Designing sustainable concrete on equivalence performance: assessment criteria for safety

Jeanette Visser and Agnieszka Bigaj,
TNO The Netherlands

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Designing sustainable concrete on equivalence performance: assessment criteria for safety

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2. Which equivalent performances to take into account
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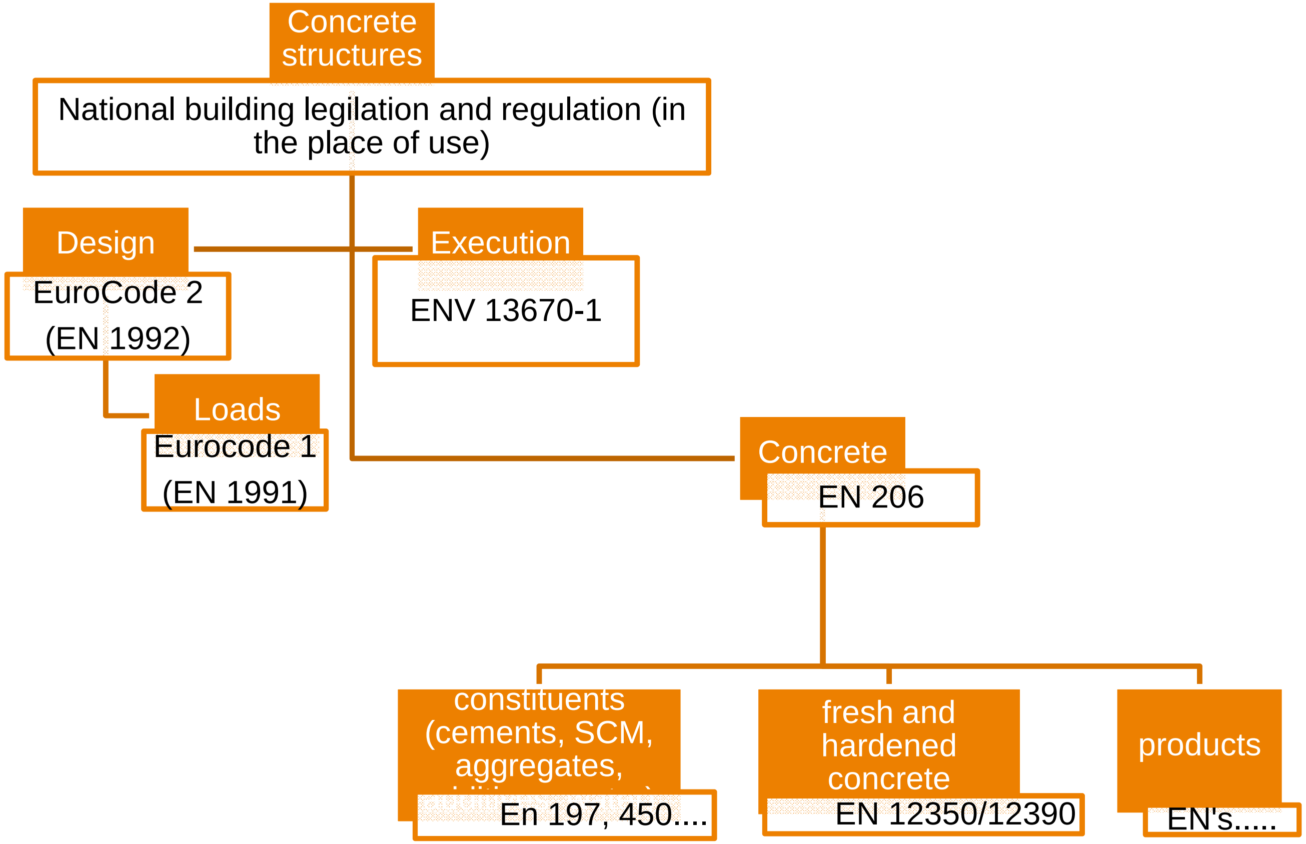
1. Introduction: why equivalent performance

- When a new material is introduced, how do we prove that it is **as safe and durable** as the materials that are already used
- Most materials are already used for a long time – plenty of experience, data from the field to set up models (e.g. model codes), etc.
- For new materials that want a fast introduction on the market a different approach has to be taken

1. Introduction: why equivalent performance

- The safety of structures is guaranteed by the National Building Regulations, of which the EuroCodes are a part



Concrete structures

National building legilation and regulation (in the place of use)

Design

EuroCode 2
(EN 1992)

Execution

ENV 13670-1

Loads

Eurocode 1
(EN 1991)

Concrete

EN 206

constituents
(cements, SCM,
aggregates,

En 197, 450....

fresh and
hardened
concrete

EN 12350/12390

products

EN's.....

1. Introduction: why equivalent performance

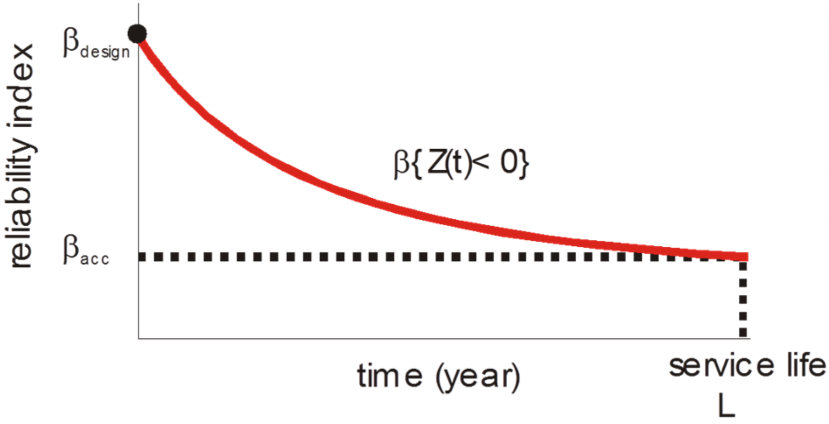
- Alternative approval routes within the standard framework:
  1. Equivalent performance concept (within EN 206): for determining the contribution of alternative binders or additives to the performance but for limited combinations
  2. Performance based design (within EN 206): to circumvent the use of deemed to satisfy rules for the concrete composition – limited to durability issues
  3. Equivalence and equivalence solution (within NBR) : **generic!**

1. Introduction: why equivalent performance

- Performance demands form the basis of the NBRs (together with functionality demands)

- Performance demands consist of clauses of the form:
  - a **quantified** limit state (e.g. 1 toilet, resistance more than xx s/m^2)
  - An **unambitious determination method** (preferable a EN – standard)

(Trivial determination methods need not to be mentioned, e.g. toilets can be counted)



1. Introduction: why equivalent performance

- The equivalence solution principle states:

A clause in the NBR does not have to be fulfilled if the (building / component / concrete) or its use differs from the clause if
THE SOLUTION IS OF AT LEAST THE SAME LEVEL OF SAFETY, ………

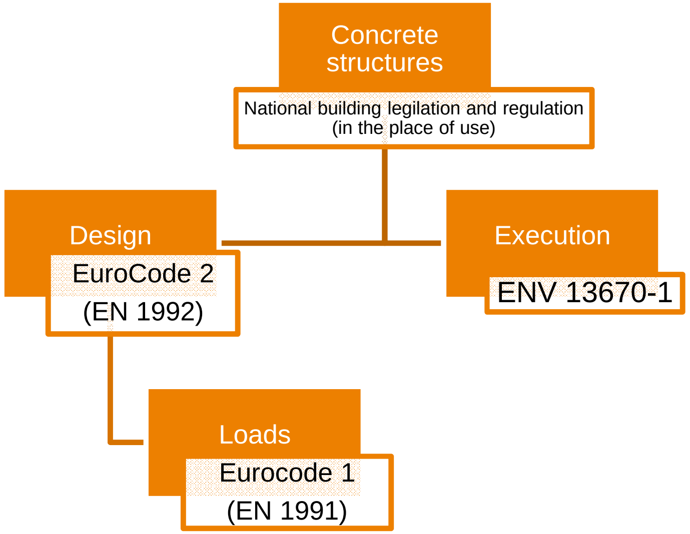
N.B. these are the six so-called ‘pillars’ or classes of performance demands in the NBR. Only safety is currently discussed

2. Which performances to take into account

- In the safety class it is ensured that a structure is able to resist its loads during its design service life

- The loads concern:

1. Mechanical loads (self weight, wind etc.)
2. Environmental loads (CO_2, acids etc.)
   = Durability!
3. Fire



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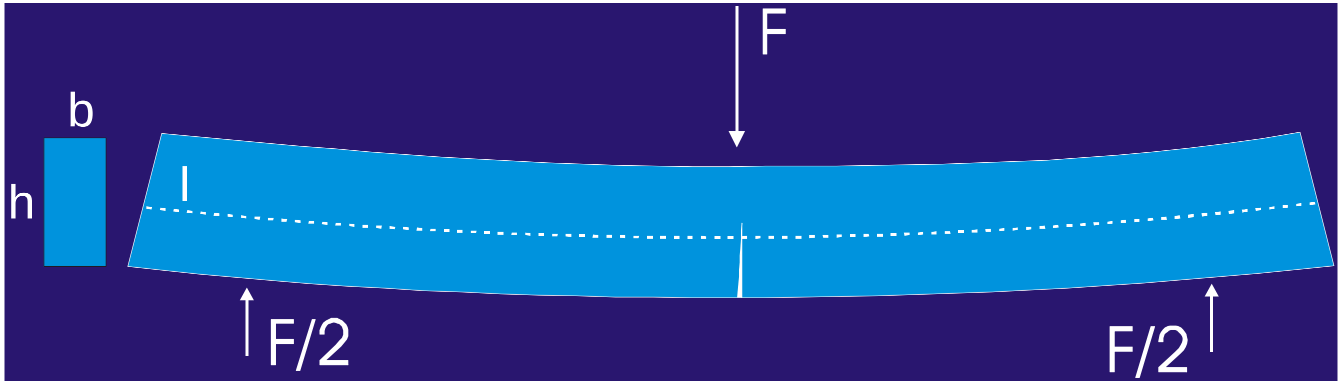
2 . Which performances to take into account

- MATERIALS need to have a certain *resistance* against:
  - Mechanical loads, including minimum compressive strength, tensile strength, elastic deformation variables etc.
  - Environmental loads, including resistance against carbonation, chloride penetration freeze/thawing in the presence of de-icing salts etc.

2. Which performances to take into account: mechanical loads

- The complete list of required ‘ resistances’ against the mechanical loads is given in the Model Codes
- They are correlated to the resistance of the concrete described by mostly its mechanical properties that determines the structural behaviour upon a load:

E.g beam: $Z = R\text{-}S = bh^2 f_c/6 – lF/4>0$



2. Which performances to take into account: mechanical loads

- Mechanical properties that determines the structural behaviour upon a load:
  - Compressive strength f_c
  - Tensile strength f_t
  - Elasticity constants E, μ
  - Creep & shrinkage
  - Stress-strain relationship for non-elastic calculations
- There are several influences on these properties that have to be included as well: age (t), temperature (if cured under higher T), relative humidity (rh)

2. Which performances to take into account : mechanical loads

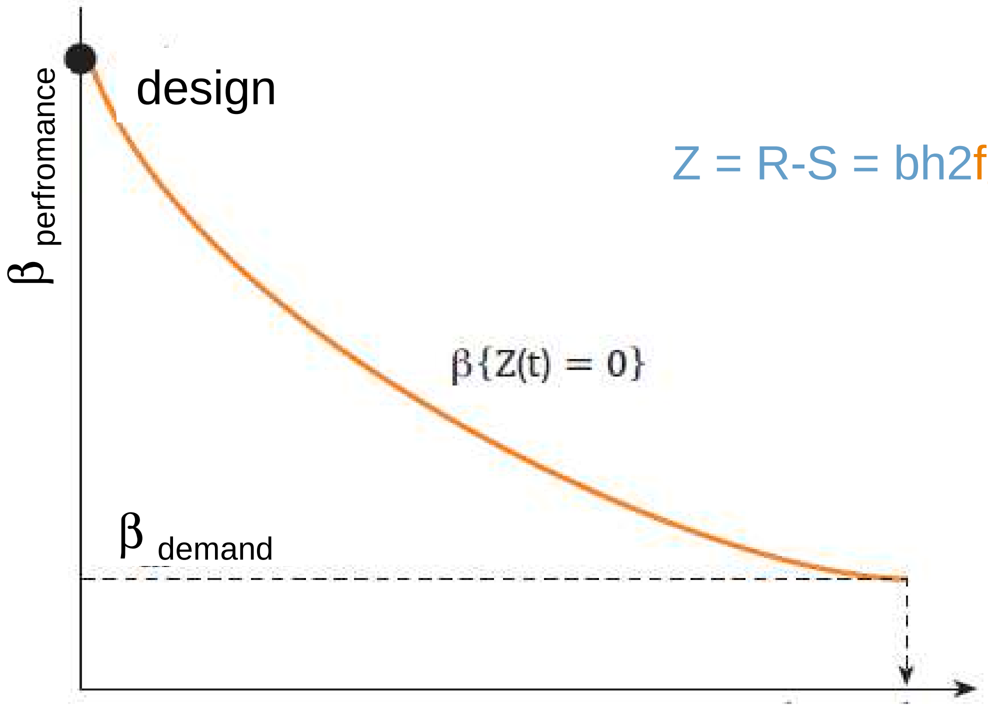
MATERIAL PROPERTY	Influences			
	test method	t	T	rh
fc (cube, prism for E)	x	x	x	
ft, (uniax, splitting)	X	X	X	X
E, (μ)				
creep, shrinkage		x	x	x
stress-strain relation				

- Is a material equivalence sufficiently proven if it is measured and the influences show the same type of behaviour as given in the Eurocode, for each variable?

3. Assessment criteria for safety: general principles

A **performance** is a **task** that is executed with a certain **quantified** result (limit state)

:

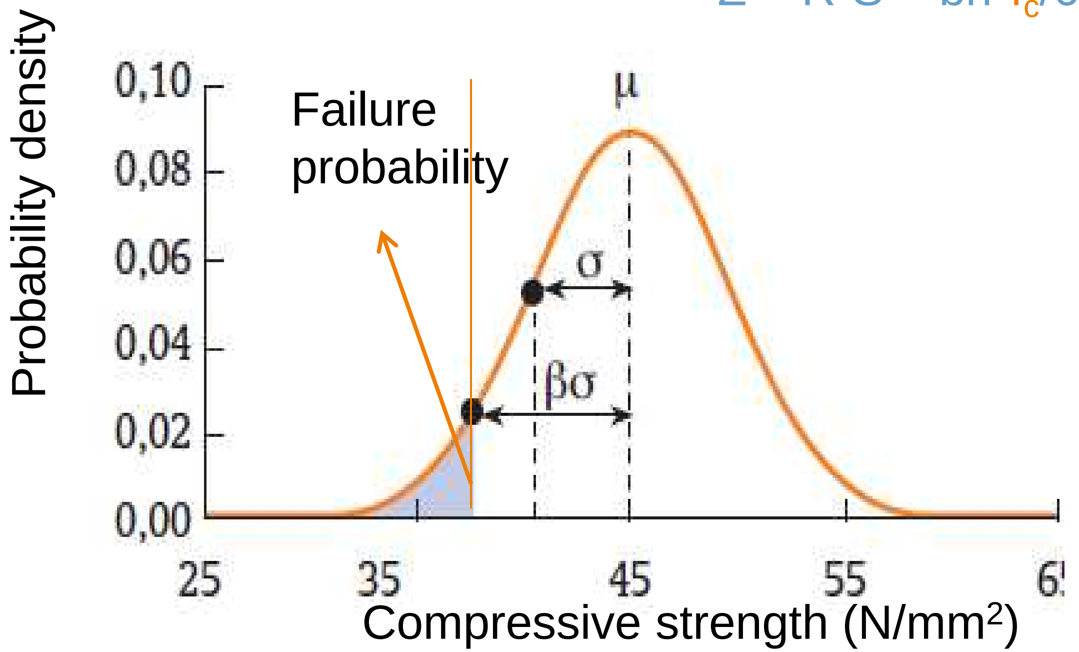


$Z = R\text{-}S = bh2f_c(t) /6 – lF(t)/4$

3. Assessment criteria for safety: general principles

- Limit states cannot be calculated on the basis of average variables e.g. because the probability that the compressive strength is actually lower is too high (= 50 %)

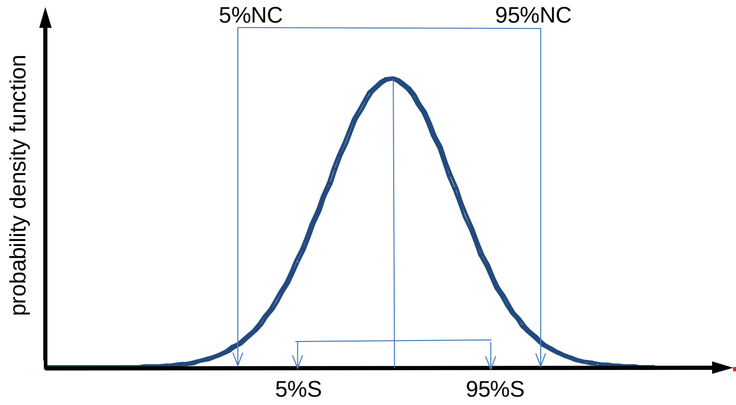
$Z = R\text{-}S = bh^2 f_c/6 - lF/4 > 0$

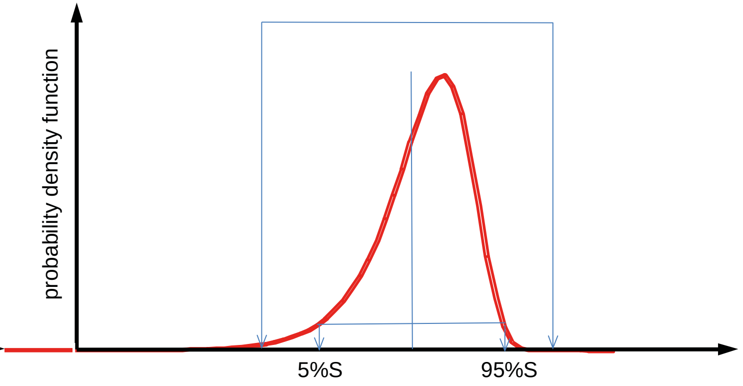


- Normally full probabilistic calculations are made

3. Assessment criteria for safety: general principles

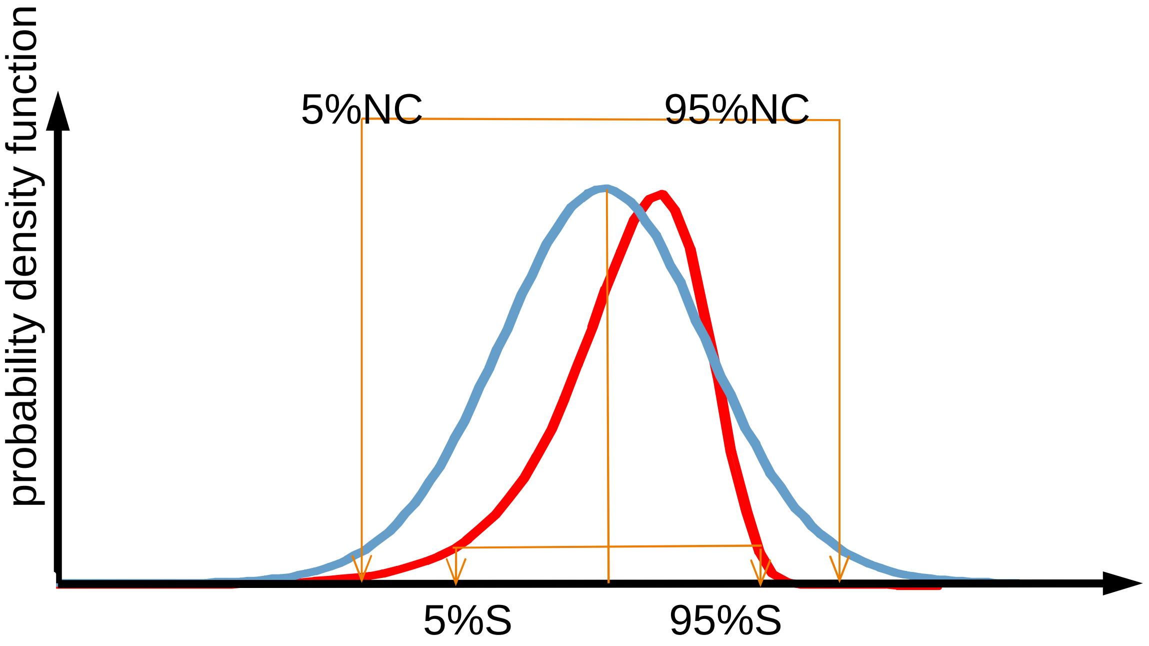
- A way of avoiding full probabilistic calculation is on the basis of characteristic values, for which **<u>equivalent or better properties</u>** can be proven by means of:
  - Characteristic values based on many measurements: real distribution, as given in model codes: $f'_{ck} = \mu - \beta\sigma = \mu(1 - \beta\nu)$
  - Characteristic values based on few measurements: student t. distribution: $f'_{ck} = \overline{x_n} - \frac{t_{n-1}}{\sqrt{n}} s_n$





3. Assessment criteria for safety: general principles

- How to prove **equivalence or better**?
  - Minimum fractile, maximum fractile or range
  - Below or above which a certain percentage is not allowed to pass
- Very important = type of distribution!



4. General set-up for the assessment criteria

- **Restrictions**
  - Materials behaving mechanically the same (i.e. brittle, linear elastic)
  - Most relationships are empirically so no application outside the range of application for which they have been tested.
  - In the model codes, two classes are given, namely density and compressive strength CLASS e.g. C8-C88
  - Especially the mechanical strength will give the range of application
  - **Single class / extreme class criteria:**

	Strength classes for concrete														Equation / explanation
f_{ck} (MPa)	12	16	20	25	30	35	40	45	50	55	60	70	80	90	
$f_{ck,cube}$ (MPa)	15	20	25	30	37	45	50	55	60	67	75	85	95	105	
f_{cm} (MPa)	20	24	28	33	38	43	48	53	58	63	68	78	88	98	$f_{cm} = f_{ck}$ +8(MPa)
f_{ctm} (MPa)	1.6	.9	2.2	2.6	2.9	3.2	3.5	3.8	4.1	4.2	4.4	4.6	4.8	5.0	$f_{ctm} = 0.30 \mathrm{x} f_{ck}{}^{(2/3)} \leq \mathrm{C}50/60$ $f_{ctm} = 2.12 \cdot \ln\left(1 + (f_{cm}/10)\right)$ $> \mathrm{C}50/60$

5. Example

- A producer of recycled aggregates noticed that the properties of his concrete varied depending on the sand-lime / brick fraction
- A brick fraction of 50 % is already allowed
- Because demolition of the next generation houses contain much more sand-lime brick (not allowed), he would like the to know the future consequences.
- First assessment of the 5 major mechanical properties

MATERIAL PROPERTY	Influences			
	test method	t	T	rh
fc, cube		3, 7, 28, 92 days		
ft, split		3, 7, 28, 92 days		
fc (prism),E, (μ) & stress-strain	x	No (28 days)		
creep, shrinkage		From 7 days		50 %

5. Example

- Tested = extreme case recycled aggregates:
  - 50 % recycled concrete/ 50 % clay brick
  - 50 % recycled concrete / 50 % sand-lime brick
- Assessment with respect to compressive strength:

(1) The characteristic strength is determined at the strength class the producer want to use it (C35)

(2) Strength development as given by the codes

$$f_{cm}(t) = \beta_{cc}(t) \cdot f_{cm} \quad \text{and} \quad \beta_{cc}(t) = exp\left\{s \cdot \left[1 - \left(\frac{28}{t}\right)^{0.5}\right]\right\}$$

With s is determined for different cements:

Strength class of cement	32.5 N	32.5 R 42.5 N	42.5 R 52.5 N 52.5 R
s	0.38	0.25	0.20

5. Example

- (1) strength class:

  as determined

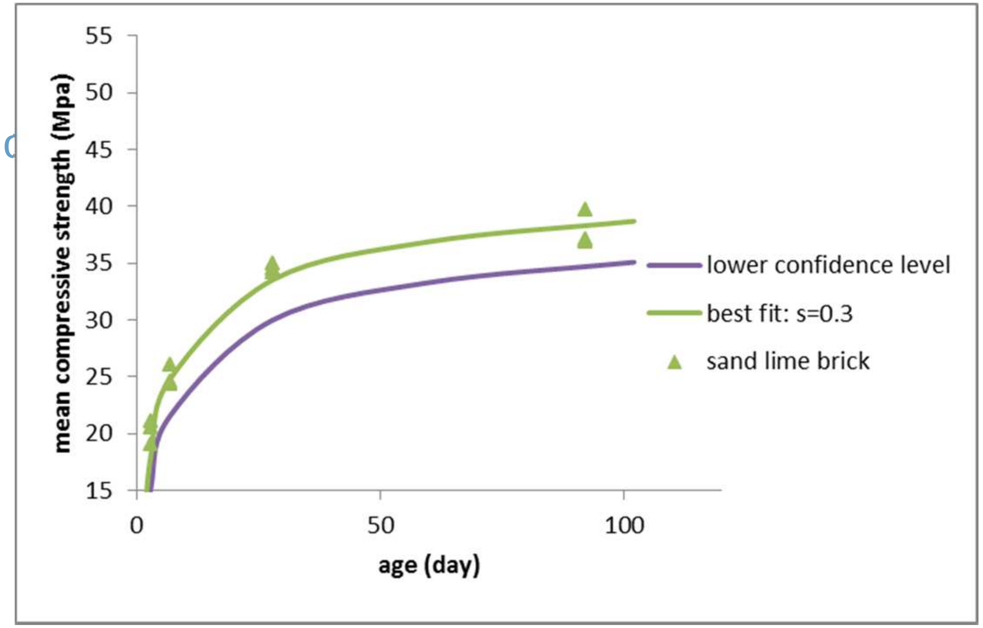
	sand lime	clay brick
Average strength	34.6	42.3
Char. strength	34.0	39.3
Strength class	C30	C35

- (2) strength development:

  95% of all measurements (12)

  within the 90% confidence regi

  (with EuroCode's s=0.25)



- Conclusion:

  strength development is

  all right but

  cost a strength class

4. General set-up for the assessment criteria

- **Single class / extreme class criteria:**
  - Mostly concerns relationships at 28 days between compressive strength and another mechanical property
  - Boundaries of application given in the codes
  - For classes, extreme classes have to be validated
  - Within one class, different criteria may apply, e.g.:
    - The characteristic values of the measured property should fall within the 95 % confidence region of the calculate values
    - All individual measurement should be larger than the 0.1 % probability limit of the calculated value

Strength classes for concrete															Equation / explanation
f_{ck} (MPa)	12	16	20	25	30	35	40	45	50	55	60	70	80	90	
$f_{ck,cube}$ (MPa)	15	20	25	30	37	45	50	55	60	67	75	85	95	105	
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f_{ctm} (MPa)	1.6	1.9	2.2	2.6	2.9	3.2	3.5	3.8	4.1	4.2	4.4	4.6	4.8	5.0	$f_{ctm} = 0.30 \mathrm{x} f_{ck}{}^{(2/3)} \leq \mathrm{C50/60}$ $f_{ctm} = 2.12 \cdot \ln\left(1 + (f_{cm}/10)\right) > \mathrm{C50/60}$

4. General set-up for the assessment criteria

- **Relationship assessment criteria:**
  - Mostly concerns simple, empirical models that contain fit constants
  - Boundaries of application also given in the codes
  - Within one model, three criteria should be formulated:
    1. A model confidence criterion (e.g. goodness of fit > 95%)
    2. A 5-95% reliability model parameters (from measured) should be larger than the predefined limits for these variables
    3. All individual measurements should fall within a certain confidence region of the model (e.g. 0.1 % probability limit)

Strength classes for concrete															Equation / explanation
f_{ck} (MPa)	12	16	20	25	30	35	40	45	50	55	60	70	80	90	
$f_{ck,cube}$ (MPa)	15	20	25	30	37	45	50	55	60	67	75	85	95	105	
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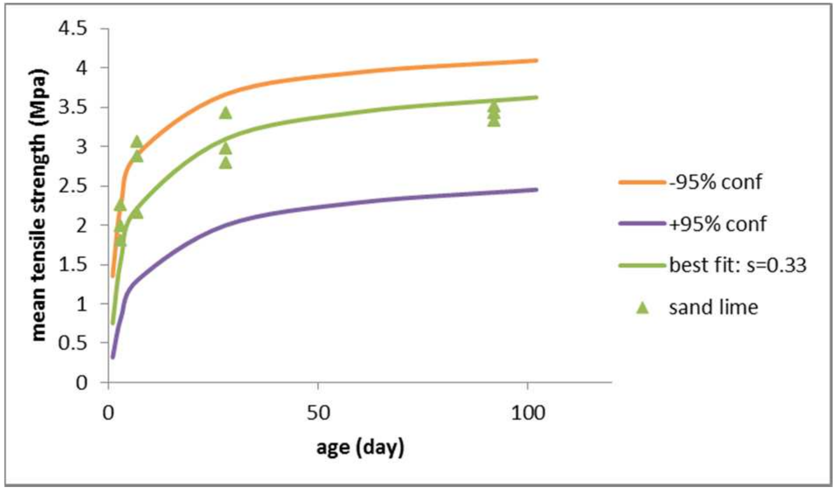
5. Example

- Assessment with respect to tensile splitting strength:
  - the characteristic strength compared to calc.value from fc: in the 90% confidence range
  - Strength build up: model confidence is 87 % < 95 %
  - Not all individuals in 0.1% - 99.9% confidence boundaries from model
  - Conclusion: tensile – compressive strength remains the same (and both slower at s=0.3/0.32) but confidence for model fails

	sand lime		clay brick	
	M	C	M	C
ftm=0.3*fck(2/3)	3.1	3.1	3.3	3.4
fctk(5%)=0.7*fctm	2.5	2.2	3.1	2.4
fctk (95%)=1.3*fctm	3.6	4.1	3.6	4.5



6. Summary and conclusions

Assessment criteria – compressive strength

	characteristic (p=0.05)	lower boundary	upper boundary	used value for individuals
f_{cm} (cube)	determines strength class	-	-	
LQRfit ageing				
confidence	>0.95	-	-	
f_{cm} (best fit)	>char. value strength class	strength class	-	characteristic value strength class
s	from measurement	0	-	p=0.95 Student t best fit value

Results for example

	mean	stdev	characteristic (p=0.05)	characteristic (p=0.95)	remark
ref.strength	34.6	0.40	33.9		strength class C25/30 (char. strength = 30)
LQRfit ageing					confidence =98.9 % >95%
$f_{cm,28d}$	33.5	1.20	32.9		char.best fit strength >30
s	0.30	0.06	0.27	0.33	char best fit > 0


6. Summary and conclusions

Assessment criteria – tensile (splitting) strength overview

	relationship	lower boundary	upper boundary	boundary for individuals
$f_{ctm,28d}$	$f_{ctm}=0.3*f_{ck}^{2/3}$	$f_{ctk,m}(5\%)>0.7*f_{ctm,c}$	$f_{ctk,m}(95\%)<1.3*f_{ctm,c}$	$f_{ctk,m}=(0.44 – 1.56) *f_{ctm,c}$
LQRfit ageing confidence	>95%	-	-	
$f_{cm,28d}$ (best fit)		$f_{ctk,m}(5\%)>0.7*f_{ctm,c}$	$f_{ctk,m}(95\%)<1.3*f_{ctm,c}$	
s		$s(5\%)>0.7*f_{s,c}$	$s(95\%)<1.3*f_{s,c}$	
individuals		between 0.1% and 99.9% confidence boundaries from model with for low strength / high s and high strength / low s		0.1%: 0.44 99.9% 1.56

Results from example

	mean	stdev	characteristic values		boundaries		criteria
			(p=0.05)	(p=0.95)	lower	upper	
individual meas.	Do not fall all within the boundaries						FAIL
model Confidence	86.9%						FAIL
$f_{ctm,28d}$	3.10	0.09	3.05	3.15	2.00	3.67	PASS
s	0.33	0.07	0.29	0.37	0.23	0.43	PASS

6. Summary and conclusions

- An assessment procedure on the basis of equivalent performance is a fast and relative easy way to prove the suitability of new types of concretes.
- The criteria are pretty strict, as they should be on the basis of the risks underlying them.
- The procedure is based on proving that the new materials behave mechanically similar to the already accepted types of concrete.