# Pipeline Stress Analysis

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IBC

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## Introduction

- **Introduction to Stress Analysis**
- **Pipeline Design Codes and their requirements**
- **How the software handles Buried Pipeline**
- **Anchor Design**
- **Stress Analysis Formulae and Load Cases**
- **Additional Construction & Operation Stresses**
- **Hot Pipeline Design**
- **Pipeline Failures**

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# Stress analysis design

- **Stress analysis is a check on pipelines after initial determination of route and wt from other requirements, Design pressure etc.**
- **Typically uses max operating temps, not design.**
- **"As laid" ground temperature can become crucial to get correct.**
- **Above 50 Deg C,use of thin wall design or CRA pipe it has become increasingly important.**

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# Stress failure

**Excess stress leads to failure. Picture shows a “mash buckle” – failure in compression.  Many failures occur due to fatigue or at bends and crossings where one part of the pipeline is fixed.**

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# Buried pipeline stresses

- **Buried pipelines are subjected to multiple stresses:**
- **Internal pressure (hoop stress)**
- **External pressure (roads, soil loads, water)**
- **Axial stress from pressure (Poissons ratio)**
- **Axial stress from expansion / contraction**
- **Bending stress – elastic bends, concentration of loads at bends**
- **Stress analysis looks at combinations**

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# Data required

- **Key data required**
- **Line pipe properties (size, wt, bend radius)**
- **De-rating factors (especially Duplex)**
- **Design and operating conditions (P & T)**
- **Soil properties inc friction soil / pipe**
- **Thermal expansion – as laid temperature**
- **Soil modelling (spring/ restraint)**
- **As laid conditions**

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# Allowable Stress

- **Allowable stress combines hoop stress from pressure, shear stress from loadings and axial stress from temperature loadings and end cap forces.**
- **Allowable stress calculated using von Mises assuming third principal stress is negligible (no torsion)**
- **$Se=(Sh^2 + Sl^2 - ShSl + 3T^2)^{1/2}$**
- **Se=0.9 for IGE TD/1, ISO 13623, EN 14161**
- **Se = 0.72 EN 1594**

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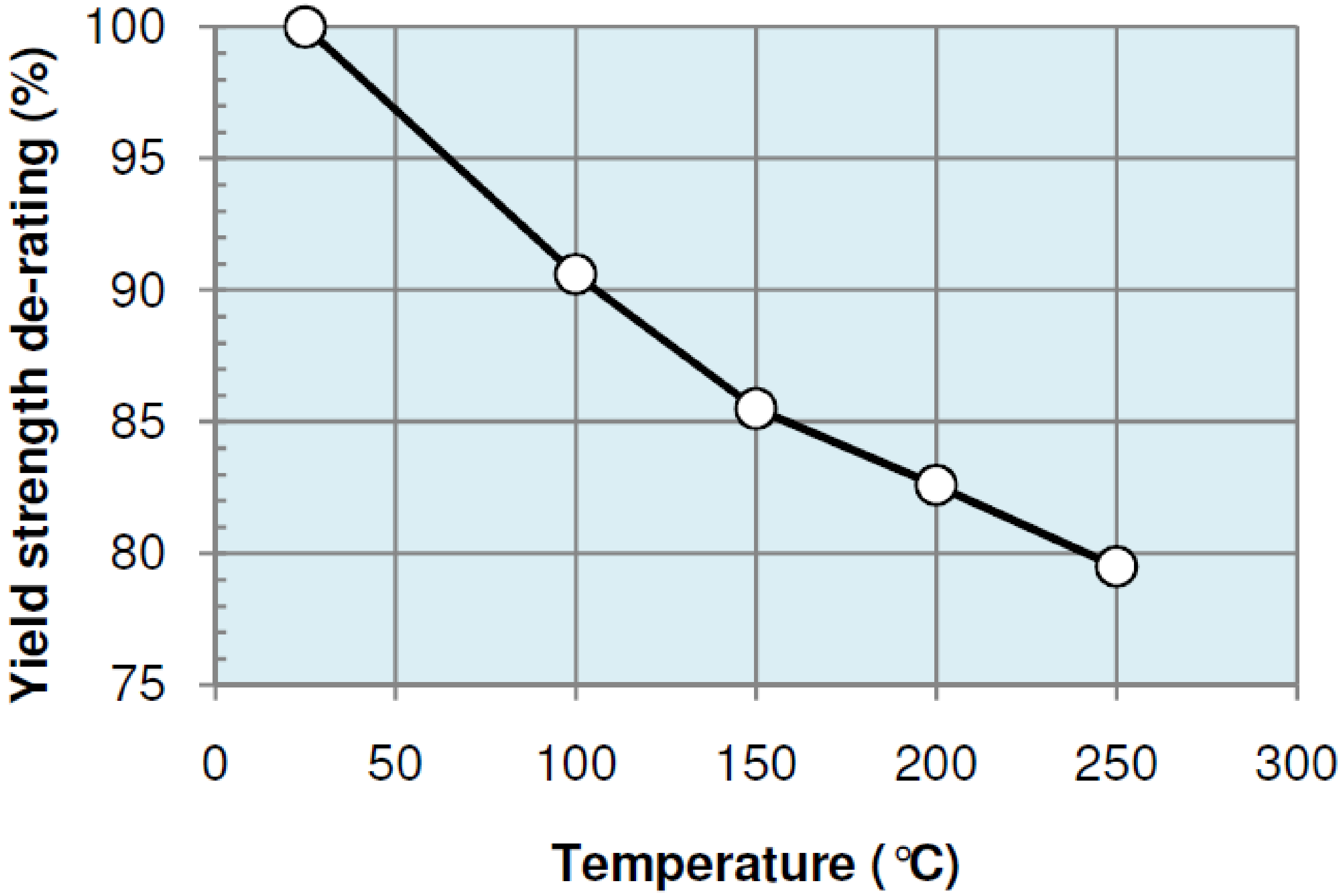
# Stress calculation

- **Equivalent stress is treated differently in the ASME codes which consider stress for restrained and unrestrained lines and bending moments from tees and other connections.**
- **ASME B 31.4 - unrestrained lines - 0.72 S, restrained lines - 0.9 S.**
- **Hydrotest can be 1.0 or 1.05 SMYS**
- **Notional anchors and end movements need to be calculated using soil friction factors, pipe size and overburden. Commonly lengths range from 80 to 200 m.**

# Material strength - Duplex

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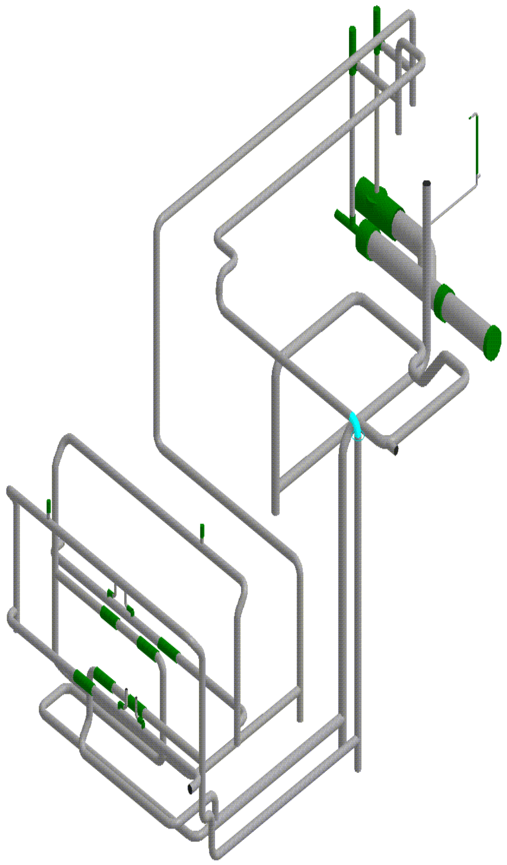
- Pipelines are modelled as straight pipe with bends supported on “springs”
- Soil models incorporate elastic and plastic deformation as springs
- Elements - bends, tees, valves modelled as individual elements



# Software available

- **Auto PIPE Plus**
- **Ceaser II (Intergraph)**
- **CAEPIPE (SST 1983)**
- **ROHR2 German 1960's**
- **Triflex.R (Windows)**
- **PSA 5 (Early Nuclear)**
- **Stroomwezen (Dutch)**

# Analysis cases

- **Stress analysis cases should include:**
- **Hoop Stress**
- **Hydrotest case (esp gas)**
- **Operating case Pressure**
- **Operating case Pressure and Temp**
- **Occasional loads without temp**
- **Solar heating empty**
- **Tee connections (buried or anchored)**

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# Sequence of design

- **Sequence of calculations**
- **Obtain data and cases**
- **Simple restrained and un restrained calculations**
- **Stress analysis using analysis software**
- **Anchors and virtual anchors**
- **Bend stress analysis**
- **Mitigation**

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# Restrained pipelines

- **Operating pipelines are subject to longitudinal stress which results from a combination of the Poisson effect if fully/partially restrained (associated with internal pressure) and thermal expansion or contraction.**
- **Other loads may contribute to longitudinal stress, e.g. bending, weight.**
- **For totally restrained sections, the longitudinal tensile stress resulting from temperature or pressure change alone, this is:**

- **SL = [E.α. (T2 – T1)] – *v*.Sh (-ve equals tension)**

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# Restrained pipelines

- **E for Carbon Steel = 210 x $10^9$ Pa**
- **a for carbon steel is between 11.5 to 14 x $10^{-6}$ /Deg C. – ASME B 31.4 quotes 11.7**
- ***V* = 0.3 Poissons ratio for steel**
- **100 bar, 24” L415 (X60), 10.3 mm wt pipeline no temp change, $S_L$ = -88 MPa from Poissons effect,**
- **Delta T of 36 C required to reduce Logitudinal stress to zero if no other forces present.**

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# Bending

- **Bending stress has a large impact on equivalent stress and longitudinal stress.**
- **Need to add and subtract to see which is worse on inside or outside of *elastic* bend.**

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# Critical areas to study

- **Key issue for most pipelines is at bends, road crossings, anchors & connections where longitudinal movement or forces can result in large stress concentrations.**
- **Bends often move against the soil restraint and can yield.**
- **Requires the use of analysis programs**
- **Check and determine all parameters used**
- **Care needed for long straight pipelines**

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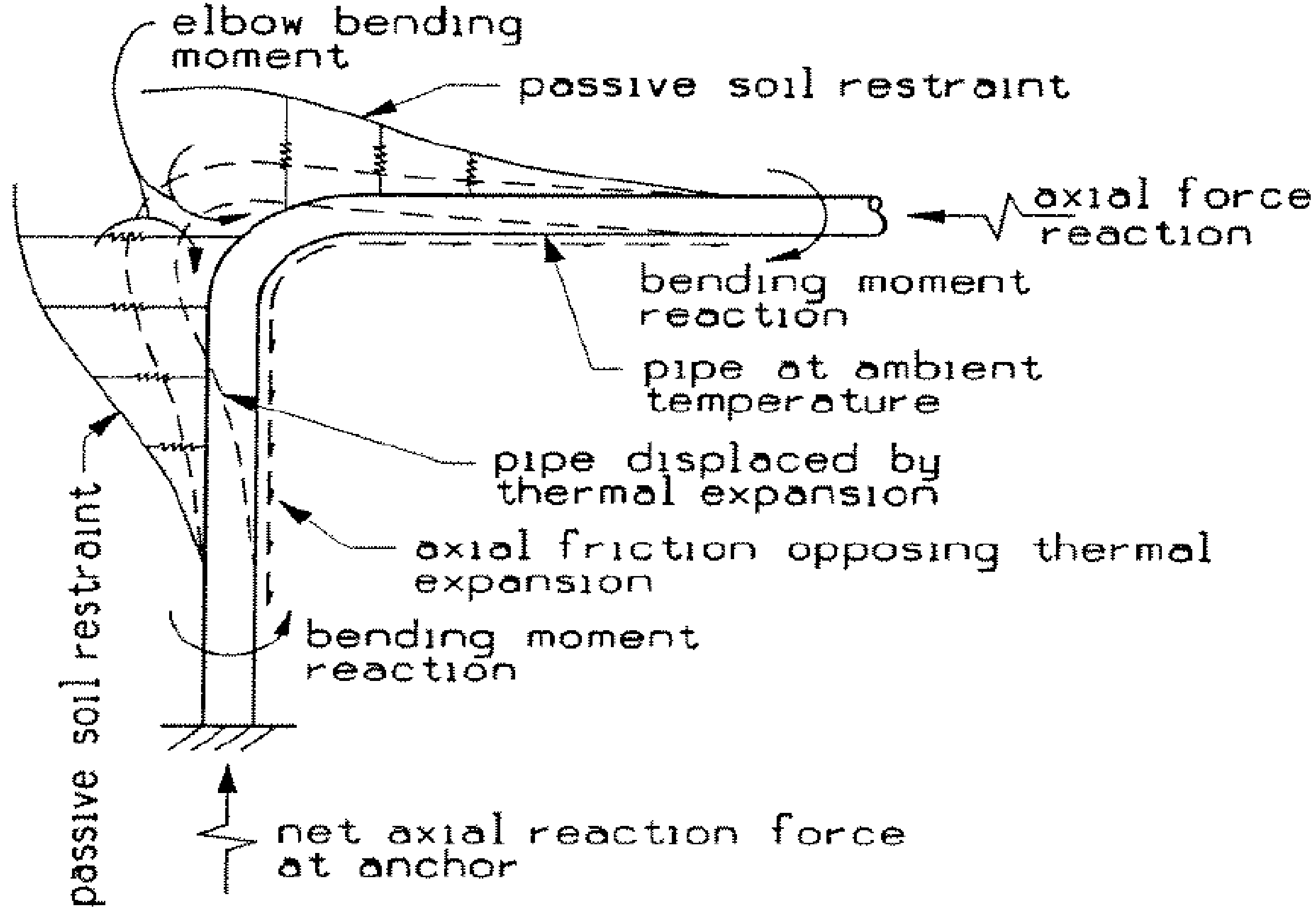
# Pipeline bend

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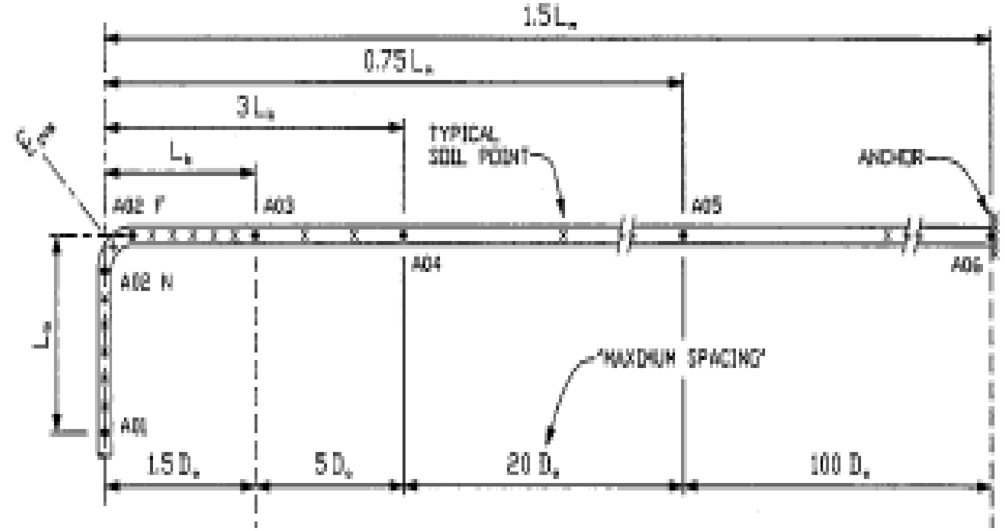
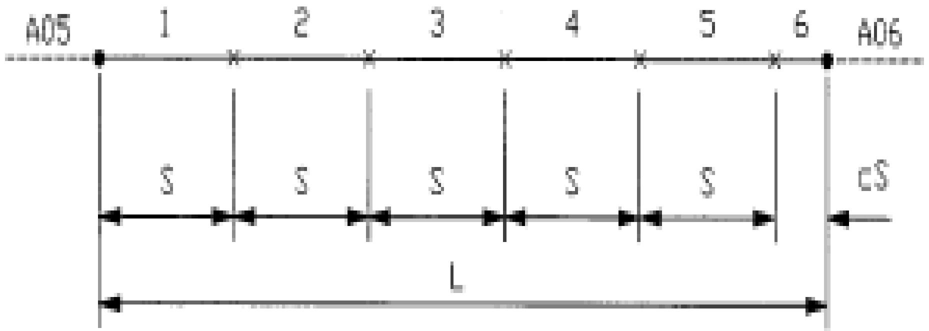
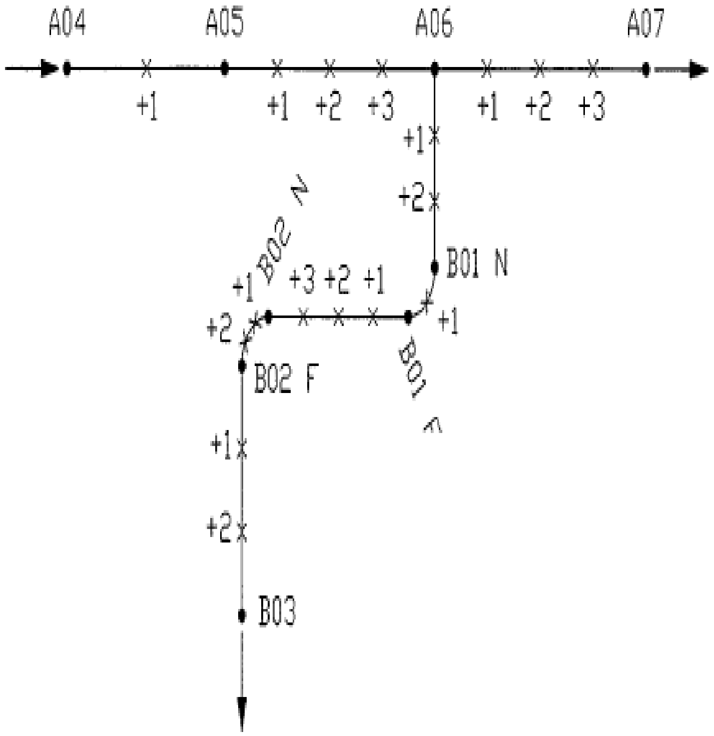
# Analysis Node density




Too many node points makes very large computer models
Thin distribution in zone 3

Analysis Critical Locations

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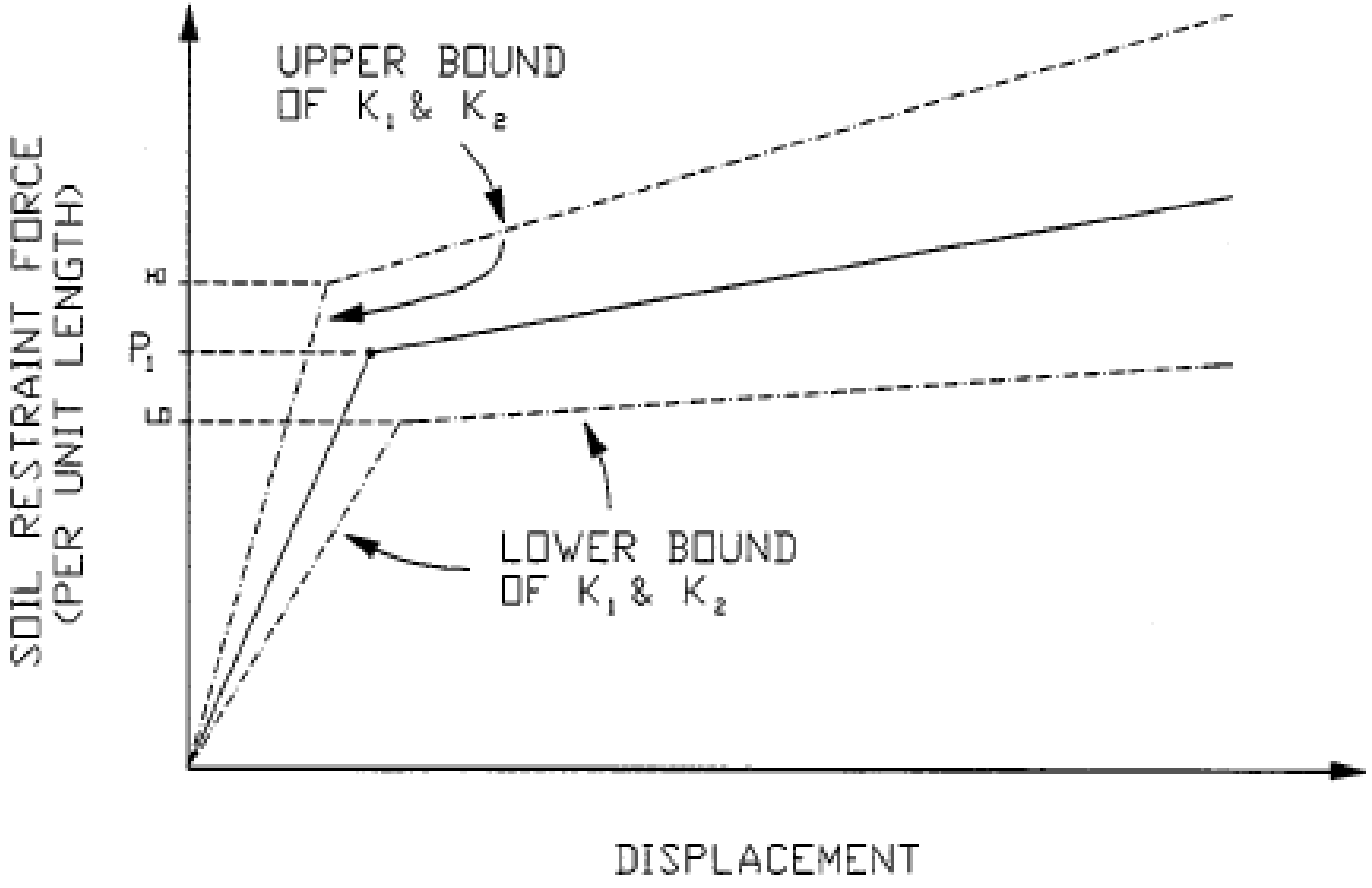
# Soil properties

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# Options for excess stress

- **Over stress options**
- **Reduce operating temperature**
- **Increase wall thickness at bends / high stress**
- **Pre-heat pipeline prior to backfill**
- **Increase as laid temp (summer)**
- **Increase bend radius to 40D**
- **Introduce more bends (e.g. 2 x 45, Z spool)**
- **Allow acceptable strain**

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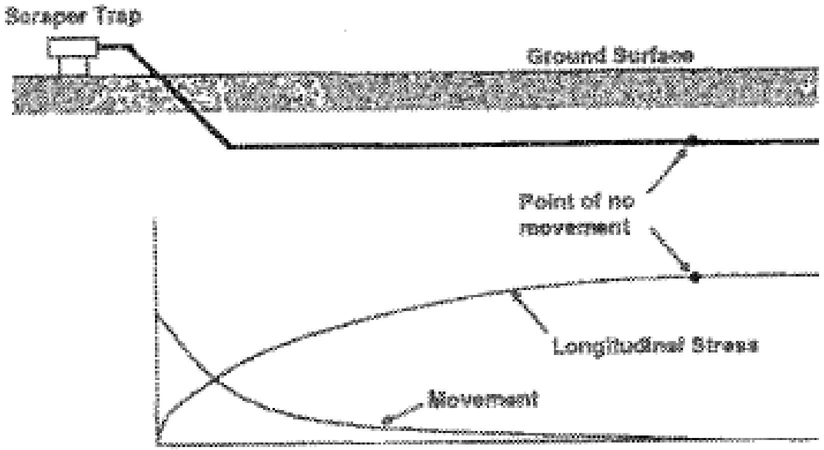
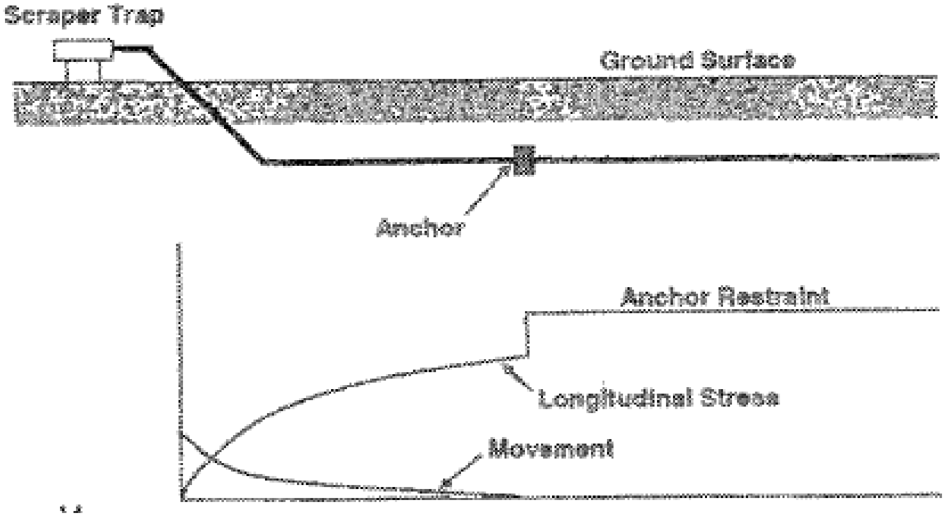
# Anchor design

Anchors should normally be avoided by good design and flexibility in the above ground piping. Anchors do not remove stress and movement and are frequently not required.  Amount of movement is usually low, but anchors forces can be very high.



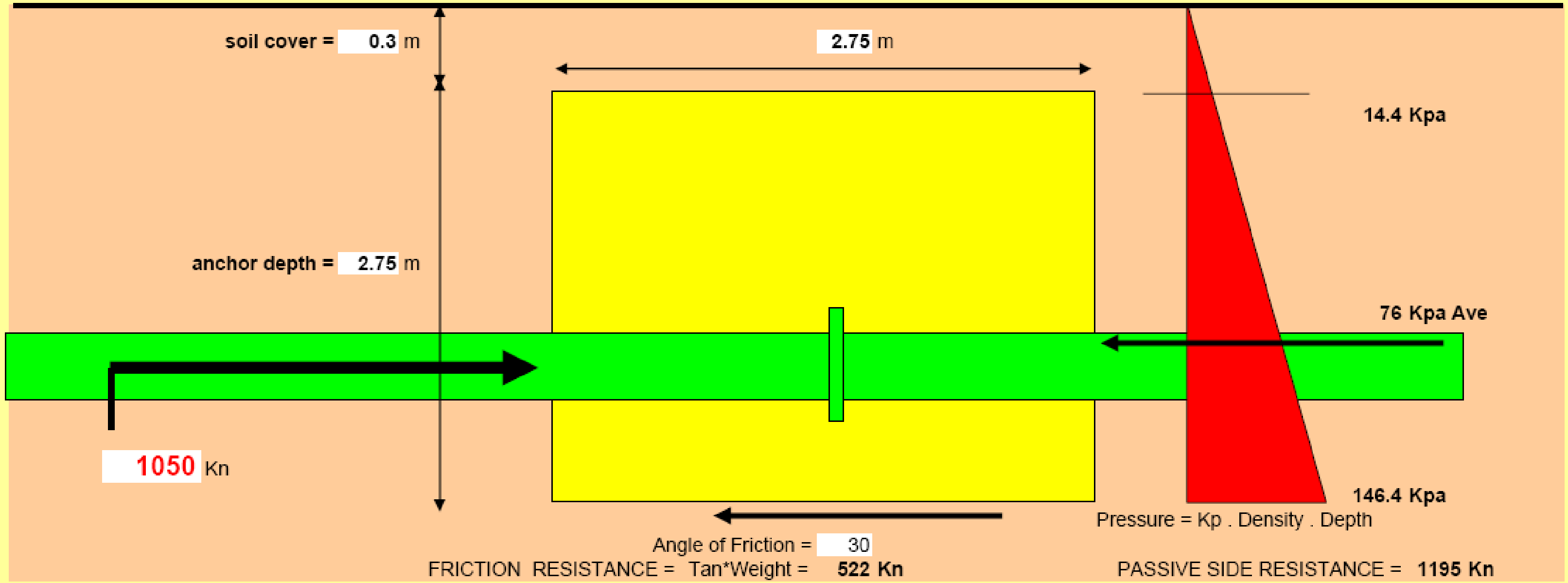



# Concrete anchor

## ANCHOR BLOCK DESIGN

Length of Footing perpindicular to Pipeline = 5.75 m
Weight of Footing = 1044 m

Soil Density = 16 Kn / mcub
Kp = 3




FACTOR OF SAFETY = RESISTANCE from SOIL / APPLIED FORCE

**FACTOR OF SAFETY = 1.635 > 1.5 Therefore OK**

POSITION OF PIPELINE WITHIN FOOTING = 1.98433 m from top of footing

| | | |
|---|---|---|
| 1195 | 0.334 | 400 |
| 521.8125 | 0.766 | 400 |

# High temp issues

- **SYMS derating affecting wall thickness**
- **High operational stresses**
- **Upheavel buckling**
- **Pipeline walking / Axial ratcheting**
- **Anchor / expansion spools**
- **Stresses at bends (Horizontal and Vertical)**
- **Profile limitations**

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# Road and rail crossing design

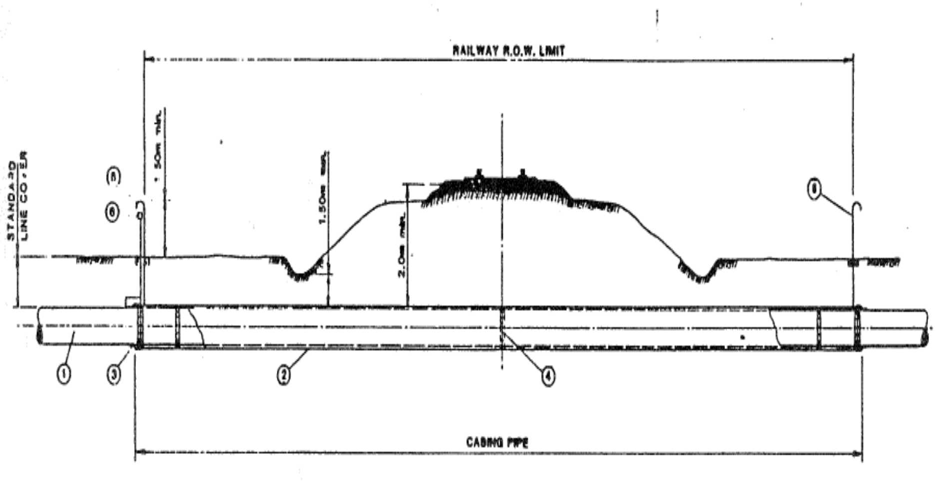
**Design to API RP 1102 – conservative equivalent stress**

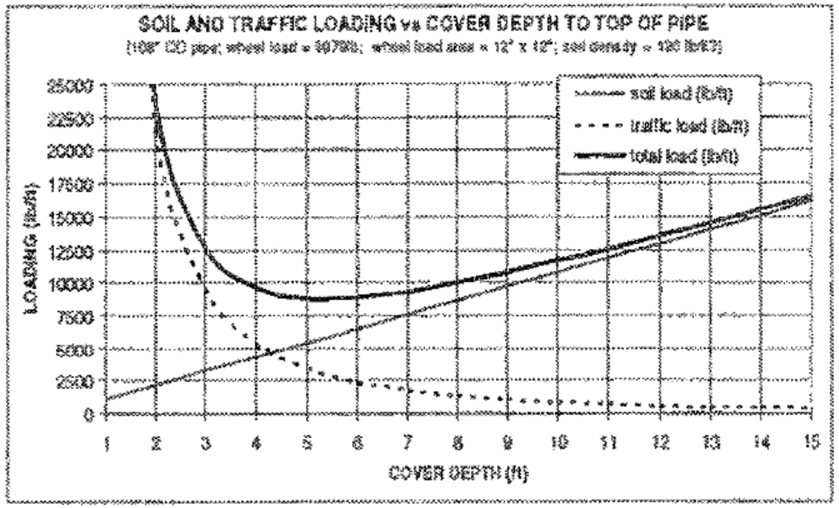
**Determine the**

- **Optimum wall thickness,**
- **Burial depth**
- **Installation techique.**

**Alternatives available for heavy farm machinery**

**The consequences of pipeline failure at crossing is very expensive**



# Upheaval buckling

- **More commonly seen offshore and in desert conditions**
- **Generally affects hot gas lines d/s of compressors or wellheads**
- **Requires initial imperfection in pipe**
- **Temperature less than 60 degrees C rarely cause problems.**
- **Increased burial or weight coating can solve issues.**

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# Upheaval buckling in sand

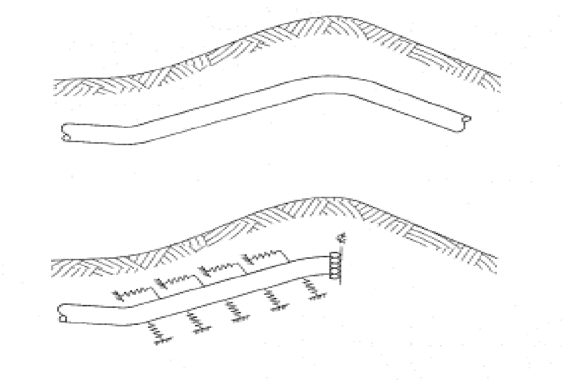
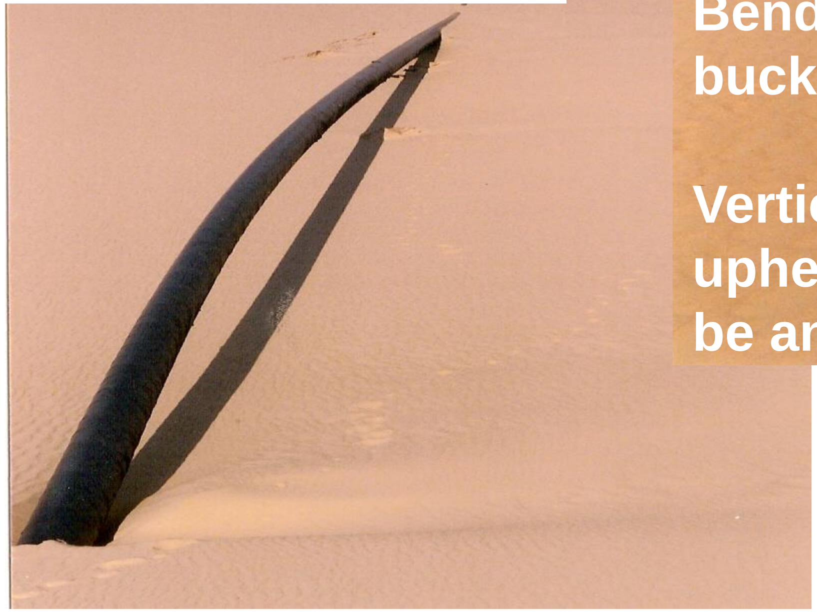


Figure 9.1-1 Model of Overbend



**Bends are susceptable to upheaval buckling**

**Vertical field bends are potential upheaval buckling points, all should be analysed**

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# Buoyancy

**Buoyancy is when volume of pipe displaced is greater than weight of pipe**
**Assume water**
**Margin is usually 1.1**
**Weight of soil is normally sufficient to keep pipe underground unless soil is very weak or waterlogged**
**Construction issues need to be studied (open trench)**

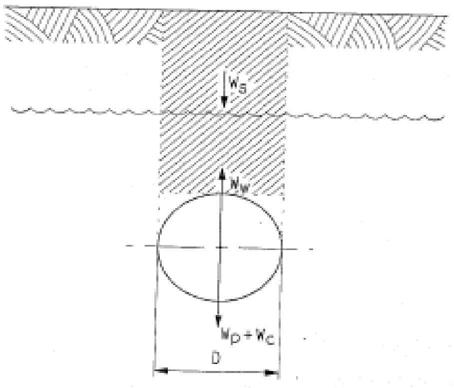


*Figure 6.1-1 Resultant Buoyancy Load on Pipe*

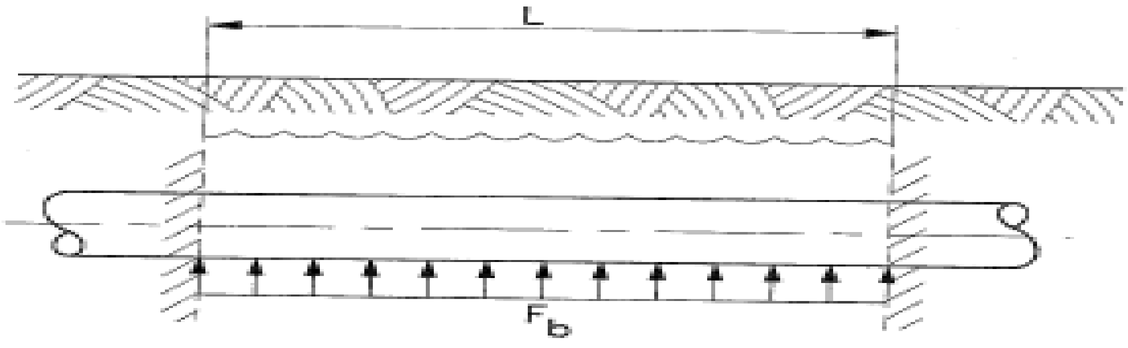


*Figure 6.1-2 Distributed Buoyancy Load on Pipe*

# Blasting

- **Pipeline stresses due to blasting can be calculated using the AGA method for stand-off distances up to 30m,**
- **Use the Morris method for Greater stand-off distances.**

- **To assess the impact of blasting new pipeline trenches on existing structures, it is usual to calculate the peak particle velocity (PPV):**

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# Post installation analysis

- **Post installation analysis is required**
- **Critical stress location may need strain gauges and monitoring of movements / cycles**
- **Requirement for complete As built data**
- **Minimum Profile (X,Y,Z)**
  - **Location of field bends (HORIZONTAL AND VERTICAL)**
  - **Pipeline data books (Wwith tie-in dates, temp, etc)**
  - **Burial depth**

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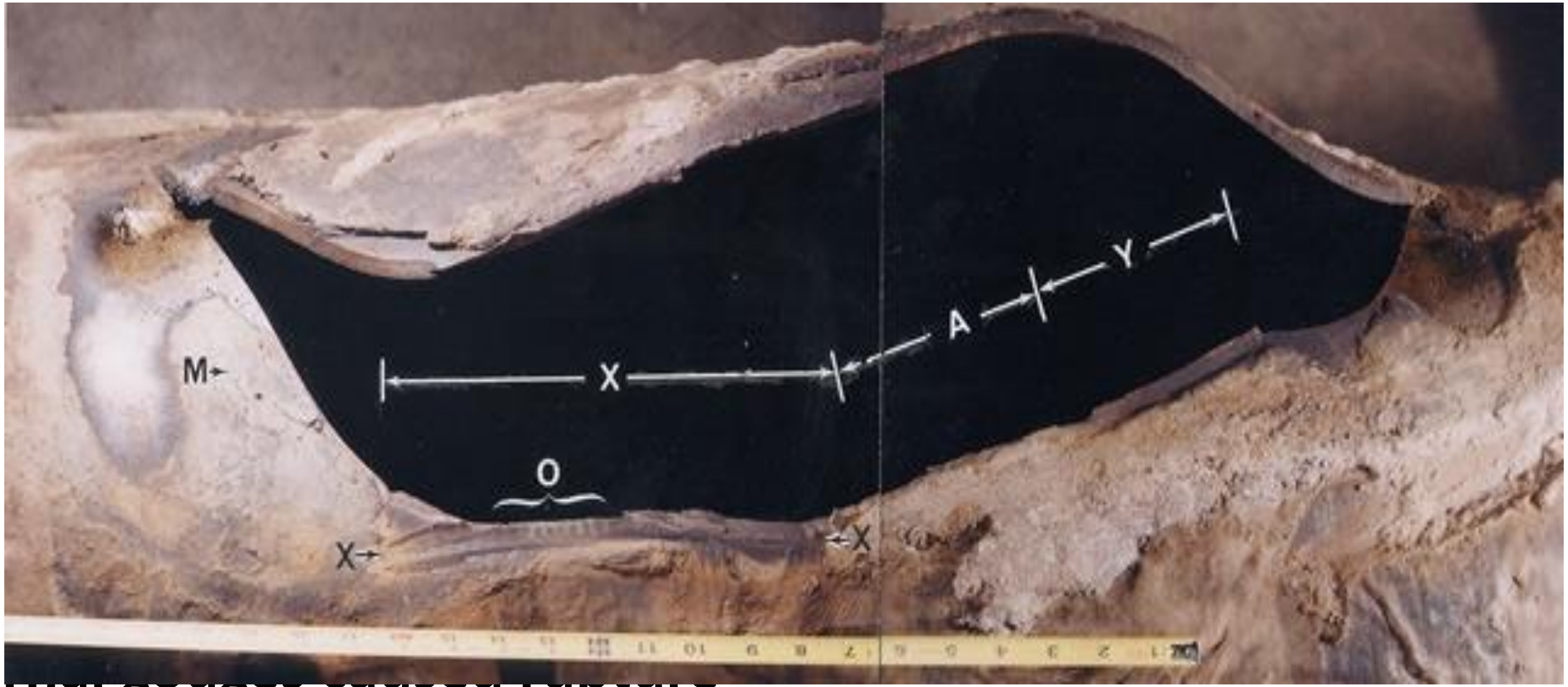
# Failures and installation errors




- **External gouges caused rupture**

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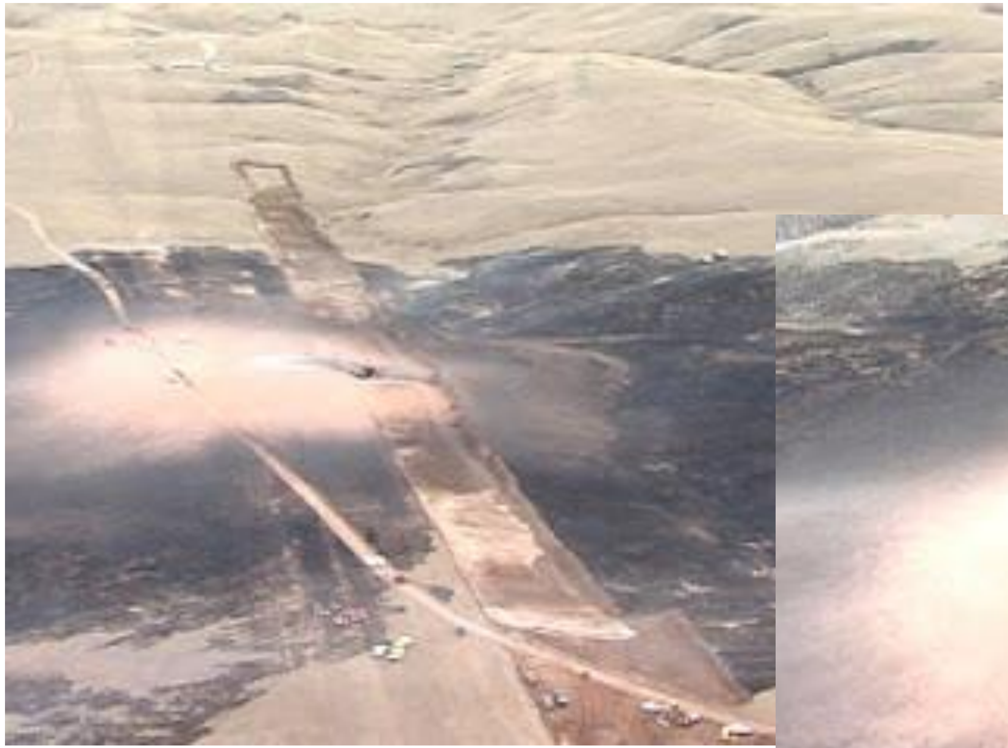
# Gas pipeline failure - USA



# Failure to locate pipeline

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# Shooting above ground section

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# Summary

- **Stress analysis required to check stresses imposed by pressure, temperature, imposed loads and bending**
- **Stresses highest at bends & connections**
- **Restrained pipelines common**
- **Hot pipelines require special attention – upheaval buckling, ratcheting, overstress**
- **Blasting**

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# Thank You

Any questions?

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