–(e) → Test valuation according to [D.5-D8]

Planing of tests in agreement with test organisation covering
- objectives and scopes
- prediction of test results
- specification of test specimens and sampling
- loading specification
- testing arrangement
- measurements
- evaluation and reporting of tests [D4] → Test evaluation according to [D5-D8]

Evaluation of tests for single material properties and for resistances [D.5, D.6]	
for presentation of resistance [6.3.5(2)] $$R_d = \frac{1}{\gamma_{Rd}} R\{X_d\}$$	for presentation of resistance [6.3.5(4)] $$R_d = \frac{1}{\gamma_M} R_K\{X_K\}$$
Determination of the **single material property** X_K and X_d from tests X_i [D.7]	Determination of **resistance $R_K(X_K)$** and R_d $\{X_K\}$ form tests R_{ei} [D8]

Contents of Annex D

Procedure via X_K: [D.7.2]

$$X_{Kn} = m_x (1 - k_n V_x)$$

k_n from table D1
m_x and V_x from

$$m_x = \frac{\Sigma x_1}{n}$$

$$S_x^2 = \frac{1}{n-1} \Sigma (x_i - m_x)^2$$

$$V_x = \frac{S_x}{m_x}$$

$$X_d = \eta_d \frac{X_K(n)}{\gamma_m}$$

Procedure via R_K: [D.8.2]

1. theoretical deterministic function R_t
2. Comparison R_{exp} - R_t to improve R_t
3. Probabilistic function $R = \bar{b} R_f \delta$
4. Mean value deviation $\bar{b} \approx \frac{1}{n} \Sigma \frac{R_{ei}}{R_{ti}}$
5. Coefficient of variation v_δ for error terms δ_i

$$\delta_i = \frac{R_{ei}}{\bar{b} R_{ti}} \qquad S_\delta^2 \approx \frac{1}{n-1} \Sigma (\delta_i - 1)^2$$

$$V_\delta^2 \approx S_\delta^2$$

6. Inclusion of v_{xi} for variables X_i

$$V_R^2 = V_\delta^2 + \Sigma V_{x_i}^2$$

Contents of Annex D

7. $R_K = \bar{b}\, grt(X_m)\; e^{-k_\infty \alpha_{rt} Q_{rt} - k_n \alpha_\delta Q_\delta - 0.5Q^2}$

k_n, k_∞ from table D1

$$Q_{rt} \approx \sqrt{\Sigma V_{x_i}^2}$$

$$Q_\delta \approx \sqrt{V_\delta^2}$$

$$Q \approx \sqrt{V_R^2}$$

$$\alpha_{rt} \approx \frac{Q_{rt}}{Q}$$

$$\alpha_\delta \approx \frac{Q_\delta}{Q}$$

8. $R_d \approx \dfrac{R_K}{\gamma_M}$

Procedure via X_d: [D 7.3]

$$X_d = \eta\, m_x (1 - k_{dn} v_x)$$

k_{dn} from table D2

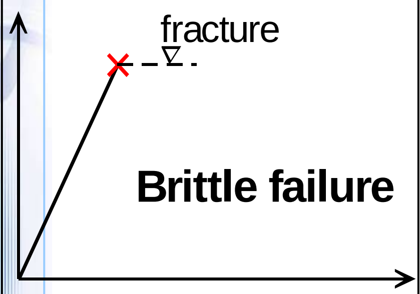
Procedure via R_d: [D 8.3]

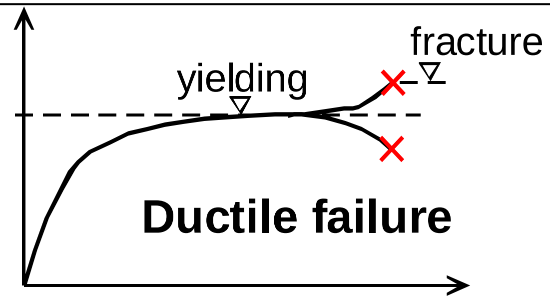
$$R_d = \bar{b}\, grt(X_m)\; e^{-k_{d\infty} \alpha_{rt} Q_{rt} - k_{dn} \alpha_\delta Q_\delta - 0.5Q^2}$$

k_{dn}, $k_{d\infty}$ from table D2

Procedure to obtain reliable values R_k

Failure modes





excluded by appropriate choice of material

1. Mode 0	**Mode 1**	**Mode 2**
excessive deformation by yielding e.g. tension bar	member failure by instability e.g. column buckling	fracture after yielding e.g. bolt
$R_d = \frac{R_k(f_y)}{\gamma_{M0}}$	$R_d = \frac{R_k(f_y, \bar{\lambda})}{\gamma_{M1}}$	$R_d = \frac{R_k(f_u)}{\gamma_{M2}}$

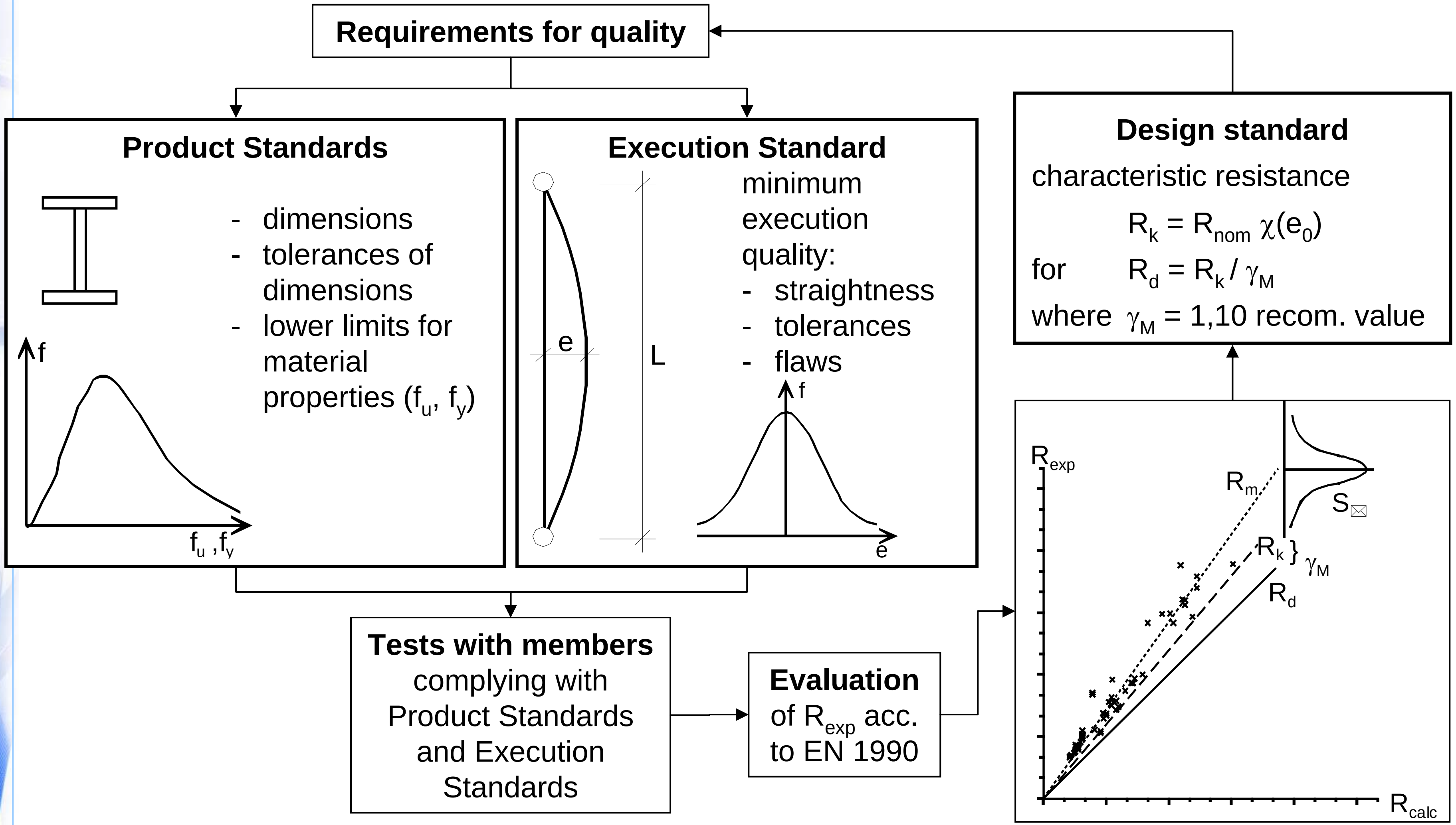
2. Test evaluation $R_d = m_R \exp(0{,}8\,\beta\,\sigma_R - 0{,}5\,\sigma_R^2)$; $\beta = 3{,}80$

3. Recommended values

$\gamma_{M0} = 1{,}00$	$\gamma_{M1} = 1{,}10$	$\gamma_{M2} = 1{,}25$

4. Characteristic value $R_k = \gamma_M R_d$

Reliability links between Product Standard, Execution Standanrd and Eurocode 3



Determination of characteristic values R_k and γ_M values from tests

Conditions for numerical value of γ_M

Product standards for materials and semi-fabricated products EN 10025

Execution standard EN 1090 – Part 2

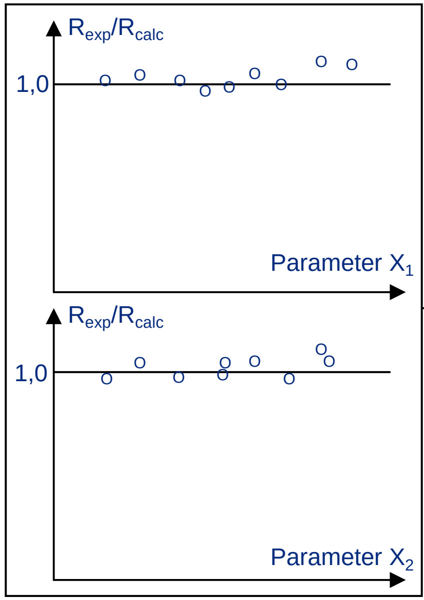
Design standard Eurocode 3

Prefabricated steel component for component testing

Component tests to determine R_{exp}

Engineering model to determine R_{calc}

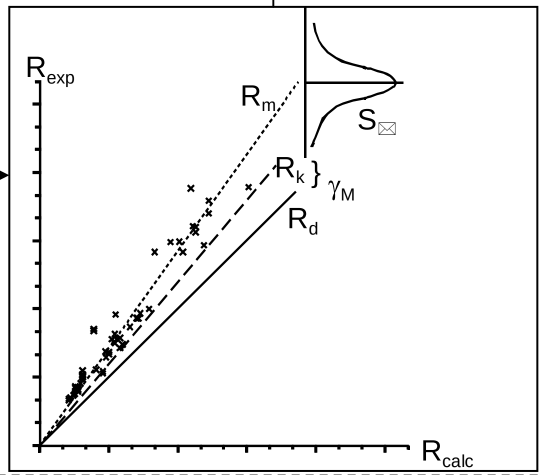
Test evaluation accord. to EN1990- Annex D



$R_k = \gamma_{Mi} R_d$

Classification accord. to γ_{Mi} (1,0; 1,10; 1,25)

$\gamma_{Mi} = R_k / R_d$



Probability distribution of experimental data

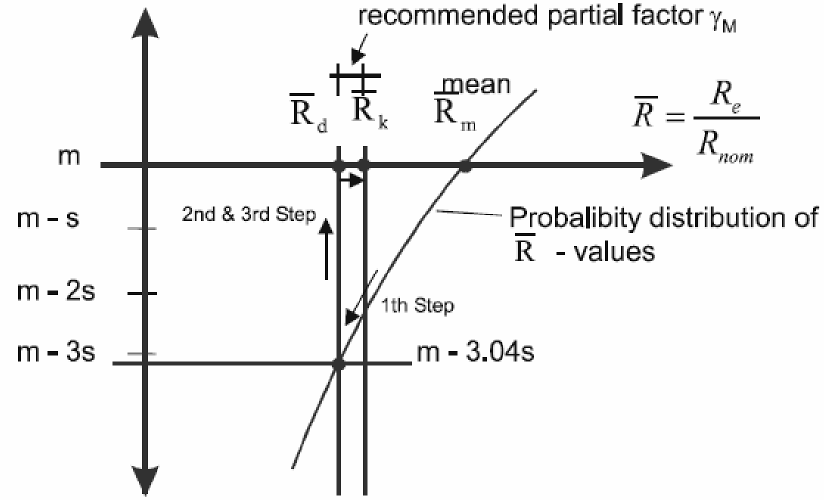
h EN: Declared values
on the basis of Eurocodes: A_{nom}, $f_{y\,nom}$

Eurocodes: Determination based on prEN 1990 - Annex D:

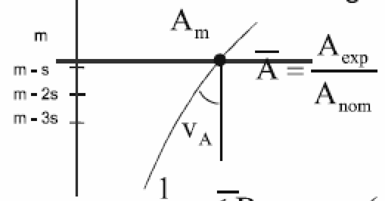
Characteristic values $R_K = k \cdot A_{nom} \cdot f_{y\,nom}$

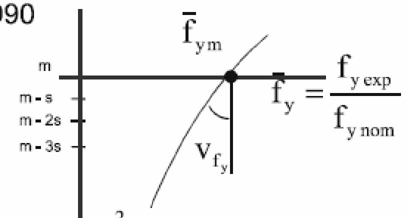
Design values $R_d = R_K / \gamma_M$

Recommended partial factor: γ_M



h EN: Requirements for factory production, control according to prEN 1990

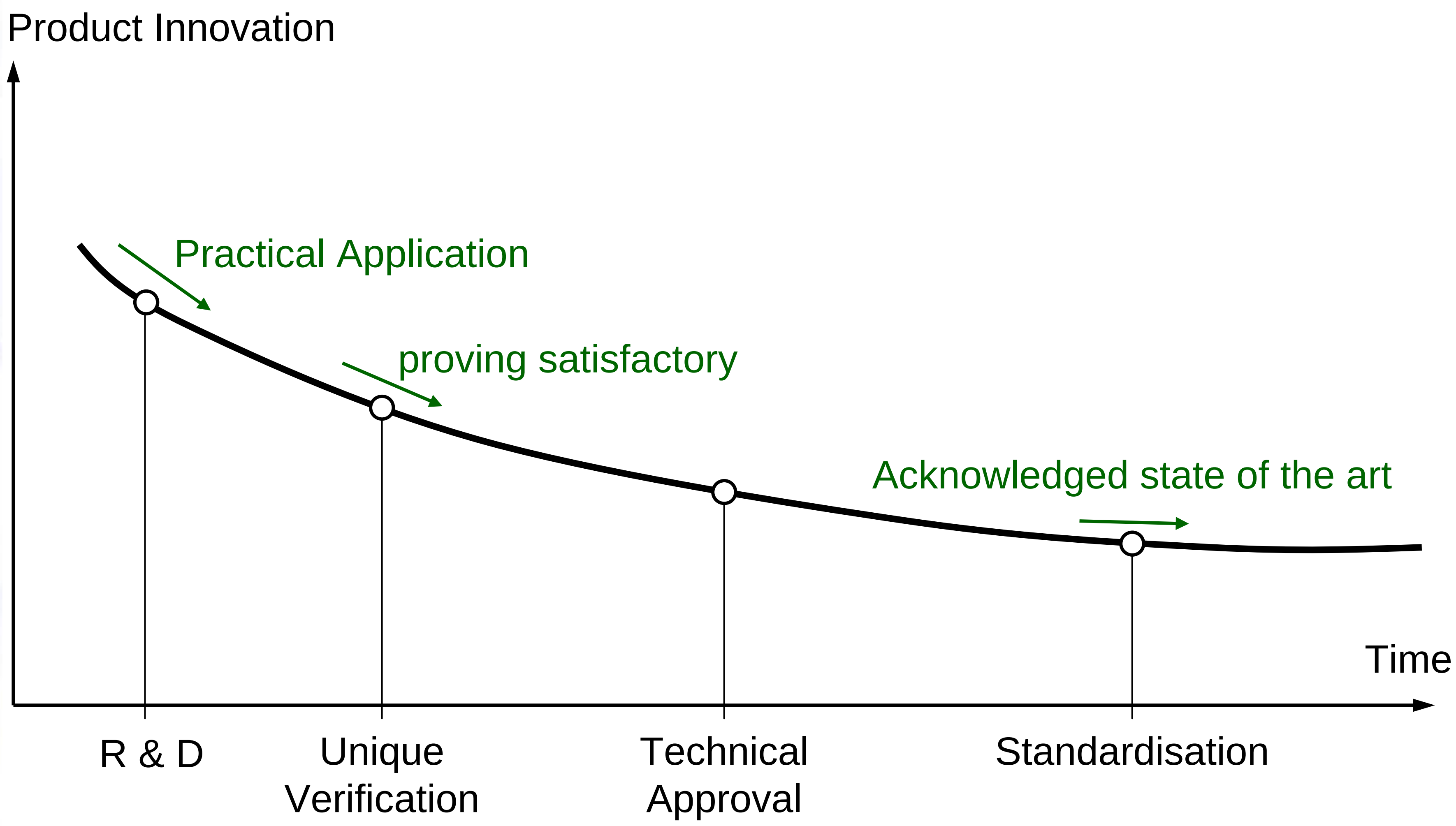




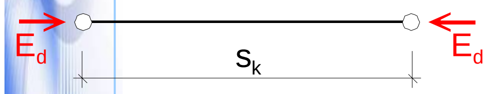
Criterion: $\frac{1}{\gamma_M} \leq \bar{R}_m \exp(-3.04\, v_R - 0.5\, v_R^2)$

with $\bar{R}_m = \bar{A}_m \cdot \bar{f}_{ym}$ and $v_R = \sqrt{v_A^2 + v_{f_y}^2}$

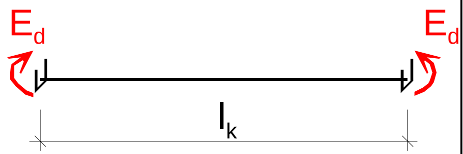
Use of test evaluation method for various regulatory routes



Common design rules for column, lateral torsional, plate and shell buckling



column buckling



lat. tors. buckl.

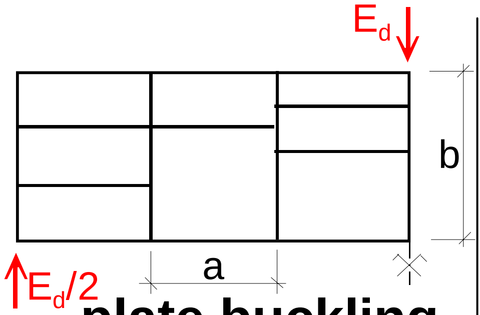
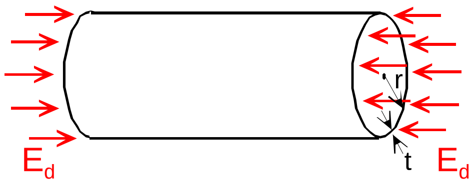


plate buckling



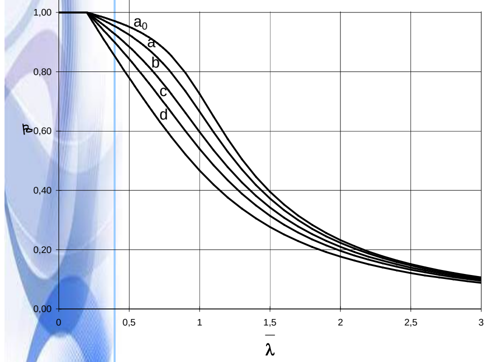
shell buckling

$$\alpha_{ult,k} E_d = R_k$$
$$\alpha_{crit} E_d = R_{crit}$$

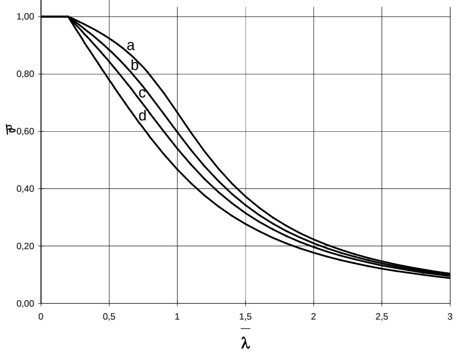
$$\bar{\lambda} = \sqrt{\frac{R_k}{R_{crit}}} = \sqrt{\frac{\alpha_{ult,k}}{\alpha_{crit}}}$$

$$\chi = \chi(\bar{\lambda})$$

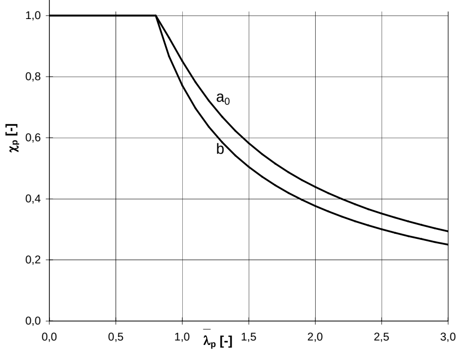
EN 1993-1-1



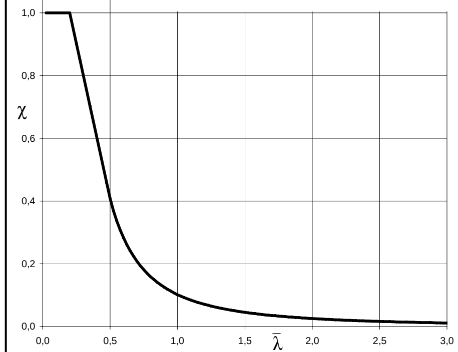
EN 1993-1-1



EN 1993-1-5



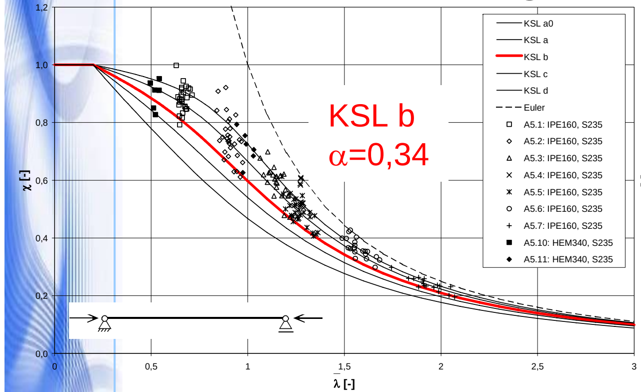
EN 1993-1-6



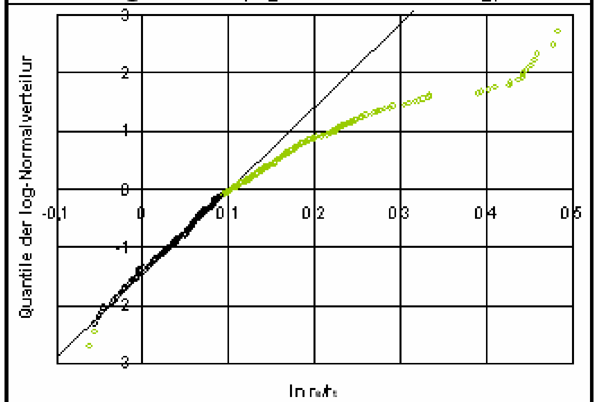
$$E_d \leq \frac{\chi R_k}{\gamma_M} \qquad 1 \leq \frac{\chi \alpha_{ult,k}}{\gamma_M}$$

Test evaluation for buckling curves and γ_M-values

Column buckling

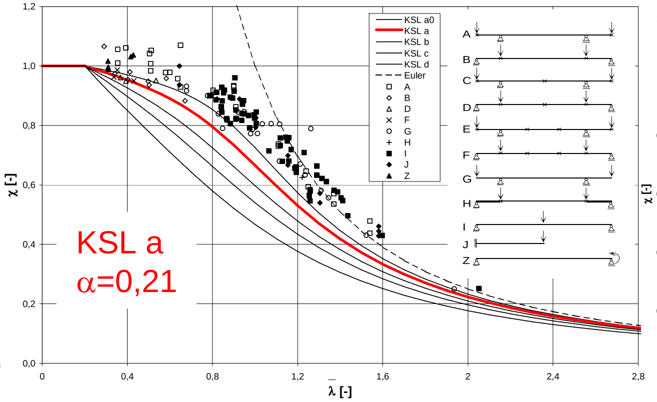


Eingangsdaten	
$\upsilon_{rt} = 0{,}08$ (Geometrie und Streckgrenze) $\upsilon_{fy} = 0{,}07$ (Streckgrenze)	
Ergebnisse (log-Normalverteilung)	



$\bar{b} = 1{,}109$		$s_\delta = 0{,}077$
$\upsilon_\delta = 0{,}0698$ (Modell)		$\upsilon_R = 0{,}1062$ (gesamt)
$\gamma_M = 1{,}160$	$\Delta k = 0{,}935$	$\gamma_M^* = 1{,}085$

Lateral torsional buckling



Eingangsdaten	
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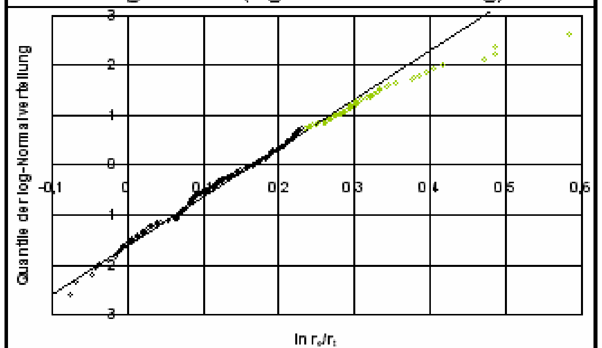
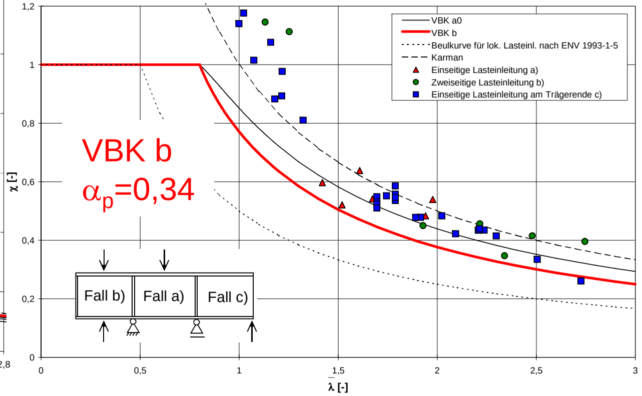
Ergebnisse (log-Normalverteilung)	



$\bar{b} = 1{,}185$		$s_\delta = 0{,}121$
$\upsilon_\delta = 0{,}1024$ (Modell)		$\upsilon_R = 0{,}1300$ (gesamt)
$\gamma_M = 1{,}199$	$\Delta k = 0{,}912$	$\gamma_M^* = 1{,}094$

Plate buckling



Eingangsdaten	
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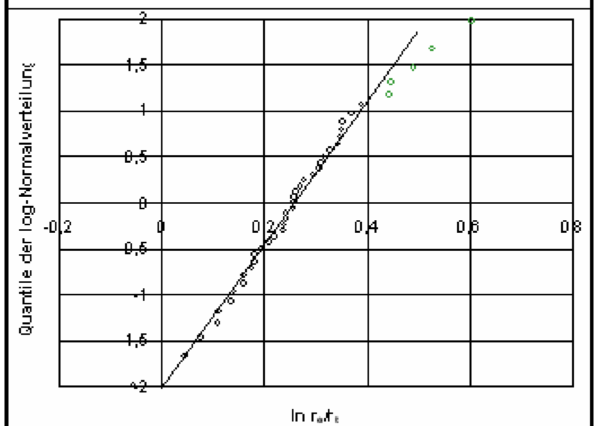
Ergebnisse (log-Normalverteilung)	



$\bar{b} = 1{,}305$		$s_\delta = 0{,}168$
$\upsilon_\delta = 0{,}1291$ (Modell)		$\upsilon_R = 0{,}1519$ (gesamt)
$\gamma_M = 1{,}235$	$\Delta k = 0{,}861$	$\gamma_M^* = 1{,}064$