TASK 2

MOORING LOAD ESTIMATION UNCERTAINTY

1. SUMMARY

2. MEAN ENVIRONMENT LOADS

   - WIND FORCE
   - CURRENT FORCE
   - WAVE-DRIFT LOAD

3. VESSEL DYNAMIC OFFSETS

   - WAVE-FREQUENCY MOTIONS
   - LOW-FREQUENCY MOTIONS

4. ESTIMATION OF LF DAMPING FORCES

   - VESSEL WAVE-DRIFT DAMPING
   - VESSEL VISCOUS DAMPING
   - VESSEL AERODYNAMIC DAMPING
   - MOORING LINE DAMPING
     - MATERIAL
     - SOIL
     - COUPLED LF-WF MOTIONS

SUMMARY

1. PURPOSE

- TO QUANTIFY LOAD UNCERTAINTIES
- TO PRODUCE INITIAL ENGINEERING ESTIMATES OF LF DAMPING

2. RELATIVE ACCURACY OF MEAN LOADS

	SEMI	SHIP
WIND	GOOD	FAIR
CURRENT	FAIR	FAIR
WAVE	FAIR	FAIR

3. RELATIVE ACCURACY OF MOTIONS

	SEMI	SHIP
WF MOTION	GOOD	GOOD
LF MOTION	POOR	POOR

4. LF DAMPING PER GOMEX 10-YEAR STORM (% OF SYSTEM CRITICAL, WD = 1000')

	SEMI (SEDCO 700)		DRILLSHIP (L=380')	
	HEAD	BEAM	HEAD	BEAM
VESSEL				
DRIFT DAMPING	.2	.2	1	2.9
VISCOUS	1.7 TO 13	2.5 TO 22	.2 TO 2.3	7 TO 26
AERODYNAMIC	2.7	1.9	2	3.4
MOORING LINES	4.6 TO 9.8	4.6 TO 9.8	4 TO 22	9 TO 24
TOTAL	9 TO 21%	9 TO 34%	7 TO 27%	22 TO 56%

WIND AND CURRENT LOAD

1. VESSEL TYPES

   - SEMISUBMERSIBLES
   - DRILL SHIPS

2. DATA SOURCE

   - MODEL TEST DATA (BASE CASE)
   - OPERATIONS MANUALS
   - LITERATURE

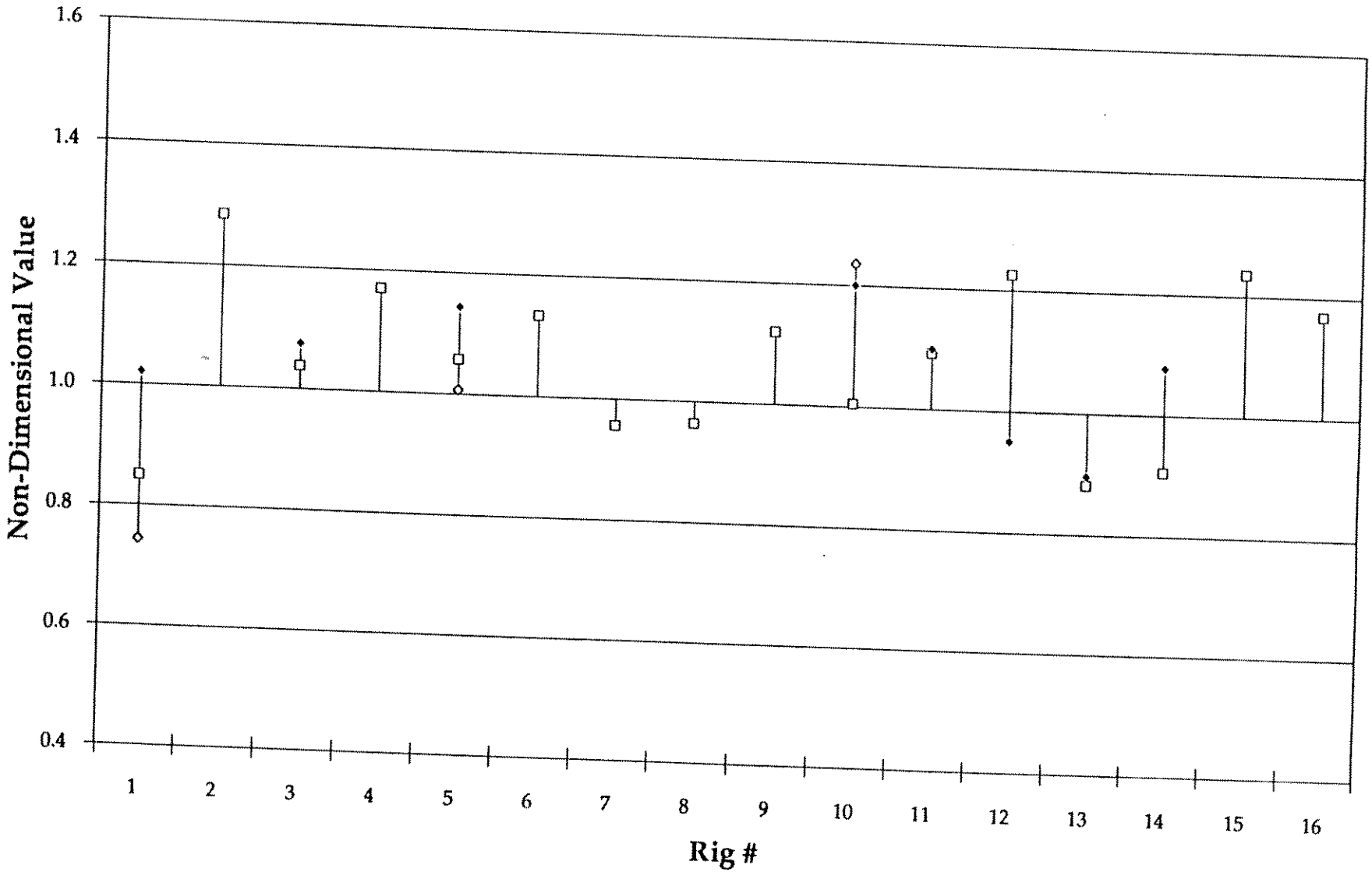
3. MAIN FINDINGS ON SEMISUBMERSIBLES

   - REASONABLE AGREEMENT FOR WIND COEFFICIENT
   - SUBSTANTIAL BODY OF KNOWLEDGE
     (DUE TO STABILITY CONCERNS)
   - SIGNIFICANT VARIATION FOR CURRENT COEFFICIENT

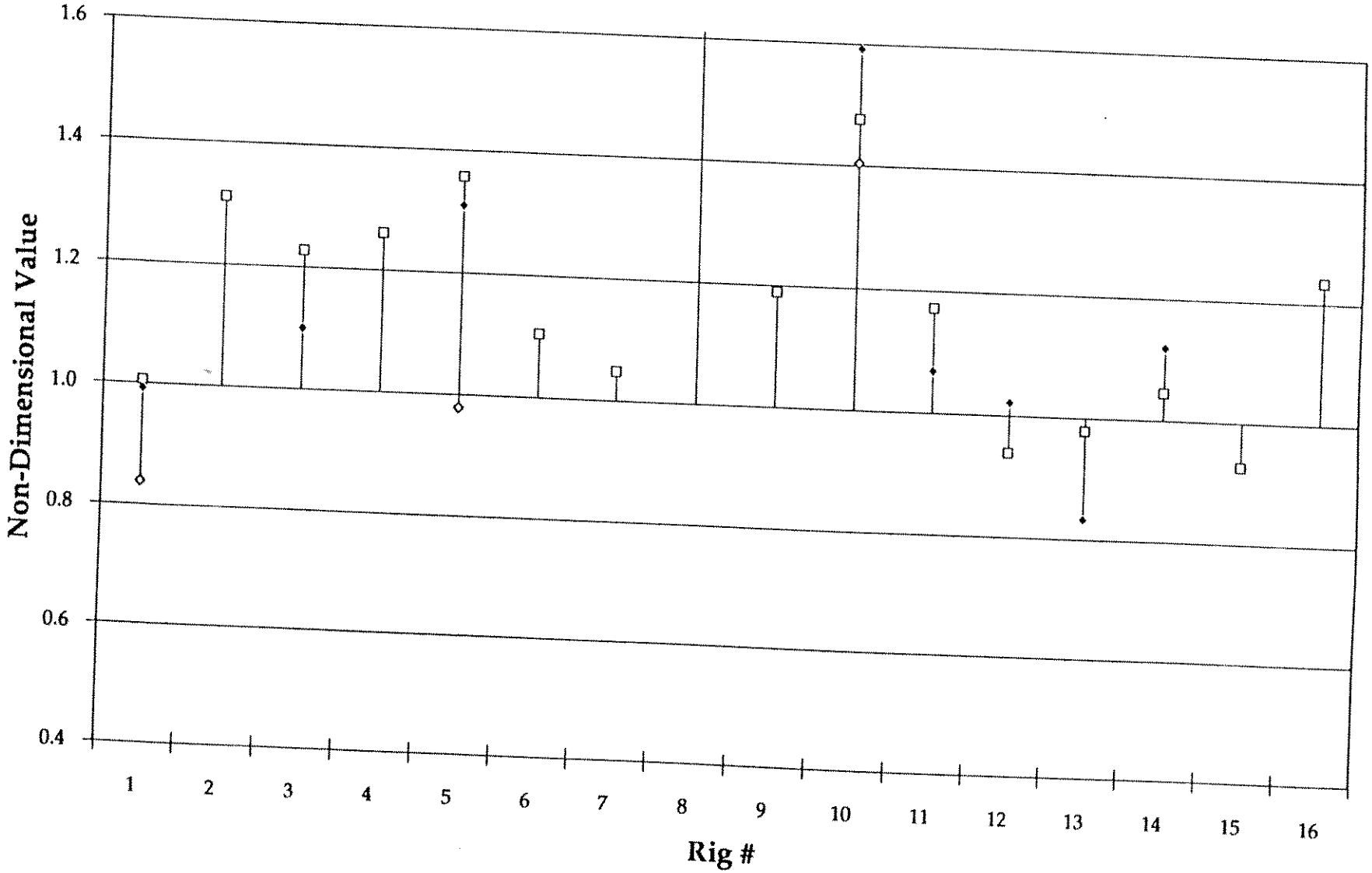
4. MAIN FINDINGS ON DRILL SHIPS

   - SCANT INFORMATION
   - SIGNIFICANT VARIATION FOR WIND COEFFICIENT
   - WIDE SPREAD FOR CURRENT COEFFICIENT

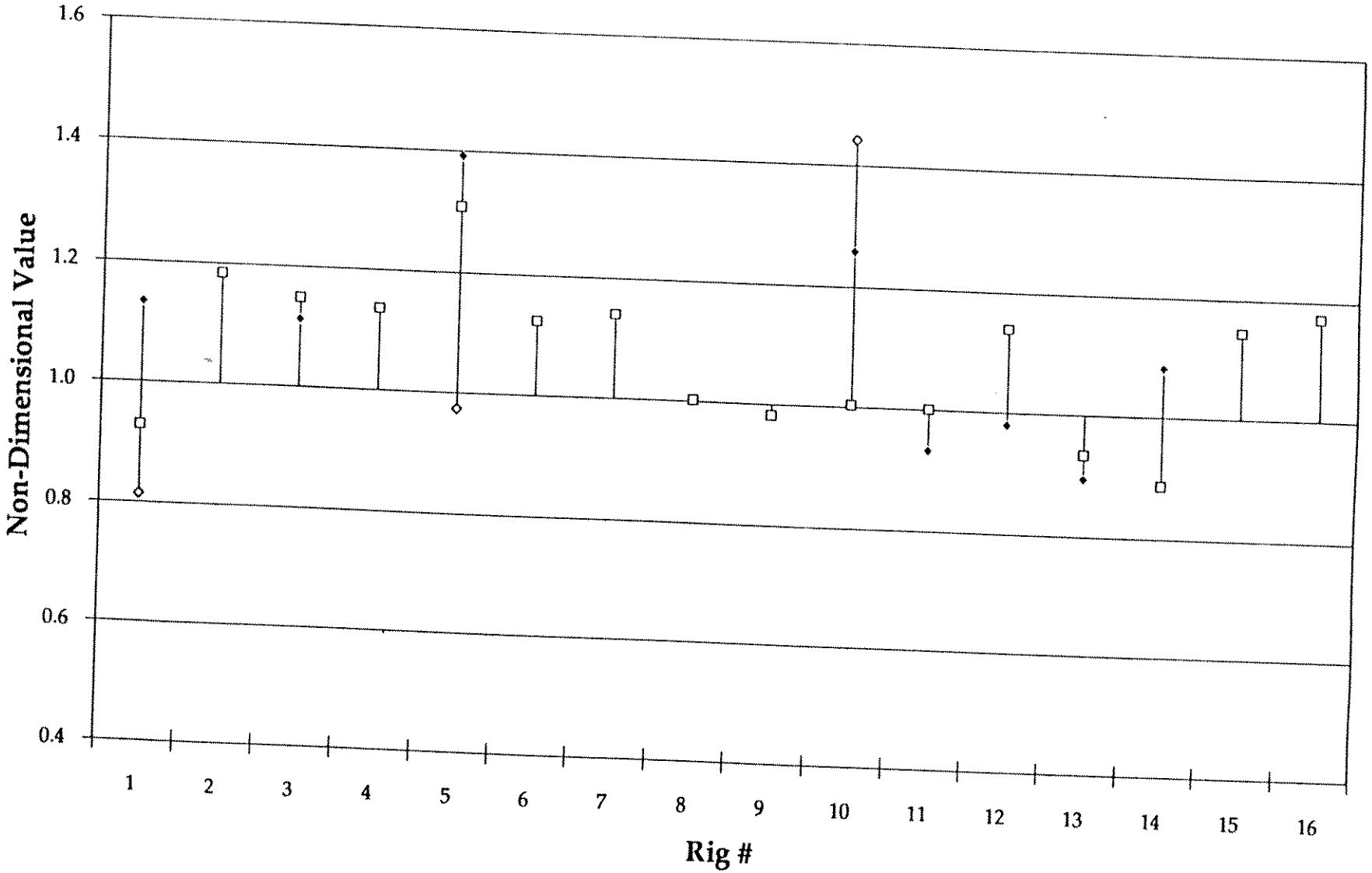
SEMI-SUBMERSIBLE - WIND COEFFICIENT - HEAD SEAS
VALUES NORMALIZED TO MODEL TEST DATA



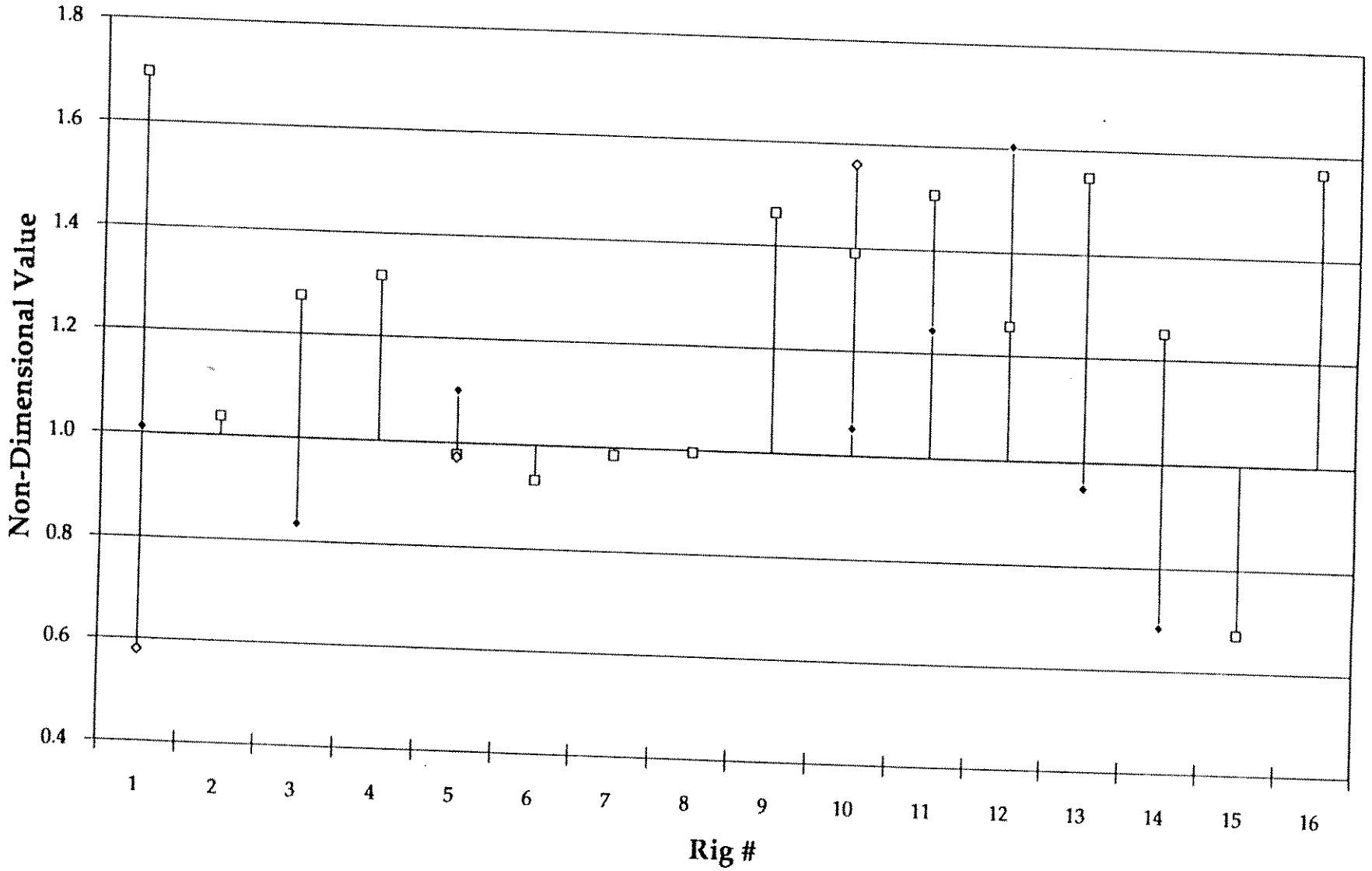
SEMI-SUBMERSIBLE - WIND COEFFICIENT - QUARTERING SEAS
VALUES NORMALIZED TO MODEL TEST DATA



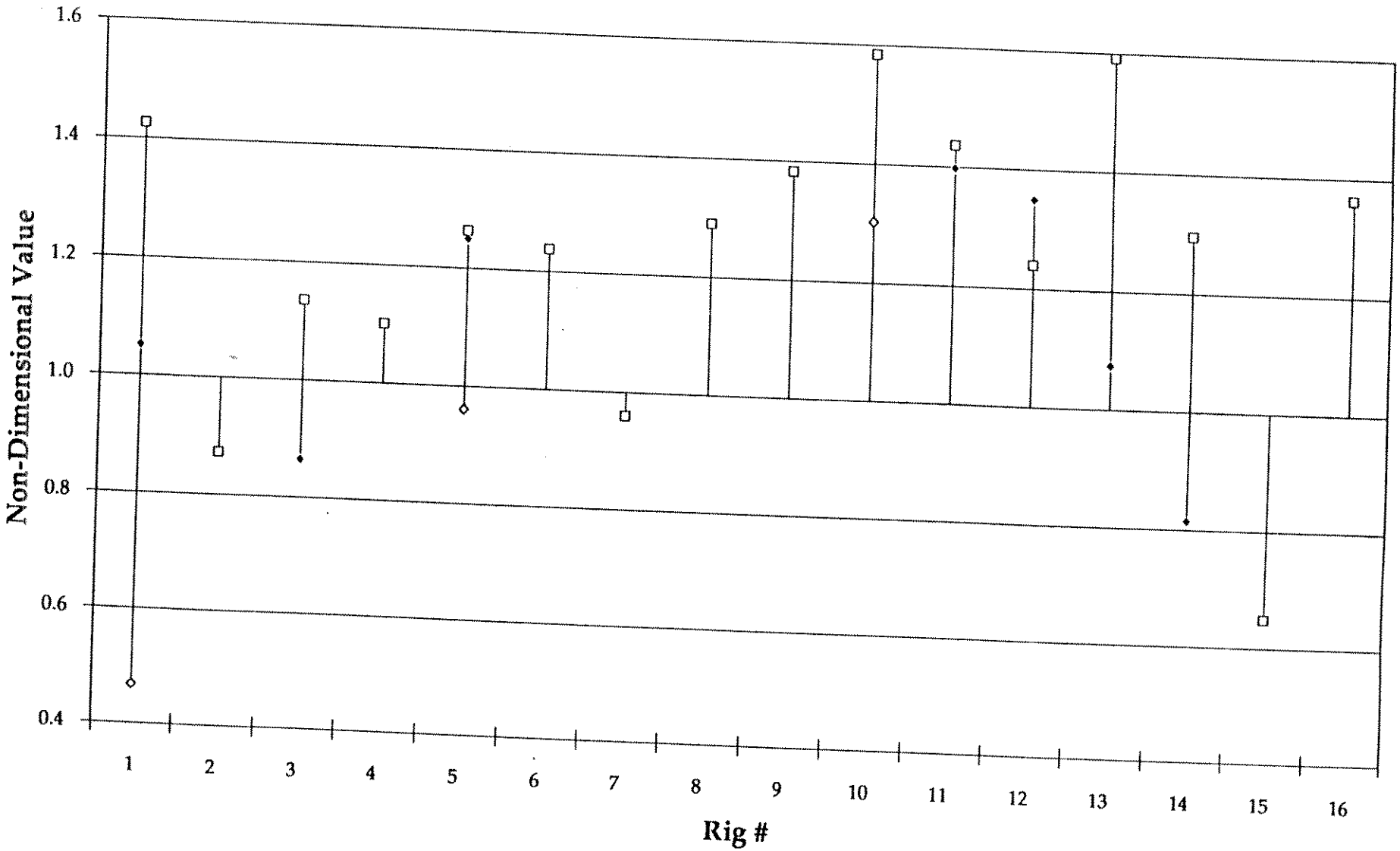
SEMI-SUBMERSIBLE - WIND COEFFICIENT - BEAM SEAS
VALUES NORMALIZED TO MODEL TEST DATA



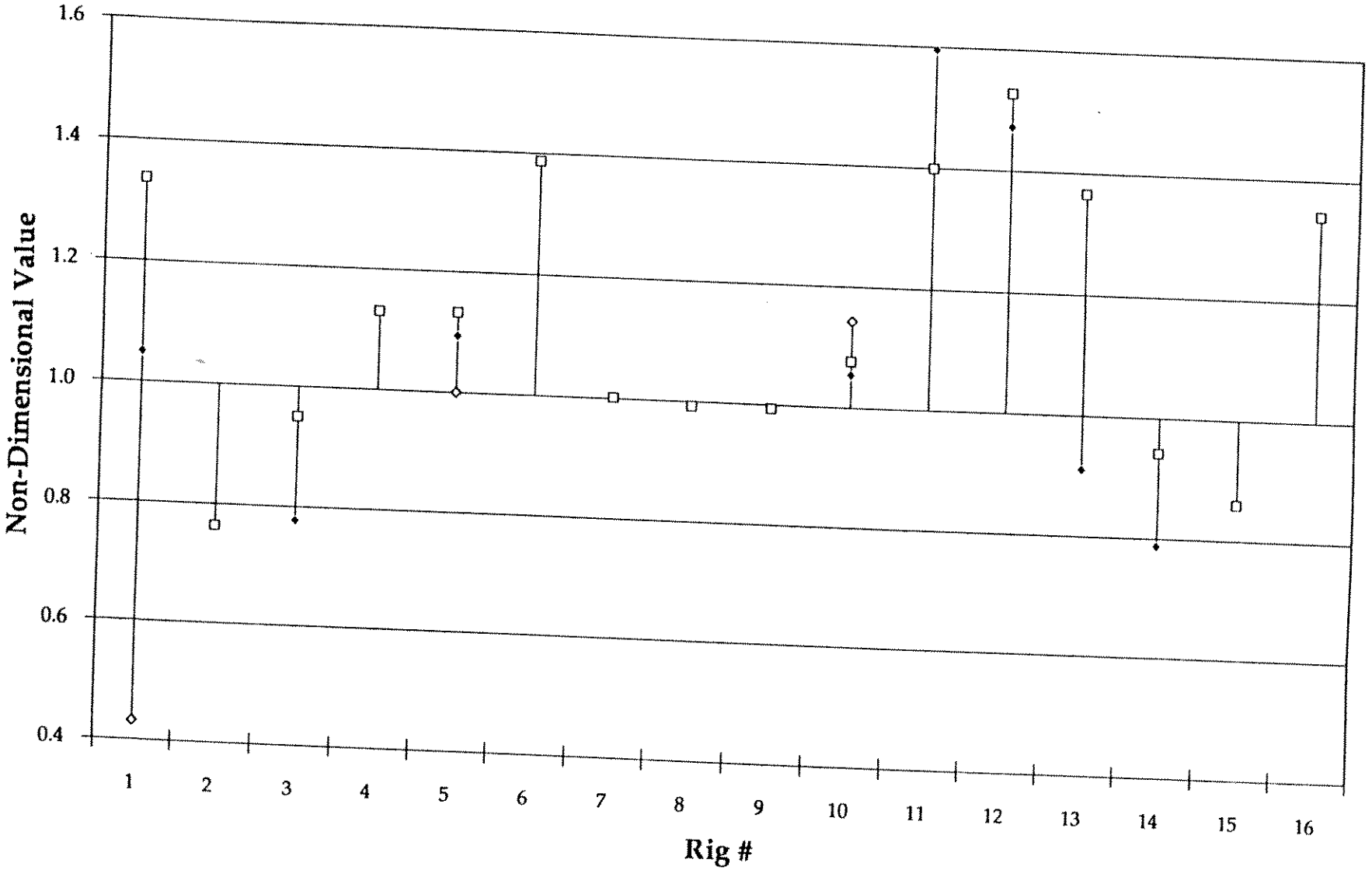
SEMI-SUBMERSIBLE - CURRENT COEFFICIENT - HEAD SEAS
VALUES NORMALIZED TO MODEL TEST DATA



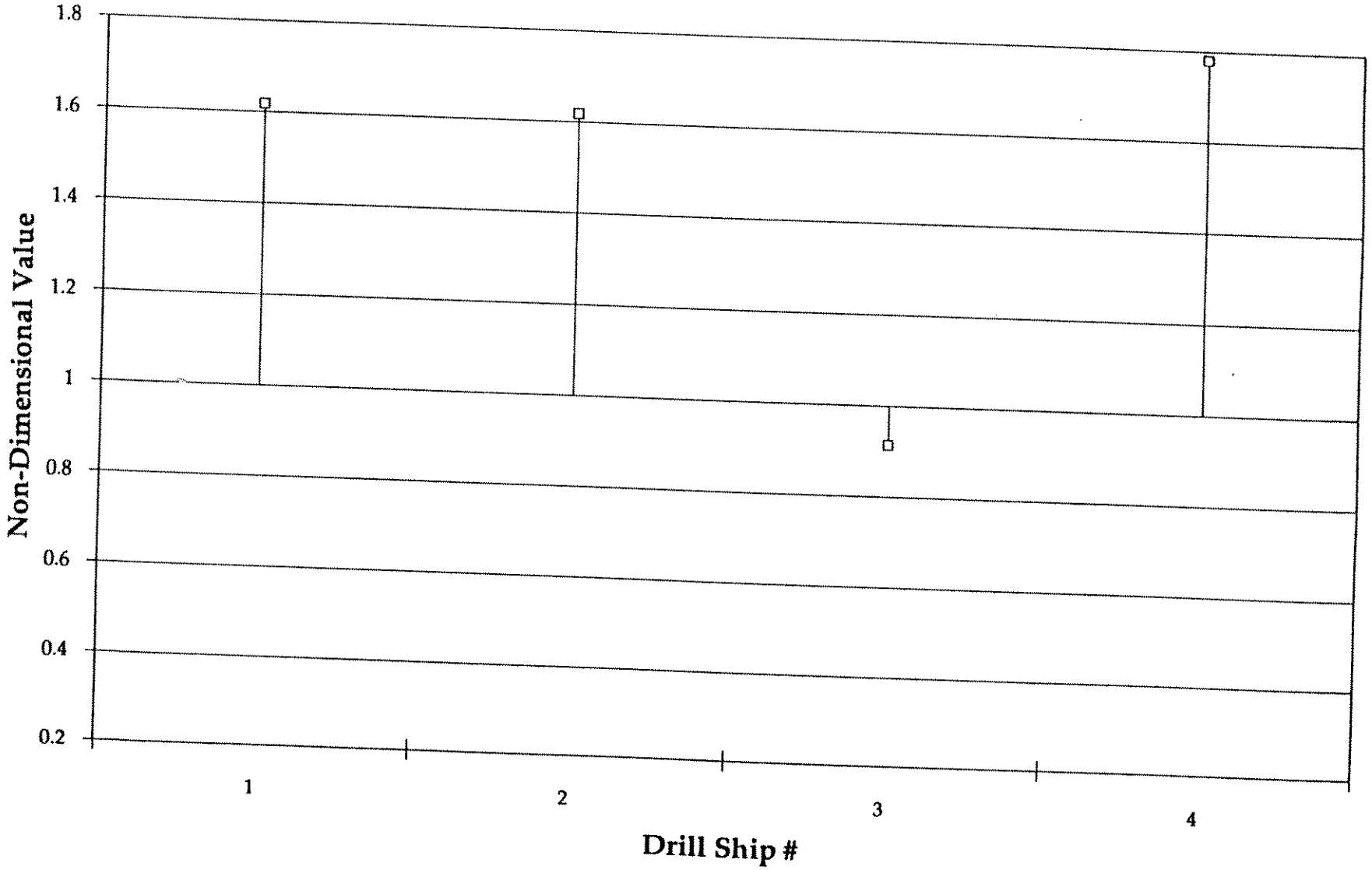
SEMI-SUBMERSIBLE - CURRENT COEFFICIENT - QUARTERING SEAS
VALUES NORMALIZED TO MODEL TEST DATA



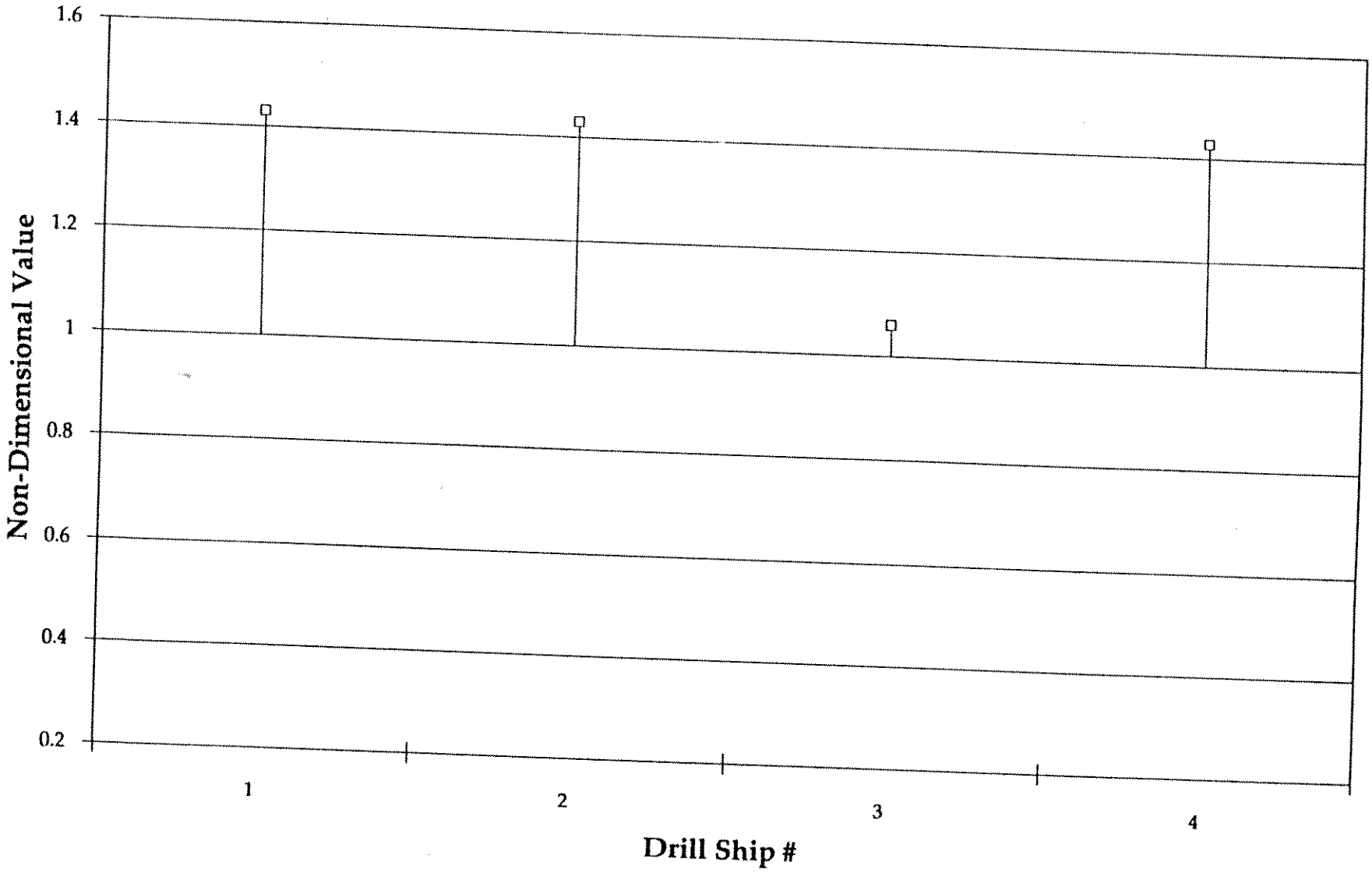
SEMI-SUBMERSIBLE - CURRENT COEFFICIENT - BEAM SEAS
VALUES NORMALIZED TO MODEL TEST DATA



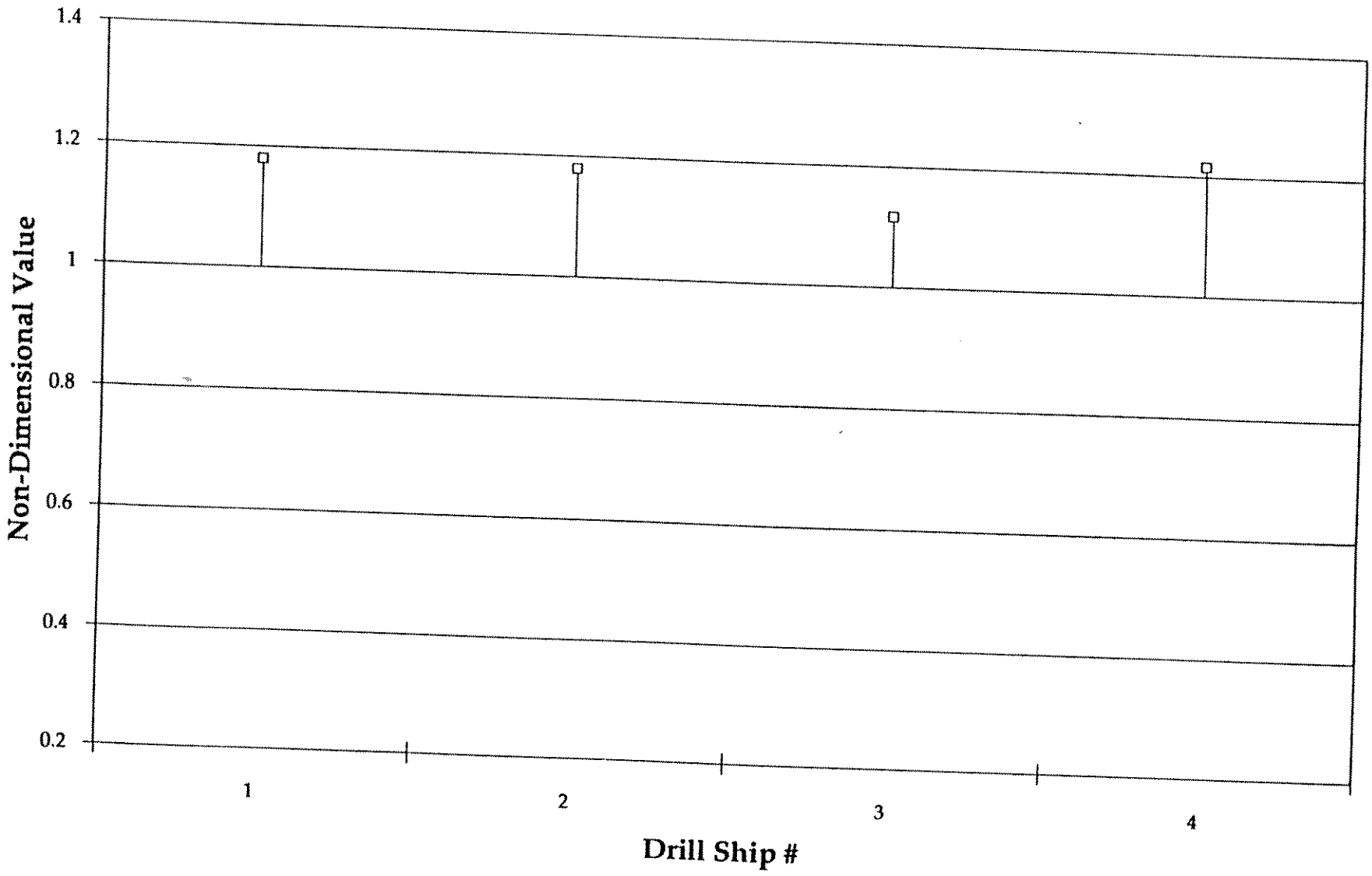
DRILL SHIP - WIND COEFFICIENT - HEAD SEAS
VALUES NORMALIZED TO MODEL TEST DATA



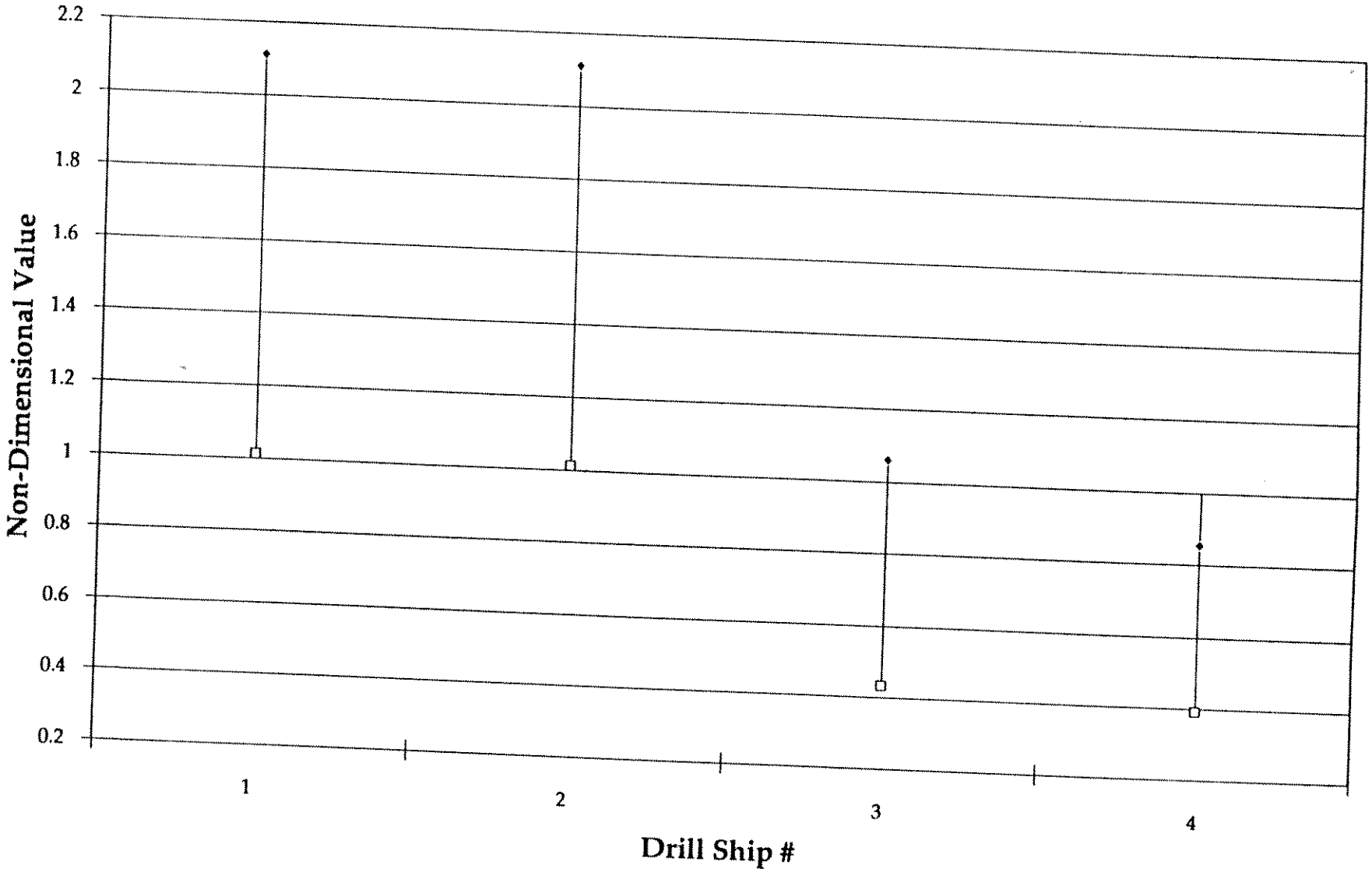
DRILL SHIP - WIND COEFFICIENT - QUARTERING SEAS
VALUES NORMALIZED TO MODEL TEST DATA



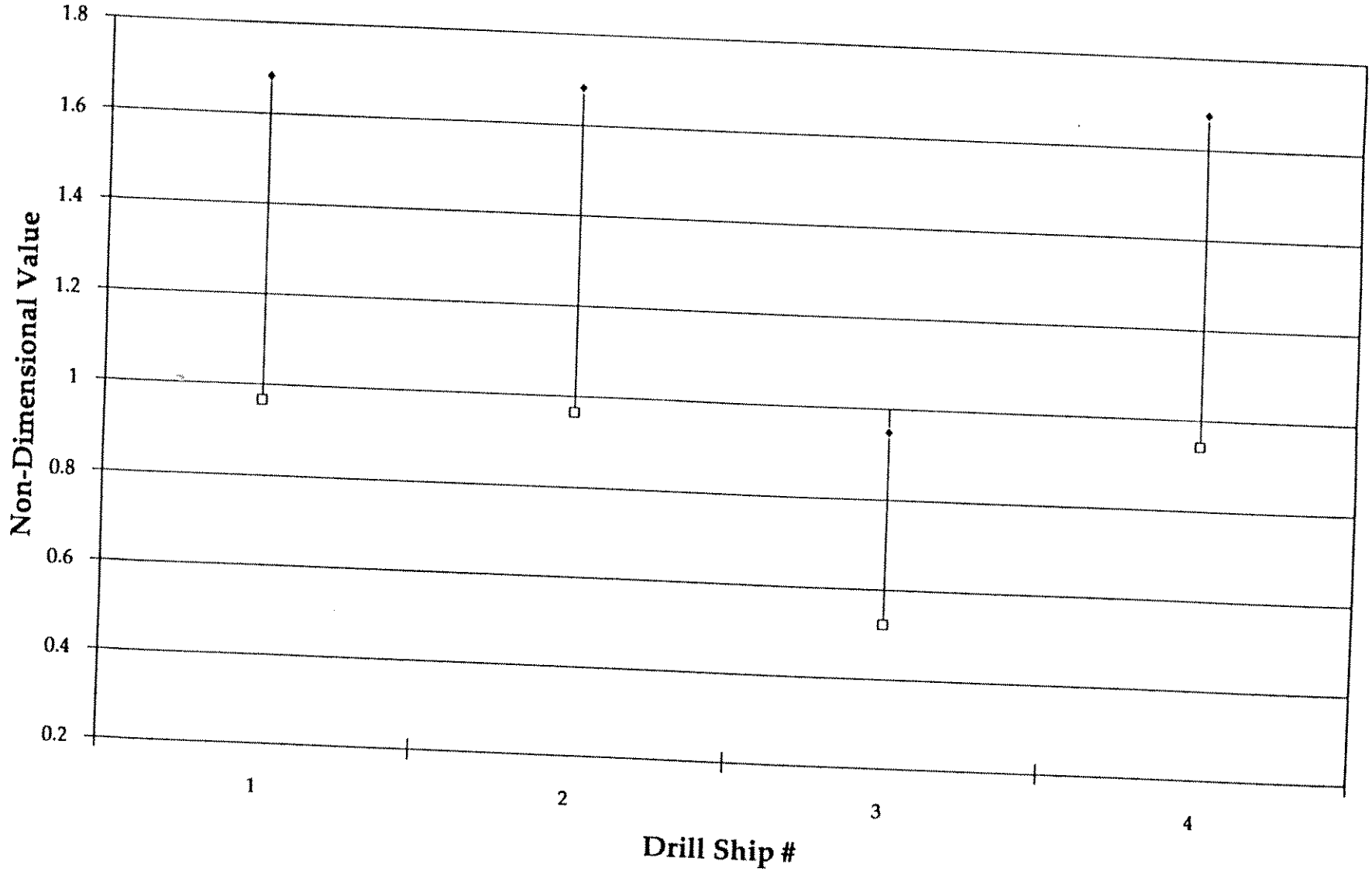
DRILL SHIP - WIND COEFFICIENT - BEAM SEAS
VALUES NORMALIZED TO MODEL TEST DATA



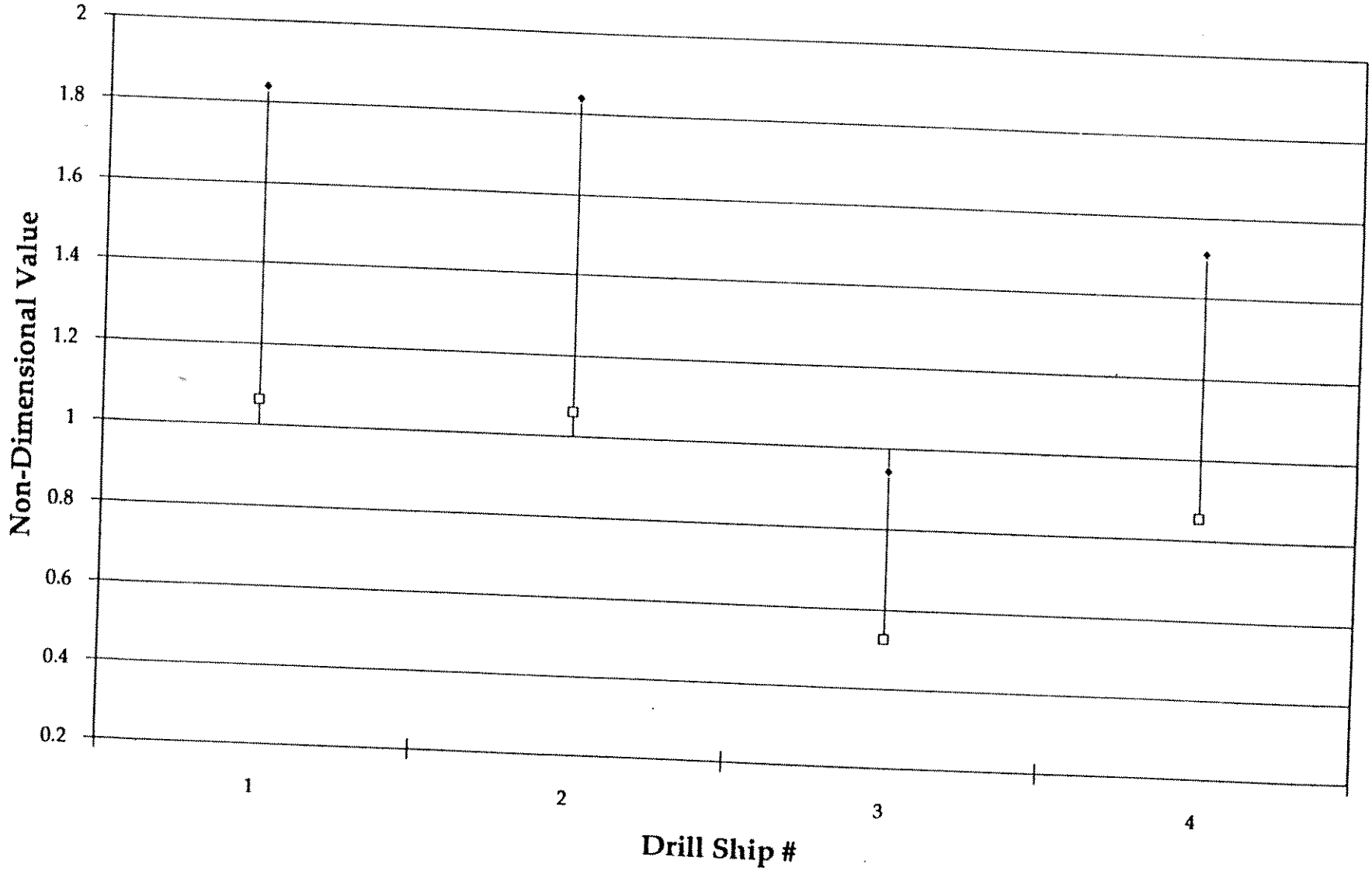
DRILL SHIP - CURRENT COEFFICIENT - HEAD SEAS
VALUES NORMALIZED TO MODEL TEST DATA



DRILL SHIP - CURRENT COEFFICIENT - QUARTERING SEAS
VALUES NORMALIZED TO MODEL TEST DATA



DRILL SHIP - CURRENT COEFFICIENT - BEAM SEAS
VALUES NORMALIZED TO MODEL TEST DATA



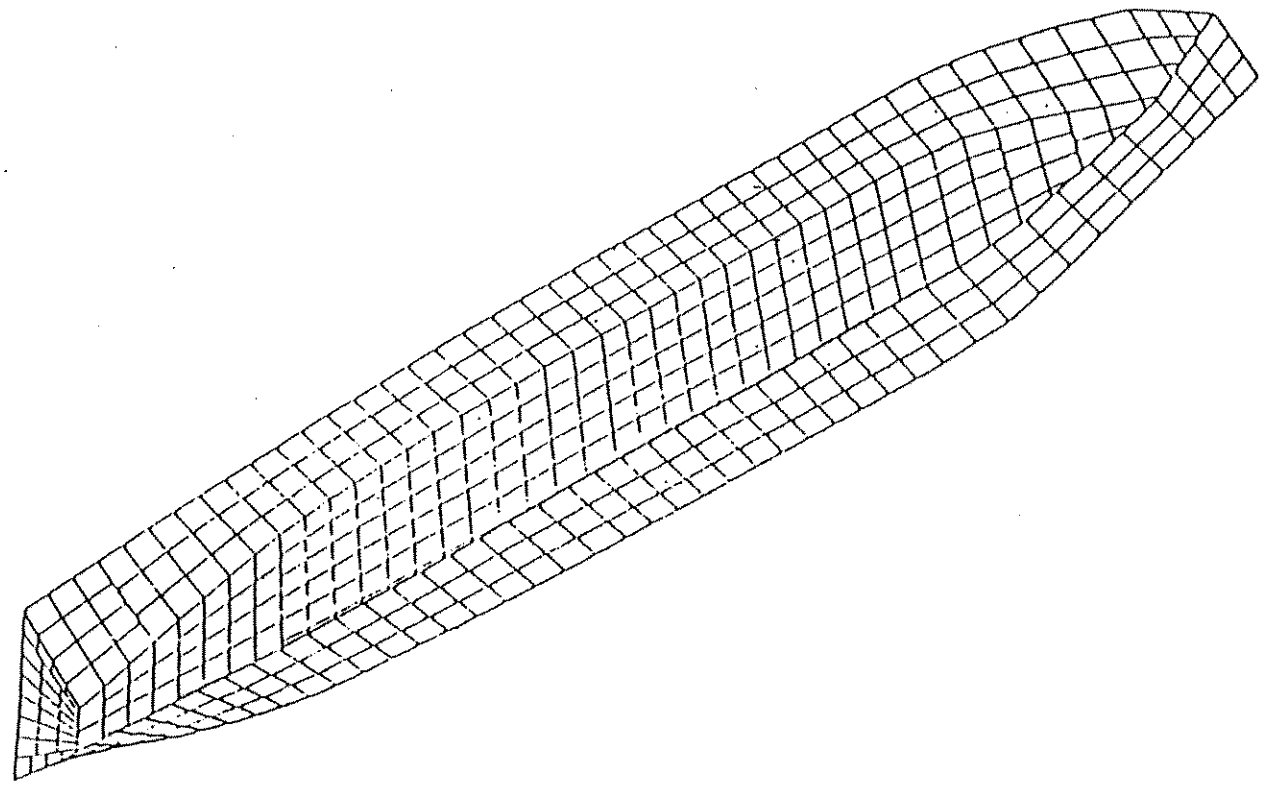
WAVE-DRIFT FORCE AND WF/LF MOTIONS

1. DATA SOURCE : FPS 2000 PROJECT

   - A TURRET-MOORED TANKER
   - RESULTS FROM SEVEN ORGANIZATIONS

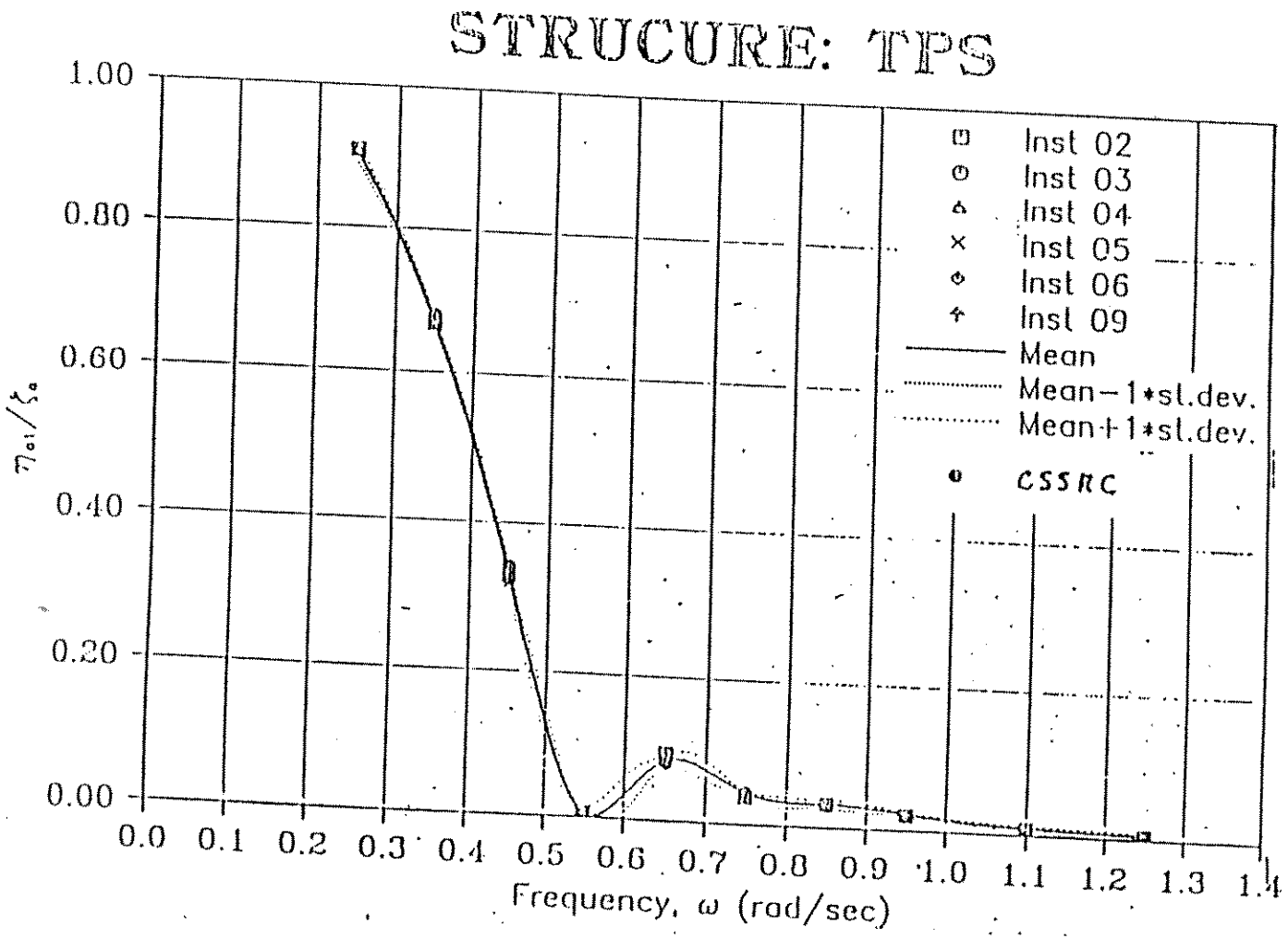
2. SCOPE OF COMPARISON

	RELATIVE CONSISTENCY
WAVE-FREQUENCY	
• SURGE FORCE	GOOD
• SURGE MOTION	EXCELLENT
LOW-FREQUENCY	
• DRIFT-FORCE COEFF.	SIGNIFICANT VARIATION
• LF MOTION	WIDE SPREAD



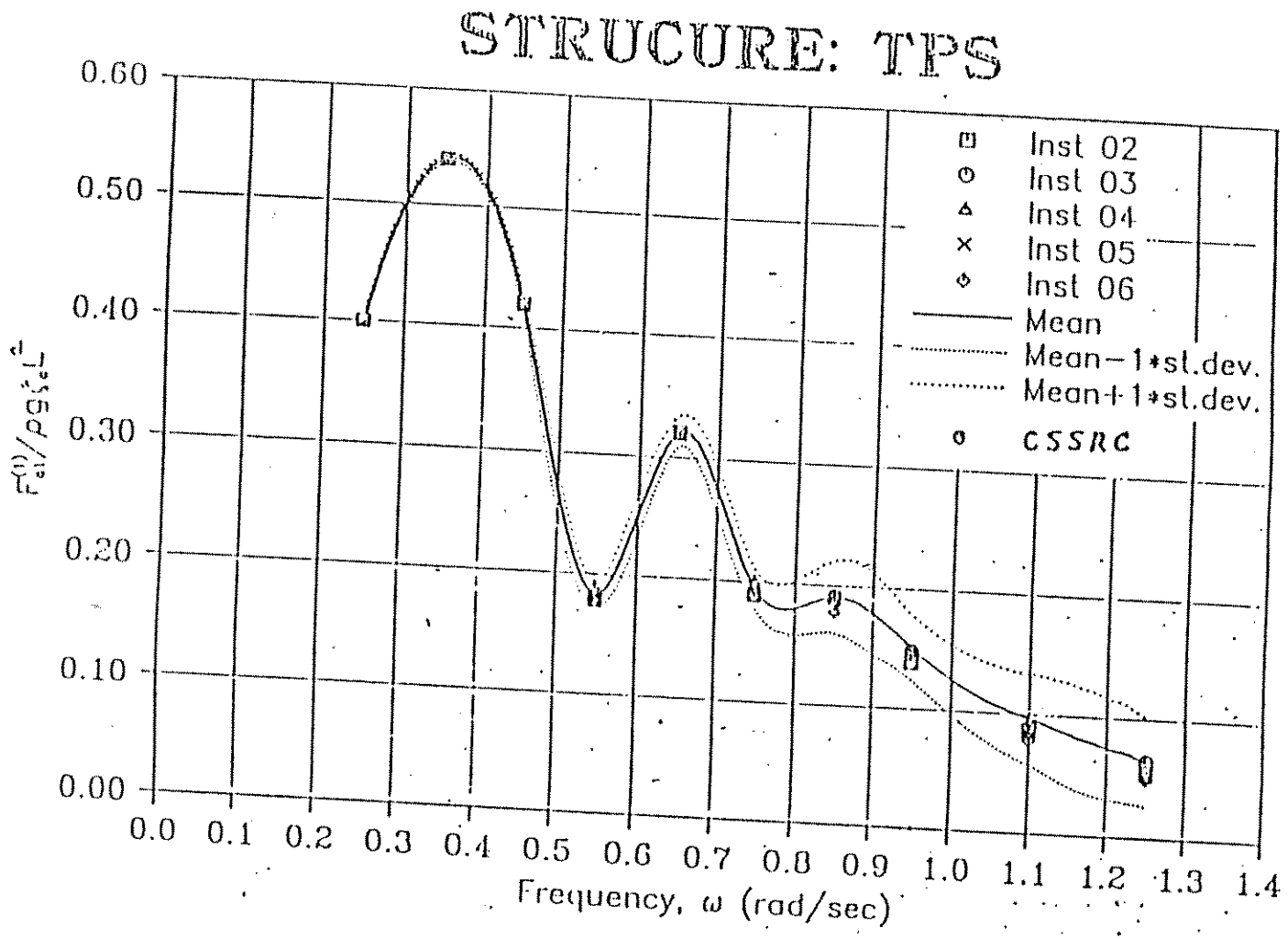
3-D HYDRODYNAMIC MODEL

Source: FPS 2000 Project
Turret Moored Production System (TPS)



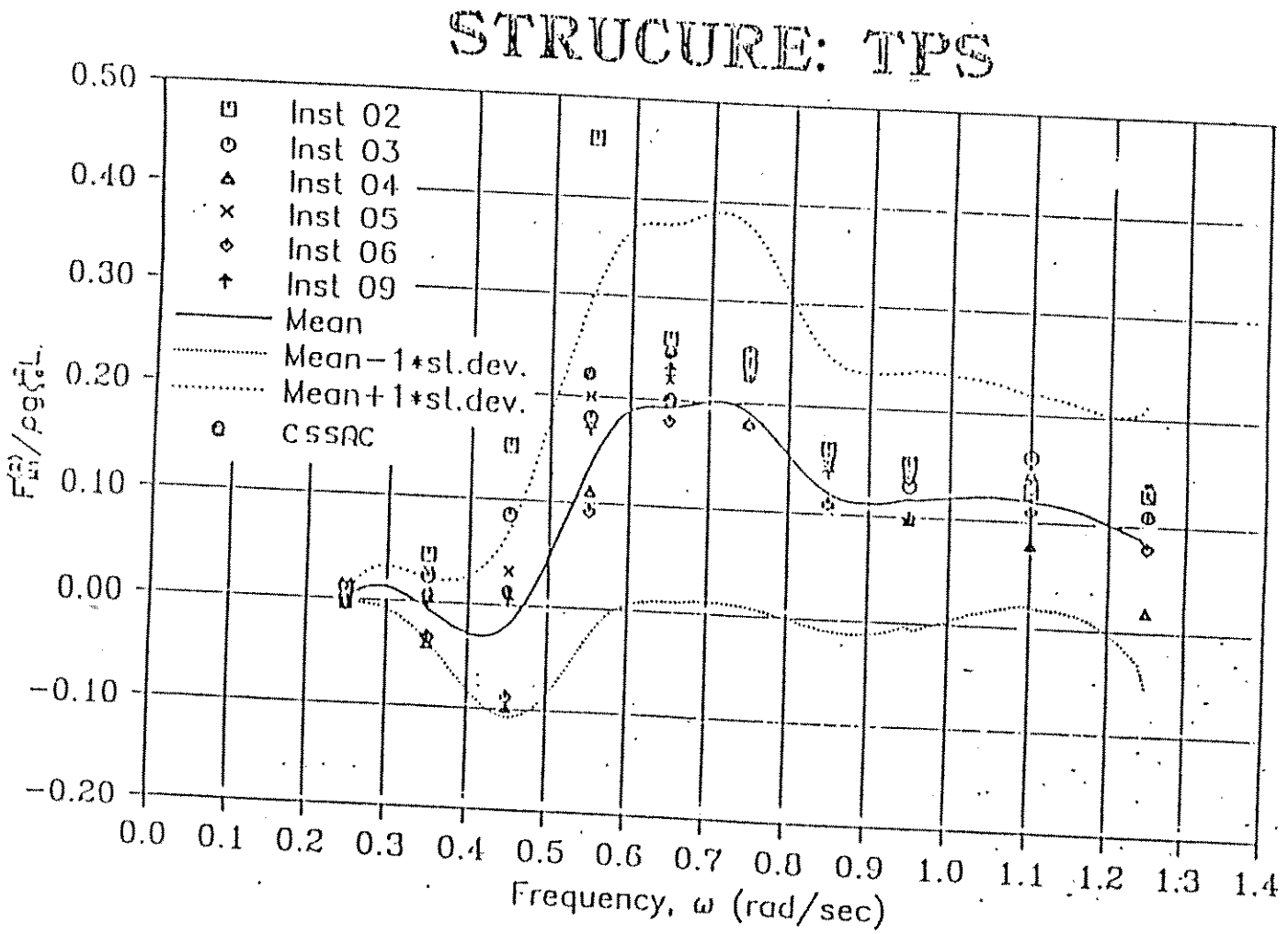
COMPARISON OF WAVE FREQUENCY SURGE RAO

Source: FPS 2000 Project
Turret Moored Production System (TPS)



COMPARISON OF WAVE FREQUENCY SURGE FORCE

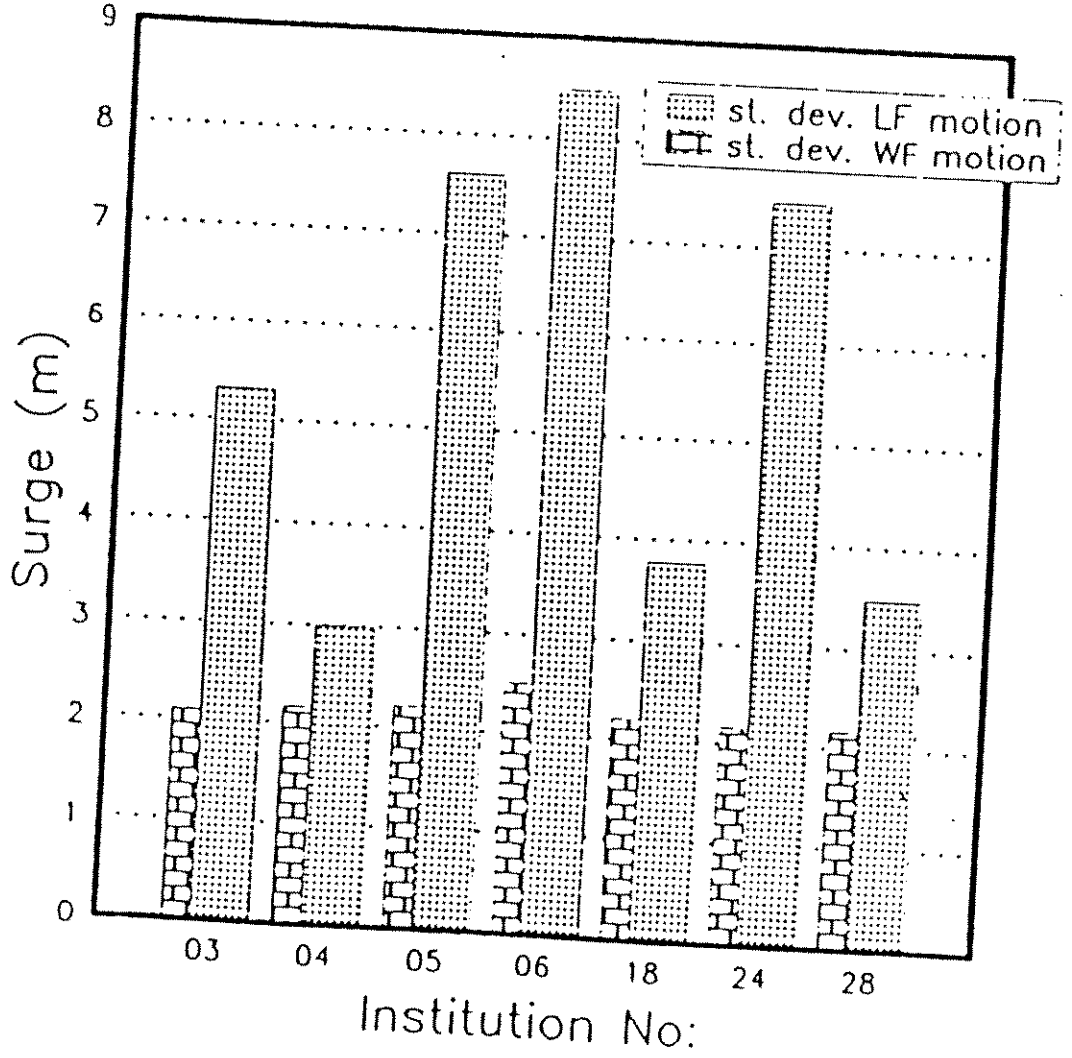
Source: FPS 2000 Project
Turret Moored Production System (TPS)



COMPARISON OF WAVE DRIFT FORCE COEFFICIENTS

Source: FPS 2000 Project
Turret Moored Production System (TPS)

SOURCE: FPS 2000 SUMMARY REPORT



TPS. Motion response in design condition (H_s = 15.5 m). Standard deviations of first order (WF) and low frequency (LF) motion response in surge. 10 degrees heading to the waves

VESSEL LF DAMPING
GVA 5000 4-COLUMN SEMISUBMERSIBLE

1. COMPUTATIONAL METHOD

- MIT/DnV JIS FOR TLP
- LIMITATIONS
  - 4-COLUMNS
  - PONTOONS IGNORED
- PRINCIPAL INVESTIGATOR: PAUL SCLAVONOUS

2. STUDY MATRIX

- SIGNIFICANT WAVE HEIGHTS (P-M): 30', 40', AND 50'
- WAVE HEADINGS: 0°, 22.5°, AND 45°
- SYSTEM STIFFNESS (KIPS/FT): 5, 10, AND 20
- WAVE-DAMPING AND VISCOUS-DAMPING

3. A DESIGN CASE : GOMEX 10-YEAR STORM
(ASSUMING K = 10 KIPS/FT)

	DAMPING (% OF SYSTEM CRITICAL)	
	HEAD SEA	BEAM SEA
WAVE DAMPING	2.8%	2.8%
VISCOUS DAMPING	1.7%	4.5%
TOTAL	4.5%	7.3%

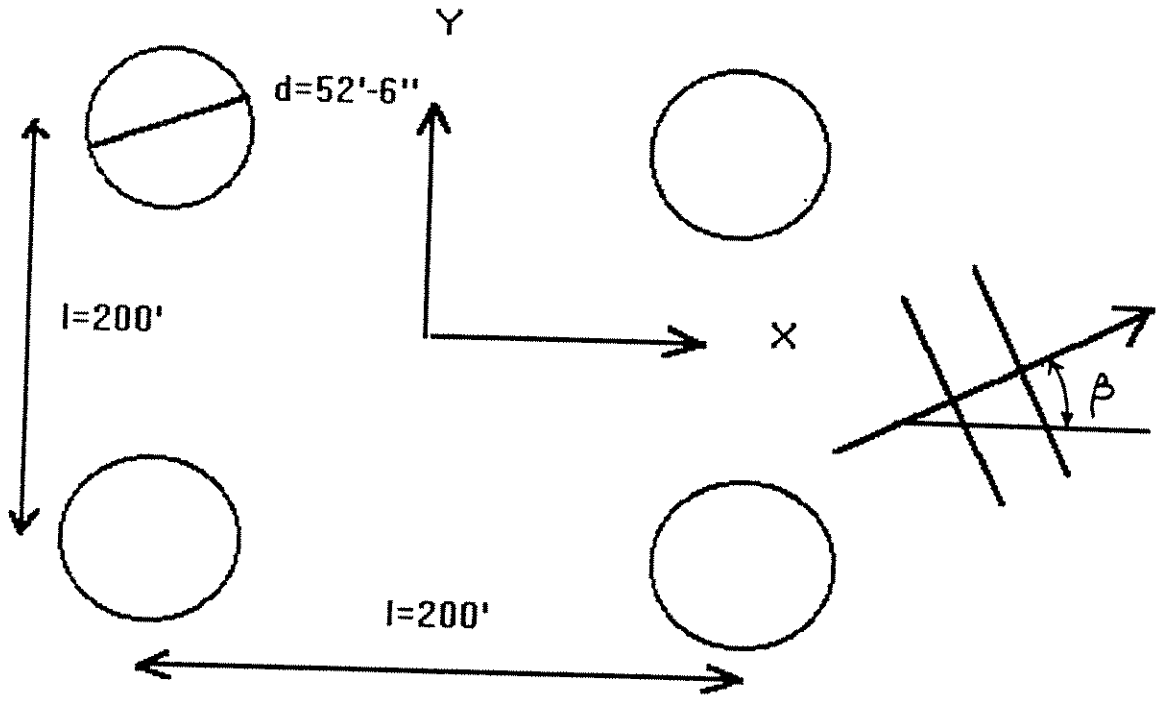
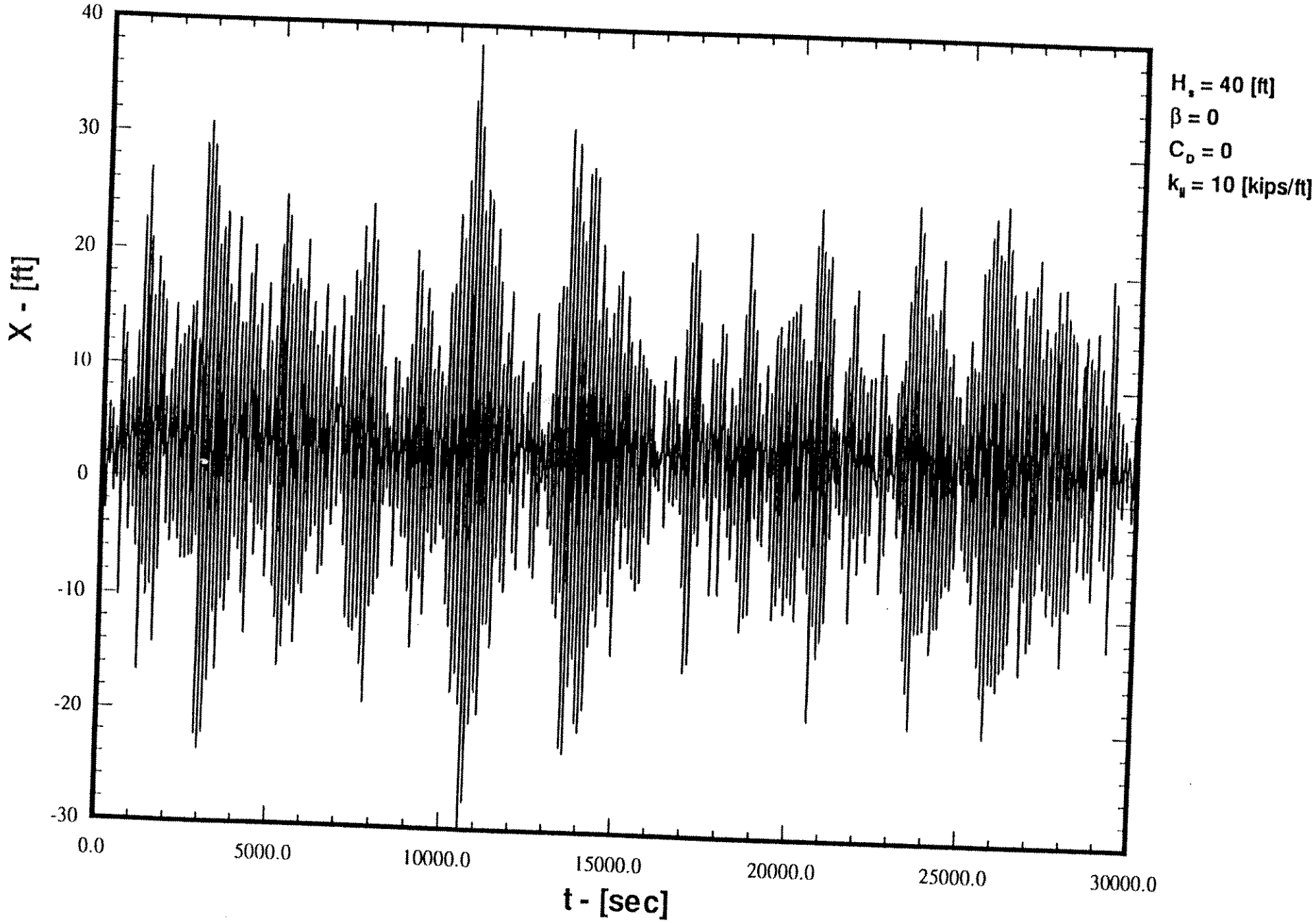
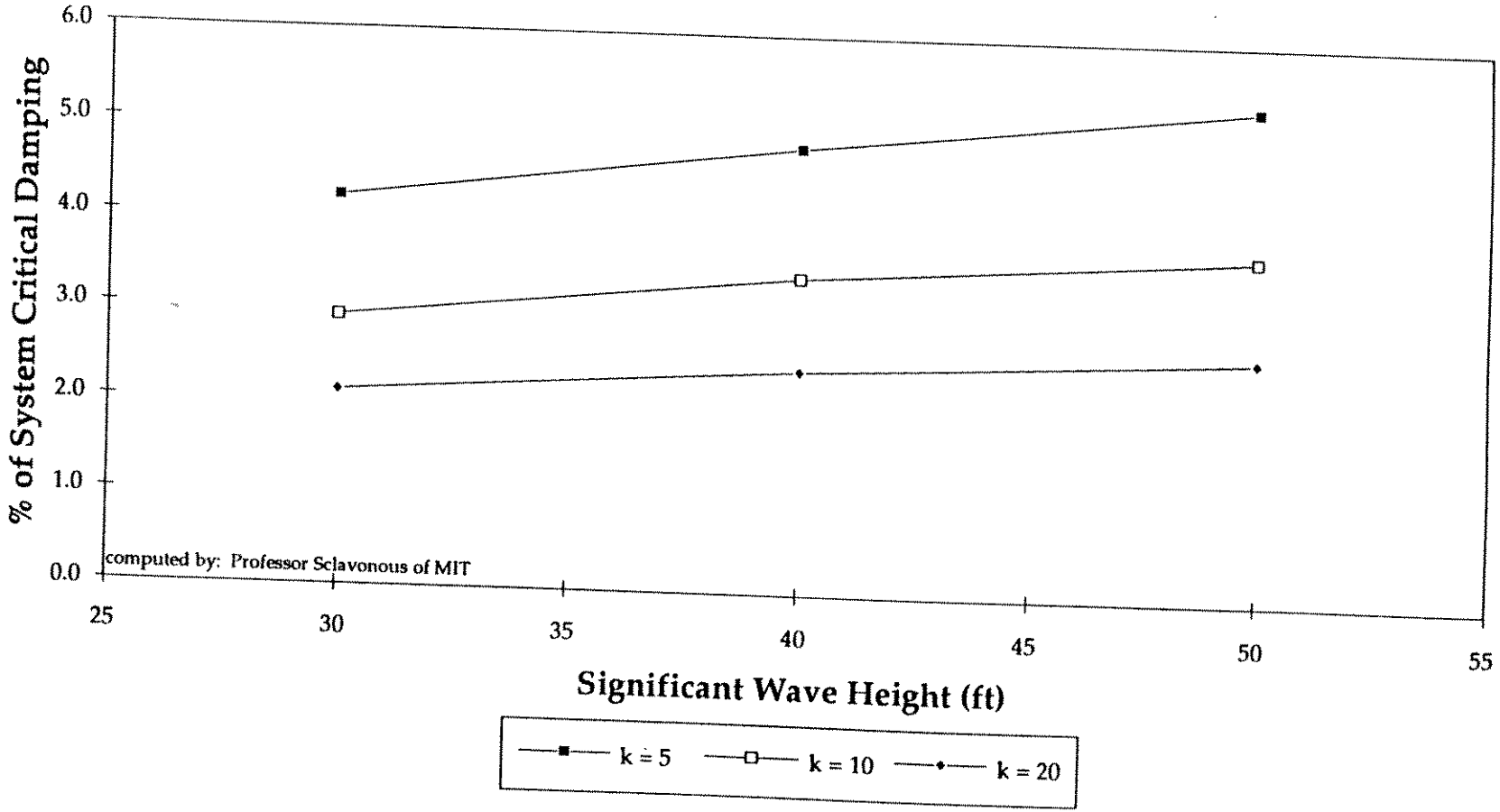


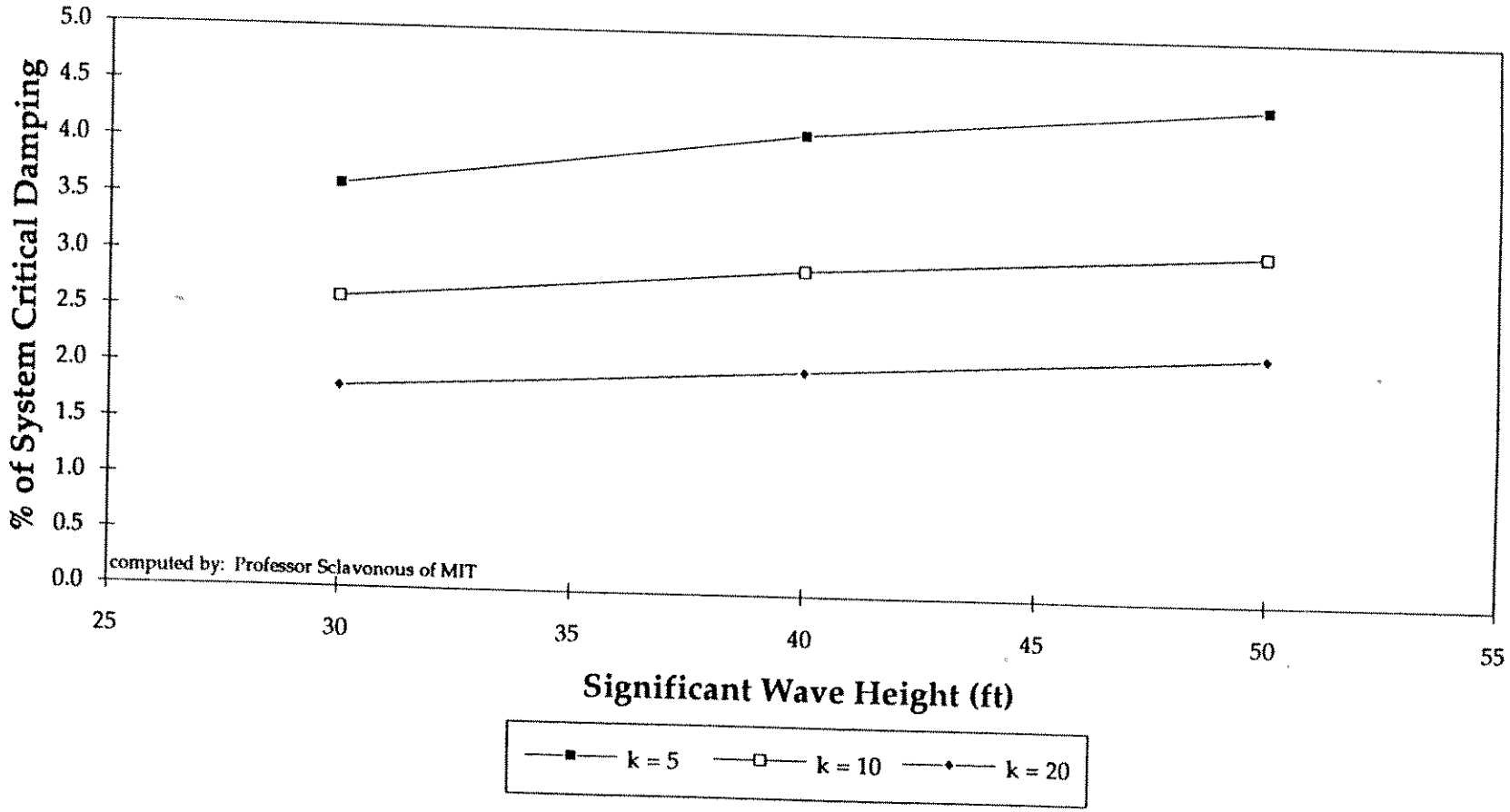
FIG. 1


Slow Drift Motion - Surge
40
30
20
10
0
-10
-20
-30
X - [ft]
0.0
5000.0
10000.0
15000.0
20000.0
25000.0
30000.0
t - [sec]
H_s = 40 [ft]
β = 0
C_D = 0
k_y = 10 [kips/ft]

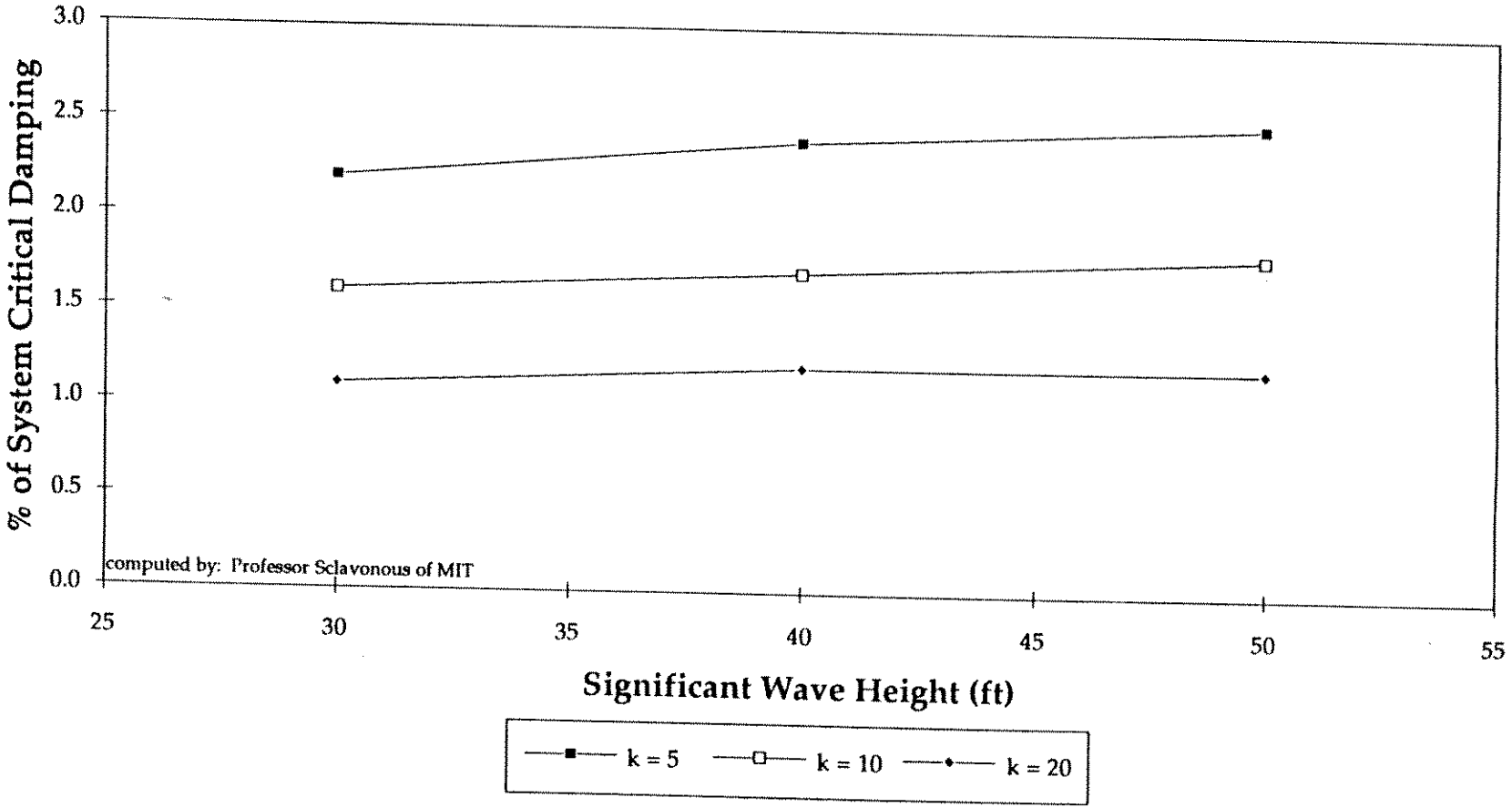
SEMI-SUBMERSIBLE/FPS (GVA 5000 CLASS)
LF SURGE WAVE DRIFT DAMPING
HEADING ANGLE = 0.0 DEGREES



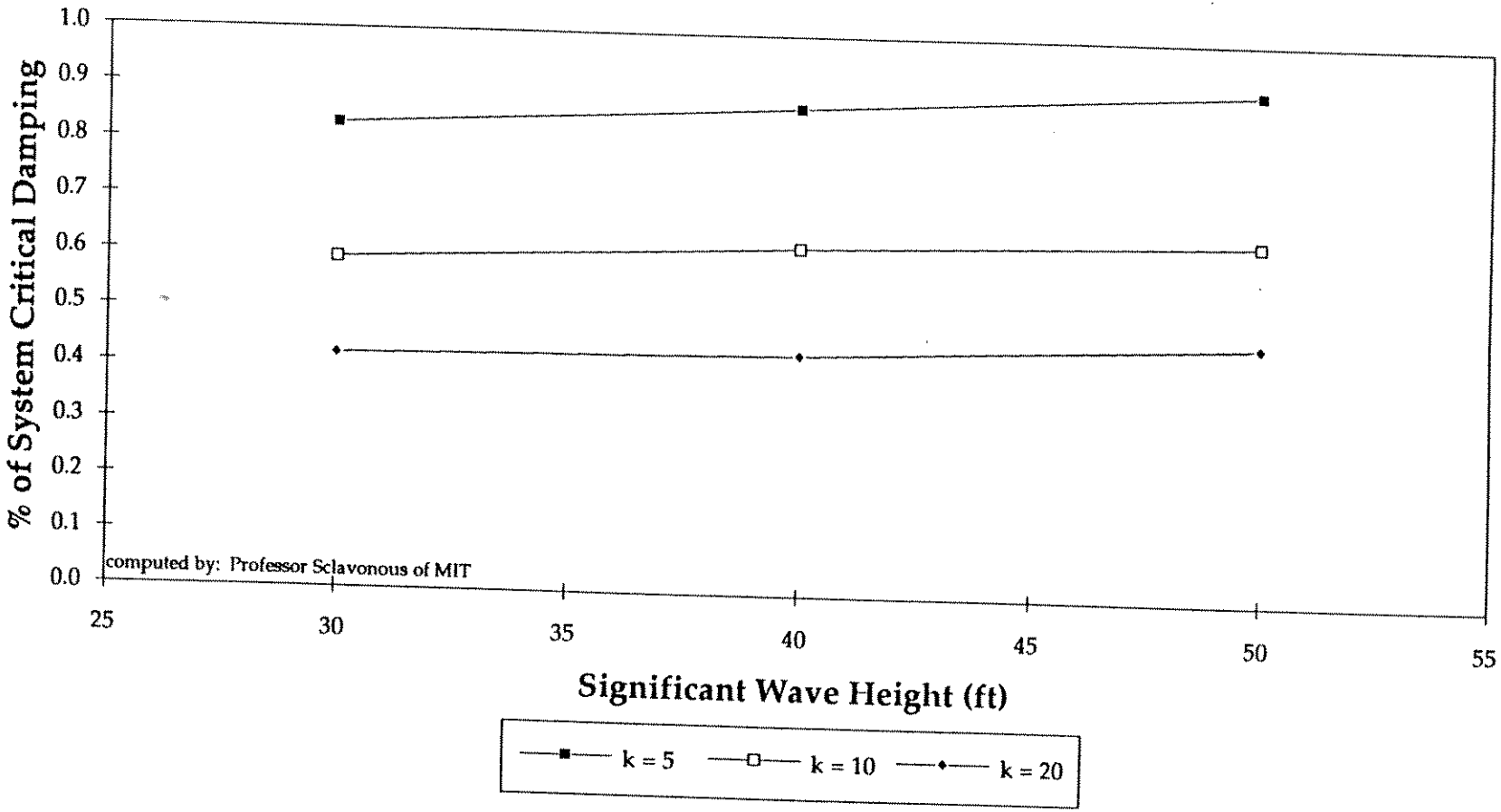
SEMI-SUBMERSIBLE/FPS (GVA 5000 CLASS)
LF SURGE WAVE DRIFT DAMPING
HEADING ANGLE = 22.5 DEGREES



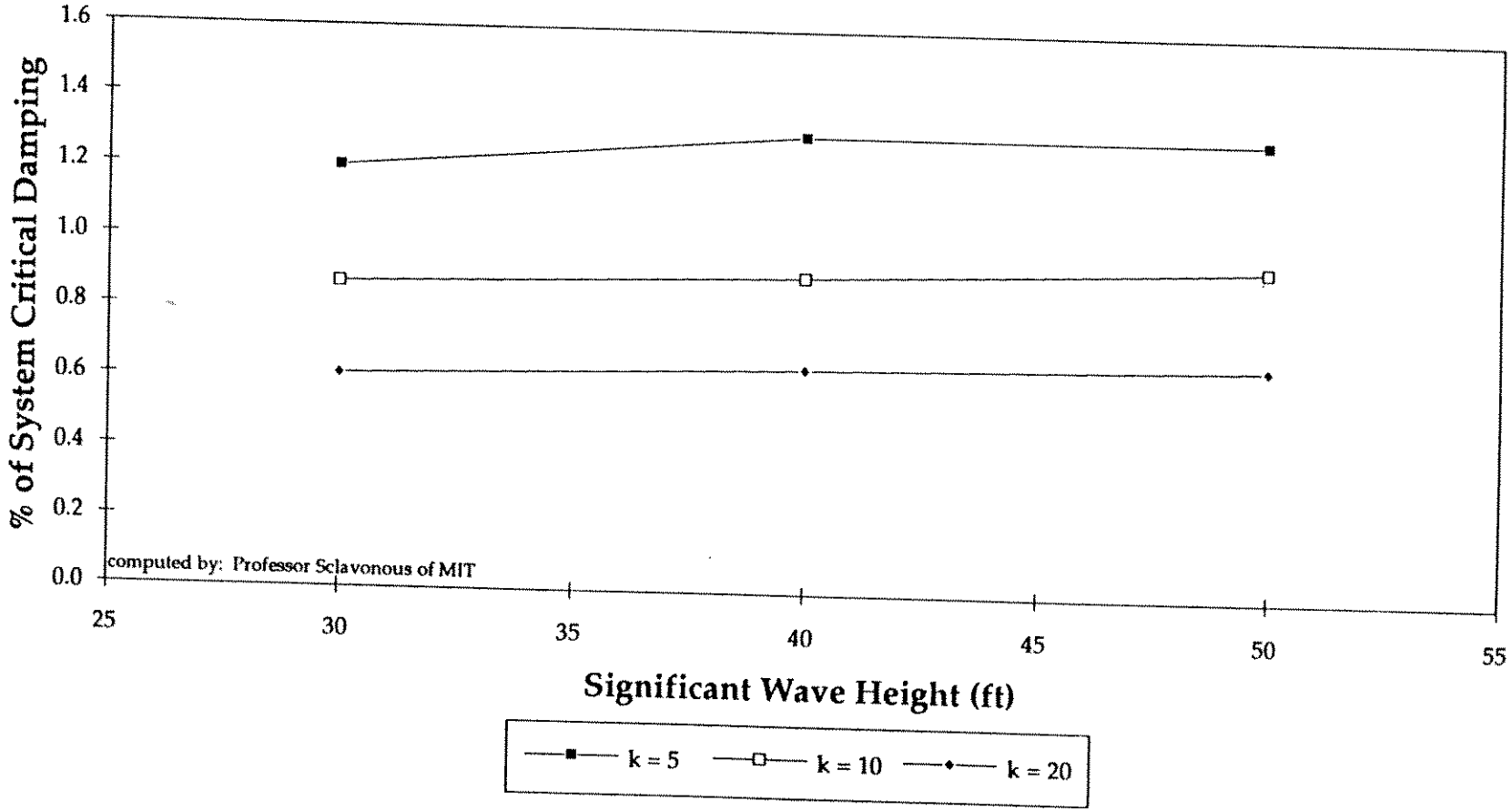
SEMI-SUBMERSIBLE/FPS (GVA 5000 CLASS)
LF SURGE WAVE DRIFT DAMPING
HEADING ANGLE = 45.0 DEGREES



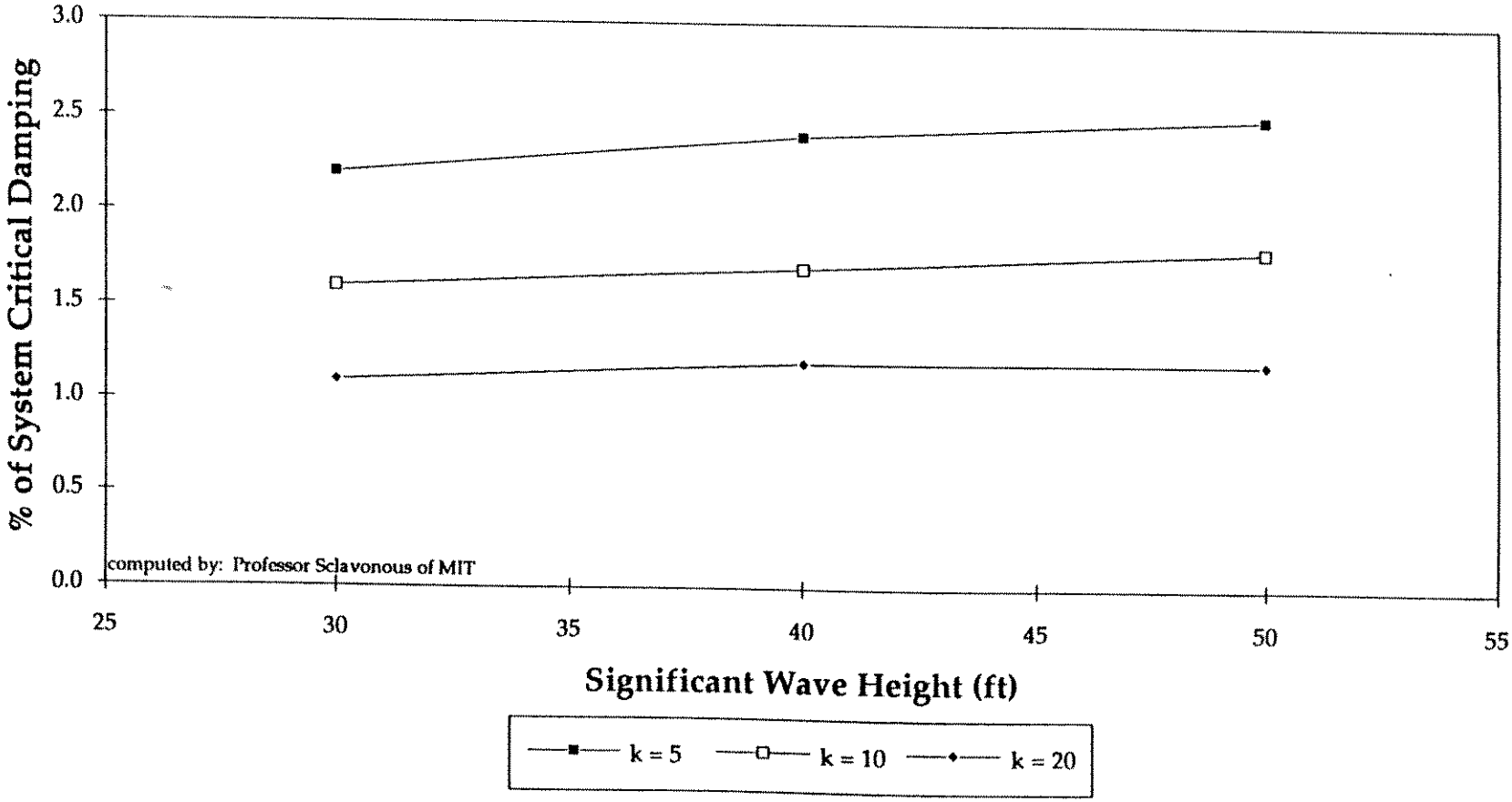
SEMI-SUBMERSIBLE/FPS (GVA 5000 CLASS)
LF SWAY WAVE DRIFT DAMPING
HEADING ANGLE = 0.0 DEGREES



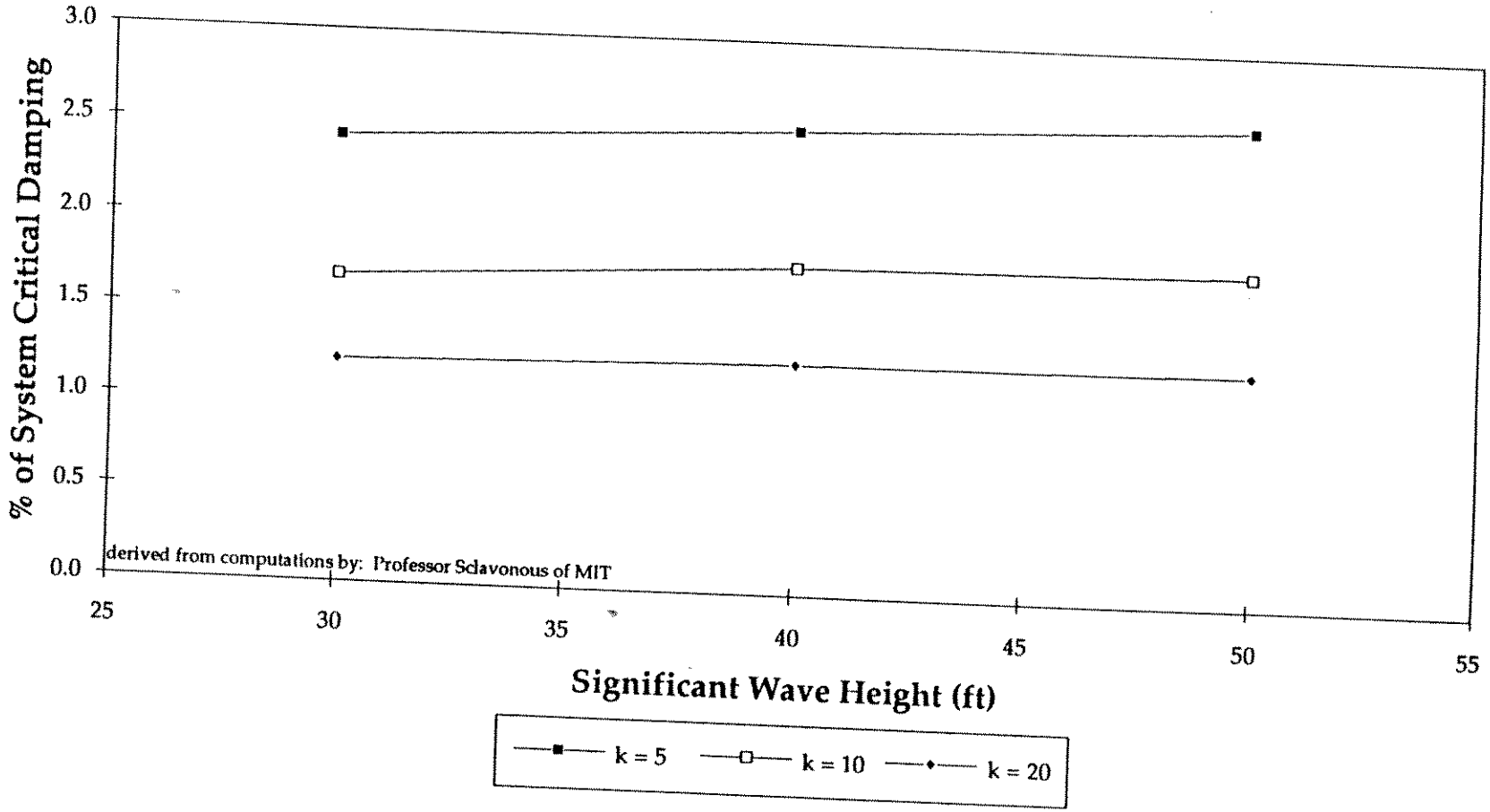
SEMI-SUBMERSIBLE/FPS (GVA 5000 CLASS)
LF SWAY WAVE DRIFT DAMPING
HEADING ANGLE = 22.5 DEGREES



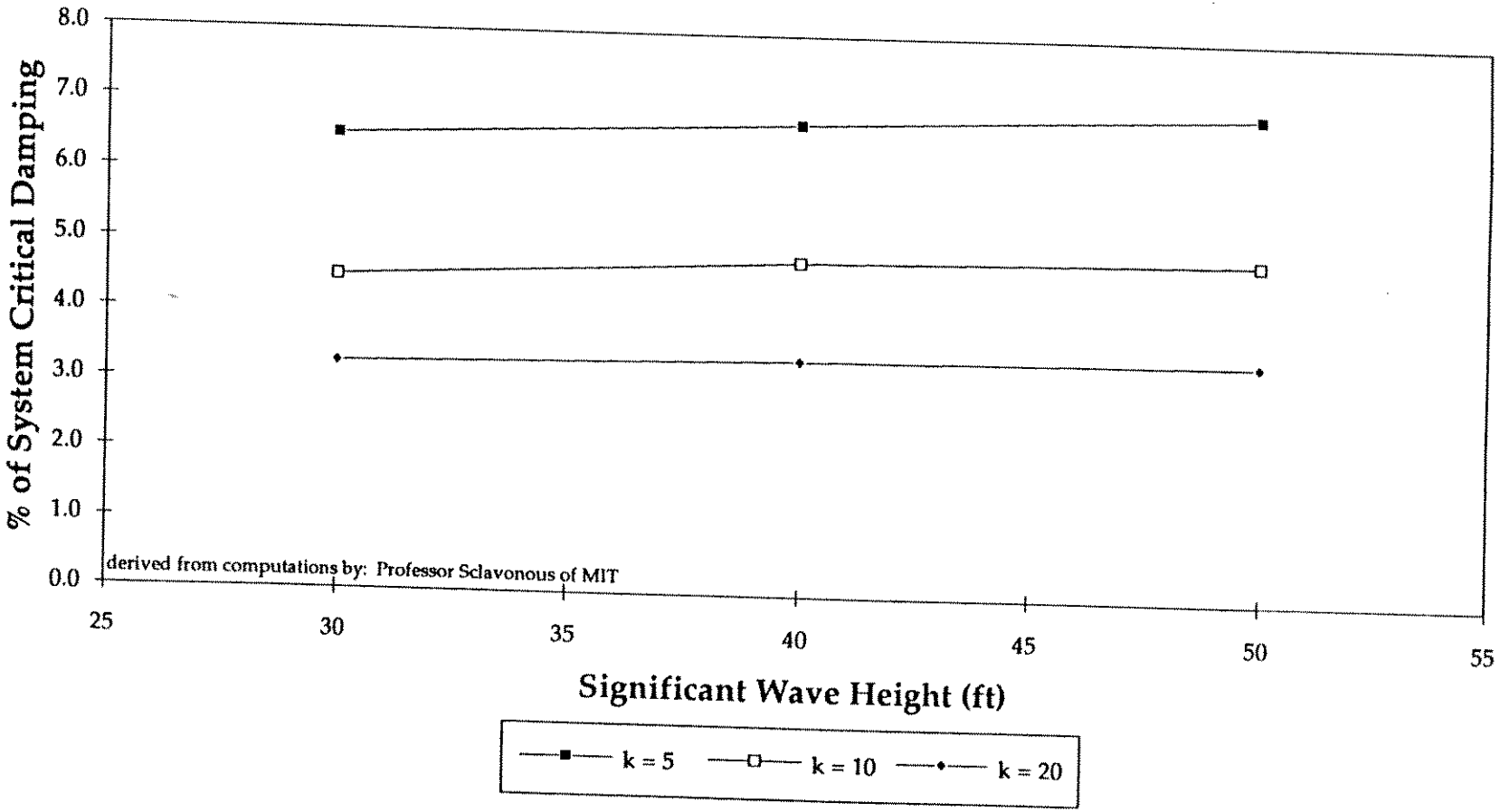
SEMI-SUBMERSIBLE/FPS (GVA 5000 CLASS)
LF SWAY WAVE DRIFT DAMPING
HEADING ANGLE =45.0 DEGREES



SEMI-SUBMERSIBLE/FPS (GVA 5000 CLASS)
LF SURGE VISCOUS DAMPING
HEADING ANGLE = 0.0 DEGREES



SEMI-SUBMERSIBLE/FPS (GVA 5000 CLASS)
LF SWAY VISCOUS DAMPING
HEADING ANGLE = 90.0 DEGREES



VESSEL LF DAMPING
SEDCO 700 SEMISUBMERSIBLE

1. COMPUTATIONAL METHODS

   - MORA 3-D PROGRAM: WAVE DAMPING
   - LINEARIZATION: VISCOUS DAMPING
   - RATIONALIZED PROCEDURE: CURRENT AND WIND
   - COLINEAR CORRELATED WIND-WAVE-CURRENT

2. STUDY MATRIX: COMPARABLE TO GVA 5000

3. A DESIGN CASE: GOMEX 10-YEAR STORM
   (ASSUMING K = 10 KIPS/FT)

	DAMPING (% OF SYSTEM CRITICAL)	
	HEAD SEA	BEAM SEA
WAVE DRIFT DAMPING	0.2%	0.2%
VISCOUS DAMPING		
• NO CURRENT	1.7%	2.5%
• 1.8-KNOT CURRENT	13%	22%
AERODYNAMIC DAMPING (72-KNOT WIND)	2.7%	1.9%
TOTAL	5-16%	5-24%

   - LF MAX. MOTION: 13 FT.
   - LF PERIOD: 90 SEC.
   - LF MAX. VELOCITY: 0.9 FT/SEC (0.5 KTS)
   - MOORING SYSTEM STIFFNESS: 12 KIPS/FT (1000' WD)

oncoming waves and decreases during the half-cycle where the structure tends to move with the waves thus giving rise to a damping force. Based on the work done in a full cycle, the wave damping coefficient may be related to the gradient of the mean drift force as

$$\bar{b}_1(f) = \frac{2\pi f^2}{g}\cos\beta\frac{dF_1^{(2)}}{df_e}$$

$$\bar{b}_3(f) = \frac{2\pi f^2}{g}\sin\beta\frac{dF_3^{(2)}}{df_e}$$

where

$F_i^{(2)}$ = the mean drift force in the i-direction.

f = wave frequency.

f_e = wave encounter frequency.

g = acceleration of gravity.

β = wave incidence angle.

$b_i(f)$ = the i-the component damping coefficient.

The mean value of the wave damping for a wave spectrum is given by

$$b_{imw} = 2\int_0^\infty S(f)\frac{b_i(f)}{(\bar{H}/2)^2}df$$

The wave damping coefficient $b_i(f)$ is proportional to the wave amplitude squared, i.e., $(\bar{H}/2)^2$, since $b_i(f)$ is proportional to the mean drift force.

The viscous damping is computed by the same linearized method as used in the response to wave frequency. The total mean damping is given by the sum of the wave damping and viscous damping, $b_{im} = b_{imw} + b_{imv}$.

The drift response analysis disregards the yawing motion and deals only with motion in the

Source: MORA Manual

ASSUMPTIONS/APPROXIMATIONS

1. COLINEAR/CORRELATED WIND-WAVE-CURRENT

H_S	WIND SPEED	CURRENT VELOCITY
20'	36 KTS	0.6 KTS
30'	72 KTS	1.8 KTS
40'	108 KTS	3.0 KTS
50'	132 KTS	4.4 KTS

2. API RP-2P LF MOTIONS

LF RMS = (REF. RMS) $\sqrt{18 / K}$

LF SIG. = 2*(LF RMS)

LF MAX = 3*(LF RMS)

3. API RP-2P WF MOTION RAOS

WF RMS BY SPECTRAL ANALYSIS

WF SIG = 2*(WF RMS)

WF MAX = 1.86*(WF SIG)

COMPUTATIONAL METHOD

1. LINEARIZED LF VISCOUS DAMPING (C_{LC})

$$C_{LC} = \frac{8}{3\pi} C_{DC} * V_{LF}$$

C_{DC}= CURRENT FORCE COEFFICIENT

V_{LF}= LF VELOCITY AMPLITUDE

2. EFFECTS OF A STRONG COLINEAR CURRENT

$$F_{DRAG} = C_{DC} [V_{CURR} + V_{LF}(t)]^2$$

$$F_{DAMPING} = (2*C_{DC}*V_{CURR})\, V_{LF}(t)$$

$$C_{DAMPING} = 2*C_{DC}*V_{CURR}$$

$$C_{CRITICAL} = 2\sqrt{(M + A)\, K}$$

$$\text{DAMPING RATIO} = C_{DAMPING}/C_{CRITICAL}$$

3. EFFECTS OF A STRONG COLINEAR WIND
(SOURCE: PROFESSOR VICKERY OF U. OF WESTERN ONTARIO)

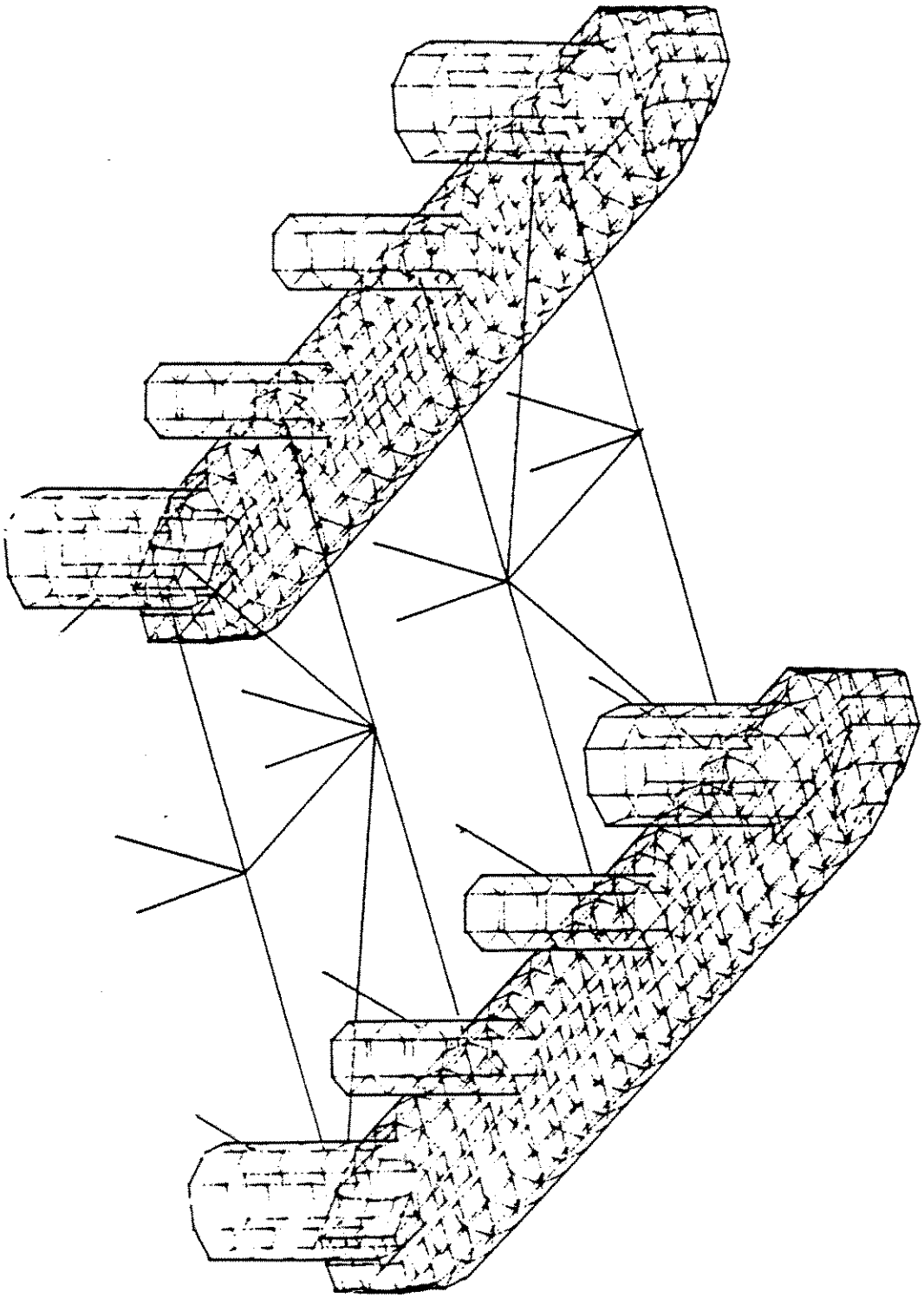
$$C_{DAMPING} = 2*C_{DW}*V_{WIND}$$

C_{DW} = WIND FORCE COEFFICIENT

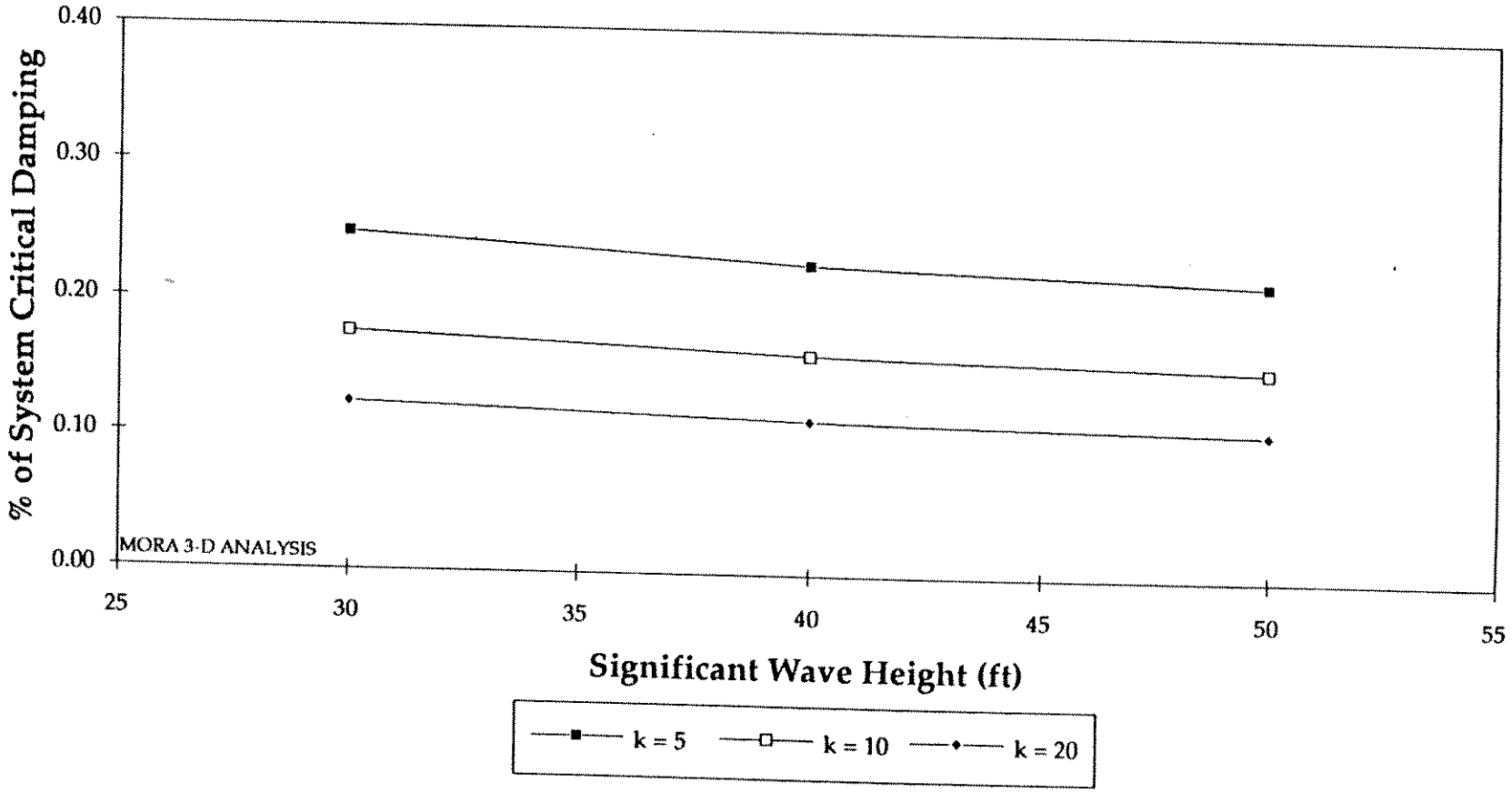
VESSEL/MOORING PARTICULARS
SEDCO 700 SEMISUBMERSIBLE IN OBLIQUE SEA

MOORING PARTICULARS	3000' WD	1000' WD	300' WD
NO. OF LINES	8	8	8
MOORING PATTERN	45° SYM.	45° SYM.	45° SYM.
LINE SEGMENT 1	3" ORQ CHAIN	3" ORQ CHAIN	3" ORQ CHAIN
(FROM ANCHOR)	2000'	2000'	4000'
LINE SEGMENT 2	3 3/8" WIRE	3 3/8" WIRE	---
	7000'	5000'	---
VESSEL PARTICULARS (SLUGS)			
MASS	1.51E+06	1.51E+06	1.51E+06
SURGE ADDED MASS	5.15E+05	5.15E+05	5.15E+05
SWAY ADDED MASS	1.28E+06	1.28E+06	1.28E+06
MEAN ENV. LOAD	668 KIPS	668 KIPS	668 KIPS
MOORING SYSTEM STIFFNESS (LBS/FT)	3700	12200	28800
VESSEL MOTIONS			
LF MAX. MOTION*	22 FT.	13 FT.	9 FT.
LF PERIOD	160 SEC.	90 SEC.	60 SEC.
WF MEAN MOTION (RMS)	3.3 FT.	3.3 FT.	3.3 FT.

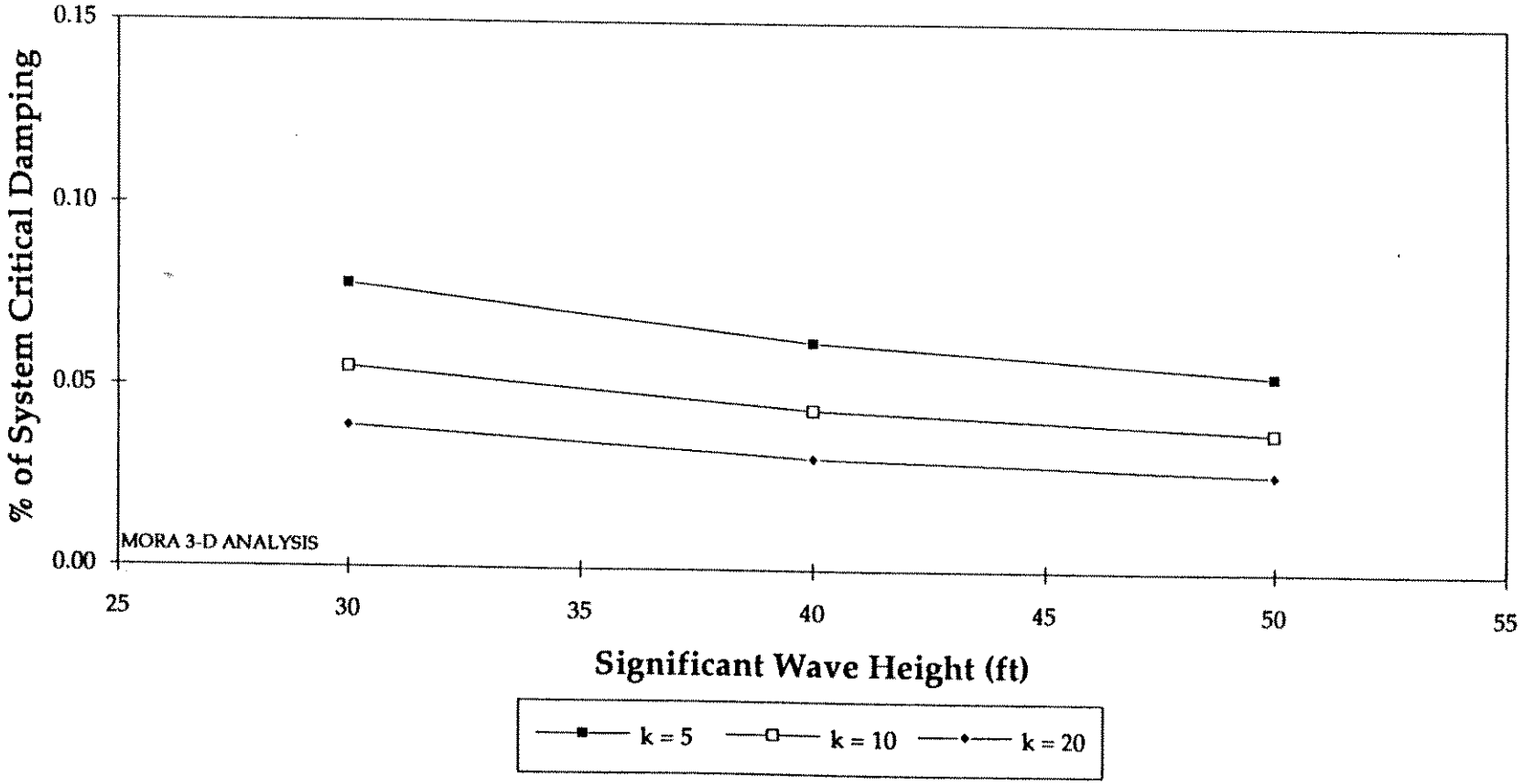
* API RP-2P BEAM SEA LF VALUES.



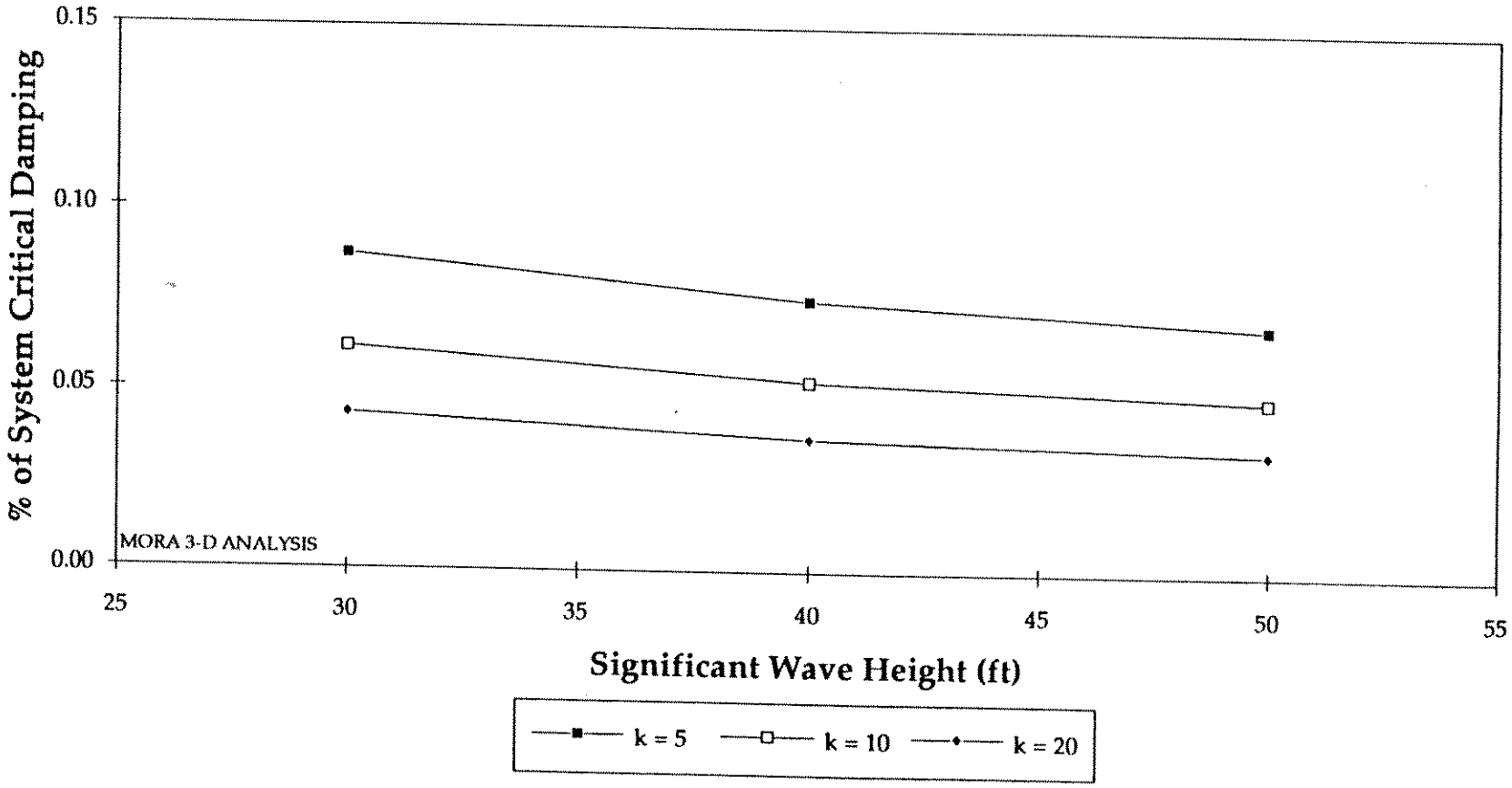
SEMI-SUBMERSIBLE (SEDCO 700 CLASS)
LF SURGE WAVE DRIFT DAMPING
HEADING ANGLE = 0.0 DEGREES



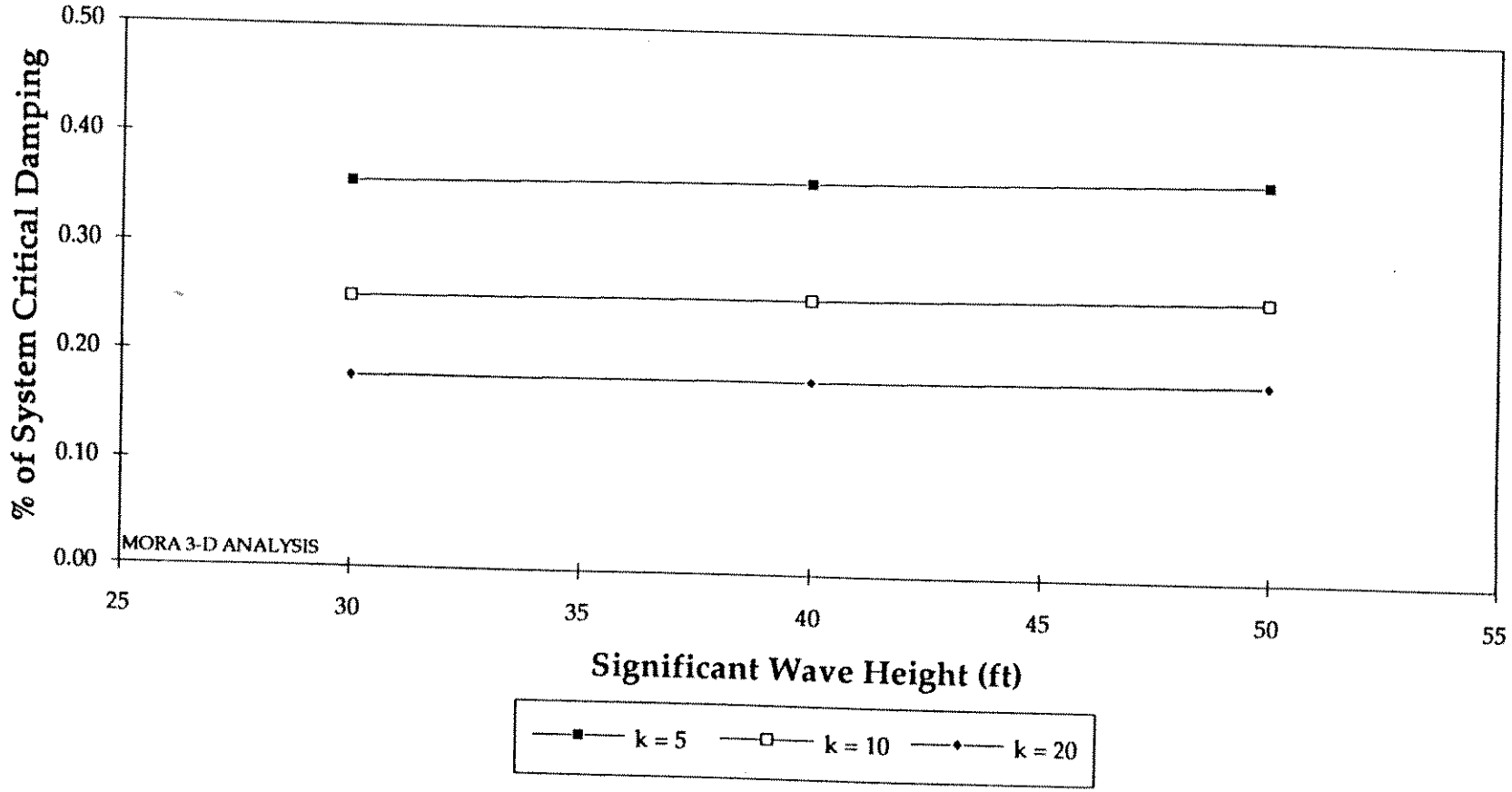
SEMI-SUBMERSIBLE (SEDCO 700 CLASS)
LF SURGE WAVE DRIFT DAMPING
HEADING ANGLE = 45.0 DEGREES



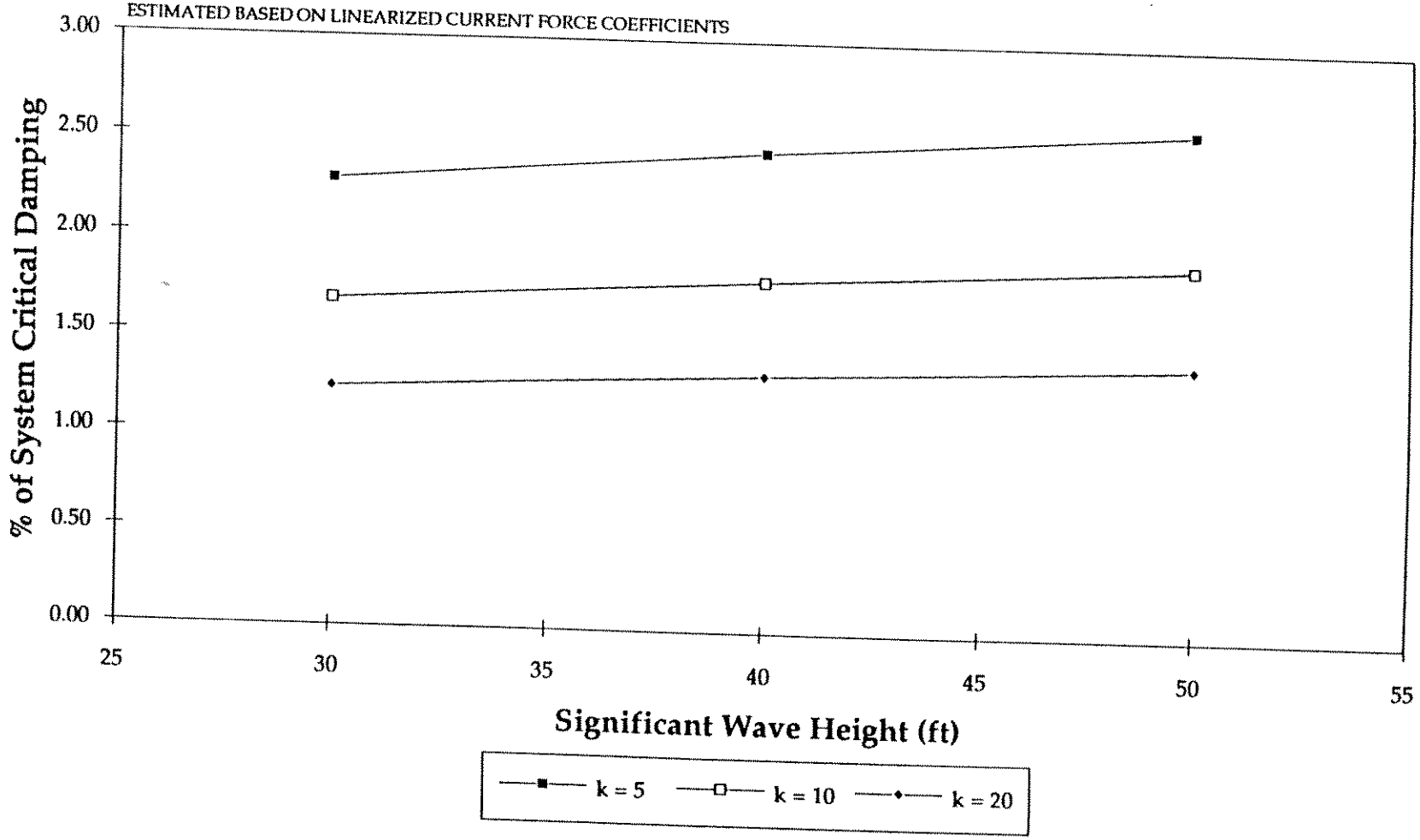
SEMI-SUBMERSIBLE (SEDCO 700 CLASS)
LF SWAY WAVE DRIFT DAMPING
HEADING ANGLE = 45.0 DEGREES



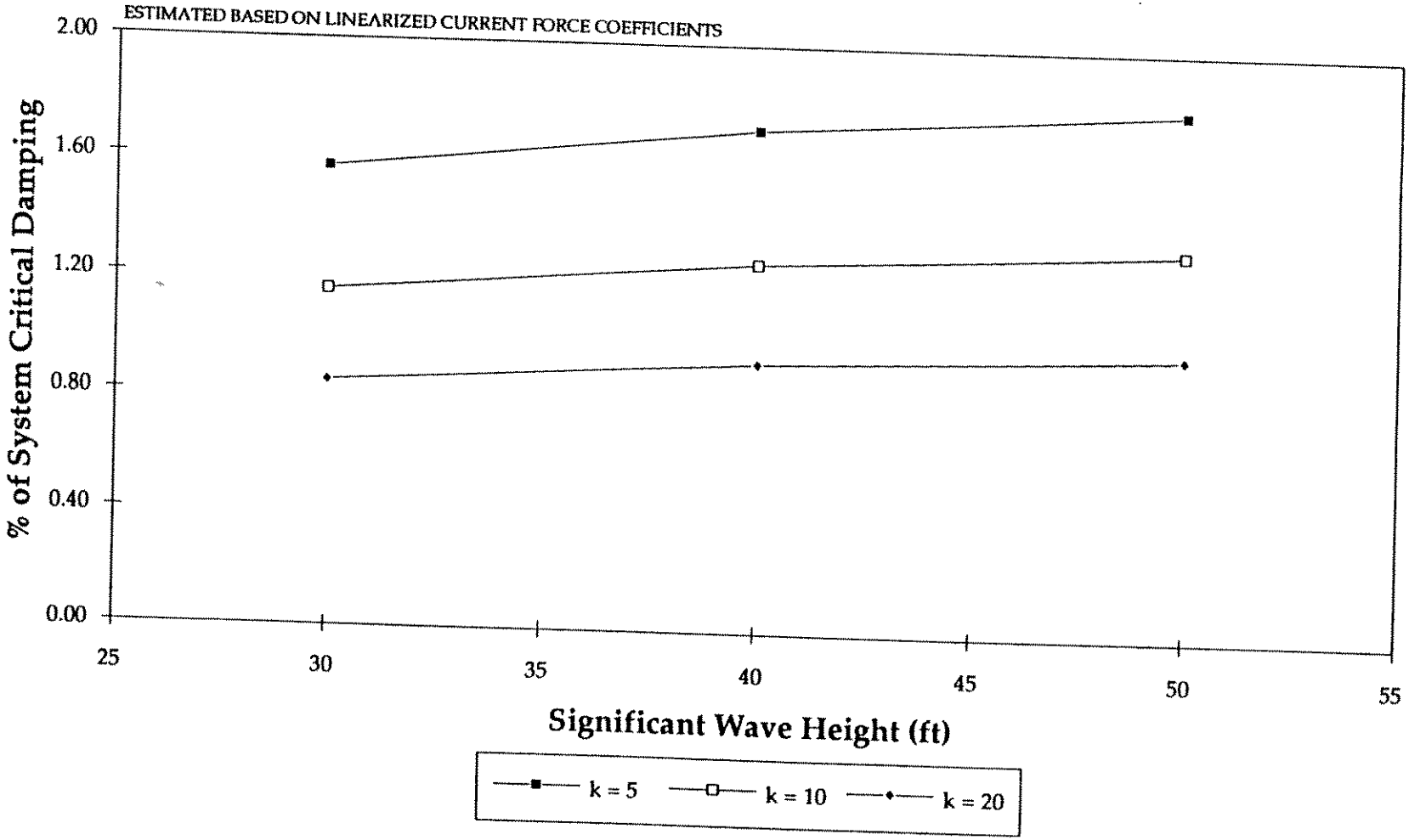
SEMI-SUBMERSIBLE (SEDCO 700 CLASS)
LF SWAY WAVE DRIFT DAMPING
HEADING ANGLE = 90.0 DEGREES



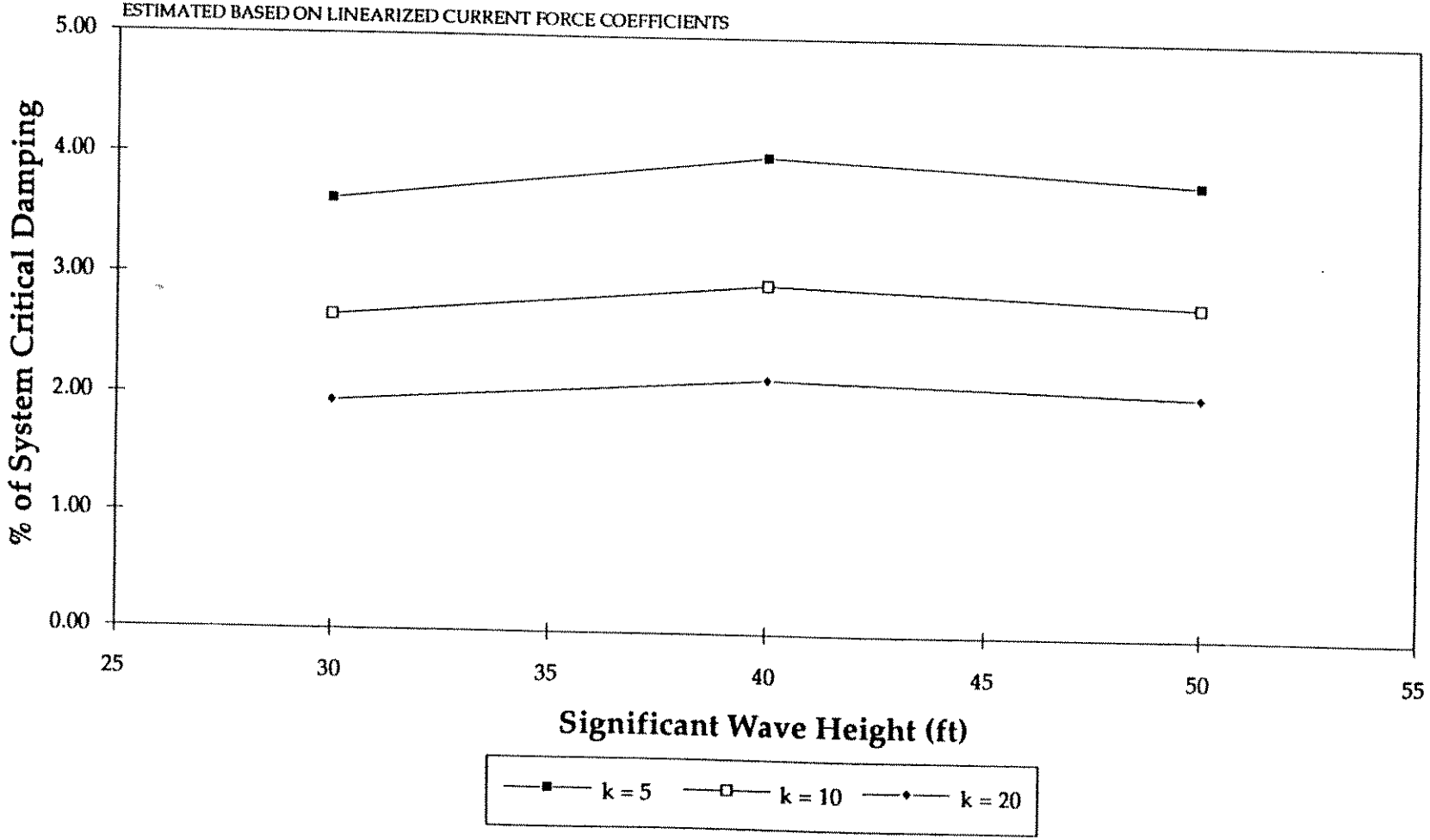
SEMI-SUBMERSIBLE (SEDCO 700 CLASS)
LF SURGE VISCOUS DAMPING
(NO CURRENT, LF MOTION ONLY)
HEADING ANGLE = 0.0 DEGREES



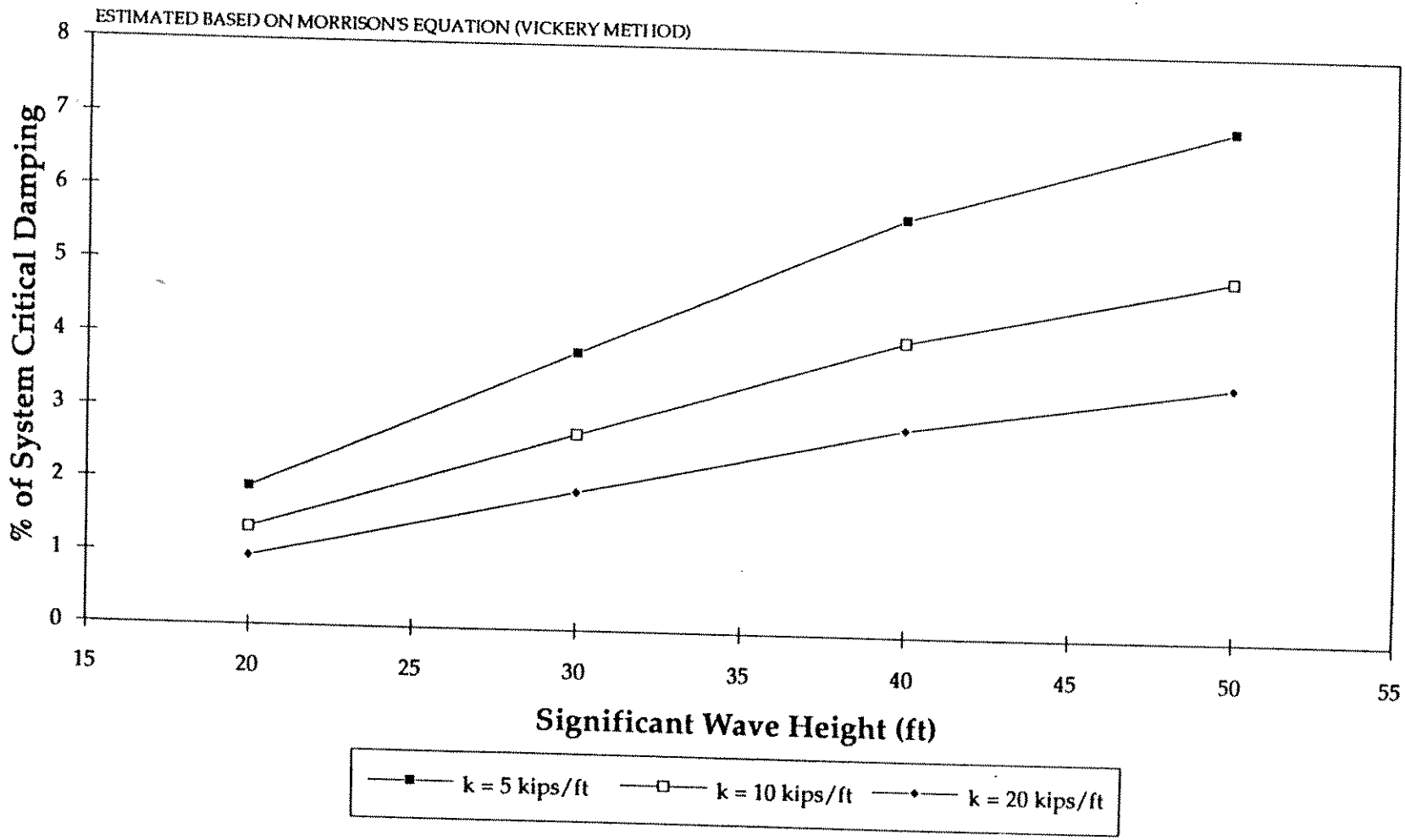
SEMI-SUBMERSIBLE (SEDCO 700 CLASS)
LF VISCOUS DAMPING
(NO CURRENT, LF MOTION ONLY)
HEADING ANGLE = 45.0 DEGREES



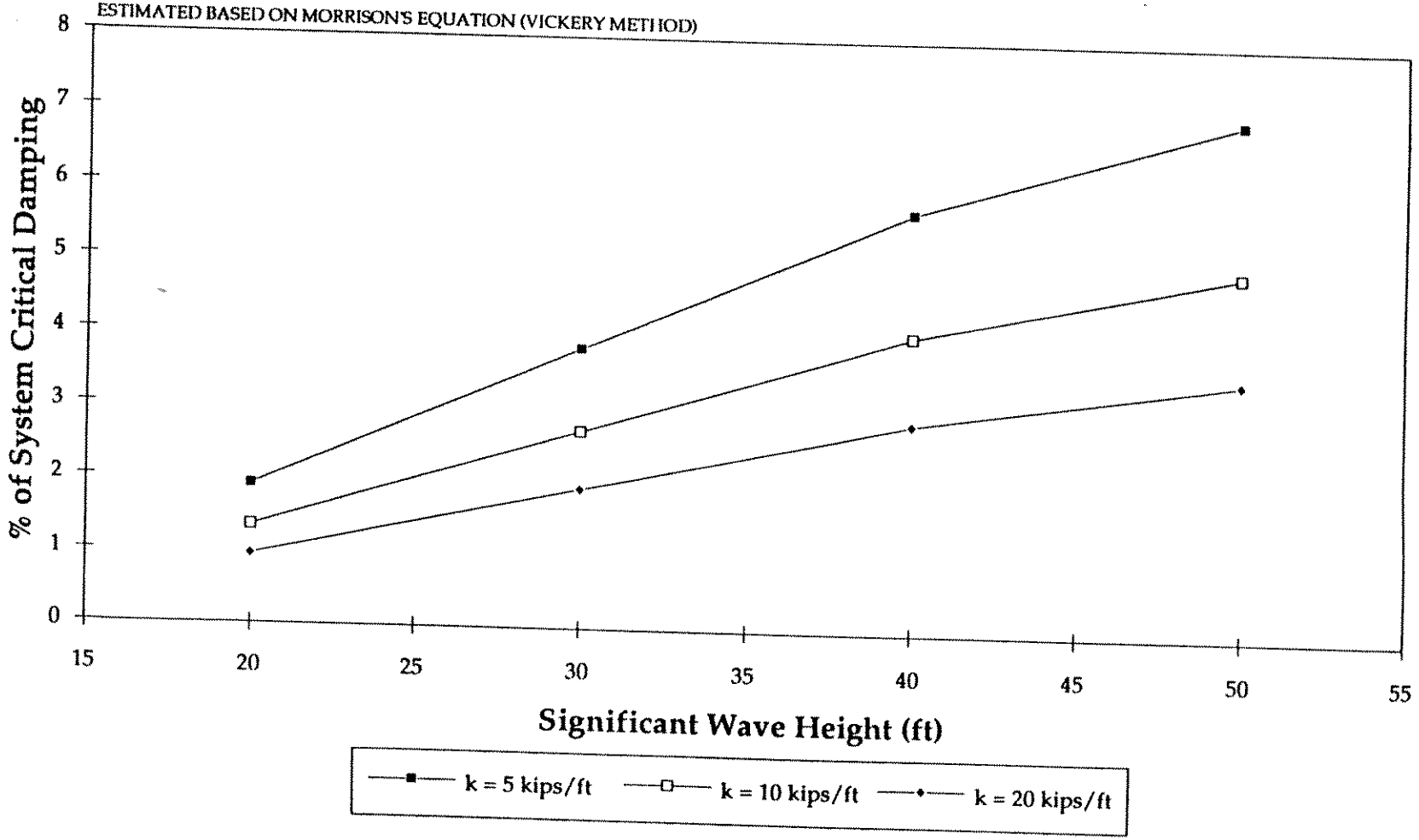
SEMI-SUBMERSIBLE (SEDCO 700 CLASS)
LF SWAY VISCOUS DAMPING
(NO CURRENT, LF MOTION ONLY)
HEADING ANGLE = 90.0 DEGREES



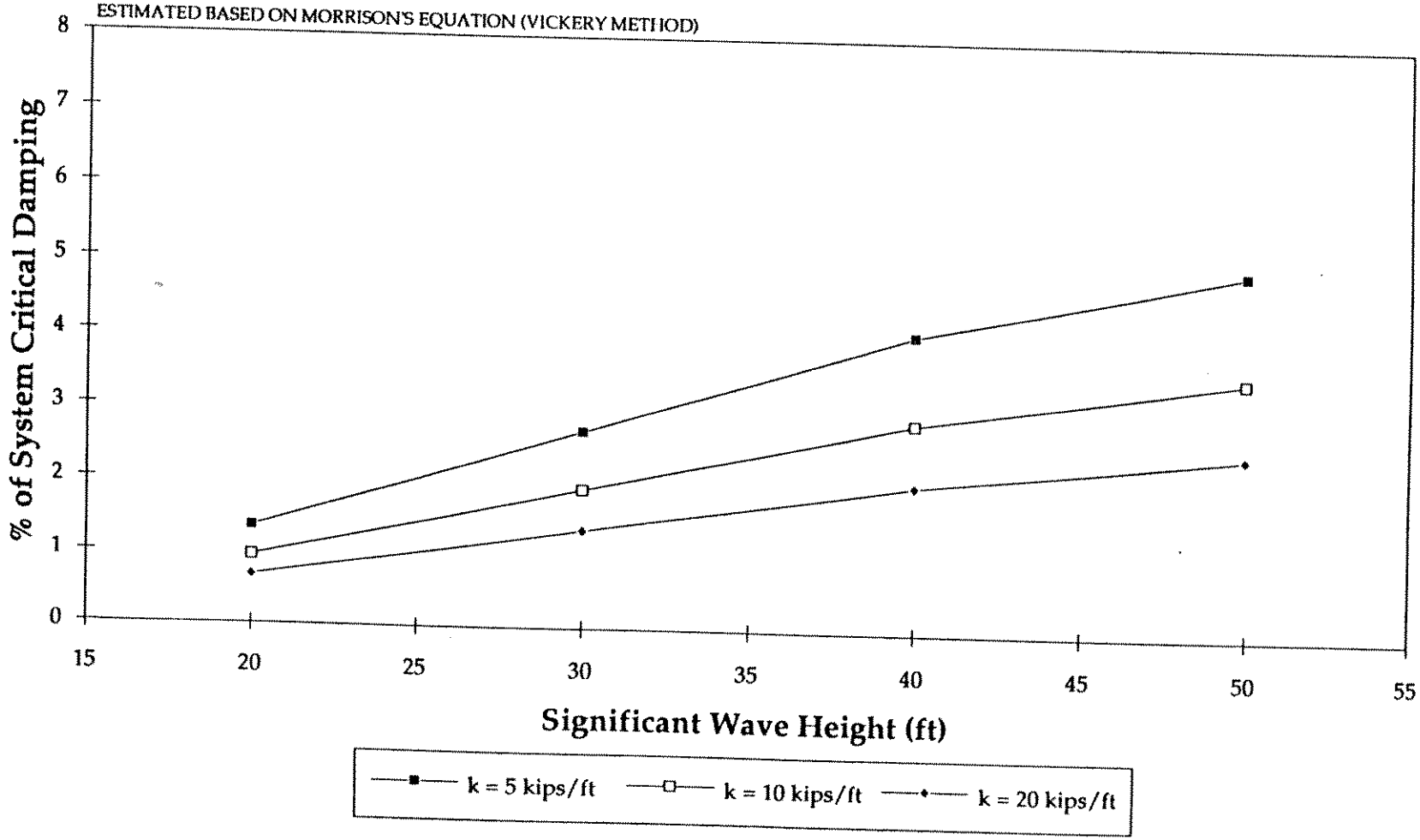
SEMI-SUBMERSIBLE (SEDCO 700 CLASS)
LF WIND INDUCED DAMPING
(LF MOTION PLUS WIND)
HEADING ANGLE = 0.0 DEGREES



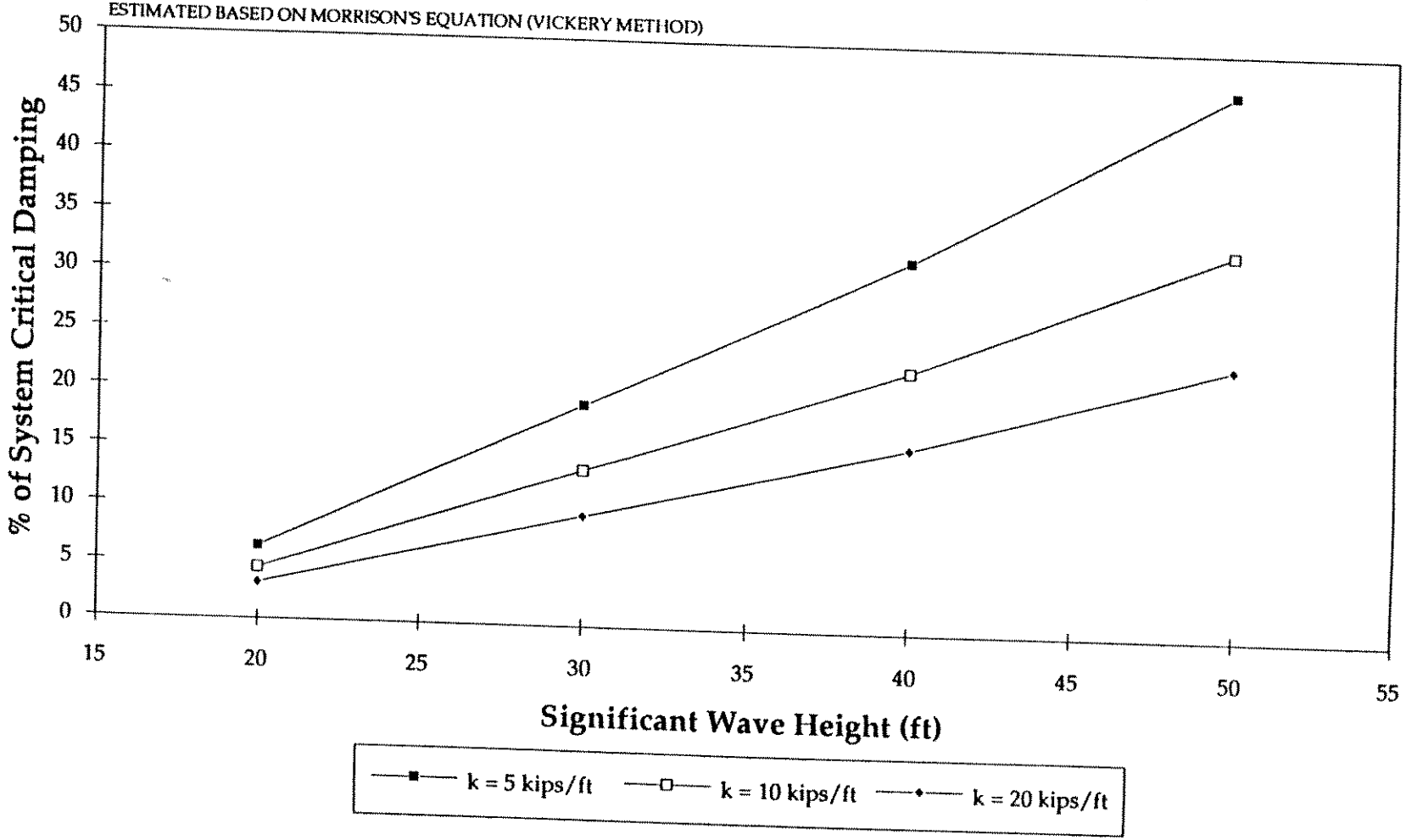
SEMI-SUBMERSIBLE (SEDCO 700 CLASS)
LF WIND INDUCED DAMPING
(LF MOTION PLUS WIND)
HEADING ANGLE = 45.0 DEGREES



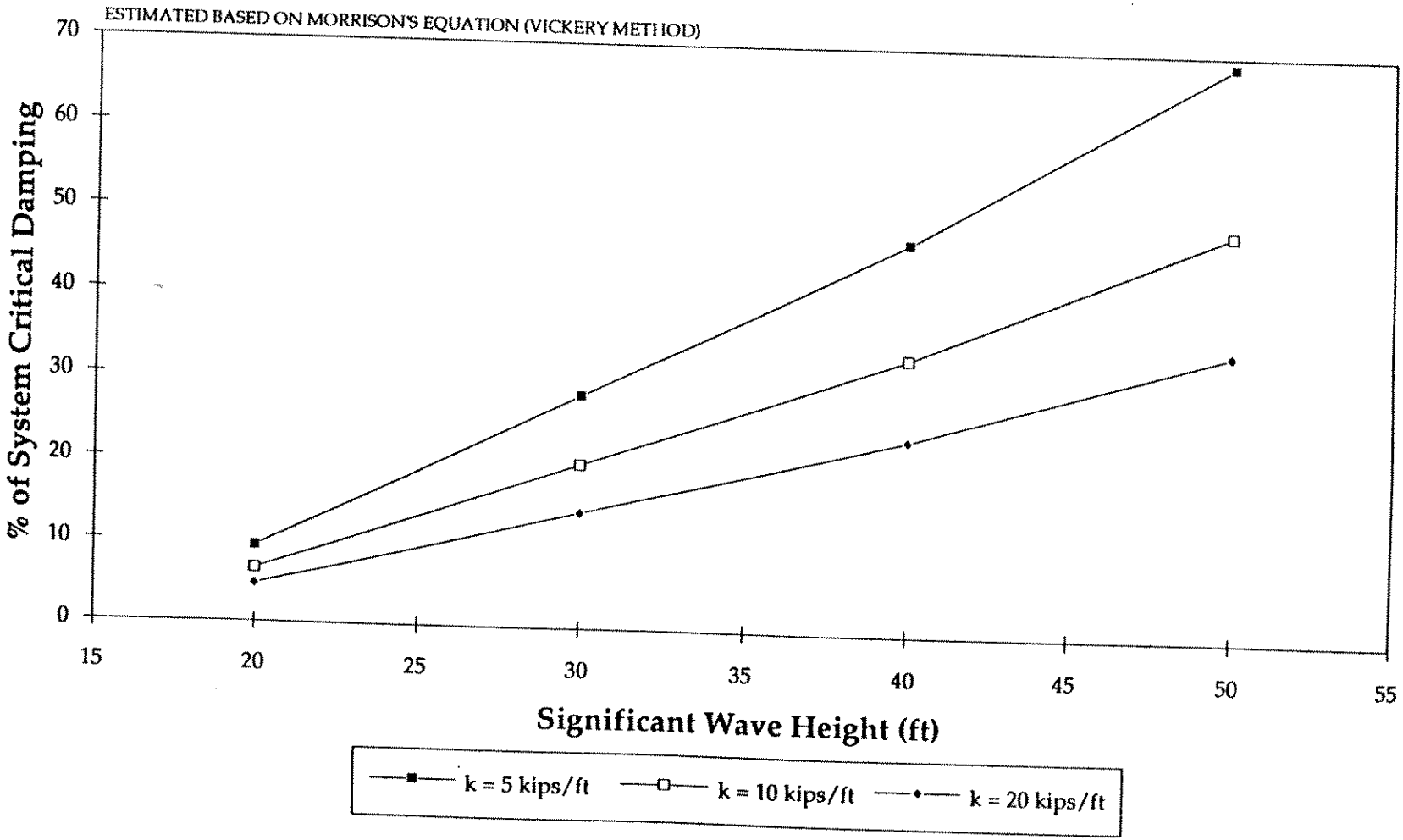
SEMI-SUBMERSIBLE (SEDCO 700 CLASS)
LF WIND INDUCED DAMPING
(LF MOTION PLUS WIND)
HEADING ANGLE = 90.0 DEGREES



SEMI-SUBMERSIBLE (SEDCO 700 CLASS)
LF CURRENT INDUCED DAMPING
(LF MOTION PLUS CURRENT)
HEADING ANGLE = 0.0 DEGREES



SEMI-SUBMERSIBLE (SEDCO 700 CLASS)
LF CURRENT INDUCED DAMPING
(LF MOTION PLUS CURRENT)
HEADING ANGLE = 45.0 DEGREES



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LF CURRENT INDUCED DAMPING
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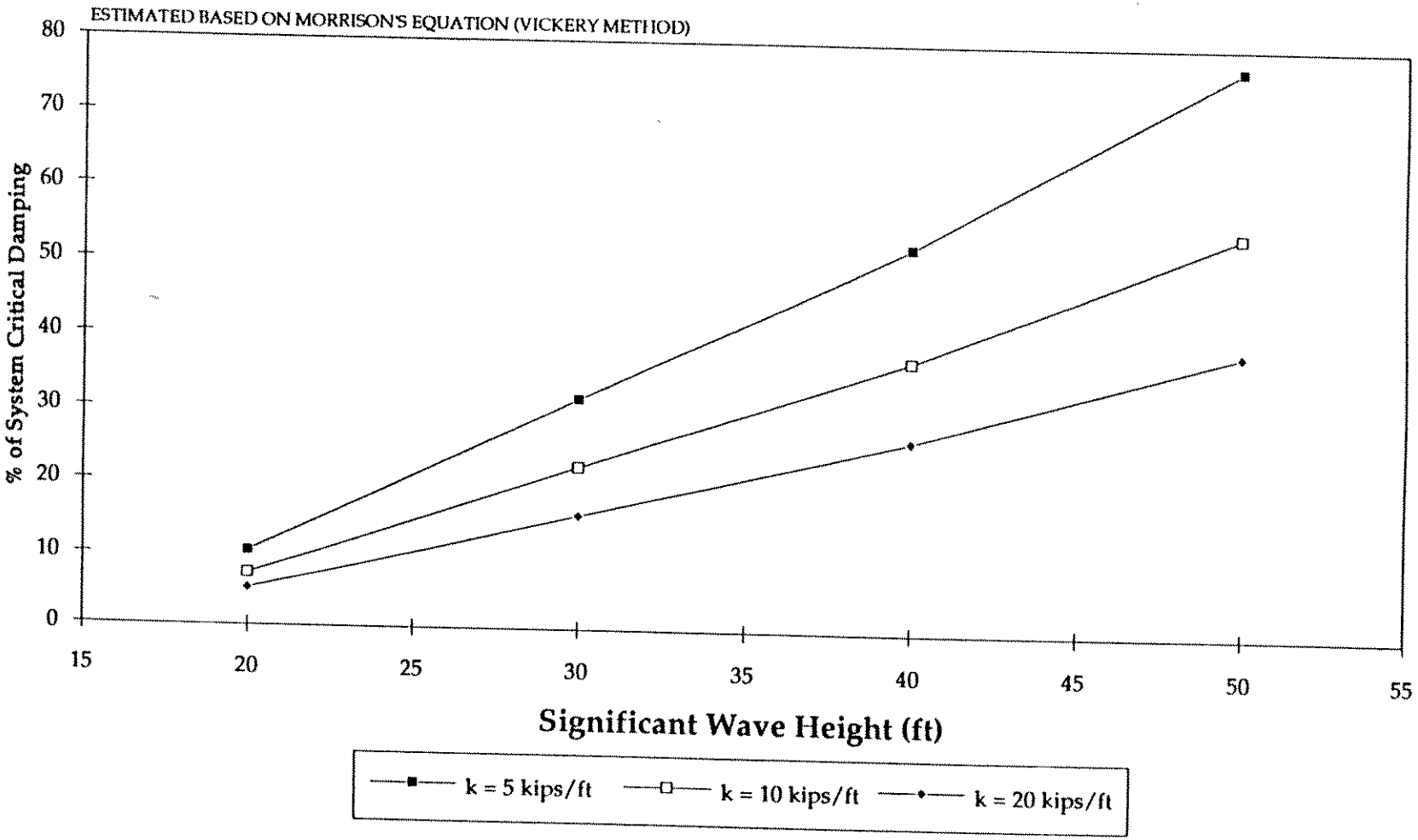


VESSEL LF DAMPING
DRILLSHIP (380' X 70' X 26')

1. COMPUTATIONAL METHODS: REF. SEDCO 700

2. STUDY MATRIX: REF. SEDCO 700

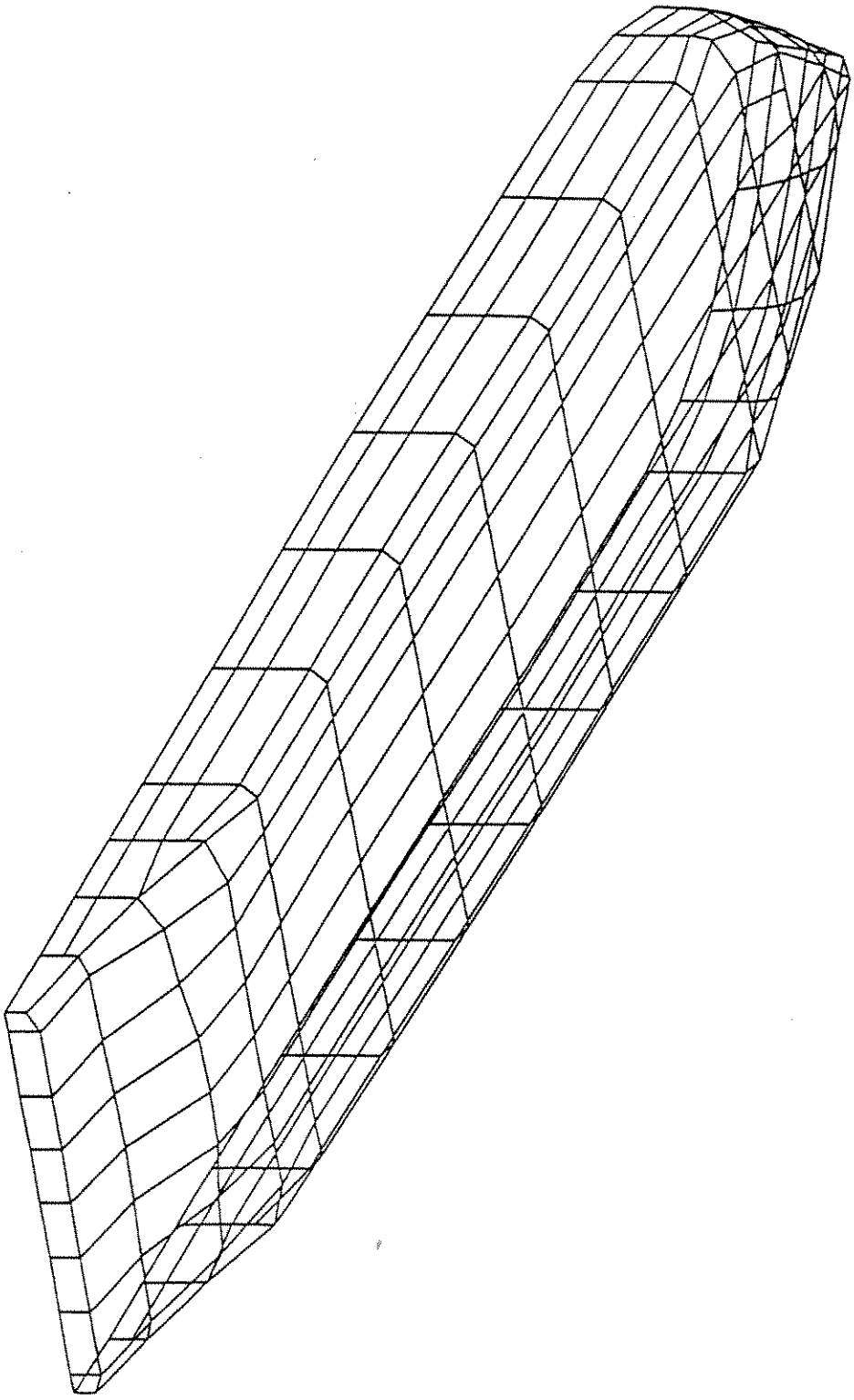
3. A DESIGN CASE: GOMEX 10-YEAR STORM

	DAMPING (% OF SYSTEM CRITICAL)	
	HEAD SEA	BEAM SEA
WAVE DRIFT DAMPING	1%	2.9%
VISCOUS DAMPING		
• NO CURRENT	0.2%	6.7%
• 1.8-KNOT CURRENT	2.3%	26%
AERODYNAMIC DAMPING (72-KNOT WIND)	1.9%	3.4%
TOTAL	1.6-5.3%	13-32%

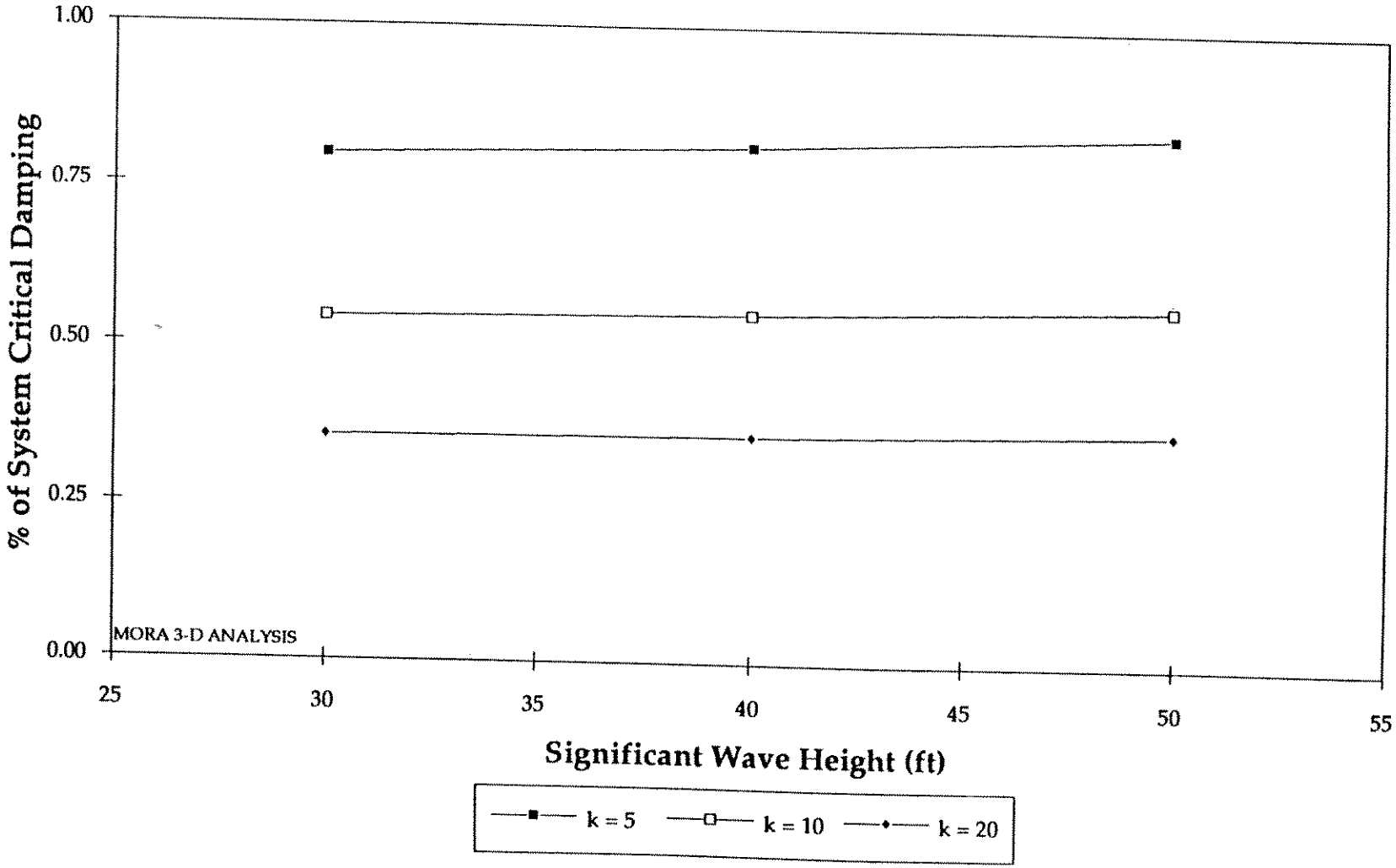
• LF MAX. MOTION:	12 FT.	22 FT.
• LF PERIOD:	120 SEC.	80 SEC.
• LF MAX. VELOCITY:	0.7 FT/SEC (0.4 KTS)	1.9 FT.SEC (1.1 KTS)
• MOORING SYSTEM STIFFNESS (1000' WD)	2.7 KIPS/FT	6.8 KIPS/FT

VESSEL/MOORING PARTICULARS
DRILLSHIP (L X B X D = 380' X 70' X 26')

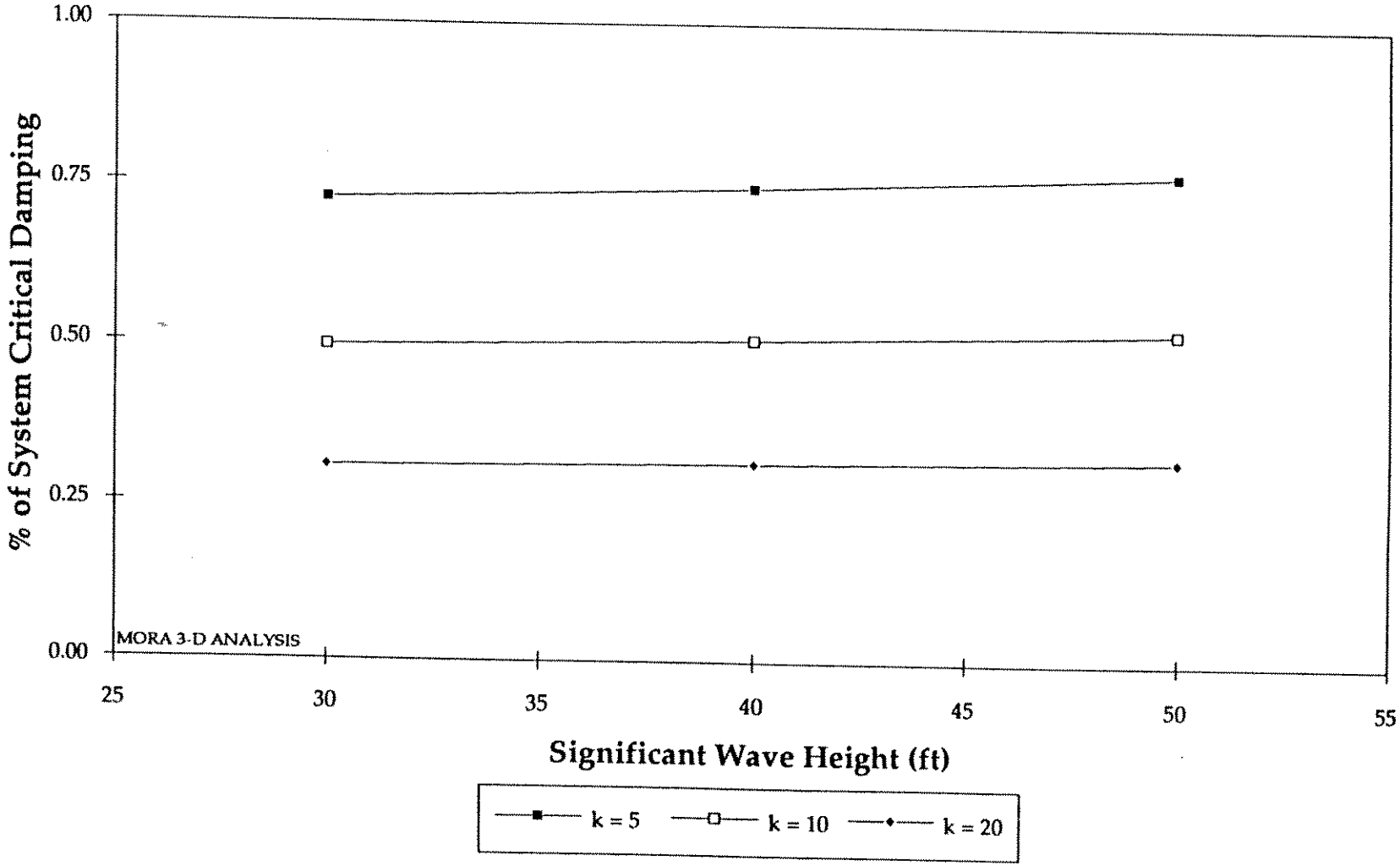
	3000' WD		1000' WD		300' WD	
MOORING PARTICULARS	HEAD SEA	BEAM SEA	HEAD SEA	BEAM SEA	HEAD SEA	BEAM SEA
NO. OF LINES	8	8	8	8	8	8
MOORING PATTERN	45°	60°	45°	60°	45°	60°
LINE SEGMENT 1 GRADE 3 2.5" CHAIN	2000'	2000'	2000'	2000'	4000'	4000'
LINE SEGMENT 2 2.5" WIRE	3500'	3500'	1500'	1500'	---	---
VESSEL PARTICULARS						
MASS (SLUGS)	8.39E+05	8.39E+05	8.39E+05	8.39E+05	8.39E+05	8.39E+05
ADDED MASS (SLUGS)	5.88E+04	5.89E+05	5.88E+04	5.89E+05	5.88E+04	5.89E+05
MEAN ENV. LOAD (KIPS)	195	590	195	590	195	590
MOORING SYSTEM STIFFNESS (LBS/FT)	600	2900	2700	6800	7900	21350
VESSEL MOTIONS						
LF MAX. MOTIONS	20'	31.8'	12.5'	21.8'	8.1'	13.3'
LF PERIODS (SEC.)	210	120	120	80	70	50
WF MOTION (RMS)	4.9'	6.7'	4.9'	6.7'	4.9'	6.7'



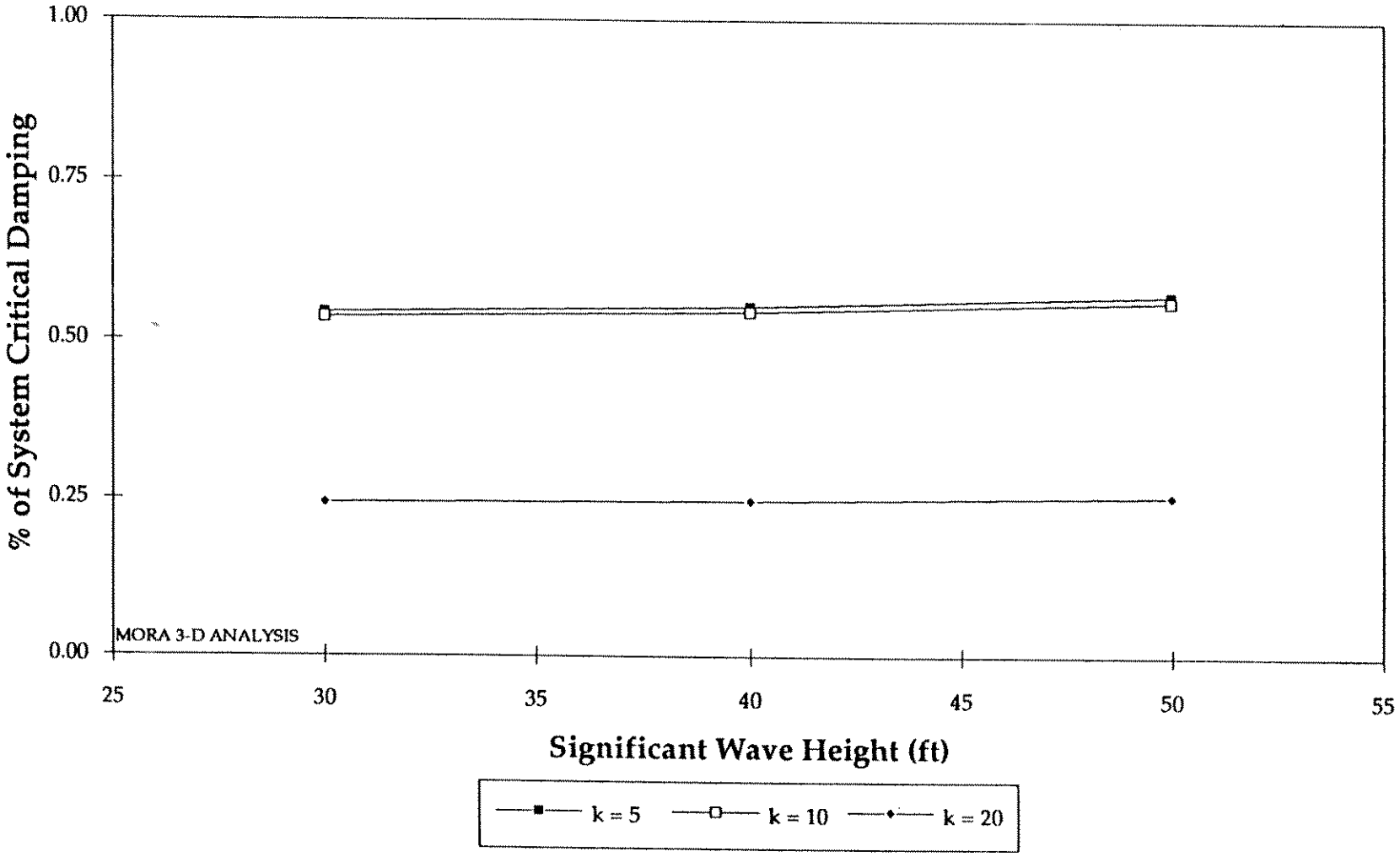
DRILL SHIP (L x B x D = 380' x 70' x 26')
LF SURGE WAVE DRIFT DAMPING
HEADING ANGLE = 0.0 DEGREES



DRILL SHIP (L x B x D = 380' x 70' x 26')
LF SURGE WAVE DRIFT DAMPING
HEADING ANGLE = 30.0 DEGREES



DRILL SHIP (L x B x D = 380' x 70' x 26')
LF SURGE WAVE DRIFT DAMPING
HEADING ANGLE = 60.0 DEGREES



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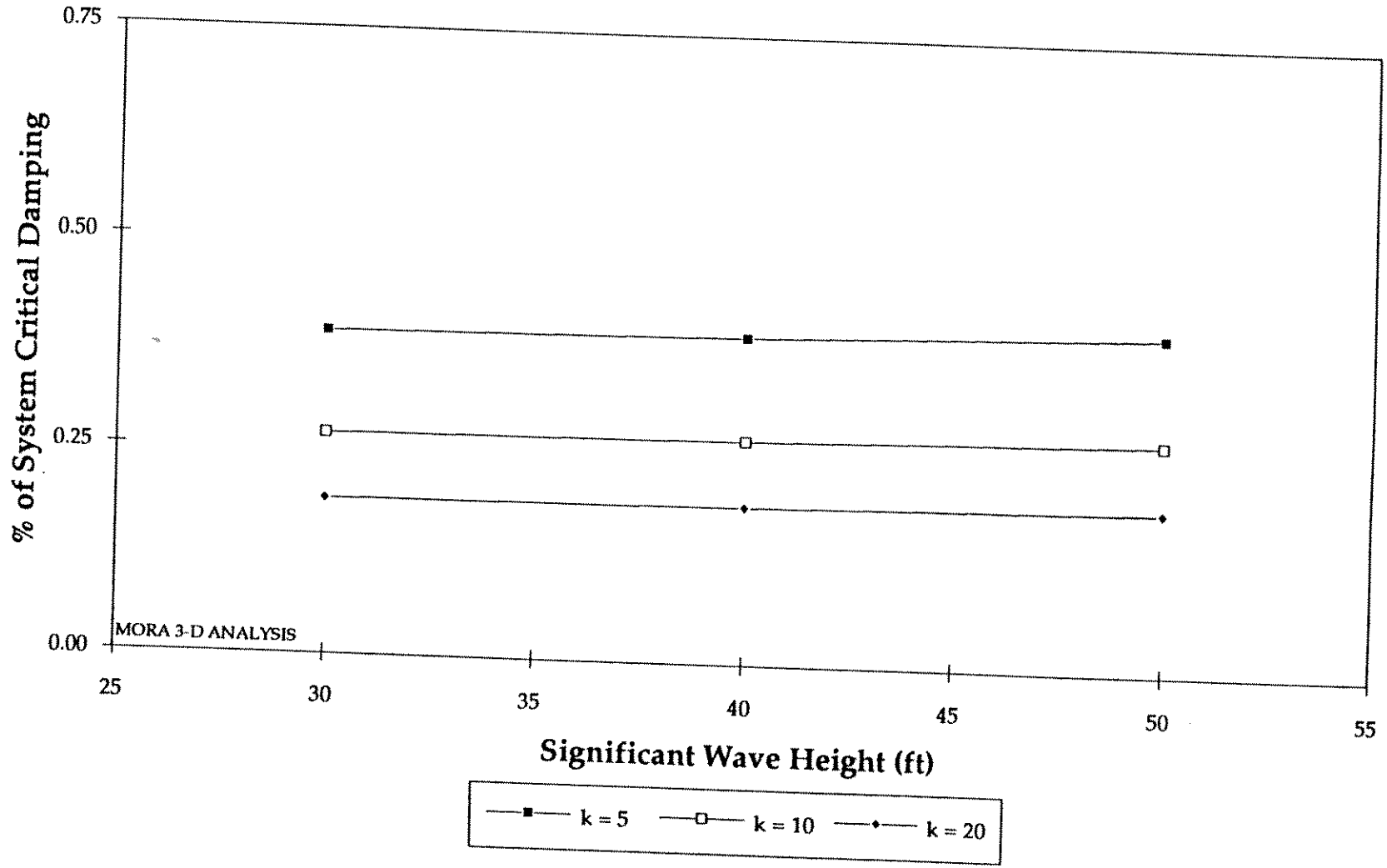
LF SWAY WAVE DRIFT DAMPING
HEADING ANGLE = 30.0 DEGREES



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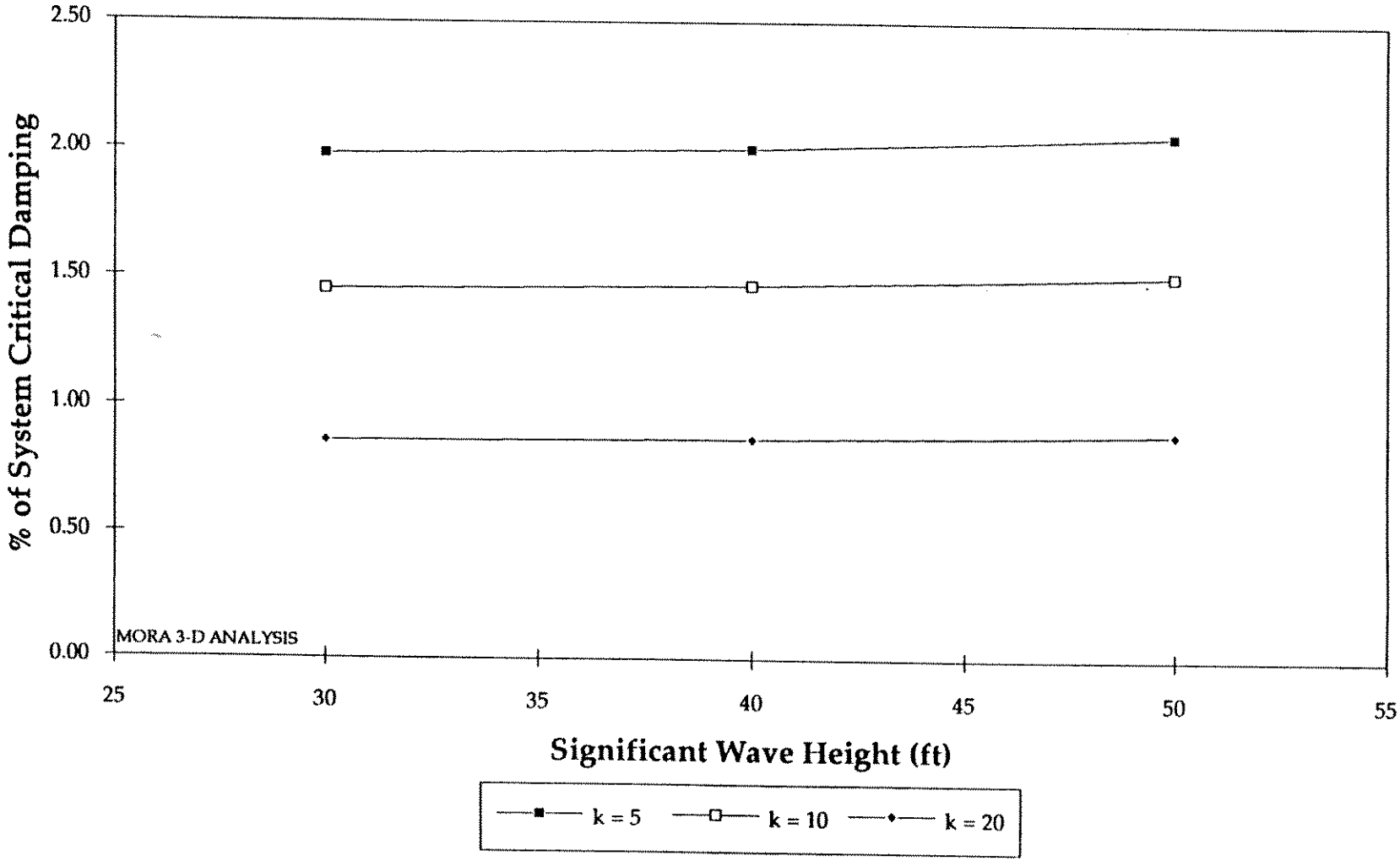
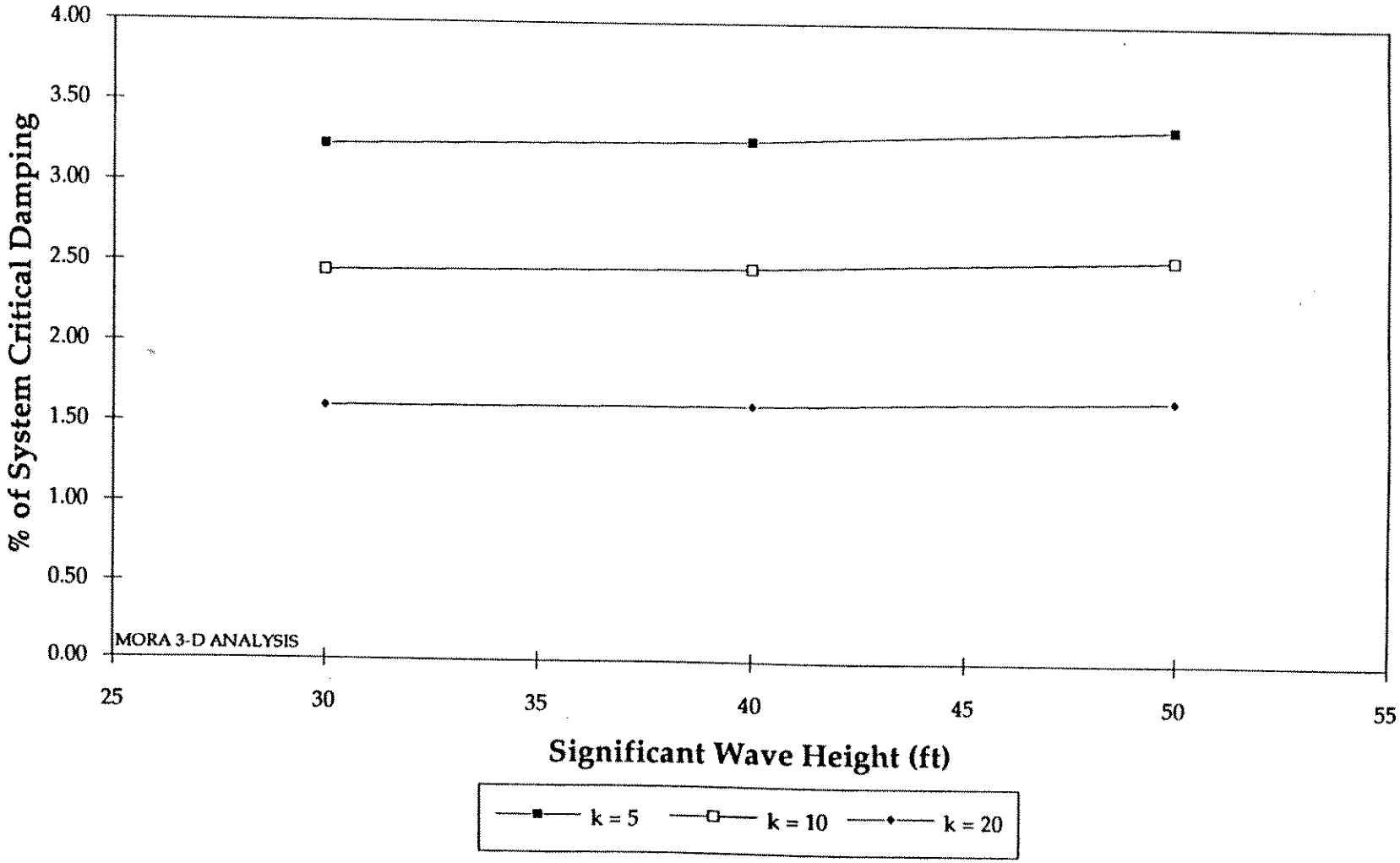
LF SWAY WAVE DRIFT DAMPING
HEADING ANGLE = 60.0 DEGREES



DRILL SHIP (L x B x D = 380' x 70' x 26')
LF SWAY WAVE DRIFT DAMPING
HEADING ANGLE = 90.0 DEGREES



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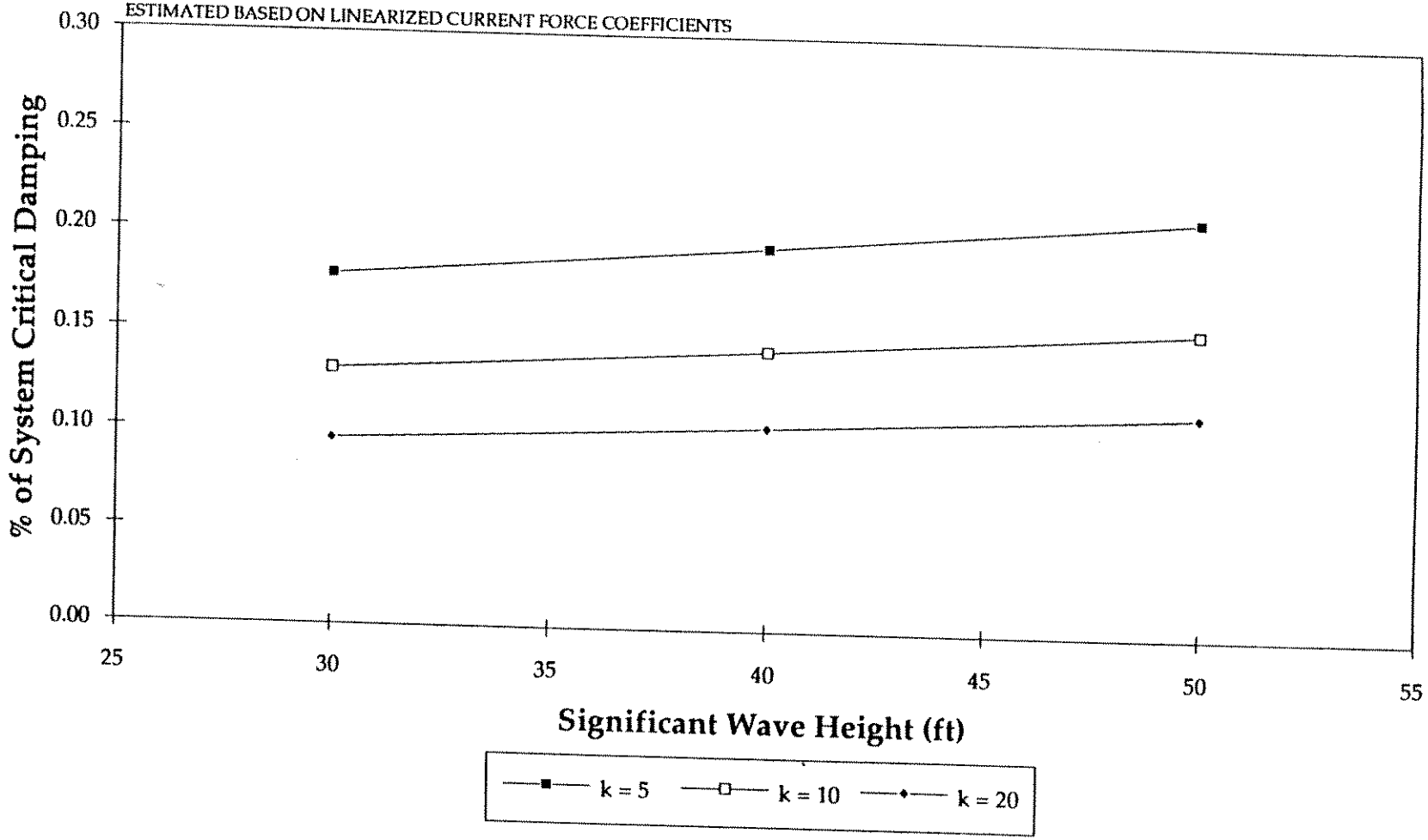
LF SURGE VISCOUS DAMPING
(NO CURRENT, LF MOTION ONLY)
HEADING ANGLE = 0.0 DEGREES



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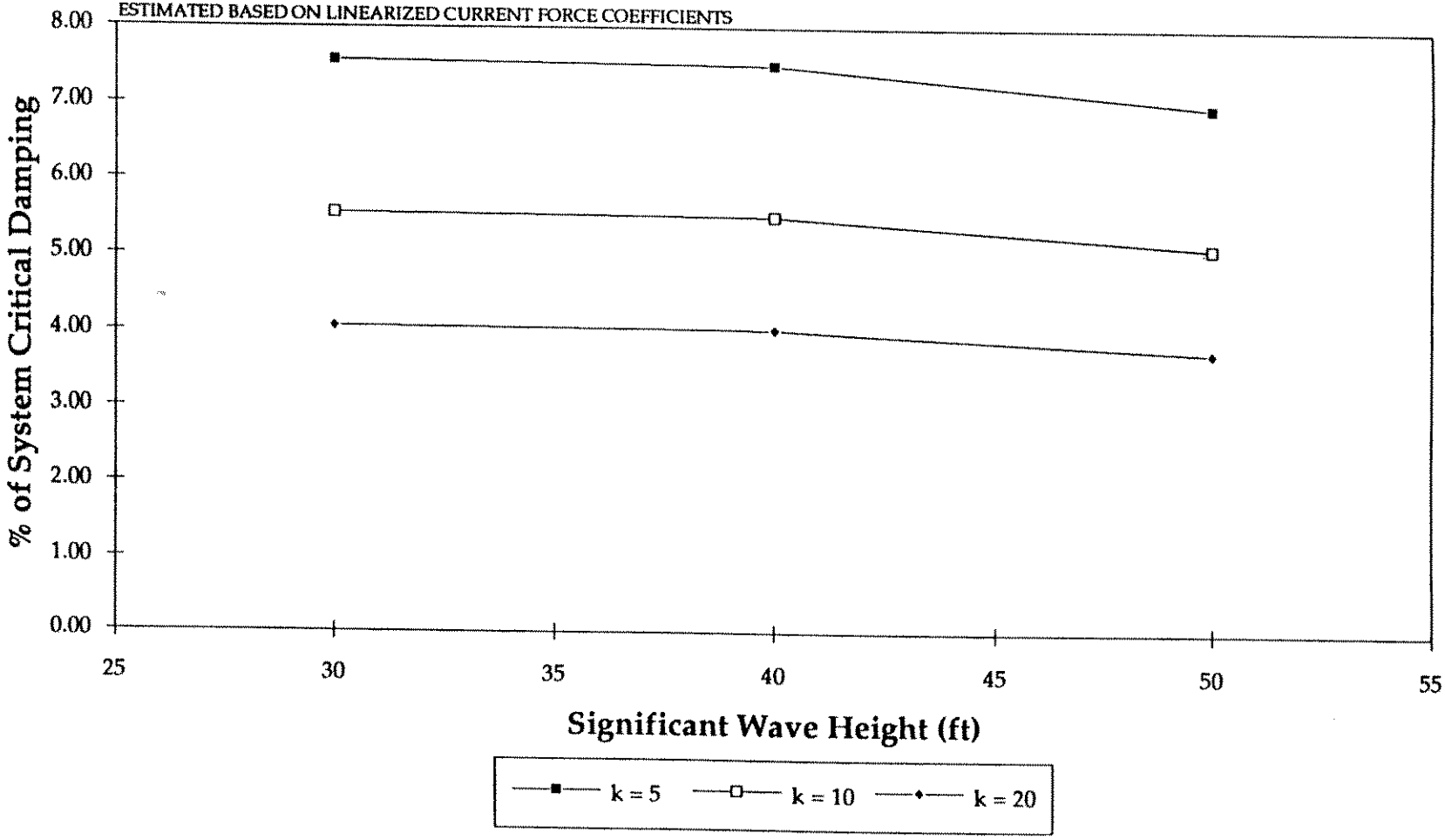
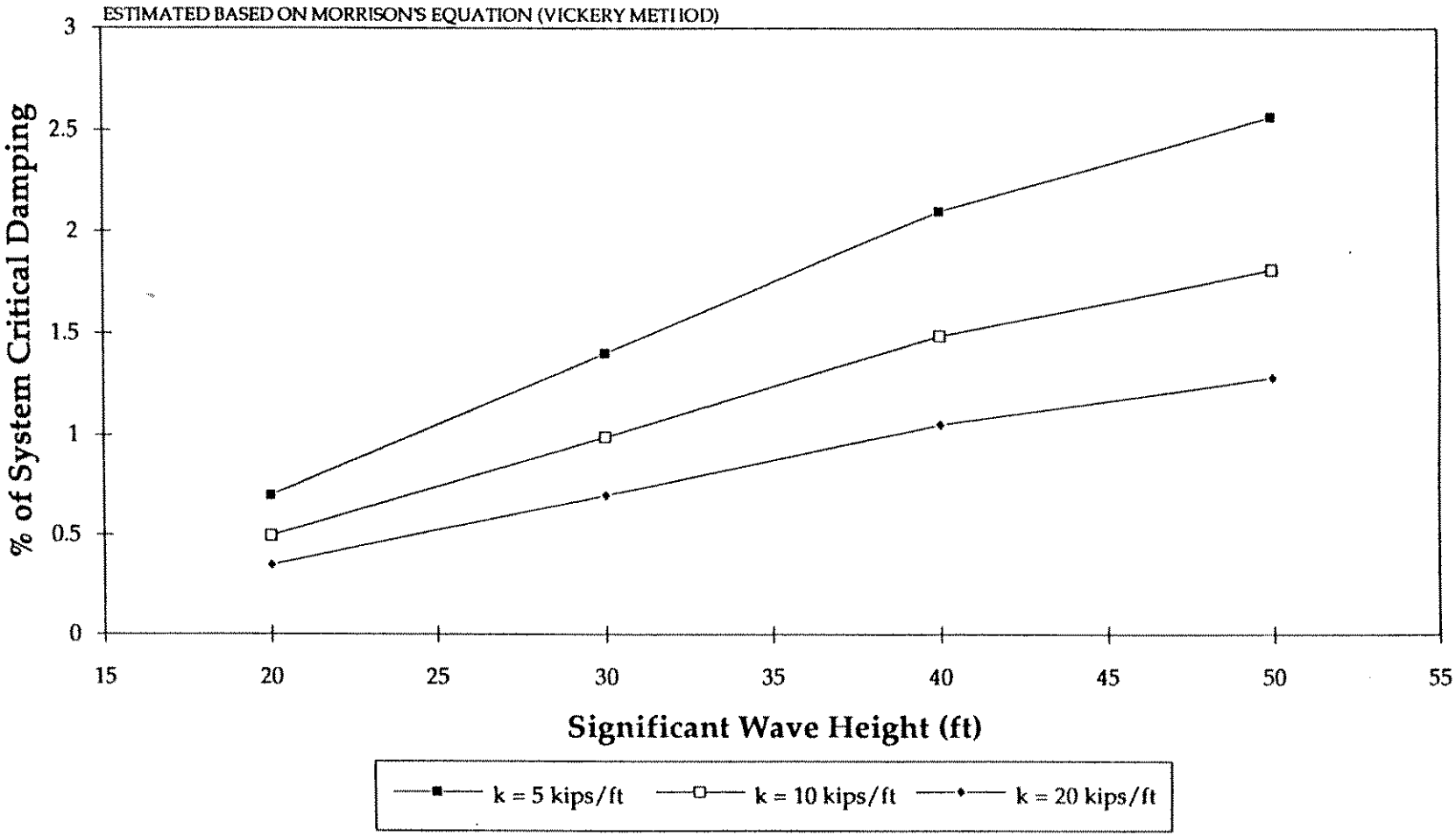


DRILL SHIP (L x B x D = 380' x 70' x 26')
LF WIND INDUCED DAMPING
(LF MOTION PLUS WIND)
HEADING ANGLE = 0.0 DEGREES



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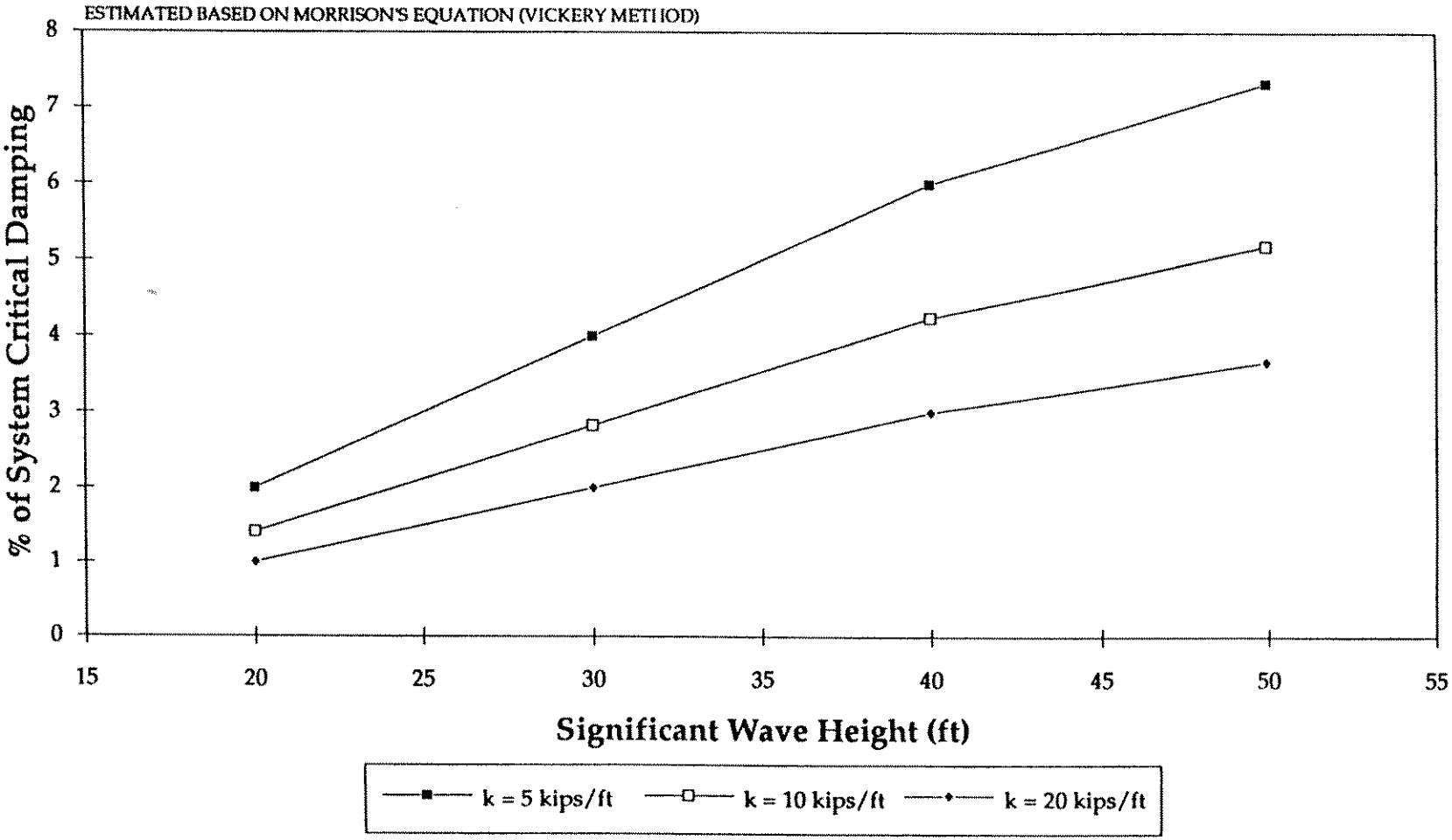
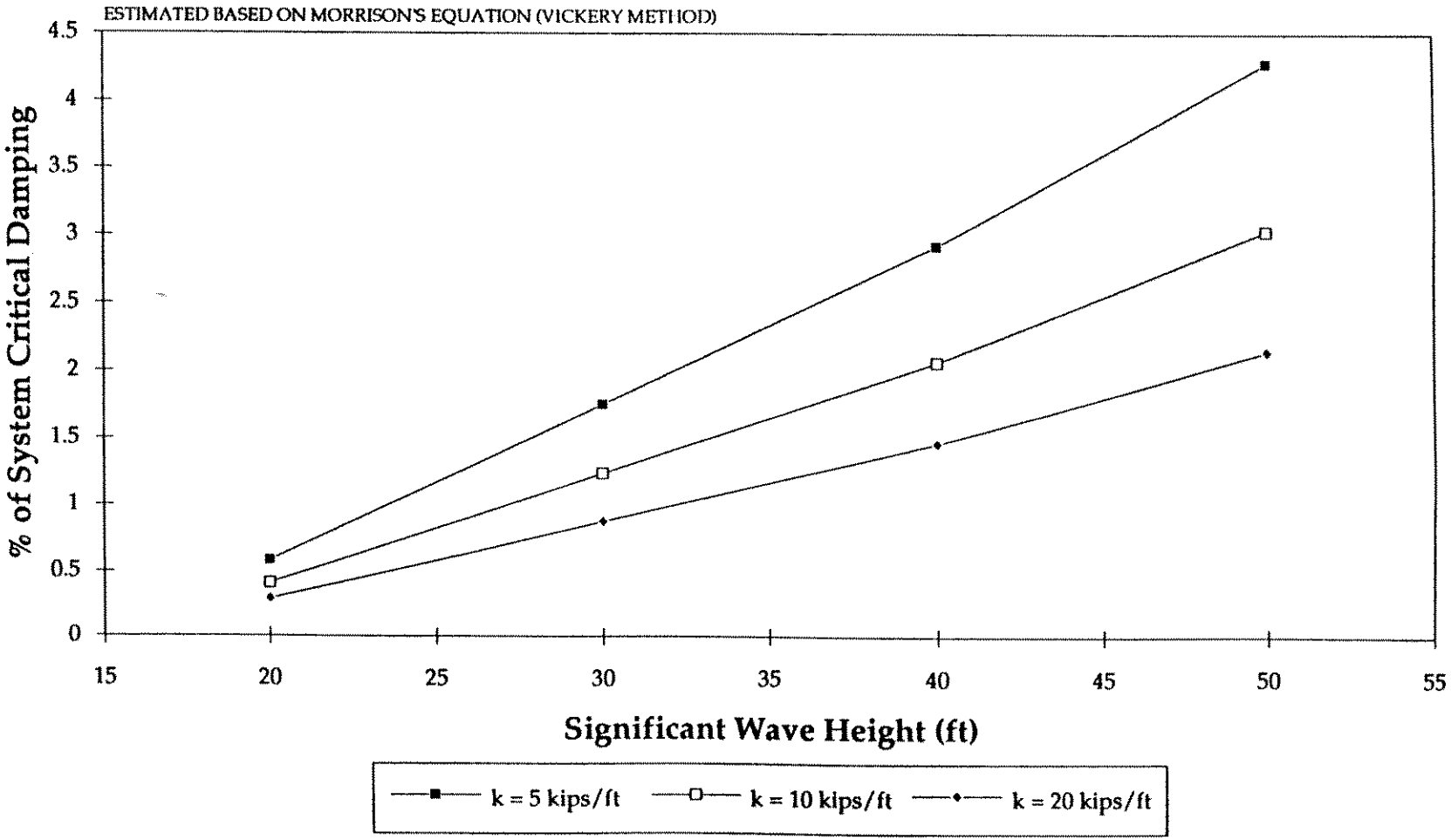


DRILL SHIP (L x B x D = 380' x 70' x 26')
LF CURRENT INDUCED DAMPING
(LF MOTION PLUS CURRENT)
HEADING ANGLE = 0.0 DEGREES



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