Pumping stations and water transport

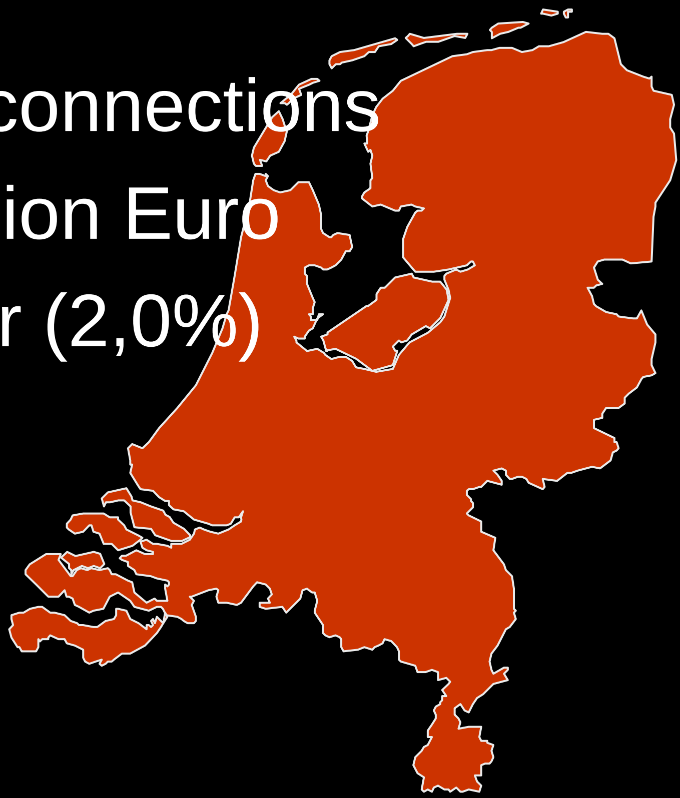
Operation and maintenance of networks

ct5550

Key figures distribution network

Some data:

- length: 110.000 km
- over 6 million household connections
- replacement value: 16 billion Euro
- growth: 2.000 km per year (2,0%)



Maintenance of supply system

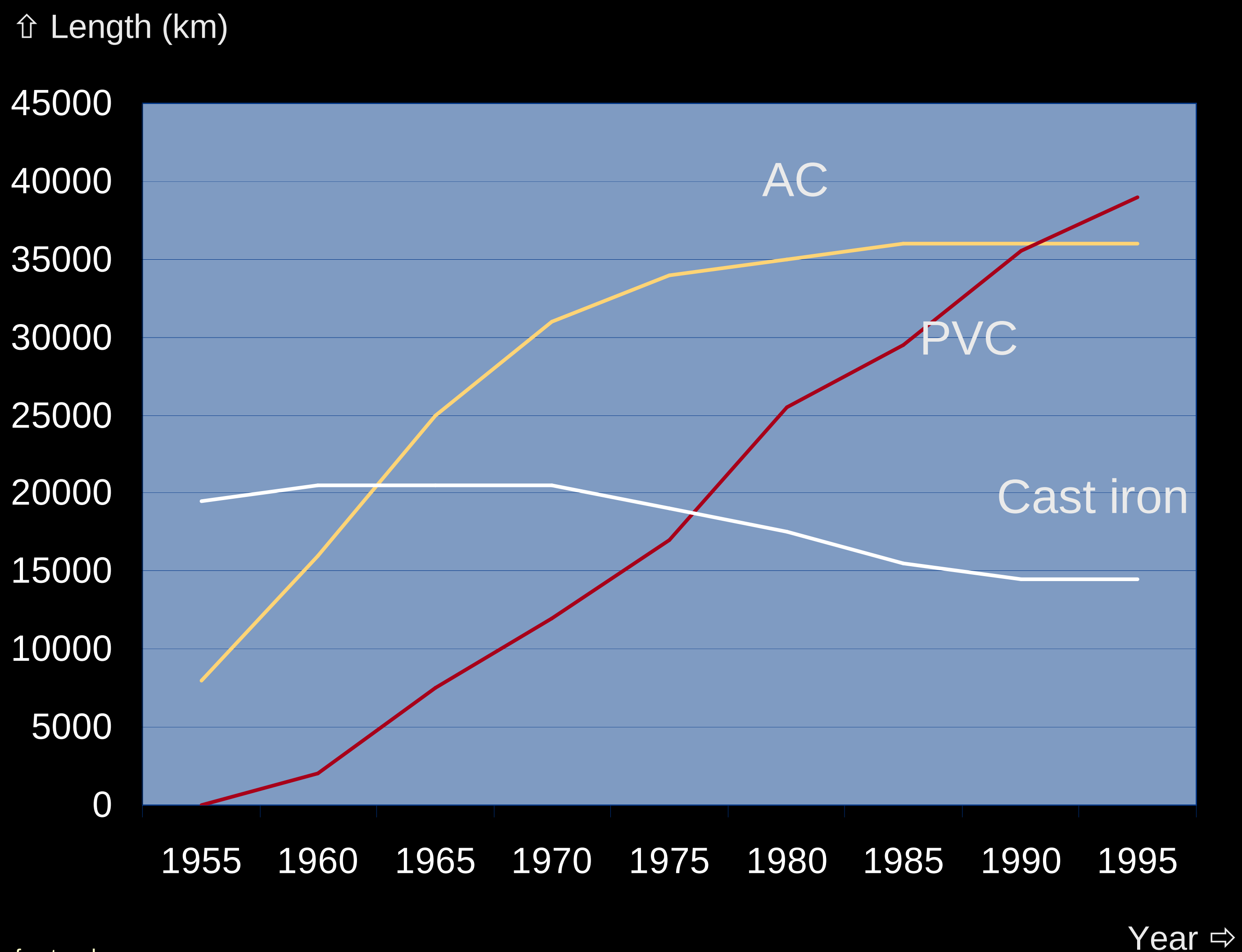
- Reactive maintenance
  - Repairing failures
  - Consequence of failure is less than consequence of prevention
- Proactive maintenance
  - Maintain to prevent failure
  - Consequence of maintenance is less than consequence of failure
- Asset management:
  - Optimal combination of reactive and proactive maintenance

Dike at Stein, 2004

Proactive maintenance program water meters

- Almost all connections are equipped with a water meter
- Over 5 million water meters, average lifetime 10-15 years
- 350.000-500.000 replacements per year
- Accuracy water meter should be within limits
- Maintenance program based on statistic sampling

Pipe network in the Netherlands



History of the network

- Three material types dominantly used:
  - (grey) Cast iron
  - Asbestos cement
  - Plastics as PVC and PE
- Material use is ‘sign of the time’

(Grey) Cast iron

- First material used for ‘modern’ drinking water systems, starting in early 19th century
- English pipe manufacturers set up first drinking water systems (Amsterdam, The Hague)
- Widely used up till 1945-1950
- Internally coated with bitumous layers or uncoated
- Present pipe age: 150 – 50 years

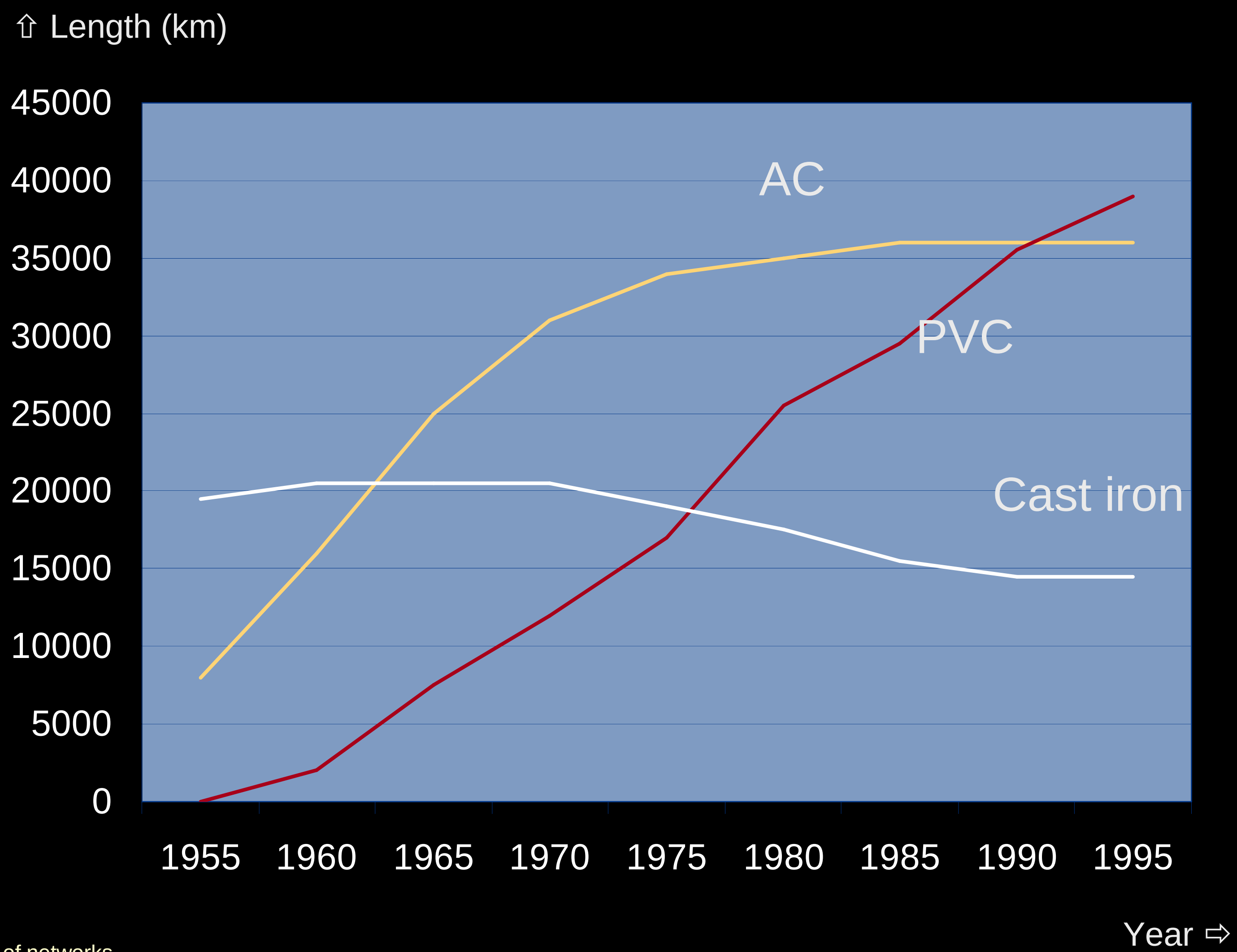
Asbestos cement

- New material post-second-world-war, starting around 1950
- Cheap, non-ferrous, easy to handle and process
- Widely used till early 1980’s
- Banned in 1990
- Present pipe age: 50-20 years

Plastics

- PVC new material early 60’s
- Cheap, non-ferrous, light, very easy to process
- Almost exclusively used starting early 80’s (ban on AC)

Pipe network in the Netherlands



Asset management: basic challenges

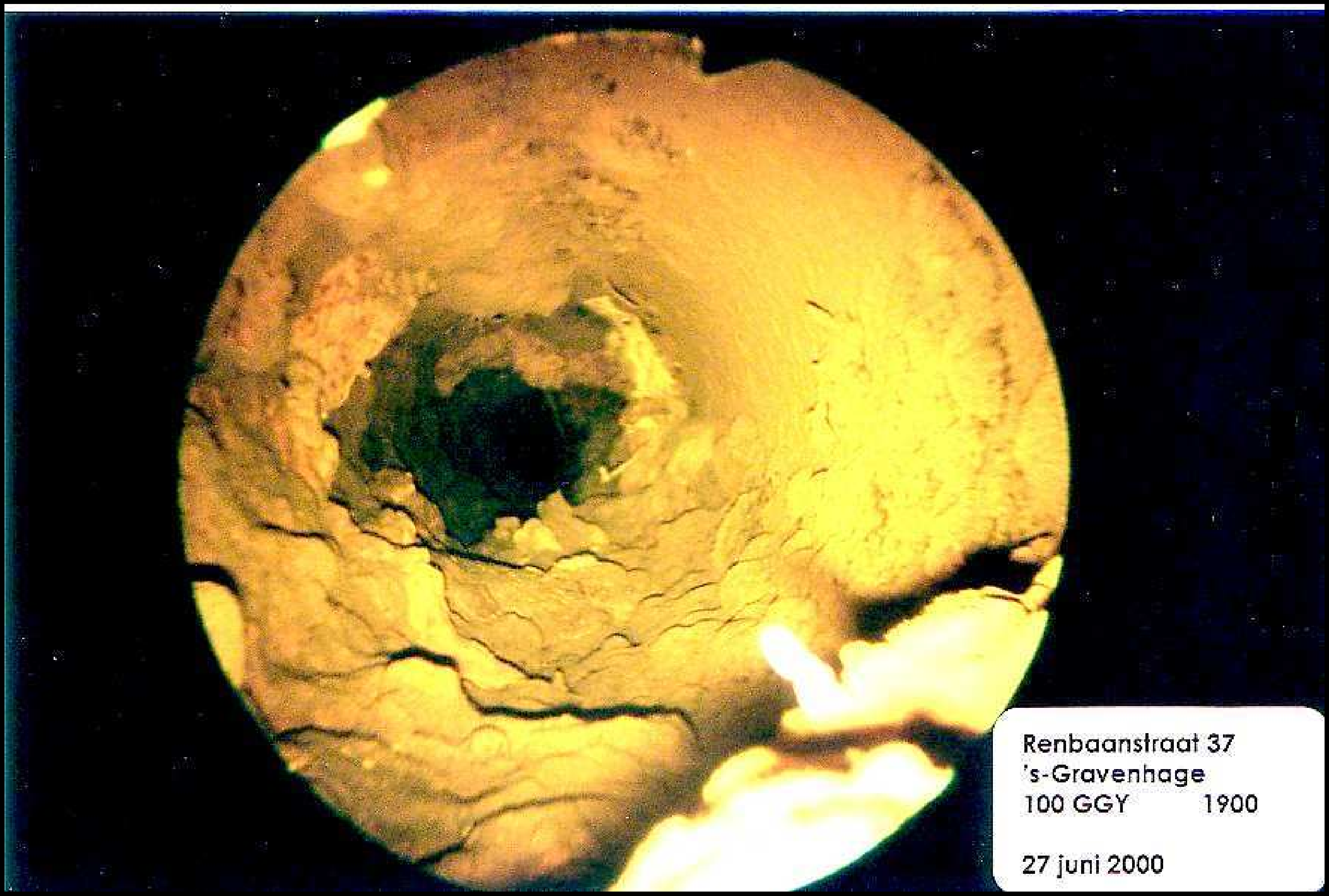
- Network maintenance
- Water quality assurance

Network maintenance

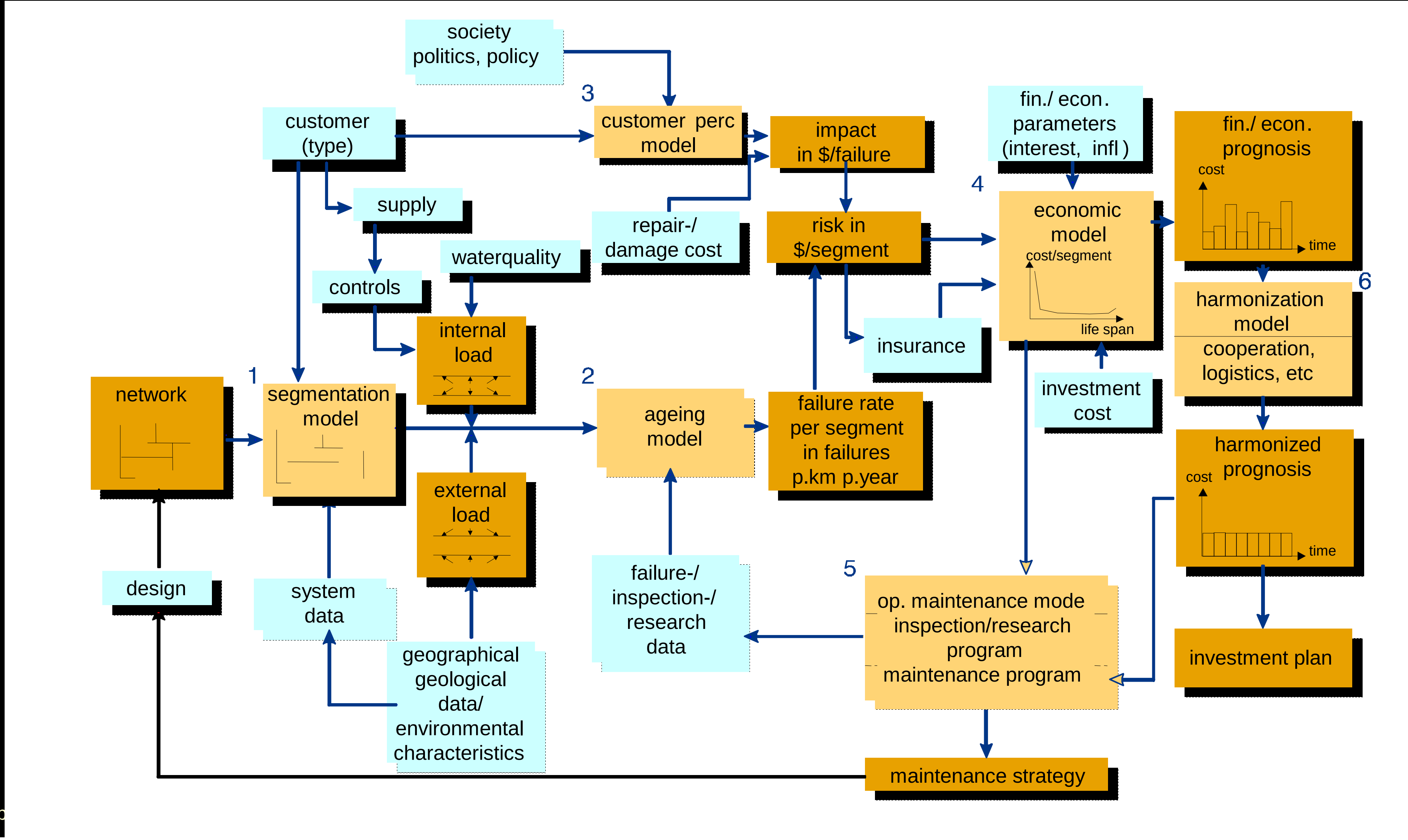
- Networks deteriorate over time
- Initial conditions are better than minimum requirements

- When does deterioration reach a critical level?

Ø100 Cast Iron (1900)



Result: Main model for water mains systems maintenance

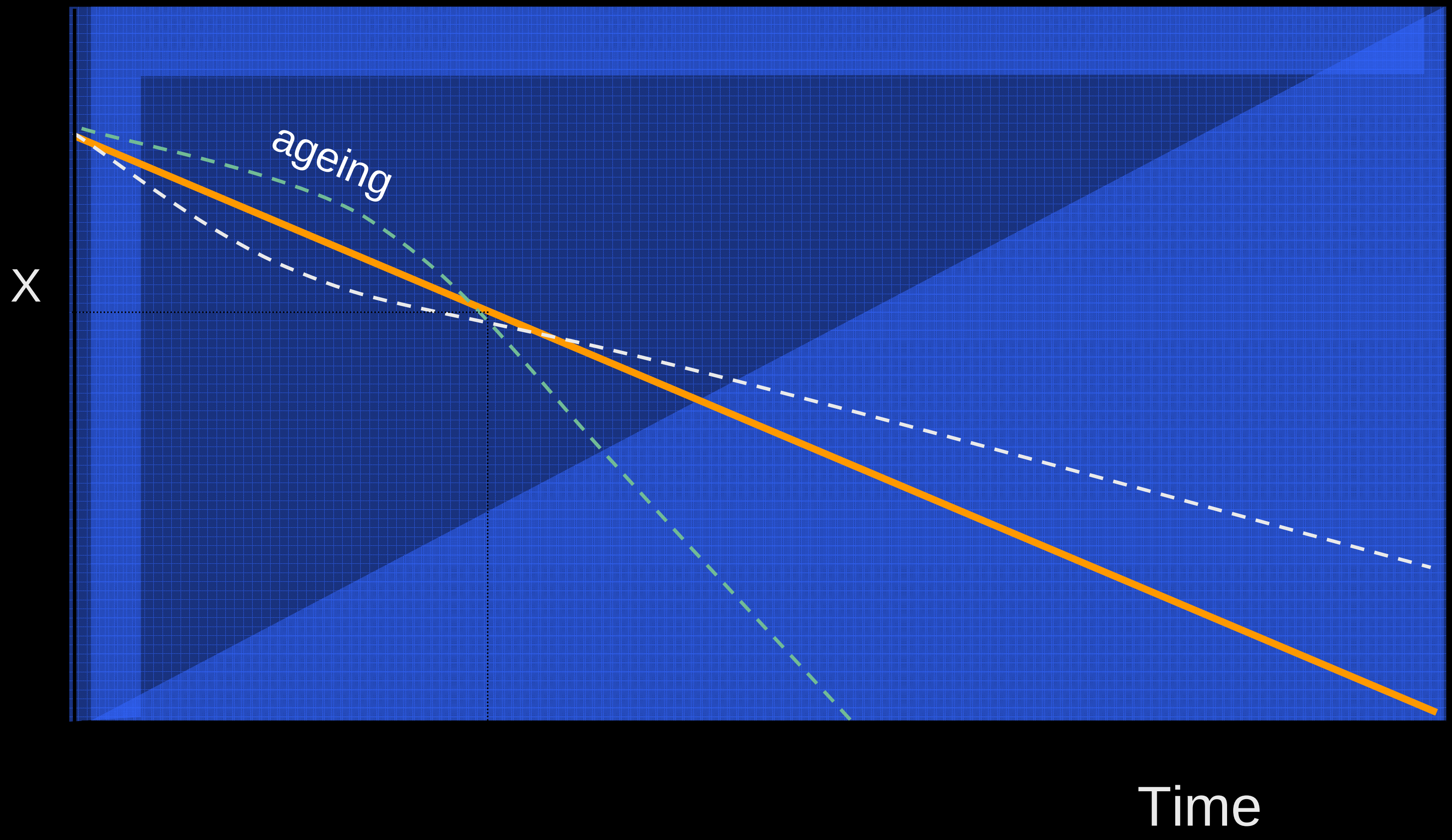


Op

Main model

society
politics, policy
3
customer perc
model
customer
(type)
impact
in $/failure
fin./ econ.
parameters
(interest, infl)
fin./ econ.
prognosis
cost
time
4
supply
repair-/
damage cost
risk in
$/segment
economic
model
cost/segment
life span
waterquality
controls
6
harmonization
model
cooperation,
logistics, etc
internal
load
insurance
1
network
segmentation
model
2
ageing
model
failure rate
per segment
in failures
p.km p.year
investment
cost
harmonized
prognosis
cost
time
external
load
design
system
data
failure-/
inspection-/
research
data
5
op. maintenance mode
inspection/research
program
maintenance program
investment plan
geographical
geological
data/
environmental
characteristics
maintenance strategy

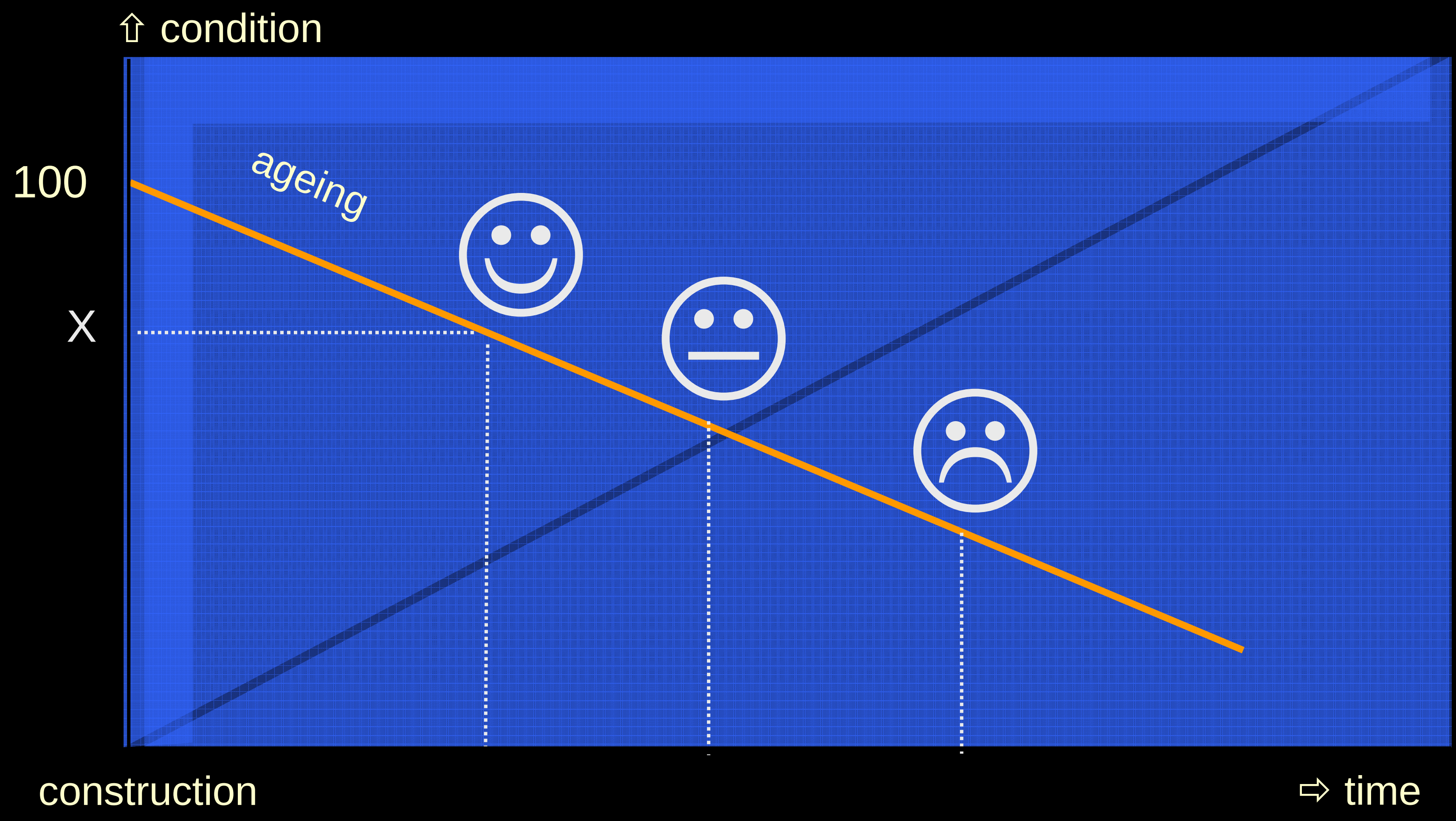
Ageing



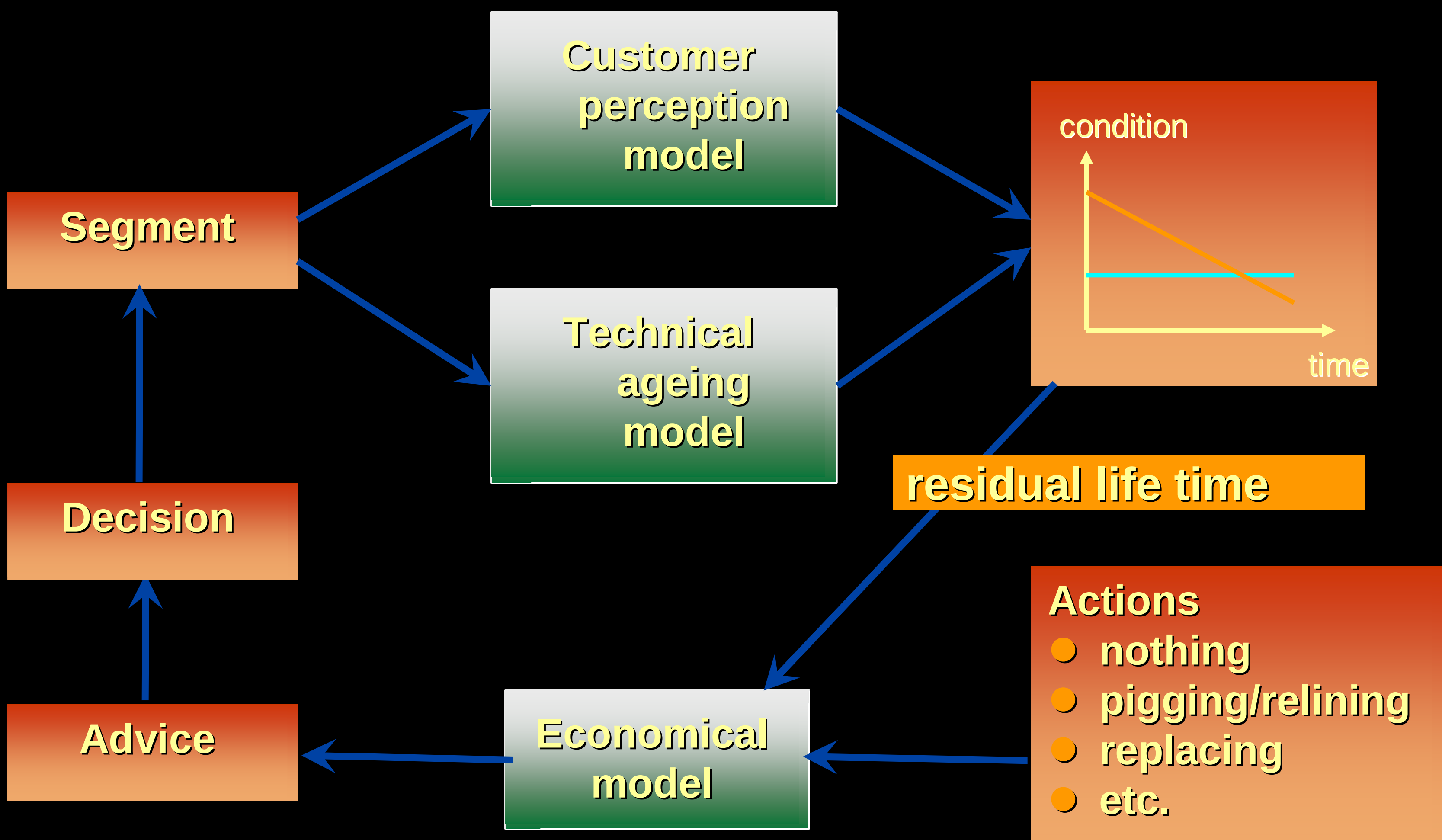
Main model

society
politics, policy
3
customer perc
model
customer
(type)
impact
in $/failure
fin./ econ.
parameters
(interest, infl)
fin./ econ.
prognosis
cost
time
4
economic
model
cost/segment
life span
supply
repair-/
damage cost
risk in
$/segment
waterquality
controls
6
harmonization
model
cooperation,
logistics, etc
internal
load
insurance
1
2
network
segmentation
model
ageing
model
failure rate
per segment
in failures
p.km p.year
investment
cost
harmonized
prognosis
cost
time
external
load
design
system
data
failure-/
inspection-/
research
data
5
op. maintenance mode
inspection/research
program
maintenance program
investment plan
geographical
geological
data/
environmental
characteristics
maintenance strategy

Customer perception



Knowledge based system



Calculation method customer perception model

Weighing main criteria:

impact & failure freq.

Weighing sub criteria impact

Impact criteria
- sensitivity interruption
- Restore supply
- traffic disturb.
- Water damage
- possible disaster
- costs / failure

Uniform calculation method donates points to criteria

Total score impact

X

Failure frequency

Adjustable calc. method

Total score failure freq.

Norm condition

condition figure between 0 en 100

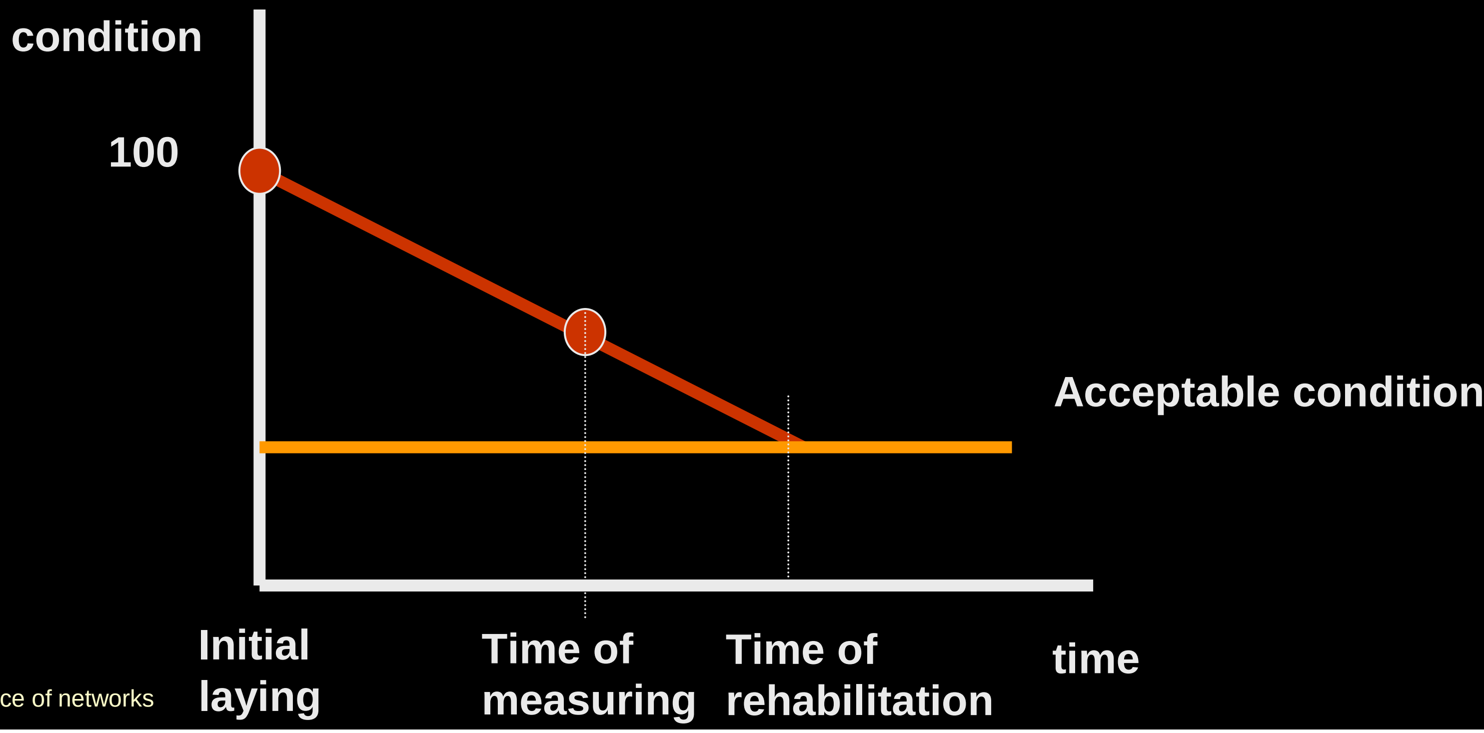
Customer perception model and technical data

Customer perception criteria

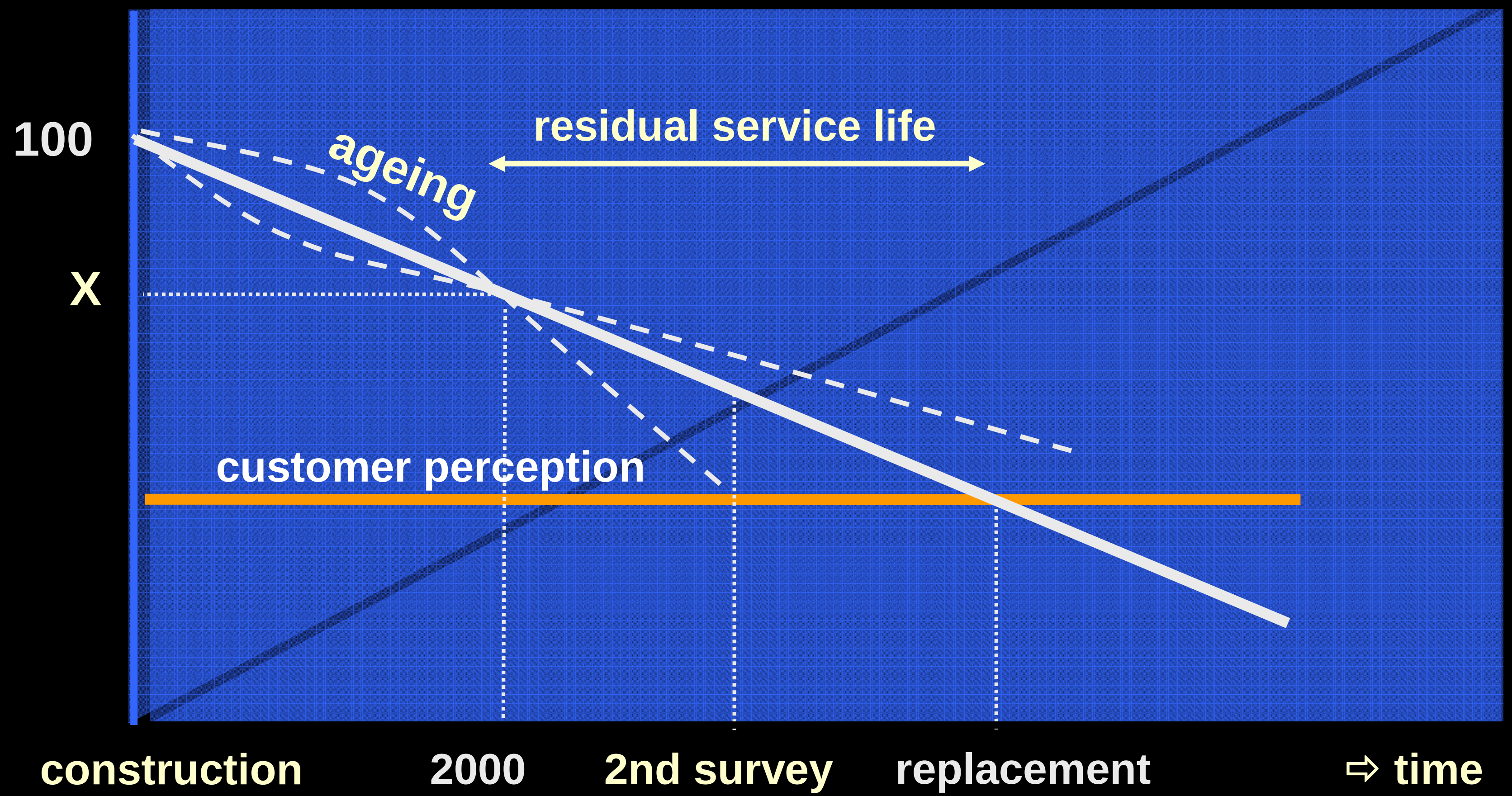
Measured pipe data

Acceptable condition

Measured condition



Decision Support System (DSS) calculation of residual service life



Customer perception data

- Data on failures and complaints!
- Customer data
  - demand, type of customer
  - relationship with other stakeholders
- Data on failure consequence
  - traffic problems, flooding, damages
  - failure costs
- Social and political developments

Ageing data:
Condition assessment cast iron

- Strength:
  - failure data analysis
  - coupon research
- Hydraulic capacity:
  - hydraulic capacity test
  - camera inspection
  - complaints analysis
- Effect on water quality:
  - iron level, biology
  - water quality monitoring

Coupon sampling

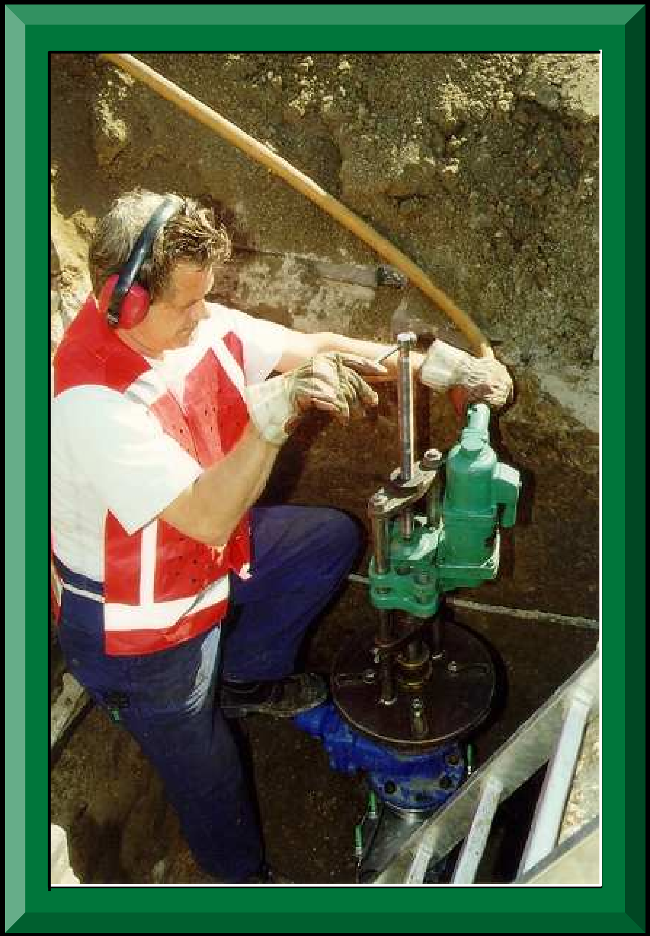


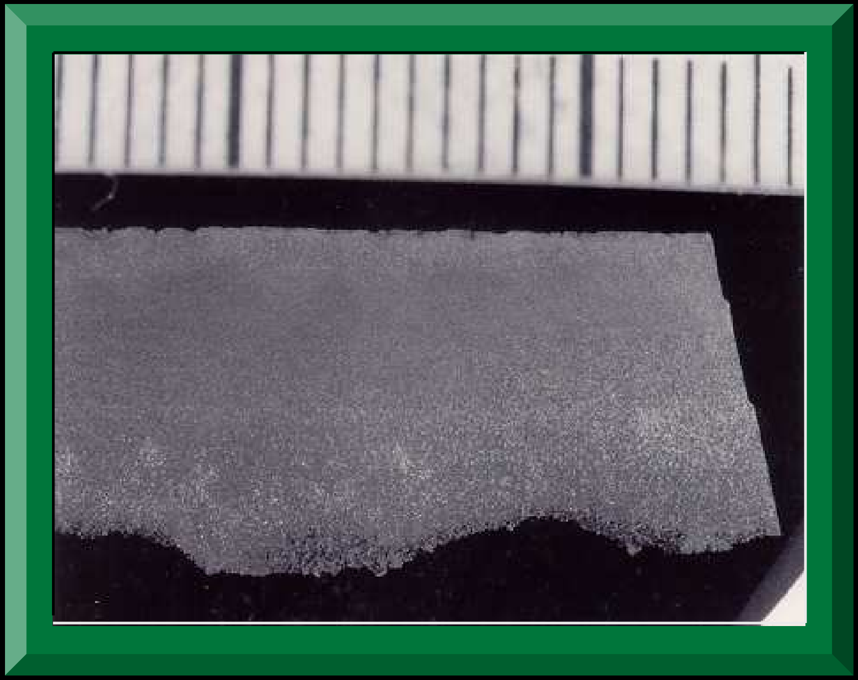
foto: Wim Maas - TWM

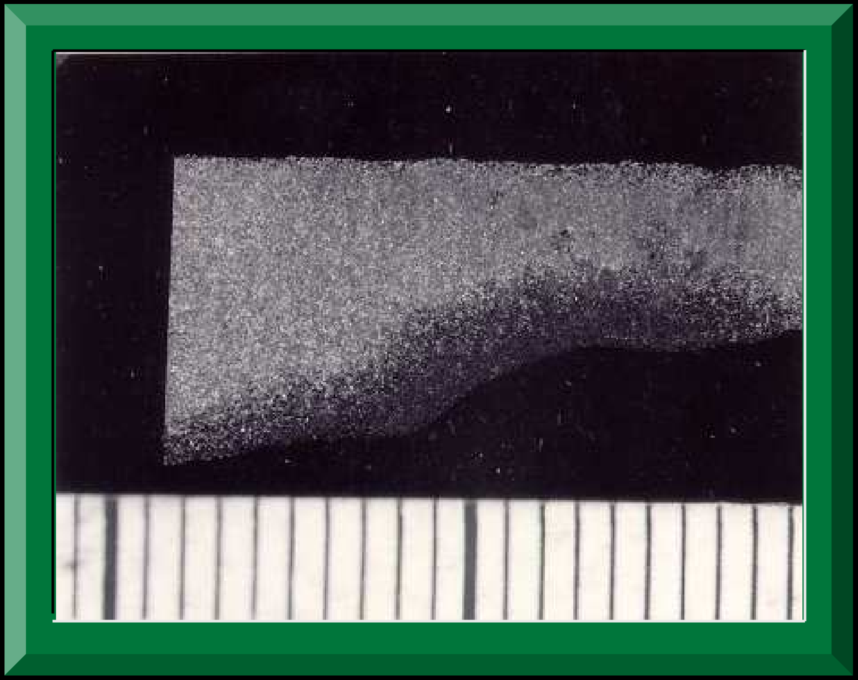
Coupon sampling

foto: Wim Maas - TWM

Coupon after blasting

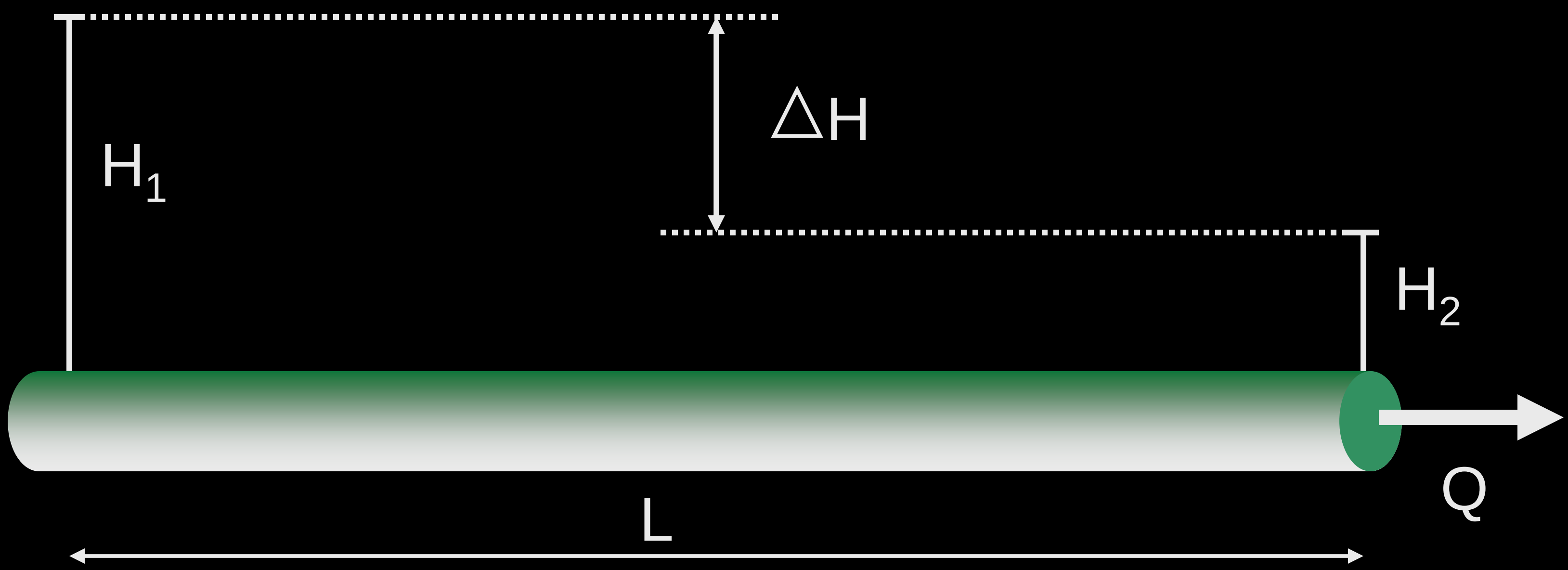
Assessment of residual wall thickness





Hydraulic capacity test

- Calculation of residual diameter from ΔH, Q and L assuming pipe roughness

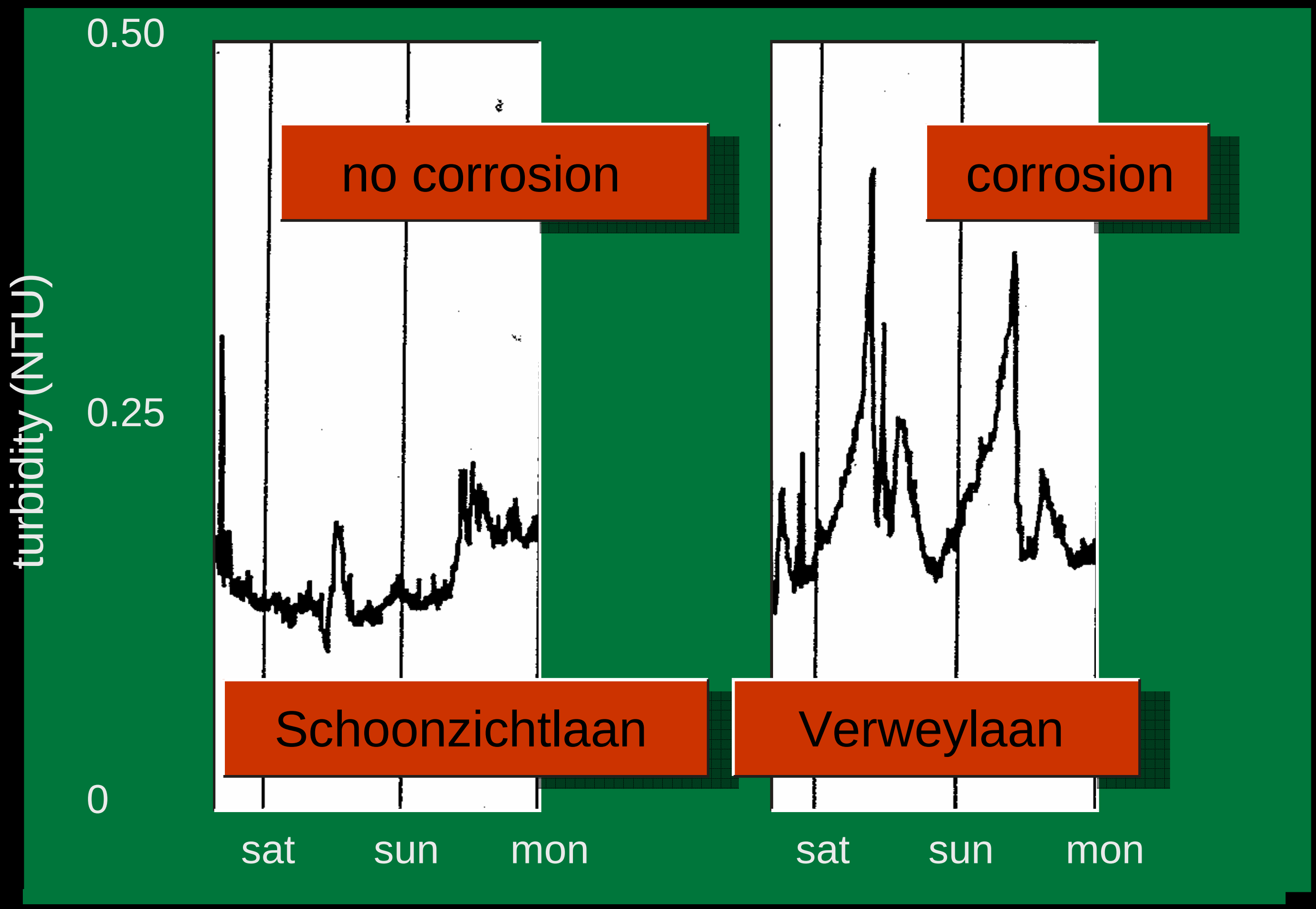


Camera Inspection

foto: Wim Maas - TWM

Camera inspection

Monitoring corrosion of cast iron



Conclusions Cast Iron

- Corrosion is not homogeneous
- Life time expenditure difficult to predict
- Multiple repair actually improves condition
- Impact on capacity and water quality most important factors

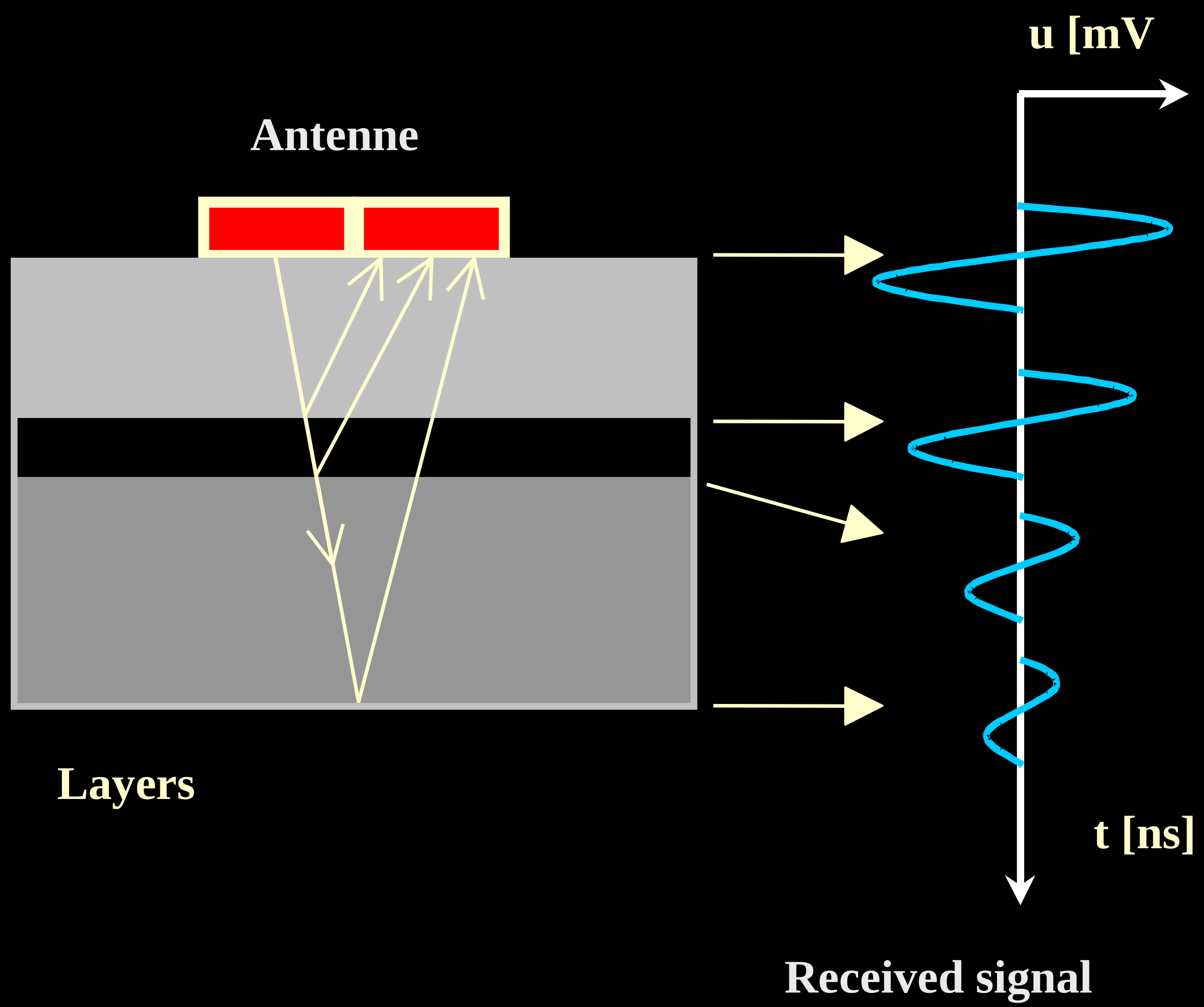
Ageing data: condition assessment asbestos cement

- Internal corrosion
  - Ca(OH)2 leaching in agressive water: SI < -0,2
  - Sulphate corrosion (> 1000 mg/l)
- External corrosion
  - Ca(OH)2 leaching: acid soils, low on calcium
  - Sulphate corrosion
- Mechanical parameters
  - Ground movements

Measuring AC-corrosion: Phenolphthalein field test

- Dripping phenolphthalein on the full sectional surface of the pipe
- the none-corroded surface colours purple, the corroded surface stays colourless

Principal geo radar technology



First results geo radar technology

- Pilot (Nuon Water) Ø800 AC-pipe
  - internal leaching with Phenolphthalein test: 9,0 - 14,6 %
  - internal leaching with geo radar: 6,4 - 16,3 %
- Geo radar technology
  - applicable for determination internal and external corrosion
  - indicative for smaller diameters
  - quantitative for larger diameters

Conclusions

- Condition assessment AC is reliable
- Deterioration is homogeneous (more dangerous than CI!)
- Corrosion risk is predictable
- Residual life time is predictable

Research on PVC condition deterioration

- PVC represents ca. 45% of total Dutch network
- PVC is dominant material for new pipes
- Ageing of PVC is ‘black box’
- Initial conditions older pipes unknown

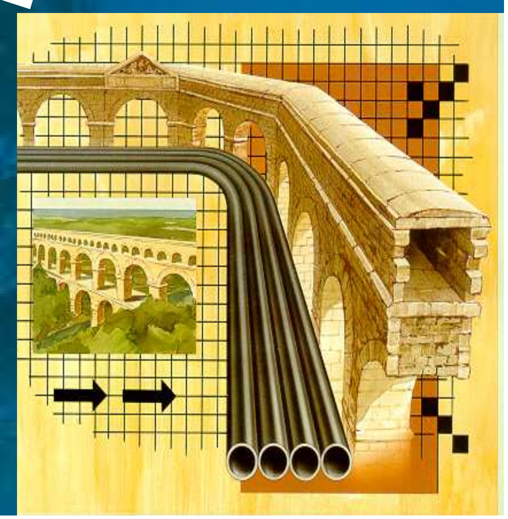
- Start of large research program beginning 2002

PVC: What do we know?

- Global schism at 1975
  - Wavin till 1975: 18 different recipes for PVC pipes
    - production processes
    - stabilisers
    - colour additives
  - Degree of fusion was no item till 1975
    - measure for material homogeneity

Long term performance prediction of existing PVC water distribution systems

TNO Science and Industry



A Boersma, **J Breen**

Content

- Introduction
- Degradation processes
  - Chemical degradation
  - Physical ageing
  - Mechanical failure
- External conditions
- Experimental validation
  - Craze initiation
  - Burst pressure
  - Slow crack growth
  - Fatigue
- Conclusions

Introduction

- PVC water pipes have been in service since 1950's
- It was assumed that these pipes have a lifetime of approx. 50 year
- Question: "Do PVC pipes have to be replaced after 50 years or can they last longer?"

Objective:

development of reliable methods for prediction of residual lifetime of PVC water distribution systems based on a thorough understanding of underlying degradation processes which is accepted within PVC pipe industry and PVC water pipe users

Introduction

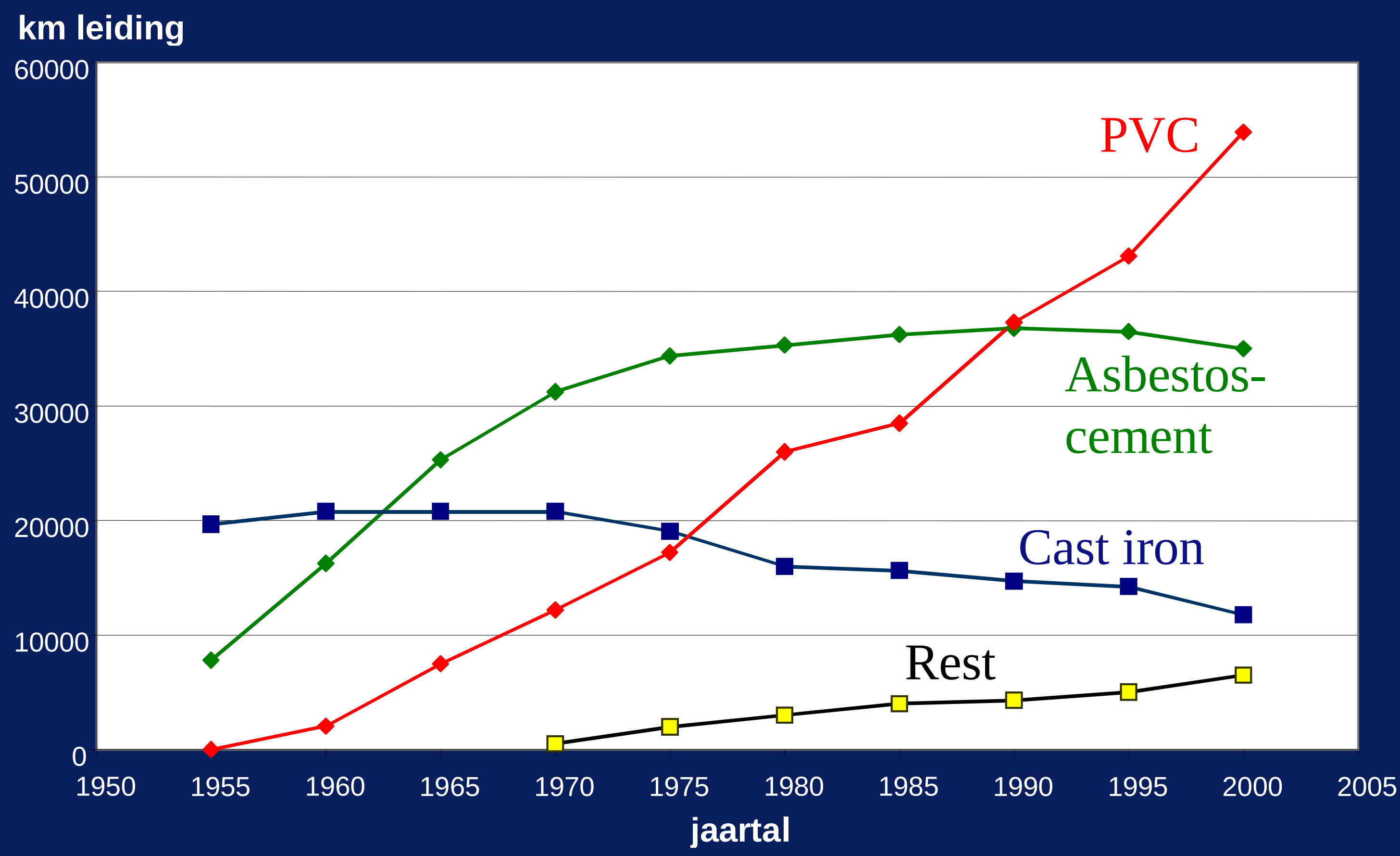
Sponsors

- water distribution companies by Kiwa
- PVC pipe manufacturers (Dyka, Pipelife, Wavin)
- PVC raw material producers (LVM, Shin-Etsu, Solvay)

- TNO (Netherlands organisation for applied scientific research)
- TNO Science and Industry (1 of 5 TNO institutes)
  - Materials Technology (1 of 8 departments)
    - Product assessment, durability and stabilisation

Introduction

Development of water distribution systems

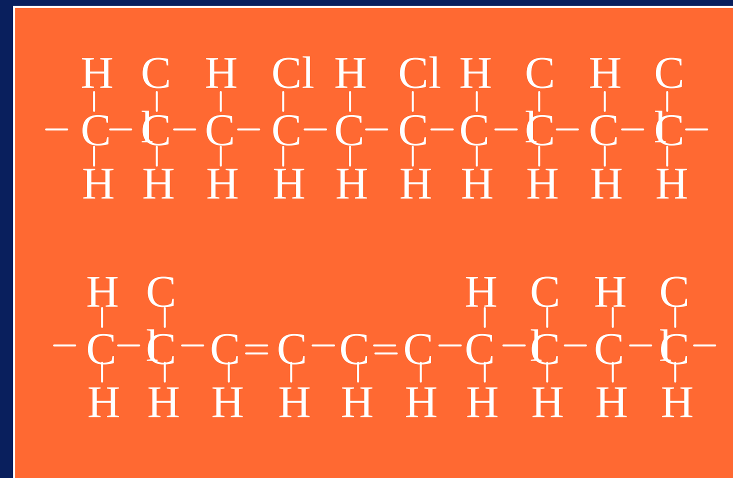


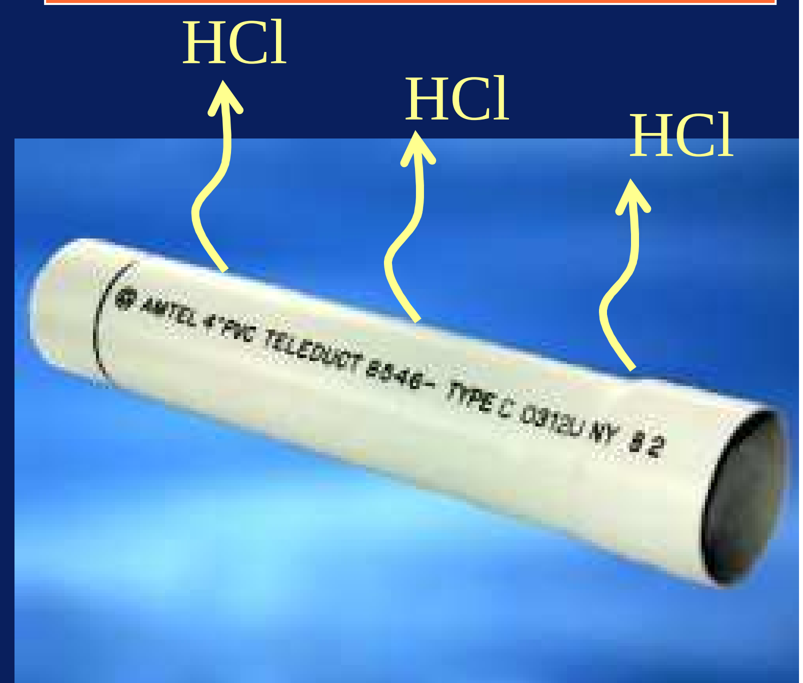
Degradation and failure processes in PVC

- Chemical degradation:
  - Change in chemical structure of the polymer
- Physical ageing
  - Change in physical structure of the polymer
- Mechanical damage:
  - Craze initiation and crack growth as a result of internal and external stresses may lead to ultimate pipe failure

Chemical ageing

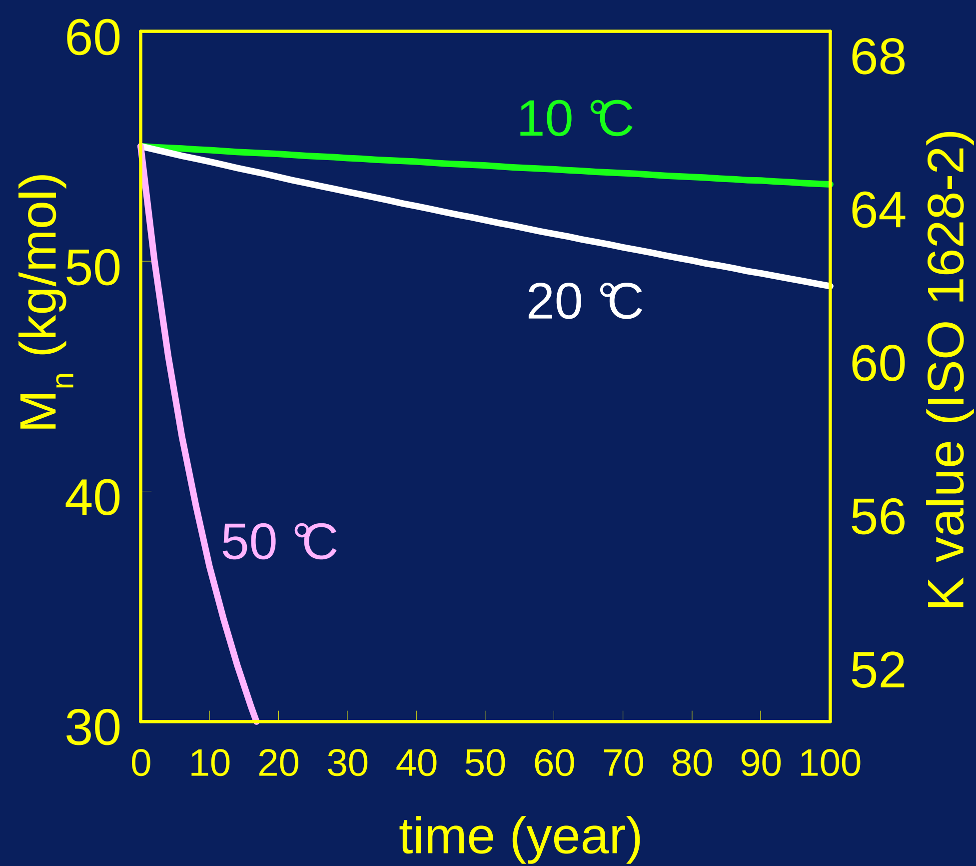
- Degradation mechanism:
  - Dehydrochlorination and thermo-oxidation
  - HCl is released influenced by thermal energy
    - Slow in service at 15 °C
    - Fast during processing at 200 °C
- Consequence:
  - Embrittlement
  - Discoloration
- Chemical physical checks:
  - K-value
  - residual amount of stabiliser
  - concentration of vinyl group





Chemical ageing

- Degradation kinetics from DHC experiments at elevated temperatures
- Most negative scenario indicates that at 10 °C the K-value decreases from 66 to 65
- Higher temperatures causes an accelerated degradation rate



Chemical ageing

- Modelling of chemical degradation indicates that the increase of the degree of degradation after 100 years at 15 °C is significantly smaller than is caused by processing

- *Conclusion:*
- *Chemical ageing at 15 °C seems not to have a significant influence the quality of PVC water distribution pipes*

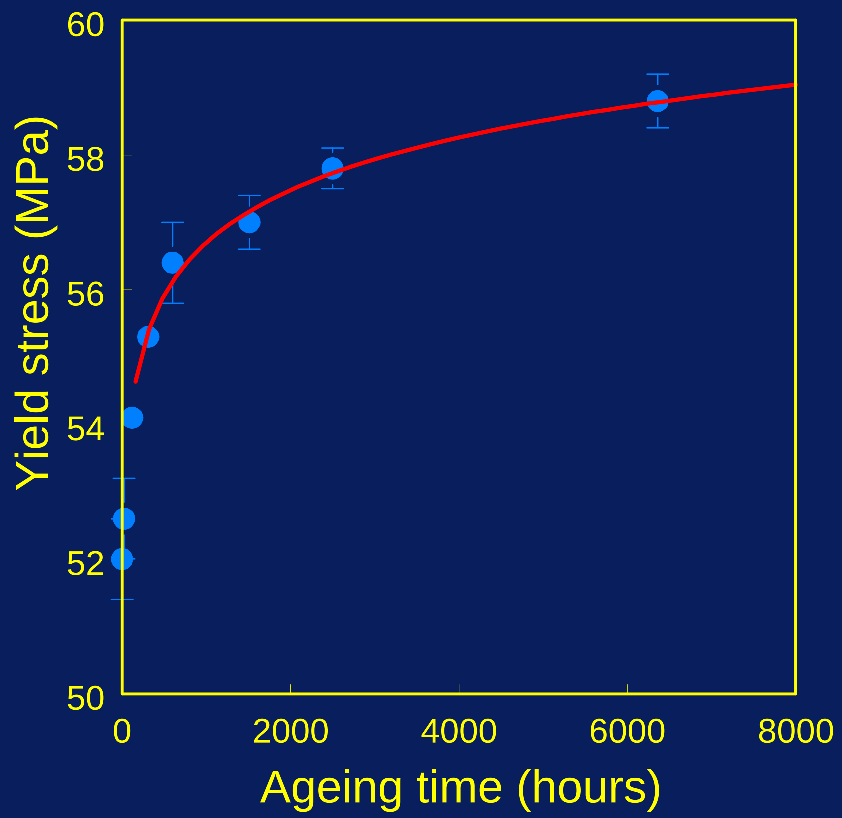
Physical ageing

- Ageing mechanism
  - Free volume relaxation (compacting of polymer)
  - Temperature dependent
    - Slow in service at 15 °C
    - Fast during cooling after extrusion of the pipes
- Consequences
  - Increase in craze initiation stress
  - Increase probability for crack growth after initiation
  - Increase in burst strength
  - Lower elongation at break
- Physical check:
  - Measurement of yield stress in stress-strain experiment

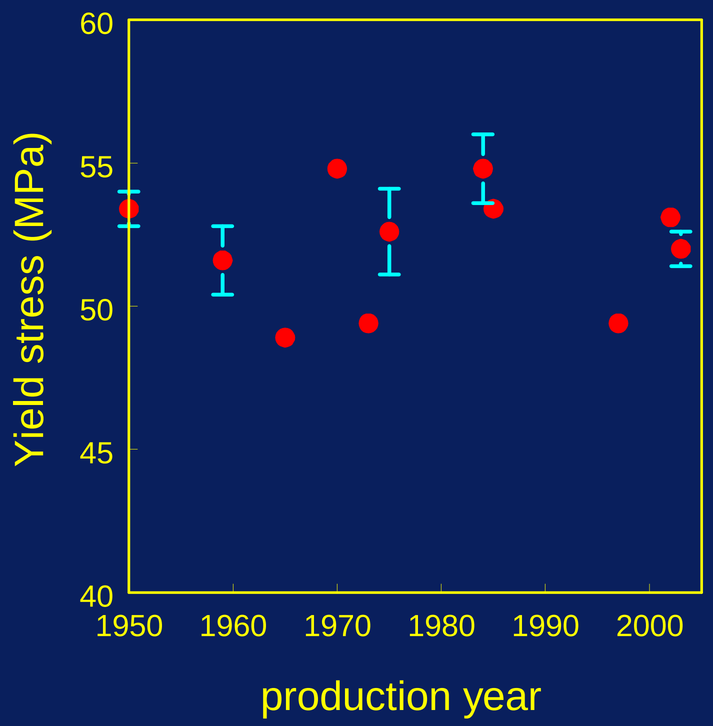
Physical ageing

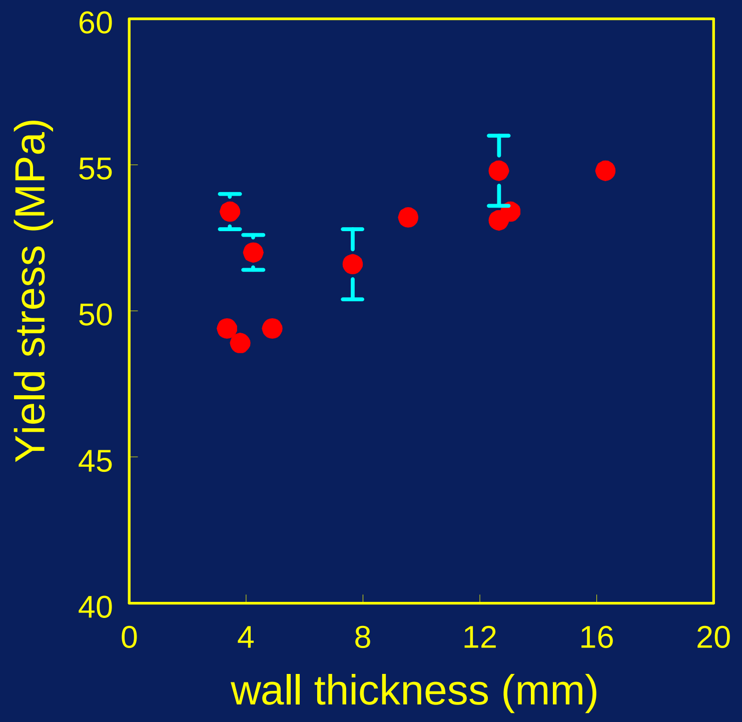
- Accelerated ageing of new PVC pipe at 60 °C leads to an increase in yield stress

- Expectation:
  The yield stress is an indication for the age of the excavated pipe



Physical ageing





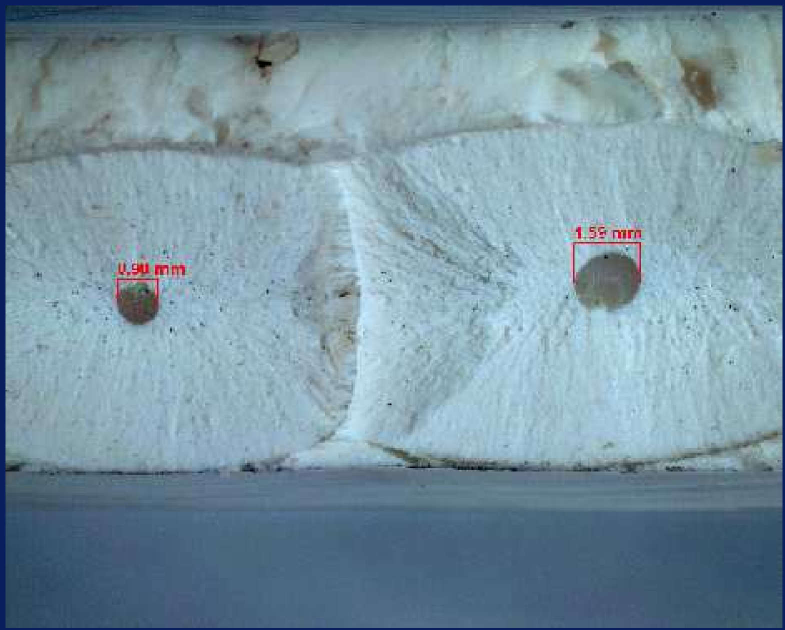
Physical ageing

- Yield stress depends on wall thickness and not on age
- Thicker wall cools more slowly and generates more physical ageing
- The state of physical ageing is determined immediately after production and hardly changes in service

- *Conclusion:*
- *Physical ageing at 15 °C seems not to have a significant influence on the quality of water distribution pipes*

Mechanical failure

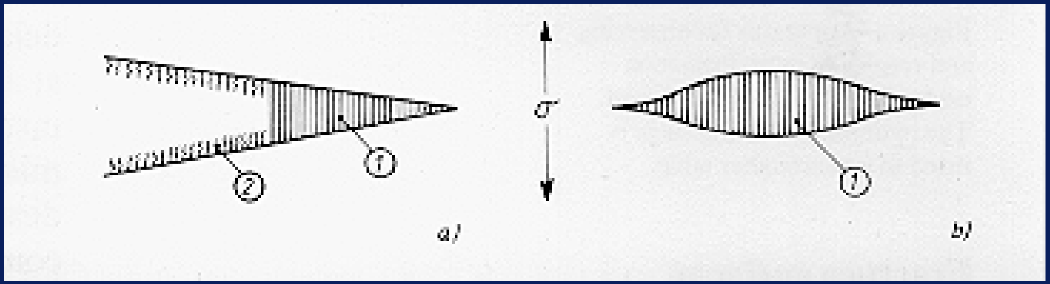
- Initiation of crazes and cracks under the influence of external stresses
- Presence of damage and particles accelerates failure
- Deformation of the surrounding soil
- Internal water pressure
- Water hammer
- Traffic load

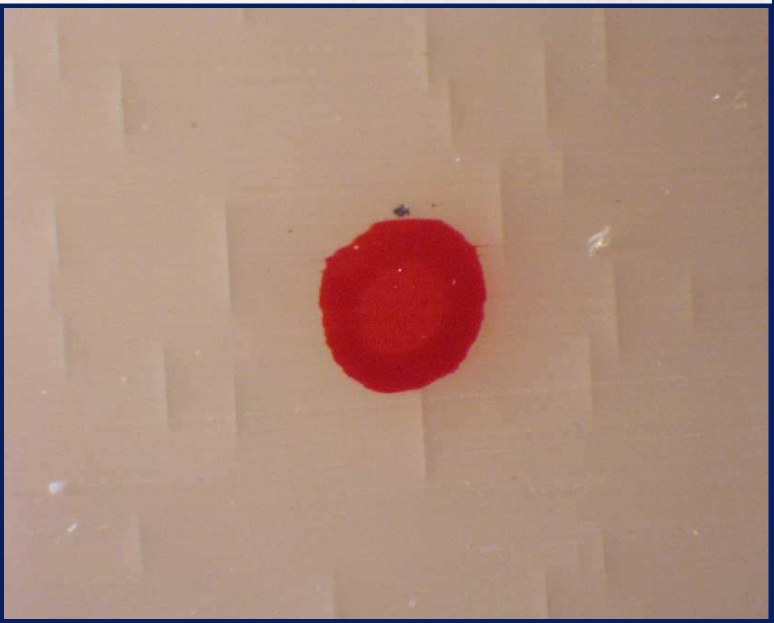


Failure mechanism

- Constant or peak load can lead to:
  - Craze initiation
  - Craze growth
  - Crack formation
  - Crack growth

- And ultimately to:
  - Pipe failure





External conditions

- PVC raw material
- Additives (stabilisers; pigments;…)
- Processing conditions (temperature, residence time in extruder; degree gelation; cooling rate; …)
- Internal stresses (size; relaxation; ...)
- Damages (scratches; “spider lines”; inhomogeneities; …)
- Mechanical loads (installation; water pressure; water hammer; soil; …)
- Effect of environmental conditions (temperature; UV; chemicals, …)

Experimental validation

- Constant loading
  - Craze initiation on tapered samples
  - Slow crack growth on small ting samples
  - Burst pressure on whole pipe segments

- Occasional loading
  - Fatigue loading of rings

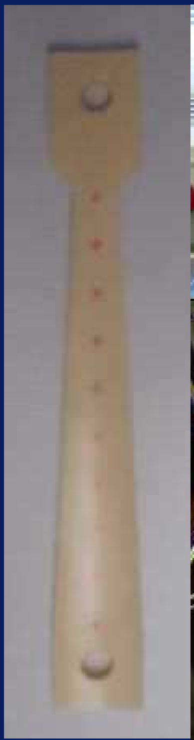
Experimental validation

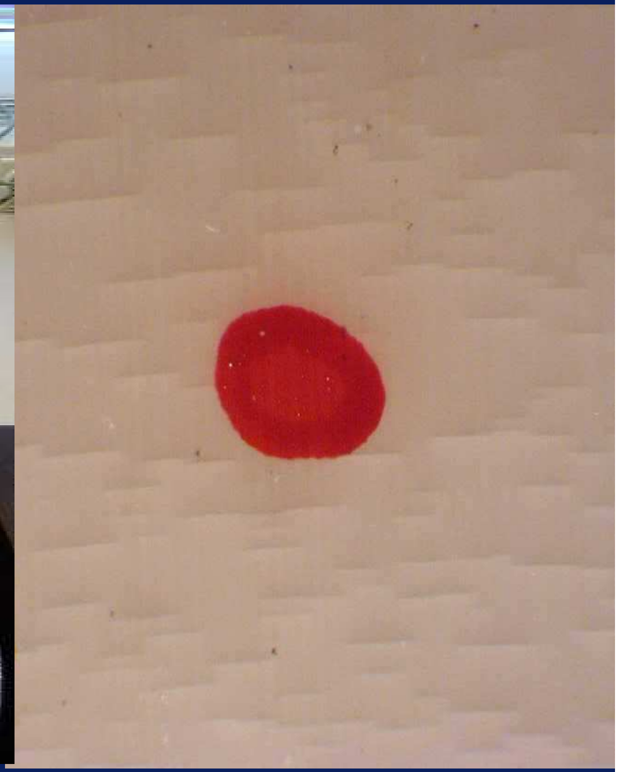
- Excavated pipes

Production year	Diameter (mm)	Wall thickness (mm)	*K*-value	Degree of gelation (%)
1959	200	7.6	71	58
1970	500	15.6	67	39
1975	315	9.7	64	38
1984	400	12.7	66	55
1997	160	4.8	67	80
2003	160	4.3	68	70

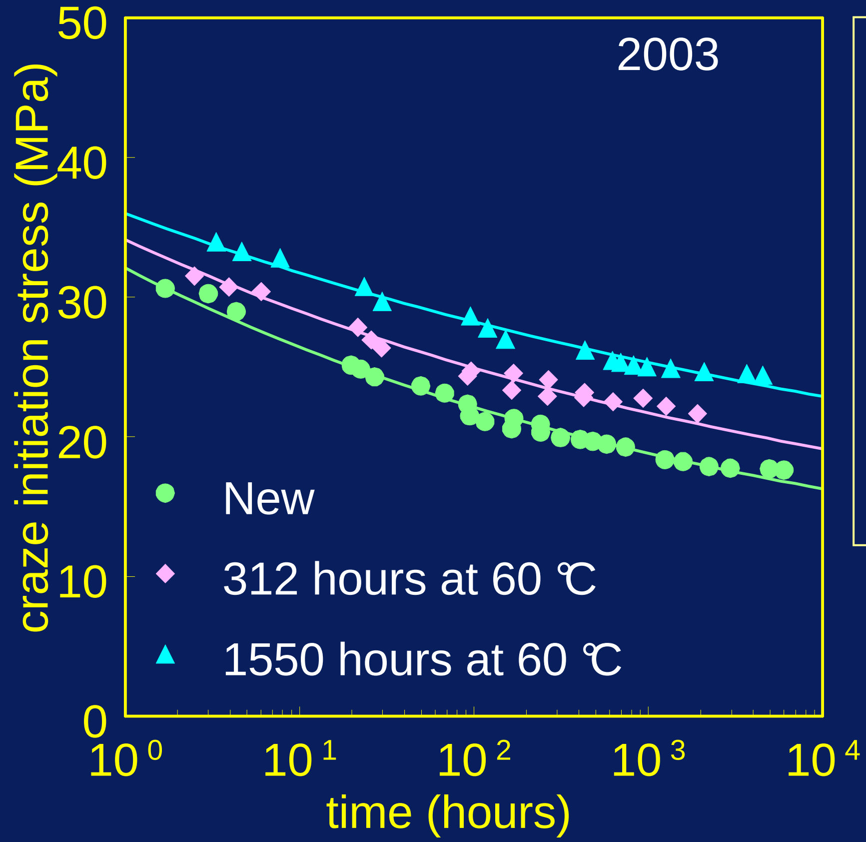
Craze initiation

- Tapered samples are stressed and the time until the formation of crazes is monitored





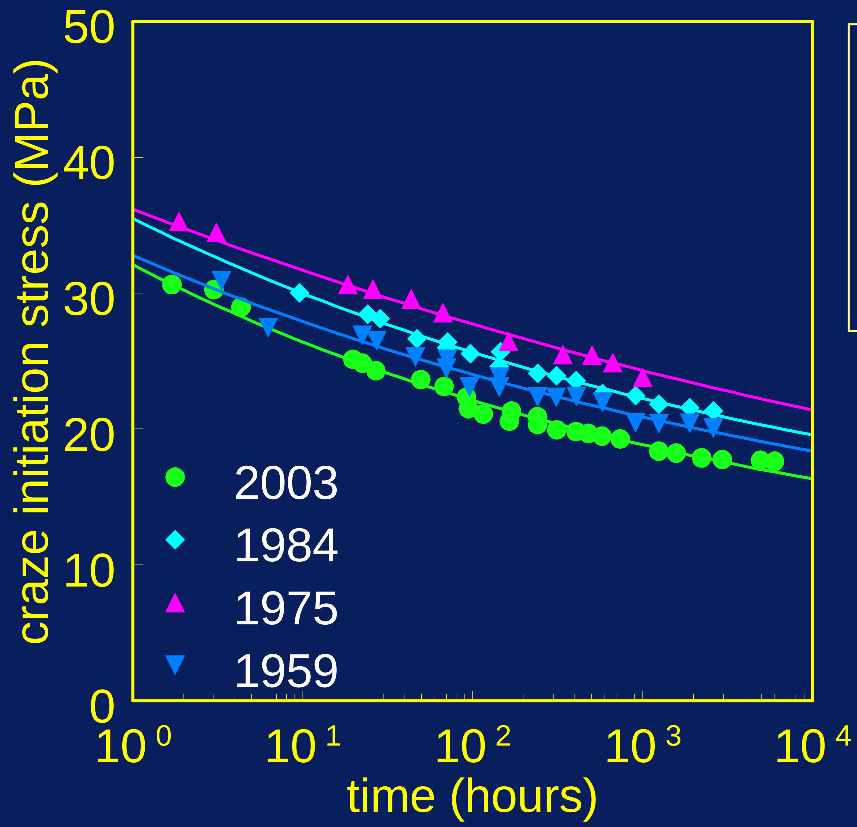
Craze initiation



Annealing of pipes at 60 °C increases physical ageing

Physically aged pipes have a higher resistance against the formation of crazes

Craze initiation



Craze initiation stress does not depend on the age of the pipe

Craze initiation

- Craze initiation stress level after 100 year service life at 20 °C

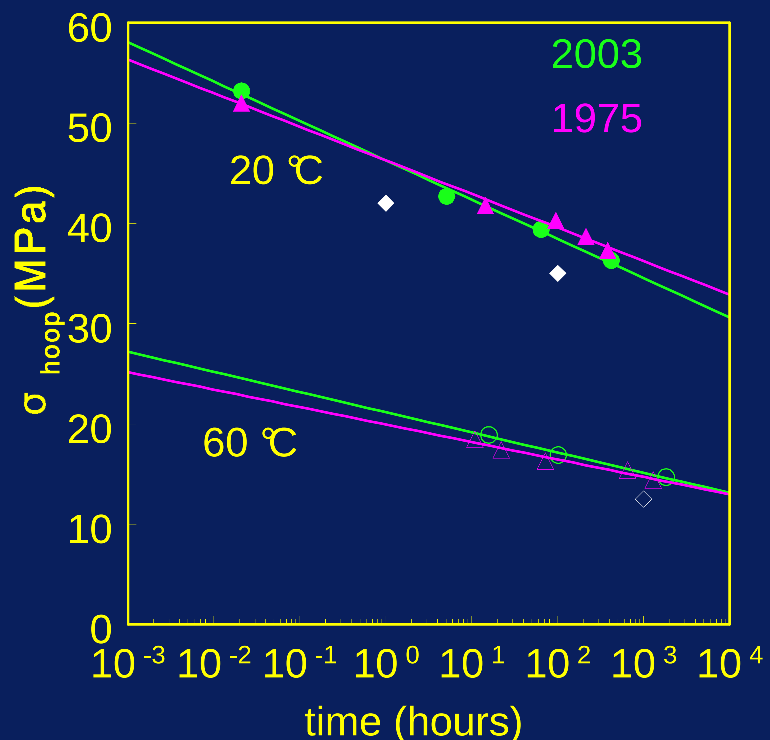
Production year	Stress level (MPa)	Uncertainty (MPa)
1959	14.3	2.1
1970	17.4	2.0
1975	16.9	0.9
1984	15.7	0.9
1997	21.4	2.7
2003	12.8	0.5

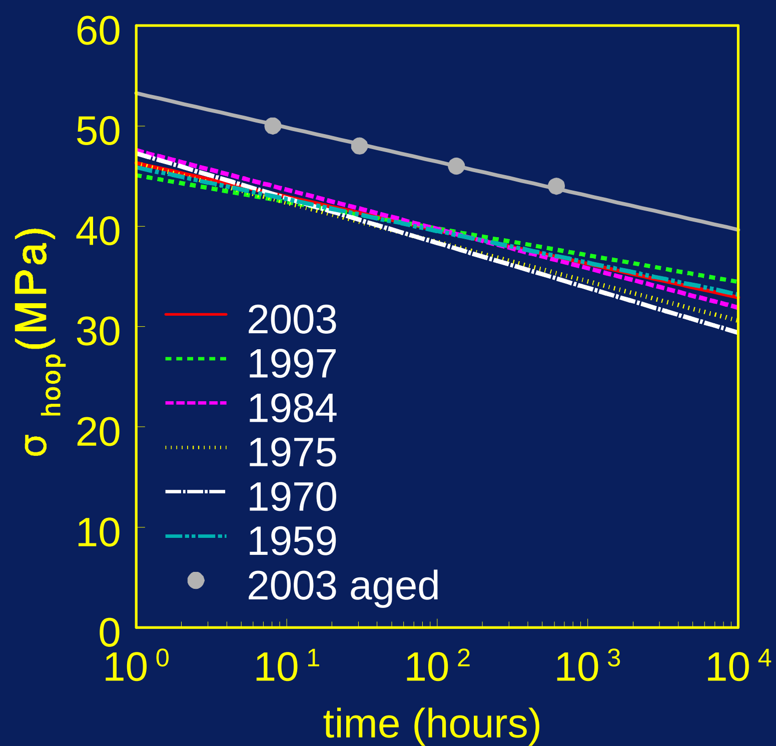
Critical values in view of the design pressure of 12.5 MPa

Burst pressure

- Pipes are hydrostatically pressurised and the time until failure is monitored

Burst pressure





All (excavated) pipes show a similar burst pressure behaviour

Ageing at 60 °C increases the resistance against internal water pressure

Burst pressure

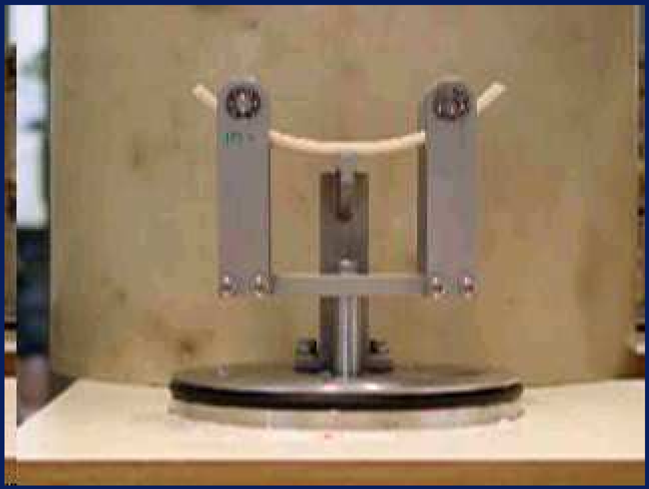
- Burst pressure stress level after 100 year service life at 20 °C

Production year	Stress level (MPa)	Uncertainty (MPa)
1959	27.0	0.5
1970	20.7	0.5
1975	23.0	0.9
1984	24.3	1.4
1997	26.3	0.6
2003	28.4	0.6

Critical values in view of the design pressure of 12.5 MPa

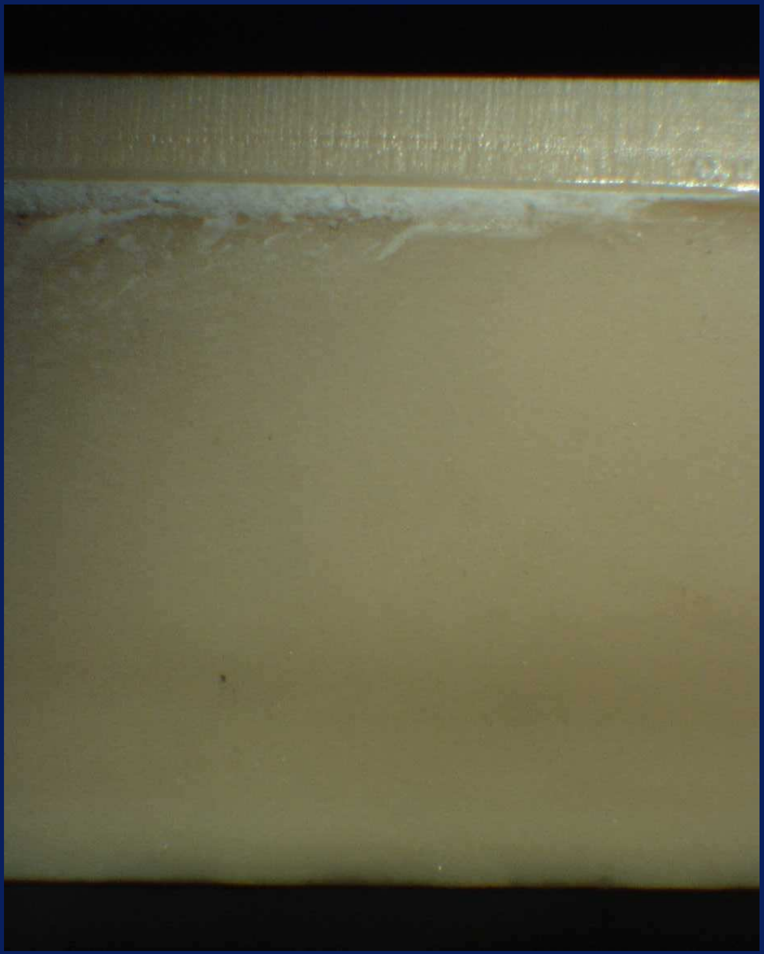
Slow crack growth

- Ring segment is notched and subjected to three point bending
- The time until failure is monitored versus applied stress



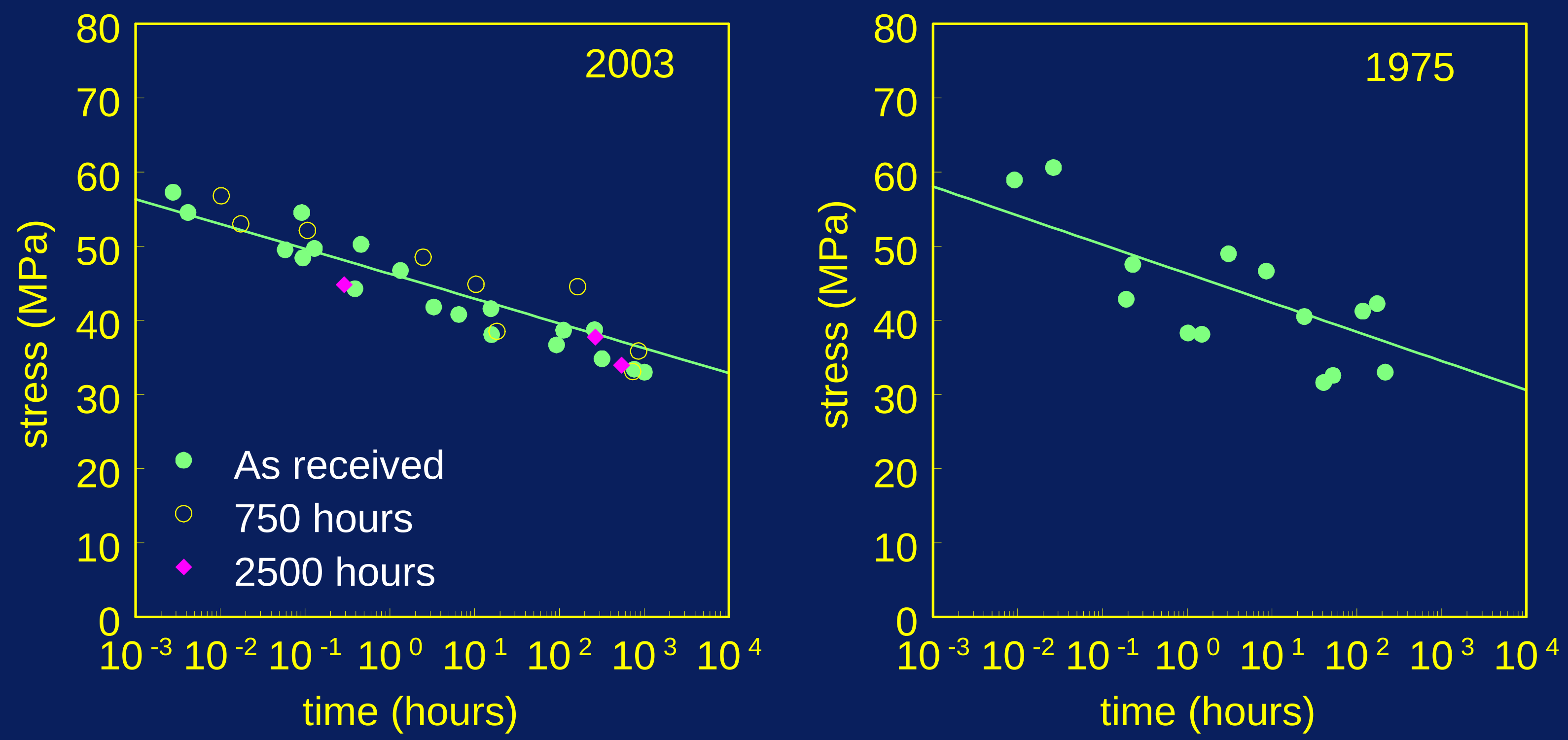
Slow crack growth

Ductile failure



Brittle failure

Slow crack growth



Slow crack growth

- All excavated pipes fail in a ductile manner
- Failure behaviour is comparable to burst pressure behaviour
- However, pipes of 1970, 1975 and 1984 show significant scatter in results
  - Low degree of gelation
  - Larger particles
- Extrapolation to 12.5 MPa for these pipes gives large uncertainty

Slow crack growth

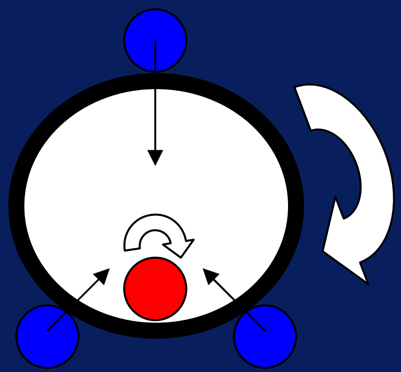
- Slow crack stress level after 100 year service life at 20 °C

Production year	Stress level (MPa)	Uncertainty (MPa)
1959	26.7	1.9
1970	17.3	5.0
1975	19.7	6.3
1984	24.4	7.1
1997	22.1	4.7
2003	21.1	2.2

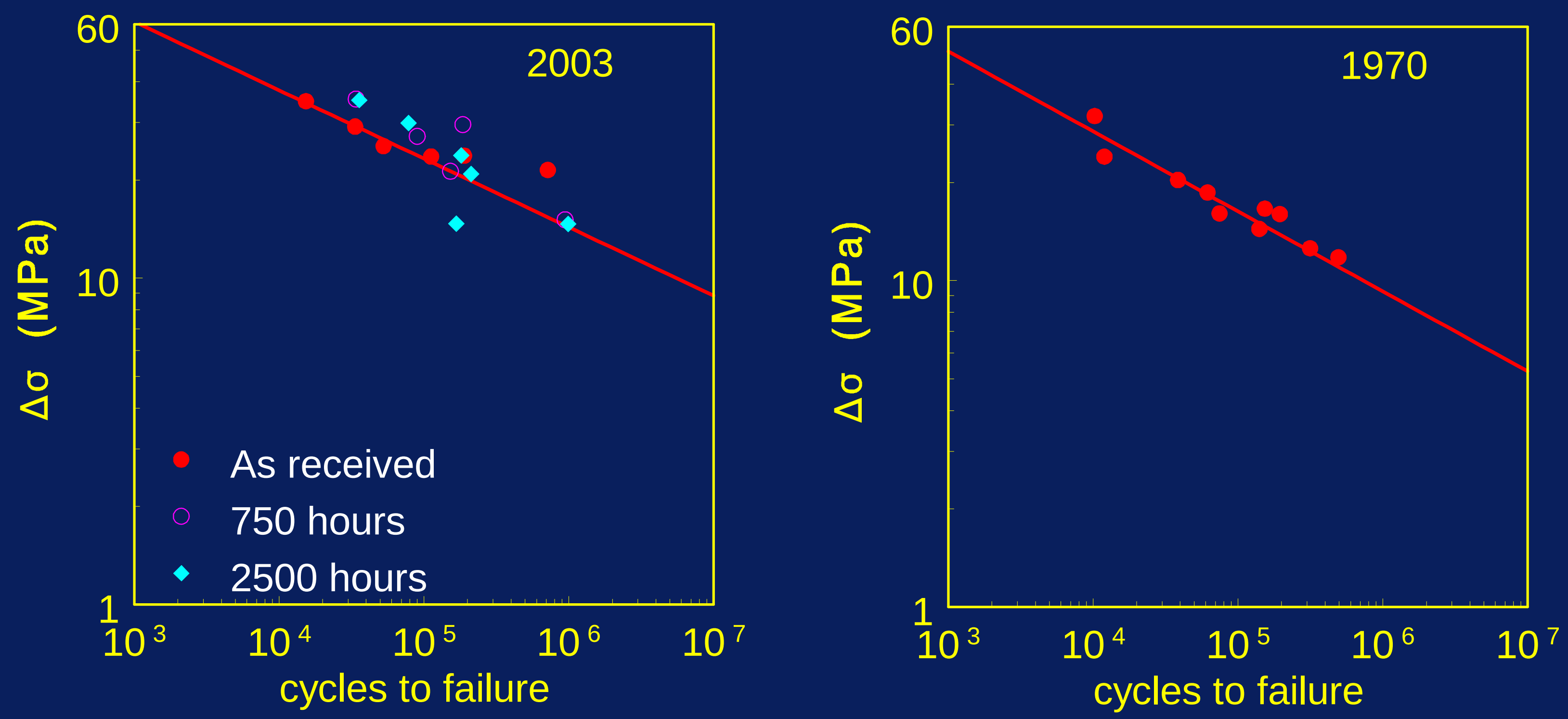
Critical values in view of the design pressure of 12.5 MPa

Fatigue

- Loaded ring is rotated
- Number of cycles until failure is monitored versus stress level applied



Fatigue


60
10
1
Δσ (MPa)
2003
As received
750 hours
2500 hours
10 3
10 4
10 5
10 6
10 7
cycles to failure
60
10
1
Δσ (MPa)
1970
10 3
10 4
10 5
10 6
10 7
cycles to failure

Fatigue

- Fatigue stress level that can be withstand for 10^7 cycles in 100 years at 20 °C (=10/hour)

Production year	Stress level (MPa)	Uncertainty (MPa)
1959	8.0	1.7
1970	4.1	1.7
1975	4.0	1.0
1984	5.5	1.7
1997	13.6	4.4
2003	8.9	1.4

- This means a deflection < 2% for the 1970, 1975 and 1984 pipes

Critical values in view of traffic load

Conclusions

- *Prediction service life of currently produced PVC water distribution pipes with the high quality control procedures on material, processing and stabilisation applied by Dyka, Pipelife and Wavin*

> 100 years

- *Provided: good control during construction activities and service e.g.*
  - *Back fill of soil*
  - *Soil settlements*
  - *Water pressure*
  - *Magnitude and occurrence of water hammer*
  - *Ground works*

Conclusions

- *Residual service life of PVC water distribution pipes in service not restricted to 50 years*

- *Residual service time determined by:*
  - *Material properties*
  - *Stabiliser package*
  - *External load of soil and traffic*
  - *Water pressure (water hammer)*
  - *Ground works*
  - *New connections*
- *Unforeseen conditions*

Unforeseen conditions

Operational condition assessment methods

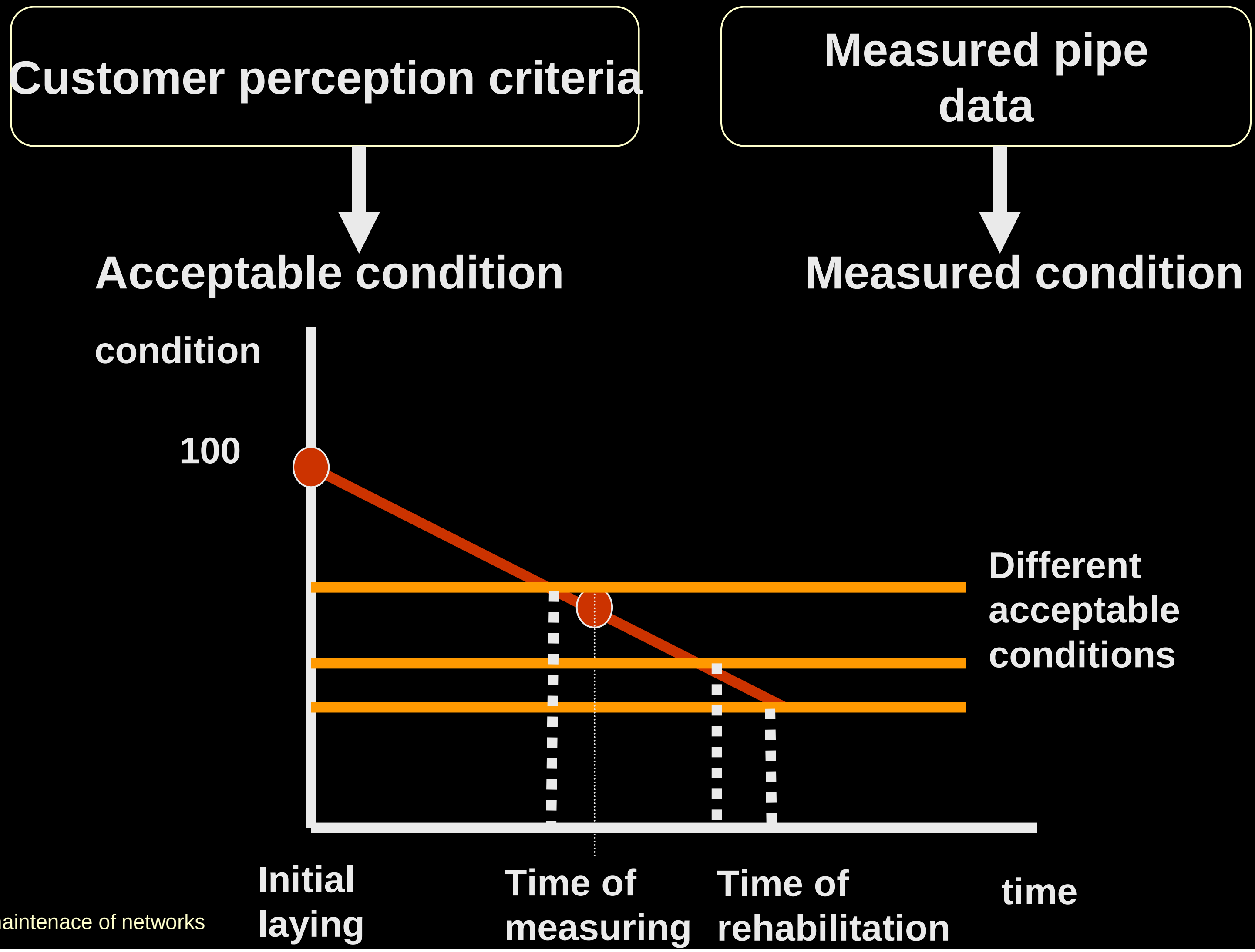



Different customer needs

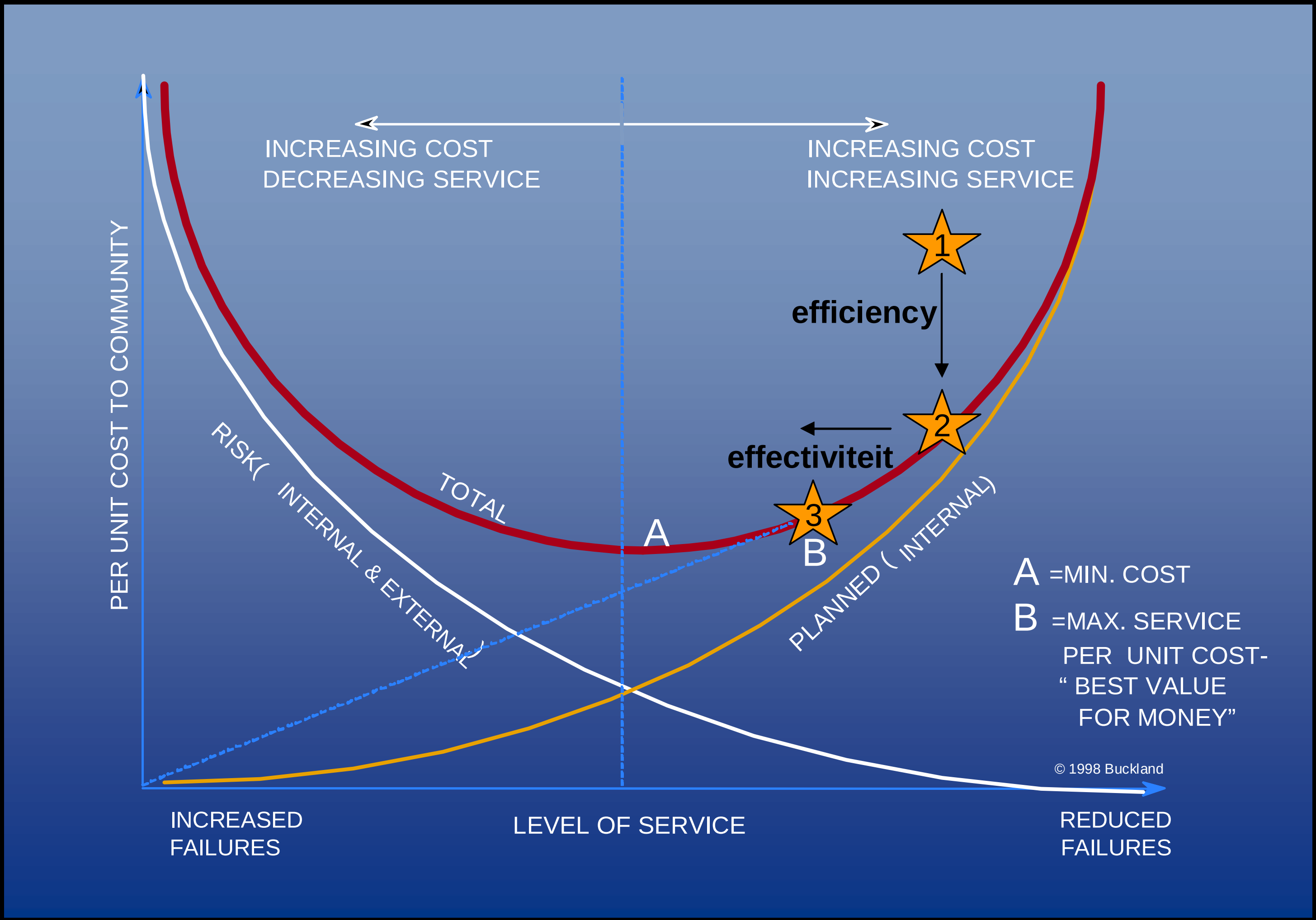
Different customer needs

Different customer needs

Customer determines time of rehabilitation



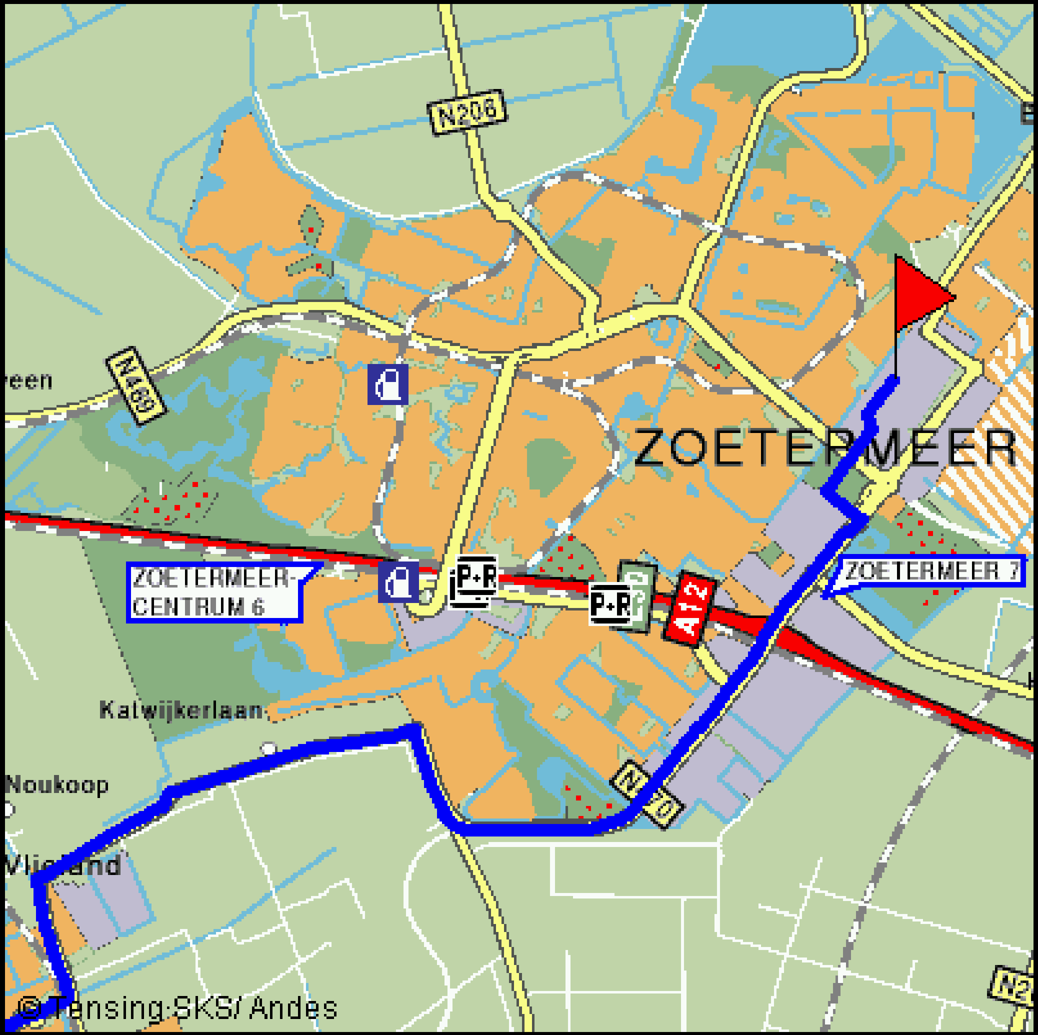
Asset management: balancing costs and performance



Closing remarks

- Condition assessment crucial factor in maintenance decisions
  - Pipes are ‘invisible’ (under ground)
- Methods for individual pipe assessment available
- Methods for ***network assessment*** are the challenge

Location Excursion Friday



Pumping stations and water transport

Operation and maintenance of networks

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