Pipelines in dikes

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in collaboration with:

Deltares

Enabling Delta Life

Outline

Pipelines in dikes

1. Introduction to pipelines and failures (15 min)
2. What's the problem with pipelines and dikes? (interactive, 15 min.)
3. Rules and guidelines (for design and assessment) (5 min.)
4. System reliability analysis (with event trees, interactive ~40 min.)
   a) Problem definition and data (5 min.)
   b) Exercise (parallel liquid pipeline) (20 min.)
   c) Plenary discussion of results (10 min.)
5. Challenges with pipeline crossings (10 min)
6. Summary and closure (5 min.)

Pipelines

Types, facts and figures

Transport media:

- Liquids (e.g. water, oil)
- Gas

Materials:

- steel, concrete, cast iron, plastic…

Diameters typically range from 50 mm to 1200 mm

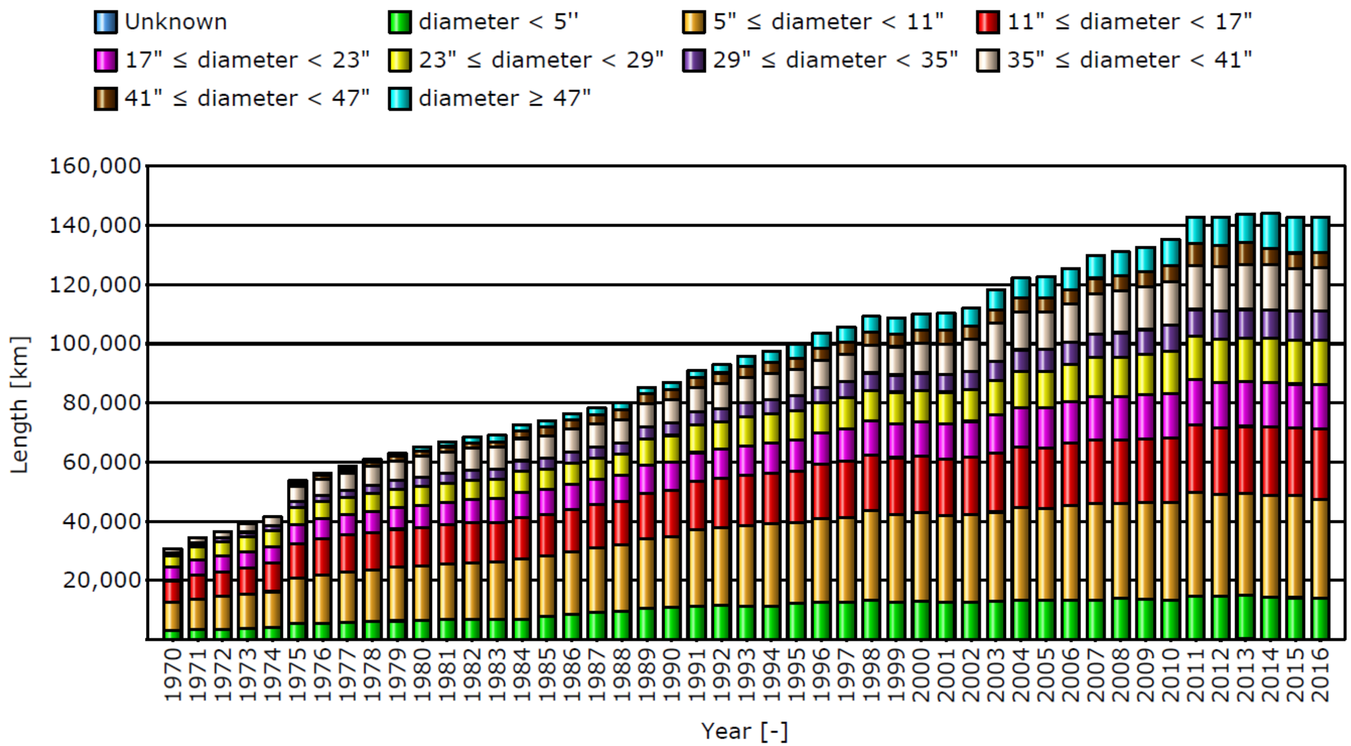
Pressures up to 25 bar (liquid) / 80 bar (gas)

Millions of kilometers of transport pipelines in Europe…

Pipelines

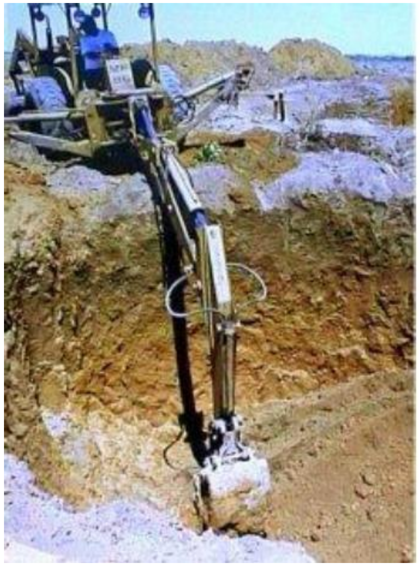
Types, facts and figures (2)

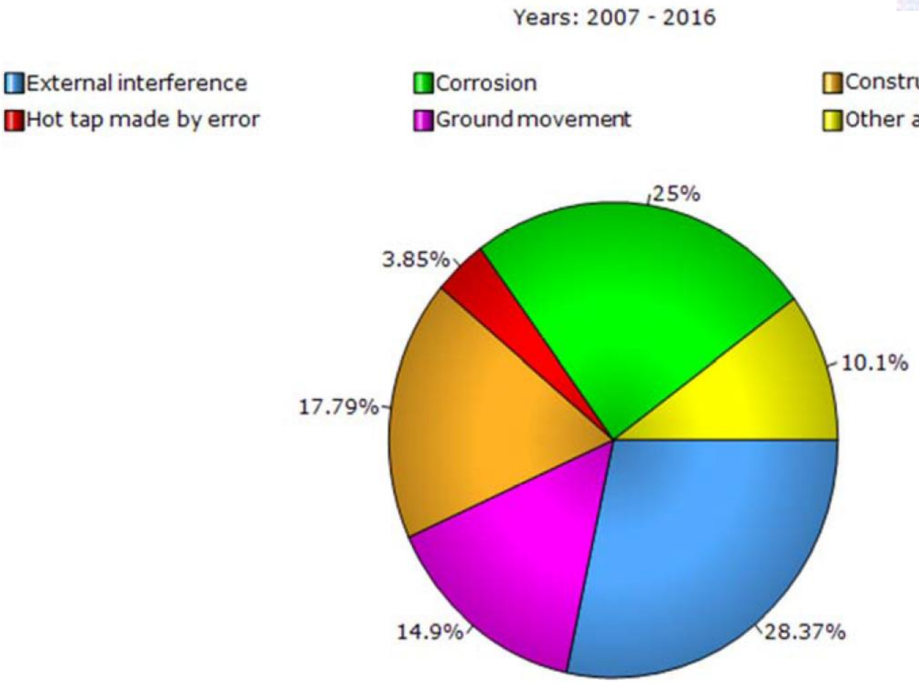
For example gas transport in Europe (source: EGIG):



Pipelines

Causes of pipeline failures





Distribution of incidents with gas pipelines
(2007-2016; source: EGIG)

Pipelines

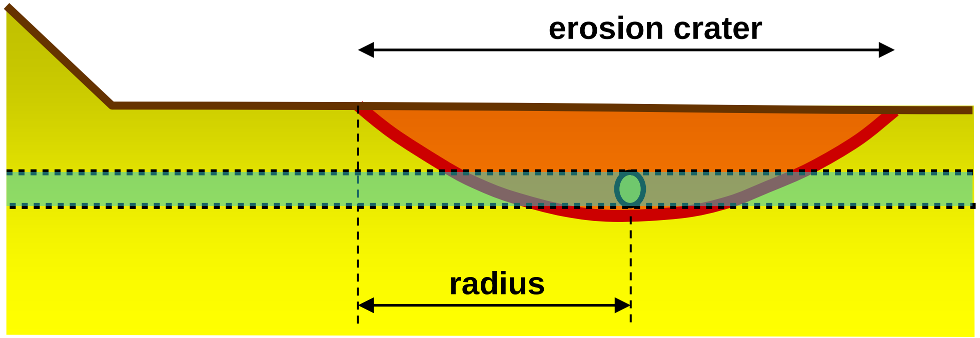
Types of pipeline failures

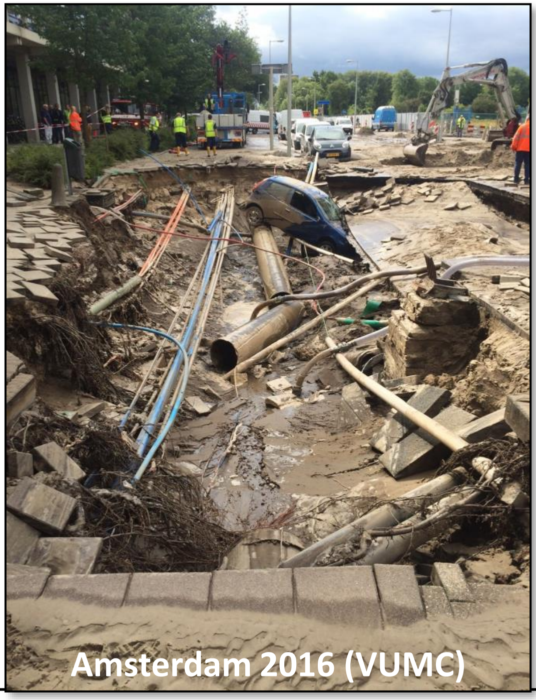
- pinholes (mostly pit corrosion)
- minor cracks / leaks
- major cracks / leaks
- shear failures etc.

Pipeline failures and effects

Fluid pipelines – major leaks (erosion craters)

high discharge in short time

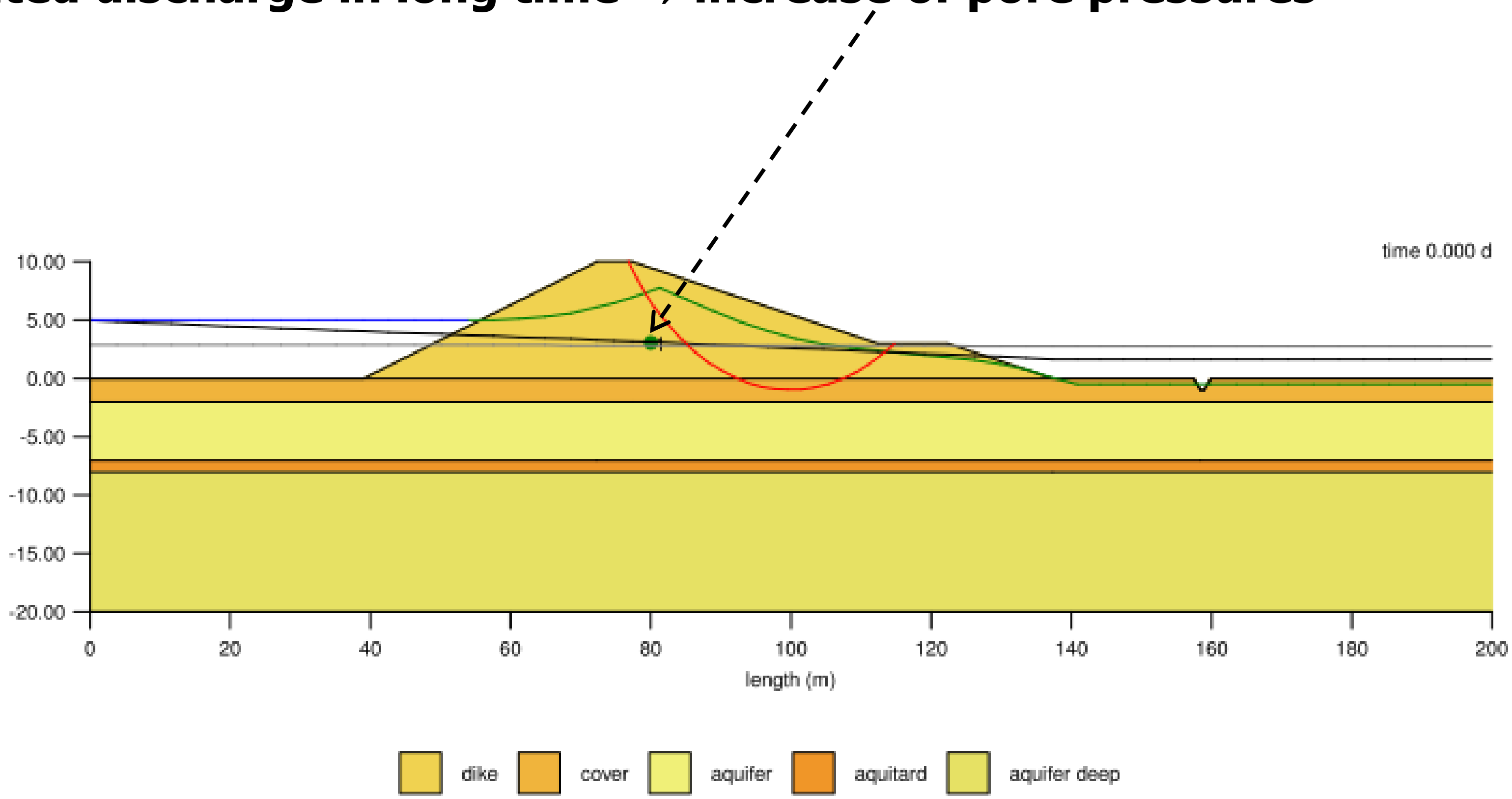




Pipeline failures and effects

Fluid pipelines – minor leaks

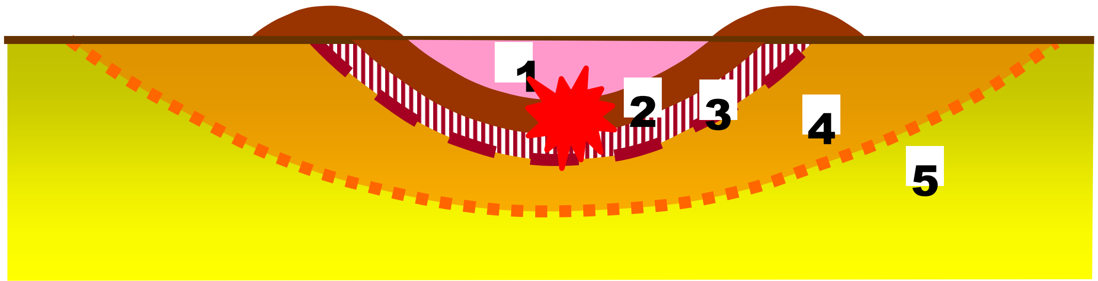
limited discharge in long time → increase of pore pressures



Pipeline failures and effects

Gas pipelines – explosions

- Explosion crater (1-3)
- Plastic zone around crater (4)
- Liquefaction

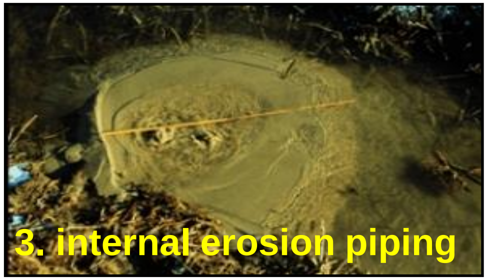


1 Krater
2 Na de explosie in de krater teruggevallen materiaal
3 Breukzone
4 Plastische zone
5 Elastische zone

What's the problem with pipelines and dikes?

Group brain storm (5 min + 6 min feedback)

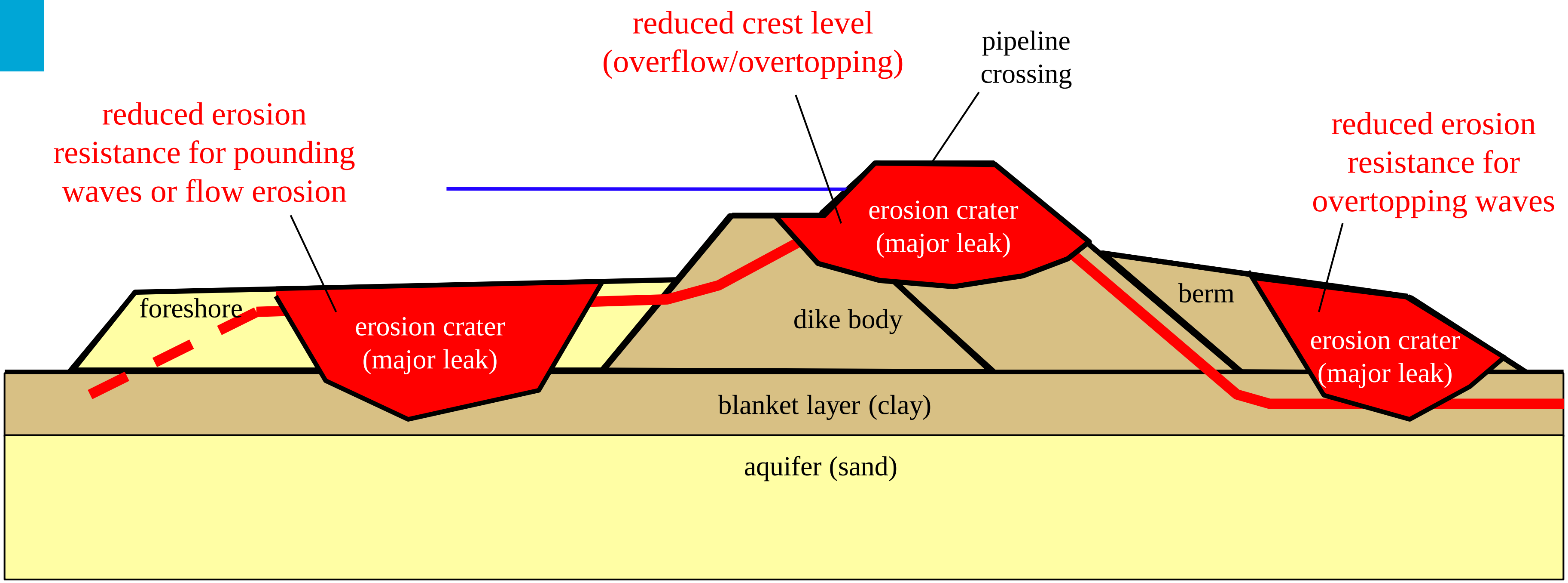
How do pipelines (intact and damaged!) affect dike failure mechanisms?



Split up into groups and discuss how pipelines can be harmful to dikes

Dike failure mechanisms

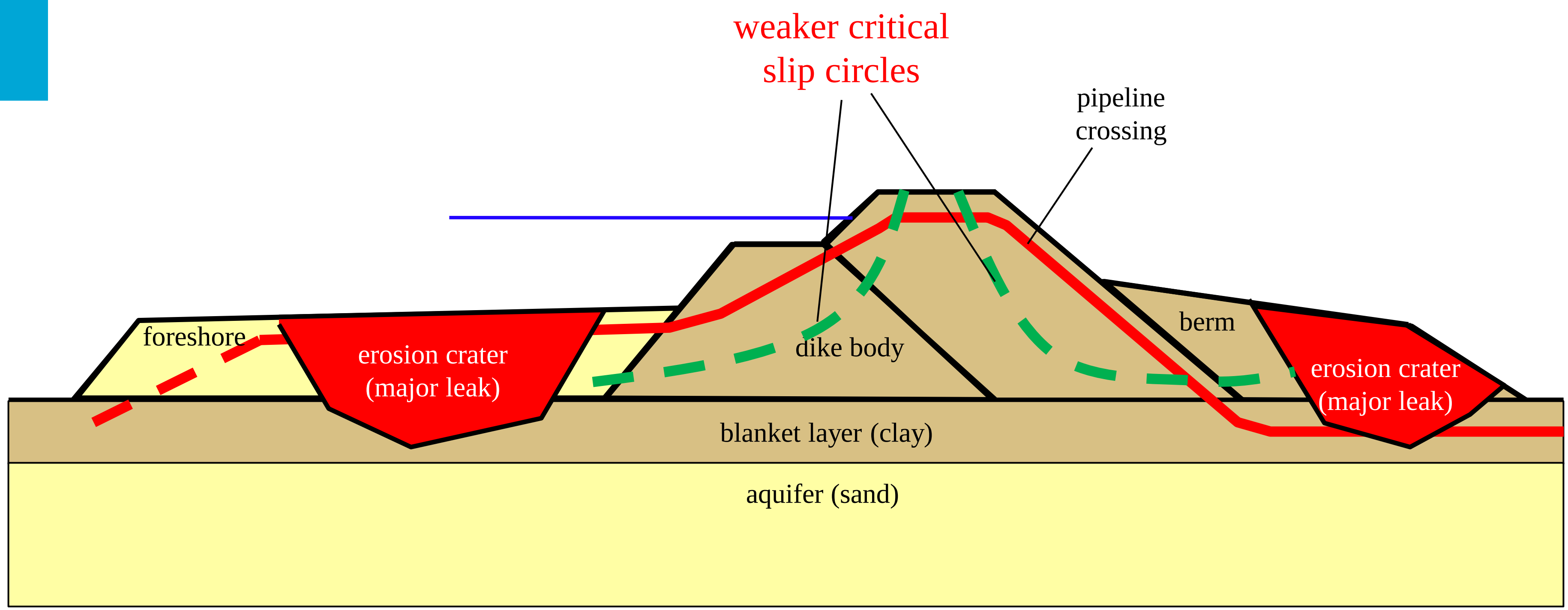
Wave impact, overflow and overtopping



Effects expected from minor leaks and additional saturation often insignificant (mainly reduced erosion resistance, but no reliable data on this available)

Dike failure mechanisms

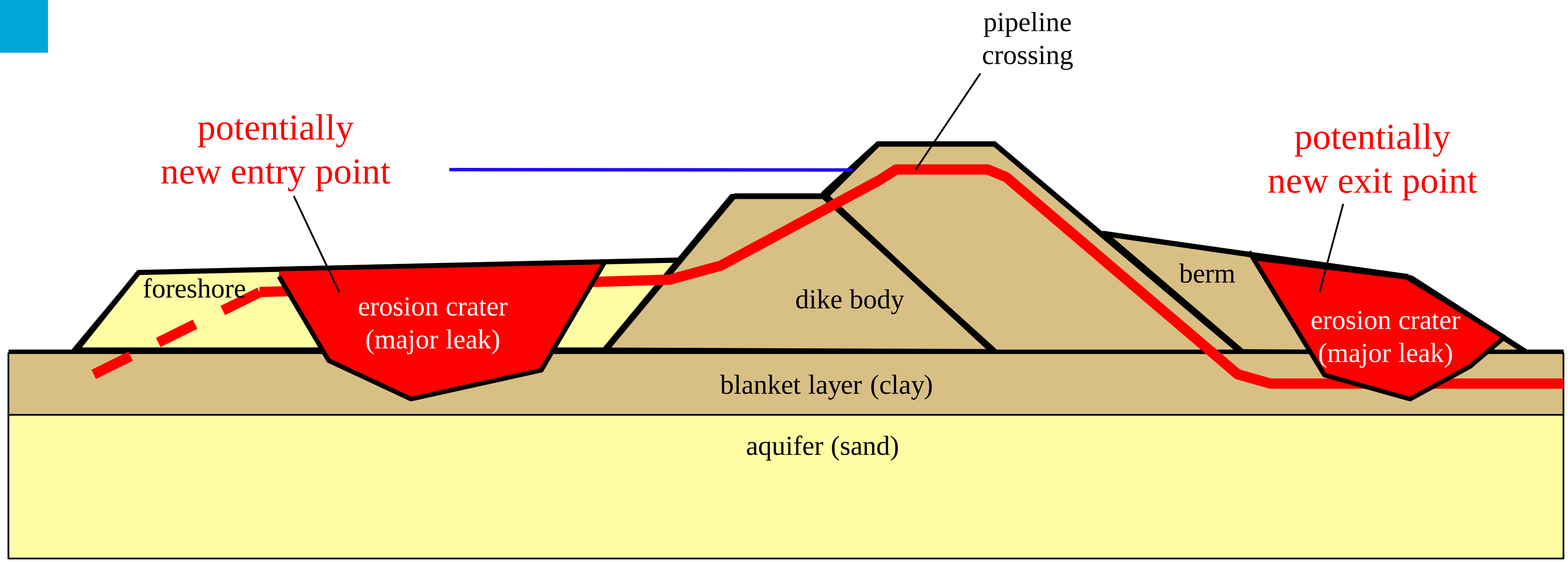
Slope instability



Elevated phreatic levels as a consequence of minor leaks and additional saturation of the dike body (hence, lower shear strength!)

Dike failure mechanisms

Internal erosion piping



Typically no unfavorable effects expected from minor leaks and additional saturation of the dike body (could be a problem for micro-instability with sand dikes, though)

Stein dike failure

Water pipeline causing slope instability

Stein dike failure

Emergency repairs

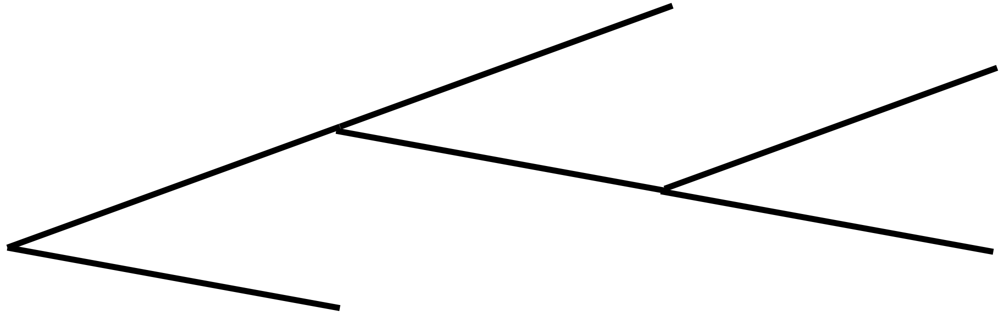
Stein dike failure

Emergency repairs

Grote zakken zand, zogeheten bigbags, versterken de dijk van het Julianakanaal in Stein. FOTO JASPER JUINEN, ANP

System reliability analysis

Event trees



Develop and example event tree for pipeline failure resulting in dike failure, from what you have just heard

Rules and guidelines

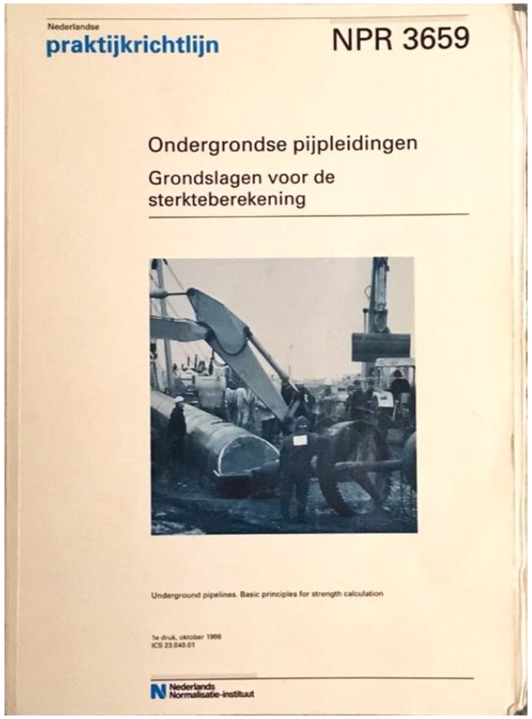
Dutch norms and guidelines

- **NEN 3650** series (Dutch standard for pipeline systems)
- **NEN 3651** (specific requirements for pipelines in/near hydraulic structures)
    - In principle, no pipelines allowed in flood defences, unless unavoidable.
    - Not entirely compatible with reliability requirements for flood defences.
    - But, opening in standards for 'integrated reliability analysis'.
- **NPR 3659** ('Praktijkrichtlijn Ondergrondse pijpleidingen - Grondslagen voor de sterkte')

Rules and guidelines

NPR 3659 – Failure probabilities (Dutch guideline)

Buismateriaal	**Faalkans** Per meter per jaar
staal (hoge druk)	$0{,}8 \times 10^{-6}$
staal (lage druk)	$2{,}5 \times 10^{-4}$
grijs gietijzer	$5{,}0 \times 10^{-4}$
nodulair gietijzer	$0{,}5 \times 10^{-4}$
PVC	$1{,}5 \times 10^{-4}$
PE	$1{,}0 \times 10^{-4}$
gewapend beton zonder plaatstalen kern	$0{,}5 \times 10^{-4}$
gewapend beton met plaatstalen kern	$0{,}1 \times 10^{-4}$
asbestcement	$0{,}5 \times 10^{-4}$



Representative for flood defences?

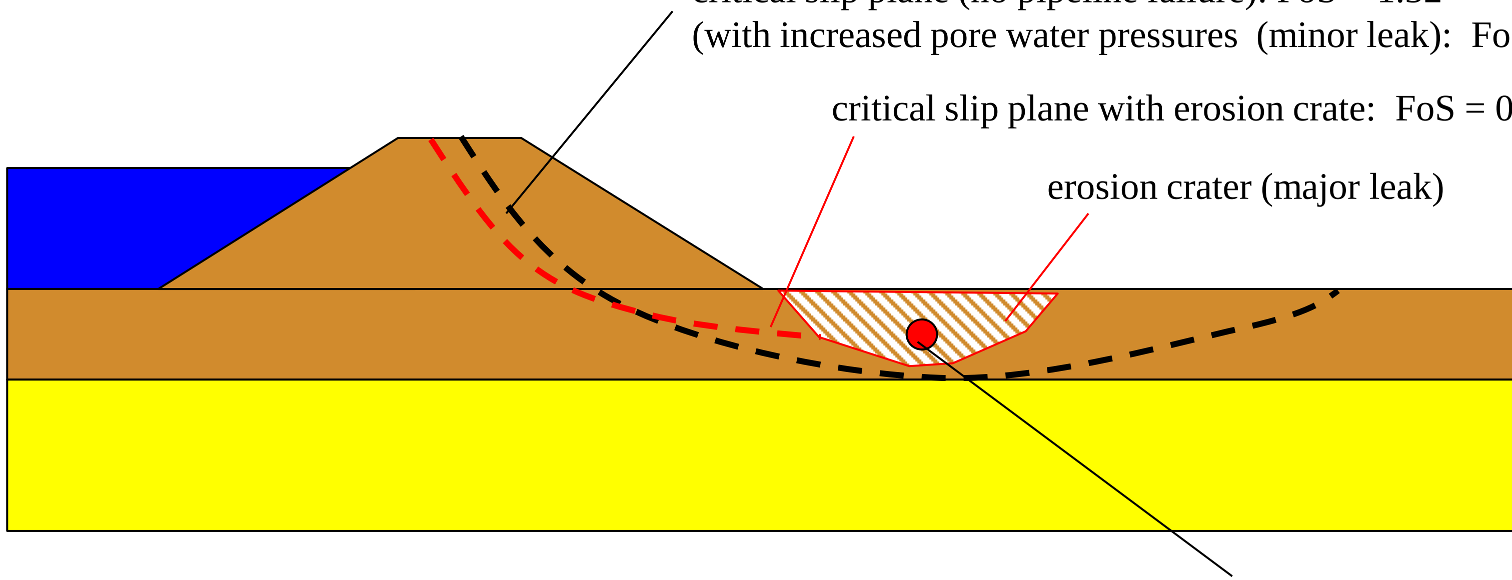
System reliability analysis (exercise)

Dike assessment with parallel liquid pipeline (macro instability)

1. Problem definition and data
2. Define target reliability for slope instability
3. System reliability analysis with event tree:
   a) determine P(major leak) and P(minor leak)
   b) determine P(slope instability|…)
   c) combine all probabilities and compare with target reliability
4. Reflect on critical contributions/factors and potential mitigation measures

Integrated reliability analysis (exercise)

Problem definition and data (1)



To estimate probability of failure based on FoS (similar to eq. 10.14 in lecture notes):

$$\beta = \frac{\gamma_n - 0.41}{0.15} + 4 \quad with \quad \gamma_n = FoS/1.06$$

model factor (γ_d)

$P_f = \Phi(-\beta)$ with Φ = standard normel CDF

Integrated reliability analysis (exercise)

Problem definition and data (2)

Safety requirements (see lecture notes 10.2):

- safety standard: 1/10.000 (annual)
- max. contribution instability: 4 %
- Length effect:
  - trajectory length: 20 km
  - sensitive fraction: 0.3333
  - independent section length: 50 m

Repair time and flood duration (for probability of flood coinciding with dike damage):

- repair time: 2 weeks (including detection)
- flood duration: 2 weeks

Integrated reliability analysis (exercise)

Problem definition and data (3)

Pipeline data

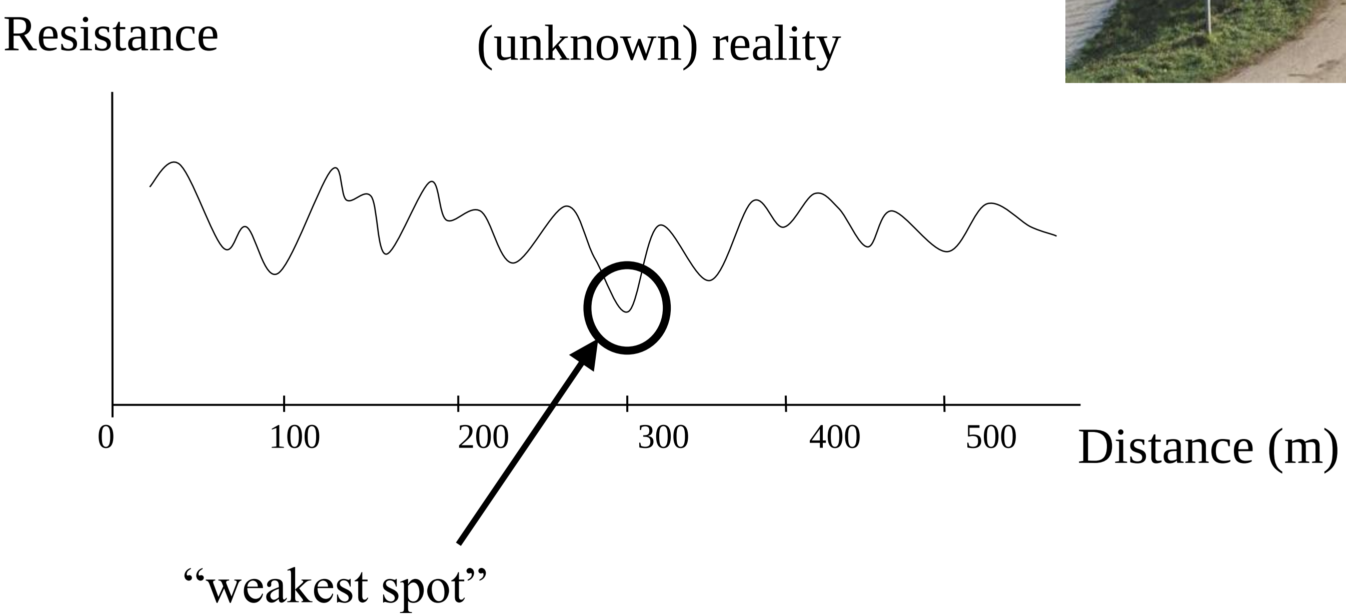
- diameter: 40 inch (1.01 m)
- operating pressure: 1.1 MPa (i.e. 11 bar or roughly 110 meter of water column; would be considered a *high pressure* pipeline)
- material: steel
- probability of pipeline failure (roughly based on indicative numbers in NPR 3659):

Pipeline material (type)	Probability of failure* (per m per year)
Steel (high pressure)	0.8×10^{-6}
Steel (low pressure)	2.6×10^{-4}
Cast iron	5.8×10^{-3}
PVC	1.6×10^{-4}
Reinforced concrete	0.2×10^{-4}

*We assume that 25% of pipeline failure lead to major leaks and 75% to minor leaks.

Length effect

Intermezzo



Length increases → probability that weakest spot is "very weak" increases
(Remember, the real conditions are unknown)

Integrated reliability analysis (exercise)

Solution to exercise – target reliability

1. Length-effect factor:

$$N = 1 + \frac{a * L}{b} = 1 + \frac{0.03333 * 20{,}000}{50} = 14.3$$

sensitive fraction (0.03333); trajectory length (20,000); independent section length (50)

2. Reliability target for slope instability:

$$P_{req,inst} = \frac{\omega}{N} * P_{req} = \frac{0.04}{14.3} * 10^{-4} = 2.8 * 10^{-7}$$

max. contribution instability (0.04); safety standard (10^{-4}); length effect factor (14.3)