Real-time levee strength monitoring and forecasts

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Mandatory assessment of Dutch Flood defences

Primary: 3585 km
Regional*: 14,000 km

*regional defences have usually a controlled water level
Periodic static assessment of height and stability (each 11 years), in order to find the sections that need to be improved.

Result Primary defences (2006):
- 1.217 km (35%)
- 1.792 km (50%)
- 549 km (15%)
Importance of stability assessment

NL: Evacuation in 1995: 210,000 people

Decision for evacuation was not based on height, but on stability!
Dutch software for levee strength assessment

Static assessment of all sections:
- Dike strength Analysis Module (DAM 1.0)
- From 2017: New tool for primary defences (Ringtoets)

Real time assessment of critical sections:
- Delft-FEWS with DAM-LIVE!
Based on annual probabilities:

Static assessment with DAM and Ringtoets

**Static assessment:**
- Ringtoets: primary defences (incl. water level calculation)
- DAM: regional levees (water level as input)

**Additional feature DAM:**
- Design of required dimensions
DAM and Ringtoets share levee data sources

- Location data*
- Cross-section geometry*
- Subsoil model
- Piezometric heads etc*

* From GIS waterboard
Software for real time assessment of critical sections

Real time assessment of critical sections:
• Delft-FEWS with DAM-LIVE!

Static assessment of all sections:
• Dike strength Analysis Module (DAM 1.0)
• New tool for regulatory assessment (Ringtoets)
Real-time strength assessment with DAM-Live

- Stability

Water level (history)

Piping: depends on water level

Slope stability: depends on water level history

Deltakres
Real-time forecasts of levee strength, for early warning

- Supports decisions on prevention, mitigation and remediation
- Uses schematizations generated by DAM

Initial levee safety level forecast

Water level | Piezometric head | Safety level
---|---|---
1.00 | 1.05 | 1.00

Improved levee safety level forecast with monitoring data

Water level | Piezometric head | Safety level
---|---|---
1.00 | 1.05 | 1.00

Monitoring data | Observations
DAM-Live uses DAM schematizations

- **Static Asset Management**
  - Levee Safety Assessment
  - Required Dimensions
  - Fragility Curves
  - Geotechnical schematizations for all cross sections

- **Real-time Early Warning**
  - Levee Safety Forecasts
  - Identification Unexpected Behavior
  - Improved Safety Forecast
  - Real-time water level forecasts

- **DAM**
  - Snapshot of static levee data

- **FEWS**
  - Real-time measured piezometric heads, deformations and temperatures
DAM uses static piezometric head field

Steady State piezometric field is very conservative for slope stability

Example: Static Water level: 3.85; Factor of Safety: 1.85
DAM-Live uses transient forecast of piezometric head

Transient forecast is more realistic (and less conservative)

Same example: Peak water level: 3.7; Minimum Factor of Safety = 2.74 (instead of 1.85)
Example of application: Groot Salland, dijkring 10
Delft-FEWS: Water Level Forecast

[Diagram showing water level forecast and geographic map with various markers and lines indicating flood risk areas.]
Predicted Failure Probability Piping

(movie)
FEWS-DAM feeds information dashboard

- Weather Forecast
- Water level forecast
- Strength forecast
- Monitoring data
- Inspection data
- Consequences
- Control measures

(Picture: Courtesy Waterboard Groot-Salland and HKV)
DAM-Live uses monitoring data (via Delft-FEWS)

- Real time stability from measured piezometric head field
- Improved forecasts with updated field and/or calibrated parameters
The Dutch IJkdijk foundation conducts research, initiates pilots and offers a portal related to sensor data of “Smart Levees”.

More info: http://www.ijkdijk.nl/en
FEWS-DAM connects to Smart Levees (Live-dikes)

_Smart Levees_ send sensor data (pore water pressures, deformations, temperatures etc.) through smart networks to information systems.
Locations of Smart Levees - 2013

- Sea dike
- Yellow River dike
- Primary river dike
- Sluice
- Regional dikes
- River dikes
Dutch Smart Levees connect to Dike Data Service Centre

Data Source

- Warm data
  - Sensors
  - Water levels
  - Precipitation

- Cold data
  - Levee and subsoil
  - Assessment results
  - Inspection data
  - Remote Sensing
  - Cooled data

Function

- Anomaly detection
- Data mining
- Strength determination

Result

- Reliable measurement data
- Direct indication of failure
- Data retrieval
- Data correlation
- Early warning with DAM-Live if strength becomes insufficient
- Parameter calibration
2012: 1 test on slope stability, 3 tests with piping prevention measures
IJkdkijk piping prevention experiment: instrumentation

Many different techniques

Alert Solutions:
- 2 rows of 5 GeoBead pore pressure meters in piping test sand
  Location: middle, 3m and 6m from middle

Empxck:
Ground Penetrating Radar surveys (remote controlled) to detect anomalies in the levee
Avoid ITC-area!

Ten Cate:
GeoDetect geotextile with fibre optics
- 5 strips at clay/test sand interface
- 3 strips in levee

StabiAlert:
Bit of a stiff steel tube
3 tubes on both sides, centre line and 5m from centre line

Koenders Instruments:
SmartDikeProbe (SDP): two tubes in lower sand, one in upper sand
FBG every 1 metre, sensor module every 2 metres

Deltareas BioGrout: stimulated sandstone

Intschi:
infrared camera multispectral sensor
(both facing downstream slope from beyond ditch)
IJkdijk: destructive slope stability experiment

This happens after raising the phreatic head

(movie)