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Engineering in GRP pipes and tanks

Fundamentals, behaviour and design philosophy

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What we will cover today

- Why GRP behaves differently (block 1)
- Why systems fail (block 2)
- Building blocks (block 3)
- Behaviour and design (block 4)
- **Standards (ISO 14692 / EN 13121) (block 5)**
- Inspection and failure detection (block 6)

What ISO 14692 actually does


We already have norms and standards.
Why ISO 14692?

GRP in tanks and pipes

Room for confusion

All made of GRP

But with different requirements

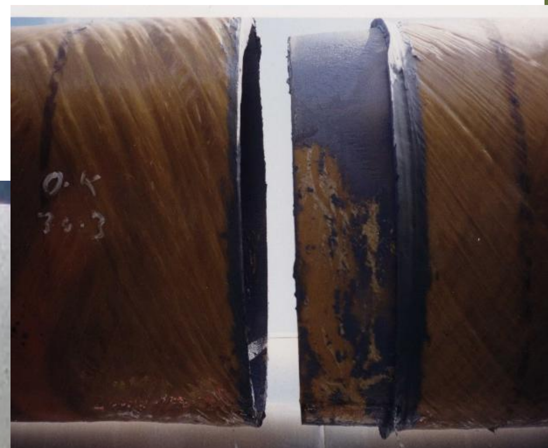
- Loads
  - Internal/external temp, P mechanical, chemical
  - Static/dynamic
  - Combined
- Service life

Traditional	Alternative
Concrete	GRP
(ductile) Iron	GRP
PVC/PE	GRP
Cst (lined)	GRP
CRA (SSt, Hastelloy, Inconel, etc)	GRP

GRP ≠ GRP

Confusion

Pn10 ≠ Pn10



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Municipal Pipe Systems

- Low pressure
- standard components
- non-critical

- focus on pipe circumferential stiffness
- UNI-Axial

Industrial Pipe Systems

- High pressure
- designed to the limit
- critical systems

- System performance
- axial behaviour
- BI-Axial

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Chemical Pipe Systems

- High and Low pressure
- Fitting intensive
- Critical

- Custom made
- focus on basic material properties

Standards

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Many different specifications

ensure long term performance, but in different ways:

- Minimum performance level, like EN 1796, EN 14364 etc
- Based on system design ISO 14692

DIN EN ISO

DIN

NEN

cen

EOTA

BSi

AFNOR

Change:

BS, Din, NEN etc.. Disappear; committed to adopt EN

CE marking

EN **ISO**

Vienna Agreement

CEN **EOTA**

- **The Pressure Equipment Directive**

- **The Construction product directive: pipelines for potable- and non-potable water CEN TC155WG14**

CE marking

- CE mark: not a quality-mark
  - it refers to the safety rather than to the quality of a product.
  - Non voluntary: CE marking is mandatory for the products it applies to.
  - Fitness for (the intended) use
- CE indicates conformity with mandatory European essential requirements.
- NO TRADE BARRIERS!

EN standards on composites

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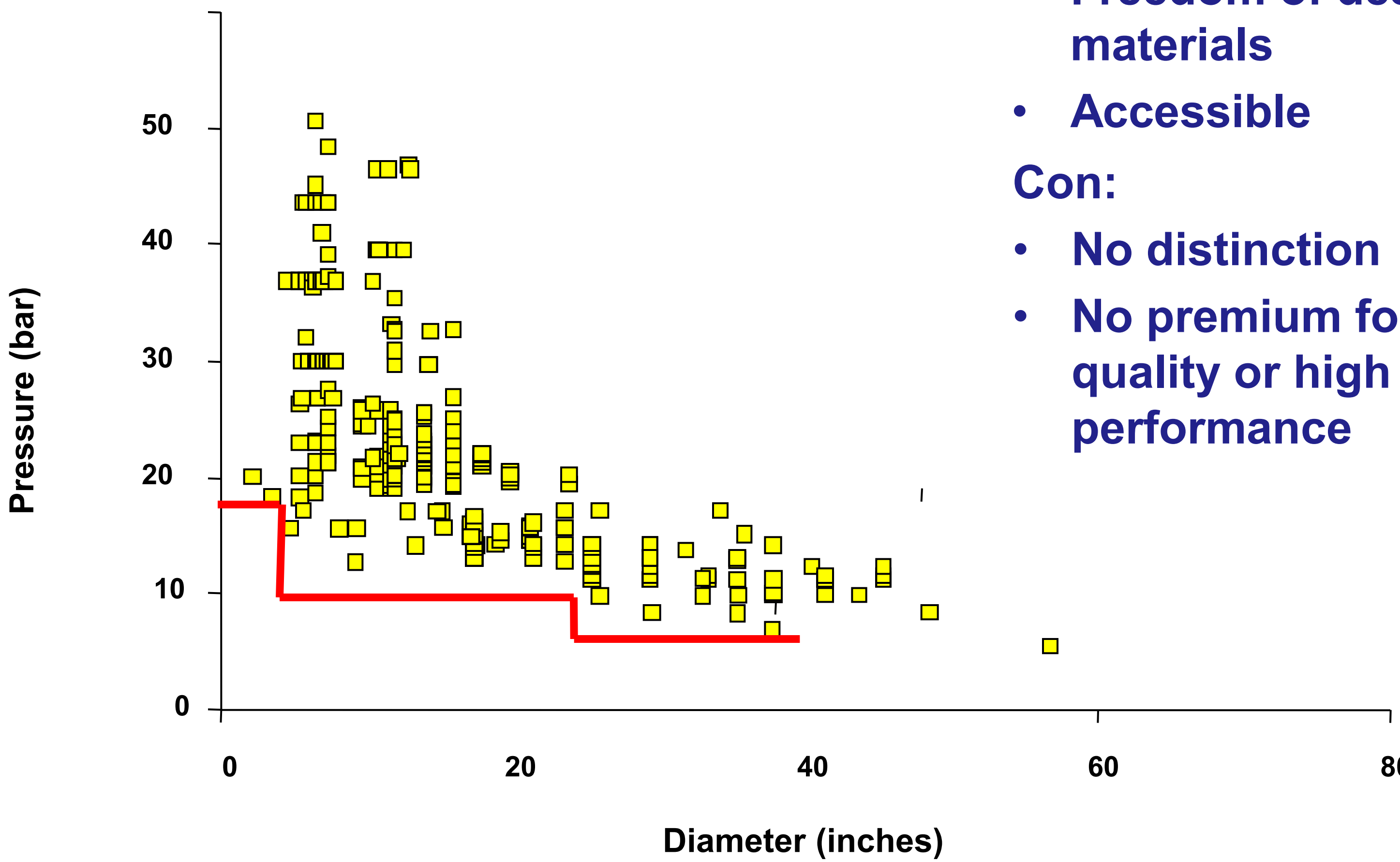
Pressure piping standards:

- Base level standards
- Strong focus on pipes
  - HDS, strain corrosion, long term ring bending
- Mainly non-tensile resistant
- Limited performance requirements for joints
- No performance requirements for fittings

Base performance level



Pro:

- Freedom of design and materials
- Accessible

Con:

- No distinction
- No premium for high quality or high performance

Performance based system design

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- No prescribed material composition
- No prescribed performance levels

Pro:

- Premium for high performance or high quality

Con:

- Expensive qualification
- No flexibility after qualification

Material compatibility

Changes in the composition officially require revalidation by re-qualification

- time consuming and expensive
- Severely limits innovation

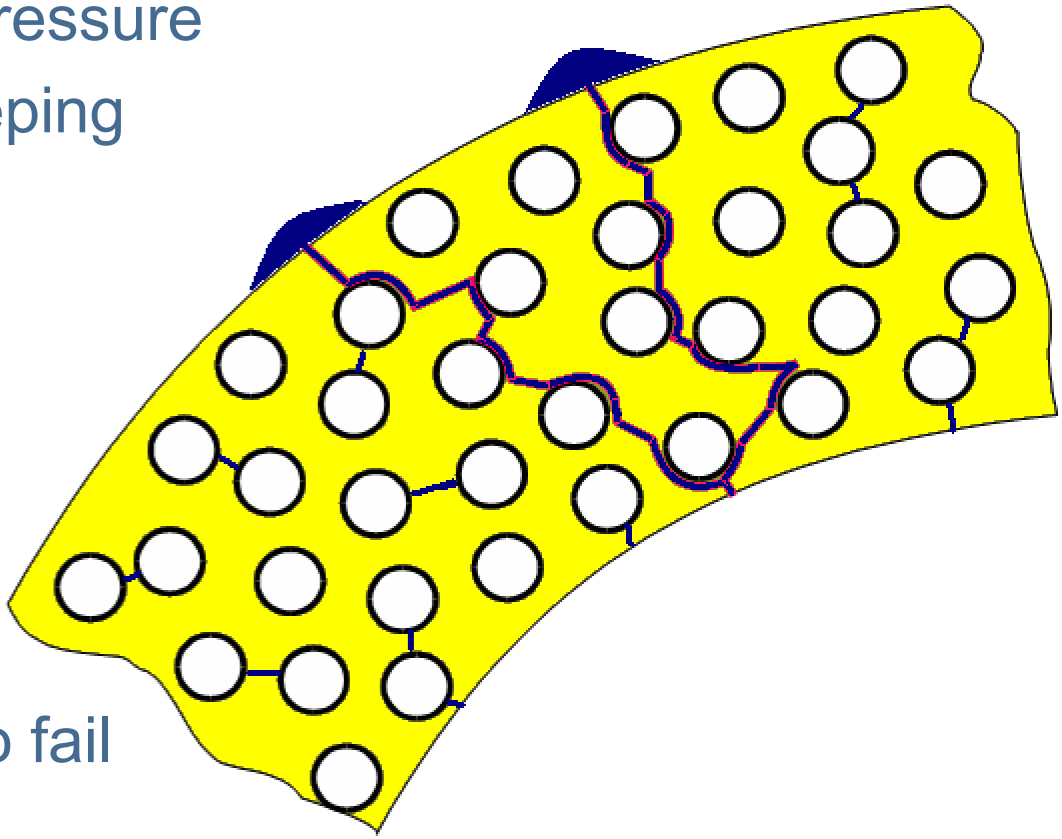
Practice:

- “trust me”
- “built so many of these installations”
- manufacturers liability
- **ASTM D 1599**
- Etc..

ASTM D 1599: alternative

Short term hydrostatic pressure

Failure mechanism: weeping within 60-70 (s)



- Wide scatter
- Material needs time to fail

Core problem: GRP strength is time dependent!

Basis for Pipe wall strength

Hydrostatic Design Basis (HDB) or LCL (95%)

- Long term hydrostatic hoop strength of pipe material
- 50 years or 20 years
- Typical value 120-125 MPa for GRE

Regression tests

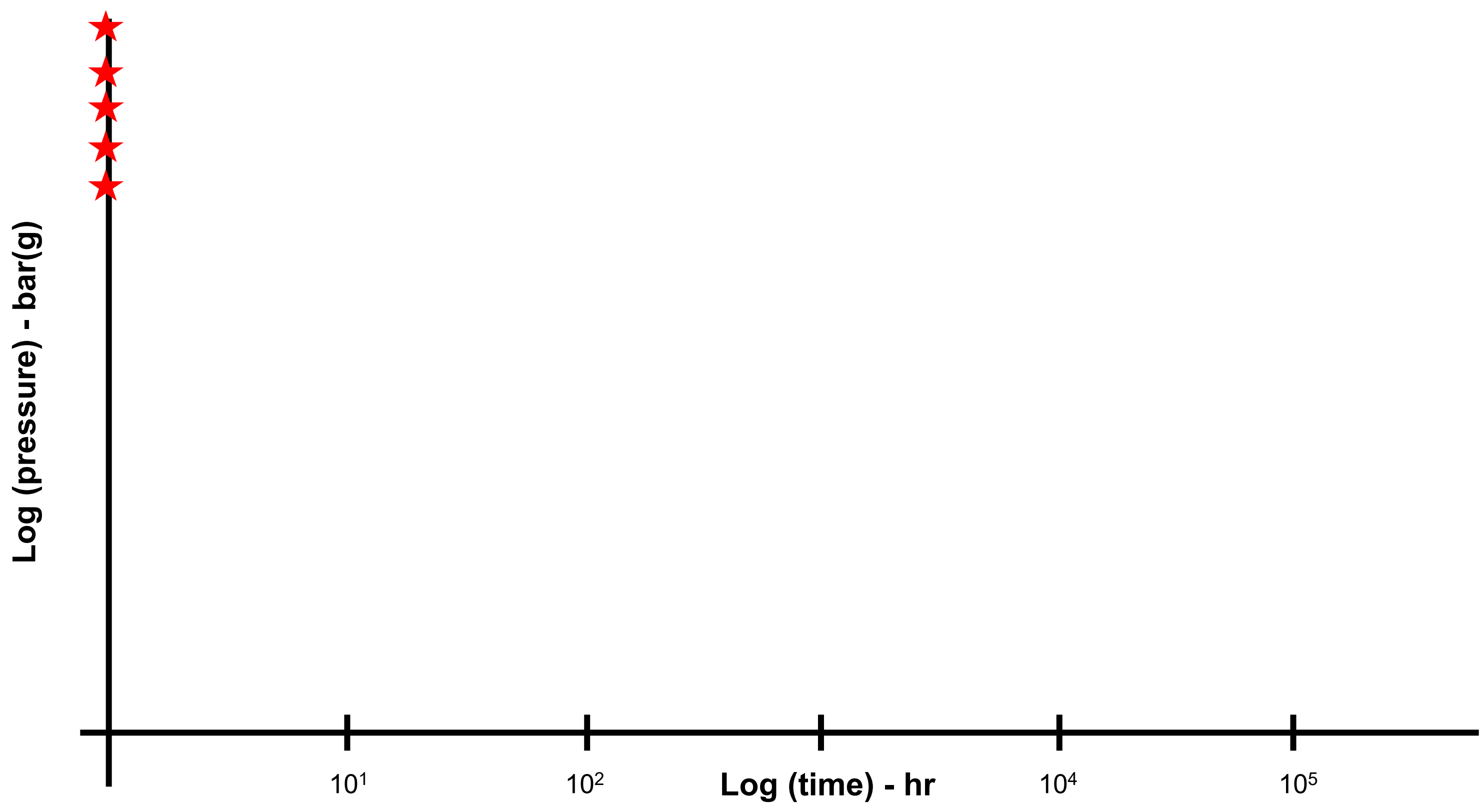
- ASTM D 2992 B

Deliverables

- **long term regression analysis:**
  - **long term hydrostatic stress for pipes**
  - **long term hydrostatic pressure for fittings**

Qualification of GRP

Regression analysis



Qualification of GRP

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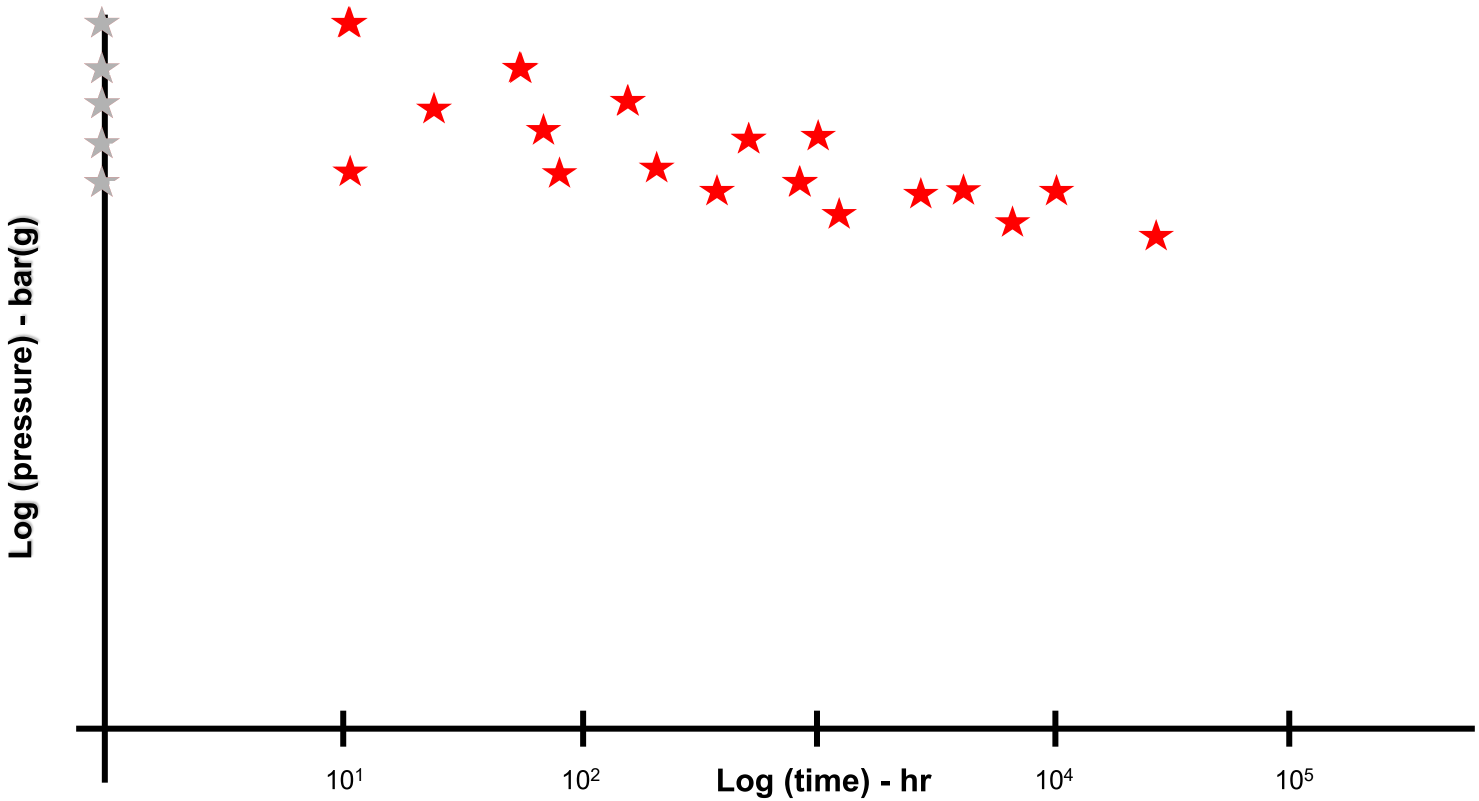
Regression analysis



Qualification of GRP

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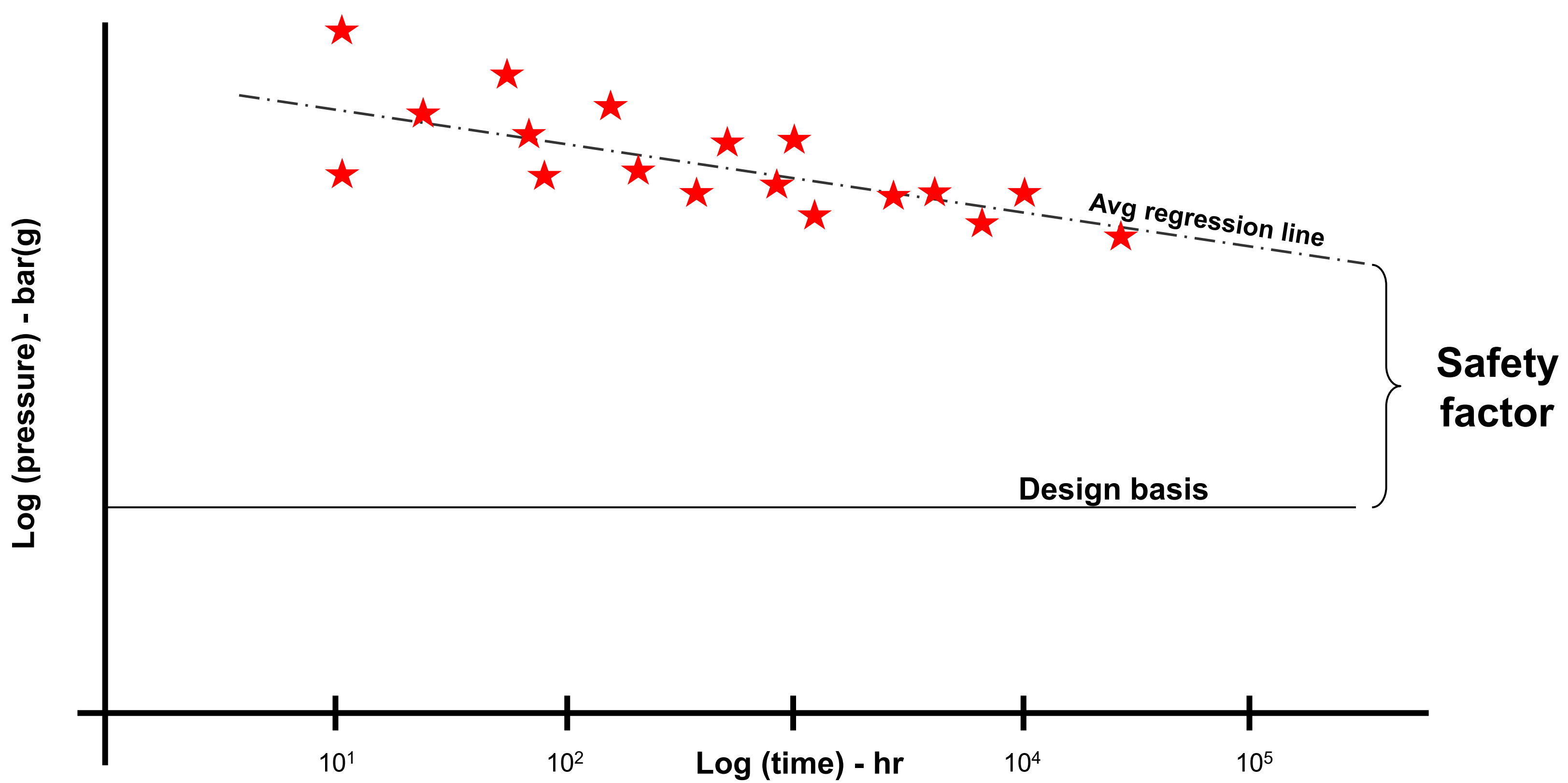
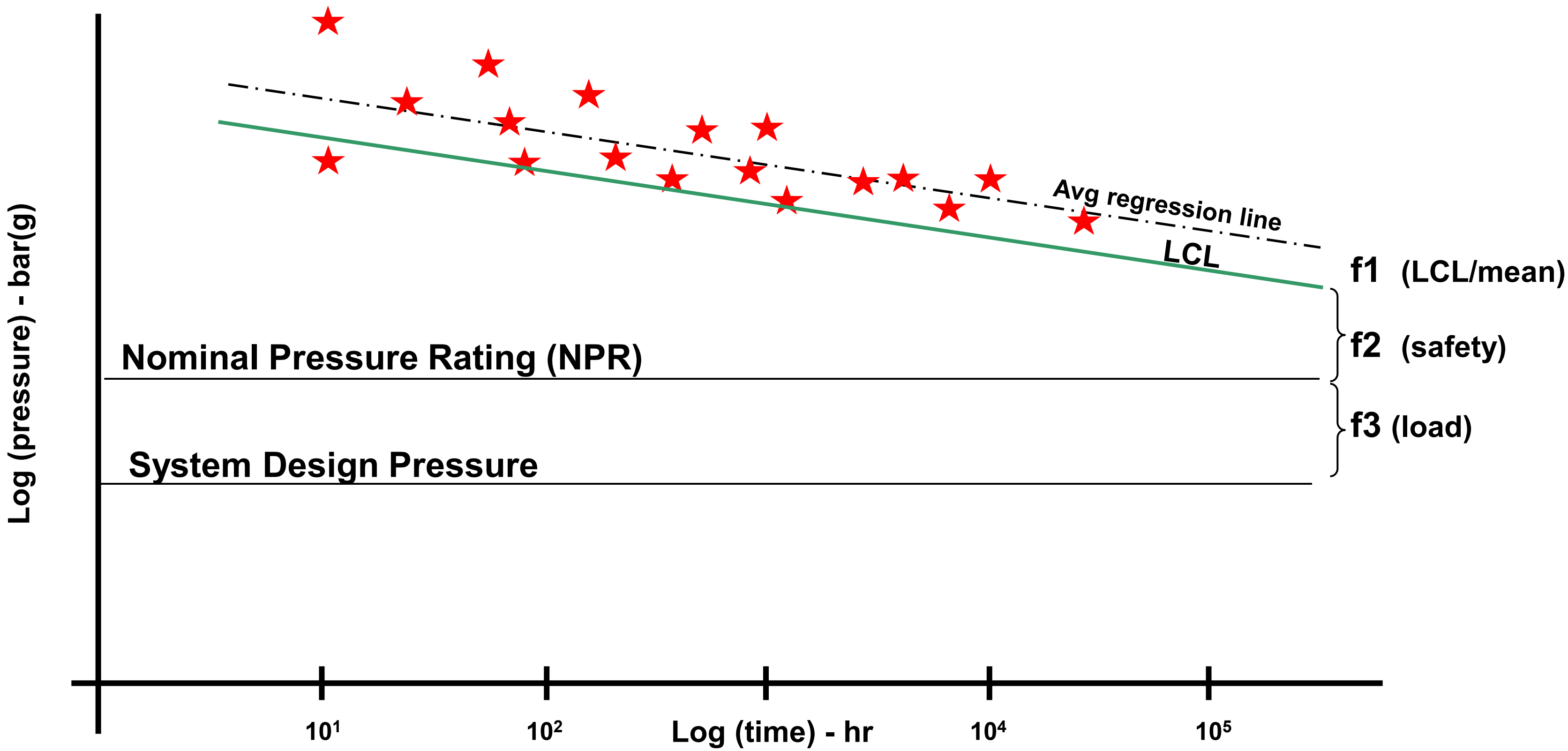
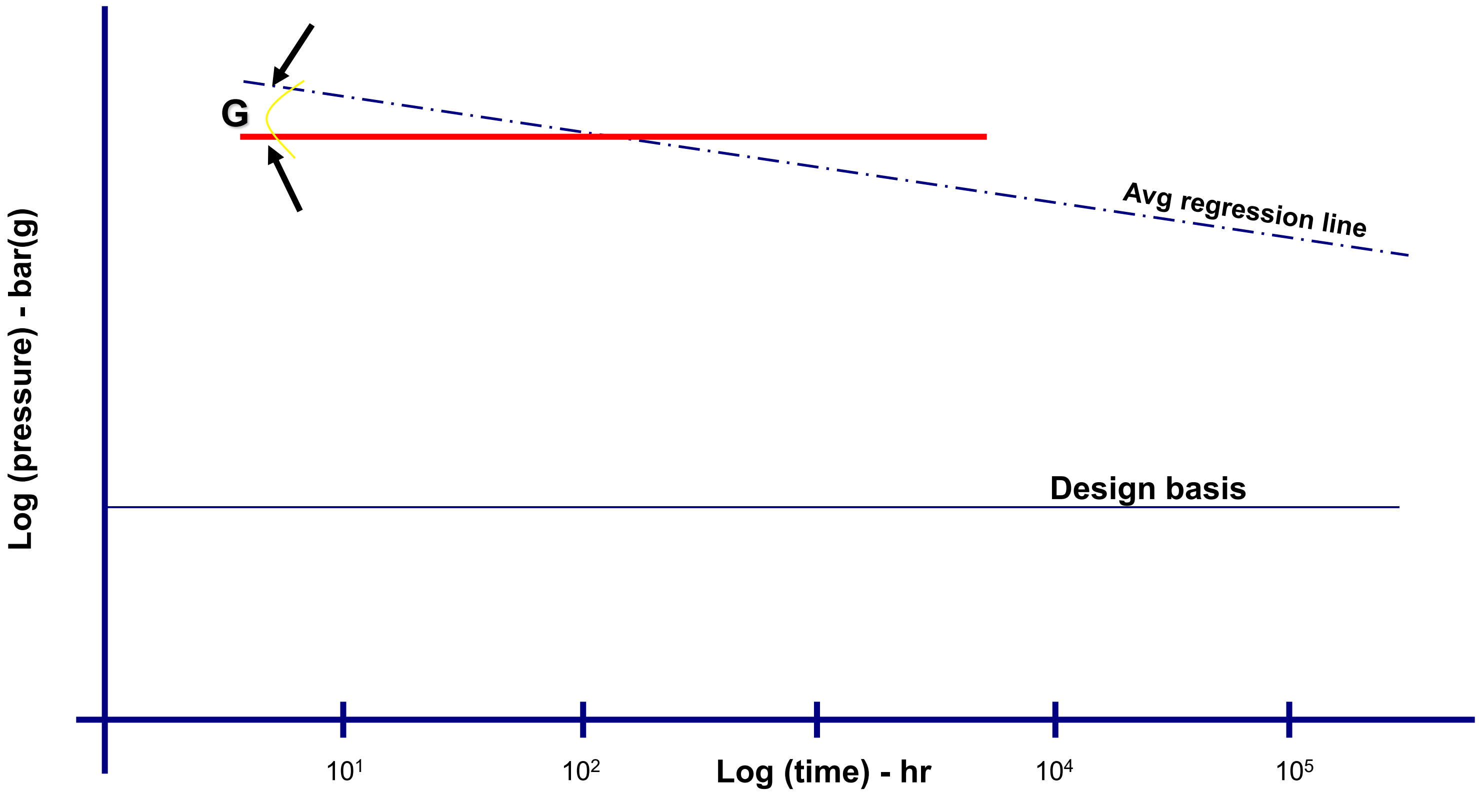


Pressure rating definition

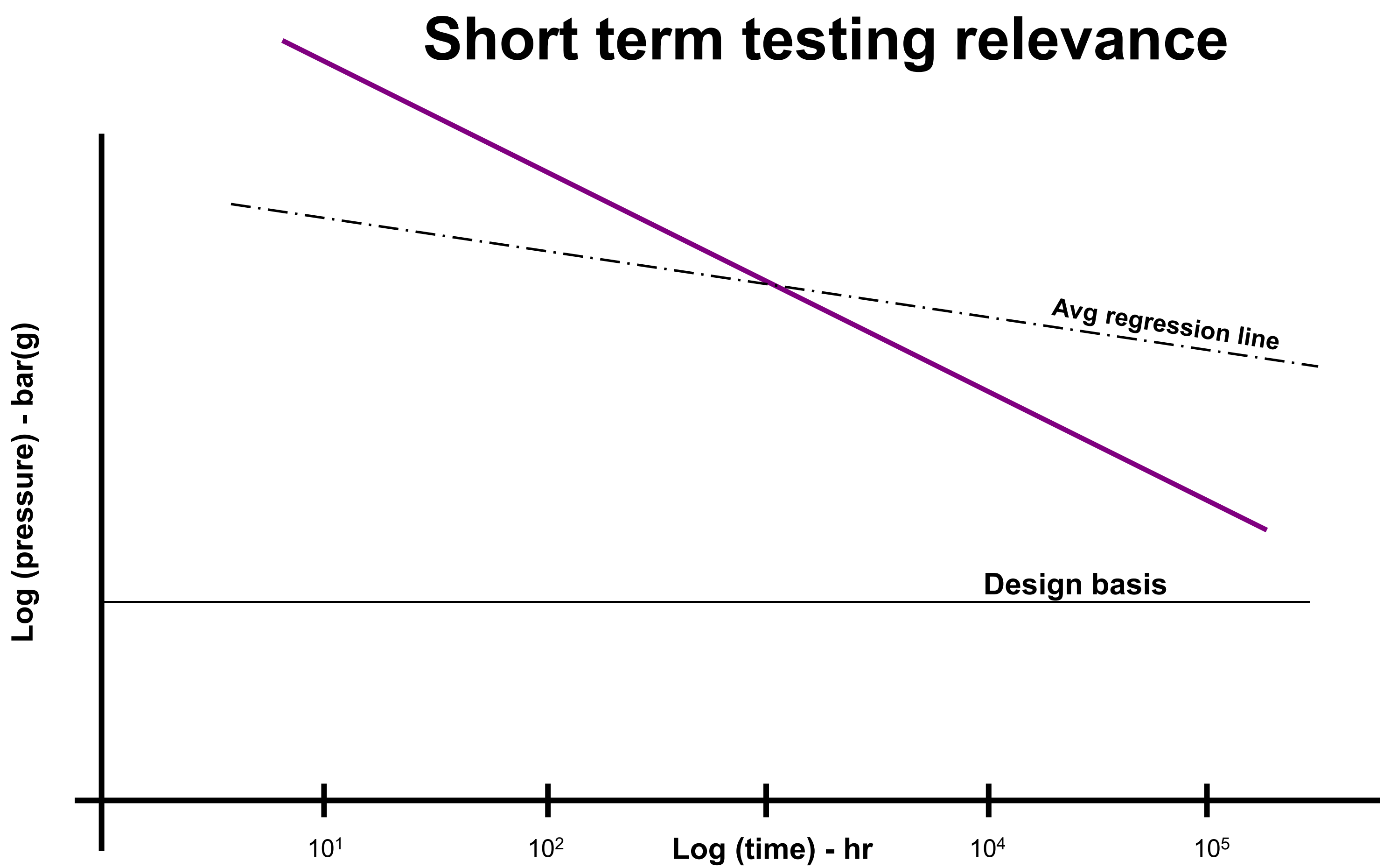


Regression analysis

Short term testing relevance



Regression analysis



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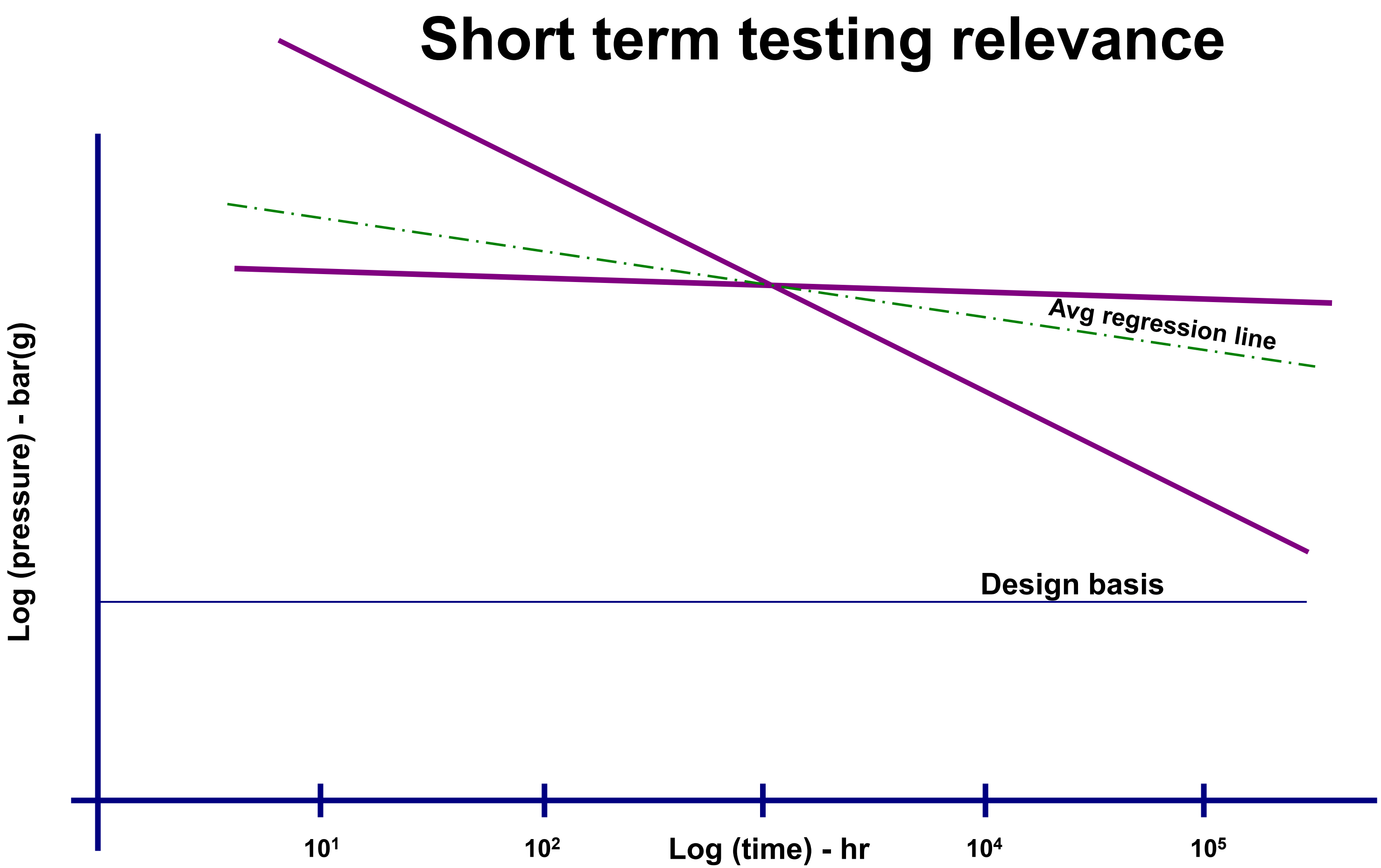

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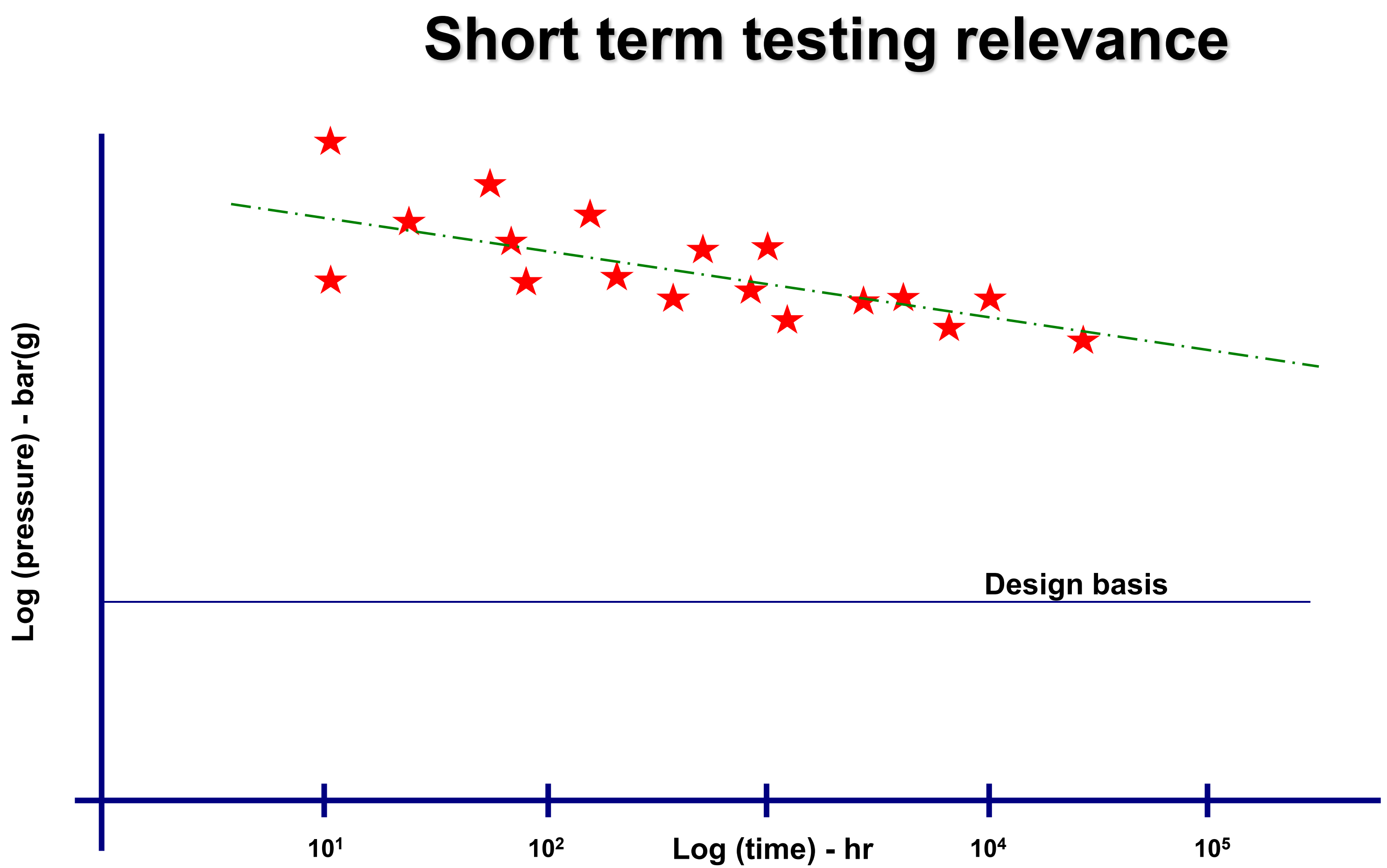

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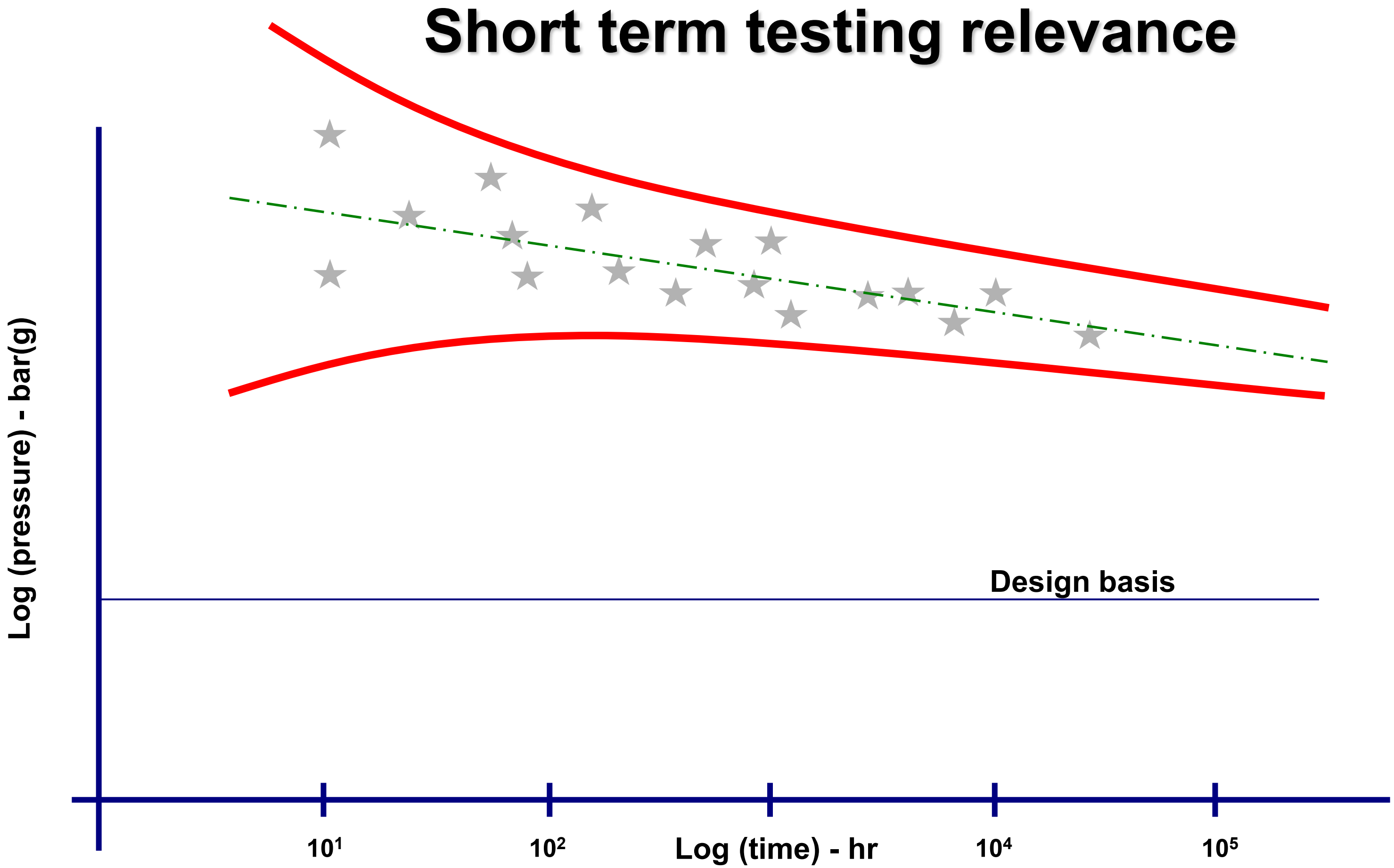

Regression analysis

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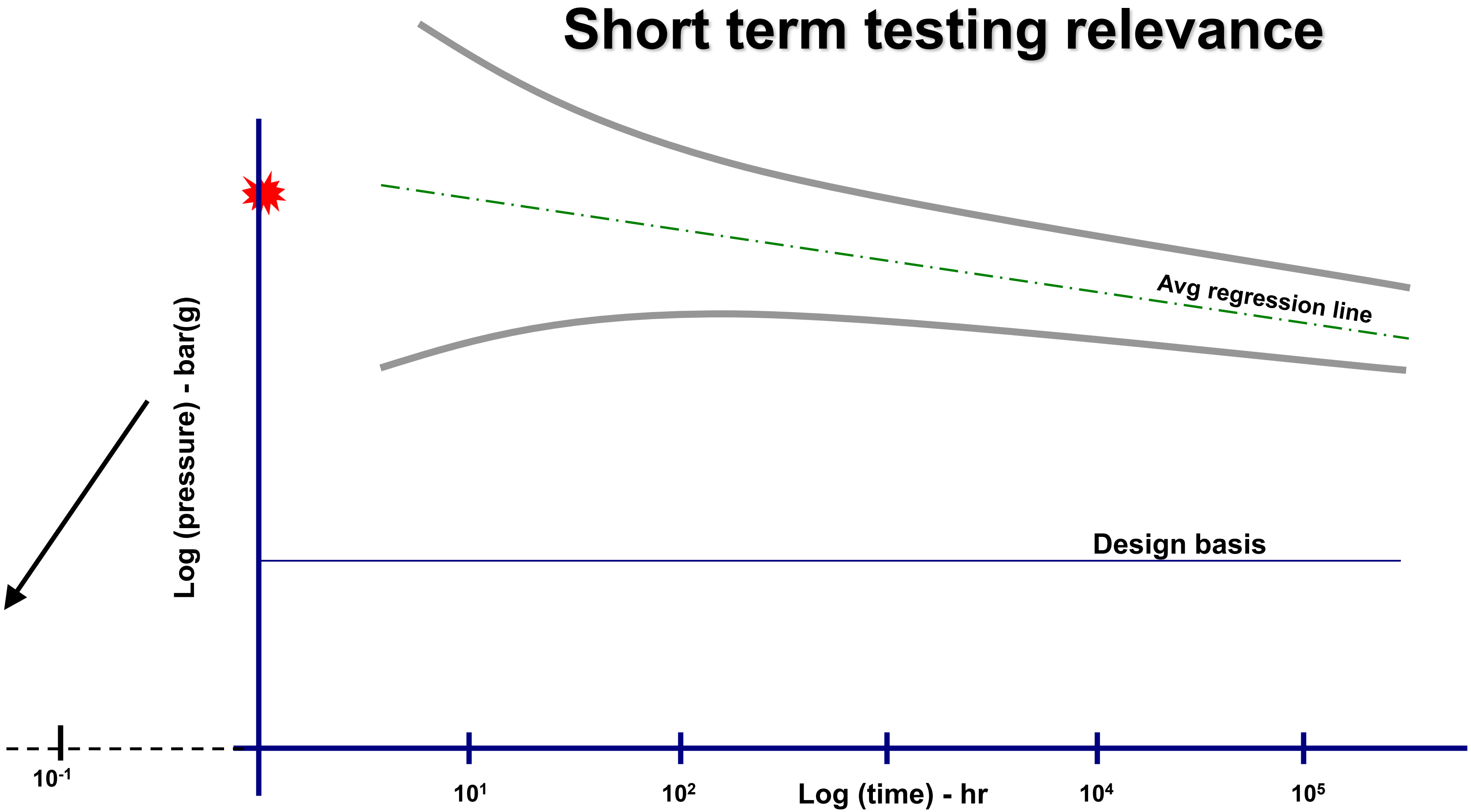

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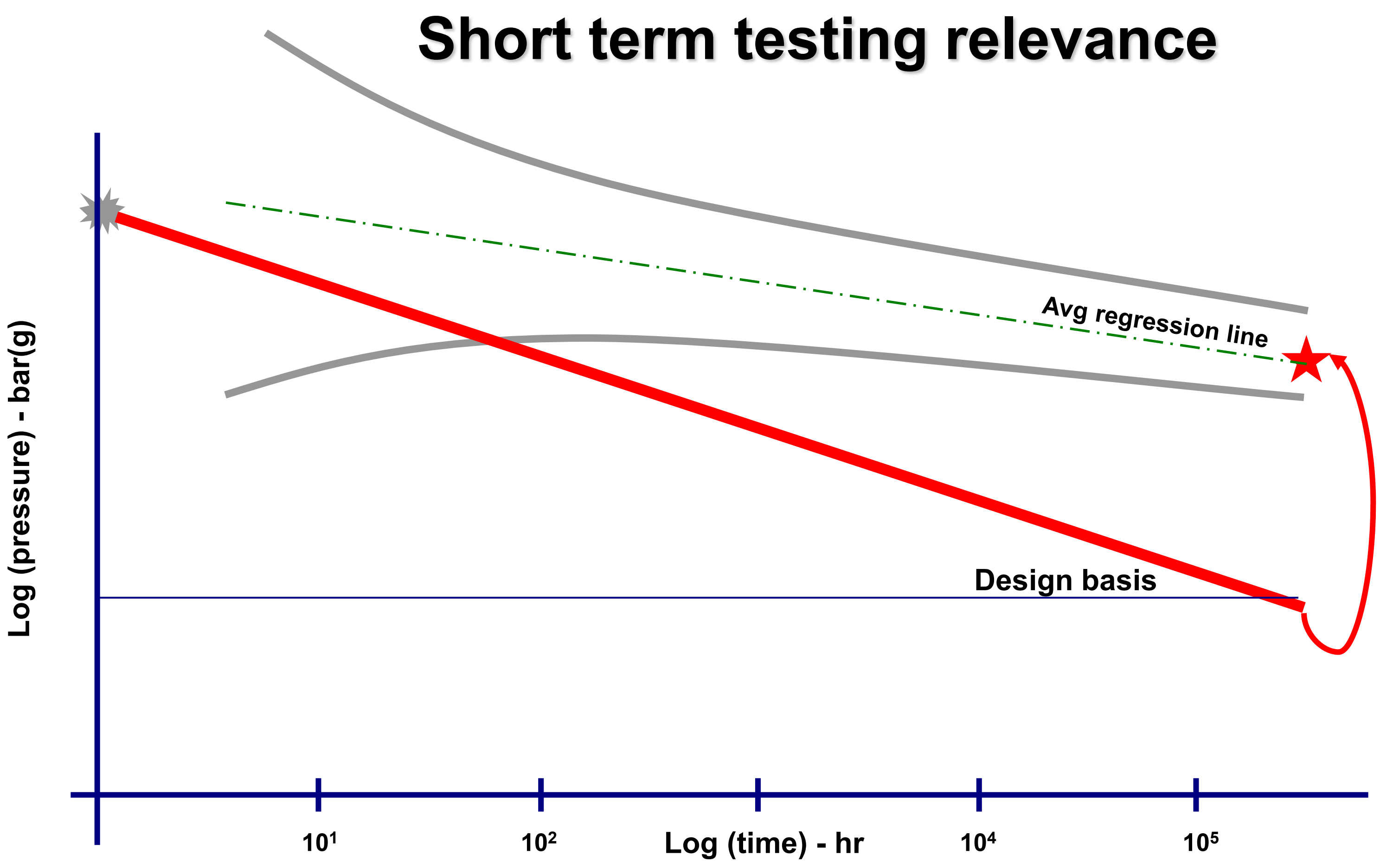

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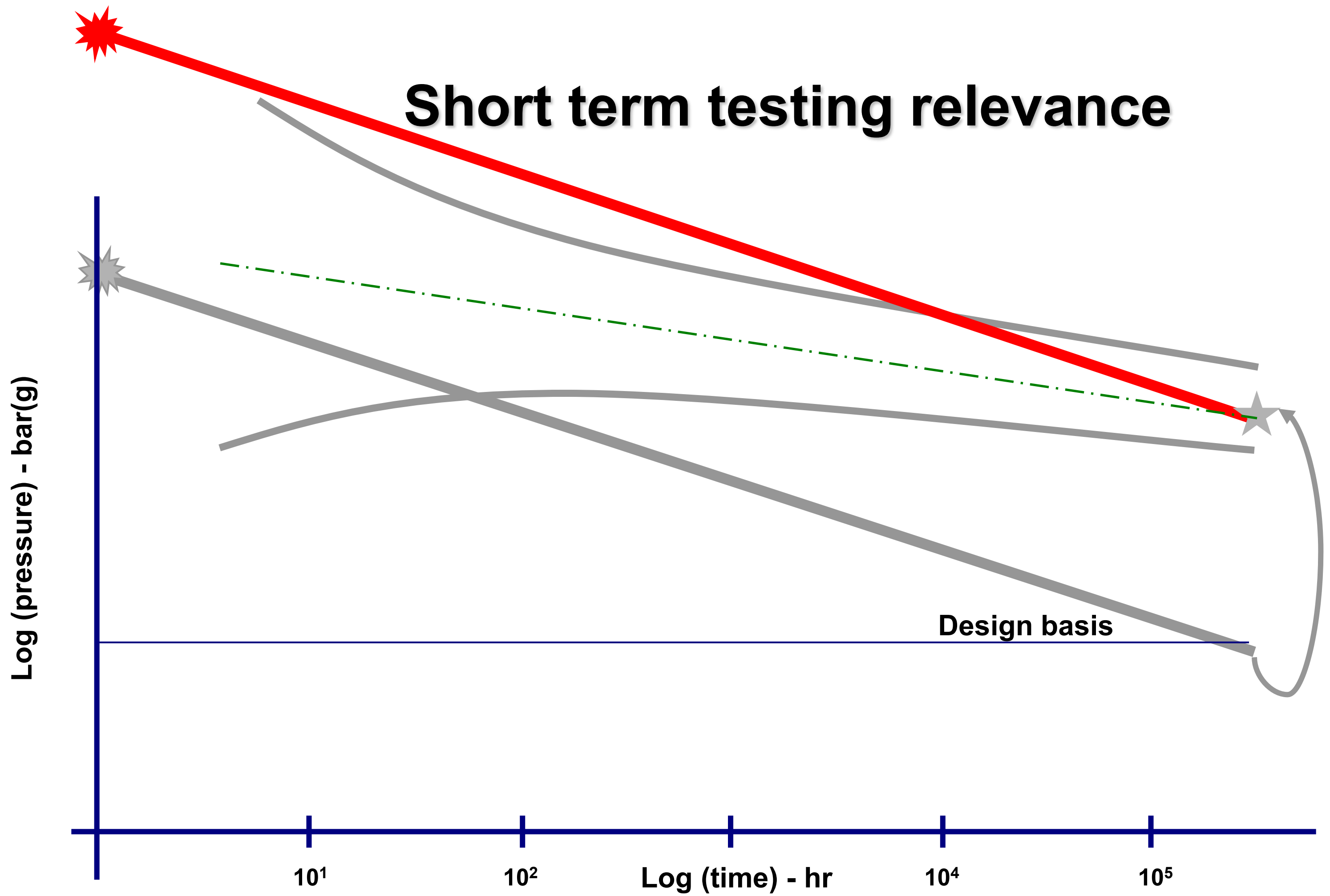

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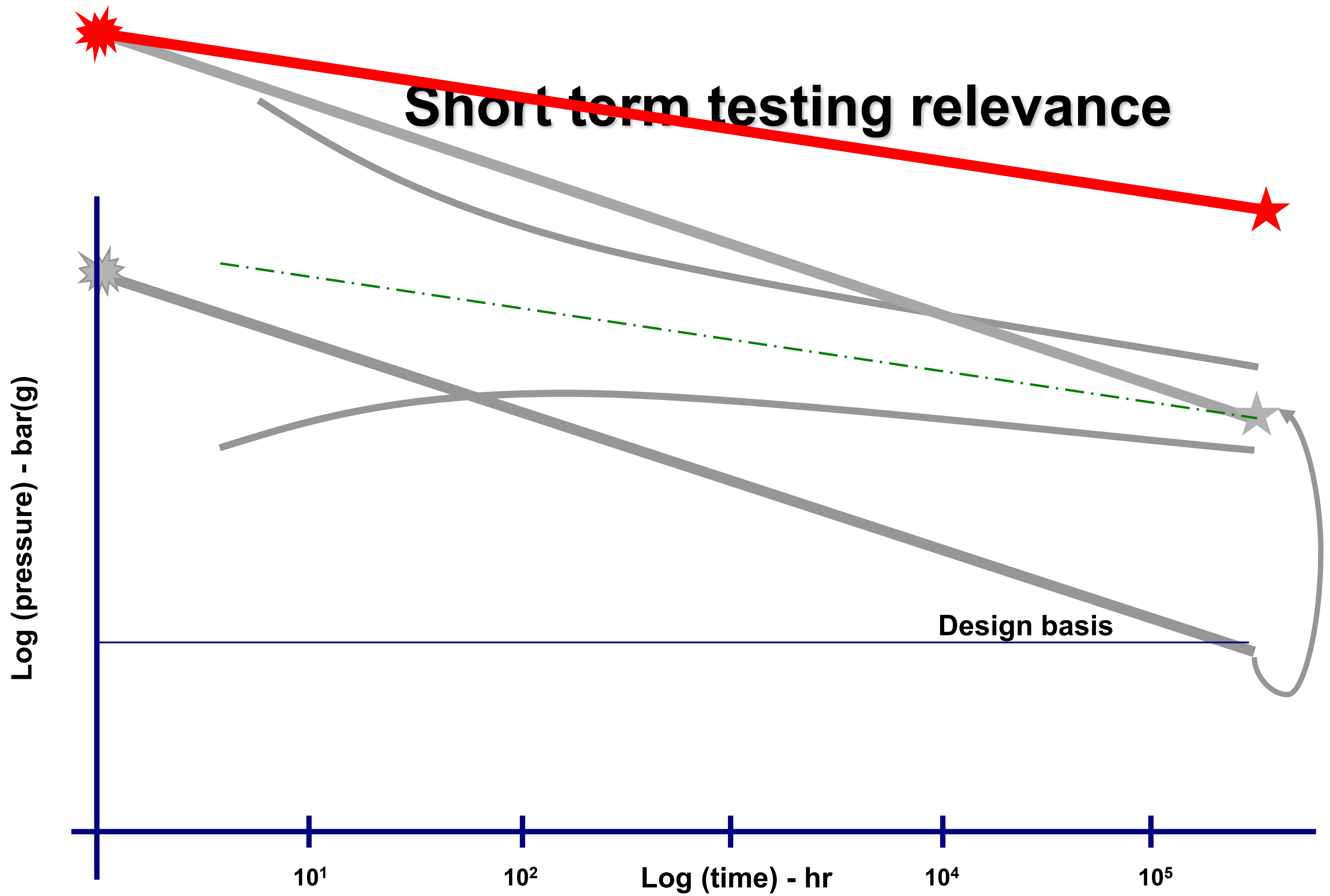

Qualification of GRP components

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Problem:

ASTM D2992 not feasible for qualification

of large quantities of full scale products:

2 yrs per test

No Alternative:

ASTM D 1599 - Short term (burst) testing??

Alternative:

ISO 14692 - Medium term testing!!

The alternative

Qualification of GRP

History:

1984 → PDO ERD 38-12
1992 → UKOOA
1998 → Shell DEP 31.40.10.19
2003 → ISO 14692

- **Long-term behaviour of full-scale components**
- **No relation between short-term and long-term strength**

EN-ISO 14692 uses medium-term 1000 hours survival testing to prdict long-term behavior

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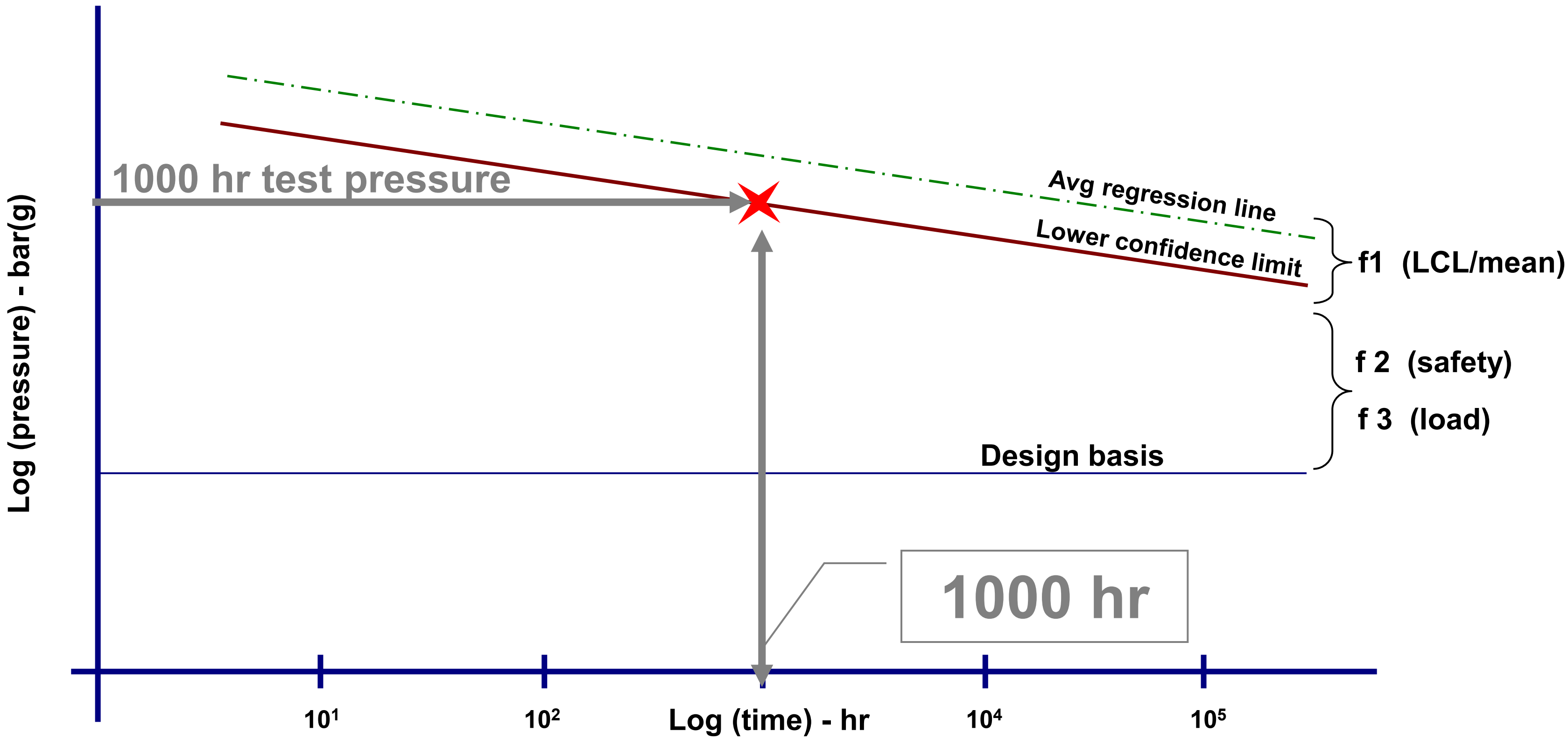
1000 hr Survival test



Idealized failure envelope

(ISO 14692)

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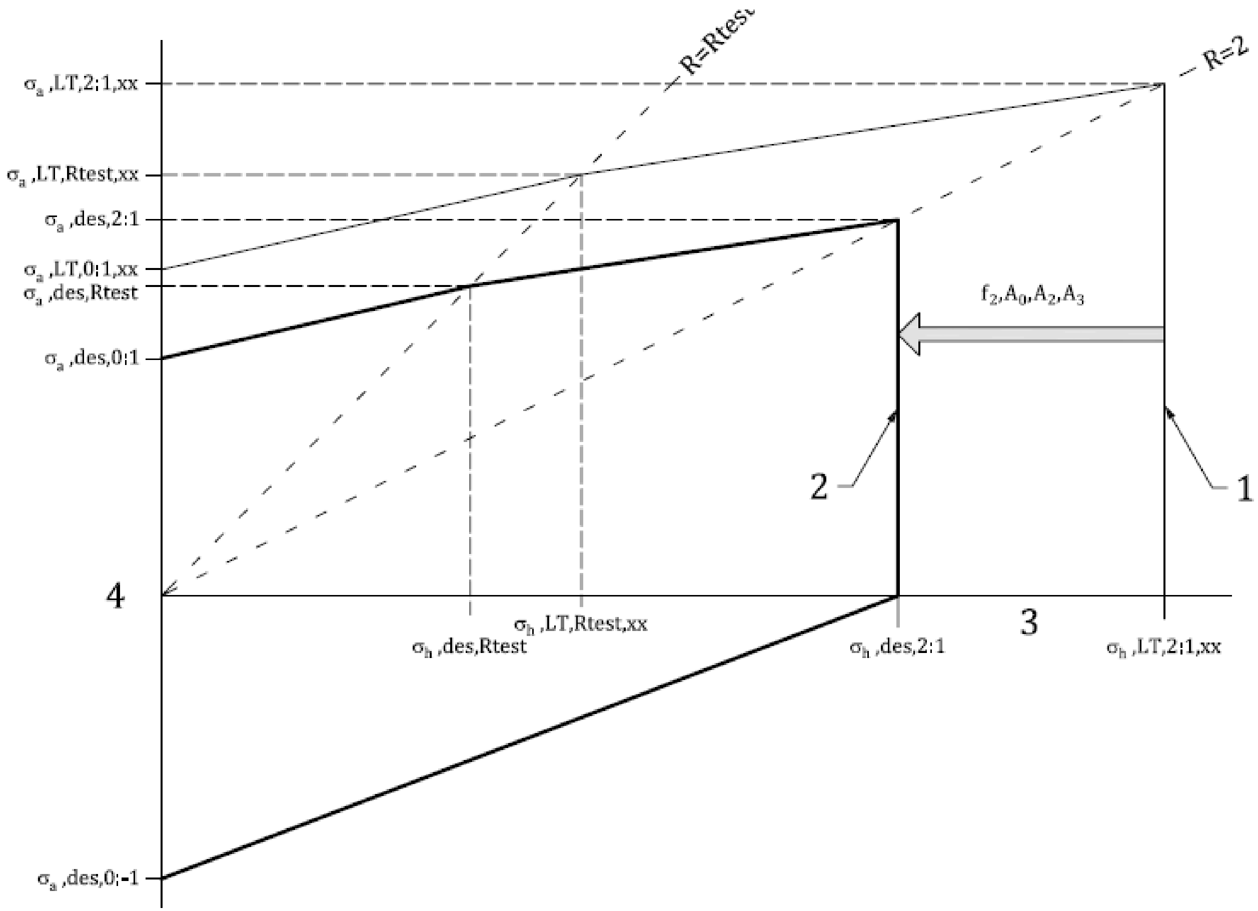

Key

1 long term envelope

2 design envelope

Figure 3 — Relationship between the long term envelope(s) and design envelope(s)

EN ISO 14692
Safety of the installed pipe system

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I.	Strength of components ISO 14692 - part 2	:Qualification.
		↕ Design Envelope
II.	Strength of pipe system ISO 14692 - part 3	:System Design.
		↕ Site Quality PLan
III.	Installation of pipe system ISO 14692 - part 4	:Training & Qualification.

EN 13121:

“GRP tanks and vessels for use above ground”.

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EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

4 parts:

Part 1: raw materials

Part 2: chemical resistance (A2)

Part 3: Design and workmanship

Part 4: delivery, installation and maintenance

Part 1: Raw Materials

- Definition of Resin:
  - Classification based on chem properties, not tradenames
  - Definition of (cured and uncured) properties
- Definition of Glass
  - Type of reinforcement (roving, csm, woven tape etc.)
  - Sizing and binders
  - Mass unit (per area or linear density)
  - Composition (warp/weft, random etc.)
- Thermoplastic linings
- Certification EN 10204 3.1b (full traceability)

Part 2: chemical resistance

Part factor A_2 used to define design factor K and F: see part 3

to determine A_2 based on:

- Media lists (only for categorised resins in part 1)
- Manufacturers data for SPL/CRL/resin/reinforcement, or
- Manufacturers data for TPL
- Service experience
- Test procedures

Part 3: design and workmanship

- Mechanical properties
  - Minimum performance required
    - Laminate strenght
    - Lap shear
    - Peel
- Unit strength approach (N per mm wall thickness)

2 alternatives

- Basic design method
  - Using minimum general properties (still: verified by testing!)
- Advanced design method
  - Using extended mechanical testing

Design approach

1. Determine material properties
2. Determine the design factor
3. Determine the maximum allowable lamina strain
    1. Per layer
    2. Laminate construction

Two limit values:

ε_d : design strain

ε_t : test strain

4. Determine the allowable design unit loading

Mechanical properties

Table 3 — Minimum properties of laminate layers

Type of reinforcement	Direction	Applicable criteria	UTUS	Unit Tensile Modulus
			U_i N/mm per kg/m² glass	X_i N/mm per kg/m² glass
CSM	All		200	14 000
CSM (furane/phenolic)	All		140	14 000
WR	Warp	$\xi \geq \frac{1}{6}$	500 x ξ	4 000+24 000 x ξ
		$\xi < \frac{1}{6}$	60	4 000
	Weft	$\xi \leq \frac{5}{6}$	500 × (1-ξ)	4 000+24 000 × (1-ξ)
		$\xi > \frac{5}{6}$	60	4 000
WR (furane/phenolic)	Warp	$\xi \geq \frac{1}{6}$	320 x ξ	4 000+24 000 x ξ
		$\xi < \frac{1}{6}$	40	4 000
	Weft	$\xi \leq \frac{5}{6}$	500 × (1-ξ)	4 000+24 000 × (1-ξ)
		$\xi > \frac{5}{6}$	40	4 000
FW	Fibre direction	$85° < \theta < 90°$	500	28 000
FW (furane/phenolic)	Fibre direction	$85° < \theta < 90°$	280	28 000

Basic Rule of Mixture

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For elastic properties

$Ec = f * E_f + (1-f) * E_m$	Ef	material property fiber
	Em	material property matrix
$f = V_f / (V_f + V_m)$	volume fraction of the fibers	
$E_c = (f/E_f + (1-f)/E_m)^{-1}$	inverse rule of mixture: perpendicular to fibers	

- Fibre area correction factor,
- Fibre diameter distribution factor
- Fibre length distribution fa tor
- Fibre orientation distribution factor

Part 3: Design and workmanship

Design factor $K = \gamma_M \cdot \gamma_{F,i} \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4 \cdot A_5$ **(overall)**

Design factor $F = \gamma_M \cdot \gamma_{F,i} \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4 \cdot \sqrt{A_5}$ **(buckling)**

- Y_M: Partial material factor = 1,4
- Y_F: Partial loading factor – EN1991-4
- A_1: Verification of material properties (1-2)
- A_2: Chemical loading (part 2) (1.1-1.4)
- A_3: Relation design temperature vs HDT (1-1.4)
- A_4: Operation cycles (1)
- A_5: Long term behaviour (1-2.4)

- **K ≤ 4(adv), 6 or 8 (basic)**
- **F ≤ 2,7(adv),3 or 4 (basic)**

The value of partial loading factor γ_F shall comply with the factor given in EN 1991-4.

For example:

$\gamma_{F,j} = \gamma_{G,j} = \gamma_{Q,j}$	partial safety factor for the load j
$\gamma_{F,w} = \gamma_{G,j} = 1{,}35$	for permanent clear loads (e.g. dead load, filling)
$\gamma_{F,p} = \gamma_{Q,j} = 1{,}50$	changing loads (e.g. pressure, wind, snow e.g.)
$\gamma_{F,r} = \gamma_{Q,j} = 1{,}00$	restraint loads (temperature e.g.)
$\gamma_{F,s} = \gamma_{Q,j} = 1{,}00$	serviceability limit states
$\gamma_{F,e} = \gamma_{Q,j} = 1{,}00$	extraordinary burden (earth quake e.g.)
$\gamma_{F,red} = \gamma_{Q,j} = 0{,}90$	for dead load, if the operational demands reduced
$\gamma_{F,w} = \gamma_{Q,j} = 1{,}35$	for mounting loads

Partial design factors

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Table 8 — Summary of design methods and partial influence factors

	Permissible design approach		
	Advanced design	Basic design	
		Either	Or
Derivation of mechanical material properties (test)	User-defined material properties in accordance to 7.9.3 the material properties shall be verified on each manufactured tank according to 17.5.3	User-defined material properties in accordance to 7.9.2 the material properties shall be verified on each manufactured tank according to 17.5.3	User-defined material properties in accordance to 7.9.2 the material properties shall be verified on each manufactured tank according to 17.5.3
Historical material test datas	Historic data only acceptable with support from a limited production test programme by an authorized inspecting authority.	Historic data acceptable if similar laminate design has been produced within 12 months of the last test.	Historic data acceptable if similar laminate design has been produced within 18 months of the last test.
Partial influence factor relating to the level of the test verification of material properties.	$A_1 = 1{,}0$ For mechanical properties $A_1 = 1{,}0$ when using historic test data and verifying tests in accordance to 7.9.3	$A_1 = 1{,}2$ (vessel cut- outs) $A_1 = 1{,}3$ (sample laminates) $A_1 = 1{,}5$ (If no additional testing is carried out and historic test data are used to support the design properties)	$A_1 = 2{,}0$
Partial design factor relating to the chemical resistance of the laminate	A_2 (from EN 13121−2:2003)	A_2 (from EN 13121−2:2003)	A_2 (from EN 13121−2:2003)
Partial influence factor relating to the design temperature of the vessel and resin HDT	A_3 (7.9.5.4)	A_3 (7.9.5.4)	A_3 (7.9.5.4)
Partial influence factor relating to cyclical loading	A_4 (7.9.5.5) = 1	A_4 (7.9.5.5) = 1	A_4 (7.9.5.5) = 1
Partial influence factor relating to long term behaviour	A_5 (7.9.5.6)	A_5 (7.9.5.6)	$A_5 = 2{,}4$
Minimum design factor K with $\gamma_F = 1{,}5$	K (minimum) = 4 K (minimum) = 5 if A_5 is not determined by test program D.15.of Annex D	K (minimum) = 6	K (minimum) = 8
Minimum buckling design factor F with $\gamma_F = 1{,}5$	$F \geq 2{,}7$	$F \geq 3{,}0$	$F \geq 4{,}0$

Limit design strain

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a. Limit resin strain $\varepsilon_{ar} = 0{,}1 * \varepsilon_R$

b. Limit lamina strain ε_d :

Table 9 — Design strain $\varepsilon_d = \varepsilon_{lim}$ for different laminates

Laminate of type of polyester resin	CSM	Mixed lam. WR	Wound laminate 0° / 90° laminate axial	Wound laminate 0° / 90° laminate circumference	Wound laminate ±65°
Polyester resin	0,30 %	0,25 %	0,20 %	0,27 %	0,27 %
Bisphenol-Vinyl resin	0,35 %	0,30 %	0,23 %	0,30 %	0,30 %
Novolak-Vinyl resin	0,30 %	0,25 %	0,20 %	0,27 %	0,27 %
Furane resin	0,20 %	0,15 %	0,15 %	0,20 %	0,15 %

c. PVDF, PP, ECTFE and PFA tpl liners: strain of the lamina
PVC-U and PVC-C: $\varepsilon_{lim} = 0{,}20\%$

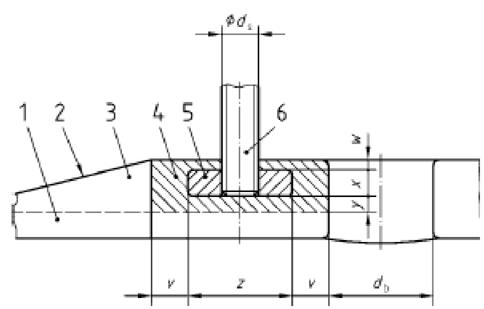
d. Limit test strain $\varepsilon_{test} \leq 1{,}3*\varepsilon_{lim}$

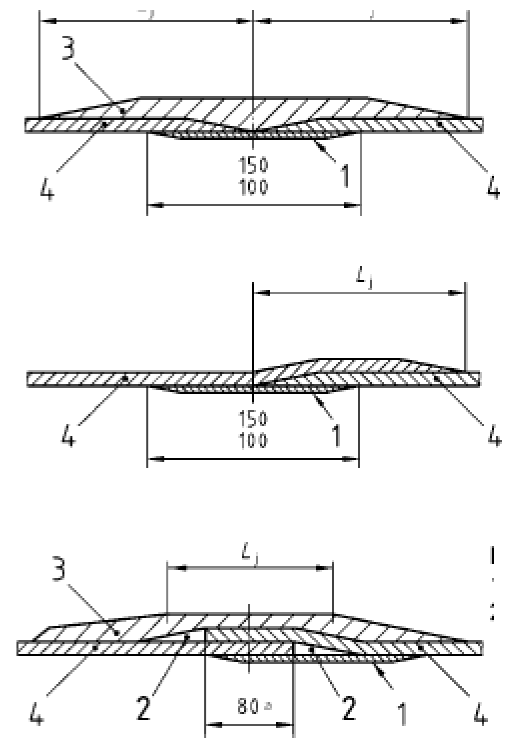
e. Either CRL or structure whichever is lower

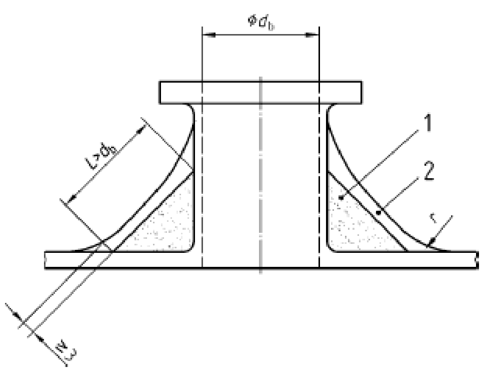
Design details

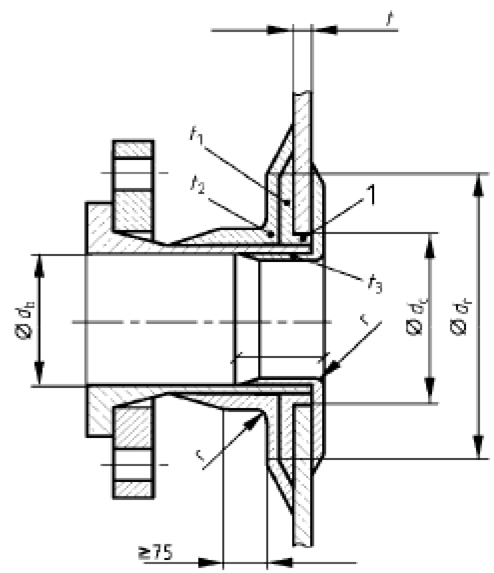
Details on:

- circumferential seams
- Branch connections
- Blind plates
- Etc.



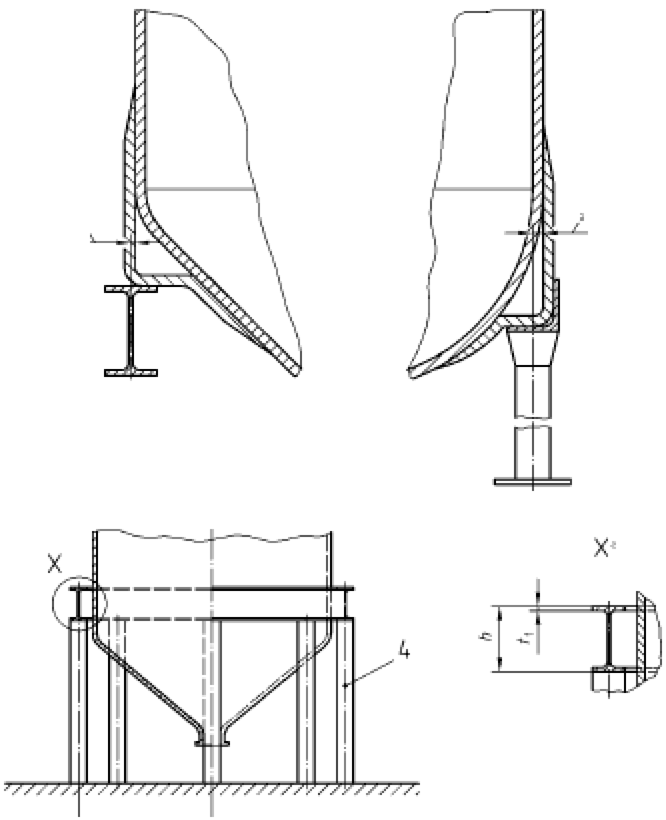


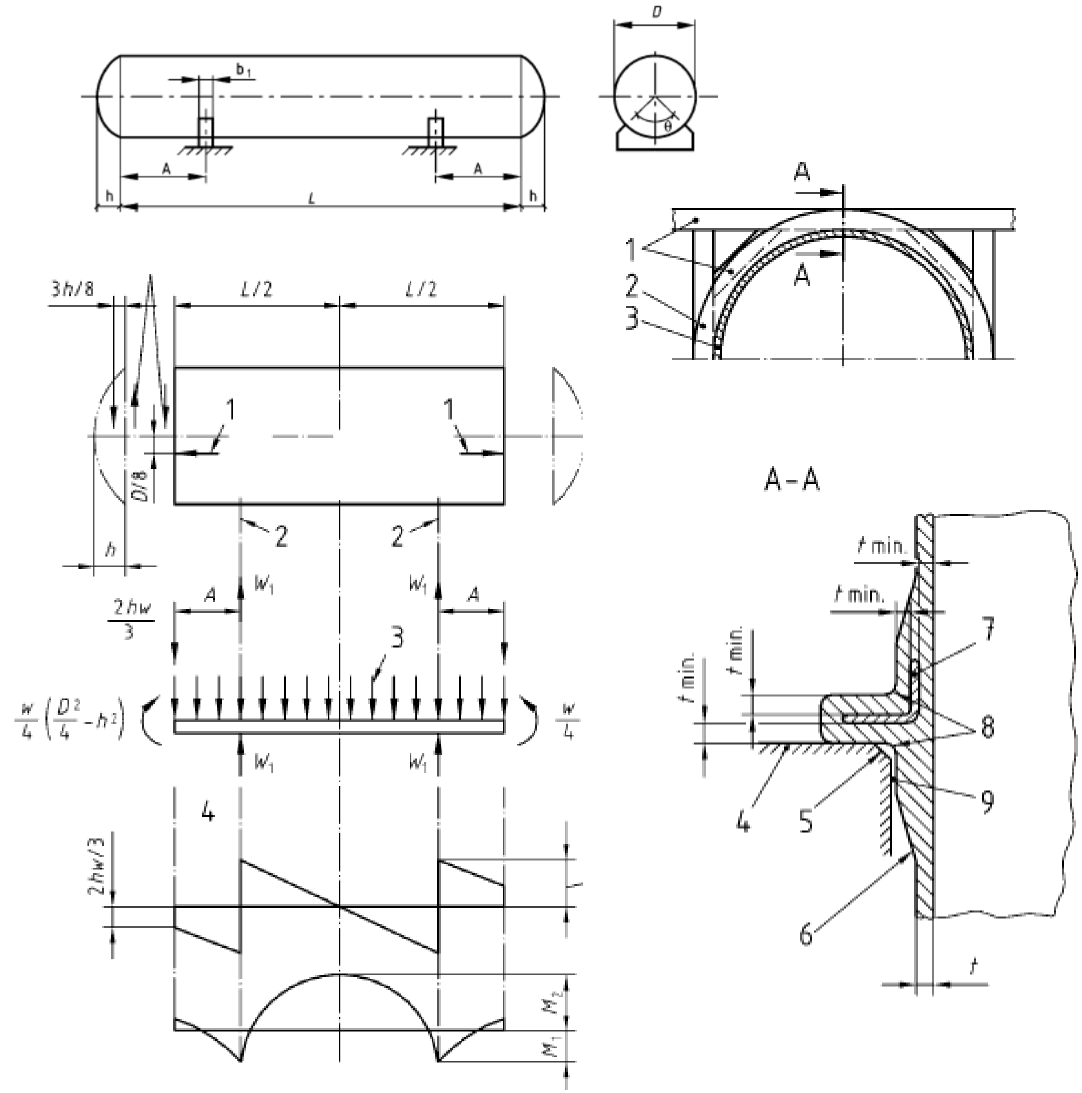




Design details

… And support details





Example

Laminate construction:

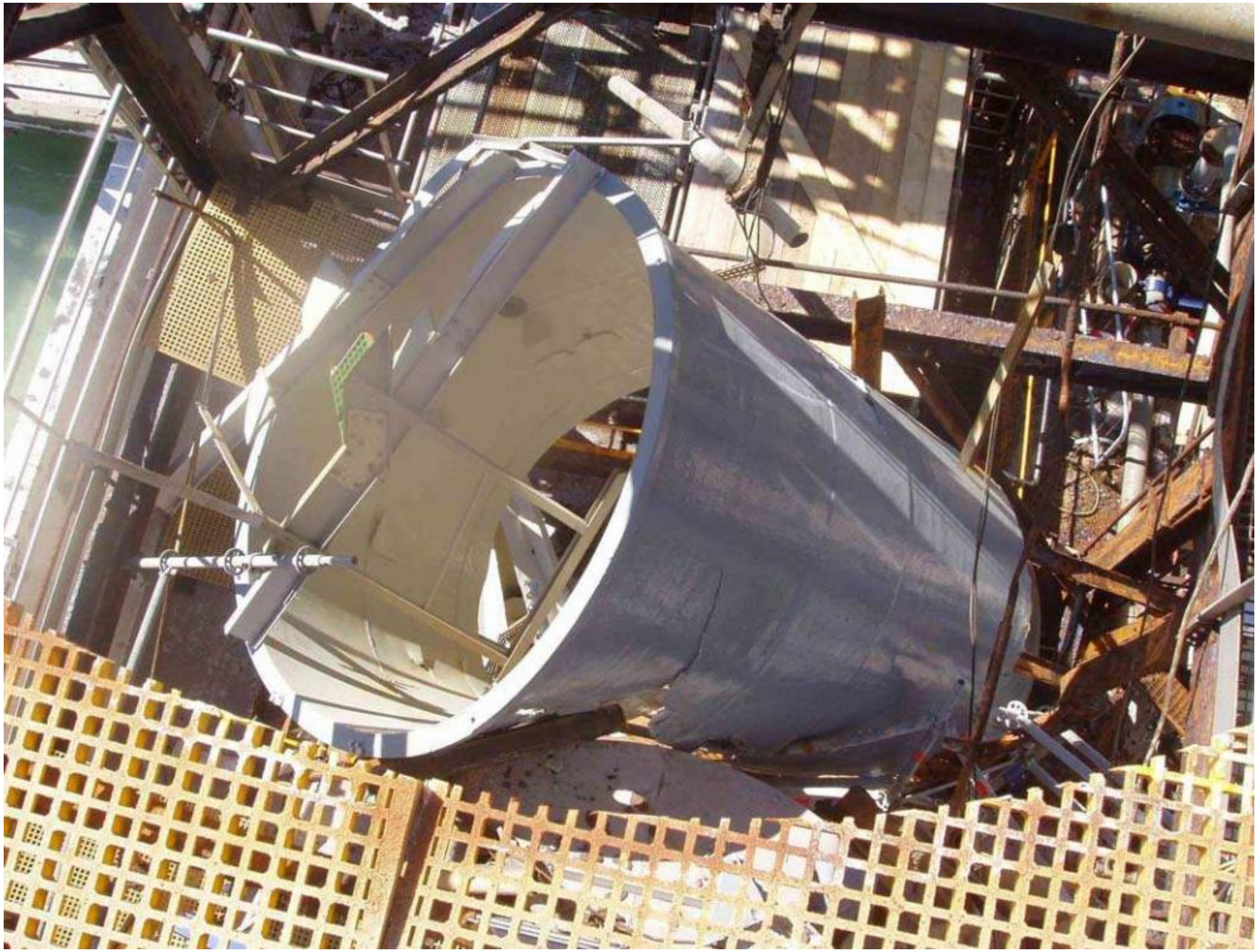
- Atlac 430 bisphenol-a vinylester resin
- 2,5 mm CBL
- 4 layers of E-glass woven roving 0/90 50/50, 360 gr/m², 55% bw
- 6 layers of CSM, 600 gr/m² 35% bw
- 4 layers of woven roving 0/90 50/50, 360 gr/m² , 55% bw
- Topcoat pure resin

Regarding the hull:

What is the laminate design unit loading?

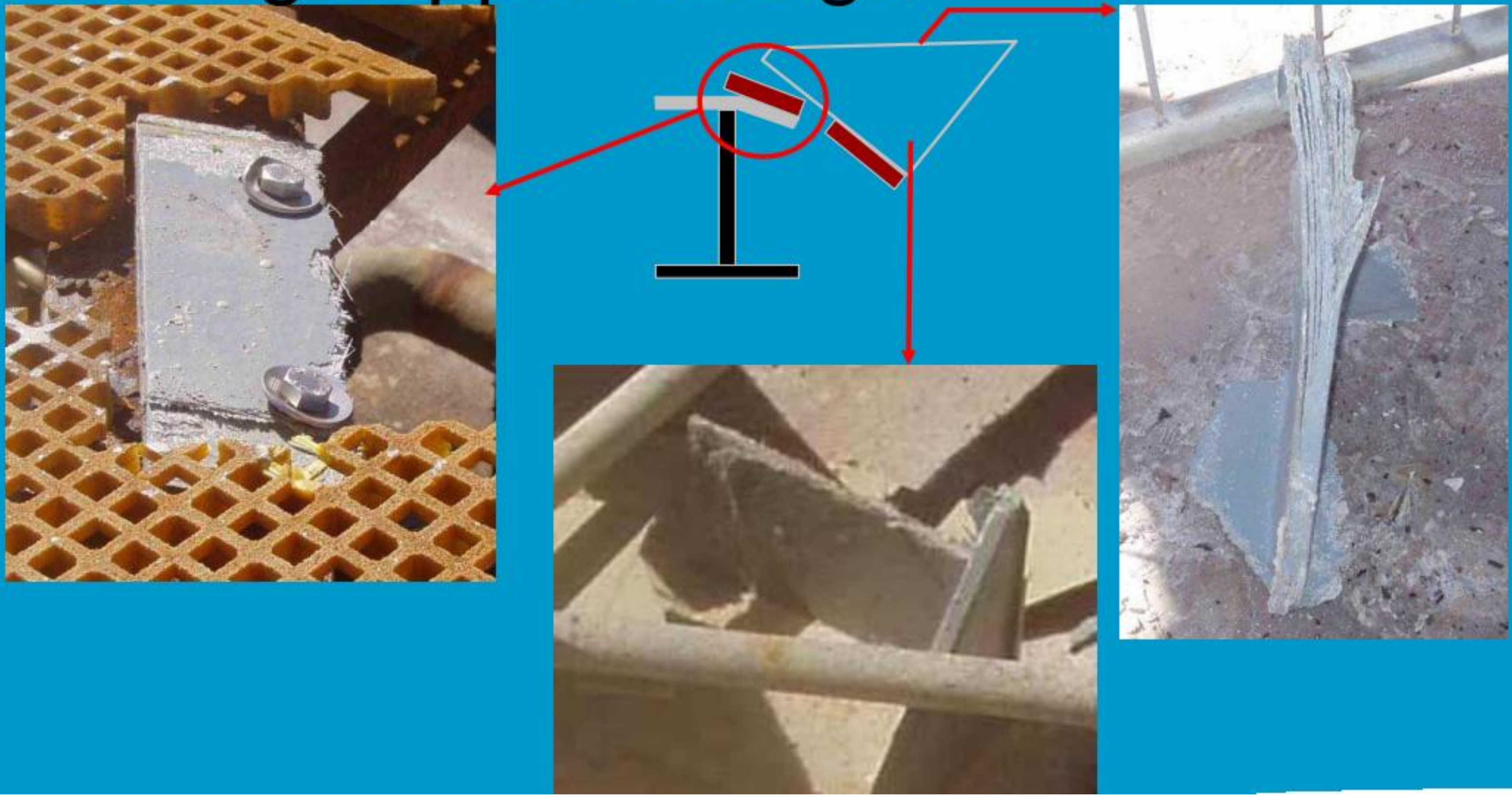
Can the laminate carry its weight and the filling?

Brine tank, 10 hrs after startup



- Derakane 411
- 12m3
- Max 18 ton
- 3^{rd} floor..

Wrong support design



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- Why systems fail (block 2)
- Building blocks (block 3)
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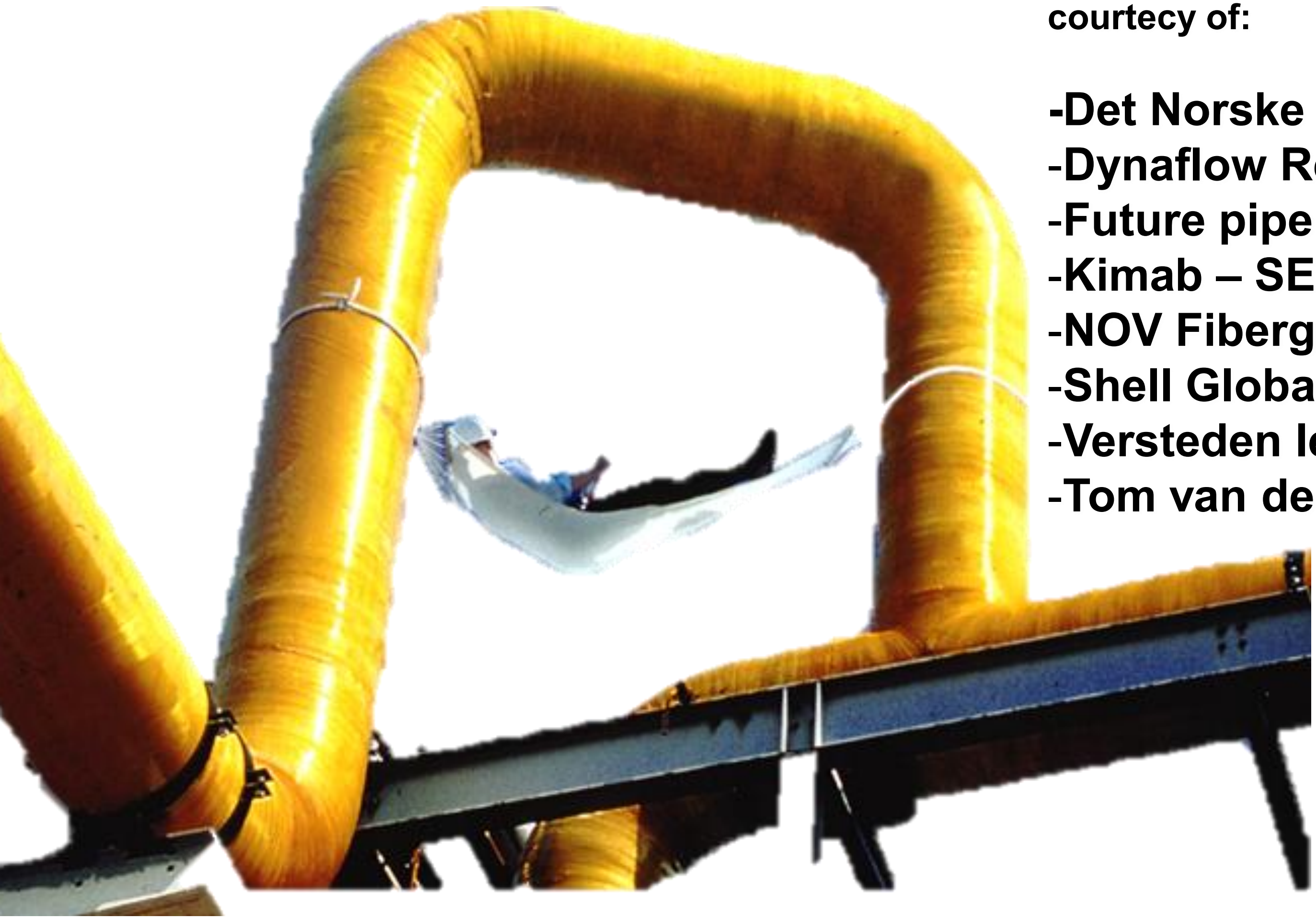
- Standards (ISO 14692 / EN 13121) (block 5)
- **Inspection and failure detection (block 6)**

We thank you for your attention



Material, pictures and information with courtecy of:

-Det Norske Veritas NL
-Dynaflow Research Group NL
-Future pipe industries NL
-Kimab – SE
-NOV Fiberglass Systems USA
-Shell Global Solutions NL
-Versteden leidingsystemen NL
-Tom van de Ven - Be