Title: Analysis of Buried Pipelines at Kozloduy

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Analysis of Buried Pipelines at Kozloduy

(Meeting of the IAEA Research Programme)

Benchmark Study for Seismic Testing and Analysis of WWER-type NPPs

San Francisco, California
13-17 October 1997

Alejandro P. Asfura

Basilio N. Sumodobila

EQE International

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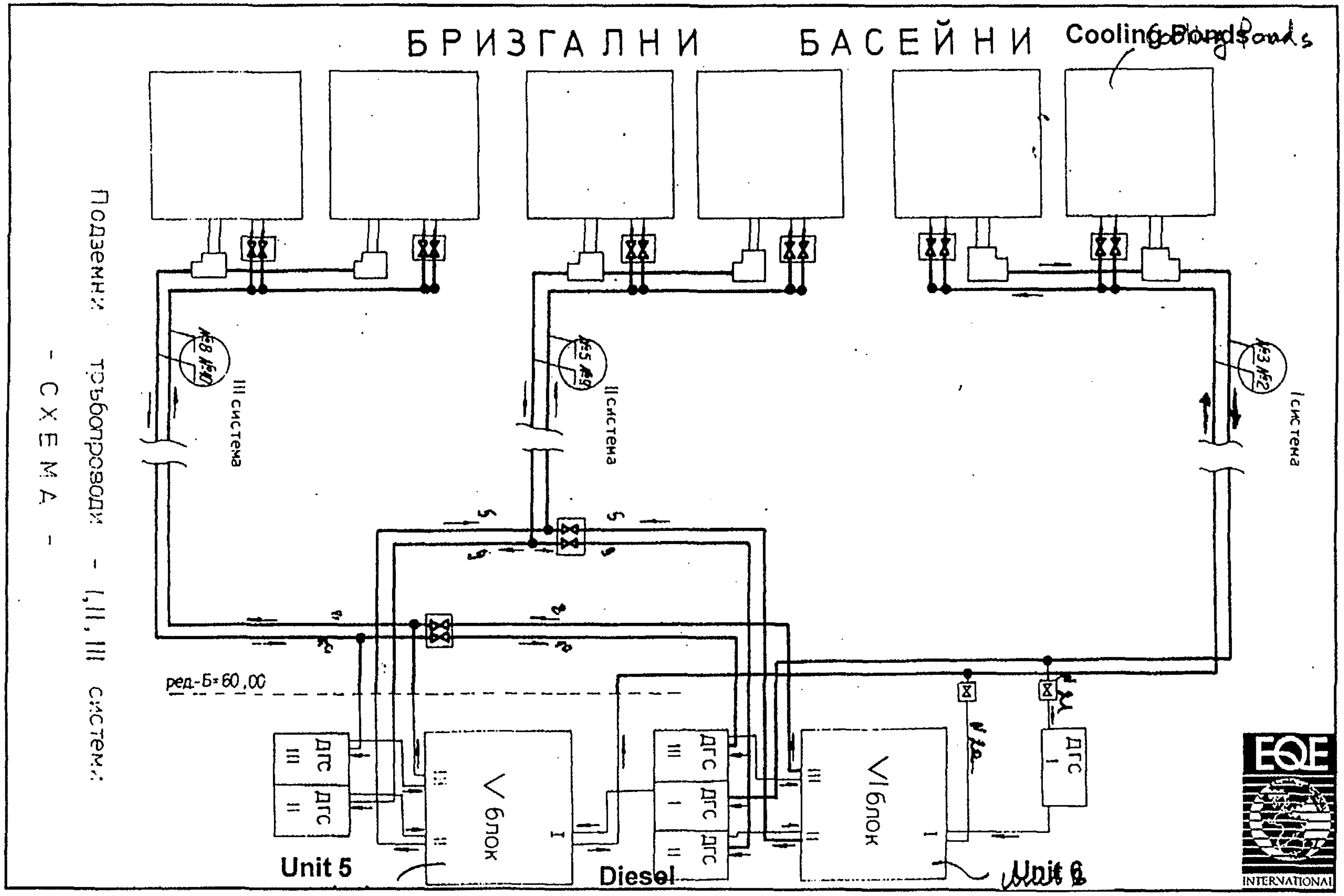
Studied Pipeline

- Pipeline No. 10 from Cooling Ponds to Diesel

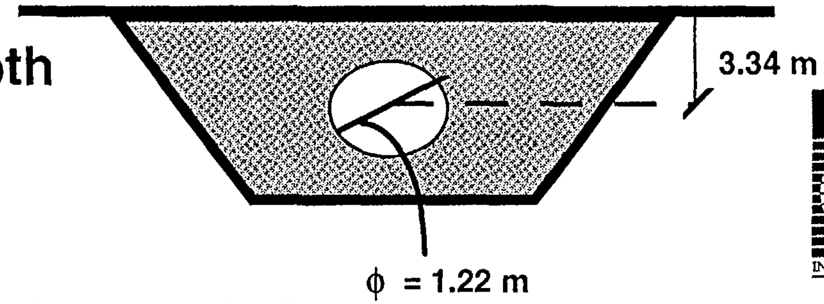


Characteristics of Studied Pipeline

- Diameter: 1220 mm
- Thickness of straight pipe: 8 mm
- Thickness of elbows: 10 mm
- Young's Modulus, $E = 2.06\ 10^5$ MPa
- Poisson's Ratio, $\upsilon = 0.3$

	Straight Pipe	Elbow
Yielding Stress	375 MPa	225 MPa
Ultimate Stress	510 MPa	370 MPa

- Internal Pressure, pi = 0.2 MPa
- Assumed Constant Depth



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Methodology Analysis Considerations

- Analyze pipeline due to wave passage
- Neglect dynamic effects
- Study selected portions of the pipeline
- Consider slippage between pipeline and soil

Analysis Procedure

1. From wave field develop soil strain and displacement fields
2. Develop nonlinear soil springs
3. Model pipeline portion in one-half of the dominant wave length using nonlinear pipe elements
4. Applying displacement field, perform nonlinear analysis (ANSYS) to calculate global response

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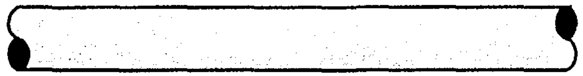
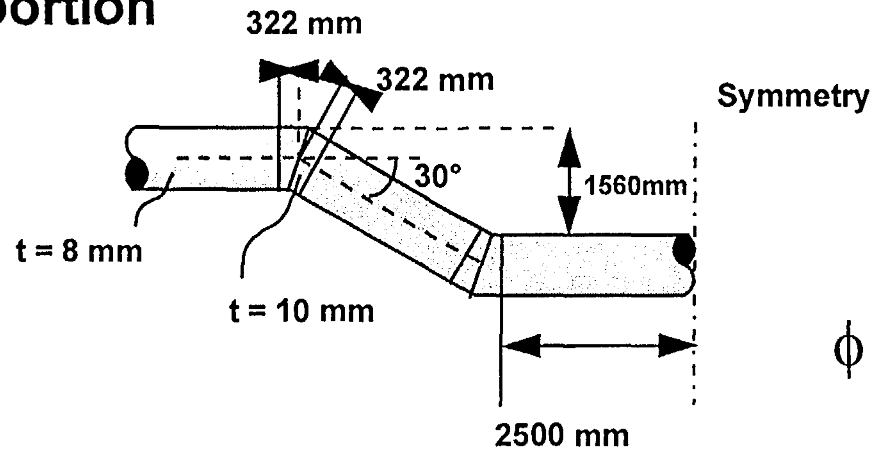
Models Studied

- Straight portion



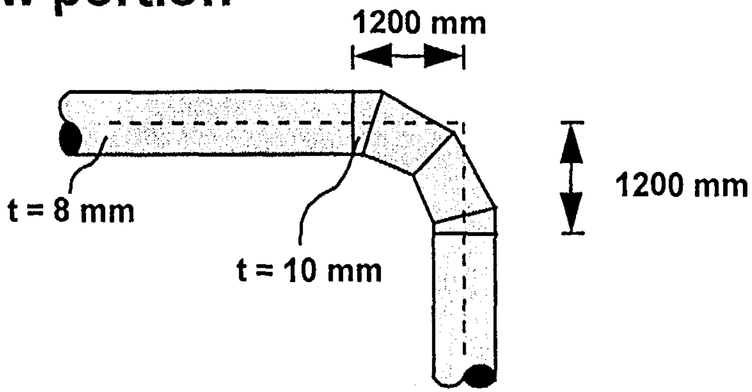
ϕ = 1220 mm
t = 8 mm

- Bent portion



ϕ = 1220 mm

- Elbow portion



ϕ = 1220 mm

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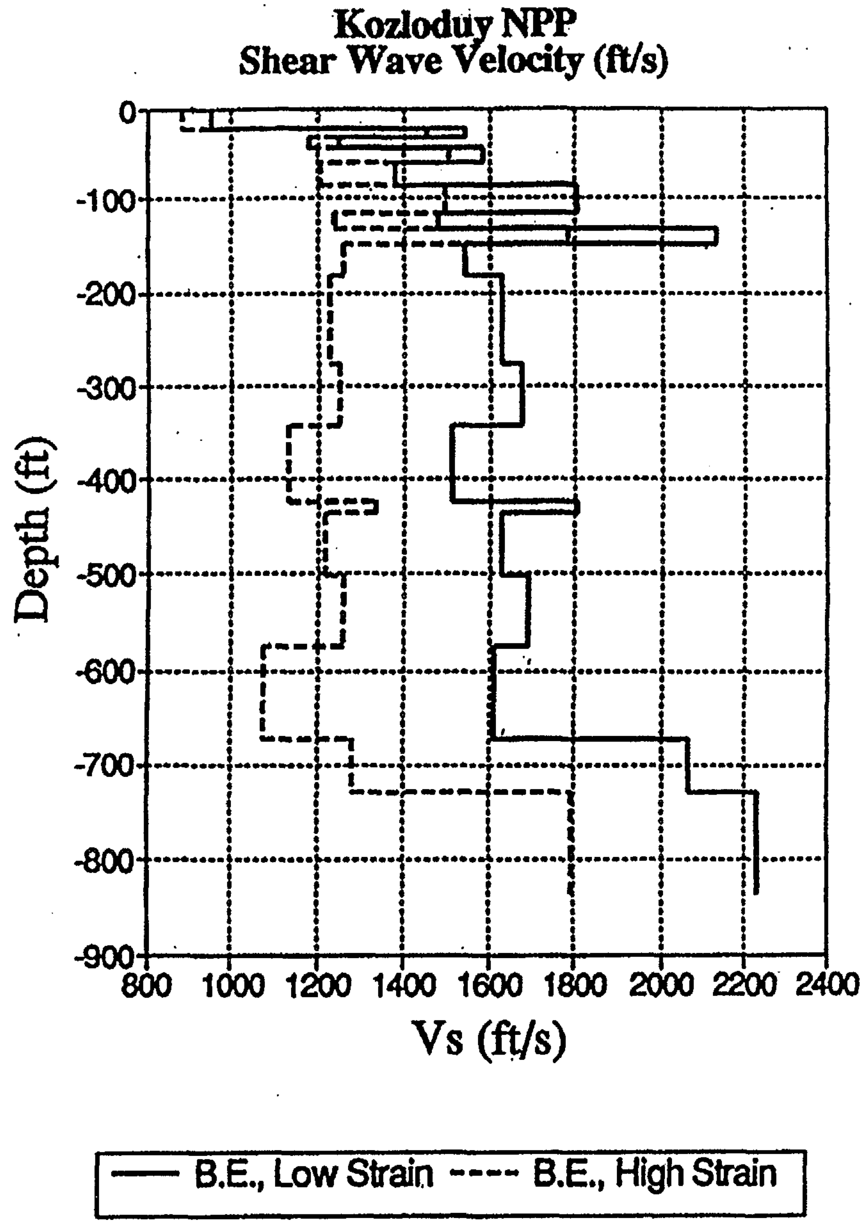
Evaluation of Soil Strain field

- Kozloduy input spectrum



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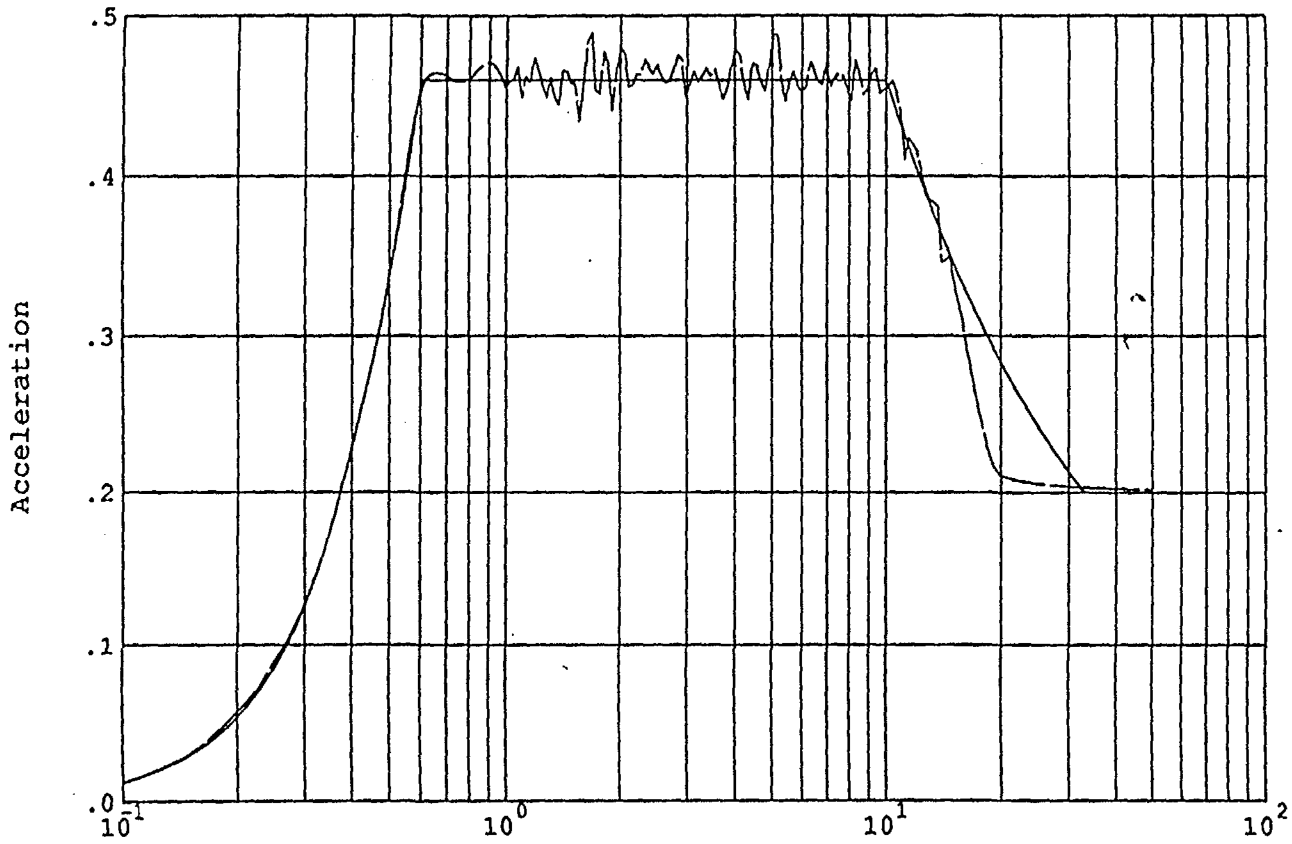

Legend:

SS Response Spectra ————————

T/H Res.Spec. LAY 1 — — — — —

Notes:

5% Spectral Damping

Acceleration in g's

Kozloduy Nuclear Power Plant - Site Specific Response Spectra
High Strain Soil Properties - T/H Response Spectra on LAYER 1

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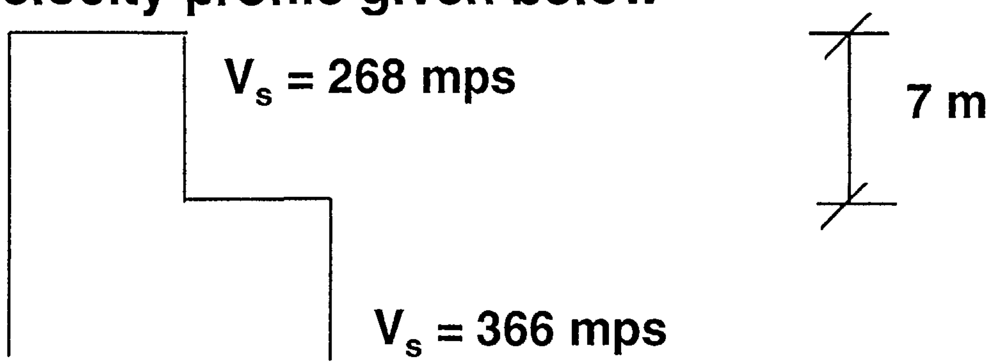
Evaluation of Soil Strain Field

- Maximum soil strain (compression/tension)

$$\varepsilon g = \frac{\dot{x}_g}{C_{ph}} = \frac{\text{maximum soil velocity}}{\text{wave phase velocity}}$$

- Maximum ground acceleration $\ddot{x}g = 0.2g$
- Maximum ground velocity $\dot{x}g \cong 48\ \ddot{x}g$ ~ 9.6 inch/sec
  ~ 0.244 m/sec
- C_{ph}: Assume Rayleigh waves and shear wave velocity profile given below



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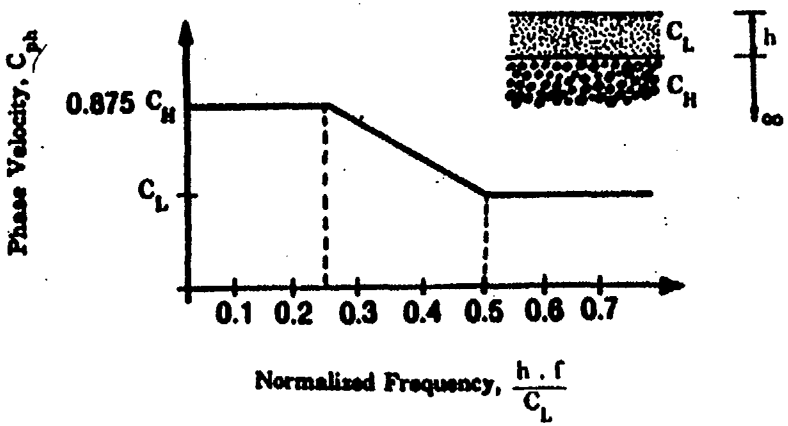
Evaluation of Soil/Strain Field

- C_{ph} (continued):From Elhmadi and O'Rourke curve



$\bar{f} = (7/268)\, f = 0.026f$

f	Comment	$\bar{f}$	C_{ph}	$\lambda = Cph/f$
0.6 Hz	"Minimum" frequency	0.016 Hz	320 mps	533.3 m
10.0 Hz	"Maximum" frequency	0.261 Hz	318 mps	31.8 m
2.55 Hz	Mean square frequency	0.067 Hz	320 Hz	125.5 m

- Frequency for analysis $f = 2.55$ Hz
  $C_{ph} = 320$ mps
  $\lambda = 125.5$ m

- $\varepsilon_g = 0.244/320 = 0.763\ 10^{-3}$

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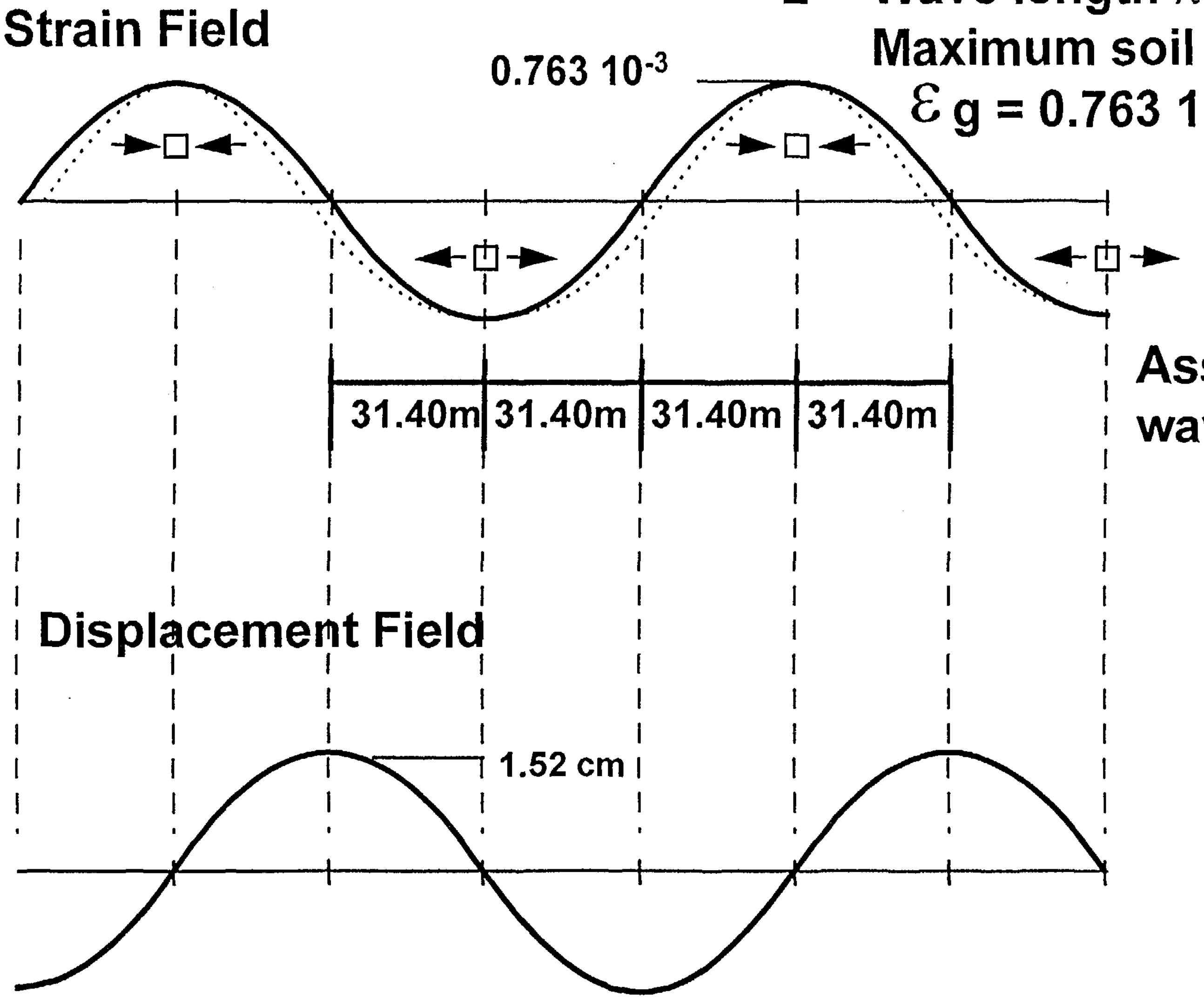
Evaluation of Soil Strain Field

- Wave length λ = 125.5 m
  Maximum soil strain
  $\varepsilon_g = 0.763 \; 10^{-3}$



Assuming sine wave

Soil Springs

- Nonlinear
- Calculated using:
  - Guidelines for the Seismic Design Oil and Gas Pipelines Systems
  - Work by Elhmadi and O'Rourke
- Approximated by bi-linear curves

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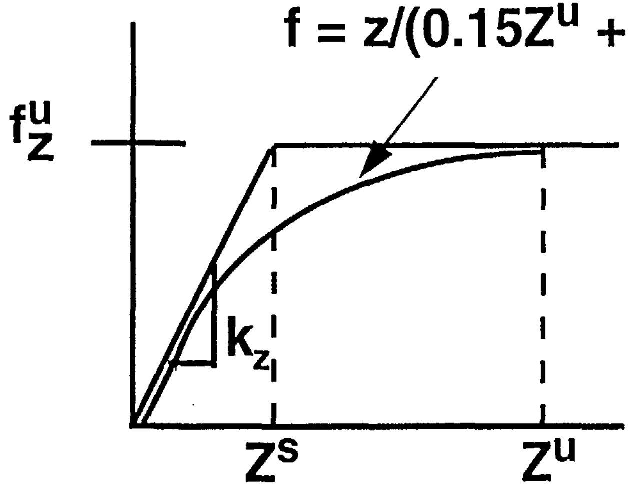
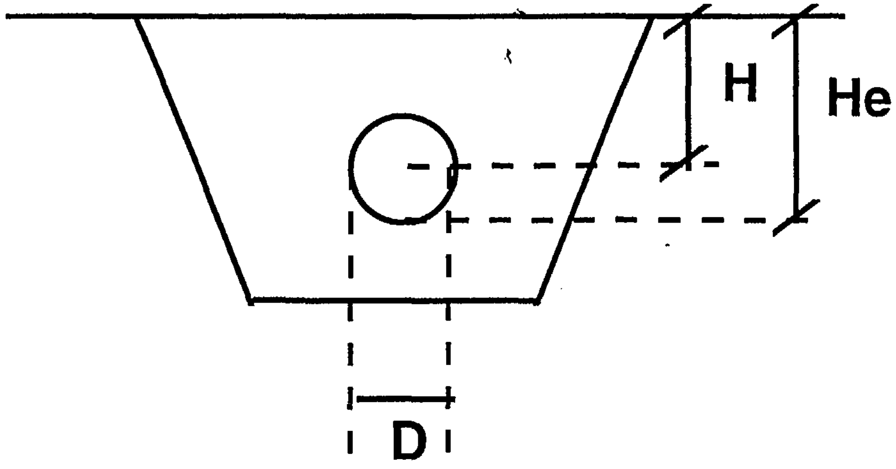
Soil Loading and Restraint Relationships

COMPONENT	RELATIONSHIP FOR FULLY BURIED PIPELINES	SOURCE OF RELATIONSHIP
AXIAL (t-x curves)	$t_u = \begin{cases} \pi D \alpha S_u & \text{for clay} \\ \frac{\pi D}{2} \bar{\gamma} H (1 + K_o) \tan\delta & \text{for sand} \end{cases}$ $x_u = \begin{cases} 0.1 \text{ to } 0.2 \text{ inches for dense to loose sand} \\ 0.2 \text{ to } 0.4 \text{ inches for stiff to soft clay} \end{cases}$	Inferred from pile shaft load transfer theory NOTE: K_o applies for at-rest conditions. However, the coefficient of soil pressure may be substantially higher in zones of large relative displacement between the pipeline and the soil.
TRANSVERSE HORIZONTAL (p-y curves)	$p_u = \begin{cases} S_u N_{ch} D \text{ for clay} \\ \bar{\gamma} H N_{qh} D \text{ for sand} \end{cases}$ $y_u = \begin{cases} 0.07 \text{ to } 0.10(H + D/2) \text{ for loose sand} \\ 0.03 \text{ to } 0.05(H + D/2) \text{ for medium sand} \\ 0.02 \text{ to } 0.03(H + D/2) \text{ for dense sand} \\ 0.03 \text{ to } 0.05(H + D/2) \text{ for stiff to soft clay} \end{cases}$ $p = \frac{y}{A' + B'y}$ (for sands) $A' = 0.15\ y_u/p_u$ $B' = 0.85/p_u$	Inferred from footing and vertical anchor plate pull-out capacity theory and laboratory tests on model pipelines simulating horizontal pipe movements (Audibert et al., 1977, 1978; Trautmann and O'Rourke, 1983a)
TRANSVERSE VERTICAL (q-z curves)	<u>Upward Direction</u> $q_u = \begin{cases} S_u N_{cv} D \text{ for clay} \\ \bar{\gamma} H N_{qv} D \text{ for sand} \end{cases}$ $z_u = \begin{cases} 0.01 \text{ to } 0.015H \text{ for dense to loose sand} \\ 0.1 \text{ to } 0.2H \text{ for stiff to soft clay} \end{cases}$ $q = \frac{z}{A'' + B''z}$ (for sands) $A'' = 0.07\ z_u/q_u$ $B'' = 0.93/q_u$	Inferred from pull-out capacity theory and laboratory tests on anchor plates and model buried pipes (Vesić, 1969; Rowe and Davis, 1982b; Trautmann and O'Rourke, 1983a)
	<u>Downward Direction</u> $q_u = \begin{cases} S_u N_c D & \text{for clay} \\ \bar{\gamma} H N_q D + \frac{1}{2}\gamma D^2 N_\gamma & \text{for sand} \end{cases}$ $z_u = 0.10 \text{ to } 0.15D$ for both sand and clay	Inferred from bearing capacity theory for footings

Transverse Spring (Per Unit Length)





$f^u_z = \gamma H D Nqh$

$Z^u = (0.02 \text{ to } 0.03) He \simeq 0.1 \text{ m}$

Nqh = 4.5 (ϕ = 30°), 11 (ϕ = 45°)

f^u_z (Nqh = 4.5) = 324.6 kN/m

f^u_z (Nqh = 11) = 793.4 kN/m

$Kz \sim 6.67\ f^u_z / Z^u$

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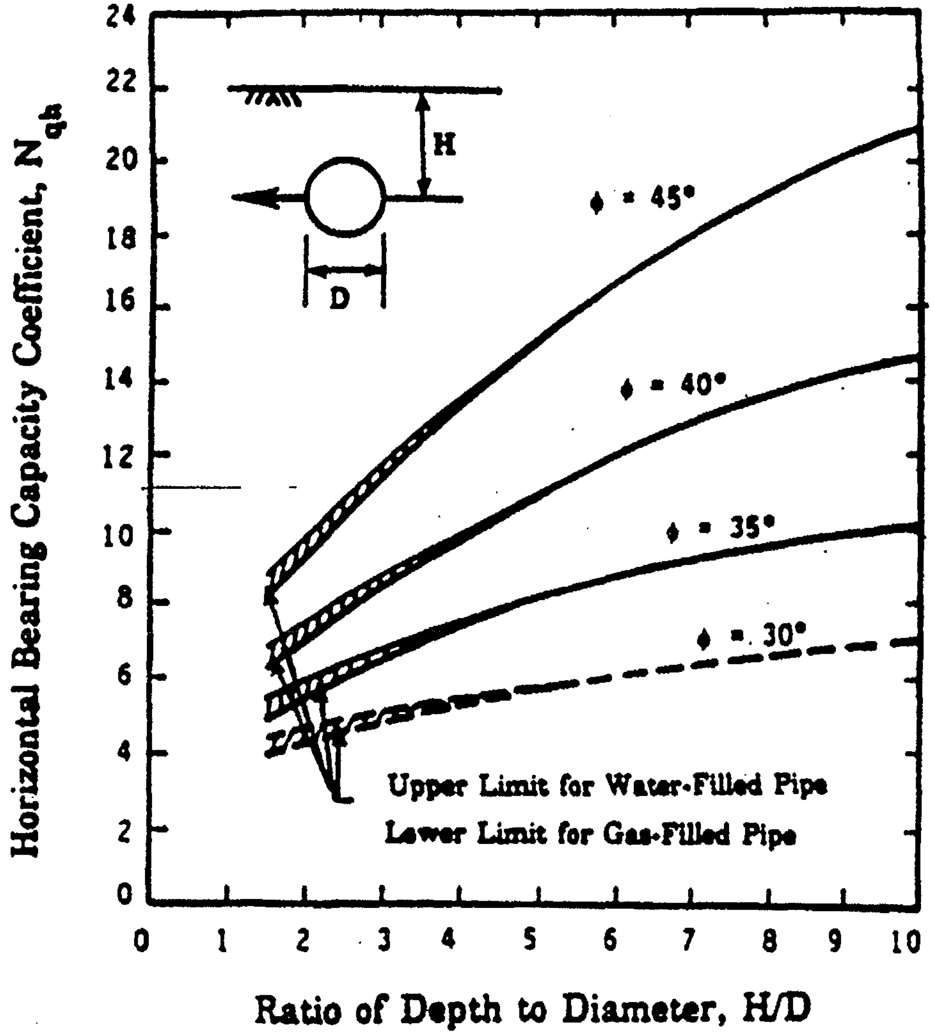
Horizontal Bearing Capacity Coefficient for Sands as a Function of Depth to Diameter Ratio of Buried Pipelines

(after Trautmann and O'Rourke, 1978)



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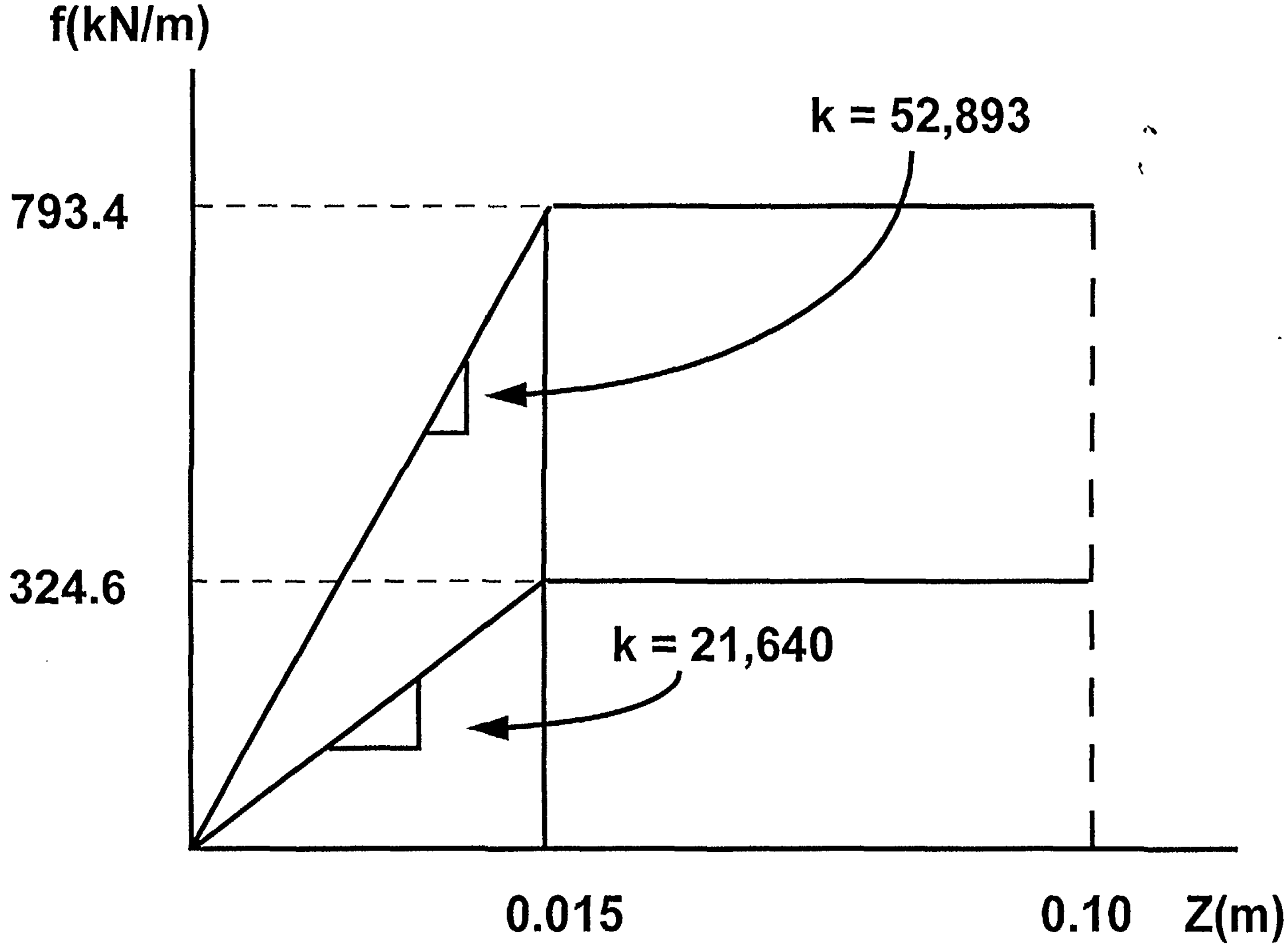
Transverse Spring



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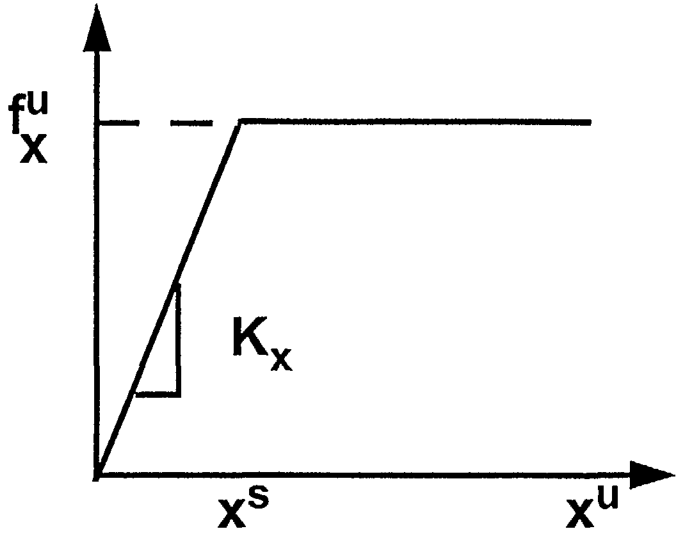

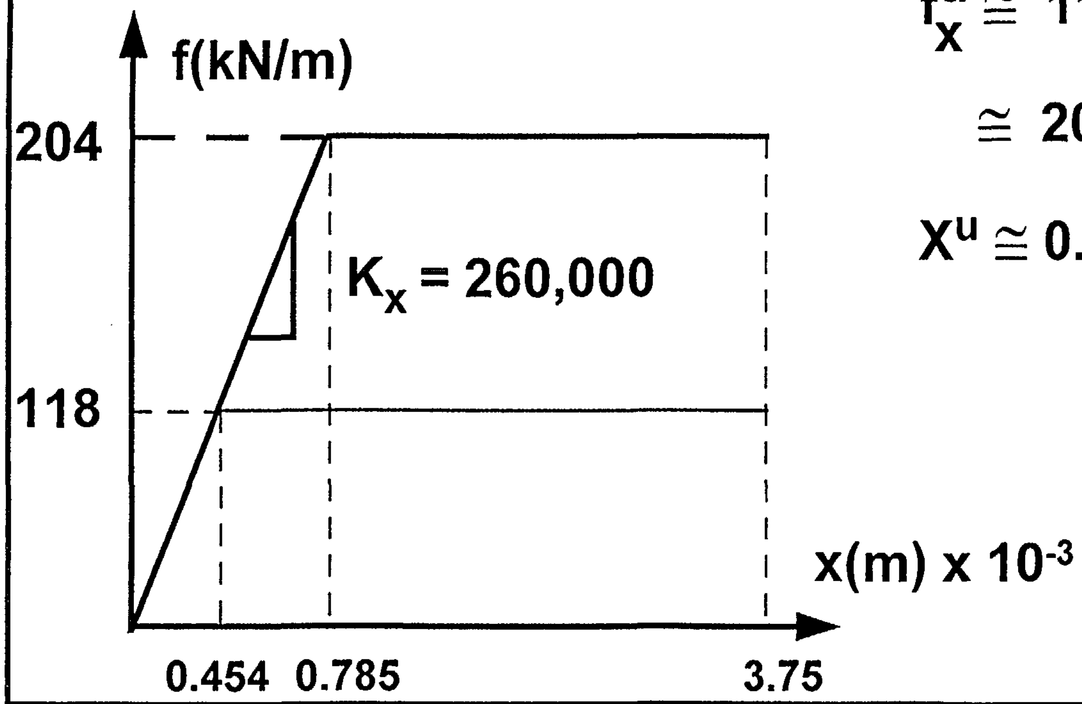

Axial Spring

$k_x \simeq 2G_s \cong 260{,}000$ kN/m/m

$f_x^u = \mu s \ \gamma \ H \ (1 + \hat{k}o)/2 \ \Pi \ D$

$\mu_s = 0.9 \tan \phi$

$f_x^u \cong$ 118 kN/m ($\phi = 30°$)

$\cong$ 204 kN/m ($\phi = 45°$)

$X^u \cong 0.00375$ m

Straight Pipe

- Conservatively assuming no slippage (soil strain equal to pipe strain)
- Pipe strain: $\varepsilon_p = 0.763\ 10^{-3}$
- Local buckling strain ($\upsilon = 0.3$): $\varepsilon_b = 0.6\ t/R = 7.87\ 10^{-3}$
- Yielding/strain: $\varepsilon y = 1.82\ 10^{-3}$

Pipe	$\varepsilon b/\varepsilon p$	$\varepsilon y/\varepsilon p$
1220 X 8	10.3	2.39
1020 X 7	10.8	2.39
820 X 6	11.6	2.39
630 X 6	15.0	2.39
1020 X 6	9.3	2.39

- No problem in straight pipe due to wave passage

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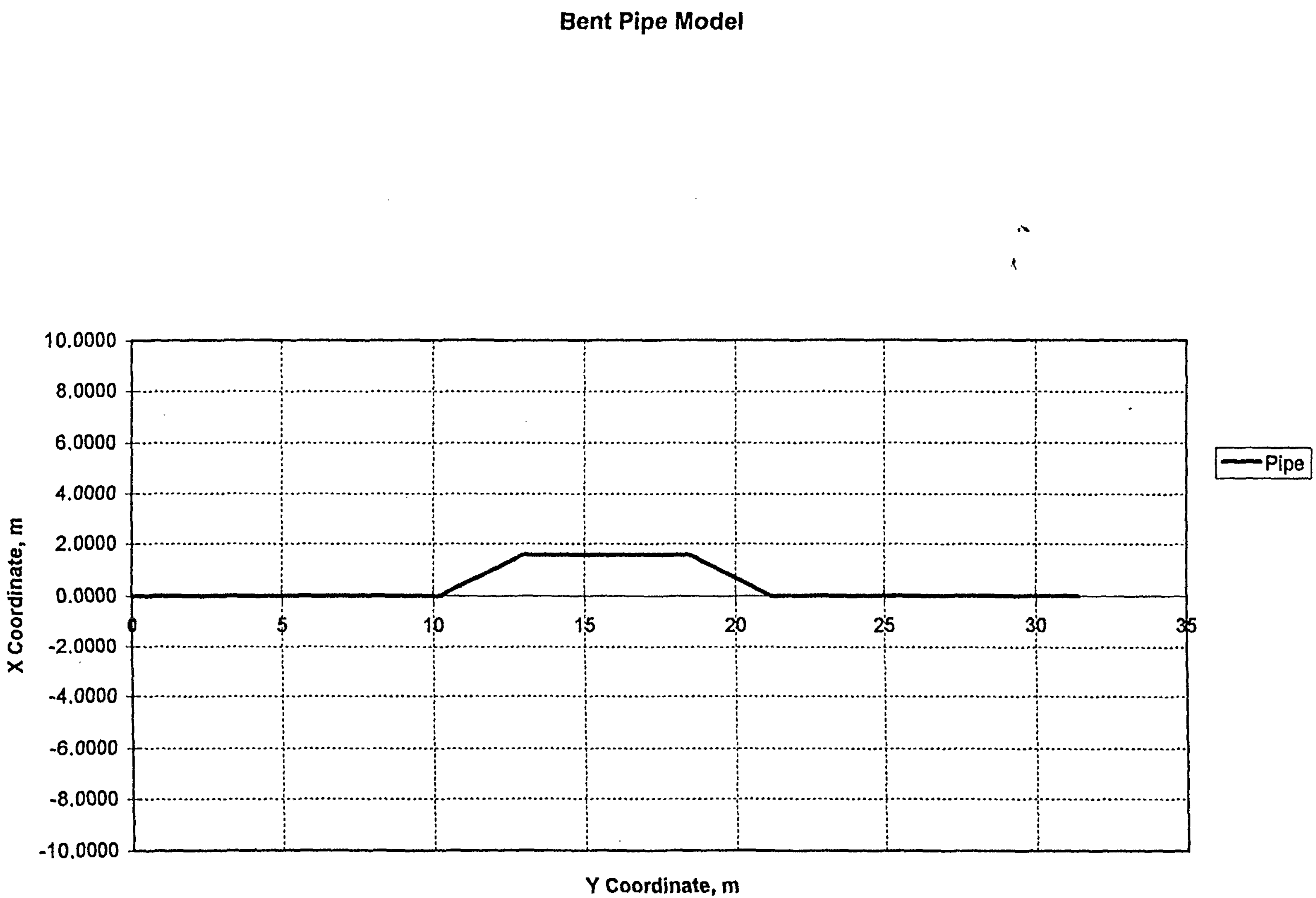
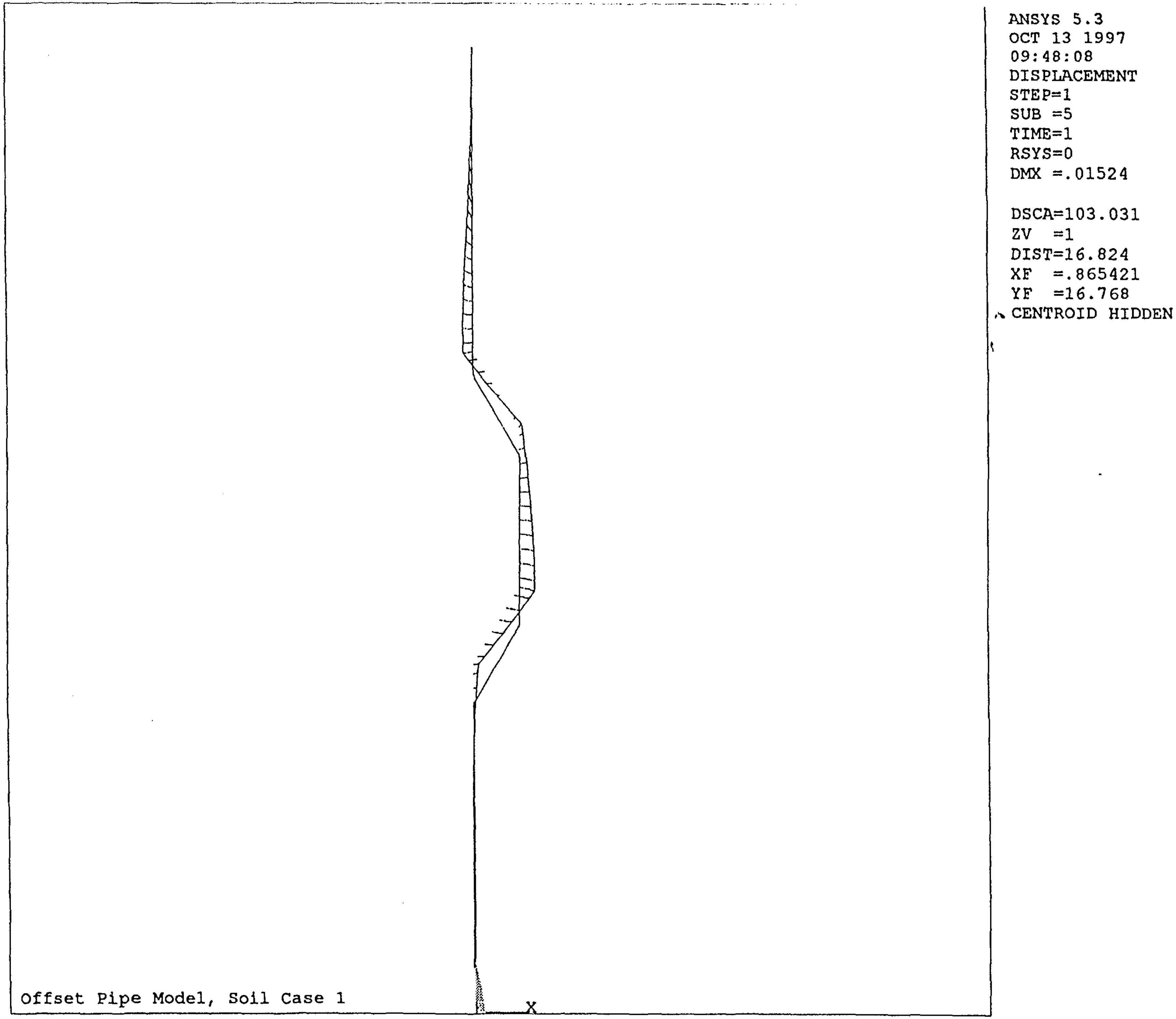
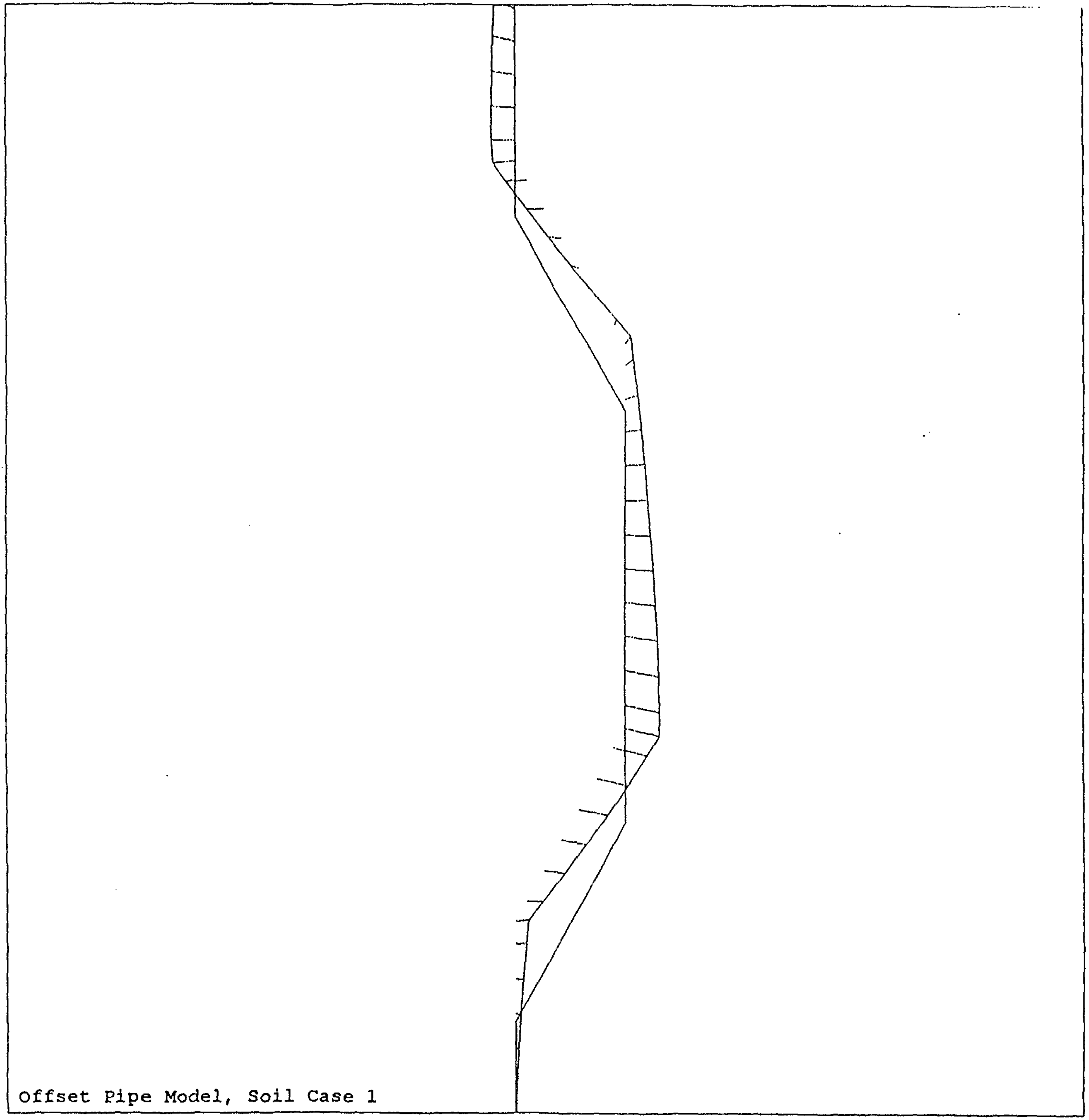

Bent Pipe Model
10.0000
8.0000
6.0000
4.0000
2.0000
0.0000
-2.0000
-4.0000
-6.0000
-8.0000
-10.0000
X Coordinate, m
0
5
10
15
20
25
30
35
Y Coordinate, m
Pipe

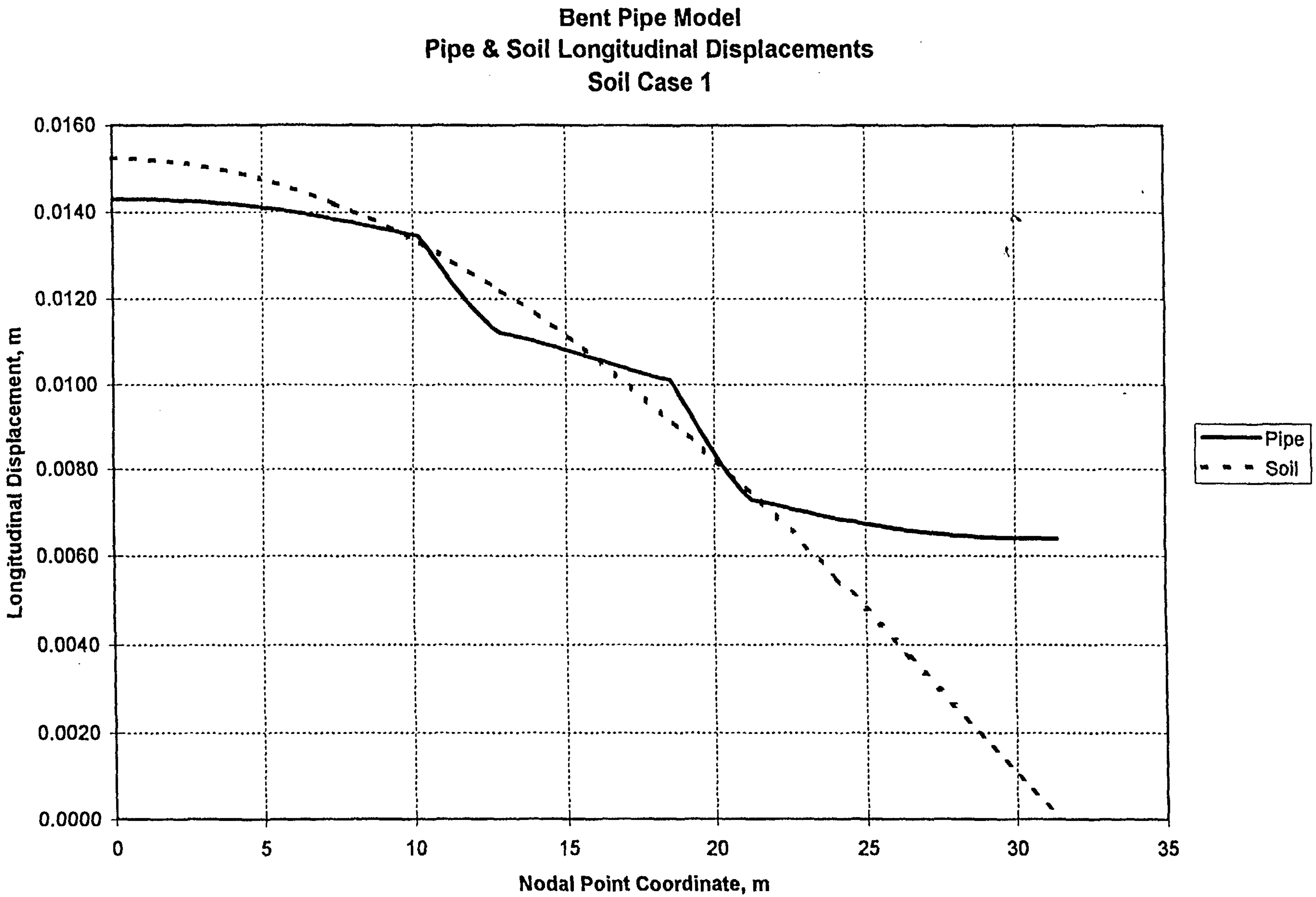


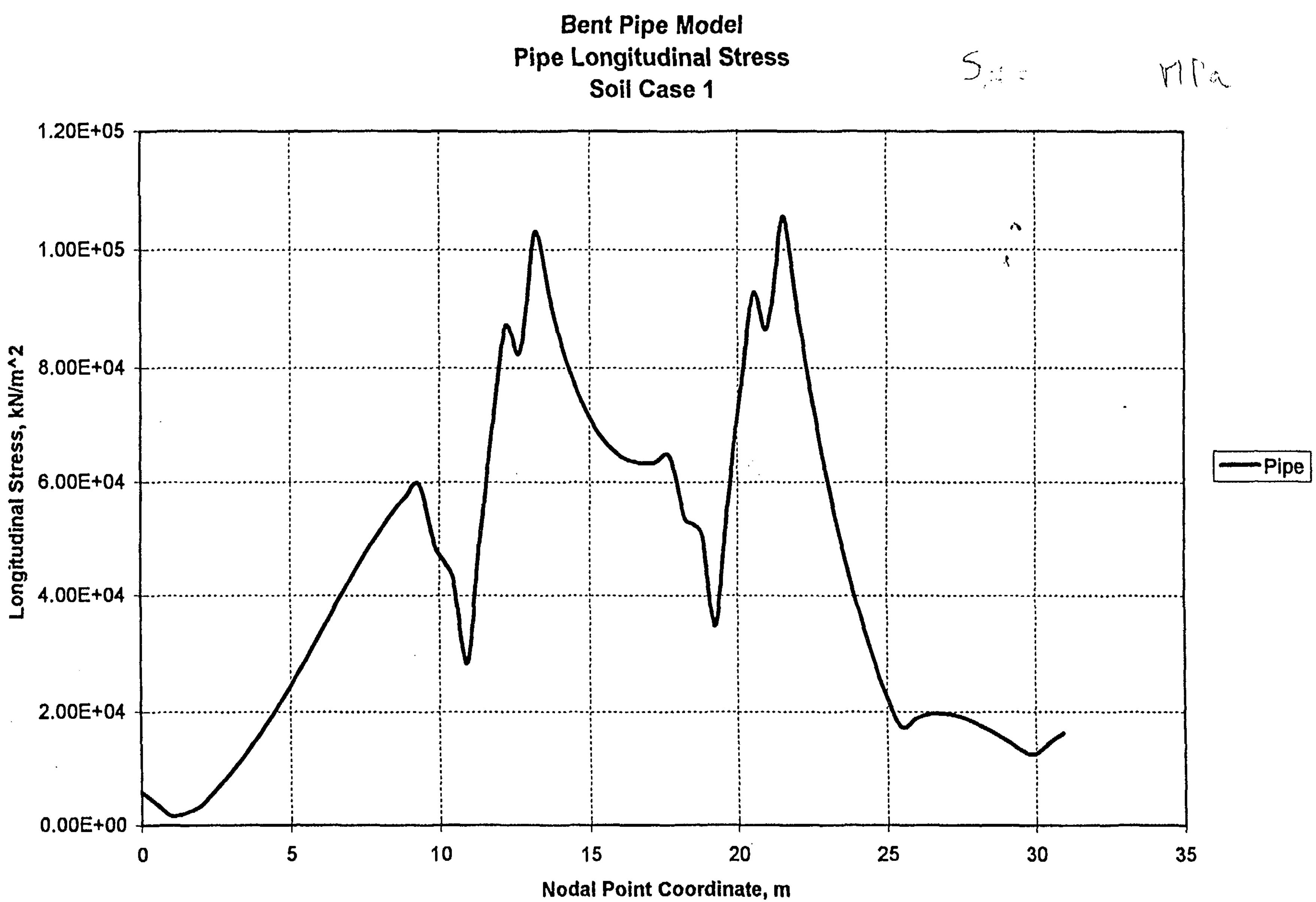
Offset Pipe Model, Soil Case 1

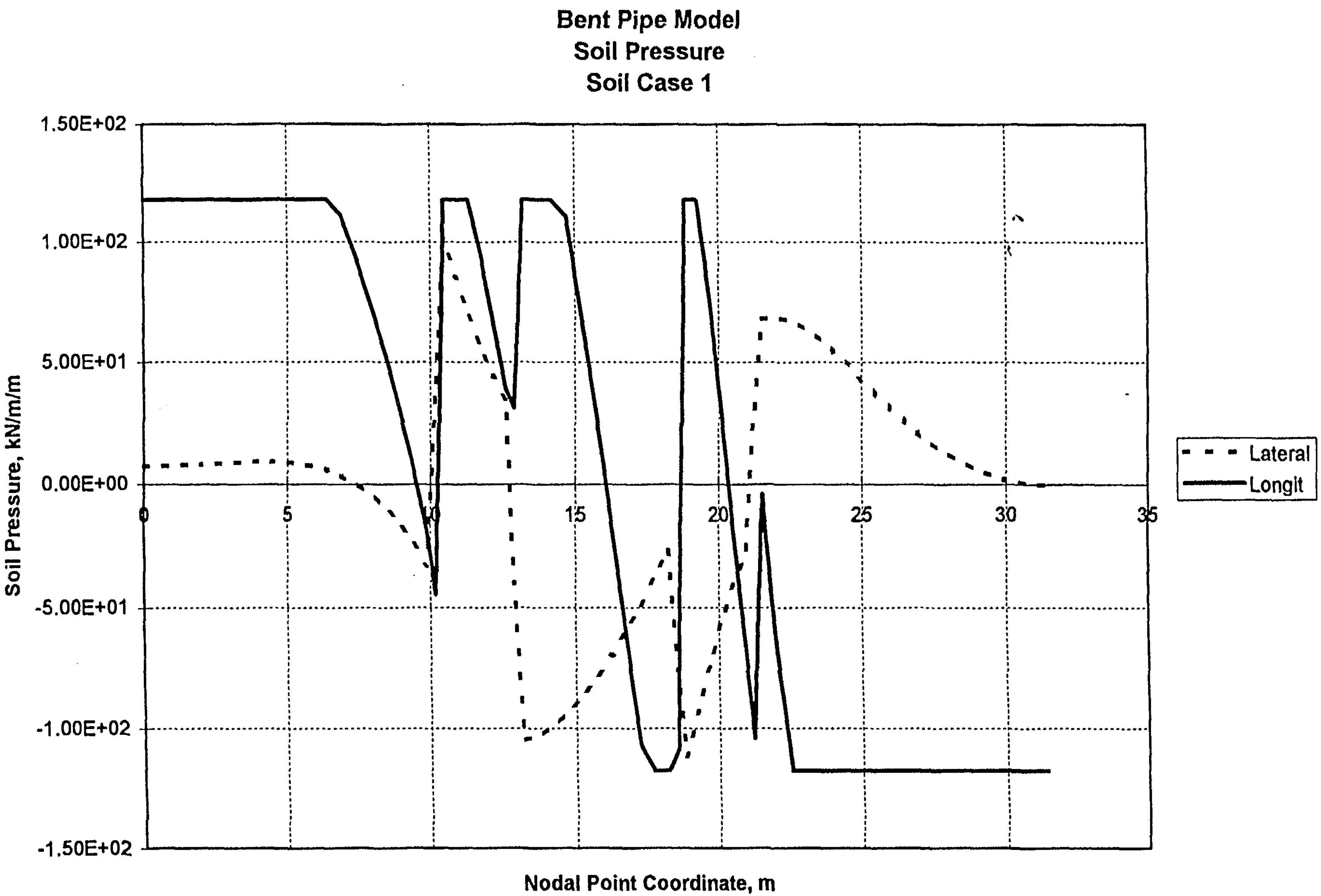


ANSYS 5.3
OCT 13 1997
09:48:56
DISPLACEMENT
STEP=1
SUB =5
TIME=1
RSYS=0
DMX =.01524

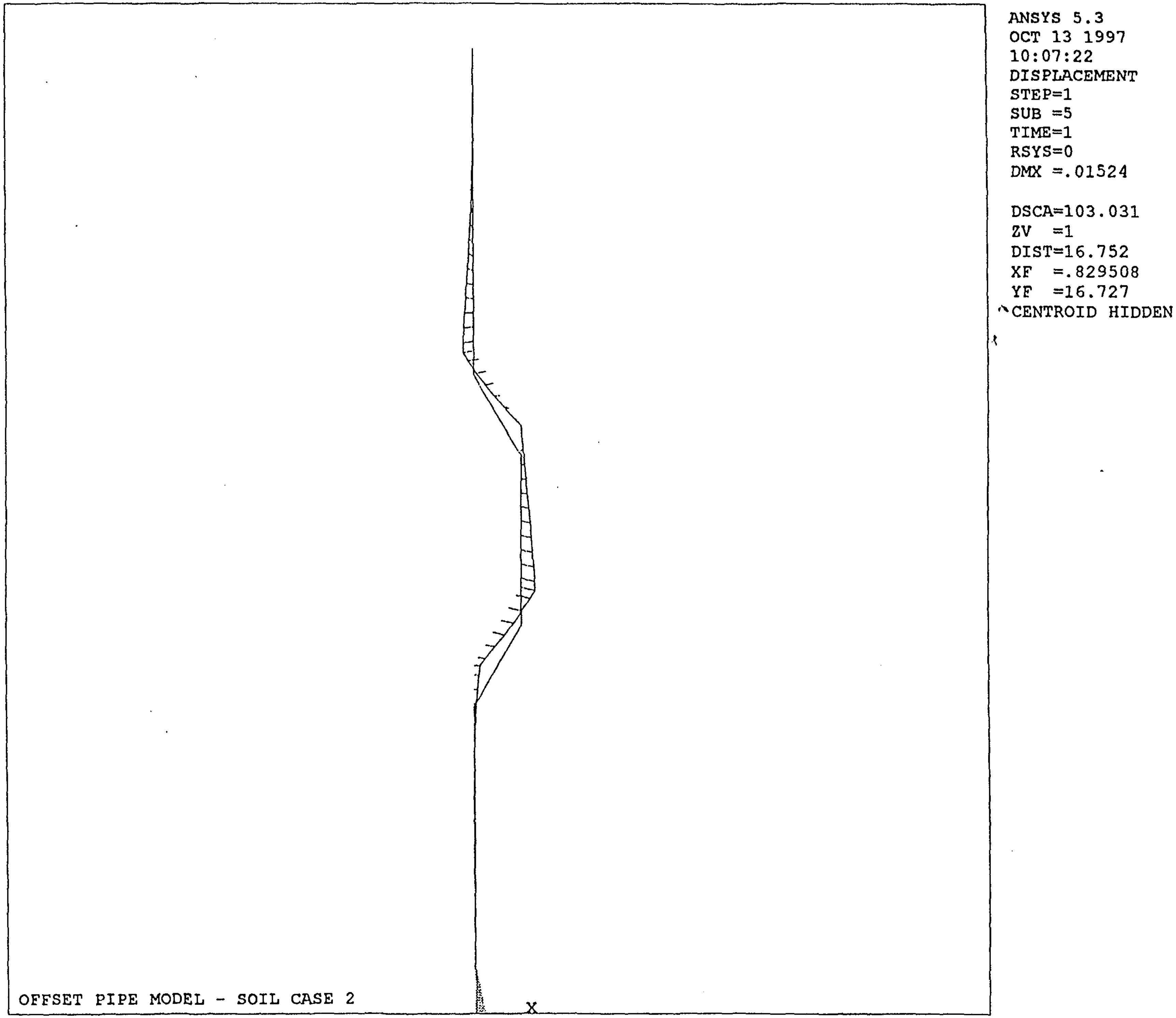
DSCA=103.031
ZV =1
*DIST=7.63
*XF =.485023
*YF =16.544
CENTROID HIDDEN


Bent Pipe Model
Pipe & Soil Longitudinal Displacements
Soil Case 1
Longitudinal Displacement, m
0.0160
0.0140
0.0120
0.0100
0.0080
0.0060
0.0040
0.0020
0.0000
0
5
10
15
20
25
30
35
Nodal Point Coordinate, m
Pipe
Soil


Bent Pipe Model
Pipe Longitudinal Stress
Soil Case 1
Longitudinal Stress, kN/m^2
1.20E+05
1.00E+05
8.00E+04
6.00E+04
4.00E+04
2.00E+04
0.00E+00
0
5
10
15
20
25
30
35
Nodal Point Coordinate, m
Pipe



Bent Pipe Model
Soil Pressure
Soil Case 1
1.50E+02
1.00E+02
5.00E+01
0.00E+00
-5.00E+01
-1.00E+02
-1.50E+02
Soil Pressure, kN/m/m
0
5
10
15
20
25
30
35
Nodal Point Coordinate, m
Lateral
Longit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OCT 13 1997
10:07:22
DISPLACEMENT
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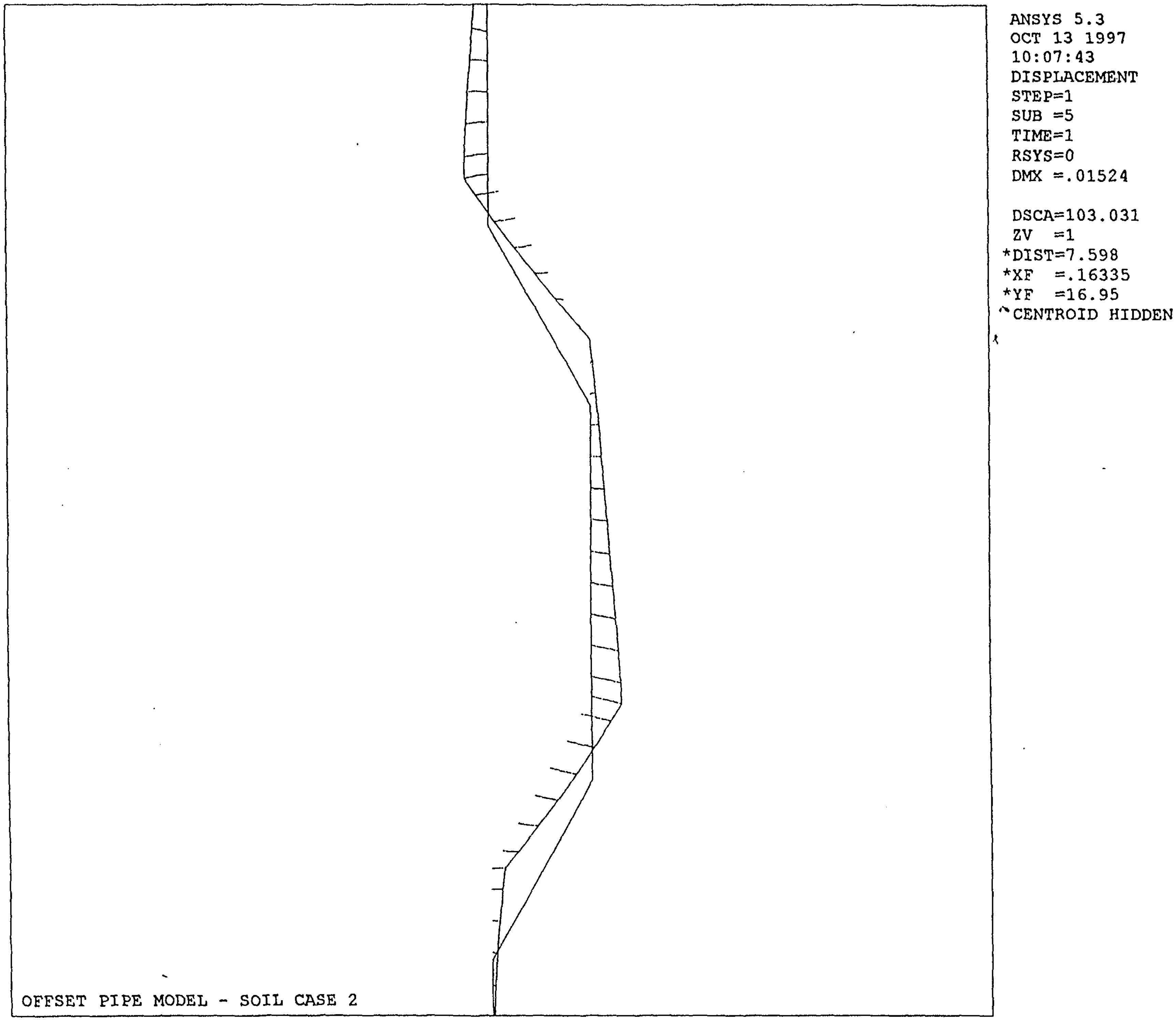
SUB =5
TIME=1
RSYS=0
DMX =.01524
DSCA=103.031
ZV =1
DIST=16.752
XF =.829508
YF =16.727
CENTROID HIDDEN
OFFSET PIPE MODEL - SOIL CASE 2
X


ANSYS 5.3
OCT 13 1997
10:07:43
DISPLACEMENT
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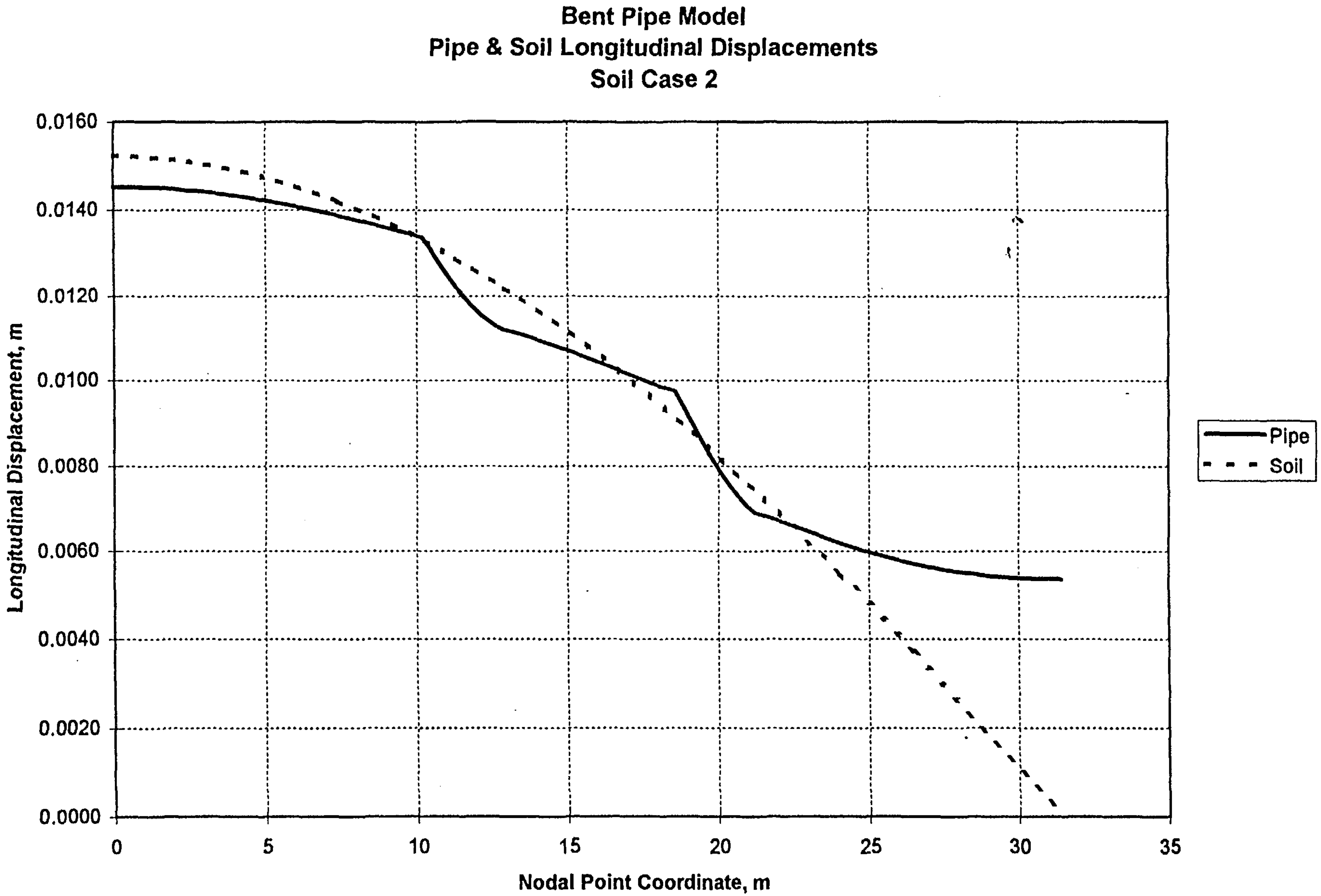
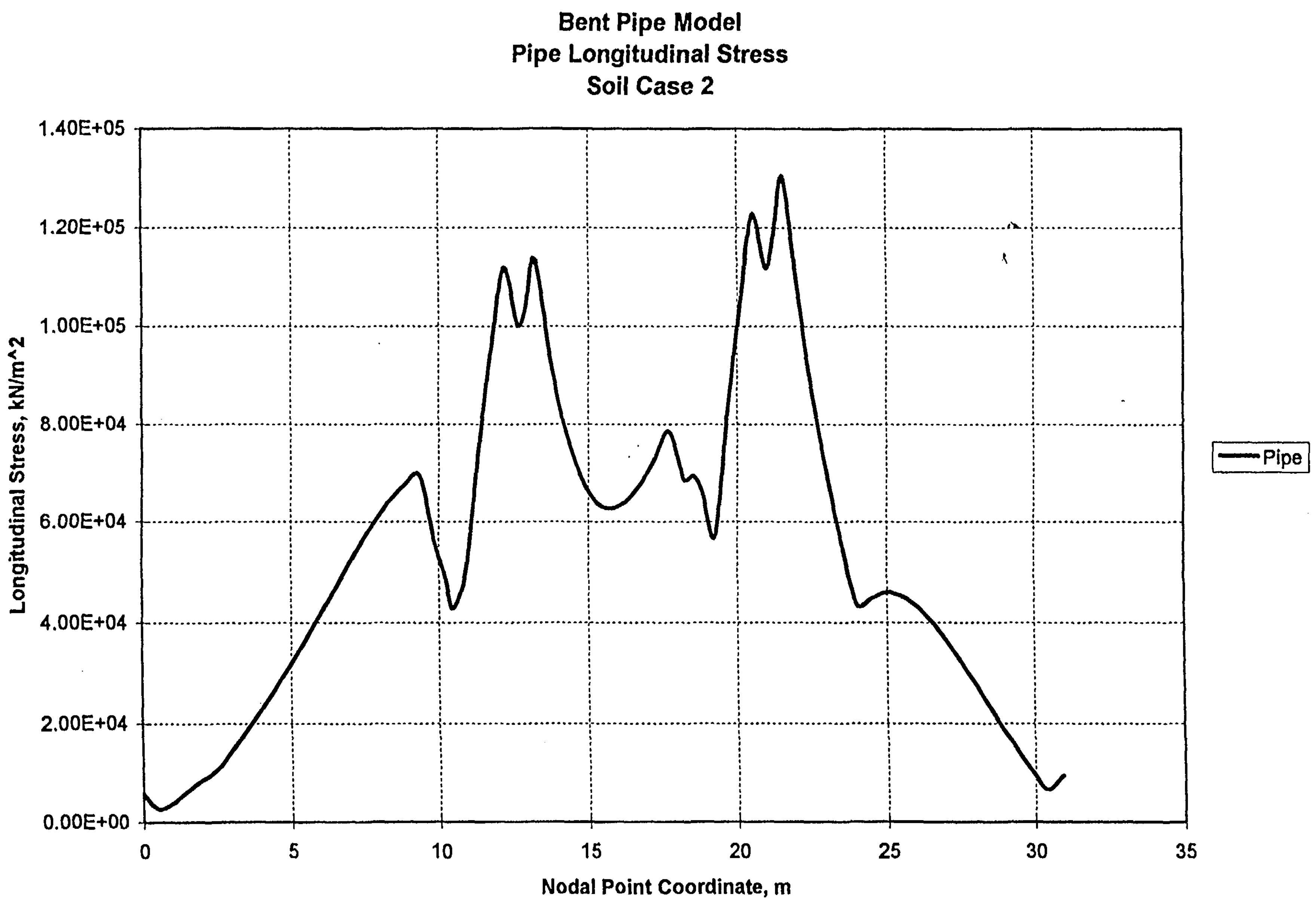
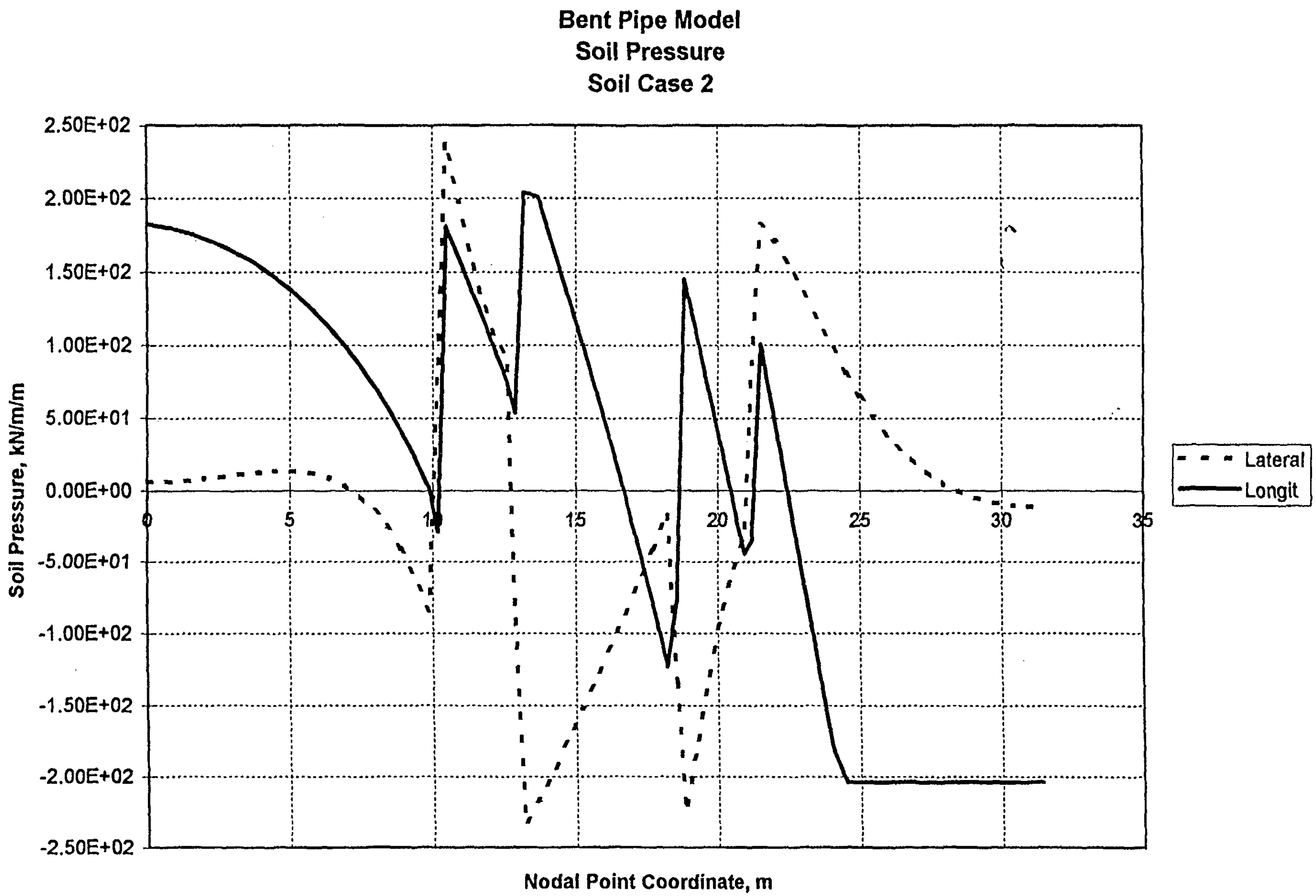
SUB =5
TIME=1
RSYS=0
DMX =.01524
DSCA=103.031
ZV =1
*DIST=7.598
*XF =.16335
*YF =16.95
*CENTROID HIDDEN
OFFSET PIPE MODEL - SOIL CASE 2

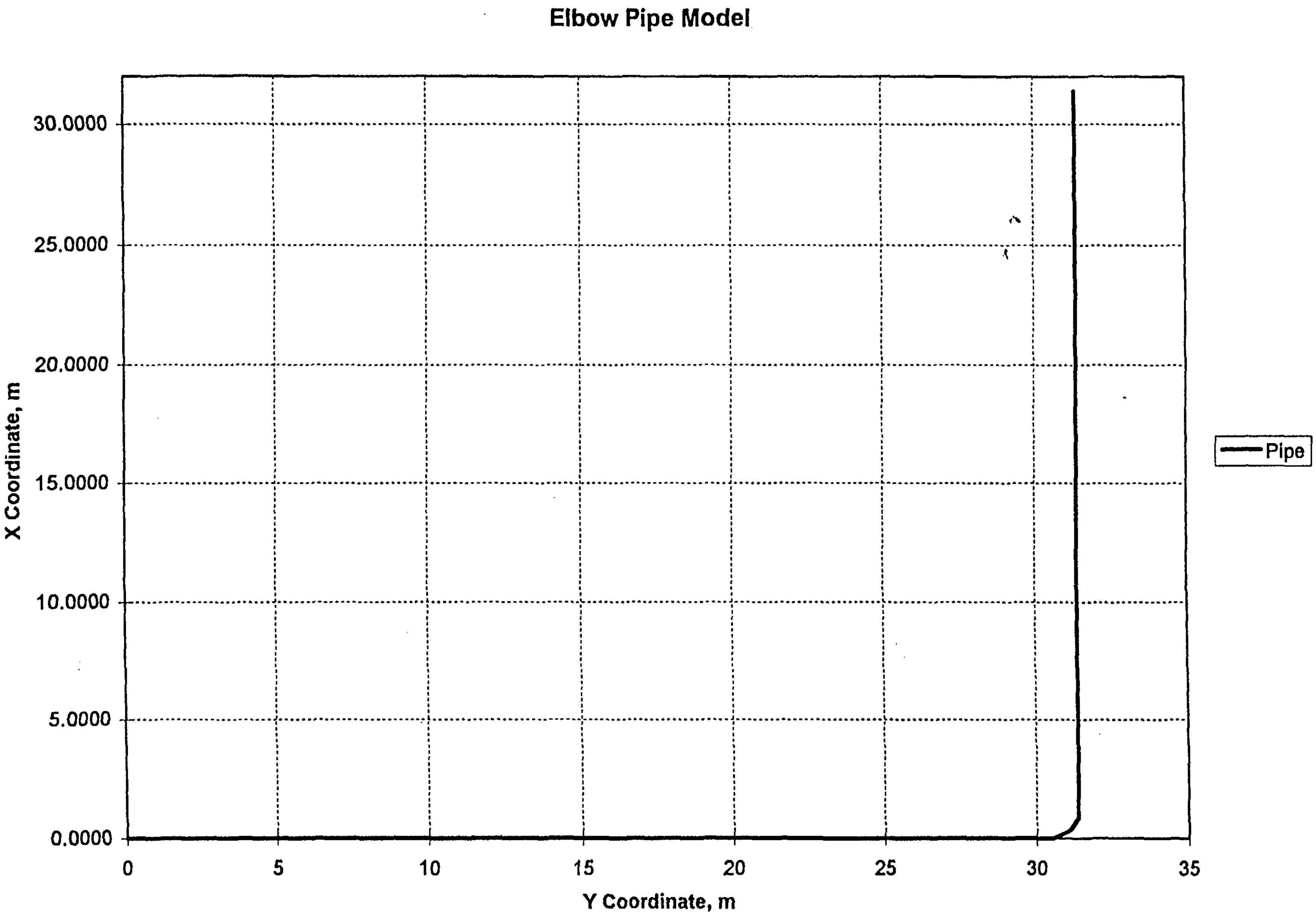

Bent Pipe Model
Pipe & Soil Longitudinal Displacements
Soil Case 2
Longitudinal Displacement, m
0.0160
0.0140
0.0120
0.0100
0.0080
0.0060
0.0040
0.0020
0.0000
0
5
10
15
20
25
30
35
Nodal Point Coordinate, m
Pipe
Soil



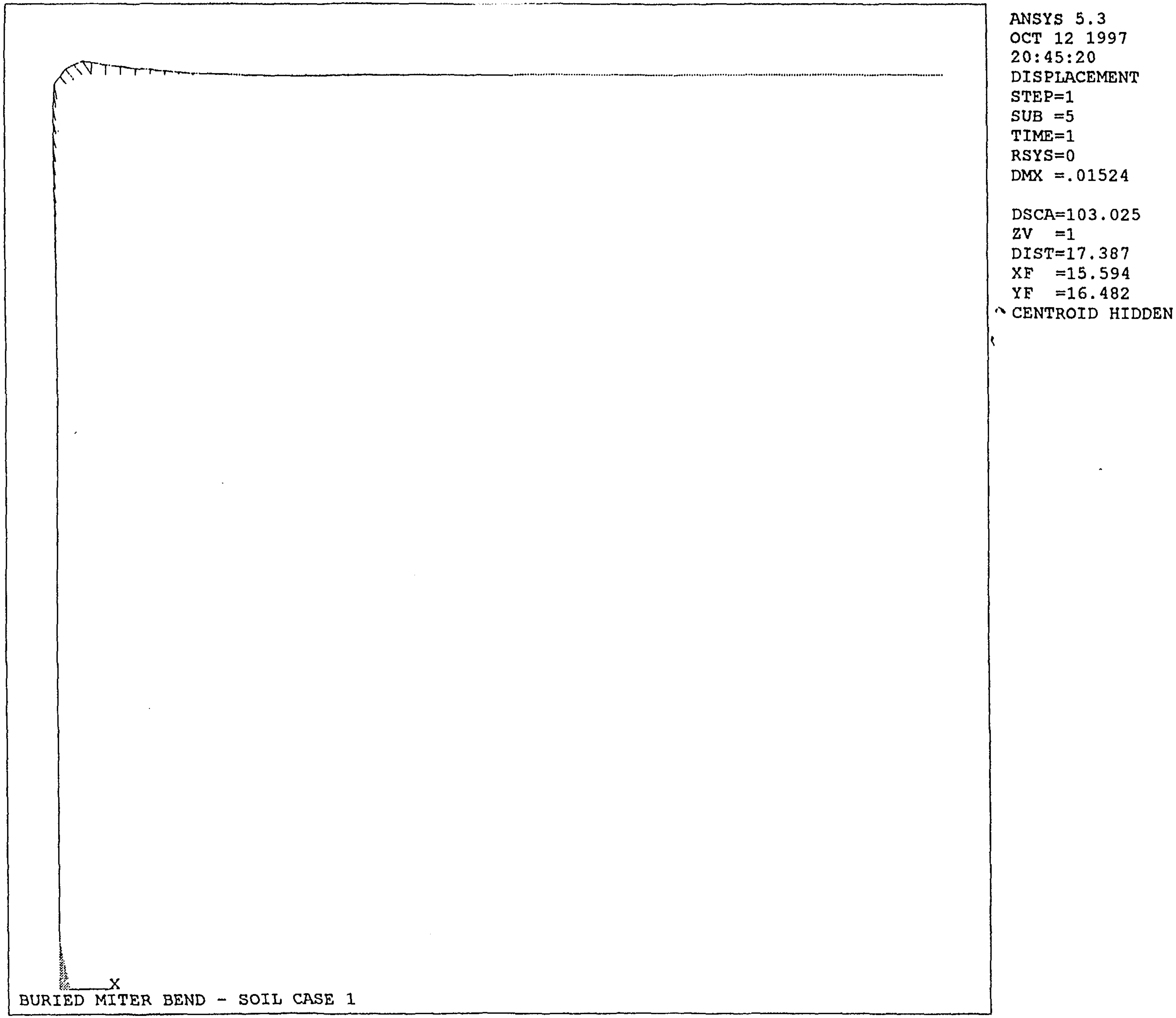
Bent Pipe Model
Pipe Longitudinal Stress
Soil Case 2
Longitudinal Stress, kN/m^2
1.40E+05
1.20E+05
1.00E+05
8.00E+04
6.00E+04
4.00E+04
2.00E+04
0.00E+00
0
5
10
15
20
25
30
35
Nodal Point Coordinate, m
Pipe

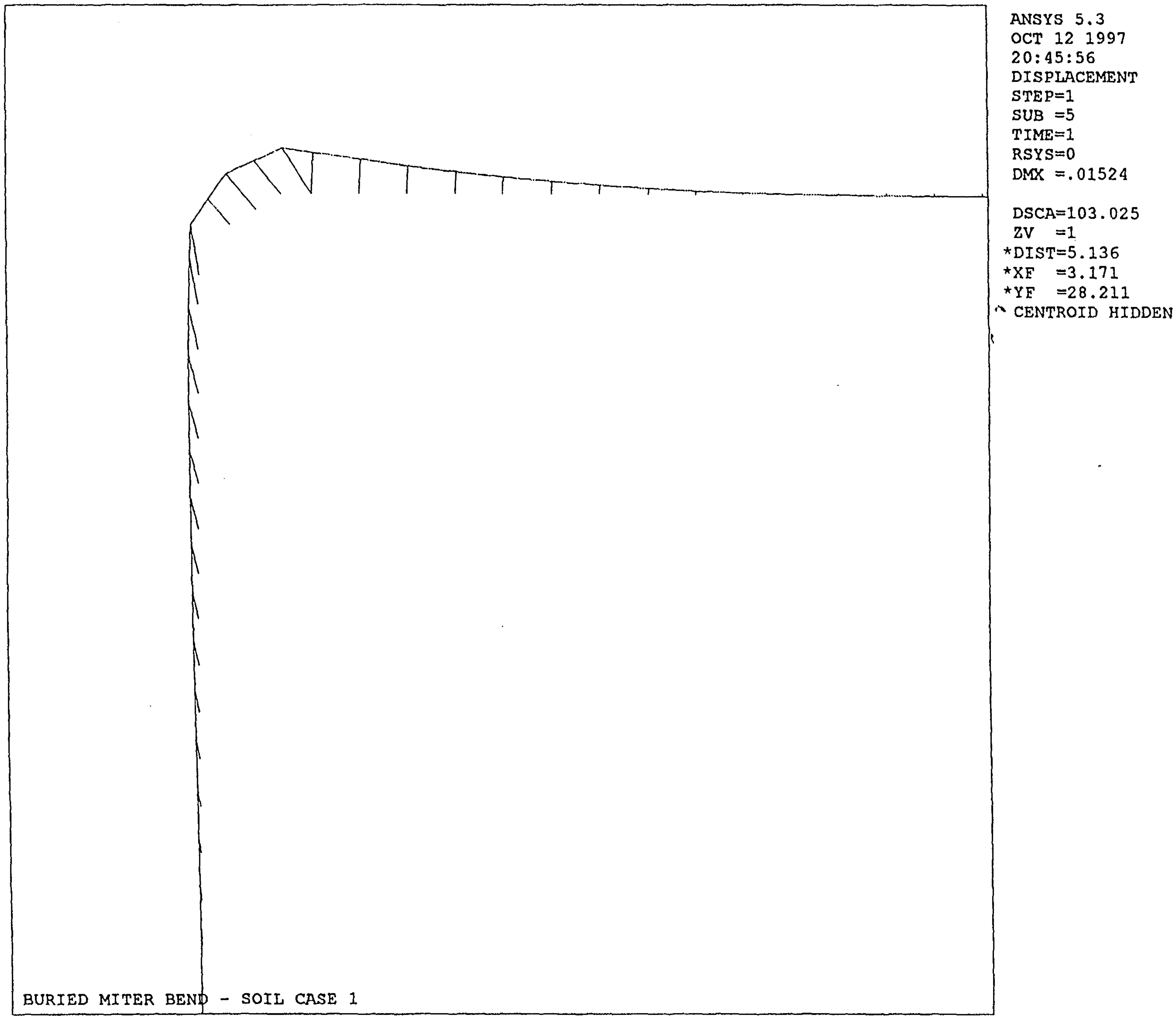


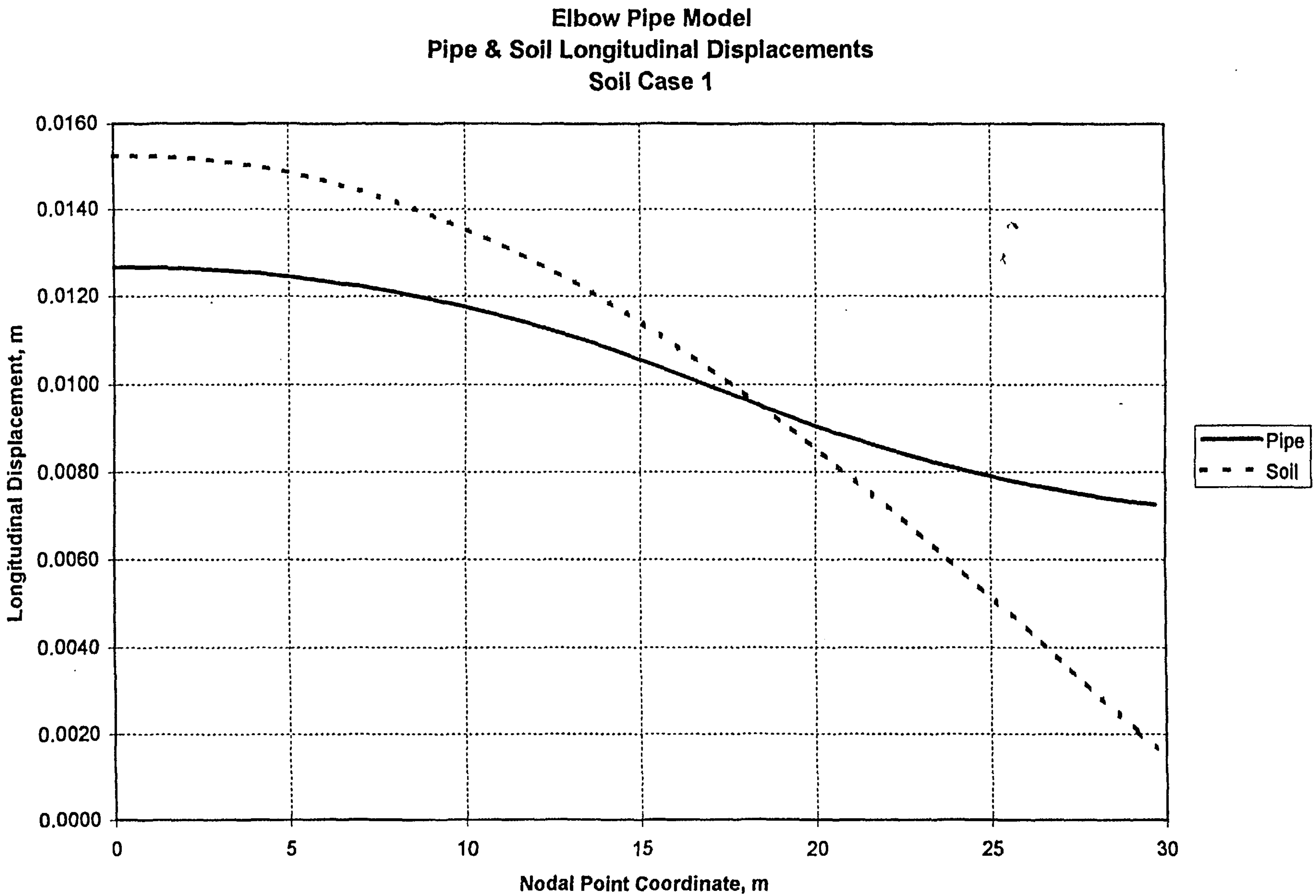
Bent Pipe Model
Soil Pressure
Soil Case 2
Soil Pressure, kN/m/m
2.50E+02
2.00E+02
1.50E+02
1.00E+02
5.00E+01
0.00E+00
-5.00E+01
-1.00E+02
-1.50E+02
-2.00E+02
-2.50E+02
0
5
10
15
20
25
30
35
Nodal Point Coordinate, m
Lateral
Longit



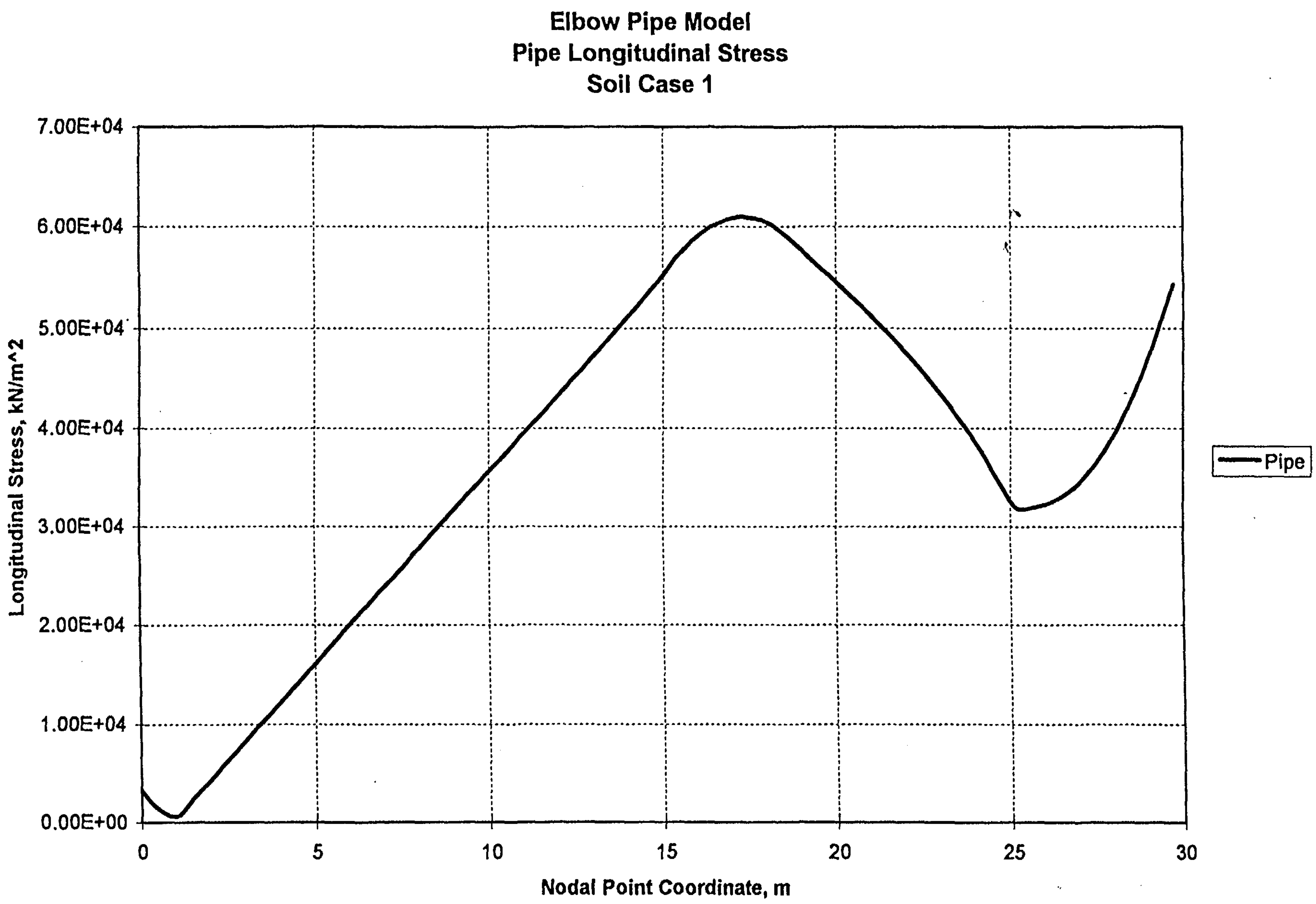
Elbow Pipe Model
30.0000
25.0000
20.0000
15.0000
10.0000
5.0000
0.0000
X Coordinate, m
0
5
10
15
20
25
30
35
Y Coordinate, m
Pipe

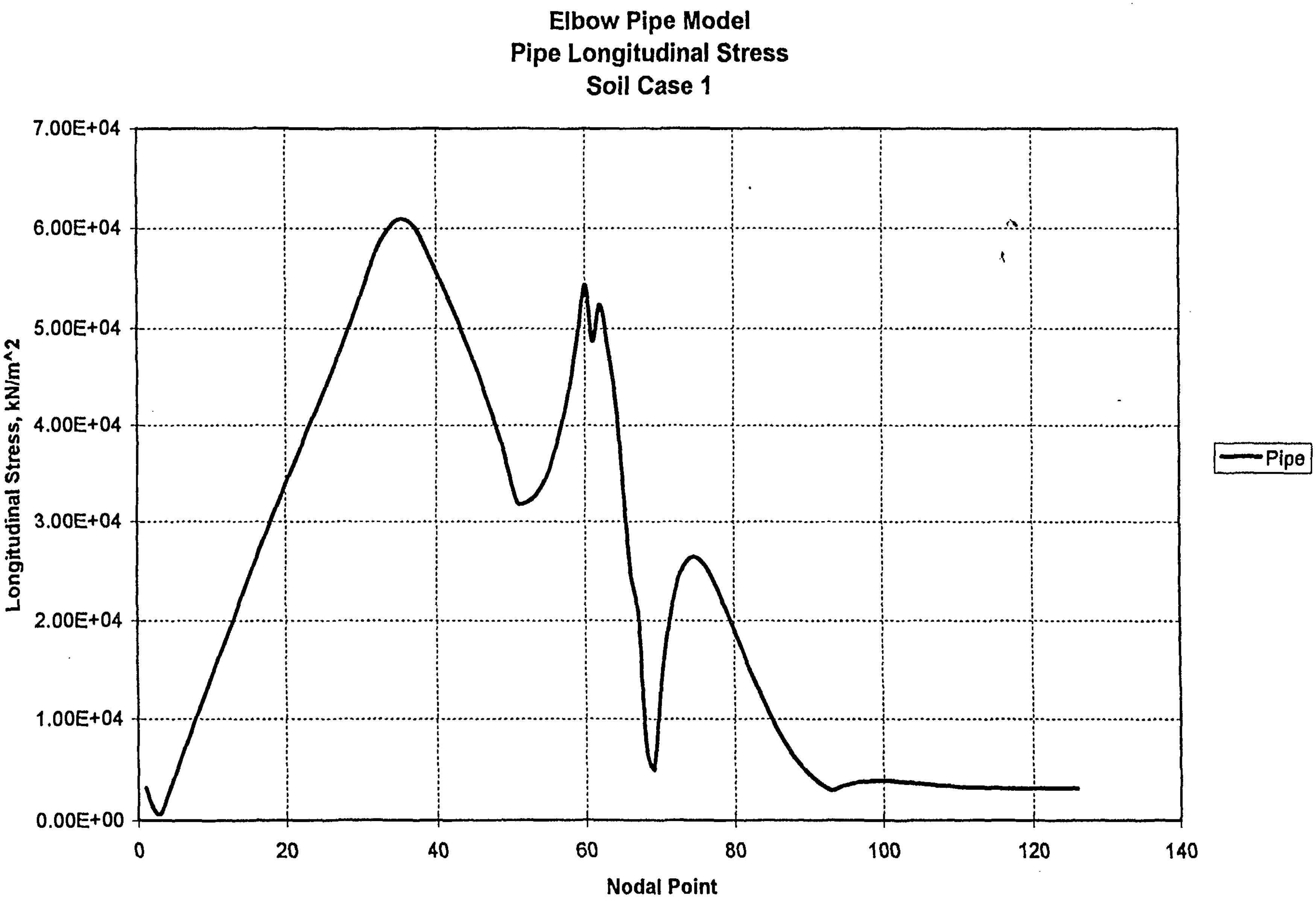

ANSYS 5.3
OCT 12 1997
20:45:20
DISPLACEMENT
STEP=1
SUB =5
TIME=1
RSYS=0
DMX =.01524
DSCA=103.025
ZV =1
DIST=17.387
XF =15.594
YF =16.482
CENTROID HIDDEN
X
BURIED MITER BEND - SOIL CASE 1

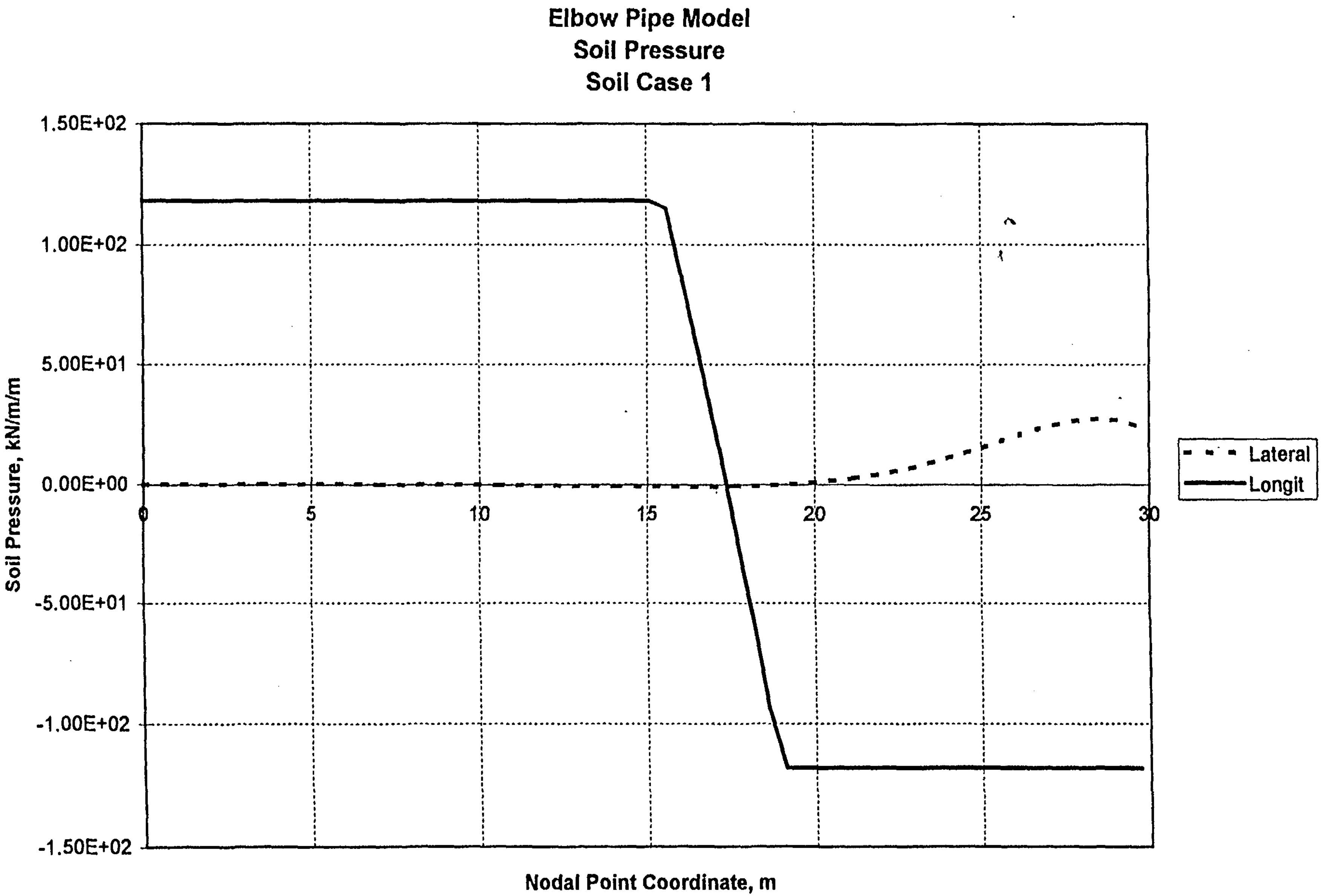

ANSYS 5.3
OCT 12 1997
20:45:56
DISPLACEMENT
STEP=1
SUB =5
TIME=1
RSYS=0
DMX =.01524
DSCA=103.025
ZV =1
*DIST=5.136
*XF =3.171
*YF =28.211
CENTROID HIDDEN
BURIED MITER BEND - SOIL CASE 1



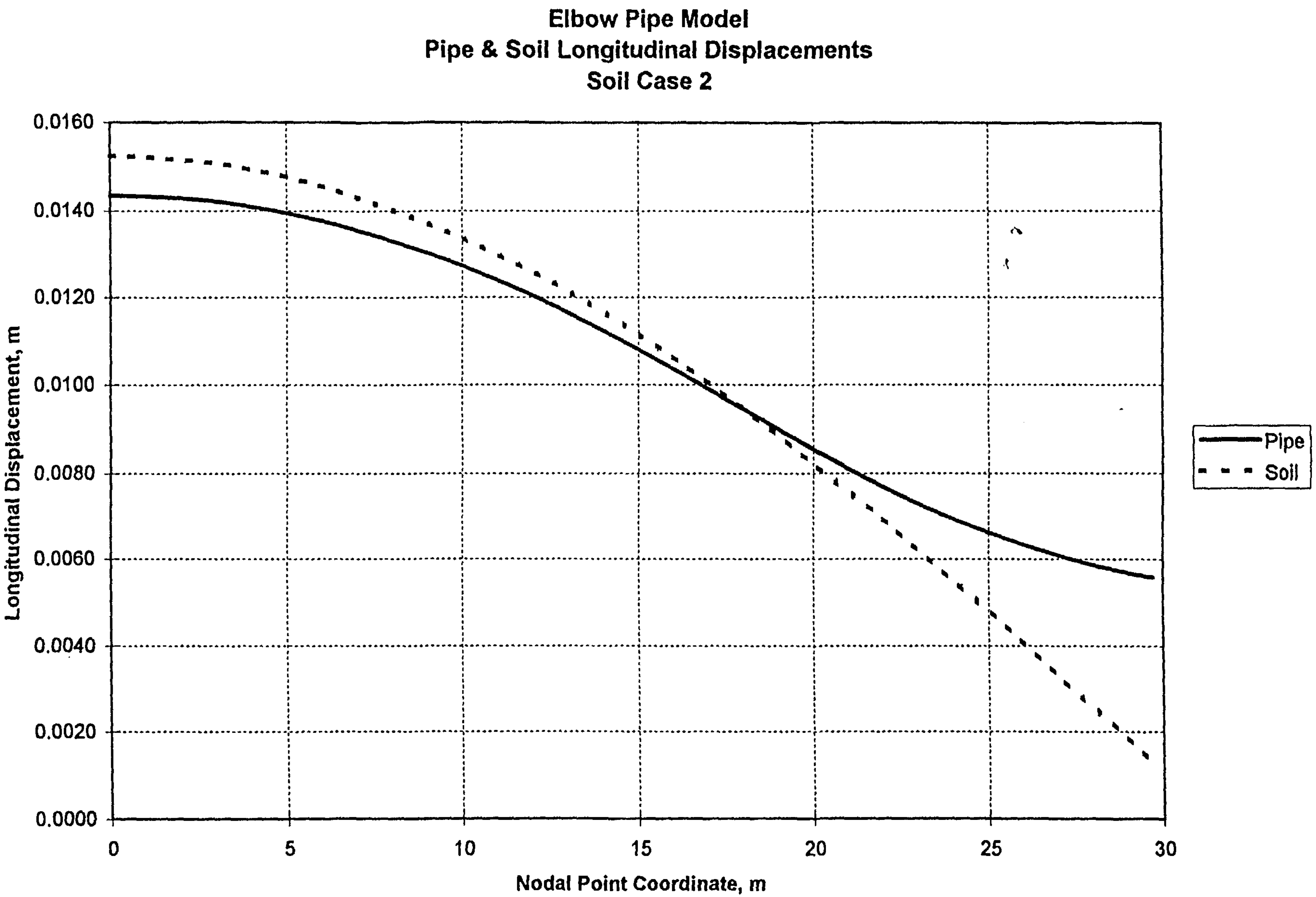
Elbow Pipe Model
Pipe & Soil Longitudinal Displacements
Soil Case 1
0.0160
0.0140
0.0120
0.0100
0.0080
0.0060
0.0040
0.0020
0.0000
Longitudinal Displacement, m
0
5
10
15
20
25
30
Nodal Point Coordinate, m
Pipe
Soil


Elbow Pipe Model
Pipe Longitudinal Stress
Soil Case 1
7.00E+04
6.00E+04
5.00E+04
4.00E+04
3.00E+04
2.00E+04
1.00E+04
0.00E+00
Longitudinal Stress, kN/m^2
0
5
10
15
20
25
30
Nodal Point Coordinate, m
Pipe

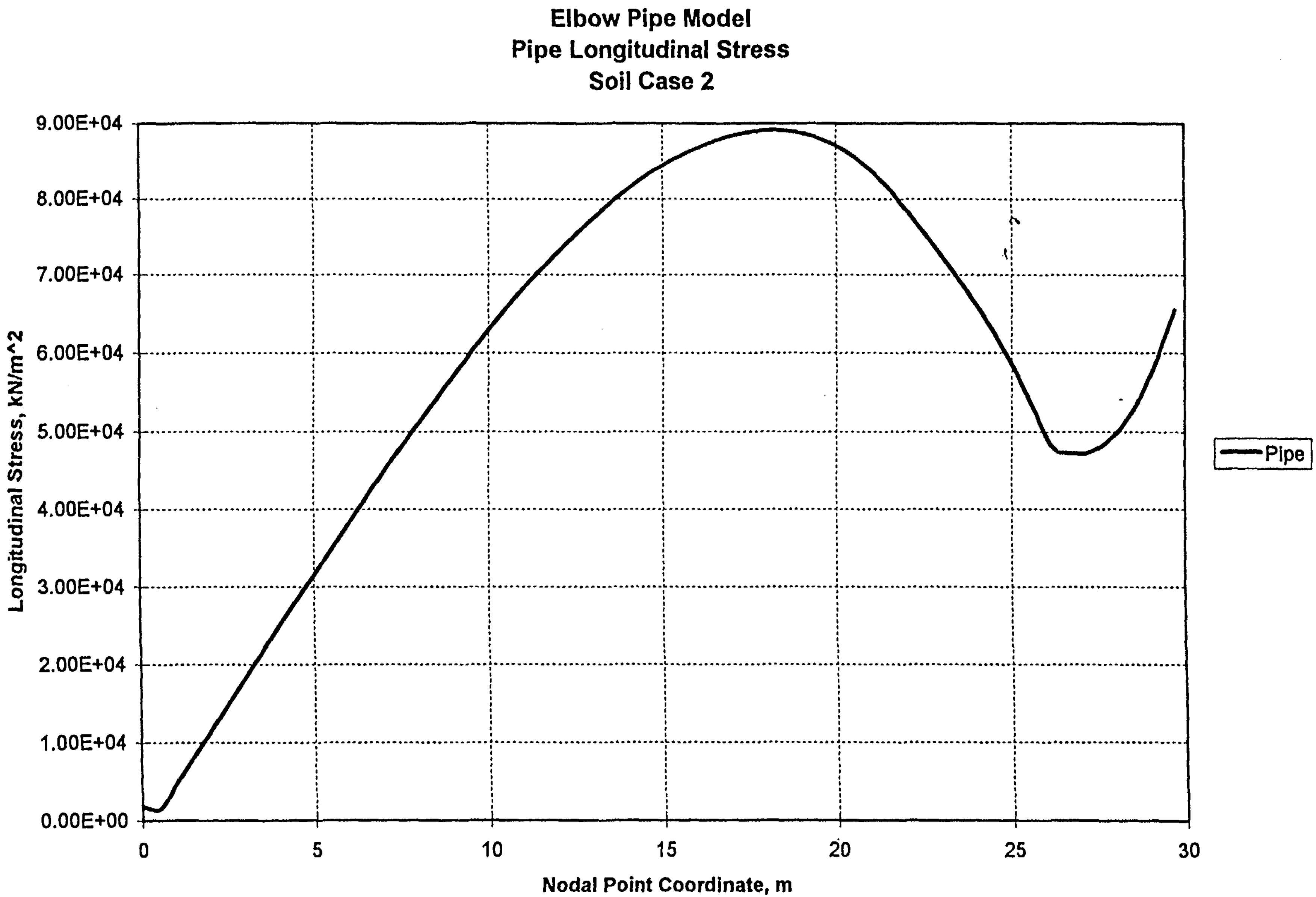

Elbow Pipe Model
Pipe Longitudinal Stress
Soil Case 1
7.00E+04
6.00E+04
5.00E+04
4.00E+04
3.00E+04
2.00E+04
1.00E+04
0.00E+00
Longitudinal Stress, kN/m^2
0
20
40
60
80
100
120
140
Nodal Point
Pipe



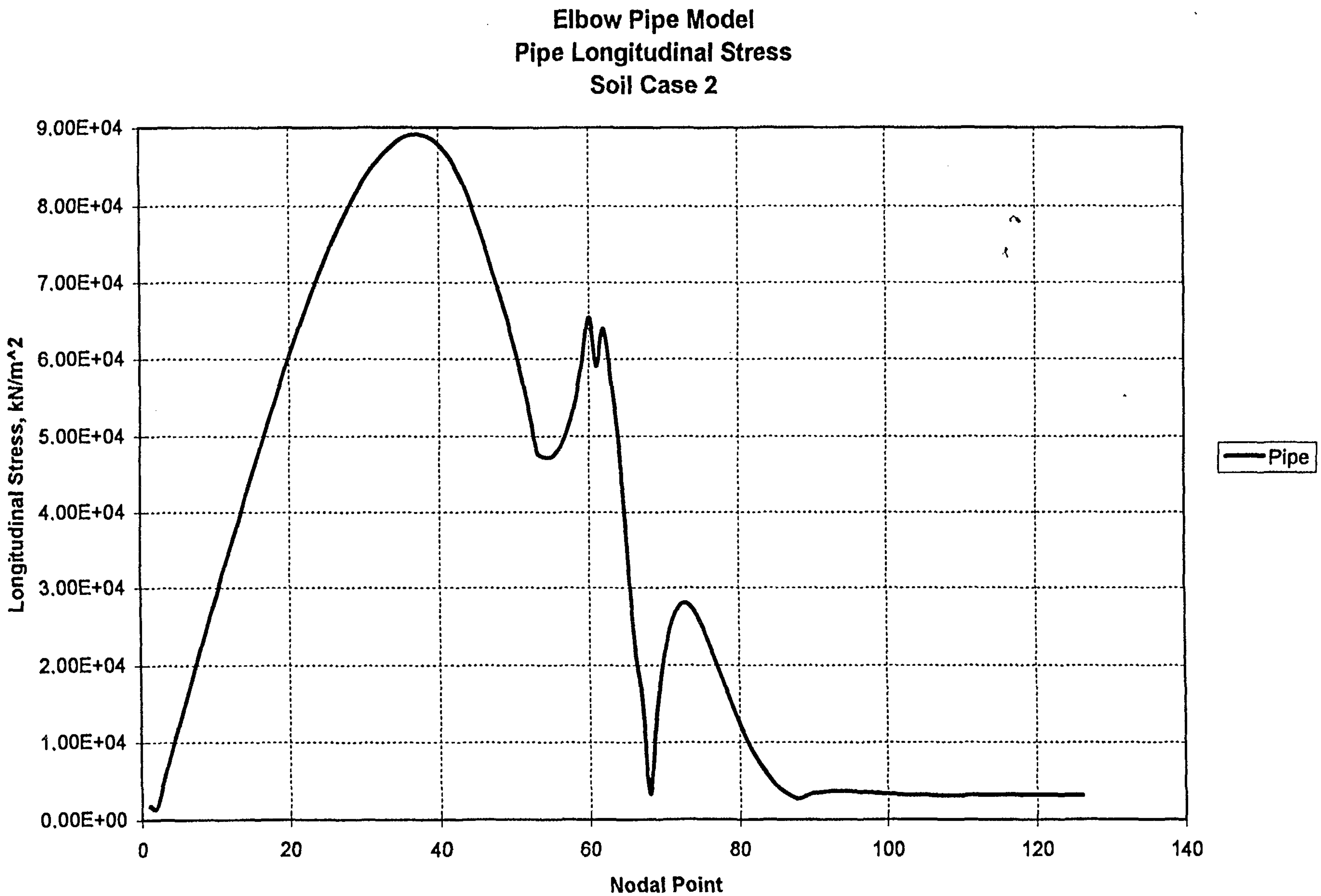
Elbow Pipe Model
Soil Pressure
Soil Case 1
1.50E+02
1.00E+02
5.00E+01
0.00E+00
-5.00E+01
-1.00E+02
-1.50E+02
Soil Pressure, kN/m/m
0
5
10
15
20
25
30
Nodal Point Coordinate, m
Lateral
Longit



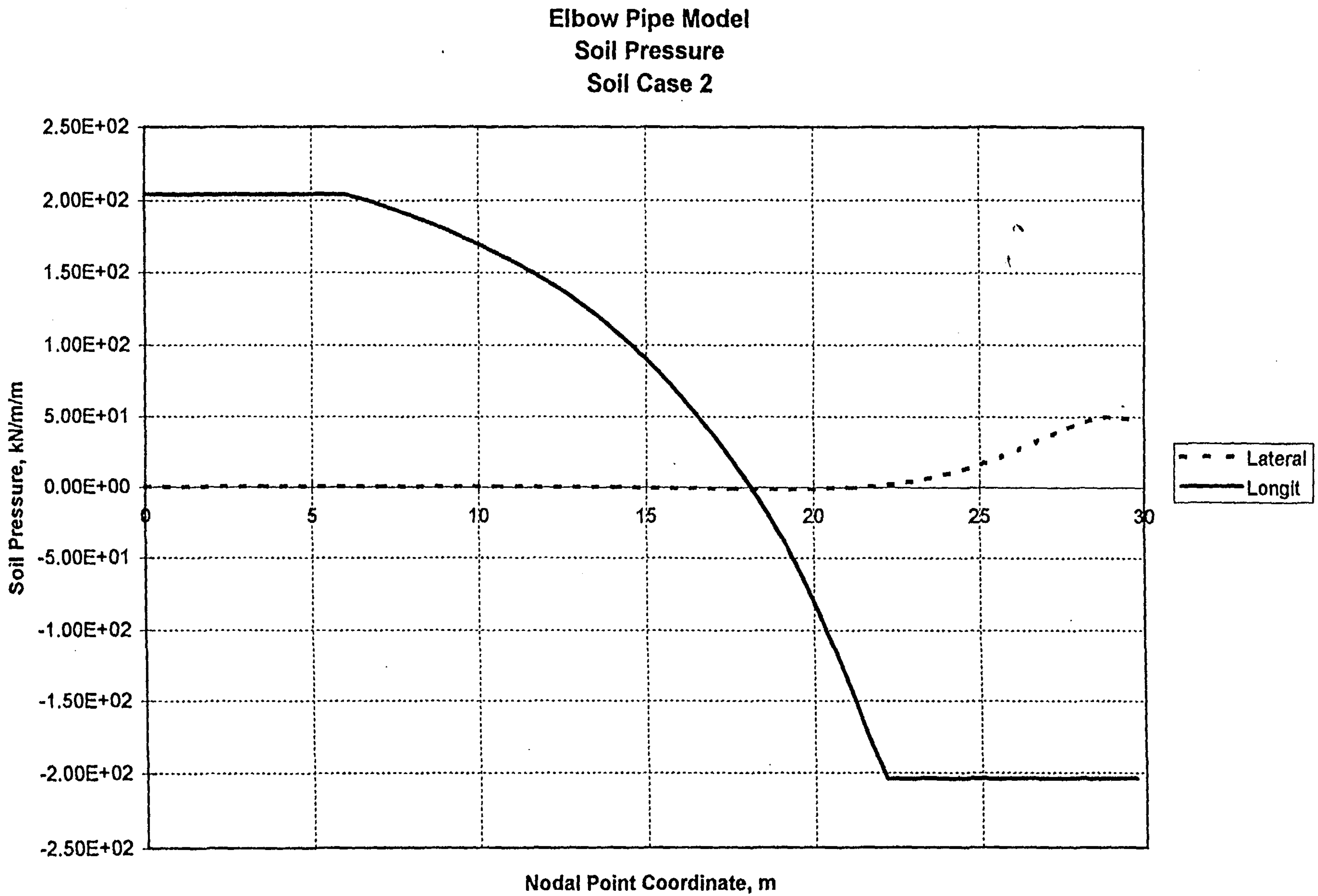
Elbow Pipe Model
Pipe & Soil Longitudinal Displacements
Soil Case 2
Longitudinal Displacement, m
0.0160
0.0140
0.0120
0.0100
0.0080
0.0060
0.0040
0.0020
0.0000
0
5
10
15
20
25
30
Nodal Point Coordinate, m
Pipe
Soil



Elbow Pipe Model
Pipe Longitudinal Stress
Soil Case 2
Longitudinal Stress, kN/m^2
9.00E+04
8.00E+04
7.00E+04
6.00E+04
5.00E+04
4.00E+04
3.00E+04
2.00E+04
1.00E+04
0.00E+00
0
5
10
15
20
25
30
Nodal Point Coordinate, m
Pipe



Elbow Pipe Model
Pipe Longitudinal Stress
Soil Case 2
Longitudinal Stress, kN/m^2
9.00E+04
8.00E+04
7.00E+04
6.00E+04
5.00E+04
4.00E+04
3.00E+04
2.00E+04
1.00E+04
0.00E+00
0
20
40
60
80
100
120
140
Nodal Point
Pipe



Elbow Pipe Model
Soil Pressure
Soil Case 2
2.50E+02
2.00E+02
1.50E+02
1.00E+02
5.00E+01
0.00E+00
-5.00E+01
-1.00E+02
-1.50E+02
-2.00E+02
-2.50E+02
Soil Pressure, kN/m/m
0
5
10
15
20
25
30
Nodal Point Coordinate, m
Lateral
Longit