

# Evaluate New Materials for Deepwater Synthetic Fiber Mooring Systems

***Minerals Management Service Contract  
M09PC00005***

***ADVANCED FIBER ROPES***

***December 4, 2009***

Taking on your toughest technical problems



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# Project and Workshop Objective

1. Determine what Modulus – Spring Constant – is required of Synthetic Fiber Rope Mooring Systems to assure the Structural Integrity of SCR and Top Tensioned Riser Systems in FPS and MODUs.
2. Evaluate what high modulus fiber materials are best suited for long-term mooring system Service.

# Moored Semi Analysis

- Numerical model usings RAMS software based on 4-Column 'Medium' Simi described in DeepStar 7404 and OTC 18467
- Hull:
  - Displacement = 60,000 short tons
  - Length/Width = 242 feet
  - Height = 170 feet
  - Deck Area = 85,000 sq ft
  - Topsides payload = 12,000 short tons

# Coupled Analysis Conditions

- 3 water depths
  - 5,000 ft
  - 10,000 ft
  - 15,000 ft
- 3 mooring rope EA stiffnesses
  - 17.2 x MBL (Low) - *polyester*
  - 34.4 x MBL (Medium) - *PEN*
  - 51.6 x MBL (High) – *aramid/HMPE*
- 4 environments
  - Fatigue event ( $H_S = 6.6$  ft)
  - 10-Yr hurricane ( $H_S = 32.8$  ft)
  - 100-Yr hurricane ( $H_S = 51.8$  ft)
  - 1000-Yr hurricane ( $H_S = 65.0$  ft)

# Mooring Model

- Nominal horizontal force = 295 kips
- MBL = 3970 kips
- Nominal pretension ~ 15% of MBL
- Aspect ratio is approximately constant

Water Depth	Horizontal Force	Pretension		Aspect Ratio
		(kips)	(% MBL)	
(ft)	(kips)	(kips)	(% MBL)	(-)
5,000	295	534	13.5%	1.07
10,000	295	557	14.0%	1.06
15,000	295	580	14.6%	1.06

# Mooring Model

## Details of Each Mooring Leg

Component Description	Component Weight		Component Length		
	In Seawater	In Air	5000-ft Water Depth	10,000-ft Water Depth	15,000-ft Water Depth
	(lb/ft)	(lb/ft)	(ft)	(ft)	(ft)
Ground Chain	218	251	656	656	656
Connector	232	266	6	6	6
Rope	7	26	1,577	3,531	5,492
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Connector	232	266	6	6	6
Rope	7	26	1,577	3,531	5,492
Connector	232	266	6	6	6
Rope	7	26	1,151	2,577	4,008
Connector	232	266	6	6	6
Platform Chain	218	251	656	656	656

# Steel Catenary Model

- Wet Insulated flowline
- 10.750-in OD x 1.375-in WT
- Shape parameter  $F_H/WD \sim 2900$
- Fully straked

<b>Water Depth</b>	<b>Horizontal Force</b>	<b>Top Tension</b>	<b>Top Angle</b>	<b><math>F_H/WD</math></b>
<b>(ft)</b>	<b>(kips)</b>	<b>(kips)</b>	<b>(kips)</b>	<b>(-)</b>
5,000	270	778	20.3	2,902
10,000	270	1,297	12.0	2,902
15,000	270	1,815	8.5	2,902

# Top-Tensioned Riser Model

- Dual-casing riser
  - Outer casing - 10.750-in x 0.650-in
  - Inner casing – 7.625-in x 0.500-in
  - Tubing – 3.500-in x 0.254-in
- Steel stress joint
  - Length = 29.2-ft
  - Wall thickness at base of taper = 1.500-in

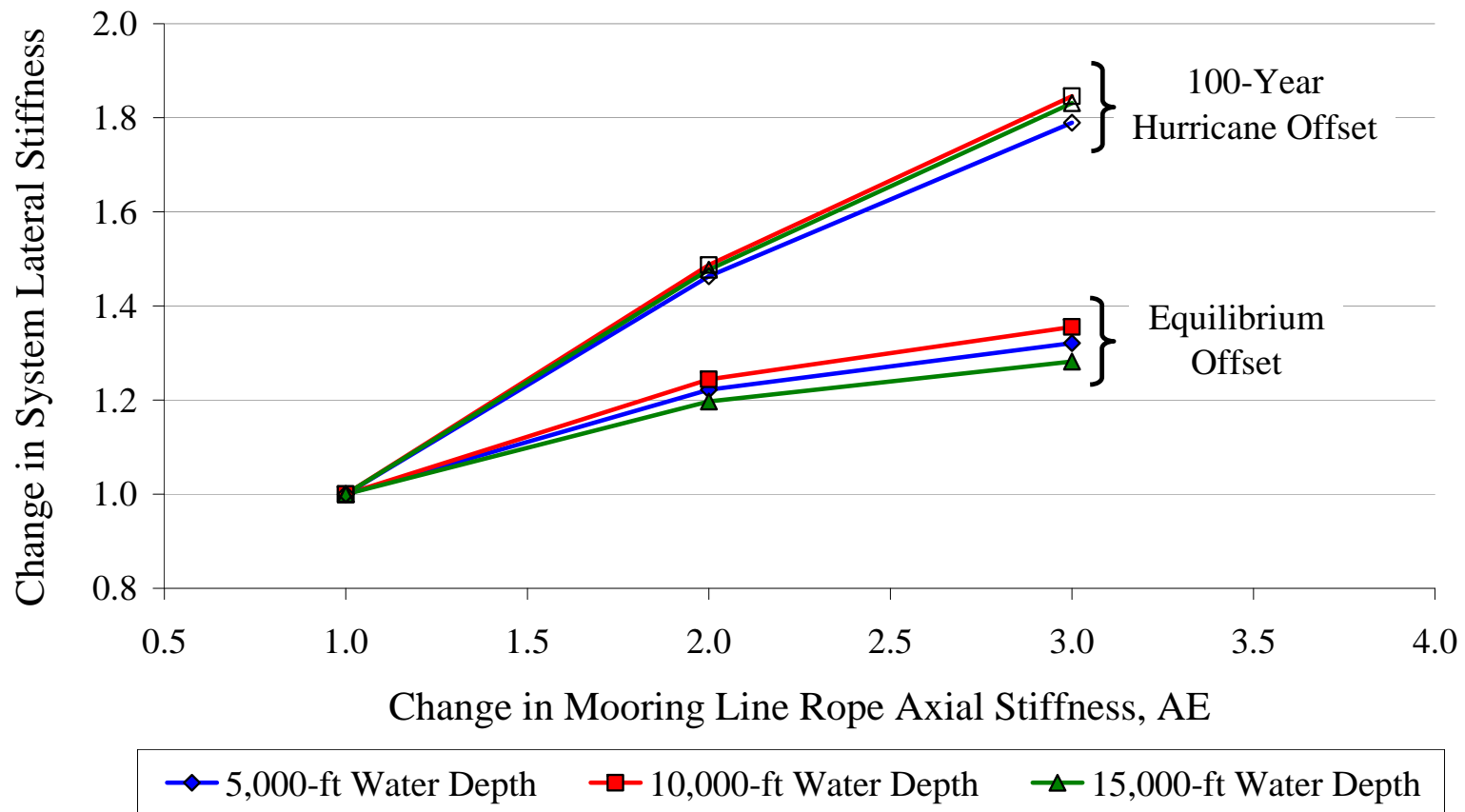
# Top-Tensioned Riser Model

- Overpull at stress joint = 200 kips
- Tensioner stiffness = 1.5% of nominal tension

<b>Water Depth</b>	<b>Nominal Tension</b>	<b>Tensioner Stiffness</b>	<b>Overpull</b>
<b>(ft)</b>	<b>(kips)</b>	<b>(kips)</b>	<b>(kips)</b>
5,000	767	11.5	200
10,000	1,289	19.3	200
15,000	1,811	27.2	200

# Lateral System Stiffness

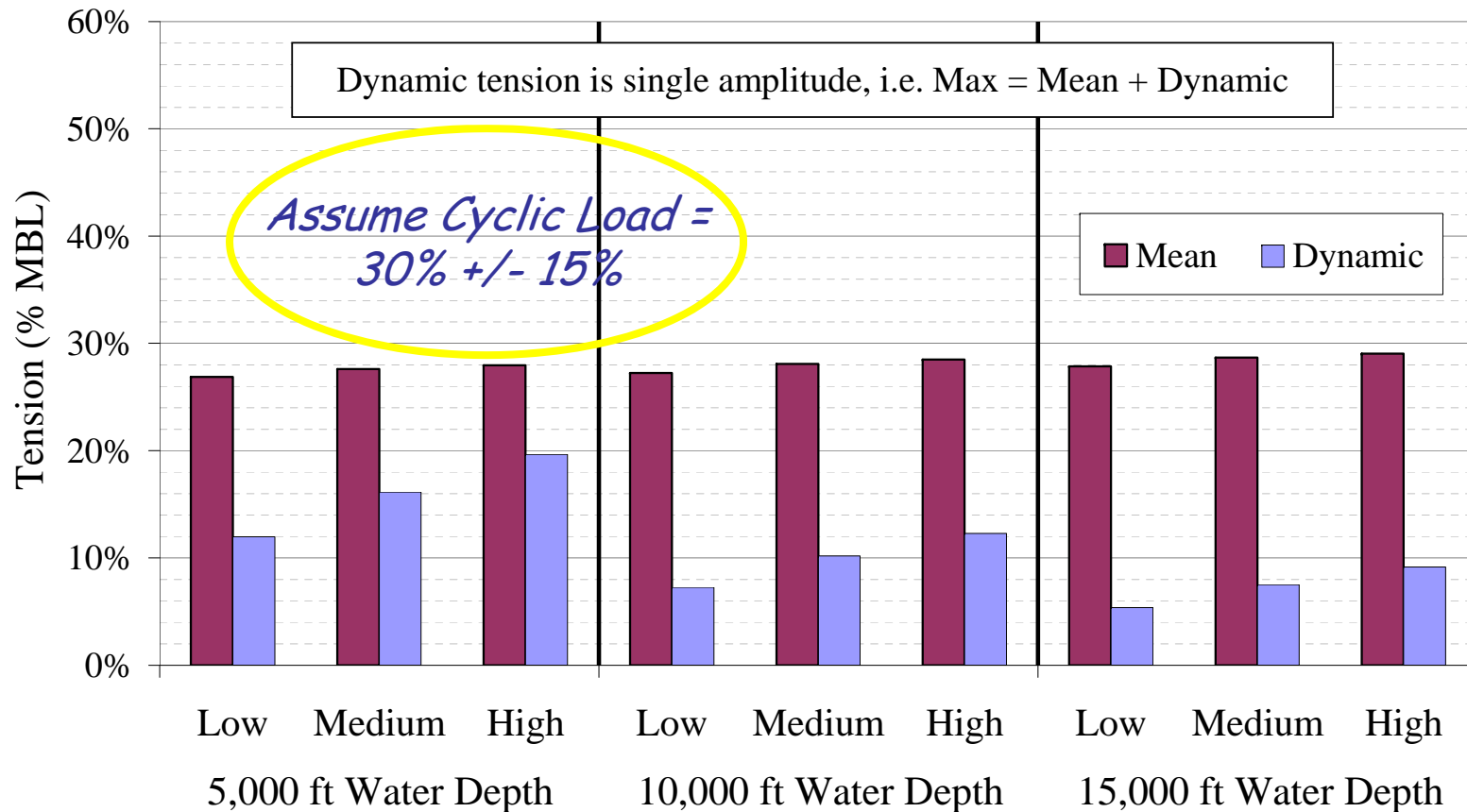
MMS Mooring Analysis Study - 12 Mooring Line Configuration  
Change in System Lateral Stiffness vs Change in Mooring Rope Axial Stiffness  
Lateral Tangent Stiffness at Equilibrium Offset and 100-Year Hurricane Offset



# Mooring Tension – 100-Yr Hurricane

MMS Mooring Analysis Study - 12 Mooring Line Configuration  
100-Yr Hurricane ( $H_s = 51.8$  ft)

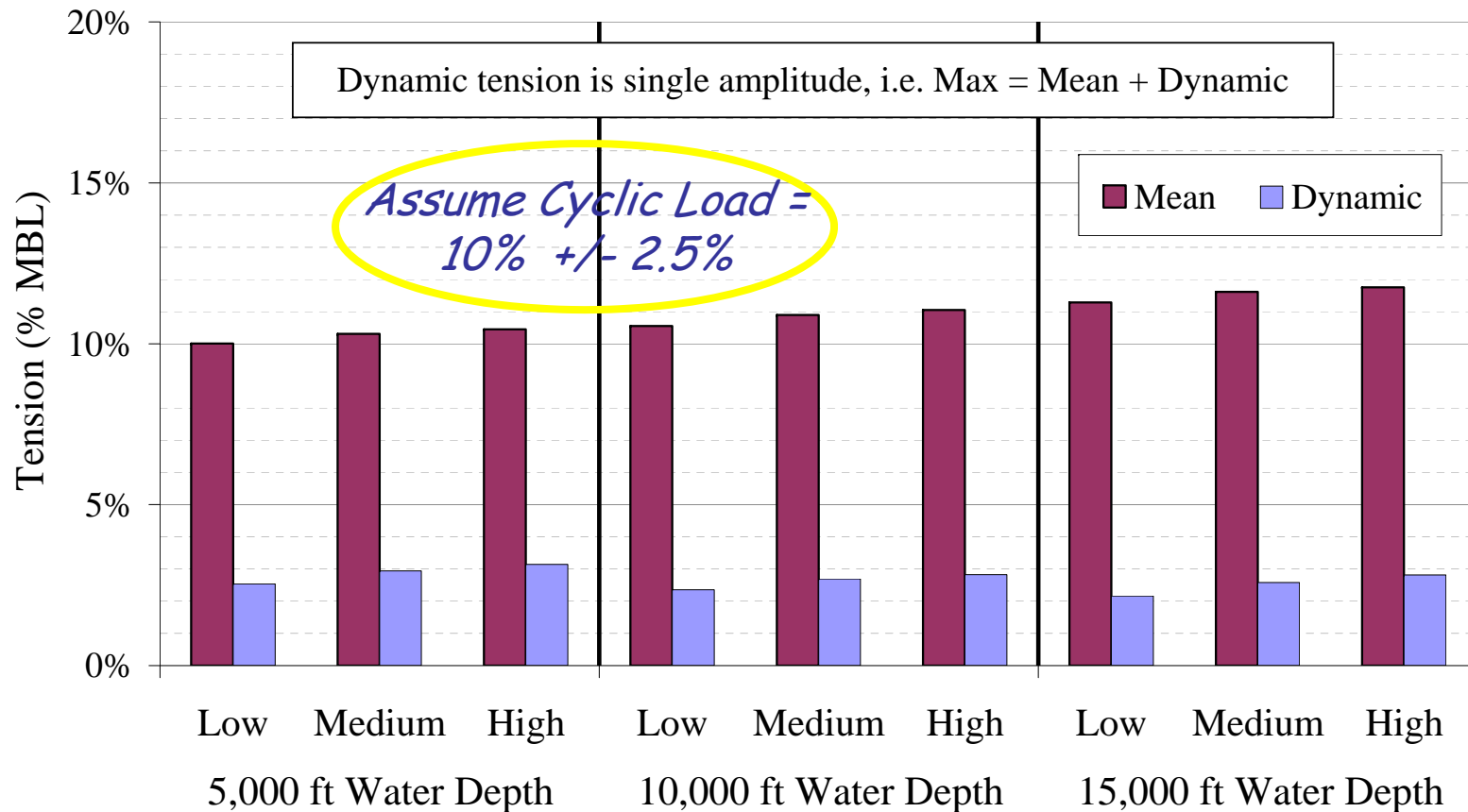
## ROPE TENSION IN MOST LOADED LINE



# Mooring Tension – 100-Yr Hurricane

MMS Mooring Analysis Study - 12 Mooring Line Configuration  
100-Yr Hurricane ( $H_s = 51.8$  ft)

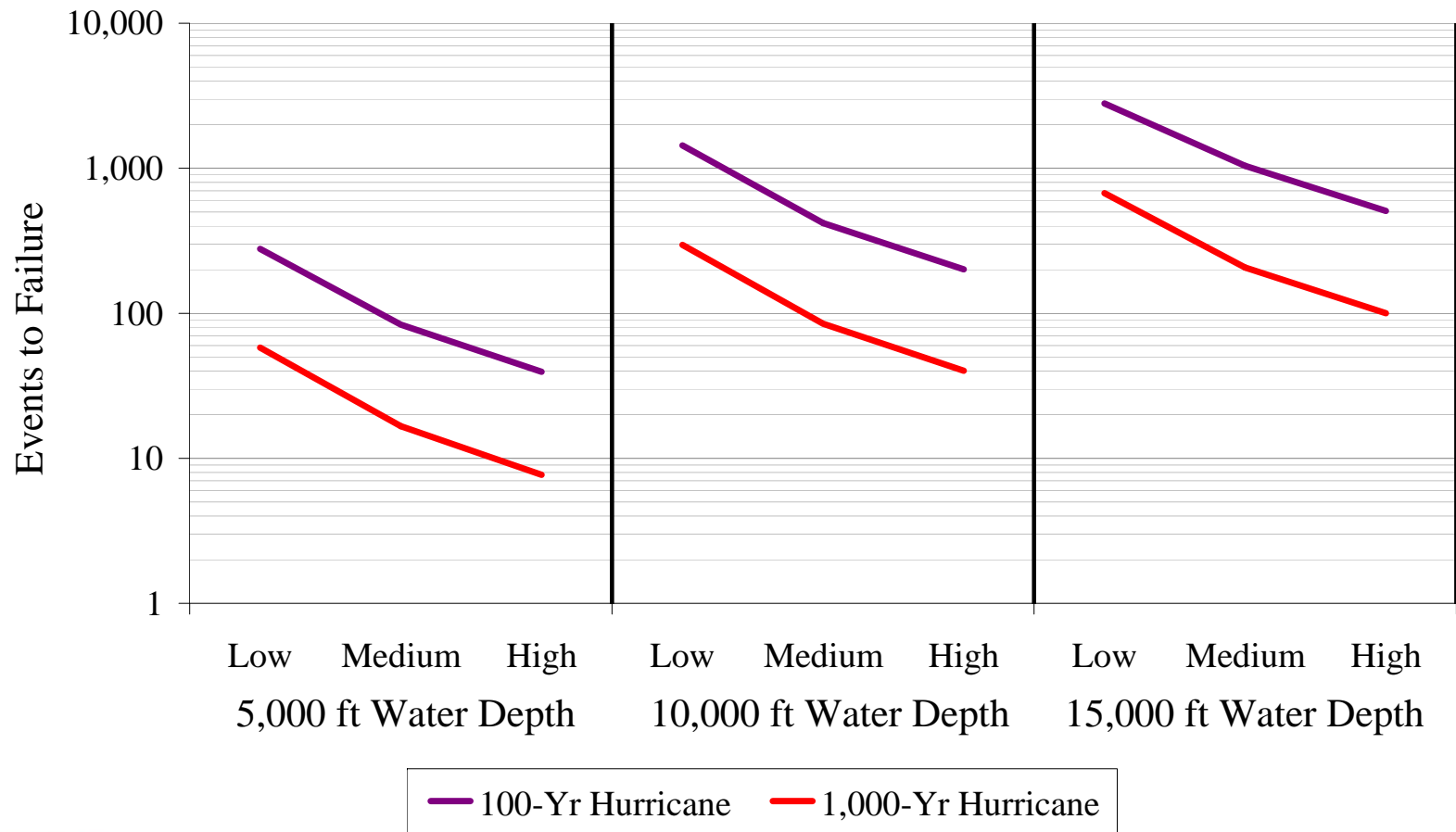
## ROPE TENSION IN LEAST LOADED LINE



# Mooring Chain Fatigue

MMS Mooring Analysis Study  
12 Mooring Line Configuration

Number of Events to Failure for Mooring Chain

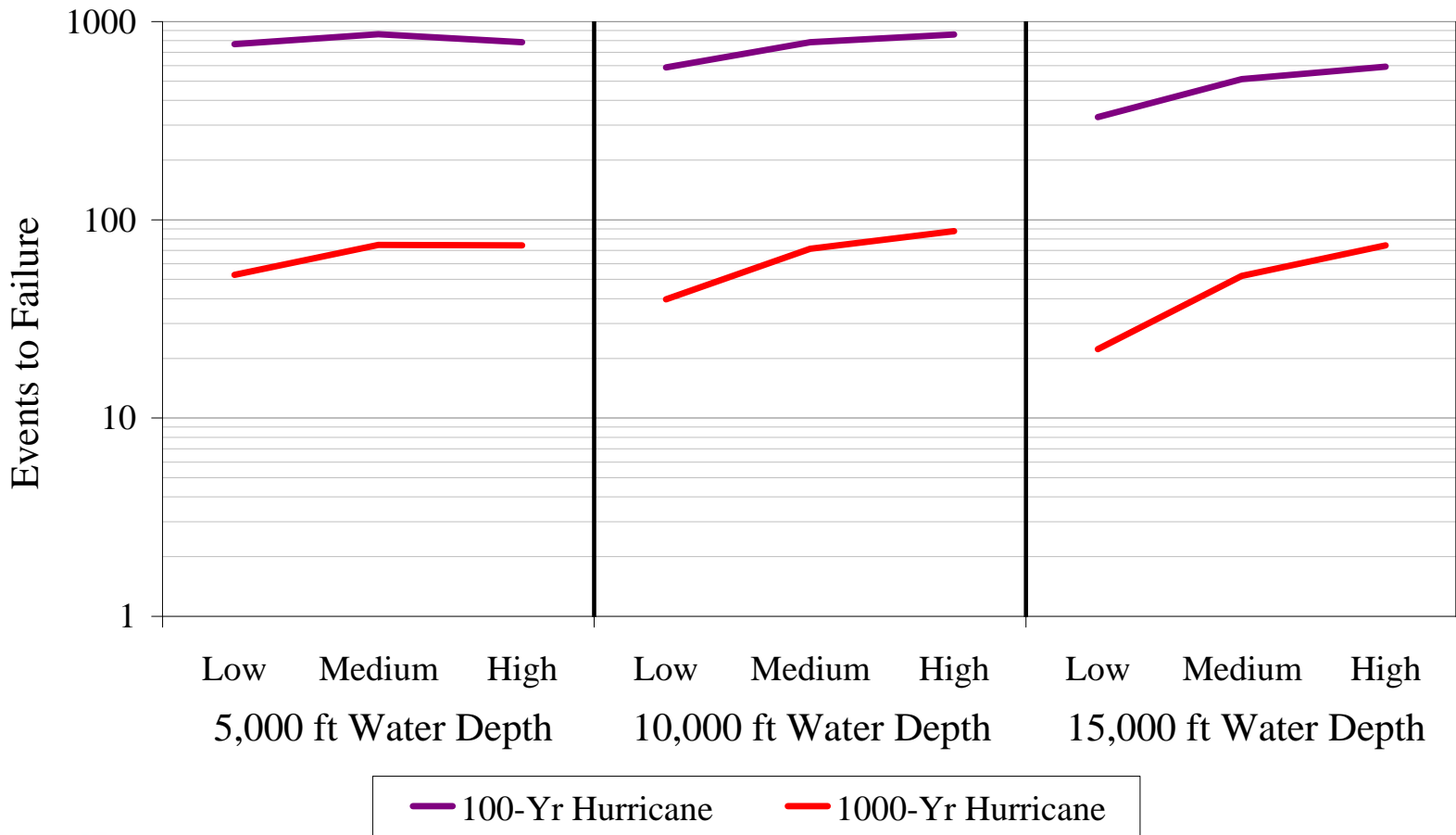


# SCR – Relative TDP Fatigue

MMS Mooring Analysis Study - 12 Mooring Line Configuration

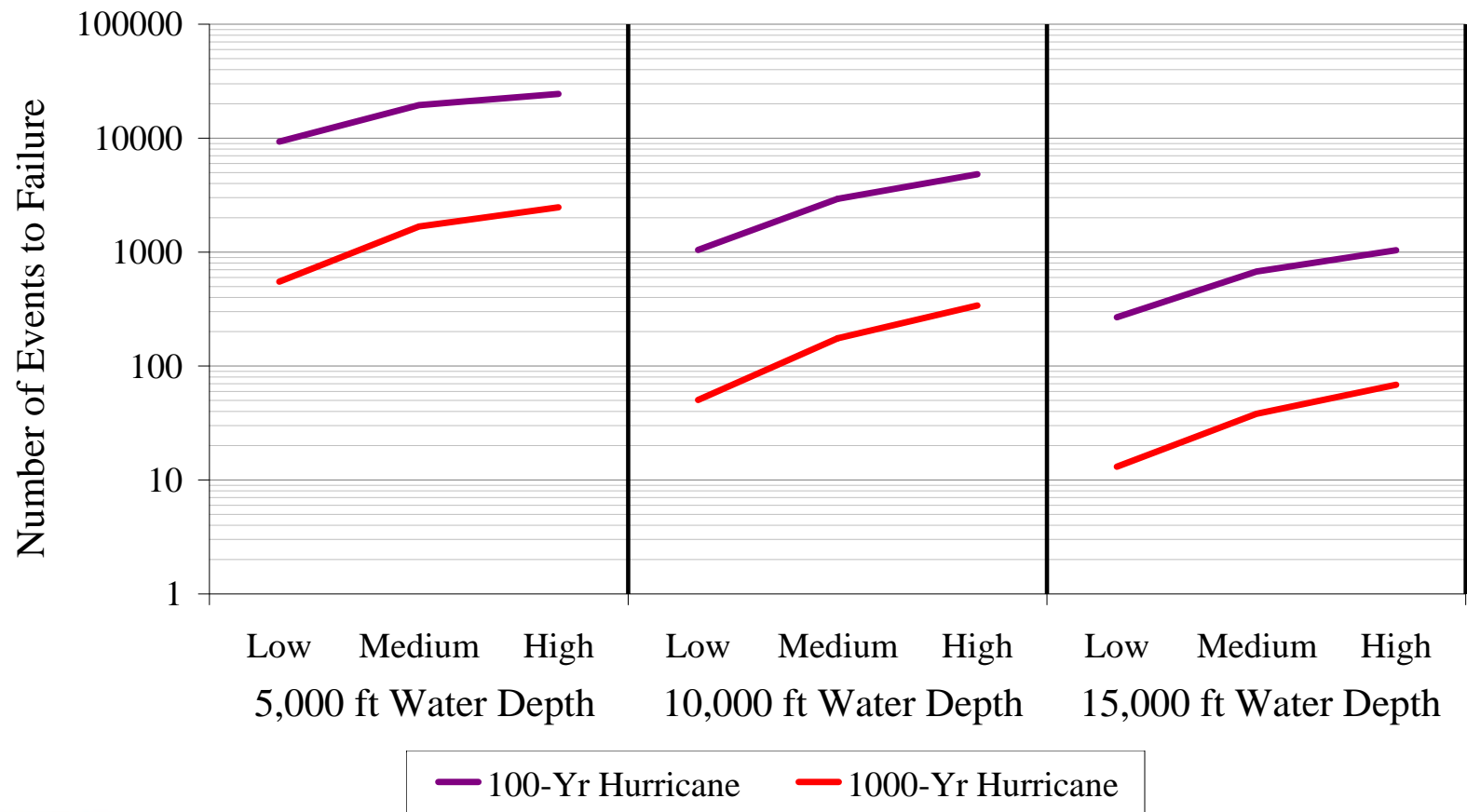
Number of Events to Failure at SCR Touchdown

Assumed Fatigue Curve: DNV C, SAF = 1.0



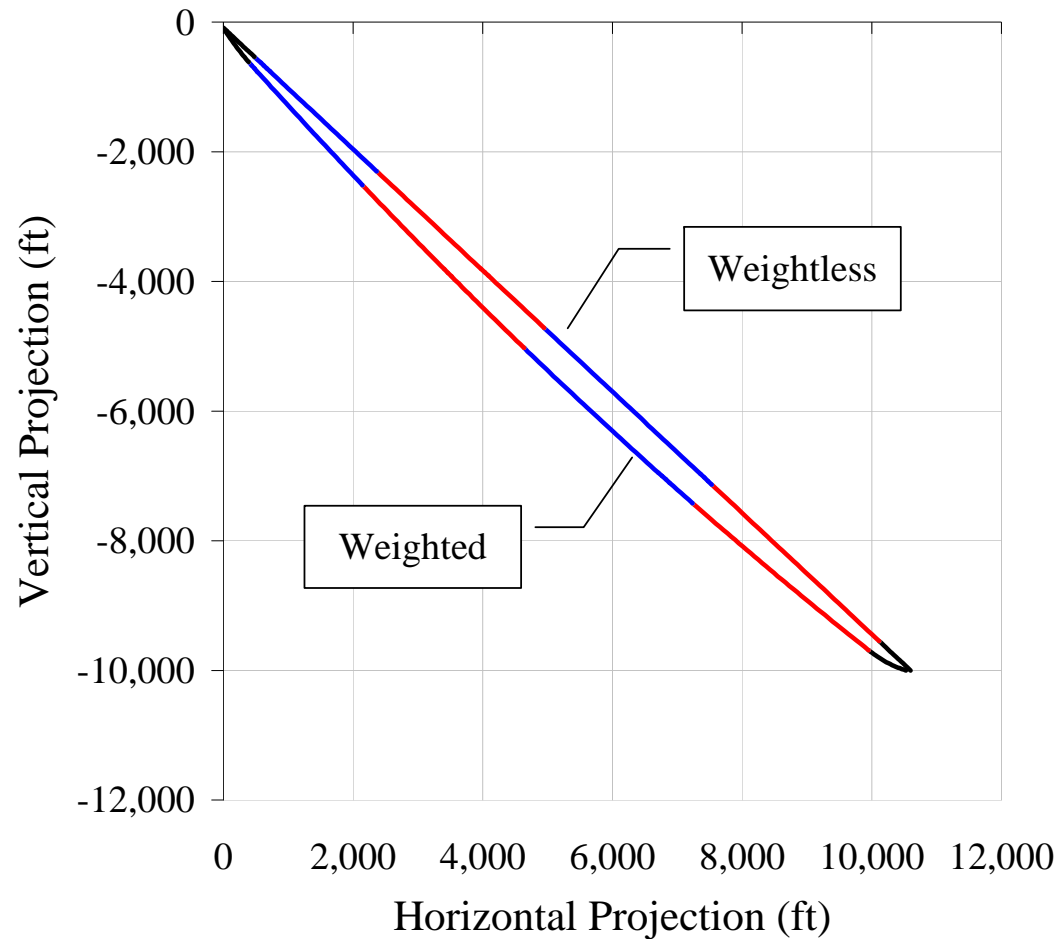
# TTR – Relative Stress Joint Fatigue

MMS Mooring Analysis Study - 12 Mooring Line Configuration  
Number of Events to Failure at TTR Seafloor Stress Joint  
Assumed Fatigue Curve: DNV B, SAF = 1.0



# Effect of Catenary Shape

Single Mooring Line Elevation at Zero Offset



# Analysis Conclusions

- Polyester 'works' for all water depths studied
- High-modulus fibers work as well
- A catenary effect is caused by the weight of steel components in the mooring leg, and that makes the mooring semi-taut, rather than taut
- Due to the catenary effect, a high-modulus fiber rope with an in line stiffness 3 times that of polyester will increase the lateral spring constant of the mooring leg only 80 % over polyester.

# Evaluation of Advanced Fiber Ropes

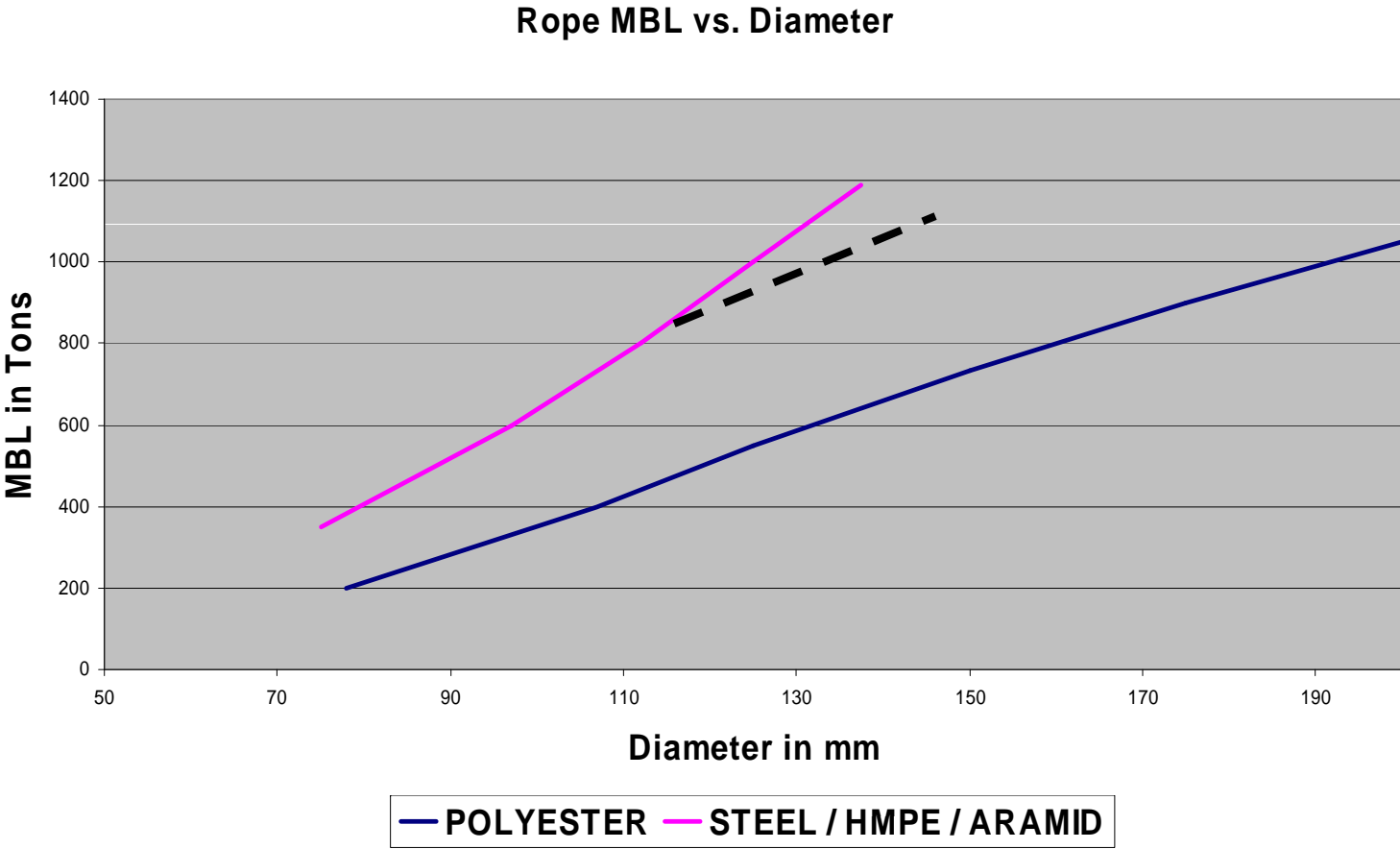
## *Fiber, Yarn, Subrope and Rope Characteristics*

Taking on your toughest technical problems

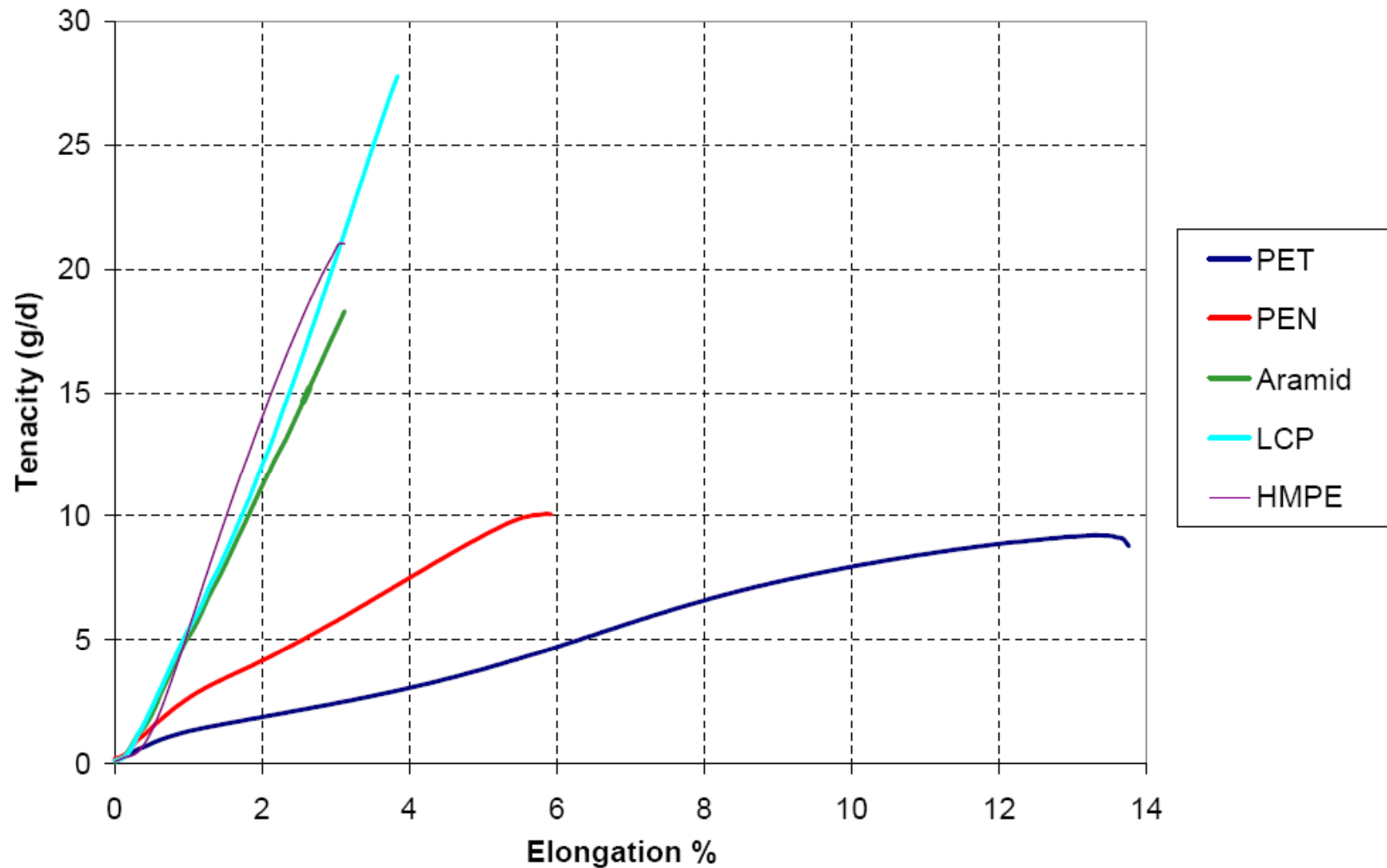


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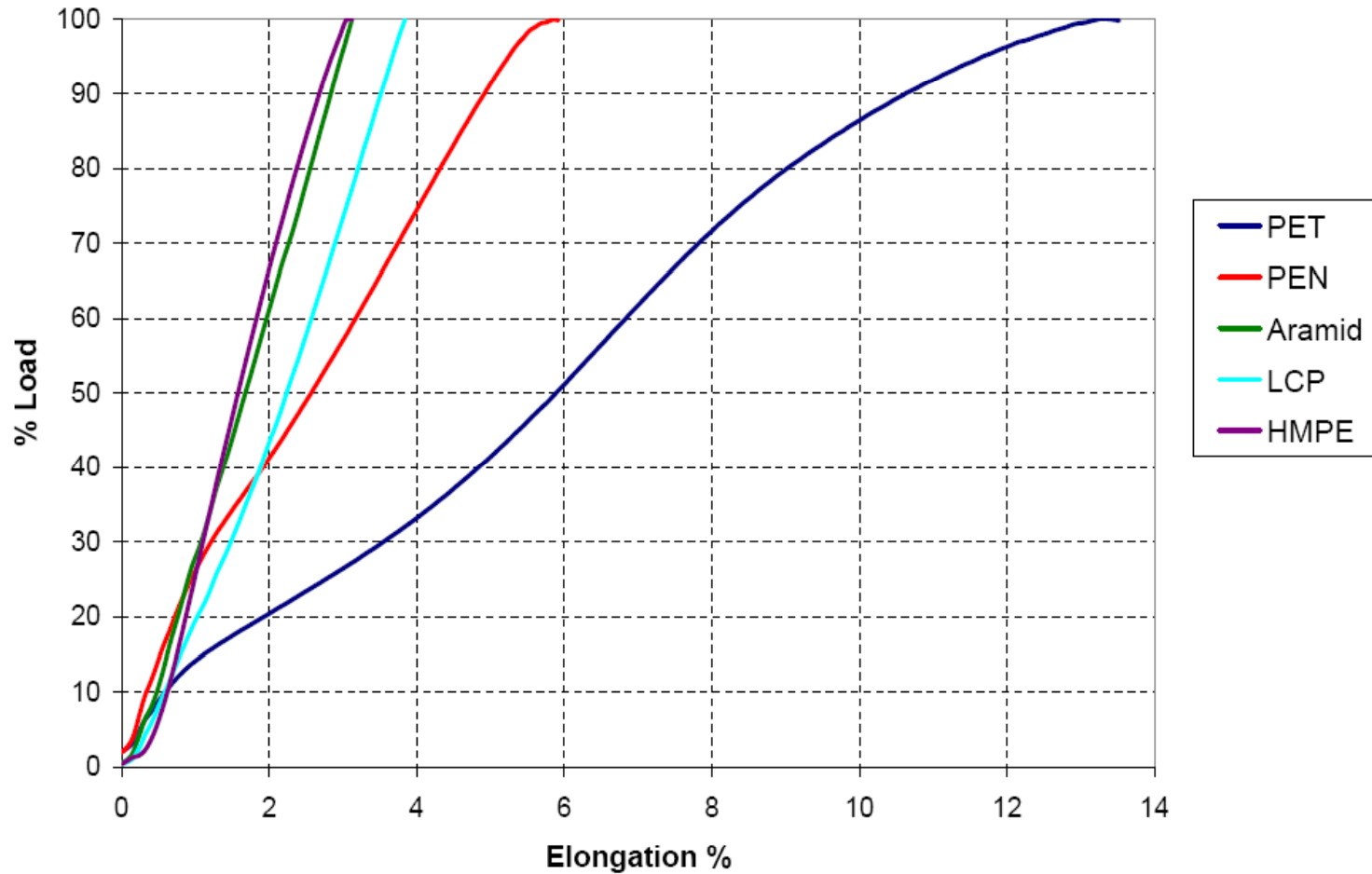
# Rope MBL vs. Diameter



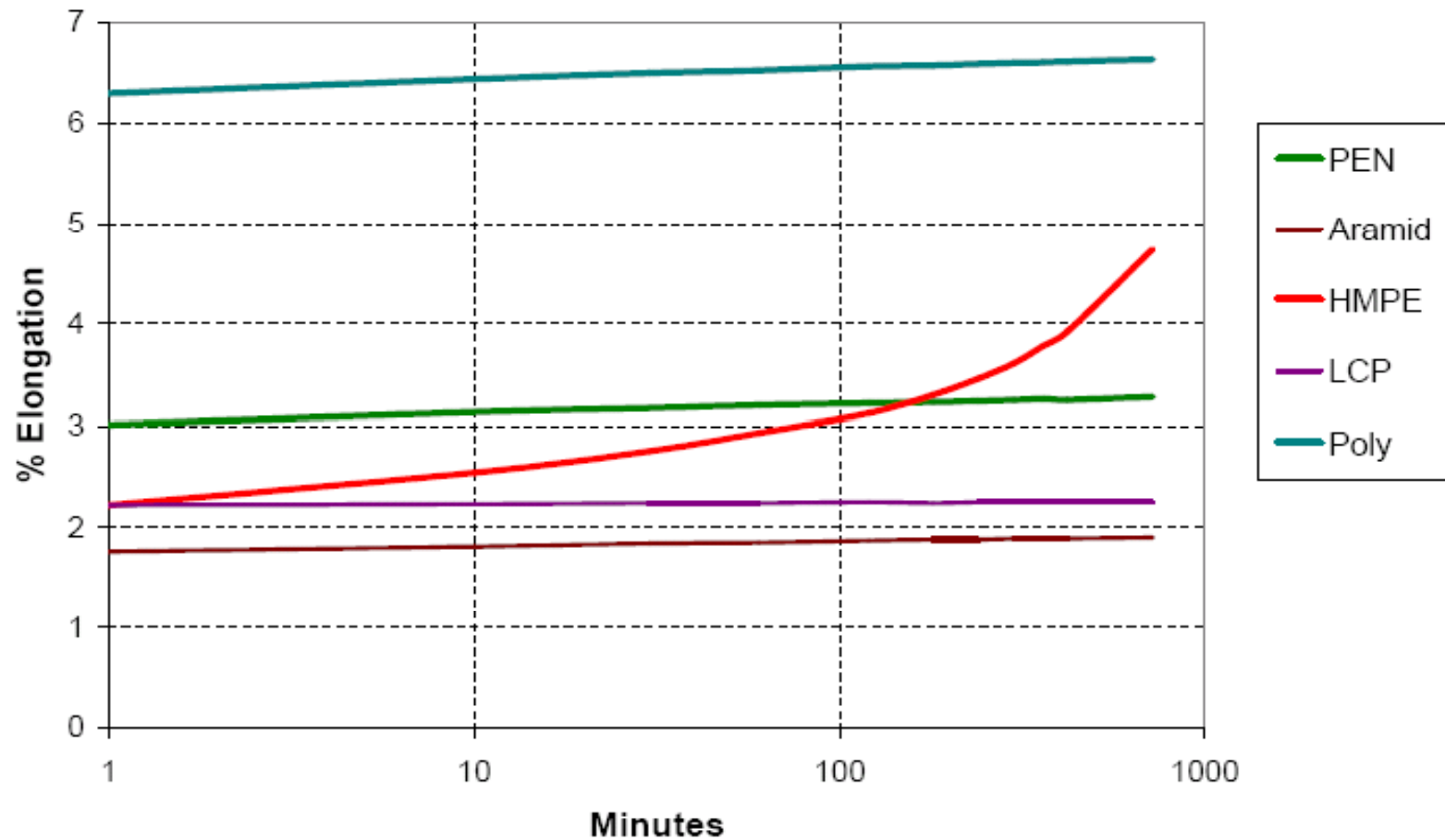
# Fiber Stress-Strain Curves



# 100% Load Curve for Hi-Mod Fibers



# Creep at 50% Load



# Yarn on Yarn Test Apparatus

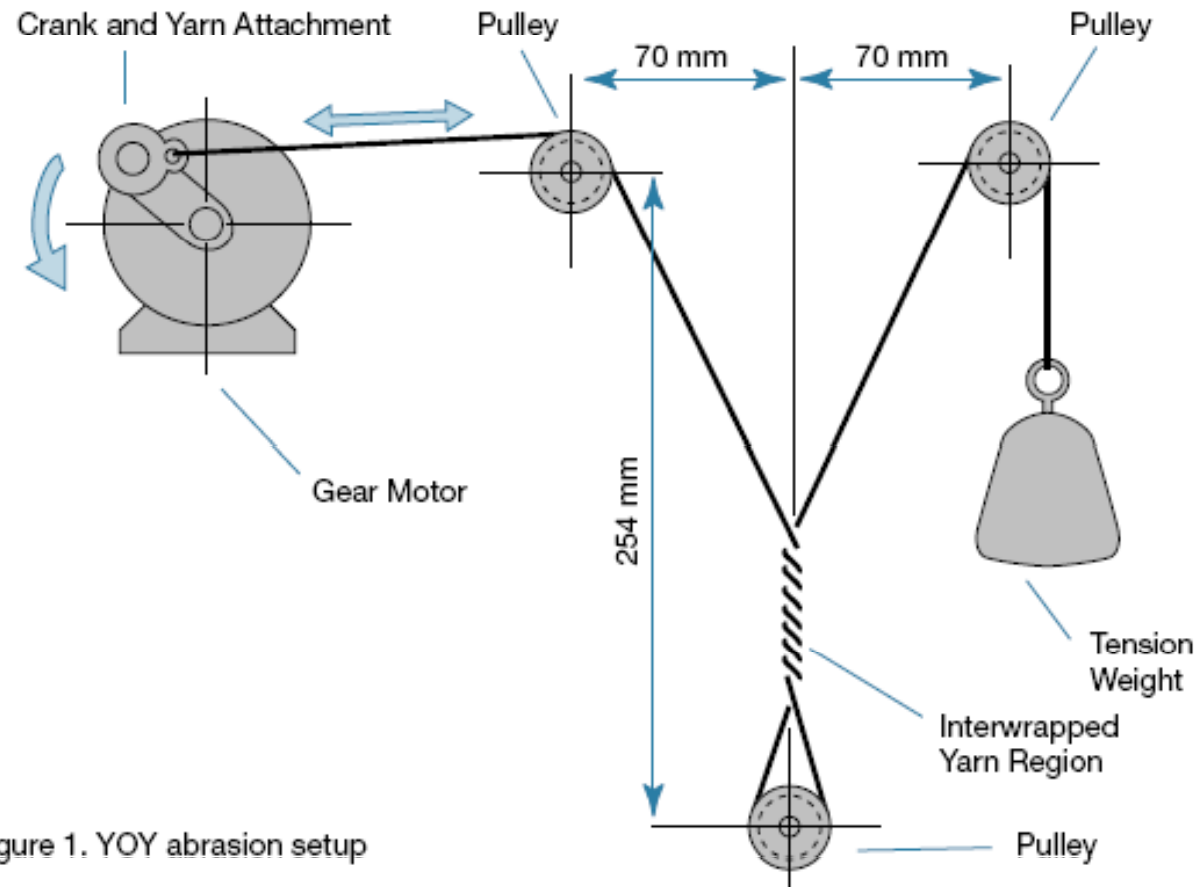
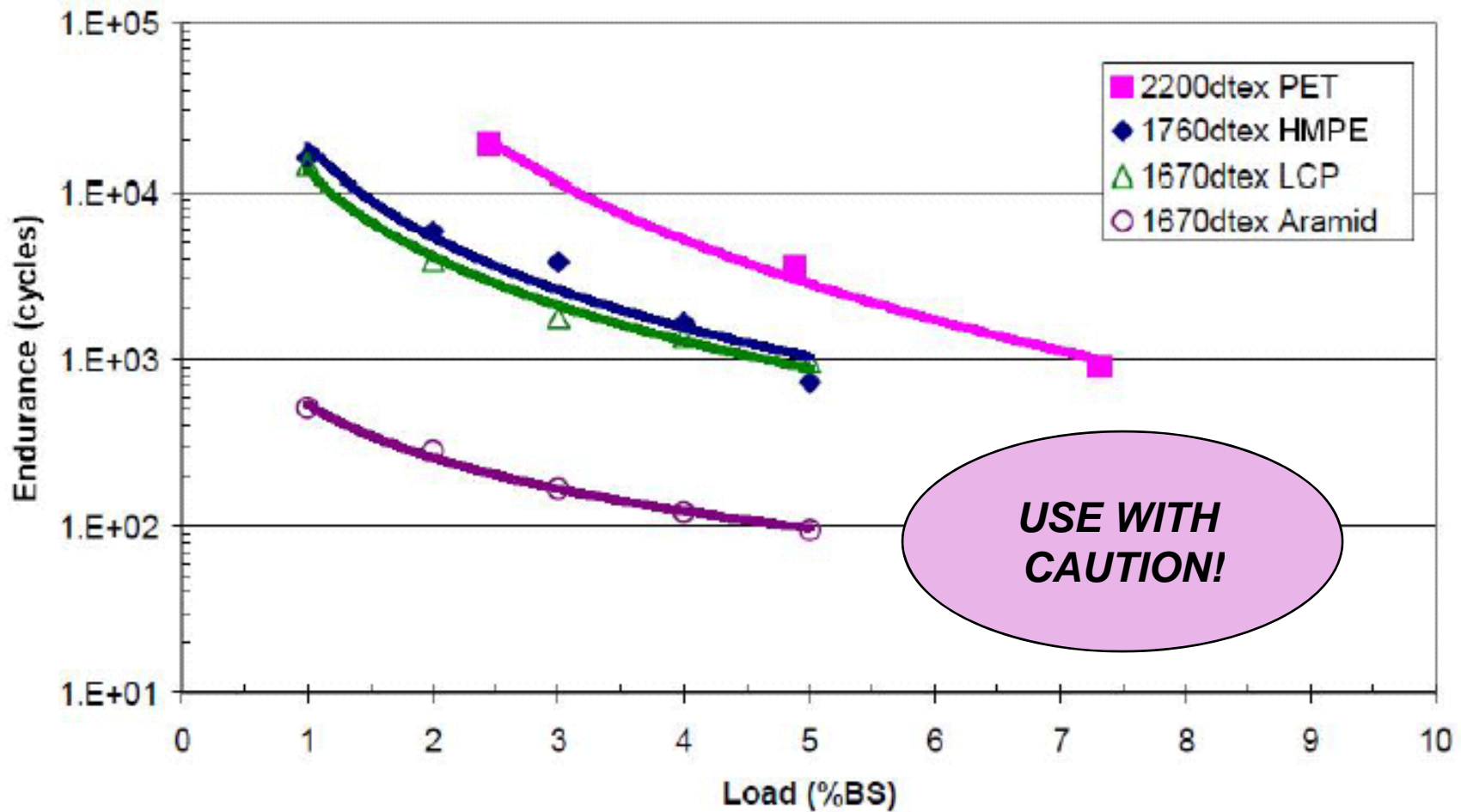


Figure 1. YOY abrasion setup

# Yarn-On-Yarn Results for Various Fibers



# Strand on Strand Test Method

## (20 Hurricane Test)

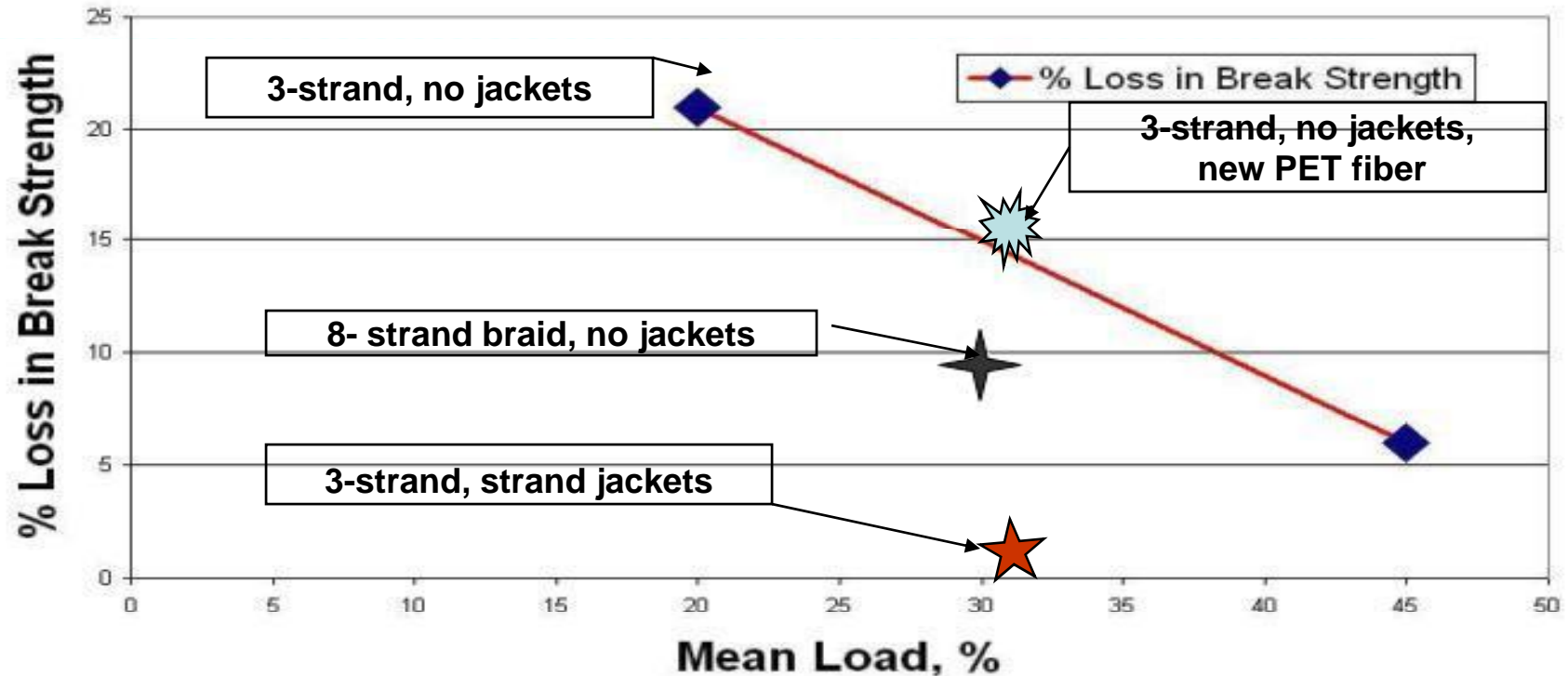
1. Individually test to break 3 subrope samples – obtain average break strength (ABS – Un-cycled)
2. Put 3 more subropes on the same pins (in parallel) and apply cyclic loads A or B for 20,000 cycles.
3. Individually test to break the 3 subrope samples previously cycled in (2) and obtain average break strength (ABS - Cycled) of these cycled samples.
4. Determine % loss in break strength of cycled subropes vs. un-cycled ones.

High Cyclic Loads A:  
30% ABS +/- 15% ABS

Low Cyclic Loads B:  
10% ABS =/- 2.5% ABS

# Strand on Strand Abrasion

## % Loss in Break Strength vs. Mean Load



**Note: A 15% loss of break strength at 30% +/-15% Load cycles for 20 Hurricanes is very acceptable. For a more realistic number hurricanes, like 1 to 3, the strength loss would be less than 3%, well within 2SM.**

# Strand on Strand Tests

4 SRs during cycling

Single SR for break test



# Materials Conclusions

- **High modulus fiber rope has benefit for drilling applications where a smaller diameter rope is easier to handle.**
- **Concerns with Aramids include low mean load cycling and abrasion issues**
- **The concern with HMPE is dealing with creep**
- **Yarn-On-Yarn abrasion testing is not appropriate for comparing various modulus materials.**
- **Strand on Strand abrasion (20 hurricane test) can be used to compare/contrast the cyclic wear of various materials.**