Causes and Consequences of Pipeline Failure

2nd UKOPA Technical Seminar – “Managing the Risk from Pipelines Containing Hazardous Fluids”

Mike Acton, Principal Consultant

Overview

- Introduction
- Causes of Failure
  - Threats and defences
- Consequences of Failure
  - Consequence modelling and validation
- Incidents
  - Case studies
- Full Scale Tests

Introduction

ADVANTICA
A Germanischer Lloyd Company

- Major Accident Hazard pipelines have a good safety record in the UK
- Worldwide experience shows that serious incidents can occur
- Need to understand causes and consequences
- QRA techniques now well established
- Supplements provide framework to support risk-based decisions

Introduction

ADVANTICA
A Germanischer Lloyd Company

- Elements of pipeline risk assessment
  - Failure cause
  - Failure mode
  - Gas or liquid outflow
  - Dispersion or pool spread
  - Ignition
  - Thermal radiation, overpressure, flash fire, toxicity
  - Effects on people
  - Risk calculations

Causes of Failure

Threats to Pipelines

ADVANTICA
A Germanischer Lloyd Company

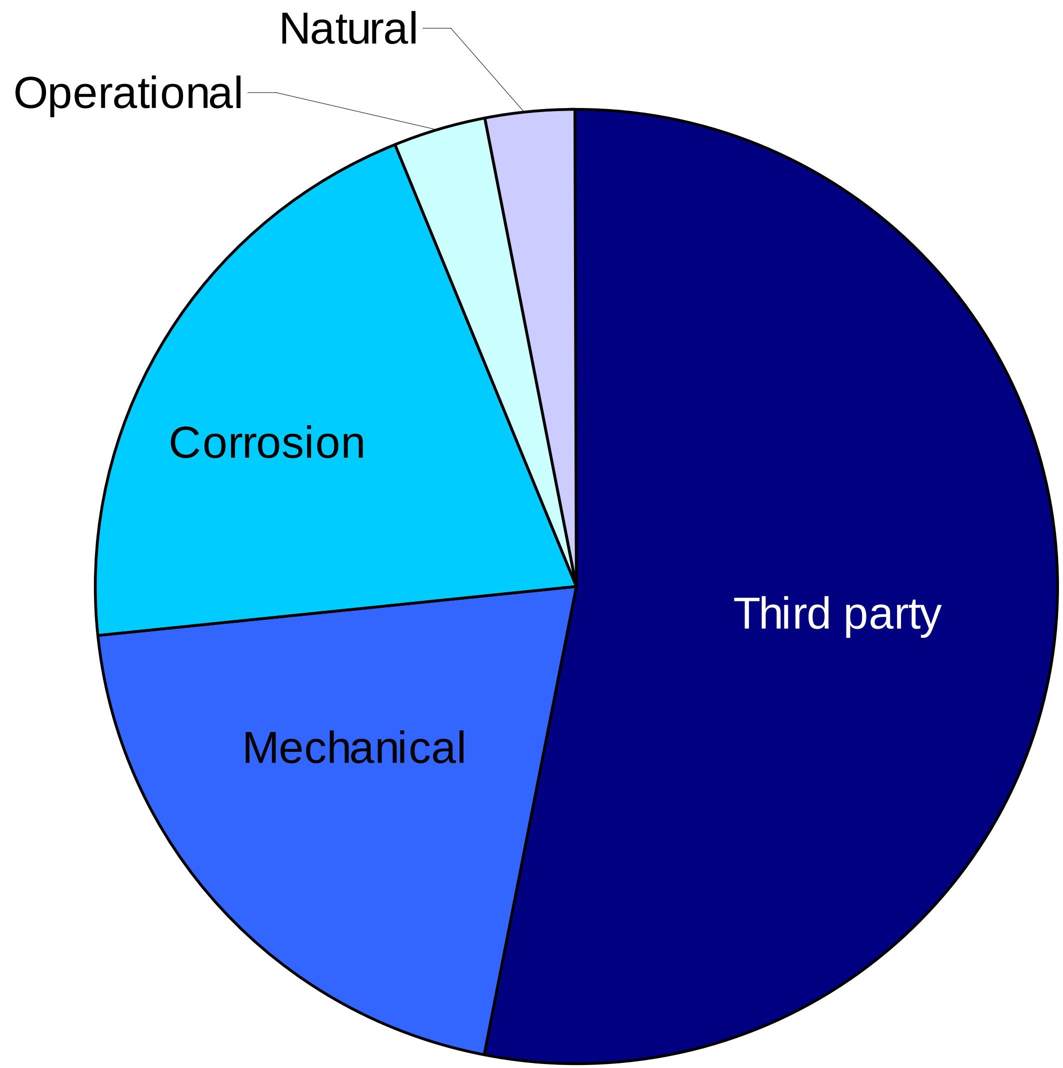
- External interference/impact
- Internal and external corrosion
- Material and construction defects
- Natural hazards
- Surge/overpressurisation
- Fatigue
- Sabotage and pilferage

- Failure modes
  - Leaks (punctures)
  - Breaks (ruptures)


Frequency by Cause (CONCAWE 2001- 2005)

ADVANTICA
A Germanischer Lloyd Company

- Typically historical failure statistics dominated by
  - Third party damage
  - Mechanical (material & construction)
  - Corrosion



External Interference

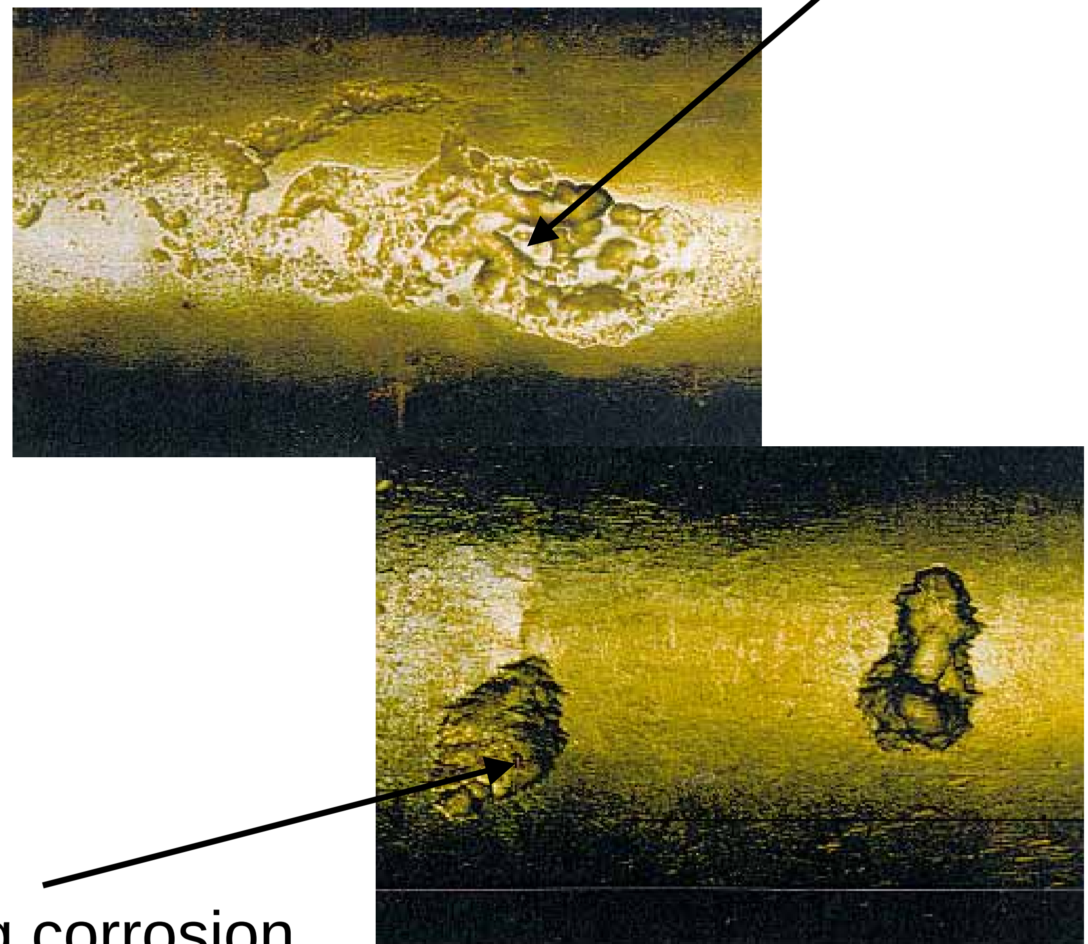
- Generally third party
  - 1st party damage also possible, e.g. during construction or maintenance
- Defences include a range of measures:
  - Pipeline design
  - Burial depth
  - Surveillance
  - Pipeline markers
  - Physical protection
  - Landowner liaison

Corrosion

ADVANTICA
A Germanischer Lloyd Company

- Range of mechanisms, e.g.
  - External corrosion
  - Internal corrosion
  - Stress Corrosion Cracking (SCC)
- Defences include:
  - Pipeline design
  - Pipeline coating
  - Corrosion management
  - In-line inspection
  - Cathodic protection

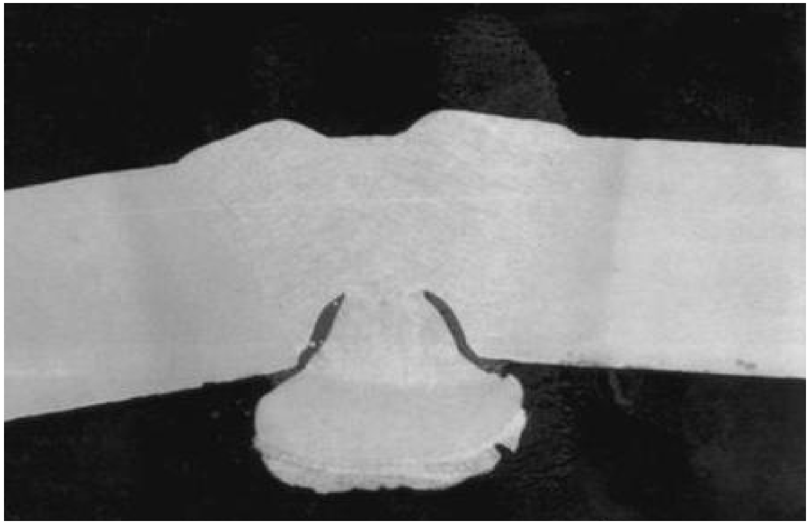
General corrosion

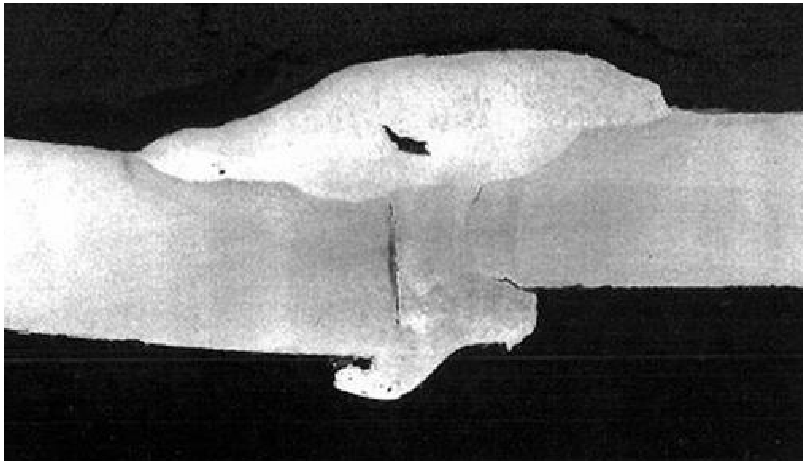


Pitting corrosion

Material & Construction Defects

- Historically a significant problem due to poor quality of steel and pipeline construction techniques
- Rare for modern pipelines systems due to
  - High quality steel
  - Quality control during pipeline fabrication
  - Improved welding and inspection
  - Hydrostatic testing





Natural Hazards

- Geotechnical
  - Landslide
  - Subsidence (natural and manmade)
  - Hydrotechnical
- Not generally a major issue for UK pipelines except in specific locations (e.g. former mining areas)

Consequences of Failure

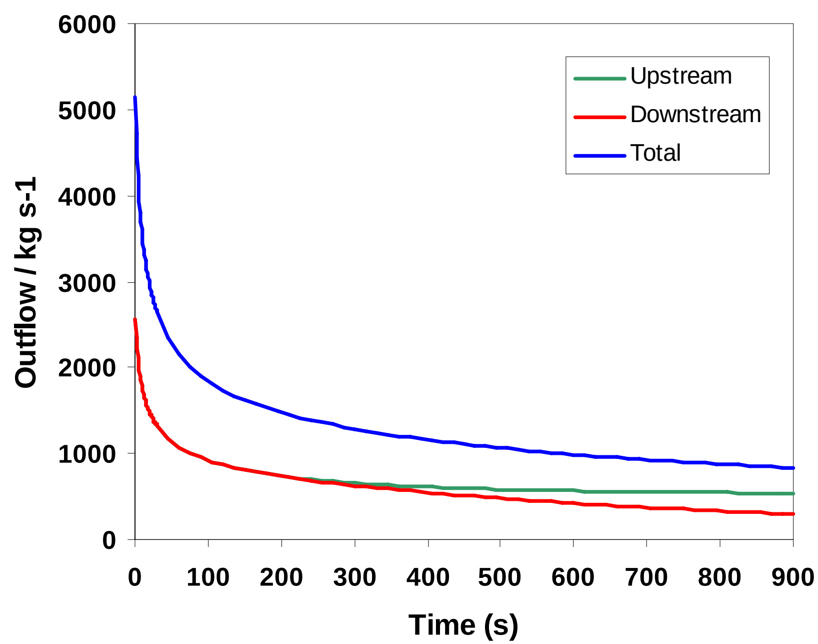
Consequences

- Behaviour and effects depend on fluid properties
- Source
  - Gas or liquid outflow
  - Exit conditions
- Dispersion, accumulation or pool spread
- Ignition
  - Immediate or delayed
- Fires (thermal radiation)
- Explosions (overpressure)
- Toxicity (poisoning)

Outflow

ADVANTICA
A Germanischer Lloyd Company

- Rapid depressurisation
- Crater formation
- Pipeline alignment
- Jet release (or releases)
- Initially transient
- Quasi steady at later times
- Decay rates determined by system



HP Natural Gas Pipelines

- Lighter than air and momentum-driven
  - Releases rise naturally into the atmosphere
- Immediate ignition
  - Transient “fireball” phase
  - Up to ca. 30 seconds duration
  - Followed by quasi-steady crater fire
- Delayed ignition
  - Quasi-steady crater (or jet) fire only

Dispersion – Liquid Pipelines

ADVANTICA
A Germanischer Lloyd Company

- Volatile liquids
  - Vapour denser than air
- Releases have relatively low momentum if impacted
  - Drifting cloud scenario if not ignited immediately

Ignition – Liquid Pipelines

ADVANTICA
A Germanischer Lloyd Company

- Immediate ignition produces jet fire
- Delayed ignition produces flash fire (and possible vapour cloud explosion)

- Sooty flames, high levels of smoke production
- Liquid rain-out and pool fire depending on composition of mixture

Explosions

- Pressure generated by:
  - Confinement
  - High speed flames
- High speed flames generated by congestion within gas cloud

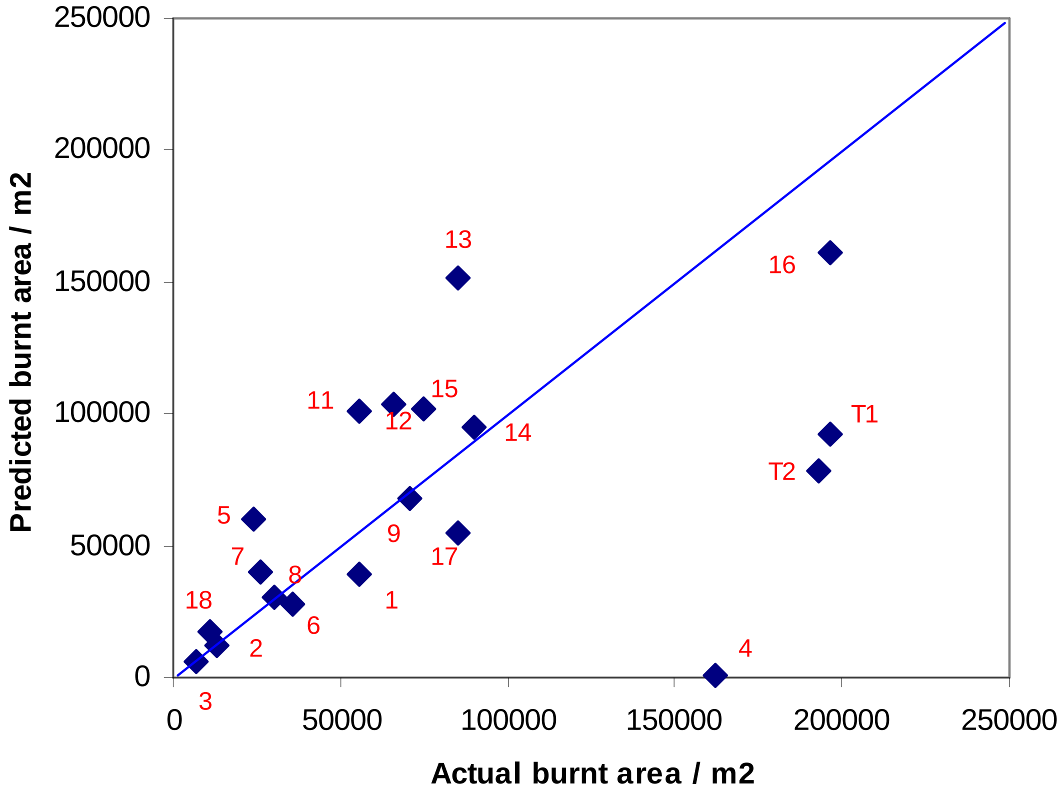
ADVANTICA
A Germanischer Lloyd Company

Model Validation

Validation - Incident Comparisons

ADVANTICA
A Germanischer Lloyd Company

- Predictions compared with documented incidents.
- Complications due to e.g.
  - Subjective nature of determining burnt area
  - Uncertainty due to fire spread
  - Wide spread in predicted and reported areas observed.



Validation – Large Scale Testing

- Consequence models developed from theoretical understanding and results from small scale tests
- Many processes scale dependent
- Validate at large scale
- Spadeadam Test Site

Validation – Full Scale Testing

ADVANTICA
A Germanischer Lloyd Company

- 76 km length
- 914 mm pipeline (36”)
- 60 bar (880 psi)
- 200 instruments deployed
  - Weather
  - Gas outflow
  - Size and shape of resulting fire
  - Thermal radiation levels
- Maximum flame heights 500 m
- Paper presented at IPC 2000

A Full Scale Experimental Study of Fires Following the Rupture of Natural Gas Transmission Pipelines
M. Acton, G Hankinson (Advantica), J Colton, M Sanai (SRI int), B Ashworth (TransCanada PipeLines)

Pipeline Incidents

Belgium, 2004, 40" Natural Gas Pipeline

ADVANTICA
A Germanischer Lloyd Company

Mechanical damage caused by construction machinery (multiple gouges)

24 fatalities, >200 injuries

Majority of fatalities – emergency services and construction personnel

Majority of injuries – people stranded in vehicles on nearby road

Belgium, 2004, 40” Natural Gas Pipeline

Belgium, 2004, 40” Natural Gas Pipeline

Belgium, 2004, 40” Natural Gas Pipeline

Belgium, 2004, 40” Natural Gas Pipeline

ADVANTICA
A Germanischer Lloyd Company

Type of machine which may have caused damage

Bellingham, 1999, 16” Gasoline Pipeline

ADVANTICA
A Germanischer Lloyd Company

Rupture of damaged pipeline (gouge)

Release of 0.25 x10^6 gallons of gasoline

Delayed ignition of release

3 fatalities, 8 injuries

Bellingham, 1999, 16” Gasoline Pipeline

THE NATION'S NEWSPAPER

USA TODAY

NO. 1 IN THE USA . . . FIRST IN DAILY READERS

When pipelines are time bombs

2 million miles of them deliver potential catastrophe every day

June 10, 1999: Three boys were killed in Bellingham, Wash., when a river of fuel exploded.

ADVANTICA

A Germanischer Lloyd Company