Free Spanning Pipelines

Discussion Session

Strudel Scour in Beaufort Sea

presented by

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Content of presentation

- Description of Strudel Scour
- Environmental processes
- Physical aspects
- Statistical information
- Impact on pipeline design
- Case studies from Beaufort sea

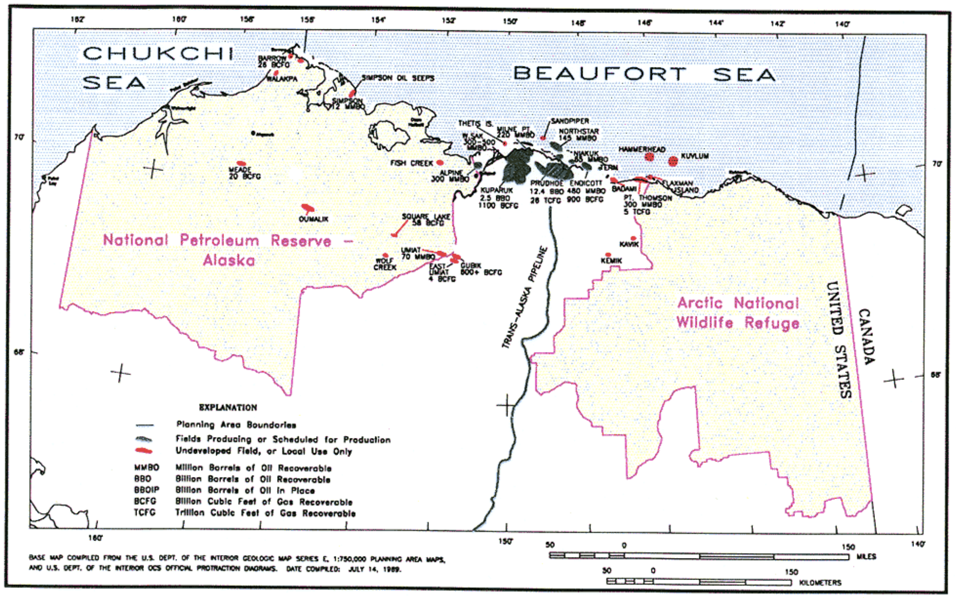

Figure 1: Map showing petroleum deposits of northern Alaska.

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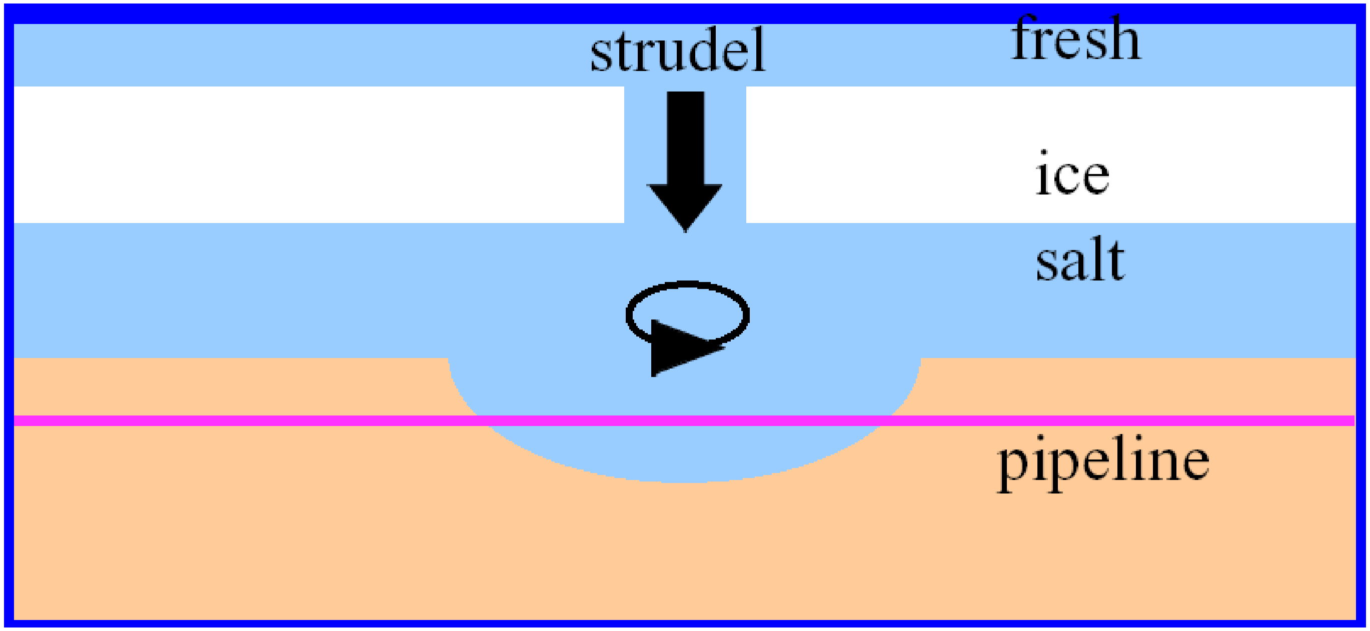
Strudel scour

- Strudel (German) → Whirlpool
- Strudel scour is a localized, seasonal phenomenon that occurs in the spring when melting fresh water in rivers and streams flows into the Beaufort Sea and out over the surface of frozen shore-fast ice.
- When this water makes its way under the ice, the resulting velocity and volume of water can be so great that a hole can be "scoured" into the seafloor.



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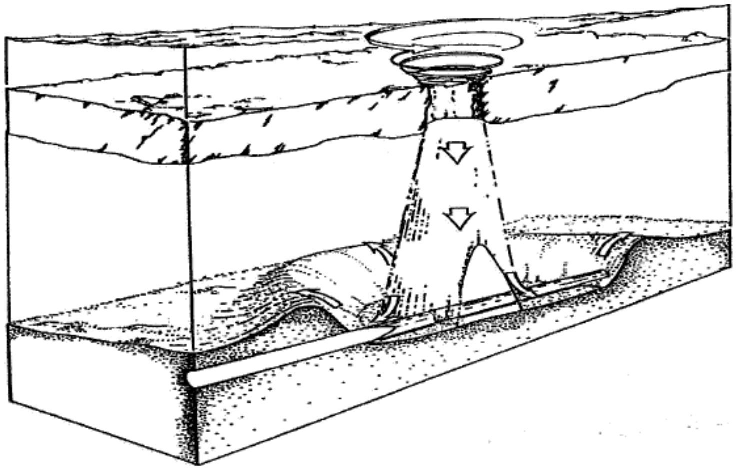
Strudel Scour

- Circular scour
  - Can start from cracks and seal holes on ice
- Linear scour
  - Mainly from linear drainage through cracks
- Areal scour
  - A series of strudel scours along a ice crack form a broader crater (as compared to single strudel craters)



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Environmental Process influencing Strudel Scour

- Snow pack thickness on land
  - Cannot be used directly to predict the river discharge
- River discharge
  - Statistical quantification is available for some river flooding
- Landfast ice thickness
  - Velocity of ice draining through the ice, partly depends on ice thickness
- Grounded ice ridges & rubble fields
  - Limited data exists to quantify the effect
- Ice jams
  - For example, in 1998 an ice jam in the East channel (Sag river) redirected the discharge to the West channel
- Flood date
  - Typically occurs in late May and early June and precedes the break-up of the ice in the nearshore area.
- Flooding extent
  - Areal extent of flooding can vary dramatically year-to-year (can be as large as 10 miles!)

Environmental Process influencing Strudel Scour

- Flood depth & volume (very important)
    - Weight of flood water will depress the level sea ice sheet & can create additional holes/cracks.
    - Volume of flood water controls the duration of scour process
    - Depth of flood water provides the hydrostatic head → influences the water jet speed
    - Distance from the shore (thicker near shore)
- Drainage features
    - Existing no. of cracks, fissures, seal holes, etc.
    - Observations (so far) suggest that both drainage features & flooding need to be concurrently present.
- Wind effects
    - Influences the location and extent of flood water
    - And also the in-filling of relic strudel scours
- Frazil ice
    - Decreases the flow velocity, but increases the scouring strength

What can limit the Strudel Scour?

- Small drainage → Weak jets
- Too deep locations
- Scour resistant soil types
- Bottomfast ice in shallow waters can prevent drainage

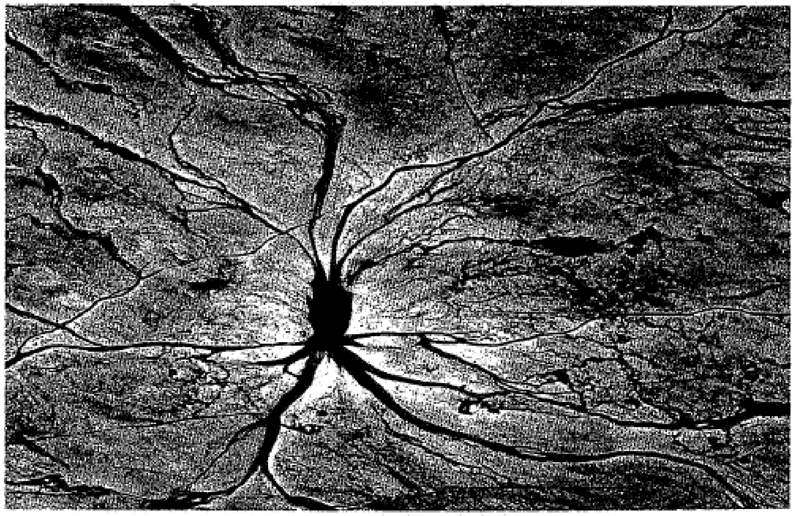


Figure 1.11. Circular Drainage Feature on the Ice Showing Strudel Formation (Reimnitz and Kempema, 1982)

Design Strudel Scour

- Site specific
- Highly localised

Example: Liberty Development Project

Water depth: 0 to 22 feet

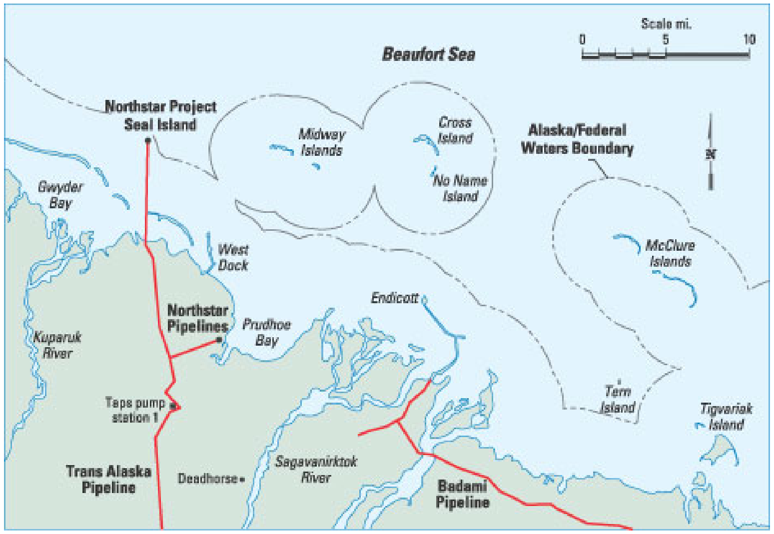
Ice thickness: 6 to 7.2 feet

Circular drainage: 1 to 20 feet

Linear drainage: up to 4500 feet

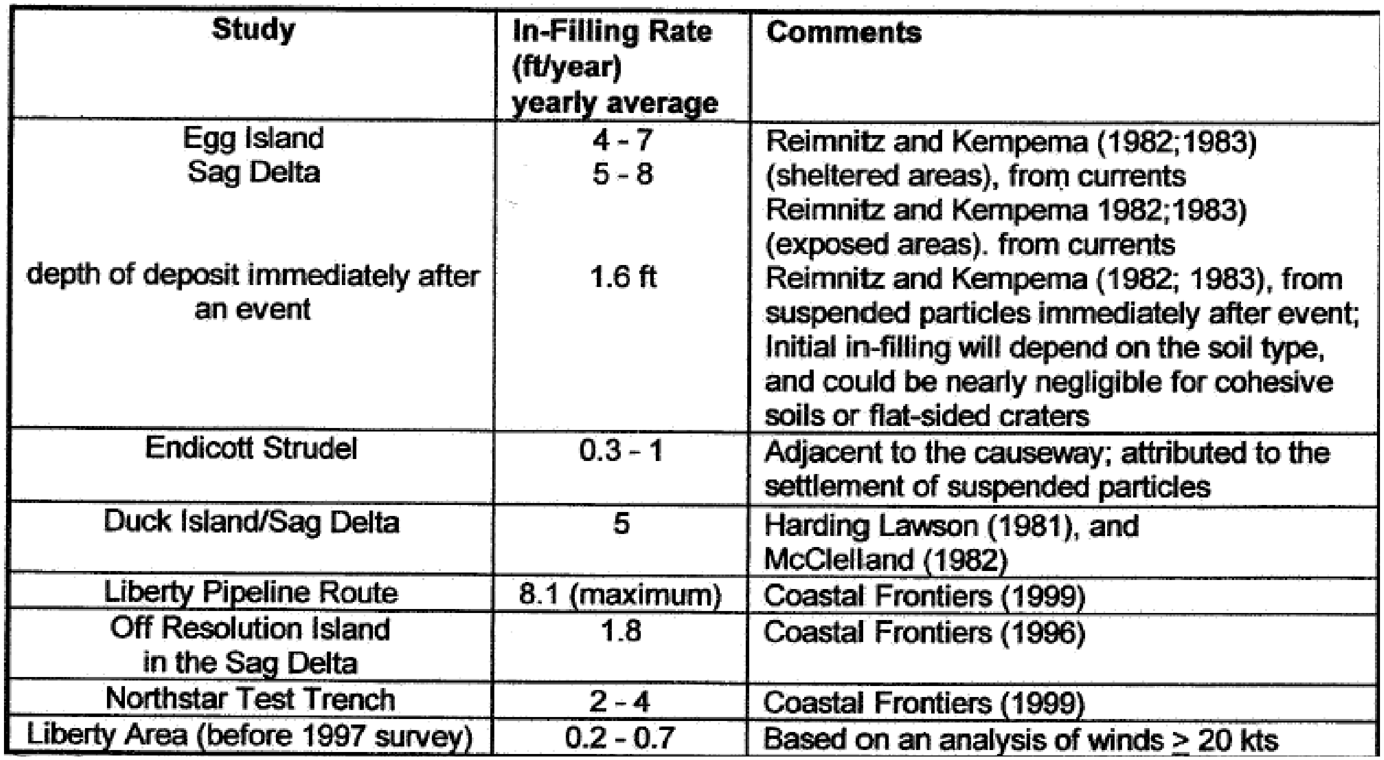
Flood water thickness: 1 to 5 feet

Flood extent: 0 to 3.3 miles



In-filling

- Immediately after the creation due to settlement of partciles in the suspension or the slumping of the walls
- In weeks, months or years after the creation, by action of waves & current.

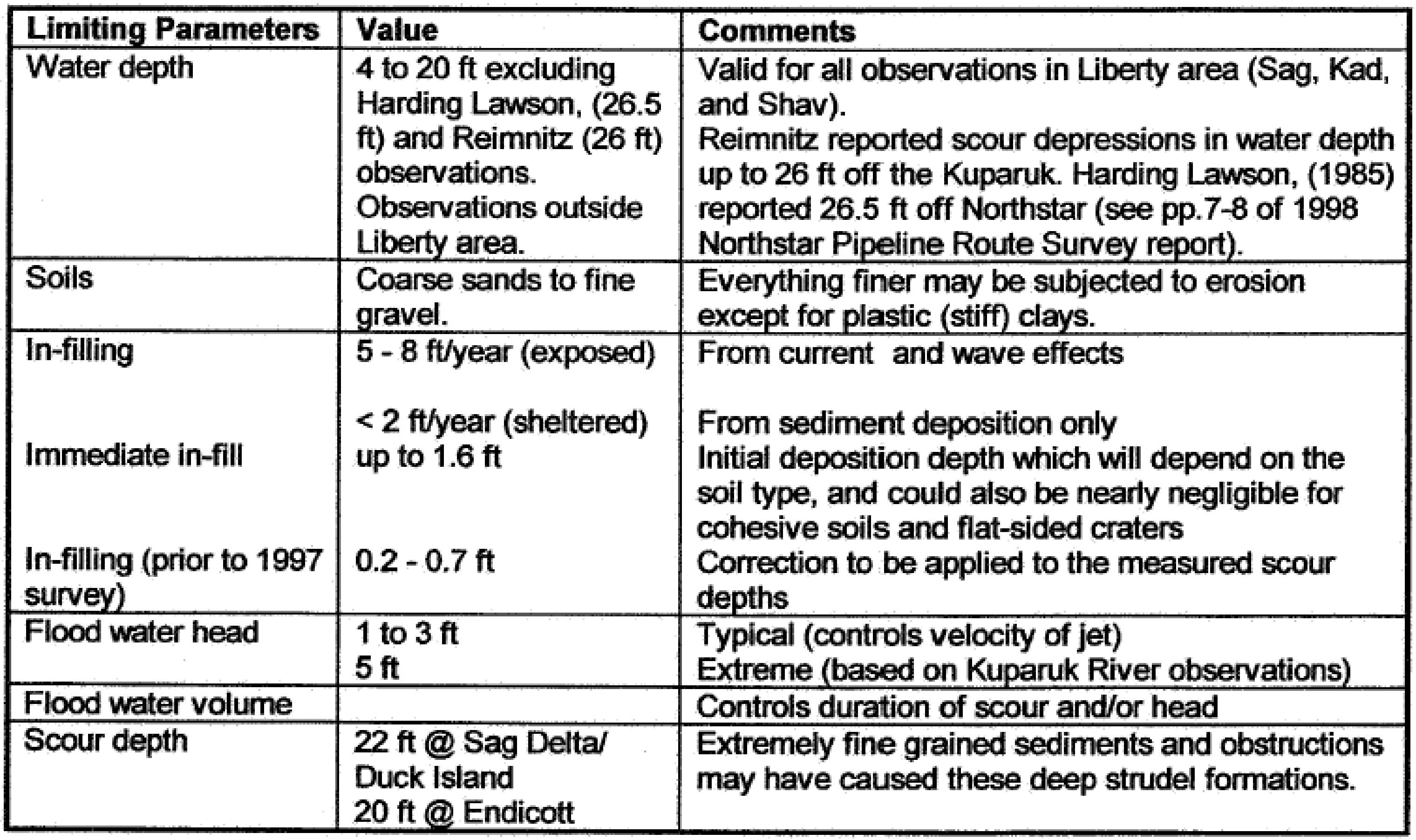


Study	In-Filling Rate (ft/year) yearly average	Comments
Egg Island	4 - 7	Reimnitz and Kempema (1982;1983) (sheltered areas), from currents
Sag Delta	5 - 8	Reimnitz and Kempema 1982;1983) (exposed areas). from currents
depth of deposit immediately after an event	1.6 ft	Reimnitz and Kempema (1982; 1983), from suspended particles immediately after event; Initial in-filling will depend on the soil type, and could be nearly negligible for cohesive soils or flat-sided craters
Endicott Strudel	0.3 - 1	Adjacent to the causeway; attributed to the settlement of suspended particles
Duck Island/Sag Delta	5	Harding Lawson (1981), and McClelland (1982)
Liberty Pipeline Route	8.1 (maximum)	Coastal Frontiers (1999)
Off Resolution Island in the Sag Delta	1.8	Coastal Frontiers (1996)
Northstar Test Trench	2 - 4	Coastal Frontiers (1999)
Liberty Area (before 1997 survey)	0.2 - 0.7	Based on an analysis of winds ≥ 20 kts

Example:

- In exposed locations in the range of 4 to 8 ft/year
- In sheltered locations in the range of less than 2 ft/year

Typical summary of strudel scour data



Limiting Parameters	Value	Comments
Water depth	4 to 20 ft excluding Harding Lawson, (26.5 ft) and Reimnitz (26 ft) observations. Observations outside Liberty area.	Valid for all observations in Liberty area (Sag, Kad, and Shav). Reimnitz reported scour depressions in water depth up to 26 ft off the Kuparuk. Harding Lawson, (1985) reported 26.5 ft off Northstar (see pp.7-8 of 1998 Northstar Pipeline Route Survey report).
Soils	Coarse sands to fine gravel.	Everything finer may be subjected to erosion except for plastic (stiff) clays.
In-filling	5 - 8 ft/year (exposed) < 2 ft/year (sheltered)	From current and wave effects From sediment deposition only
Immediate in-fill	up to 1.6 ft	Initial deposition depth which will depend on the soil type, and could also be nearly negligible for cohesive soils and flat-sided craters
In-filling (prior to 1997 survey)	0.2 - 0.7 ft	Correction to be applied to the measured scour depths
Flood water head	1 to 3 ft 5 ft	Typical (controls velocity of jet) Extreme (based on Kuparuk River observations)
Flood water volume		Controls duration of scour and/or head
Scour depth	22 ft @ Sag Delta/ Duck Island 20 ft @ Endicott	Extremely fine grained sediments and obstructions may have caused these deep strudel formations.

Why do we require Statistical analyses?

- To estimate the probability of exceedence of a given free span for sea bottom scours that are large and deep enough to create that free spans.

- To establish and fit, (as much as possible through statistical significance tests), the tail of the distribution of the scour width data set with depth measurements.

- To estimate the annual density of strudel scours occurring along the pipeline route.

Statistical analyses of Circular Strudel Scours

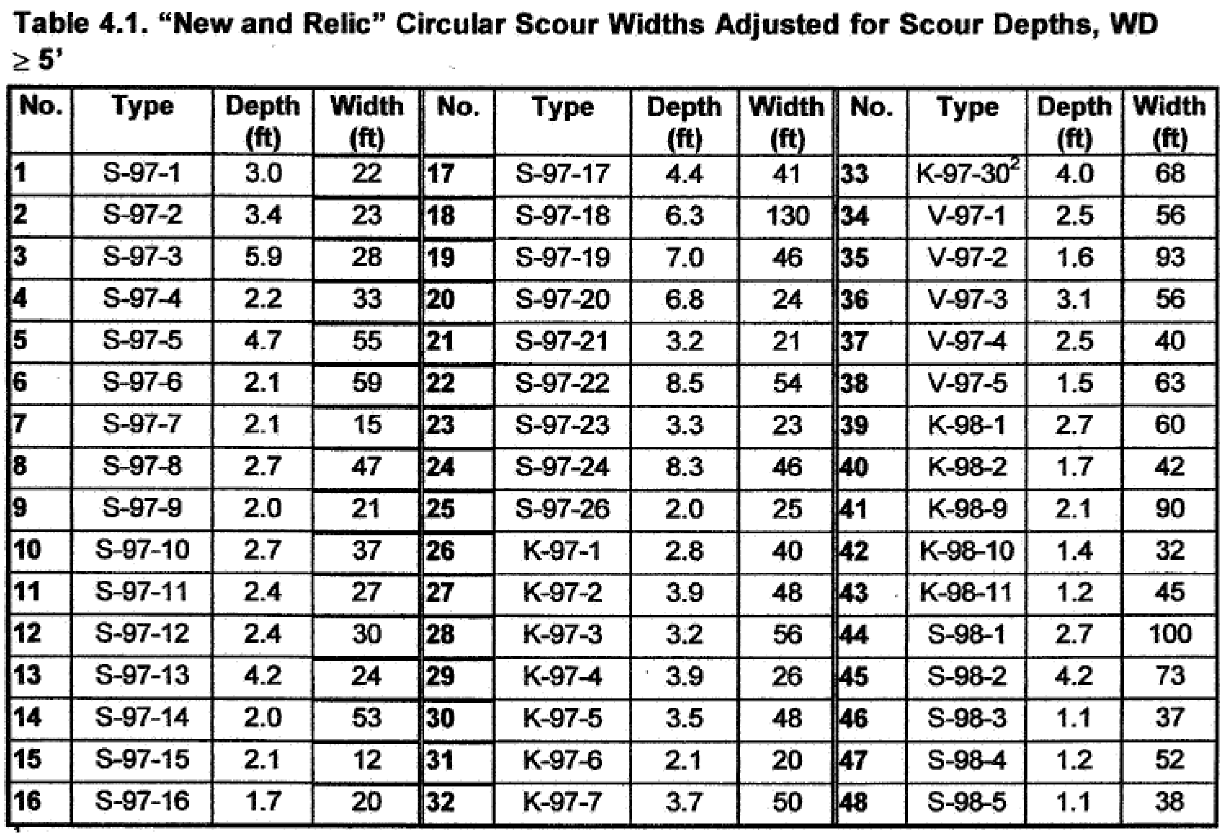


Table 4.1. "New and Relic" Circular Scour Widths Adjusted for Scour Depths, WD ≥ 5'

No.	Type	Depth (ft)	Width (ft)	No.	Type	Depth (ft)	Width (ft)	No.	Type	Depth (ft)	Width (ft)
1	S-97-1	3.0	22	17	S-97-17	4.4	41	33	K-97-30^2	4.0	68
2	S-97-2	3.4	23	18	S-97-18	6.3	130	34	V-97-1	2.5	56
3	S-97-3	5.9	28	19	S-97-19	7.0	46	35	V-97-2	1.6	93
4	S-97-4	2.2	33	20	S-97-20	6.8	24	36	V-97-3	3.1	56
5	S-97-5	4.7	55	21	S-97-21	3.2	21	37	V-97-4	2.5	40
6	S-97-6	2.1	59	22	S-97-22	8.5	54	38	V-97-5	1.5	63
7	S-97-7	2.1	15	23	S-97-23	3.3	23	39	K-98-1	2.7	60
8	S-97-8	2.7	47	24	S-97-24	8.3	46	40	K-98-2	1.7	42
9	S-97-9	2.0	21	25	S-97-26	2.0	25	41	K-98-9	2.1	90
10	S-97-10	2.7	37	26	K-97-1	2.8	40	42	K-98-10	1.4	32
11	S-97-11	2.4	27	27	K-97-2	3.9	48	43	K-98-11	1.2	45
12	S-97-12	2.4	30	28	K-97-3	3.2	56	44	S-98-1	2.7	100
13	S-97-13	4.2	24	29	K-97-4	3.9	26	45	S-98-2	4.2	73
14	S-97-14	2.0	53	30	K-97-5	3.5	48	46	S-98-3	1.1	37
15	S-97-15	2.1	12	31	K-97-6	2.1	20	47	S-98-4	1.2	52
16	S-97-16	1.7	20	32	K-97-7	3.7	50	48	S-98-5	1.1	38

- Probabilistic analyses can be performed.
- Data from new and relic strudels need to be considered.
- Exponential (thin tail) or lognormal distributions (thick tail) are more often applied.
- Scour Width Sample mean is 44.77ft and Standard deviation is 23.64ft for this site.
- Usual problem is limited data sets are only available.
- Hence statistical fits based on limited data is applied.
- Adjustments due to infilling should also be considered.
- Infilling may introduce a bias towards shallower scours!

Statistical analyses of Linear Strudel Scours

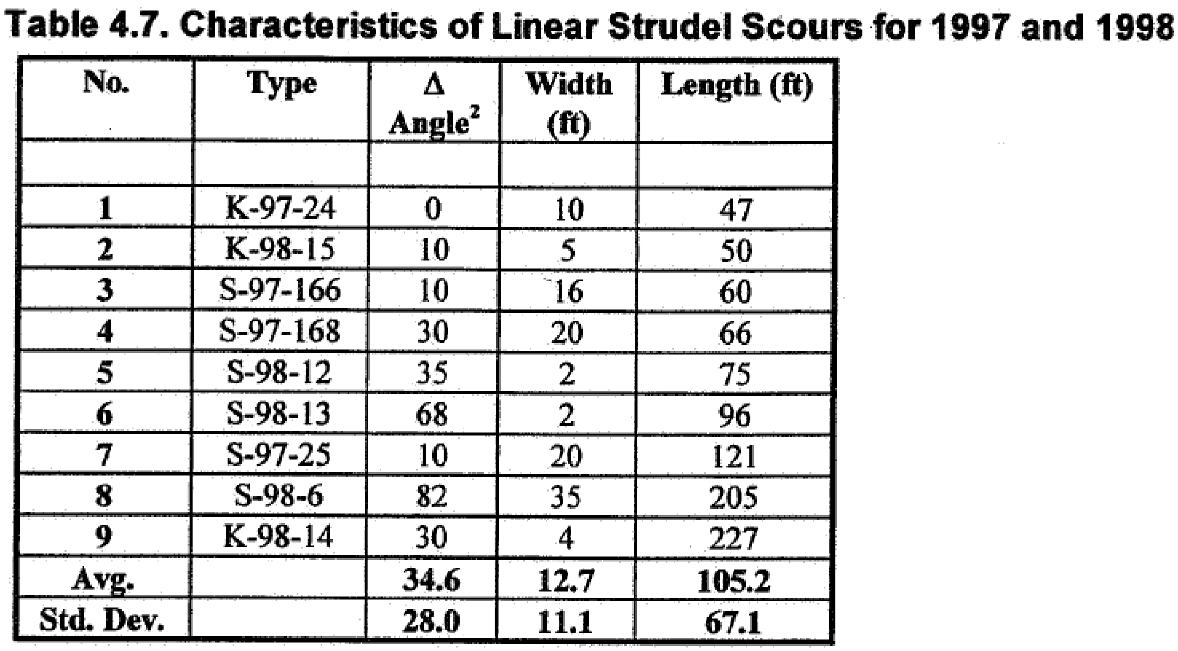


Table 4.7. Characteristics of Linear Strudel Scours for 1997 and 1998

No.	Type	Δ Angle²	Width (ft)	Length (ft)
1	K-97-24	0	10	47
2	K-98-15	10	5	50
3	S-97-166	10	16	60
4	S-97-168	30	20	66
5	S-98-12	35	2	75
6	S-98-13	68	2	96
7	S-97-25	10	20	121
8	S-98-6	82	35	205
9	K-98-14	30	4	227
Avg.		**34.6**	**12.7**	**105.2**
Std. Dev.		**28.0**	**11.1**	**67.1**

- Three important parameters are required to estimate the probability of exceedence of a freespan:
  - Length
  - Width
  - Orientation
- Note that a linear scour is not necessarily rectangular, but more like a tadpole shaped.
- Width and depth is typically reported at the widest end (head) of the linear scour.
- Tail section is 25%-50% of the head section.
- Depth of the tail section is usually shallower than the head section.
  - More unlikely to reach the buried pipe.

Assuming exponential fit for both circular & linear scours, probabilistically speaking, the maximum width at the head of a linear scour is significantly narrower than the circular ones.

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Distribution Fits for Circular Strudel Scours

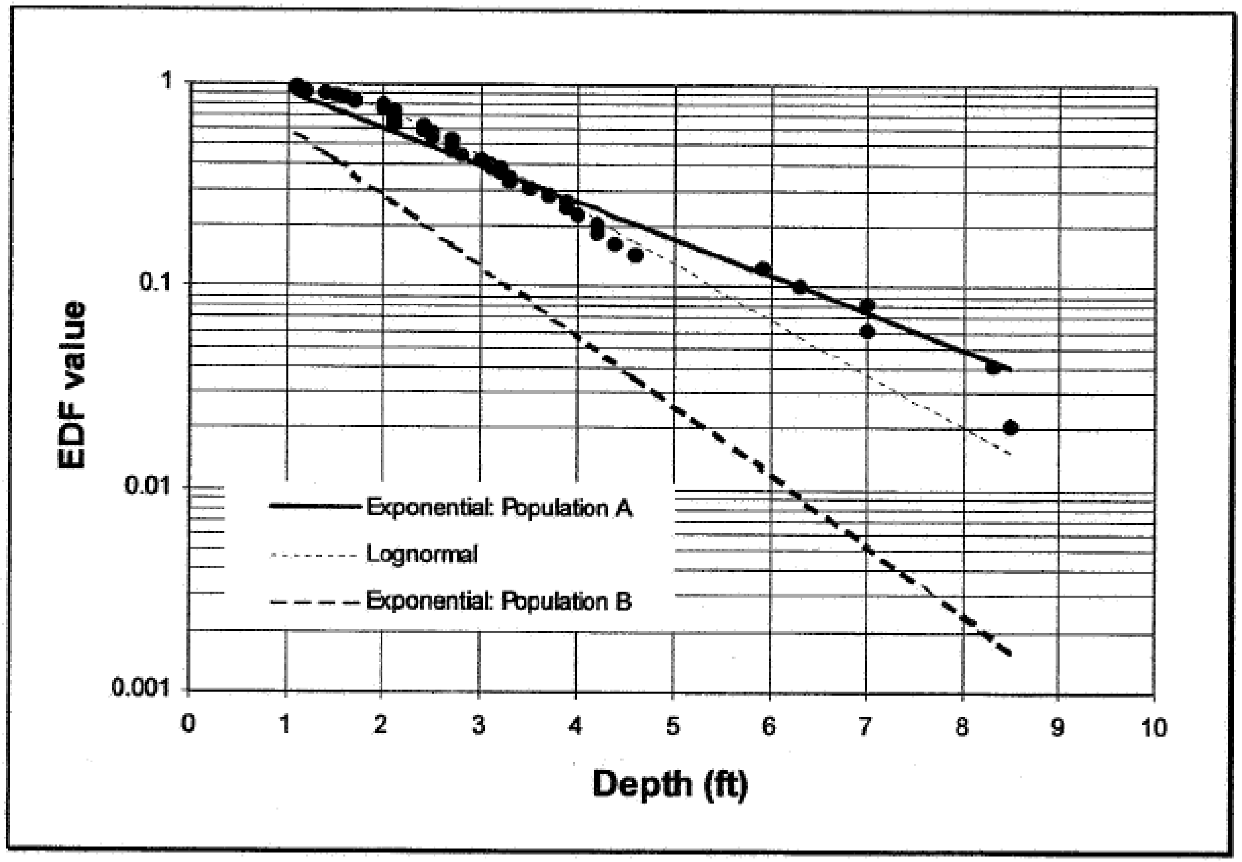
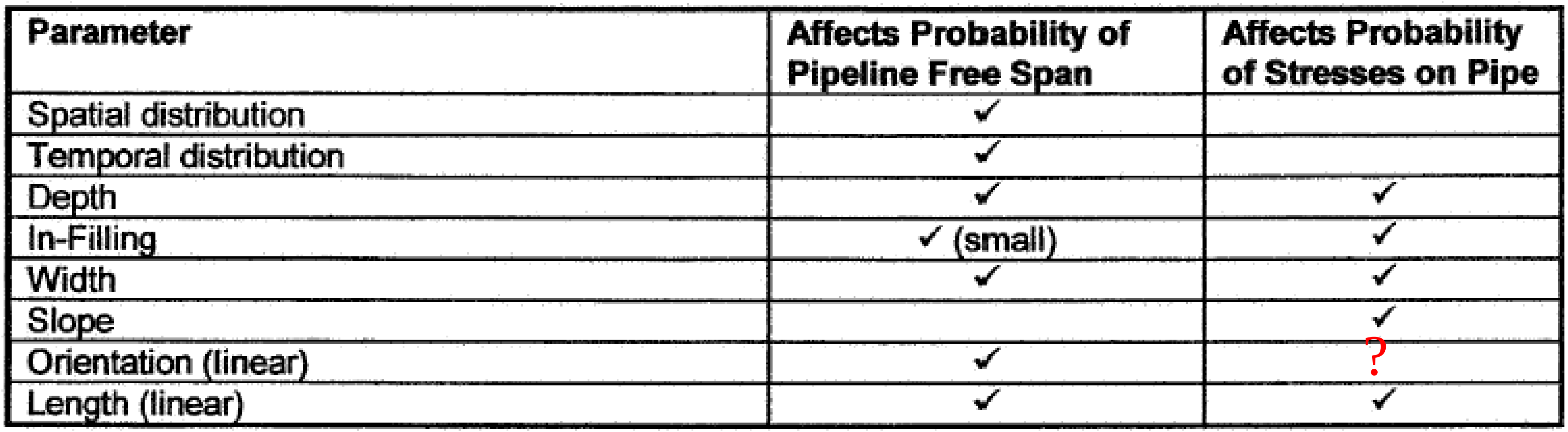


Figure 4.10. "New and Relic" Exponential and Lognormal Scour Depth Distribution Fits

Impact on pipeline design



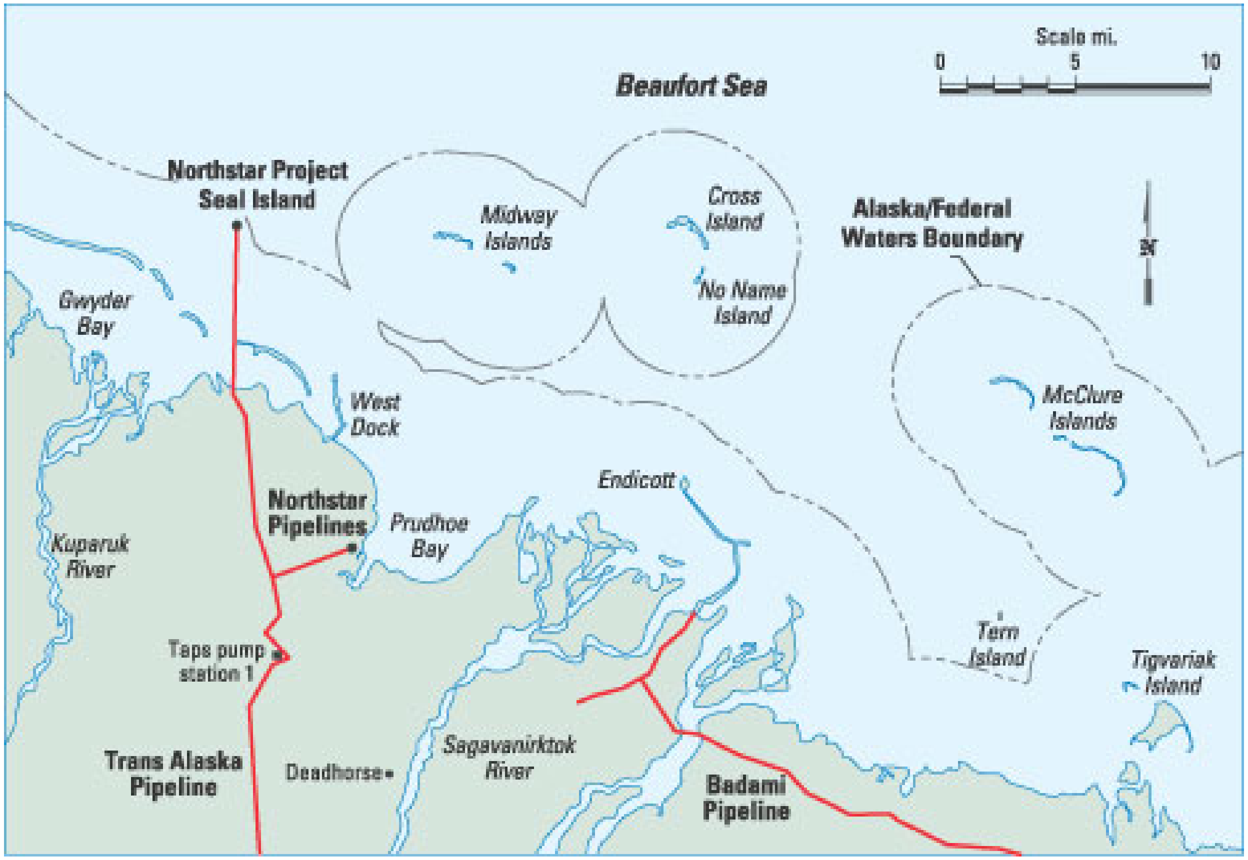
Parameter	Affects Probability of Pipeline Free Span	Affects Probability of Stresses on Pipe
Spatial distribution	✓	
Temporal distribution	✓	
Depth	✓	✓
In-Filling	✓ (small)	✓
Width	✓	✓
Slope		✓
Orientation (linear)	✓	?
Length (linear)	✓	✓

ULS – Increased drag loading

Fatigue - VIV

Northstar Development Project – Case study

- Average date of Kuparuk river overflooding Simpson Lagoon is May 29. (+/- 1 week)
- Strudel scours are common in Kuparuk river delta
- For the proposed pipeline route Strudel Scour evaluation is required.



Data based on Intec Engg report.

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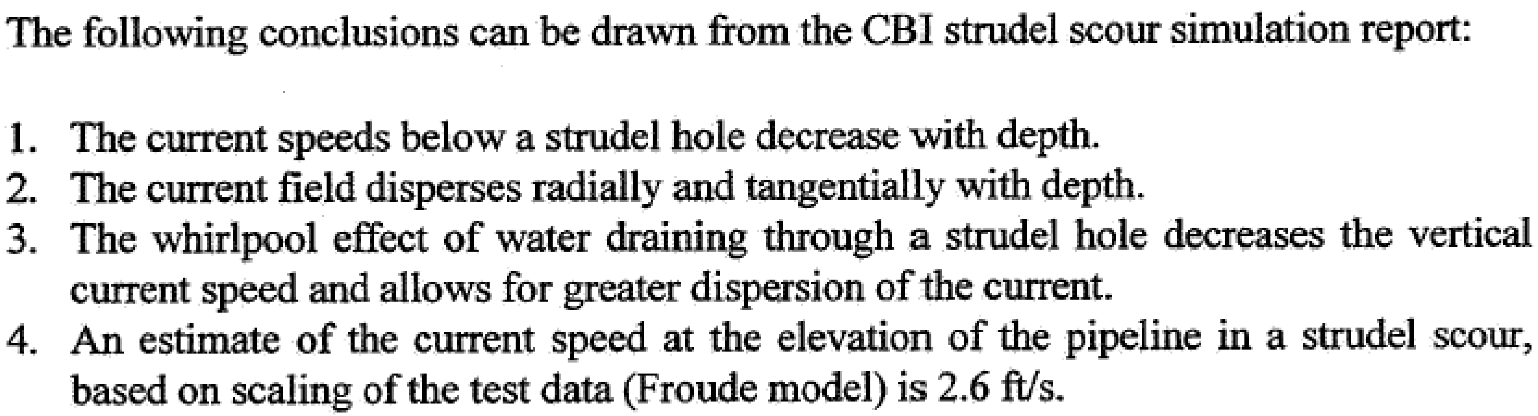
Northstar Development Project – Analyses

- Site specific strudel data was applied
- 100 year Average Return Period extreme event strudel is considered
- 100 year ARP scour diameter is 90 ft.
- Water current speed flowing down through a strudel hole of 5ft/s was applied.
- Span analyses : To evaluate the pipeline integrity, assuming that a strudel is formed directly over the pipeline
  - Mechanical integrity
  - Dynamic response to strudel jet
  - VIV assessments were made
- Probability of a strudel scour exposing this pipeline was limited, due to:
  - Length of the route susceptible to strudels
  - Depth of strudel scour vs pipeline depth of cover
  - Scour depth vs water depth

Pipelines were trenched and the backfill thickness was 7 feet with a negative tolerance of 1 foot, i.e. a minimum backfill of 6ft.

Strudel current speed

- Theoretical Water current speed flowing down through a strudel hole of 5ft/s.
- CBI Strudel Simulations performed in 1983-84:



The following conclusions can be drawn from the CBI strudel scour simulation report:

1. The current speeds below a strudel hole decrease with depth.
2. The current field disperses radially and tangentially with depth.
3. The whirlpool effect of water draining through a strudel hole decreases the vertical current speed and allows for greater dispersion of the current.
4. An estimate of the current speed at the elevation of the pipeline in a strudel scour, based on scaling of the test data (Froude model) is 2.6 ft/s.

- Design current of 5ft/s

Load cases

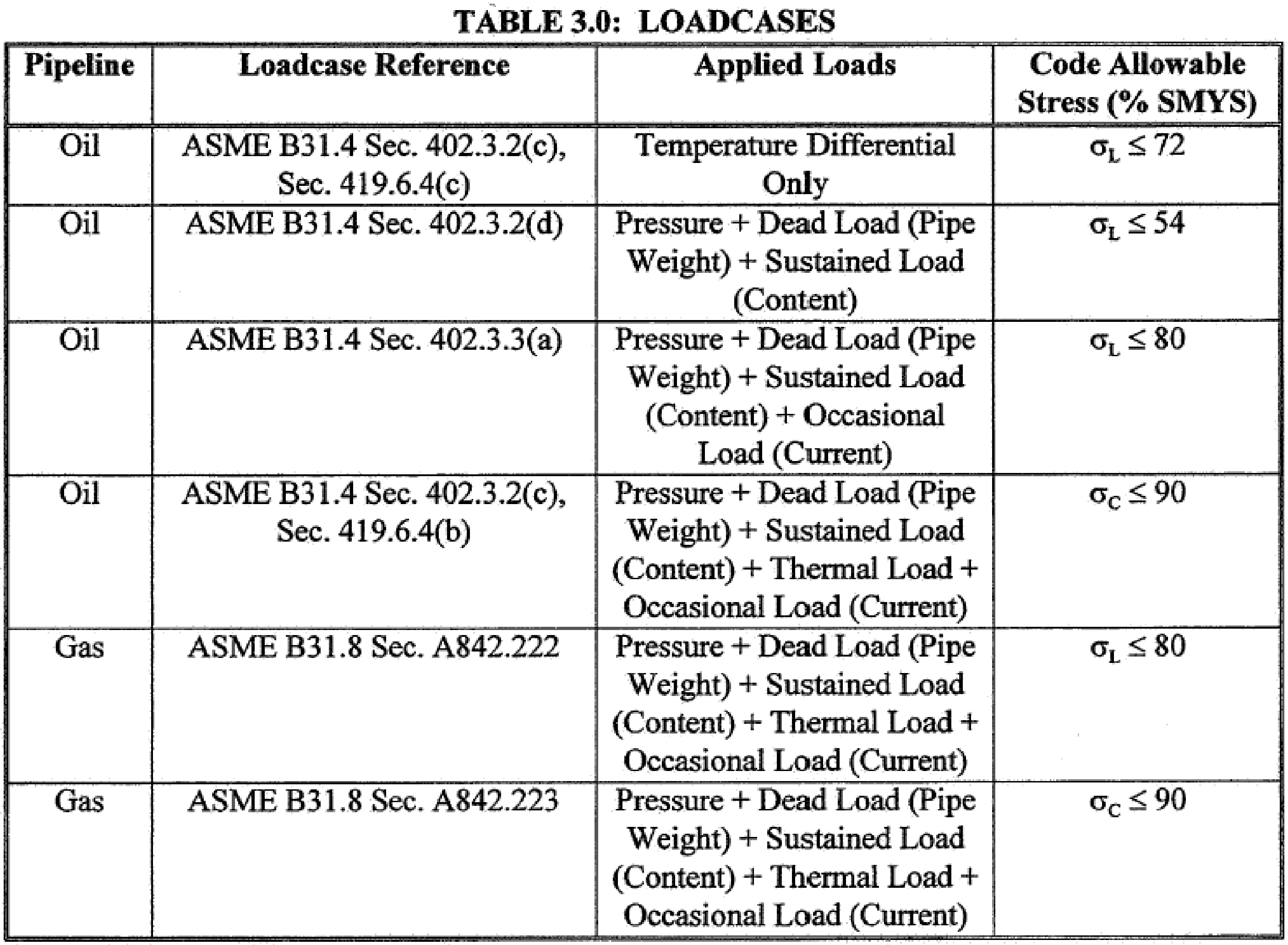


TABLE 3.0: LOADCASES

Pipeline	Loadcase Reference	Applied Loads	Code Allowable Stress (% SMYS)
Oil	ASME B31.4 Sec. 402.3.2(c), Sec. 419.6.4(c)	Temperature Differential Only	$\sigma_L \leq 72$
Oil	ASME B31.4 Sec. 402.3.2(d)	Pressure + Dead Load (Pipe Weight) + Sustained Load (Content)	$\sigma_L \leq 54$
Oil	ASME B31.4 Sec. 402.3.3(a)	Pressure + Dead Load (Pipe Weight) + Sustained Load (Content) + Occasional Load (Current)	$\sigma_L \leq 80$
Oil	ASME B31.4 Sec. 402.3.2(c), Sec. 419.6.4(b)	Pressure + Dead Load (Pipe Weight) + Sustained Load (Content) + Thermal Load + Occasional Load (Current)	$\sigma_C \leq 90$
Gas	ASME B31.8 Sec. A842.222	Pressure + Dead Load (Pipe Weight) + Sustained Load (Content) + Thermal Load + Occasional Load (Current)	$\sigma_L \leq 80$
Gas	ASME B31.8 Sec. A842.223	Pressure + Dead Load (Pipe Weight) + Sustained Load (Content) + Thermal Load + Occasional Load (Current)	$\sigma_C \leq 90$

Results from strudel scour section on pipeline

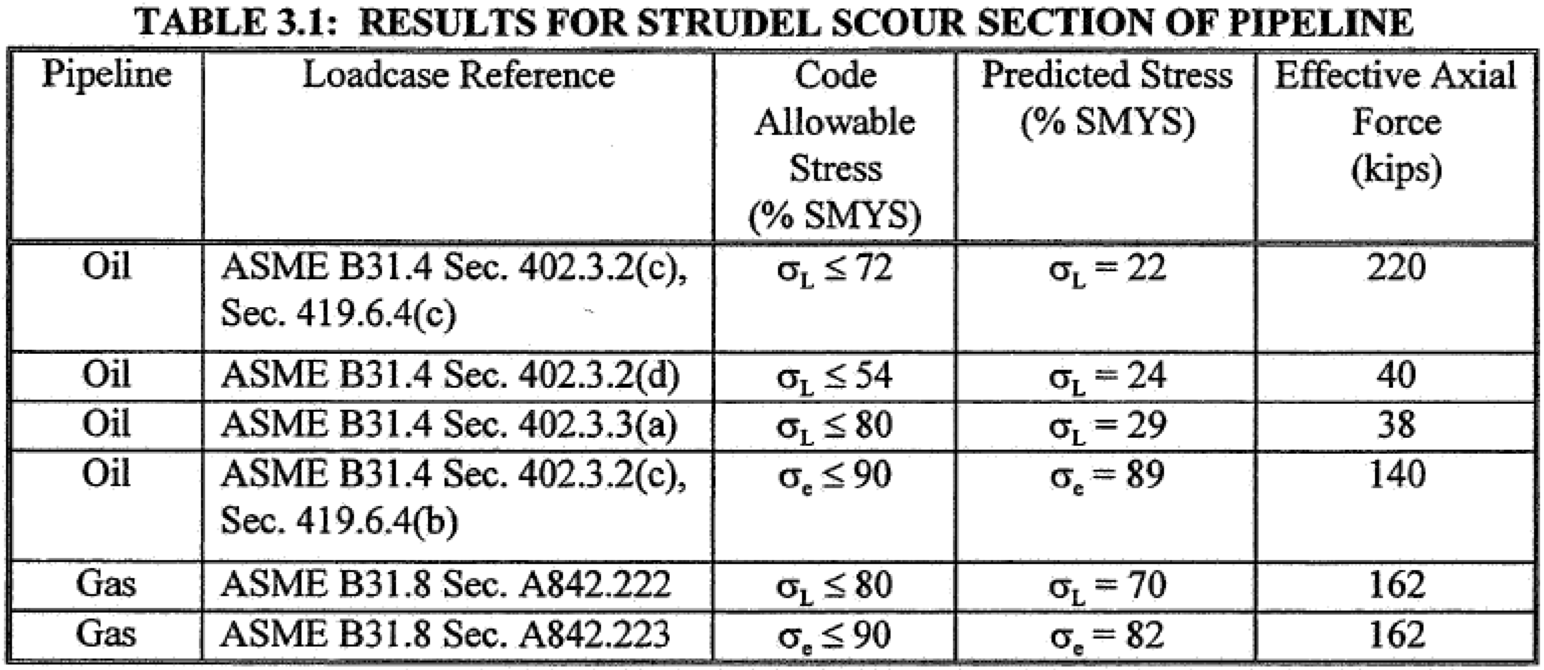


TABLE 3.1: RESULTS FOR STRUDEL SCOUR SECTION OF PIPELINE

Pipeline	Loadcase Reference	Code Allowable Stress (% SMYS)	Predicted Stress (% SMYS)	Effective Axial Force (kips)
Oil	ASME B31.4 Sec. 402.3.2(c), Sec. 419.6.4(c)	$\sigma_L \leq 72$	$\sigma_L = 22$	220
Oil	ASME B31.4 Sec. 402.3.2(d)	$\sigma_L \leq 54$	$\sigma_L = 24$	40
Oil	ASME B31.4 Sec. 402.3.3(a)	$\sigma_L \leq 80$	$\sigma_L = 29$	38
Oil	ASME B31.4 Sec. 402.3.2(c), Sec. 419.6.4(b)	$\sigma_e \leq 90$	$\sigma_e = 89$	140
Gas	ASME B31.8 Sec. A842.222	$\sigma_L \leq 80$	$\sigma_L = 70$	162
Gas	ASME B31.8 Sec. A842.223	$\sigma_e \leq 90$	$\sigma_e = 82$	162

Northstar Development Project – VIV

- Shear 7 software
- CF fatigue was considered

It was concluded that for a design scour of 90ft diameter, a strudel jet of 11ft/s is required.

For the 5ft/s current load, span length in excess of 140ft is required for VIV to occur.

Few issues

- Physical models of Strudel scour are still not yet fully understood
- Applied assessment tools
- Exposed pipeline and the effect of a pipe in trench
- Further evolution of free spans
- In-line VIV assessments

Summary

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- Environmental processes
- Statistical information
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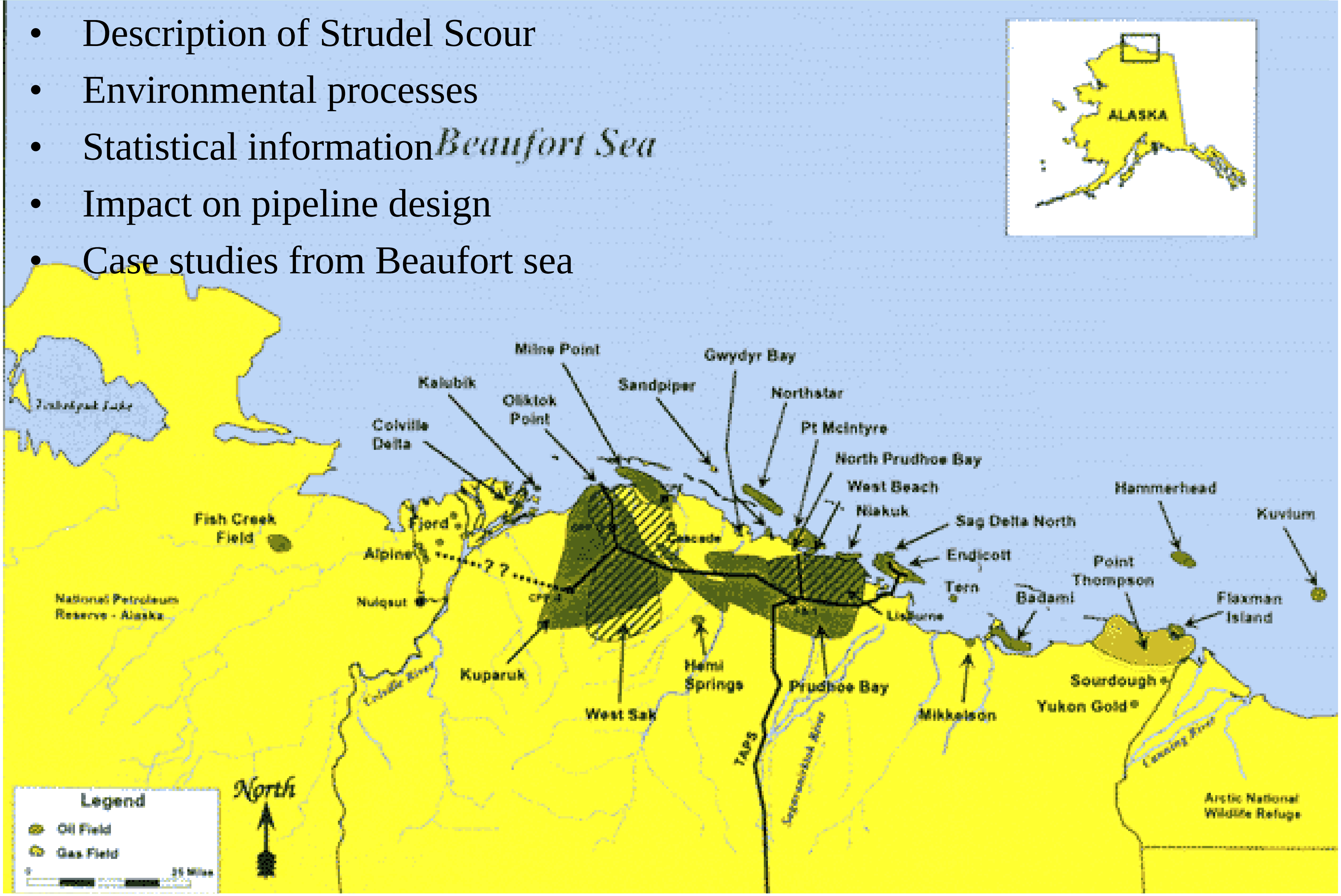


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