FMC EnergySystems
FMC SOFEC Floating Systems

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Understanding Fatigue for Deepwater Mooring Systems

- The Footprint of Fatigue

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Objective: 7 Case Studies

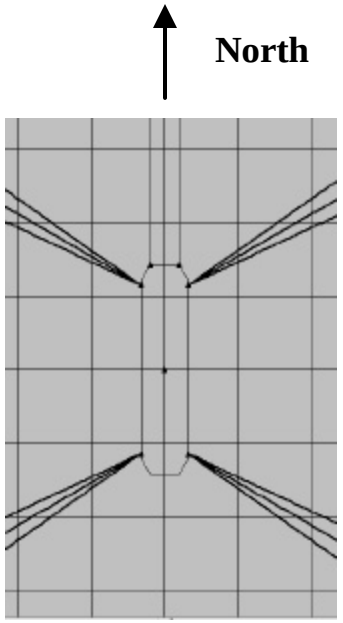
- Show high T_h on flowlines influences fatigue life of chain
- Increasing the EPS improves fatigue life
- Compare fatigue life computations from 3 guidelines
- Need to account for flowline tensions in FEED studies

Assumptions for 7 Cases:

- Intact Mooring Analyses only
- Water Depth 1000 meters
- Maximum offset is 5% of W.D.
- Assume meets API RP 2SK Safety Factors
- Studless Chain, Sheathed Spiral Strand Wire
- All mooring legs use same size components

Additional Assumptions for 7 Cases:

- All systems have 12 legs
- 55, 60, and 65 degree plan angles
- Vessel heading is “South”
  - middle of swell sector
- Buoy to the “North”
- All analyses use Ballast Condition
- 20 year design life
- 0.4 mm/yr corrosion and wear allowance

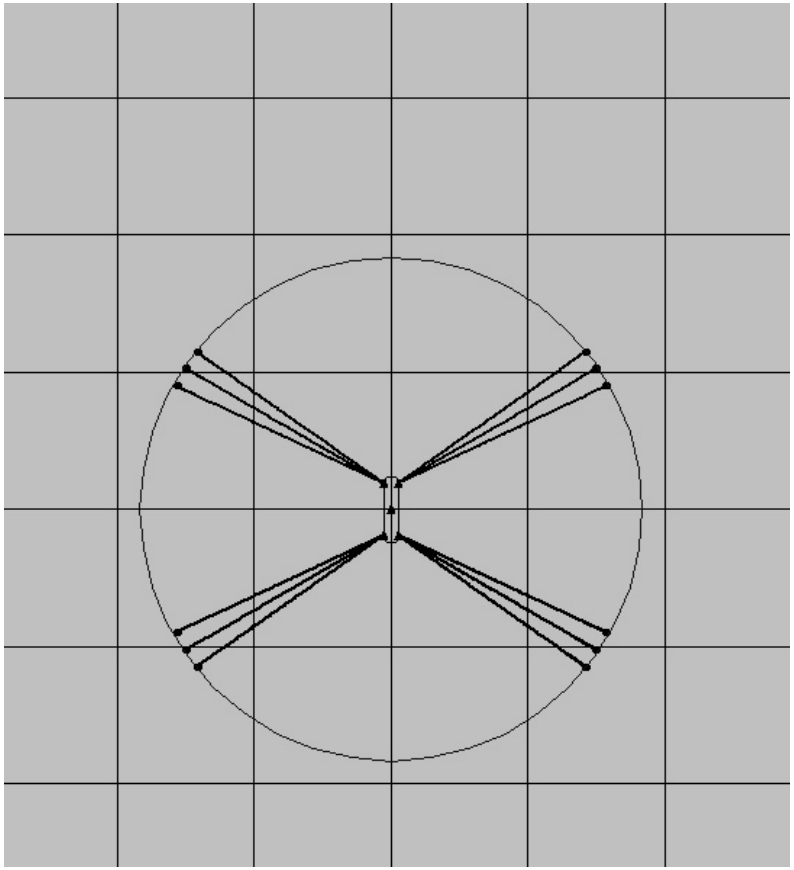


Environmental Conditions

- 100-Year Winds
  - Swell from 3 directions (S, SSE, and SSW)
  - Wind and Current together, from 16 Directions (every 22.5 degrees)
  - Total of 48 Cases analyzed
- Fatigue Seastates
  - Swell from the South 70% occurrence
  - Swells from SSE, SSW 15% occurrence each
  - 33 cases of Hs, Tp, wind and current directions, each swell direction
  - Total of 99 Fatigue cases

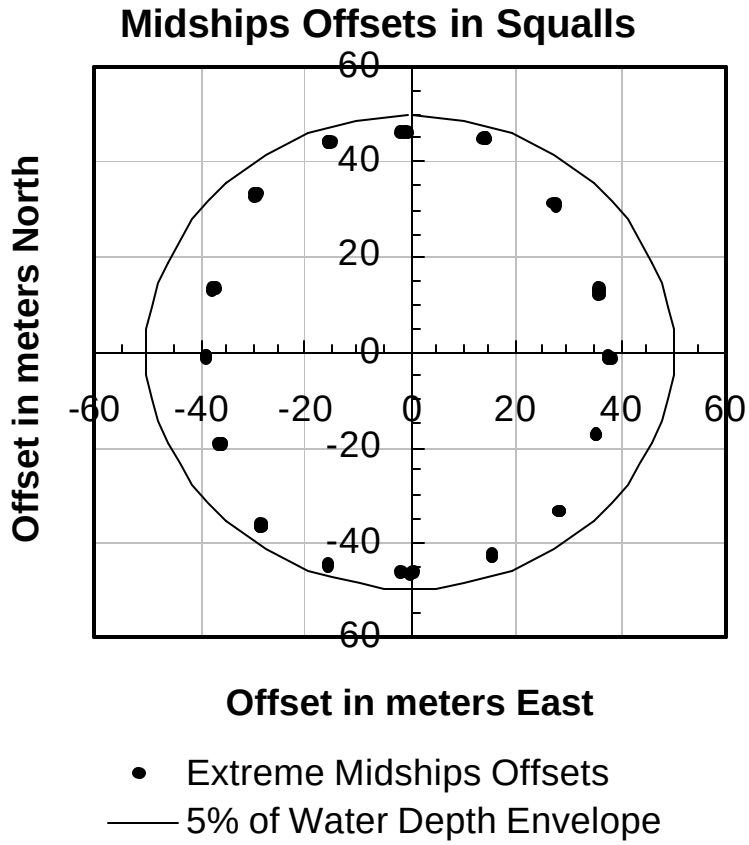
Case 1 (Base Case)

- FPSO, no buoy or flowlines
- EPS = WD for all mooring legs



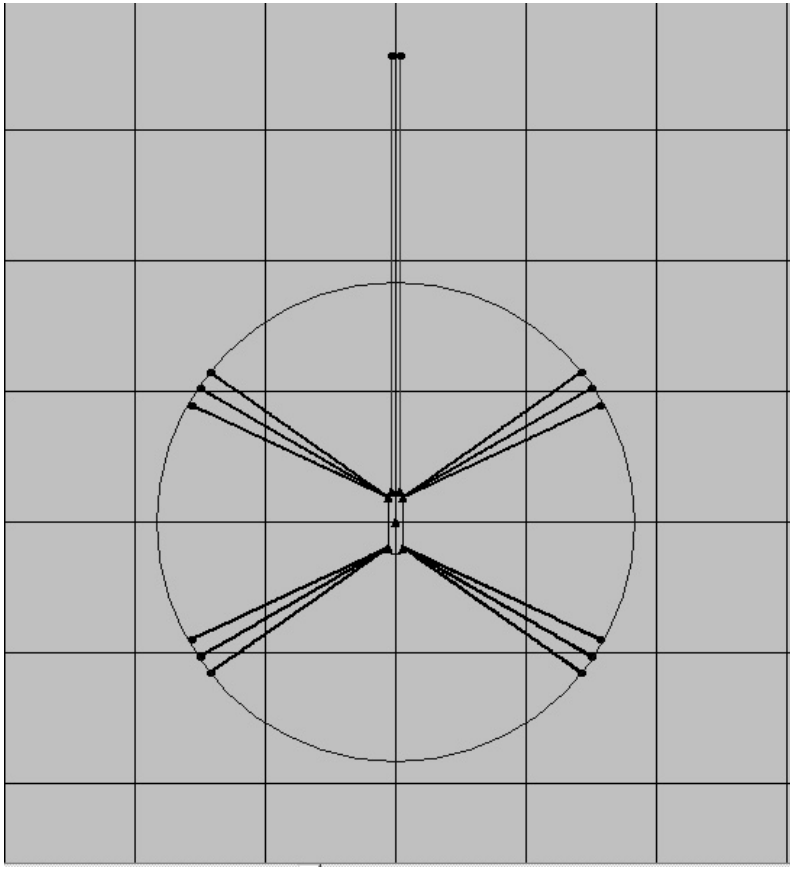
Case 1 Results

- Maximum Line Load 537 MT
  - 90 mm wire
  - 103 mm R4 chain
- Chain Fatigue Life (current API RP 2SK edition):
  - 2200+ yrs for “South”
  - 15,000 yrs for “North”



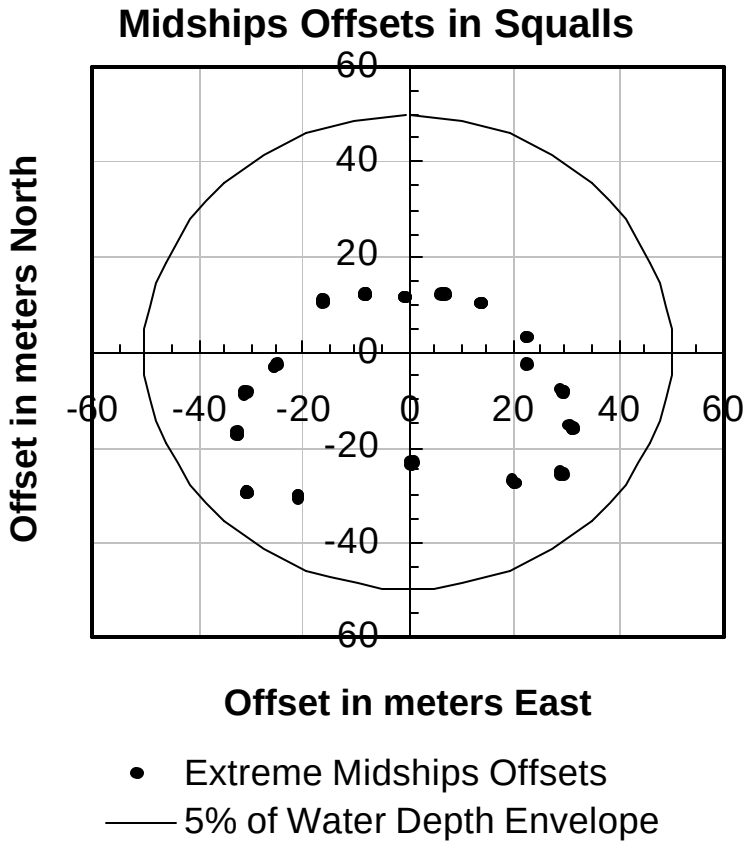
Case 2 (Base Case with Flowlines)

- An FPSO with an export buoy to the North
- EPS = WD for all mooring legs



Case 2 Results

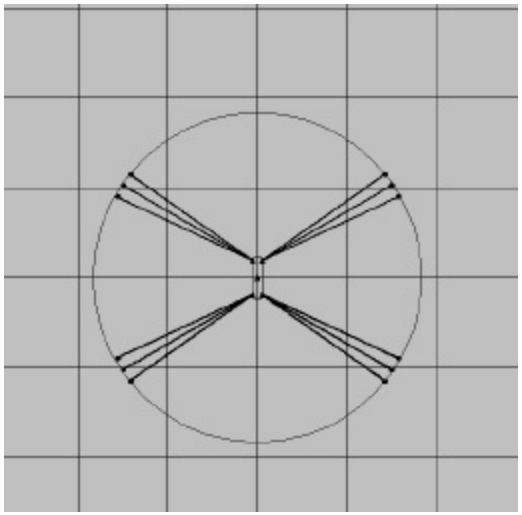
- Maximum Line Load 655 MT
  - 100 mm wire (1.69)
  - 114 mm R4 chain
- Chain Fatigue Life (current API RP 2SK edition):
  - 27 yrs for “South”
  - 110,000+ yrs for “North”



Case 2 Required Chain Size:

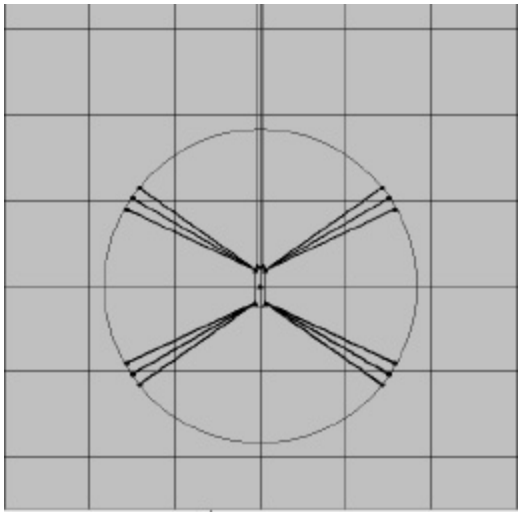
Fatigue Life in years			
Chain Size: Based on:	114 mm R4 Max Load	162 mm ORQ Fatigue	Minimum Required
Current API RP 2SK	27	212	200
API RP 2SK for 2005	9	57	60
POSMOOR	7	63	160

162 mm is min. to meet API,
Other codes need larger chain.



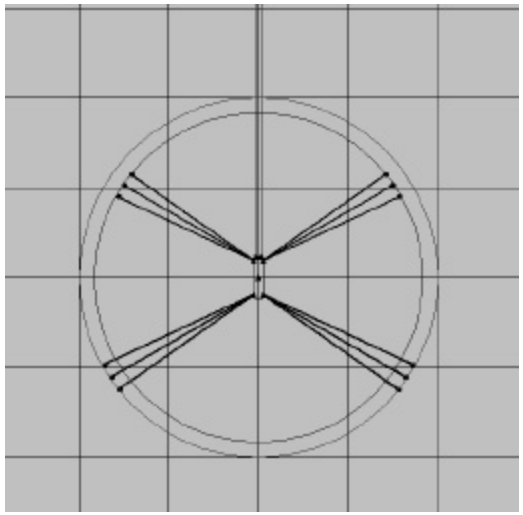
Case 1 EPS=WD, No Buoy

103 mm R4
2218 yrs API
521 yrs new API
376 yrs POSMOOR



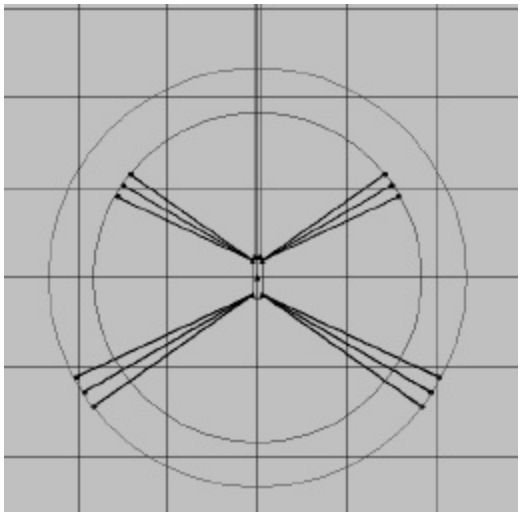
Case 2 EPS=WD

162 mm ORQ
212 yrs API
57 yrs new API
63 yrs POSMOOR



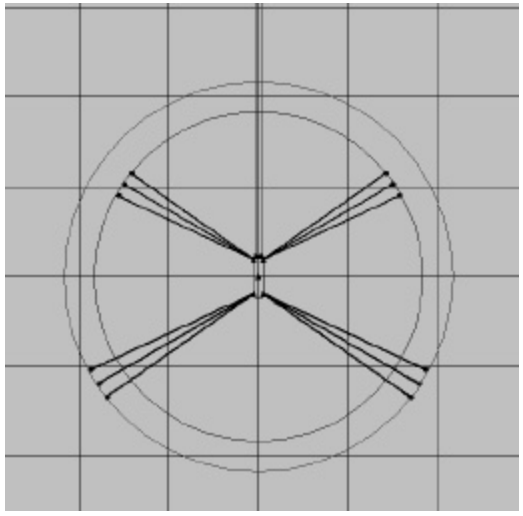
143 mm ORQ
210 yrs API
57 yrs new API
107 yrs POSMOOR

Case 3 EPS=WD+10%



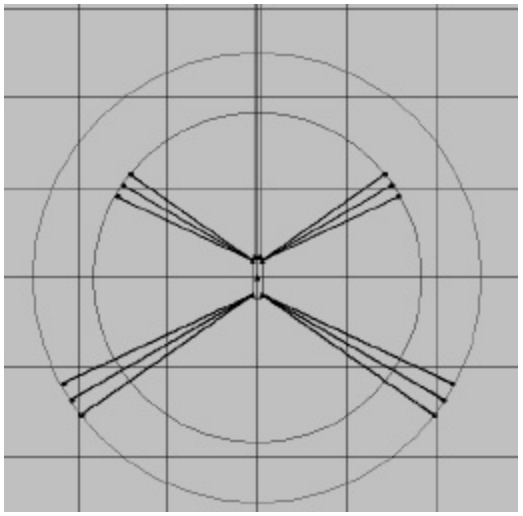
117 mm ORQ
211 yrs API
59 yrs new API
92 yrs POSMOOR

Case 5 EPS=WD+30%



131 mm ORQ
216 yrs API
60 yrs new API
103 yrs POSMOOR

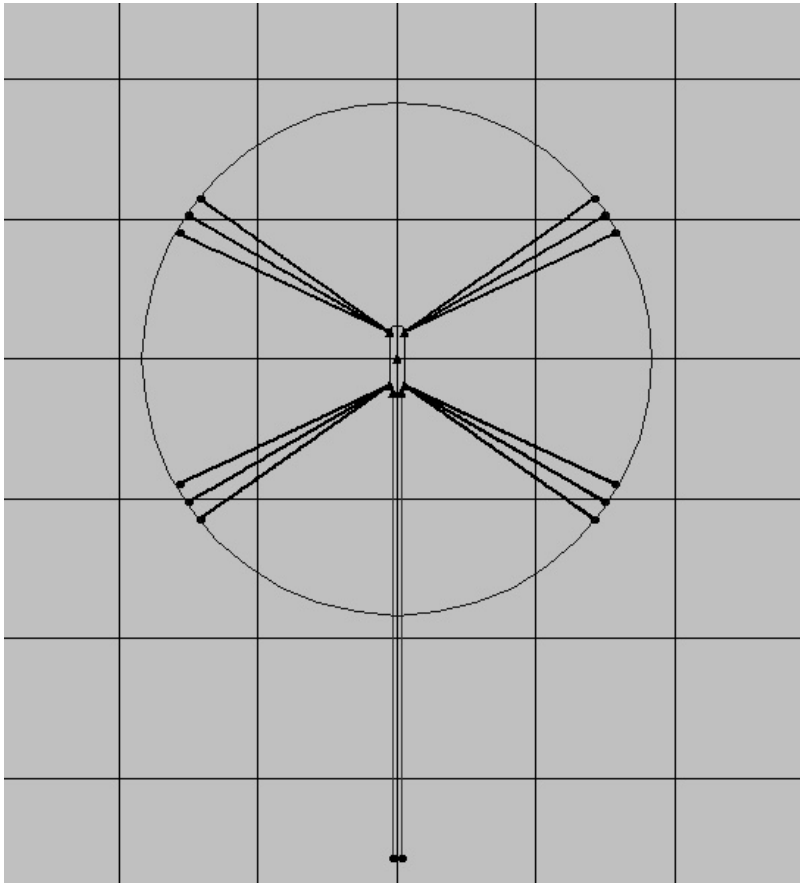
Case 4 EPS=WD+20%



107 mm R3S
203 yrs API
58 yrs new API
84 yrs POSMOOR

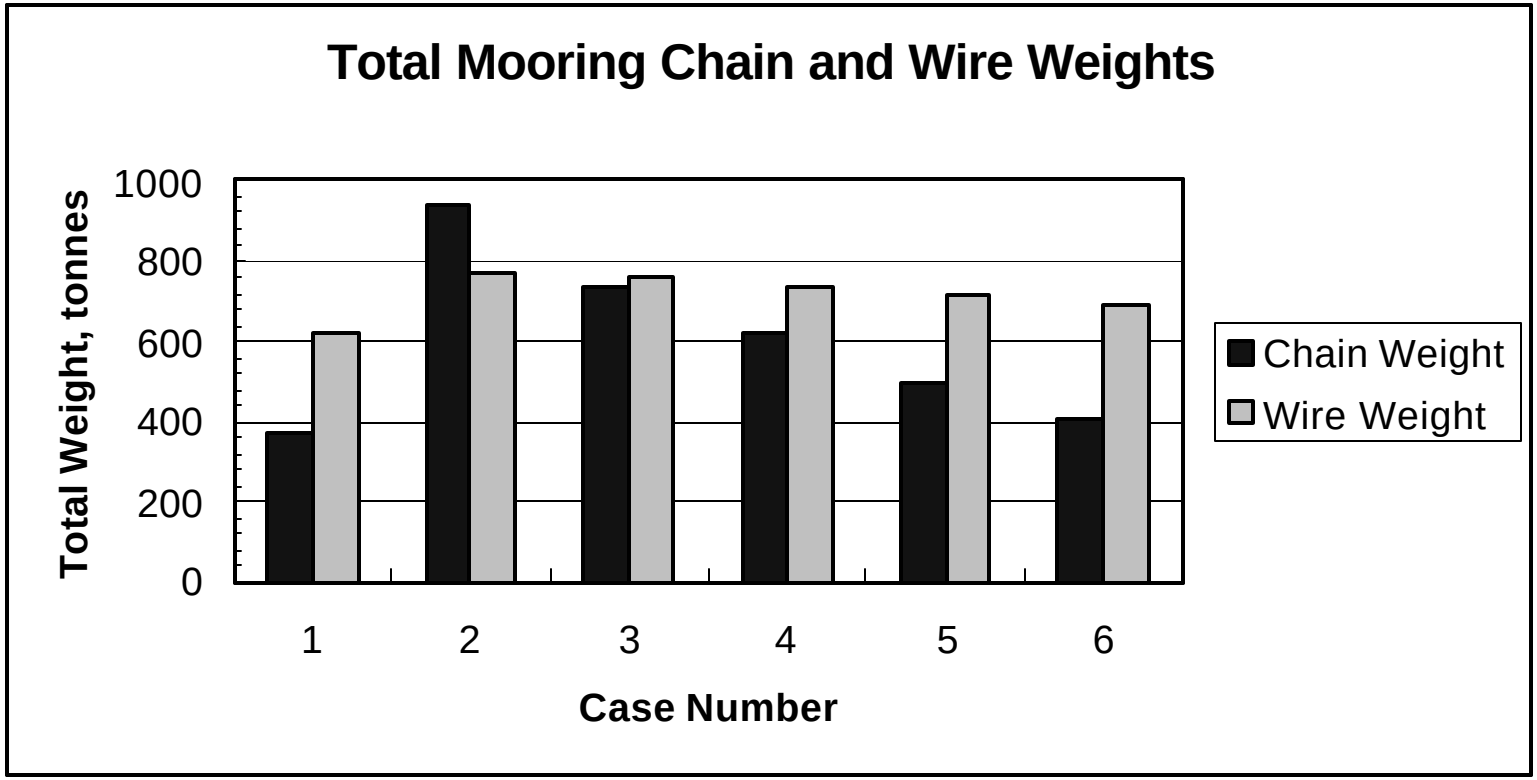
Case 6 EPS=WD+40%

Case 7 (EPS=WD) Fatigue Results for N legs:

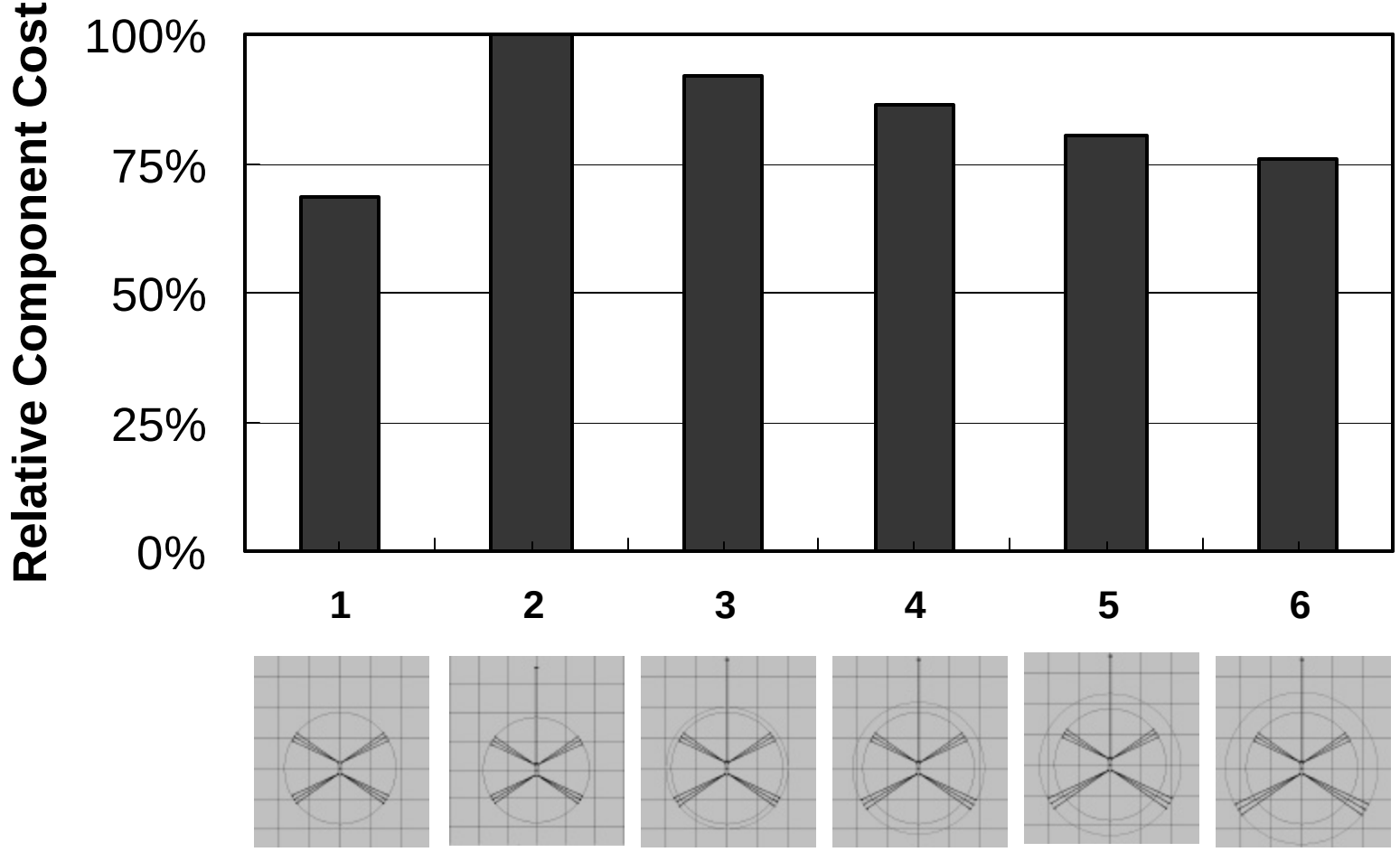


- 136 mm Chain, based on API Fatigue:
  - 220 yrs current API RP 2SK
  - 63 yr API RP 2SK for 2005
  - 57 yrs POSMOOR
- Note legs away from swell can have fatigue problems

Total Weights Required for Cases 1-6:



Relative Chain + Wire Costs for Cases 1-6:



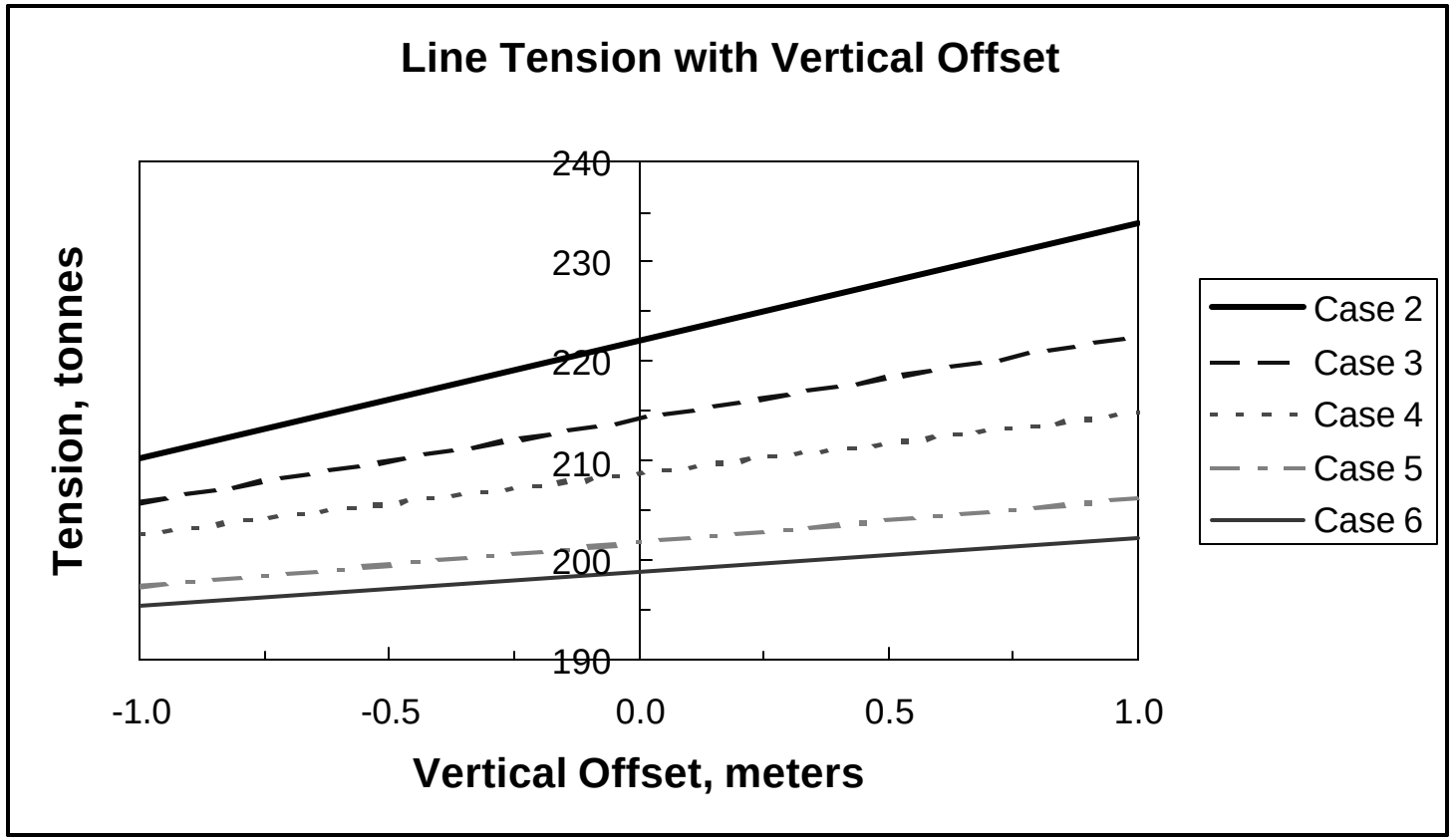
“South” Leg Pretensions as % of Chain BS & Wire MBL:

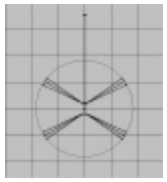
Case Number	Pretension tonnes	Chain BS (@10yrs) tonnes	Percent of Chain BS	Wire MBL tonnes	Percent of Wire MBL
1	107	989	11%	892	12%
2	222	1685	13%	1106	20%
3	214	1367	16%	1065	20%
4	209	1174	18%	1004	21%
5	202	960	21%	944	21%
6	199	816	24%	892	22%

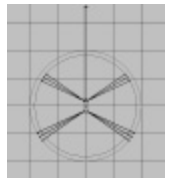
Why does the fatigue life improve as EPS increases?

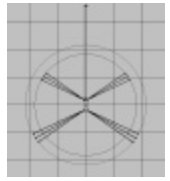
- WF damage is >> LF damage
- $D = N * (2^{1/2} * R_{rms})^{M} * \Gamma(1+ M / 2) / K$
- $D \; \mathbf{Q} \; (\Delta T/BS)^{3.36}$
- As EPS increases, $\Delta T/BS$ decreases

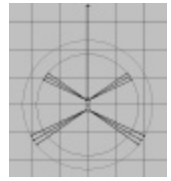
Tension Change as FPSO Heaves with a 2 meter wave:

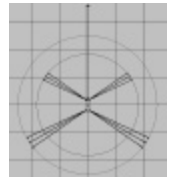



Case 2


Case 3

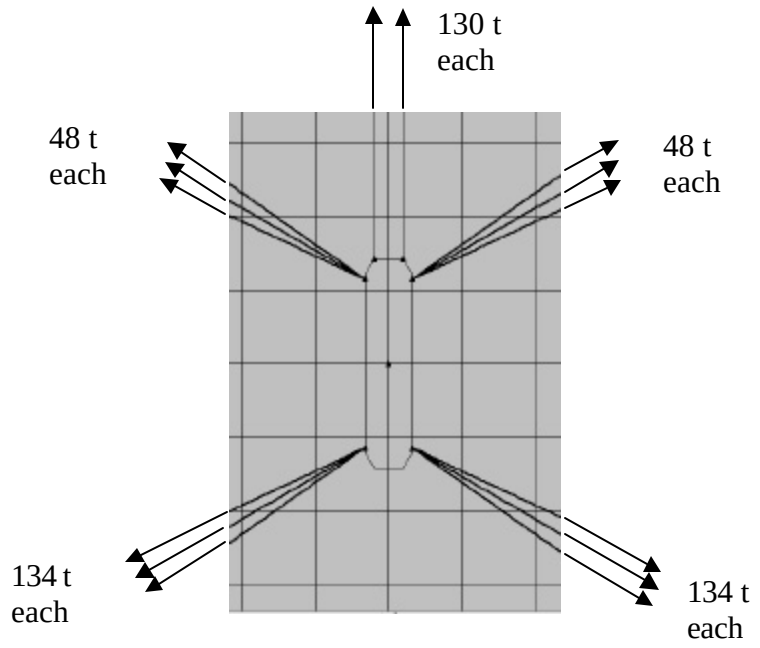

Case 4


Case 5

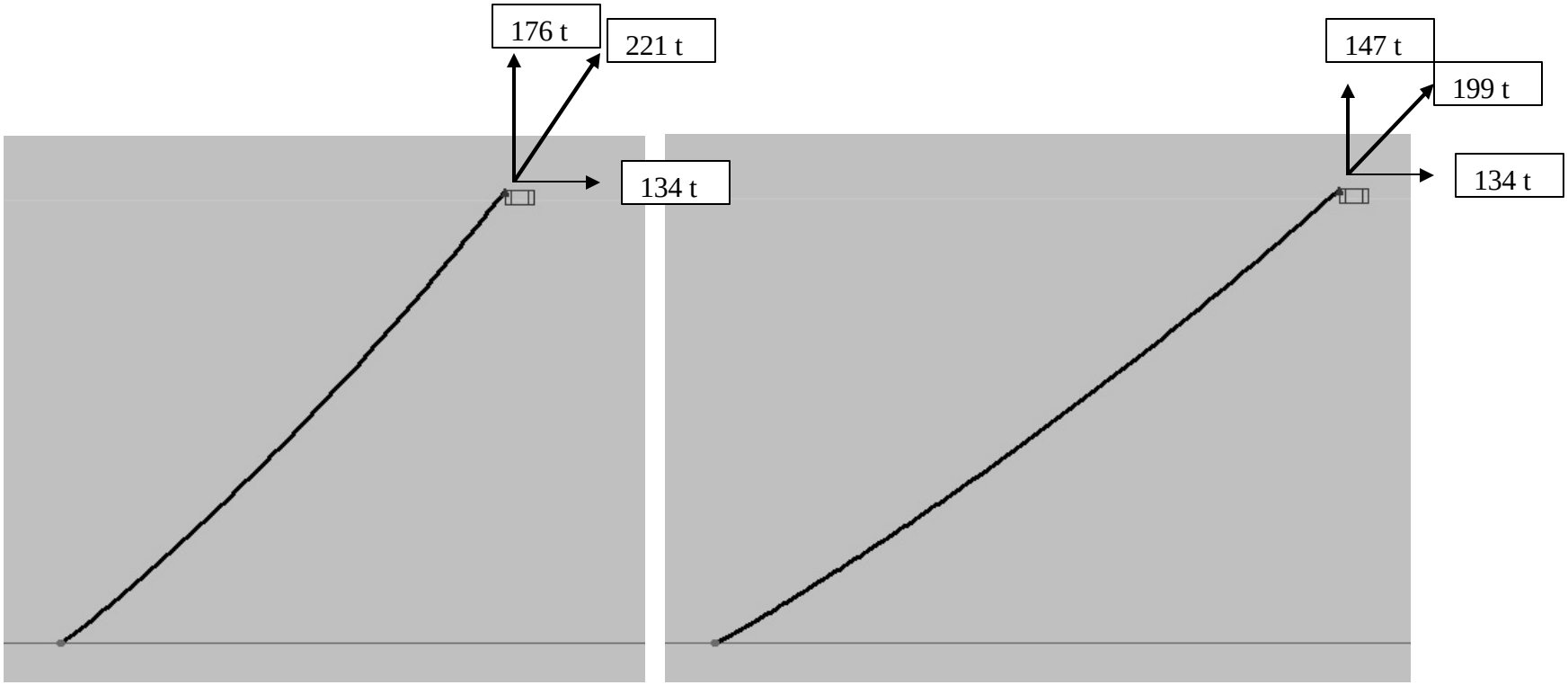

Case 6

Horizontal Tension Components Balance:

- Offloading Lines exert 130 tonnes T_h each
- "North" lines are at lower tensions – add to pull of flowlines
- "South" lines at higher T_h tension to balance pull to North



Line Tension has Vertical & Horizontal Components:



Case 2

Case 6

Conclusions

- Analyzing a mooring system w/o export flowlines is not equivalent to one with flowlines.
- Increasing the allowable anchor radius (EPS) is an effective means of increasing the fatigue life of the mooring chain.
- Fatigue damage can occur in mooring legs away from the swell, too.

Conclusions

- New API RP 2SK Guideline (2005):
  - fatigue life factor of safety is SF=3.
  - Automatically assuming SF=10 will require greatly increased chain sizes.