Software Engineering with Formal Methods :

The Development of a

Storm Surge Barrier Control System

Seven Myths of Formal Methods Revisited

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Overview

- The storm surge barrier and BOS
- Approach to Software Development
- Experiences with the use of formal methods:

  Seven Myths of Formal Methods revisited

  (*Seven Myths of Formal Methods*,
  Anthony Hall, IEEE Software 6(9), 1990)

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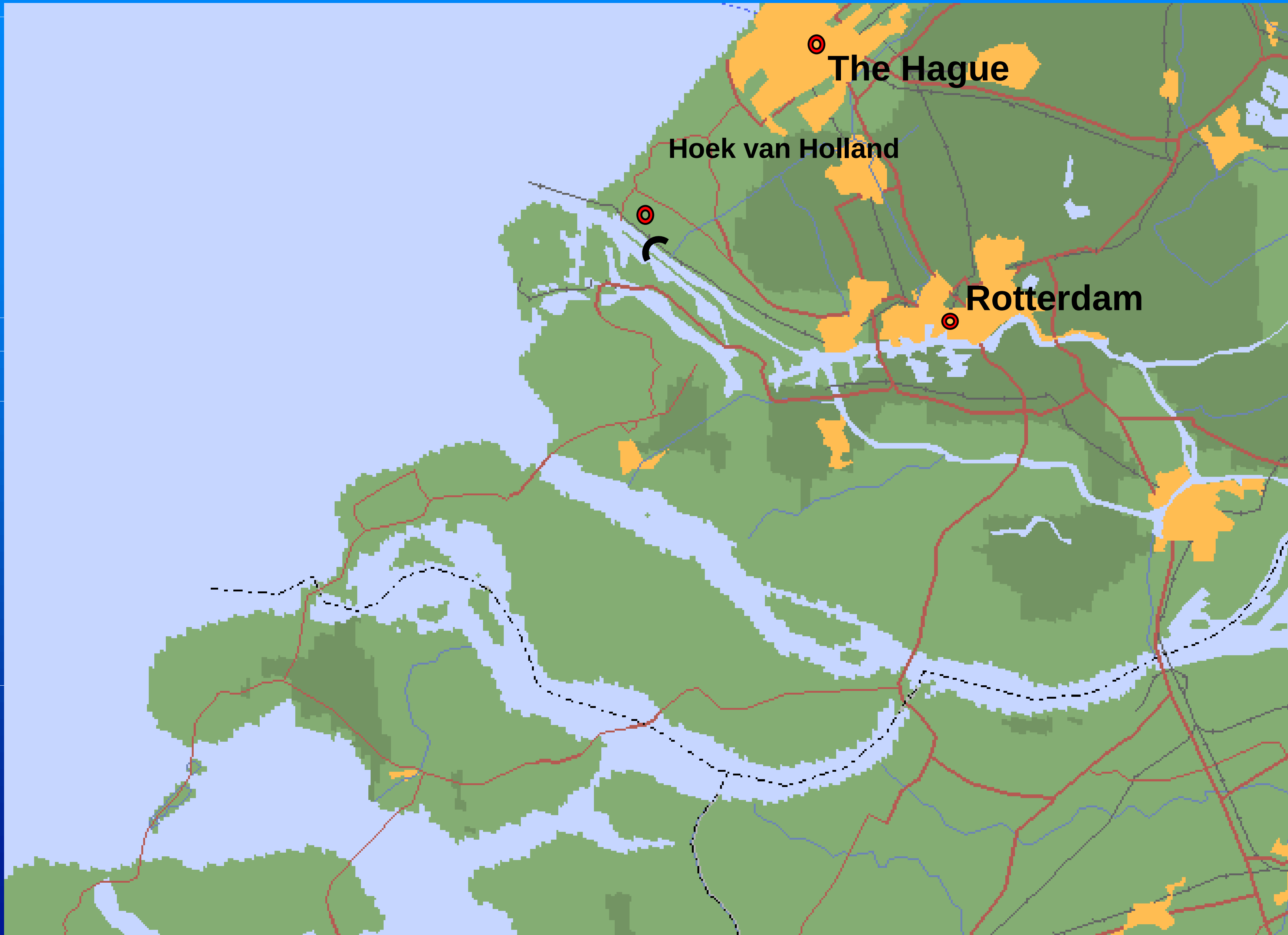
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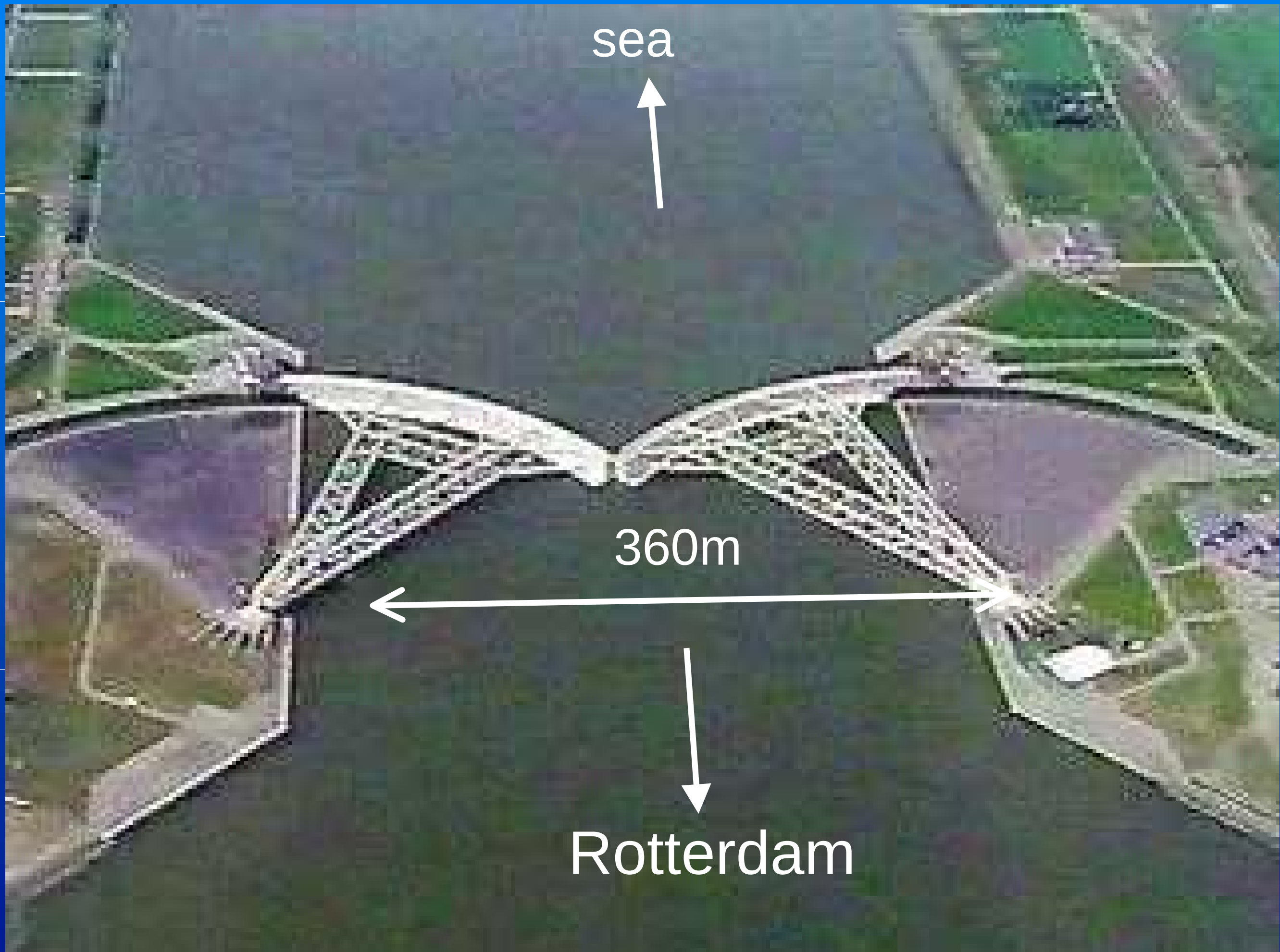
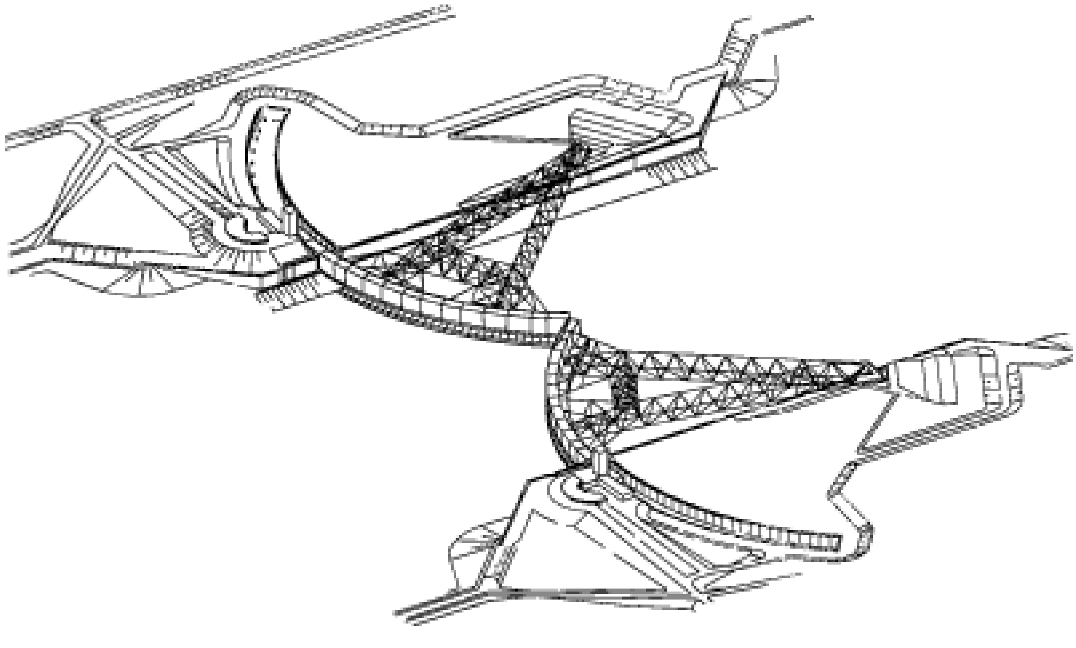
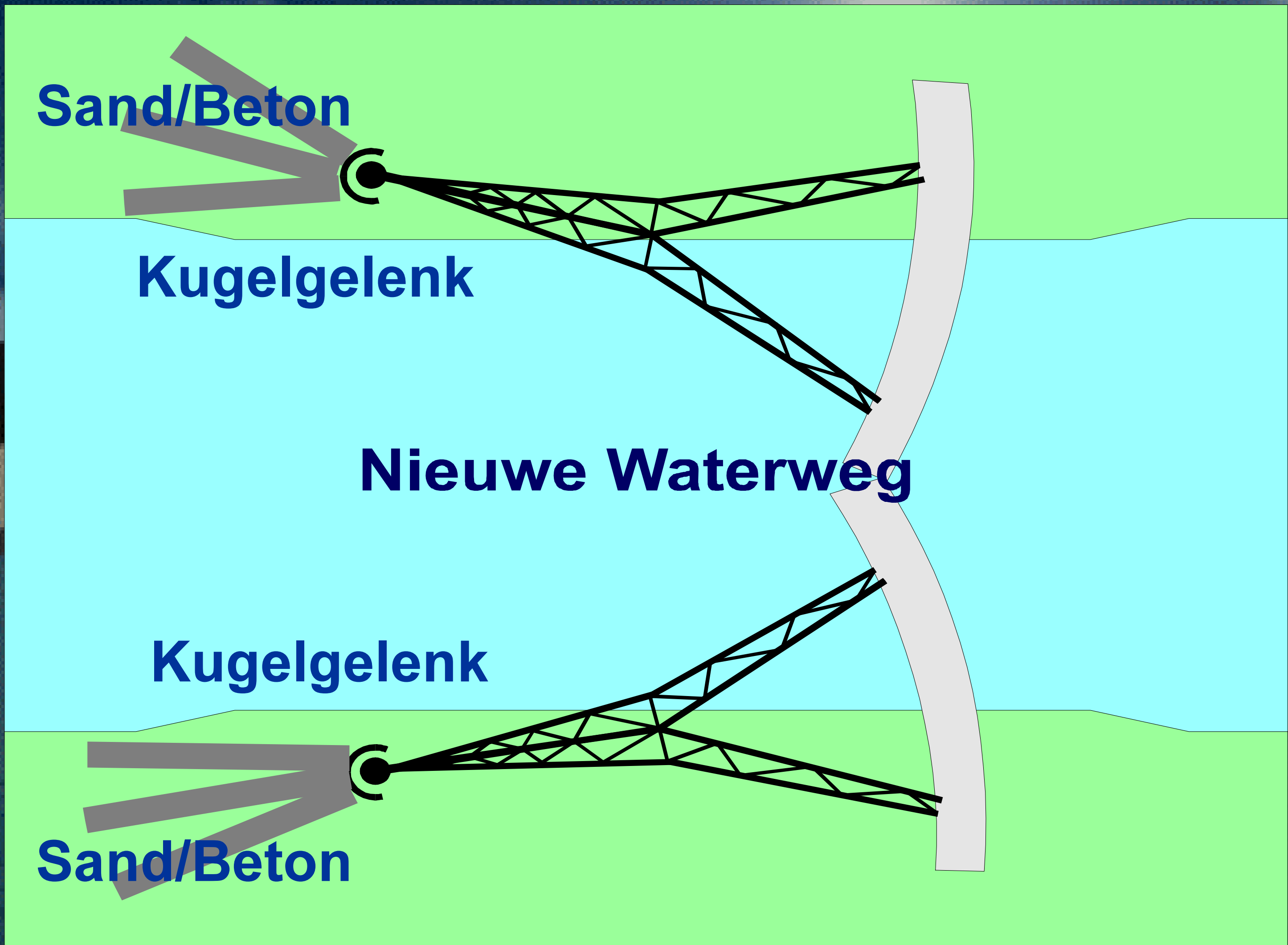
Storm surge barrier



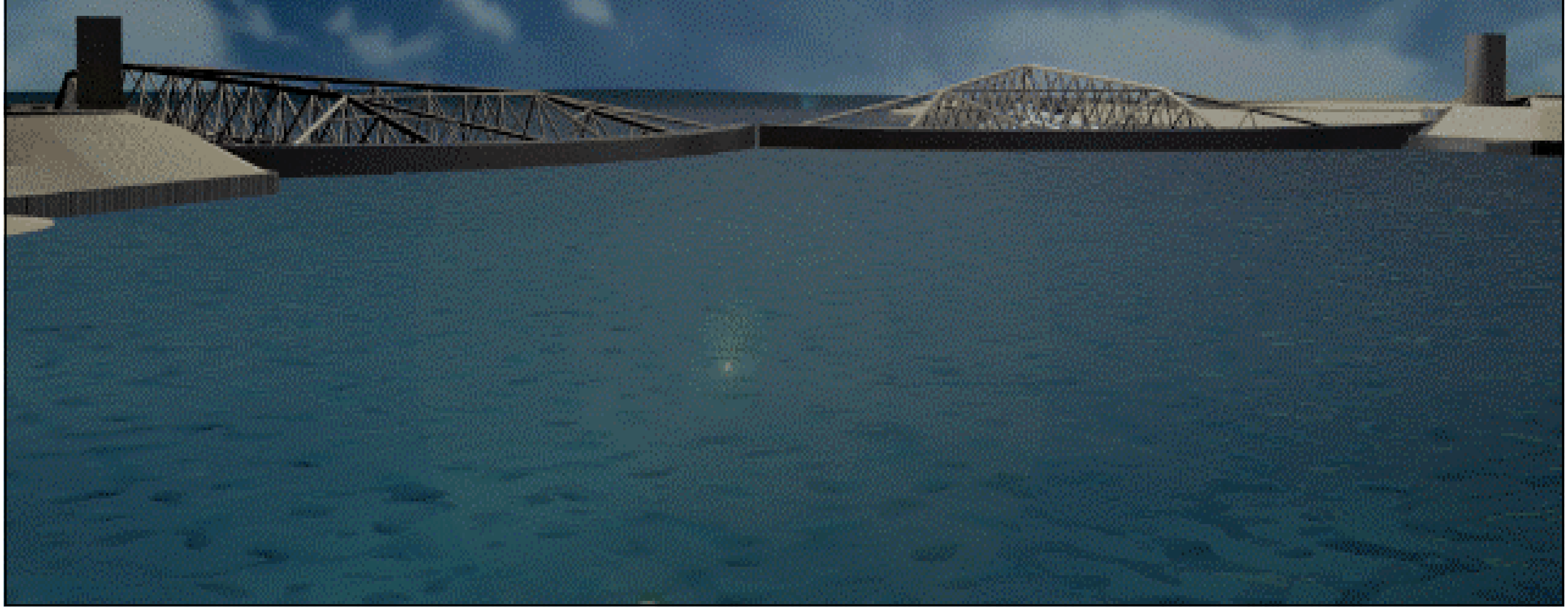


The storm surge barrier



As reliable as a dyke

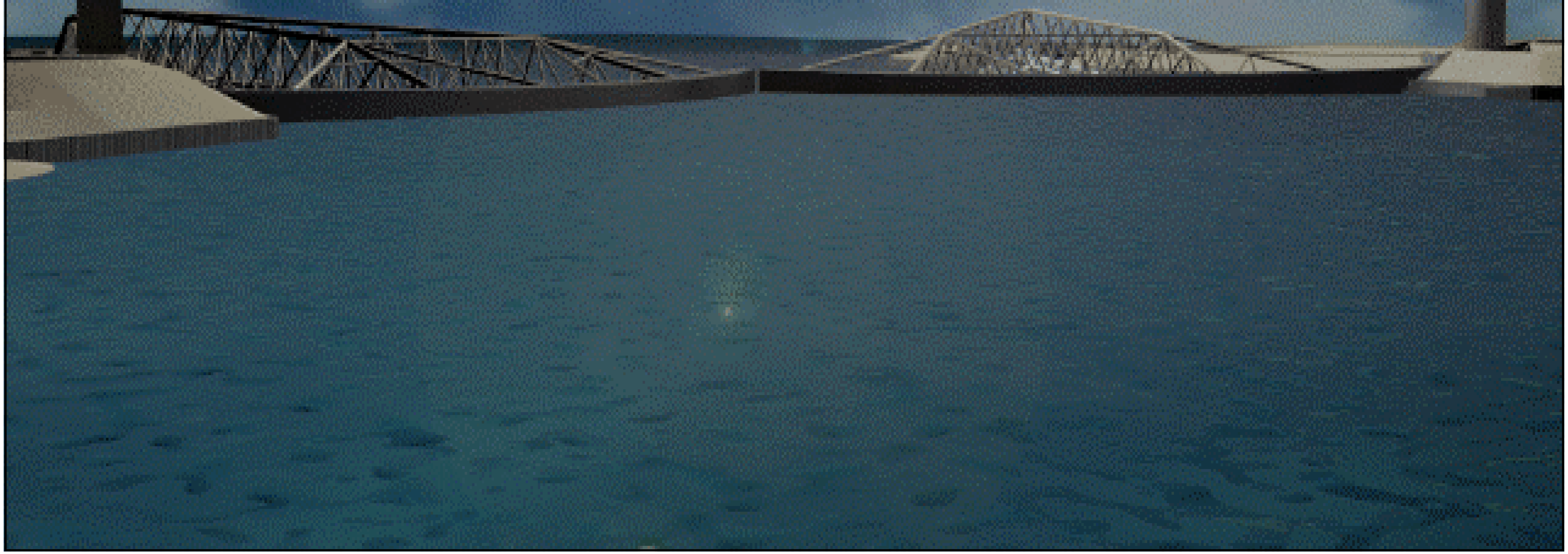
- Risk of failure dike: 1 in 10.000 years
- Extreme high water: 1 in 10 years
- Risk of failure barrier: 1 in 1.000 closures



Why a BOS?

- Risk of failure in decision: 1 in 100.000
- Failure probability human: 1 in 1.000 -10.000
- Decision process must be done automatically

=> BOS



What does BOS do?

- Decide when to close the barrier
- Decide when to open the barrier
- Control the barrier in the Nieuwe Waterweg
- Control the barrier in the Hartelkanaal
- Decide when maintenance is allowed
- Decide if a test closure is allowed and perform it

How does it work?

- Acquire data
- Predict water levels
- Decide and control
- Archive

How was it built?

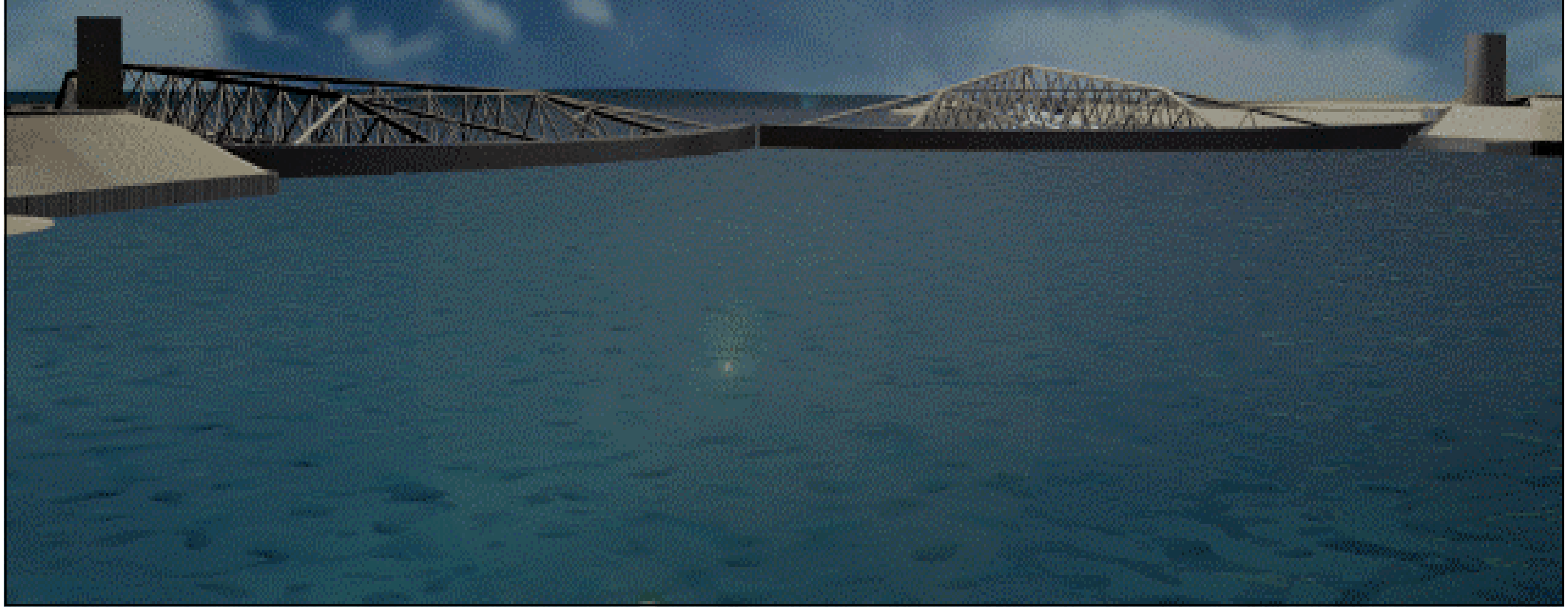
- Functional requirements drawn by RWS
- Required reliability 1 in 100.000
- Technical design and software by CMG (fixed-price)
- 25 person-years, 3 years from start to end
- 450.000 lines of code

High reliability

- Hardware
  - Fault-tolerant Stratus Continuum computer
  - Multiple communication lines and a private satellite channel
- Software
  - Reliability 1 in 100.000 cannot be shown by testing: it would take 2000 year!
  - Certification according to ISO 9001
  - Standard for safety-critical systems: IEC 1508

Result

- Delivered october 1997 within budget and on-time
- Since then it has rightly been in alert twice
- On October 3, 1998 the first test closure



Standard IEC 61508

- Recommendation for implementing safety critical software

- No measure of reliability or safety for software

- Based on "Best Practices"

- Recommends and forbids particular development techniques based on *Safety Integrity Level* SIL:

P_{fail}	10^{-2}	10^{-3}	10^{-4}	10^{-5}
SIL	1	2	3	4
				$\Uparrow$ BOS

- *Highly Recommended* for SIL 4:
    - inspections
    - independent testing
    - .....
    - *formal methods*

BOS Approach

- Risk based / failure analysis
- Well-defined project life-cycle, strict configuration management
- Use of best, feasible practices
- No guarantee of correctness, but increase of confidence by combination of validation techniques: *Validation & Verification Plan*
- V & V plan:
  - reviews and inspections
  - coding standards and static checking
  - coding assertions
  - developer testing (white box)
  - independent module/integration/system testing with coverage measurement
  - formal specifications
  - model checking
  - simulation

Formal Methods in BOS

Starting Points

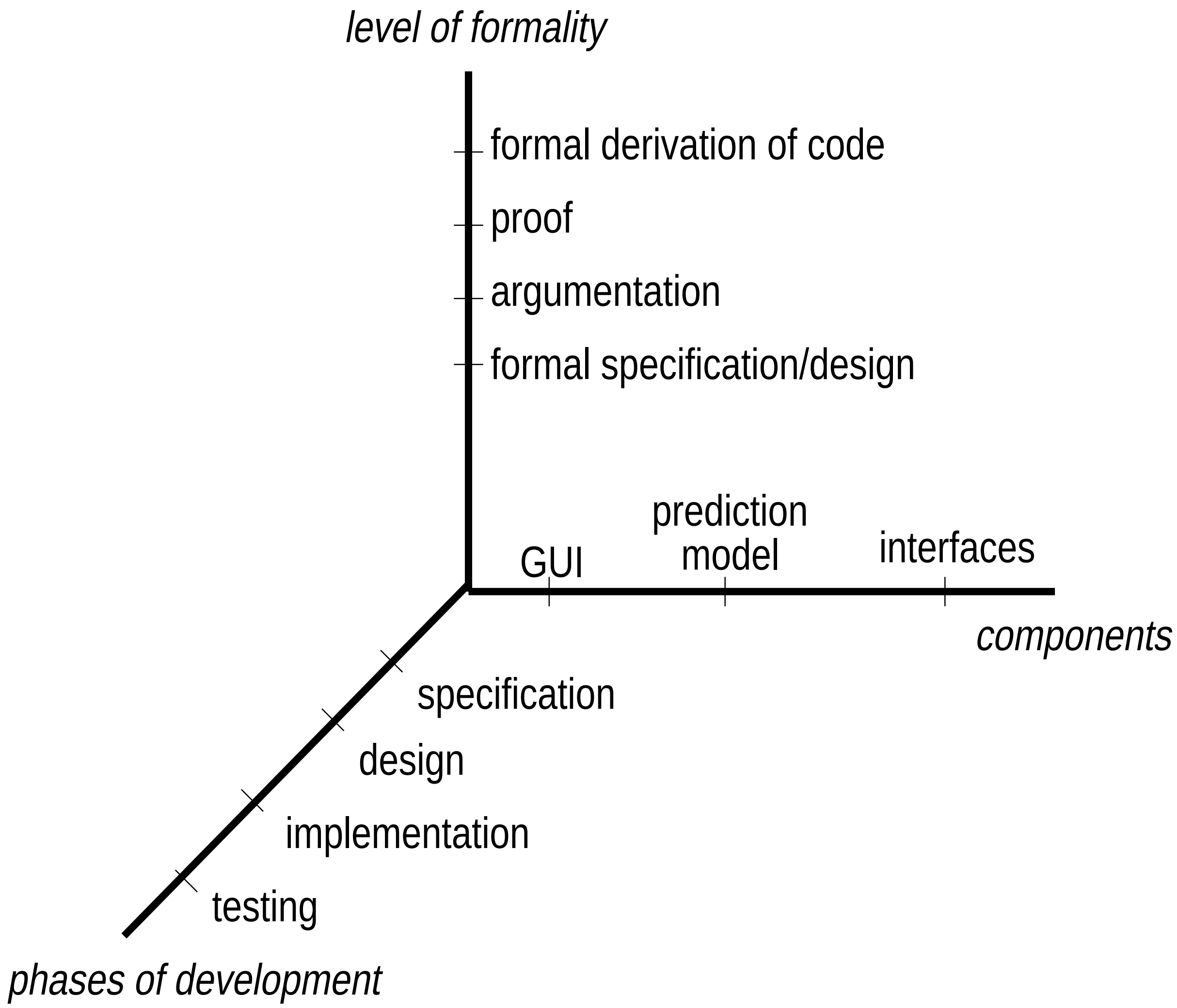
- Goal:
  To increase the reliability and correctness of the BOS software
- Cooperation CMG – University of Twente
- Integration in development trajectory
  not a parallel, academic exercise
- Fixed time – fixed price project
- Non-formal (Dutch + Hatley & Pirbhai) specification given

Formal Methods in BOS

How to Start ?

- where to apply ?
- which formal techniques ?
- in which phases of development ?
- how to learn FM ?
- how to manage FM ?
- how to combine with other (non-formal) SE techniques ?
- expected costs and benefits ?

Where to apply FM



Seven Myths of Formal Methods

Are the *seven myths of formal methods* really myths for the BOS project ?

(From: *Seven Myths of Formal Methods*, Anthony Hall, IEEE Software 6(9), 1990)

1. *FM guarantee correctness*
2. *FM are about program proving*
3. *FM are only for safety-critical systems*
4. *FM require highly trained mathematicians*
5. *FM increase development costs*
6. *FM are unacceptable to users*
7. *FM are not used on real software*

Myth 1

FM guarantee correctness

BOS: no guarantee of correctness

increased confidence in correctness
through increased precision and
early detection of defects

No guarantee of correctness:

- No single method can guarantee correctness

- FM not applied with all their rigour:
  - System too large for manual proof
  - No usable tools for automatic proof
  - Don't be too formal during first time use of FM

- Not all aspects of behaviour in single formalism

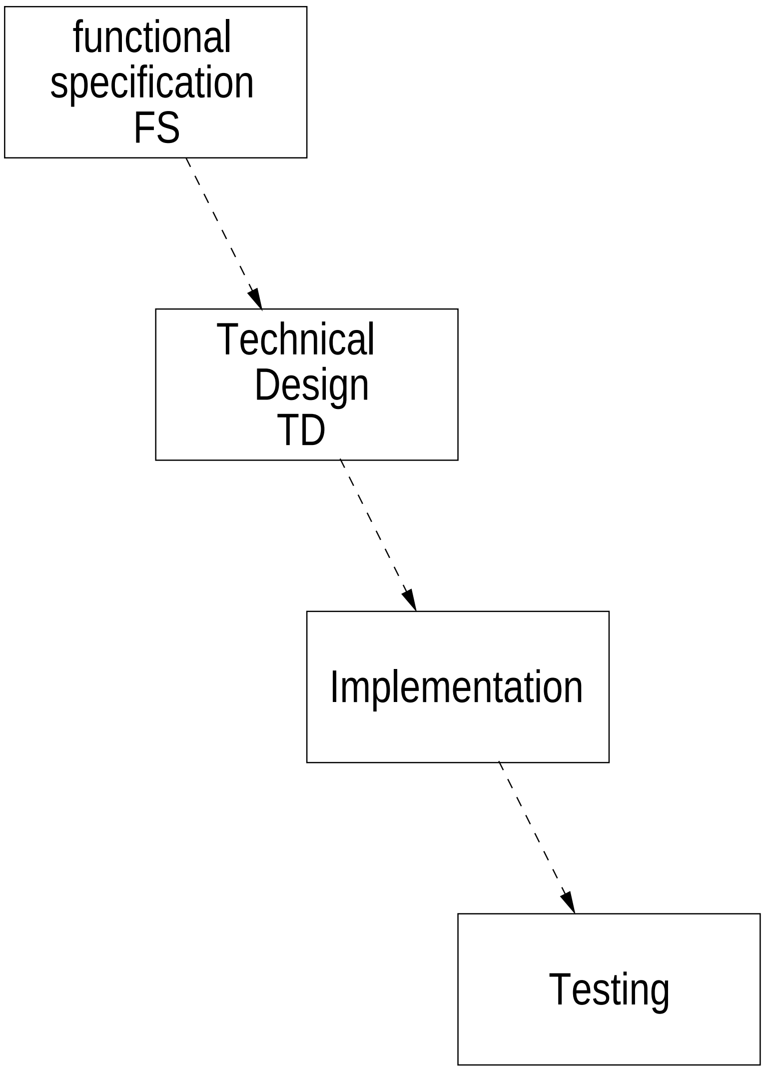
- Not all system components formally specified

- Difference formal model $\leftrightarrow$ reality

- Specification not formal

- Implementation and testing based on formal specifications but no formal derivation or proof

Development Trajectory



Myth 2

FM are about program proving

BOS: no program proved, but

- ∘ formal description of design
- ∘ model checking of some protocols

Result:

- process of formally specifying
  leads to early detection of errors
- precise, unambiguous, complete
- understanding, argumentation and simulation
- precise basis for implementation and testing

Early phases most critical;
implementation / testing no big problem

Myth 3

FM are only for safety-critical systems

BOS: safety-critical and FM used

Other systems:

- almost all systems critical –
  safety, economic, company image

- BOS experience:
  better quality with (almost) same costs

- lot of costs in learning

Myth 4

FM require highly trained mathematicians

BOS: software engineers can learn FM

- FM based on relatively simple mathematics
- No need to learn all mathematical background for using FM
- No complete proofs
  Model checking by few persons
- No mathematicians, please:
  - If they have a model they can calculate
    Problem: to get the valid model
  - they aim at "elegant" solutions
    not at practical ones
- Not mathematics of FM is difficult
  but learning effective usage in SE

Learning FM

- learning formal languages not difficult
- learning formal method difficult
- difficulties:
  - how to make models / level of abstraction
  - what to formalize and what not
  - how to manage FM
  - how to use the tools effectively
  - attitude and mentality change
  - developing specification styles / standards
  - developing coding techniques
  - developing reviewing techniques for FM
  - embedding in SE process
    integration with existing methods

Learning FM

- courses only to learn the formal language

- university knowledge restricted to formal language knowledge

- learning *usage* on the job

- potential conflict: learning ↔ project progress

- guru (hero) necessary

- potential conflict: guru task ↔ guru's task

- breaking point in thinking about FM:
  before break: FM are a burden
  after break: real benefits
  how did we ever manage without FM?

- not everybody likes FM

Myth 5

FM increase development costs

BOS: probably yes, a little bit

But:

- No real comparison: no non-formal BOS
- Much of costs in learning – first time costs
- More important:

  shift in costs
  from implementation and testing
  towards specification and design

Shift in Efforts

- Design phase more important and much longer

- Gain in implementation and testing

- Design more detailed

- Earlier detection of problems / defects
  "first think and then build"

  In principle, independent from FM
  but without FM easier to escape from it

- Difficult to measure / manage progress
  during design

- Planning of implementation and testing
  very precise

Myth 6

FM are unacceptable to users

BOS: user (RWS) was satisfied

- informal explanations of formal specifications are necessary
- simulation of formal models was very useful to show defects (SPIN with MSC)

Myth 7

FM are not used on real software

BOS: used successfully

And with a next, BOS-like system,
CMG will use FM —
and try to increase the level of formality

> *Dad, when you were young, were there really people who developed their software without formal methods ?*
> *How did they manage ?*

Benefits & Costs

+ better software quality
+ more preciseness
+ problems and defects earlier detected
+ better basis for testing
+ no major problems found during testing
+ better planning of implementation and testing phase
+ efficient reviewing of code based on formal design with uniform style
+ estimated better maintainability (if FM specs kept up to date)

Benefits & Costs

- ◦ design phase longer;
  implementation and testing phase shorter

- ◦ increase in professionalization:
  good projects get better; bad projects get worse

- ◦ likely longer overall development,
  mainly due to learning

- – learning to make effective use of FM not easy

- – integration with current SE practice is weak

- – tool support is insufficient for large systems

Comparison with "Seven Myths"

Observations of Anthony Hall and BOS mostly agree

Minor differences of BOS w.r.t. Hall:

- distinction specification $\leftrightarrow$ design
- distinction specification $\leftrightarrow$ model
- FM not ideal for conceptual modelling and high-level structuring
- importance of tools:
  - learning
  - stimulating
  - check of specifications
  - model checking
  - but insufficient:
    - functionality
    - size which can be handled
    - integration with SE tools

Conclusion FM Usage

- FM do increase quality

- FM are usable in industrial context

- FM require some learning and adaptation, not completely off-the-shelf

Conclusion FM Research

- Not so much need for new FM theories
  but making existing FM theories
  better applicable

- Integration of data and process formalisms

- Better tools needed w.r.t. to size of models

- Integration within SE practice

- Bottle-neck in early development phases

- Proving code correct w.r.t. formal specification
  is not important

- Getting the formal specification is important

More about the Storm Surge Barrier:

http://www.minvenw.nl/rws/dzh/svk/engels/