LESSON 9

TOPIC 2

Construction Monitoring and Quality Assurance - Foundations

CONSTRUCTION MONITORING AND QUALITY ASSURANCE

Lesson 9 - Topic 2
Foundations

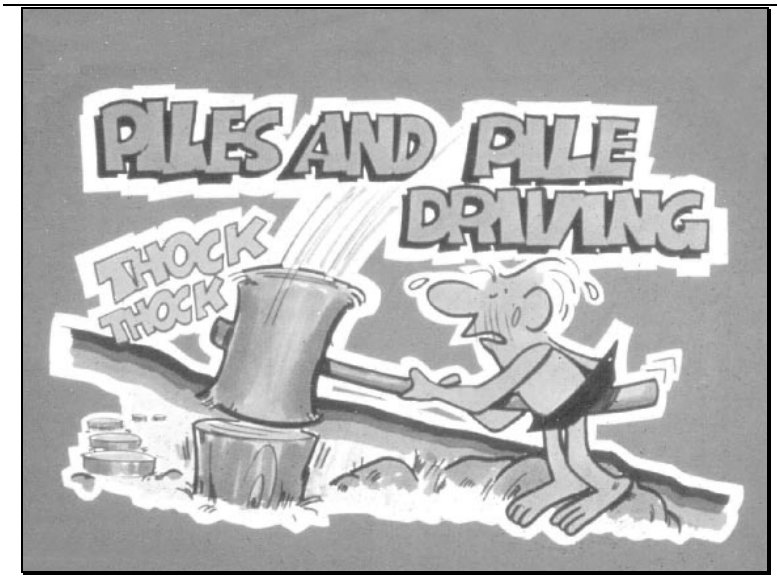
Slide 9-2-1

CONSTRUCTION MONITORING AND QUALITY ASSURANCE
Foundations

1. Apply Dynamic Analysis to Pile Design
2. Evaluate Pile Equipment Acceptability

ACTIVITY: Wave Equation Applications

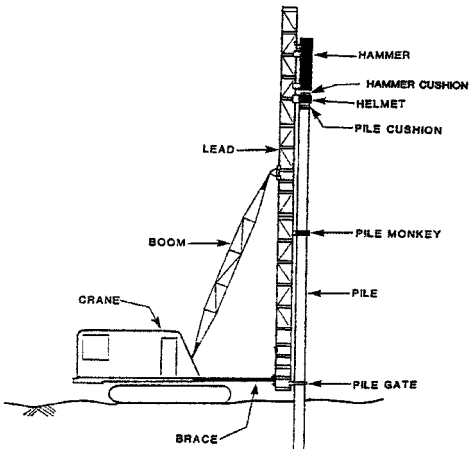
Slide 9-2-2



Slide 9-2-3

Both the Pile and the Driving Equipment Must Be Sized to Permit Pile Installation to the Designed Length Without Damage

Slide 9-2-4

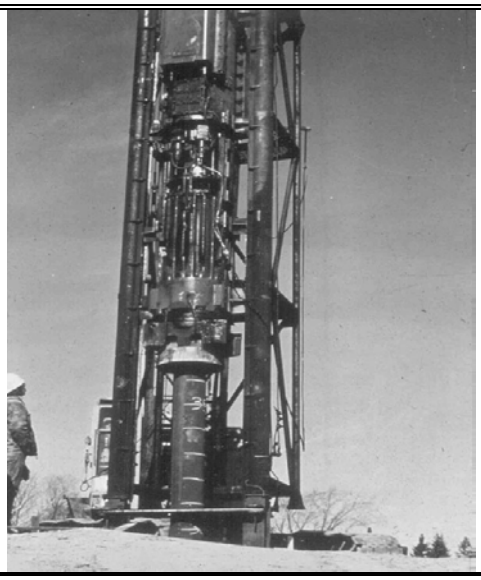


Pile Support System

Slide 9-2-5

Slide 9-2-6

Slide 9-2-7



Slide 9-2-8

Slide 9-2-9

Driving System Analysis

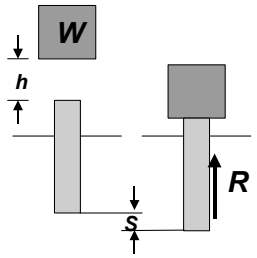
Slide 9-2-10

The Fundamental Pile Driving Formula

Hammer Energy = Work of Soil Resistance

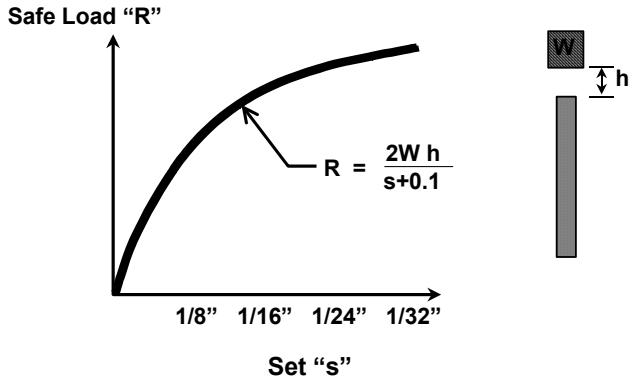
$$W\,h = R\,s$$

$$R = \frac{W\,h}{s}$$



Slide 9-2-11

The ENR Bearing Graph



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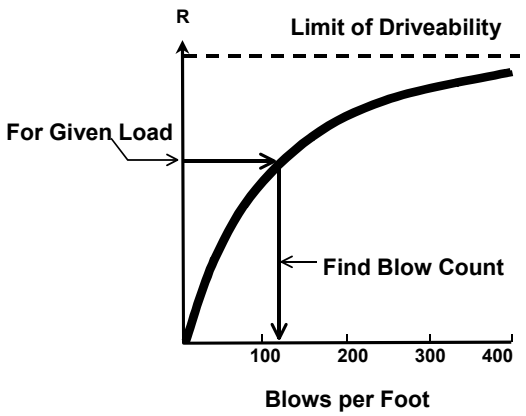
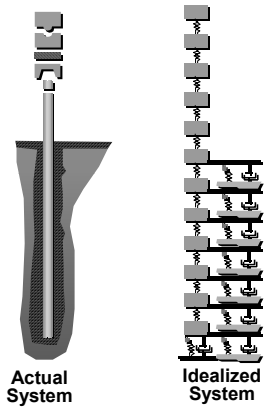
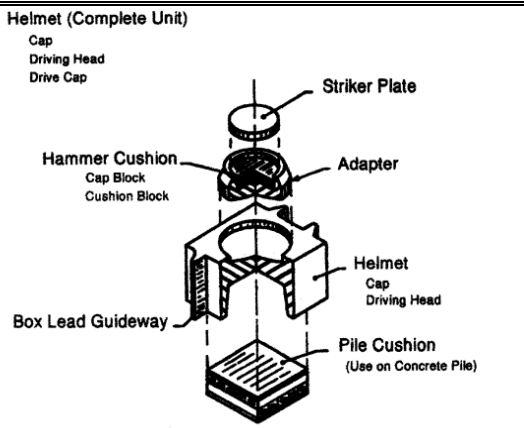


Slide 9-2-13

Comparison of A Typical Hammer-Pile-Soil System to Smith's Idealization



Slide 9-2-14



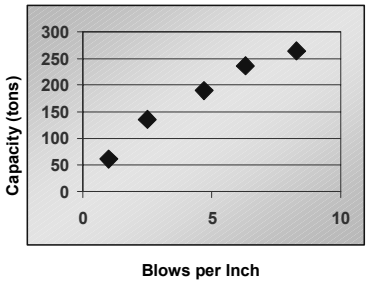
Note: The helmet shown is for nomenclature only. Various sizes and types are available to drive H, pipe, concrete (shown) and timber piles. A system of inserts or adapters is utilized up inside of the helmet to change from size to size and shape to shape.

Slide 9-2-15

Pile Driving Analysis – Wave Equation Output

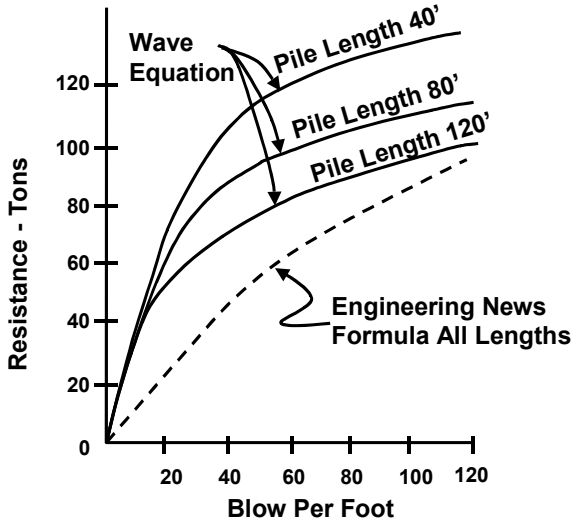
14" Square Prestressed Concrete Pile

6" Micarta Cap Block, 6" Hardwood Pile Cushion



Blows Per Inch	Capacity (tons)	Max Comp Stress (PSI)	Max Tensile Stress (PSI)
1.0158	61	3738	2394
2.5309	136	3874	1661
4.6649	190	3984	1367
6.3113	236	4036	1208
8.2801	264	4076	1086

Slide 9-2-16

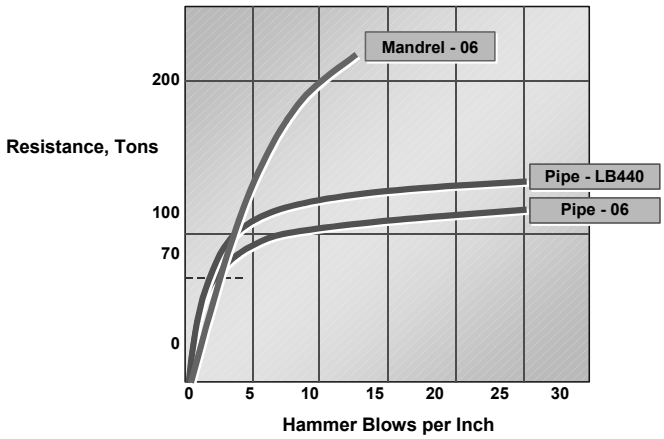


Slide 9-2-17

Pile Mandrels for Shell Piles

- ***Removable pneumatic device for thin wall pile installation***
- ***High stiffness greatly improves driveability***
- ***Requires "doodle hole" for insertion into pile***

Slide 9-2-18



Slide 9-2-19

Slide 9-2-20

Allowable Stress Levels in Piles

Pile Type	*Allowable Driving Stress*
Steel	*0.9 Fy*
Concrete	*(0.85 F'c – Effective Prestress) In Compression*
	(3 √F'c + Effective Prestress) In Tension
Timber	*3 F'a (Not to Exceed 3000 psi)*
Where:	*Fy = Yield Strength of Steel* *F'c = 28 day Concrete Cylinder Strength* *F'a = Allowable Comrpessive Stress of Timber Including Allowance for Treatement Effects*

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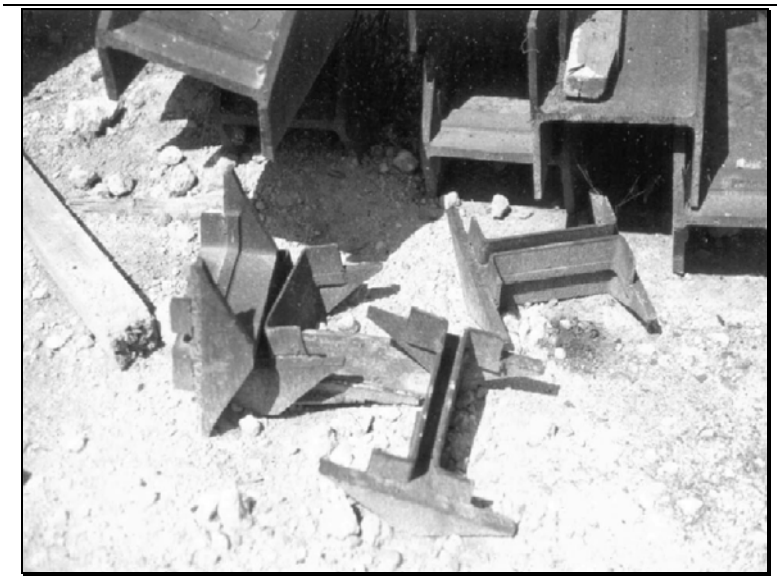
Slide 9-2-22

Slide 9-2-23



Slide 9-2-24

Construction Considerations in Design

Intelligent Preparation of Plan and Specifications Can Only Be Done By One Who Understands the Construction Operation As Well as Structural Design Concepts

Slide 9-2-25

SOILS AND FOUNDATIONS WORKSHOP

Standard Specifications

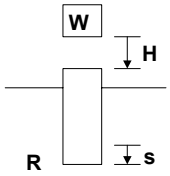
"In the Absence of Pile Load Tests the Safe Bearing Value for Piles Shall be Determined by the Following Formulae:

ENR Formulae or Modifications"

Slide 9-2-26

SOILS AND FOUNDATIONS WORKSHOP

ENR Formula Factor of Safety



Fundamental Formula

$W^{\#}H(ft) = R^{\#}s(ft)$

$$R = \frac{WH}{s}$$

Where R = ultimate soil resistance

ENR Formula

$$P = \frac{2\,W^{\#}H(ft)}{s(in) + 0.1}$$

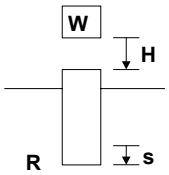
Where P = design load in #

Slide 9-2-27

SOILS AND FOUNDATIONS WORKSHOP

ENR Formula Factor of Safety

To find F.S. between P and R, revise ENR to be dimensionally correct and compare the resulting equation for P with R



$$R = \frac{WH}{s}$$

$$P = \frac{2\,W^{\#}H(ft)}{s(in) + 0.1}$$

$$P = \frac{2WH}{s + 0.1}(1/12) = \frac{WH}{6s}$$

$$R = 6P$$

Safety Factor = 6

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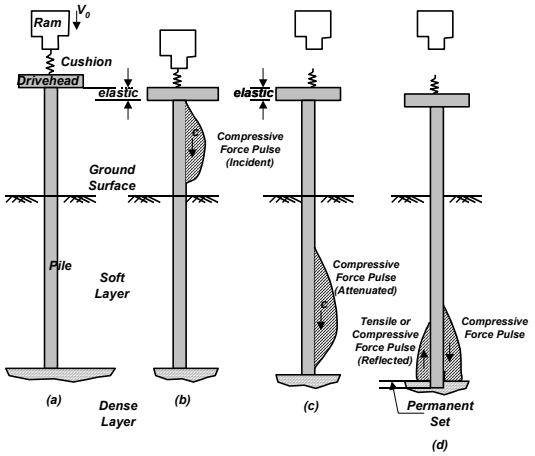
SOILS AND FOUNDATIONS WORKSHOP



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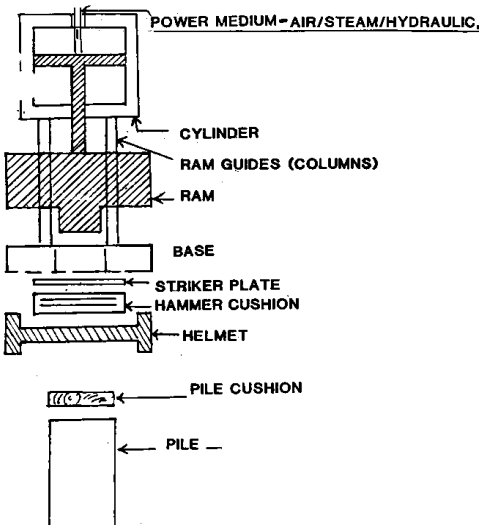
SOILS AND FOUNDATIONS WORKSHOP

Important Driving System Properties



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SOILS AND FOUNDATIONS WORKSHOP

IMPORTANT PILE PROPERTIES

1. LENGTH

2. CROSS SECTIONAL AREA

other contributing pile properties

3. MATERIAL

4. DAMPING

Slide 9-2-31

SOILS AND FOUNDATIONS WORKSHOP

Instructor Demonstration of Pile Stiffness

Slide 9-2-32

SOILS AND FOUNDATIONS WORKSHOP

IMPORTANT

SOIL VALUES

DISTRIBUTION OF SOIL RESISTANCE IN FRICTION & POINT BEARING

DAMPING

QUAKE

TOTAL SOIL RESISTANCE TO BE OVERCOME DURING DRIVING TO ESTIMATED LENGTH

Slide 9-2-33

SOILS AND FOUNDATIONS WORKSHOP

2. The Output of most interest is the summary table of extreme values for all the ultimate resistances analyzed.

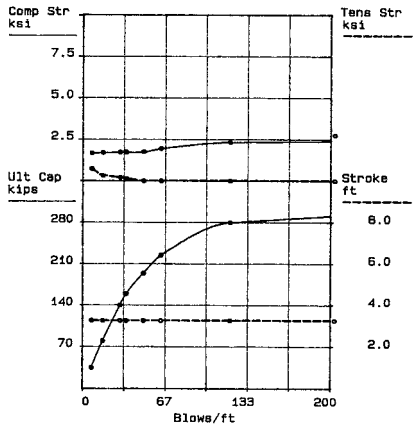
WAVE EQUATION SUMMARY

R_{ult} Kips	Blow Count BPF	Stroke Ft.	Tensile Stress Ksi	Compressive Stress Ksi	Transfer Energy Ft-Kip
35.0	7	3.27	-0.73	1.68	13.6
80.0	16	3.27	-0.32	1.71	13.6
140.0	30	3.27	-0.20	1.73	13.0
160.0	35	3.27	-0.14	1.73	13.0
195.0	49	3.27	-0.00	1.75	12.8
225.0	63	3.27	0.0	1.96	12.7
280.0	119	3.27	0.0	2.34	12.6
350.0	841	3.27	0.0	2.75	12.5

Slide 9-2-34

SOILS AND FOUNDATIONS WORKSHOP

The data from the summary table of wave equation output is usually plotted to produce curves of blow count versus resistance and stress.



WAVE EQUATION BEARING GRAPH

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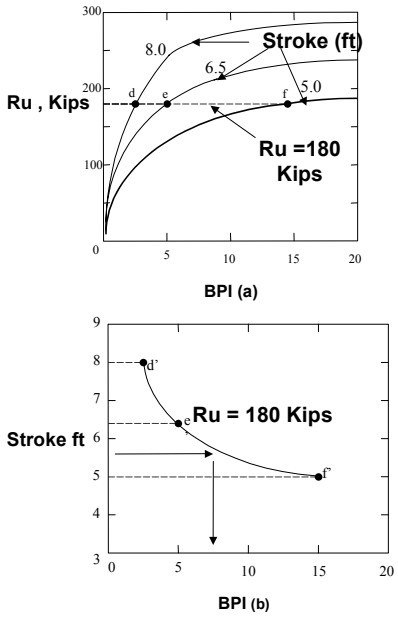
SOILS AND FOUNDATIONS WORKSHOP



Slide 9-2-36

SOILS AND FOUNDATIONS WORKSHOP

General Criteria for Acceptable Pile Driveability

1. Hammer Blows Between 30-144 per foot

2. Acceptable Driving Stress

Pile Type	Allowable Driving Stress
Steel	0.9 F′ y
Concrete	(0.85 F′c – effective prestress) in compression
	(3 √F′c + effective prestress) in tension
Timber	3 F′a (not to exceed 3000 psi)

Where: Fy = Yield strength of steel
F′c = 28 day concrete cylinder strength
F′a = allowable compressive stress of timber including allowance for treatment effects

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SOILS AND FOUNDATIONS WORKSHOP

Example: Determine If The 14" Square Concrete Pile Can Be Driven To A Driving Capacity Of 225 Kips By Using The Wave Equation Output Summary. Assume The Concrete Compressive Strength Is 4000 psi And The Pile Prestress Force Is 700 psi.

WAVE EQUATION OUTPUT SUMMARY

R_{ult} Kips	Blow Count BPF	Stroke Ft.	Tensile Stress Ksi	Compressive Stress Ksi
35.0	7	3.27	-0.73	1.68
80.0	16	3.27	-0.32	1.71
140.0	30	3.27	-0.20	1.73
160.0	35	3.27	-0.14	1.73
195.0	49	3.27	-0.00	1.75
225.0	63	3.27	0.0	1.96
280.0	119	3.27	0.0	2.34
350.0	841	3.27	0.0	2.75

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SOILS AND FOUNDATIONS WORKSHOP

Solution:

Acceptable driveability depends on achieving the hammer blows between 30 and 144 at the driving capacity, and assuming that the allowable compressive and tensile driving stress are not exceeded.

1. ***At R_{ult} = 225 Kips, blow count = 63 which is between 30 and 144. O.K.***

2. ***For concrete piles, the allowable driving stresses are:***
   - ***Compressive stress allowed = 0.85 F'c – prestress = 3400 – 700 = 2700 psi, actual Max. compressive stress up to 225 Kips from wave equation output summary is 1.96 ksi or 1960 psi ≤ 2700 psi allowed value. O.K.***
   - ***Tensile stress allowed = $3\sqrt{F'c}$ + prestress = 190 + 700 = 890 psi, actual Max. tensile stress up to 225 Kips from wave equation output summary is 0.730 ksi or 730 psi < 890 psi allowed value. O.K.***

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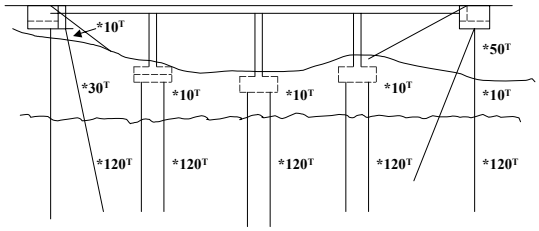
SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 8

Design Phase Driveability Analysis



The Profile Shows the Calculated Driving Resistance in Each Soil Layer at Each Footing for the Proposed 12″ Diameter Steel Pipe Piles (Steel F_y = 36 ksi). Using the Maximum Driving Resistance at Any Footing, find the Anticipated Maximum Driving Stress and Blow Count From the Wave Equation Summaries Shown for Three Pile Sizes. Compare These Values to the Recommended Friction Pile Values for Blow Count and Driving Stress to Determine the Minimum Acceptable Pile Wall Thickness for the Pipe Piles at This Site.

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SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 8

GRLWEAP S & F STUDENT EXERCISE 0.250″ WALL THICKNESS

R_{ult} Kips	Bl Ct bpf	Stroke (eq. Ft)	Min str. ksi	Max str. ksi	Enthru kip-ft
260.0	35.3	3.25	-0.85	36.34	14.8
360.0	111.8	3.25	-0.98	42.07	13.8

GRLWEAP S & F STUDENT EXERCISE 0.312″ WALL THICKNESS

R_{ult} Kips	Bl Ct bpf	Stroke (eq. Ft)	Min str. ksi	Max str. ksi	Enthru kip-ft
260.0	31.8	3.25	-0.68	28.58	15.1
360.0	72.9	3.25	-0.70	35.98	14.2

GRLWEAP S & F STUDENT EXERCISE 0.375″ WALL THICKNESS

R_{ult} Kips	Bl Ct bpf	Stroke (eq. Ft)	Min str. ksi	Max str. ksi	Enthru kip-ft
260.0	30.2	3.25	-0.45	24.67	15.2
360.0	58.8	3.25	-0.95	30.47	14.5

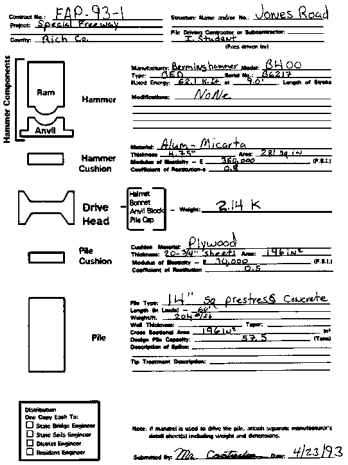
Slide 9-2-41

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 9
Hammer Approval

The contractor has submitted the pile equipment data form and the wave equation analysis for a 14 ″square prestressed concrete pile (f′c = 5,000 psi and 700 psi prestress) with a design capacity of 115 kips and a driv ing resistance of 300 kips. Should you accept or reject this hammer?

Pile and Driving Equipment Data



Slide 9-2-43

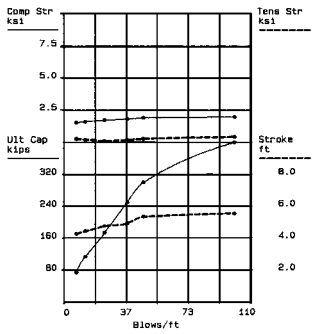
SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 9 (CONT'D)

Federal Highway 01/28/93 GRLWEAP S&F STUDENT EXERCISE HAMMER APPROVAL

Rut kips	Bl Ct bpf	Stroke (ft) down	up	min Str ksi	i,t	max Str ksi	i,t	ENTHRU kip-ft	Bl Rt b/min
75.0	7.2	4.3	4.3	-.30	(7, 19)	1.54	(2, 12)	13.2	56.7
115.0	12.5	4.5	4.5	-.20	(9, 21)	1.62	(2, 12)	11.7	55.3
175.0	24.0	4.8	4.7	-.11	(10, 21)	1.73	(2, 12)	10.1	53.8
250.0	37.3	5.0	5.1	-.19	(9, 30)	1.82	(2, 12)	8.8	52.4
300.0	47.0	5.4	5.3	-.28	(8, 29)	1.90	(2, 12)	8.8	50.9
400.0	102.2	5.6	5.7	-.41	(5, 28)	1.96	(2, 12)	8.1	49.5

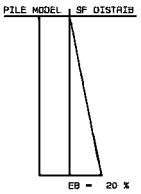
G R L W E A P – Federal Highway Admin.
S&F STUDENT EXERCISE HAMMER APPROVAL 01/29/93



BRMNGHMR B400/5.0
Efficiency .720
Helmet 2.14 kips
H Cushion 20705 k/in
P Cushion 511 k/in

G = .100 .100 in
J = .050 .100 s/ft

Pile Length 60.00 ft
P-Top Area 196.00 in2



Slide 9-2-44

SOILS AND FOUNDATIONS WORKSHOP

Construction Monitoring and Quality Assurance

- ***Apply dynamic analysis to pile design***
- ***Evaluate pile equipment acceptability***

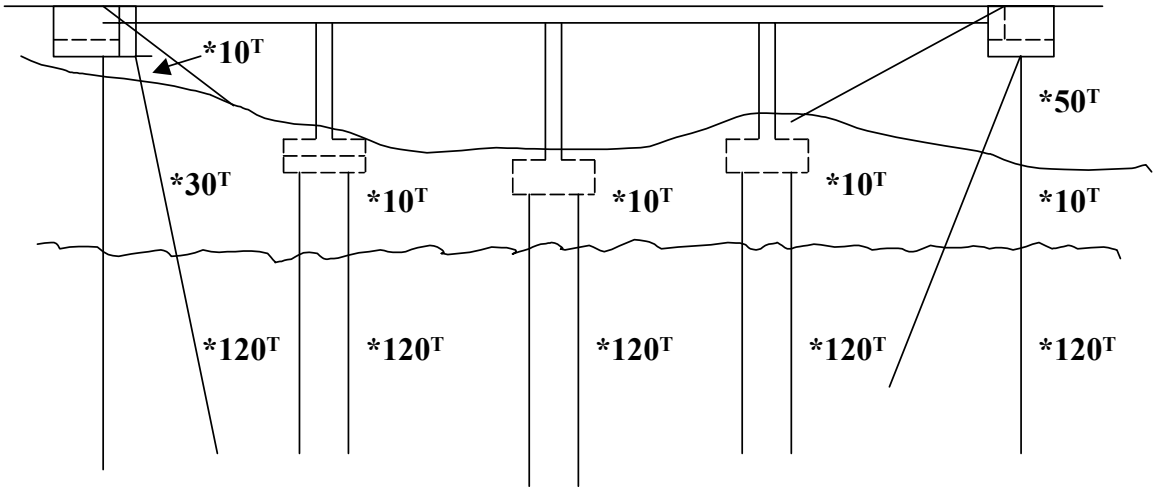
Activities: Wave Equation Applications

Slide 9-2-46

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 8

Design Phase Driveability Analysis



The Profile Shows the Calculated Driving Resistance in Each Soil Layer at Each Footing for the Proposed 12″ Diameter Steel Pipe Piles (Steel F_y = 36 ksi). Using the Maximum Driving Resistance at Any Footing, find the Anticipated Maximum Driving Stress and Blow Count From the Wave Equation Summaries Shown for Three Pile Sizes. Compare These Values to the Recommended Friction Pile Values for Blow Count and Driving Stress to Determine the Minimum Acceptable Pile Wall Thickness for the Pipe Piles at This Site.

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 8

GRLWEAP S & F STUDENT EXERCISE 0.250″ WALL THICKNESS

R_{ult} Kips	Bl Ct bpf	Stroke (eq. Ft)	Min str. ksi	Max str. ksi	Enthru kip-ft
260.0	35.3	3.25	-0.85	36.34	14.8
360.0	111.8	3.25	-0.98	42.07	13.8

GRLWEAP S & F STUDENT EXERCISE 0.312″ WALL THICKNESS

R_{ult} Kips	Bl Ct bpf	Stroke (eq. Ft)	Min str. ksi	Max str. ksi	Enthru kip-ft
260.0	31.8	3.25	-0.68	28.58	15.1
360.0	72.9	3.25	-0.70	35.98	14.2

GRLWEAP S & F STUDENT EXERCISE 0.375″ WALL THICKNESS

R_{ult} Kips	Bl Ct bpf	Stroke (eq. Ft)	Min str. ksi	Max str. ksi	Enthru kip-ft
260.0	30.2	3.25	-0.45	24.67	15.2
360.0	58.8	3.25	-0.95	30.47	14.5

SOILS AND FOUNDATIONS WORKSHOP

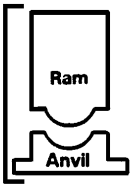
STUDENT EXERCISE NO. 9
Hammer Approval

The contractor has submitted the pile equipment data form and the wave equation analysis for a 14 ″square prestressed concrete pile (f′c = 5,000 psi and 700 psi prestress) with a design capacity of 115 kips and a driv ing resistance of 300 kips. Should you accept or reject this hammer?

Pile and Driving Equipment Data

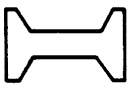
Contract No.: FAP-93-1 Structure Name and/or No.: Jones Road
Project: Special Freeway
County: Rich Co. Pile Driving Contractor or Subcontractor: I. Student (Piles driven by)

Hammer Components



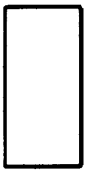
Hammer
Manufacturer: Berminghammer Model: BH00
Type: DED Serial No.: B6217
Rated Energy: 62.1 ft-kt at 9.0' Length of Stroke
Modifications: None

Hammer Cushion
Material: Alum-Micarta
Thickness 4.75" Area: 281 sq in
Modulus of Elasticity – E 350,000 (P.S.I.)
Coefficient of Restitution-e 0.8



Drive Head – Helmet, Bonnet, Anvil Block, Pile Cap – Weight: 2.14 K

Pile Cushion
Cushion Material: Plywood
Thickness: 20-3/4" sheets Area: 196 in²
Modulus of Elasticity – E 30,000 (P.S.I.)
Coefficient of Restitution 0.5



Pile
Pile Type: 14" sq prestress Concrete
Length (in Leads) – 60'
Weight/ft. 204#/ft
Wall Thickness: Taper:
Cross Sectional Area 196 in² in²
Design Pile Capacity: 57.5 (Tons)
Description of Splice:
Tip Treatment Description:

Distribution
One Copy Each To:
- ☐ State Bridge Engineer
- ☐ State Soils Engineer
- ☐ District Engineer
- ☐ Resident Engineer

Note: if mandrel is used to drive the pile, attach separate manufacturer's detail sheet(s) including weight and dimensions.

Submitted By: Mr. Contractor Date: 4/23/93

SOILS AND FOUNDATIONS WORKSHOP

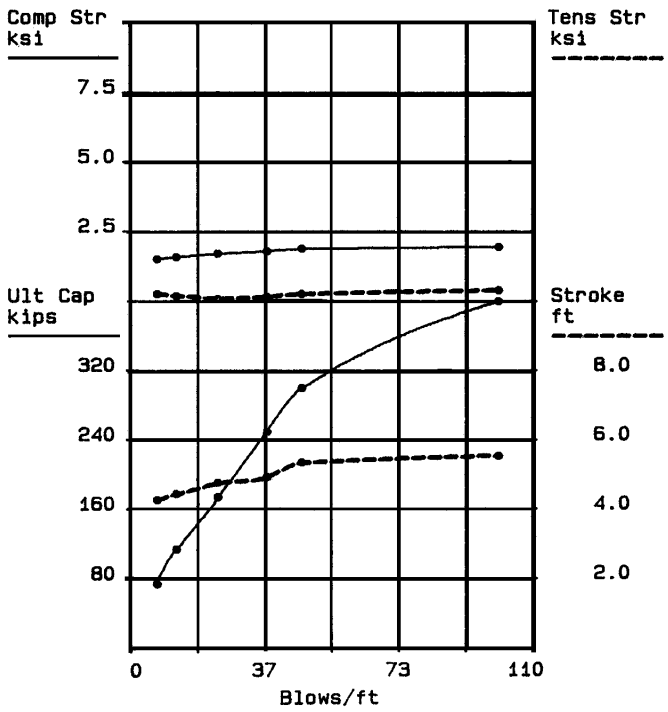
STUDENT EXERCISE NO. 9 (CONT'D)

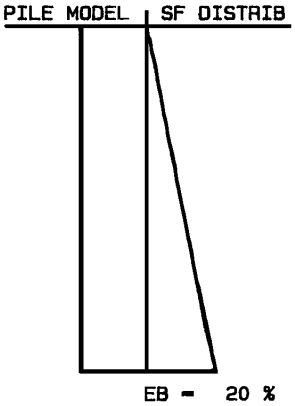
Federal Highway 01/28/93 GRLWEAP S&F STUDENT EXERCISE HAMMER APPROVAL

Rut kips	Bl Ct bpf	Stroke (ft) down	Stroke (ft) up	min Str ksi	i,t	max Str ksi	i,t	ENTHRU kip-ft	Bl Rt b/min
75.0	7.2	4.3	4.3	-.30	(7, 19)	1.54	(2, 12)	13.2	56.7
115.0	12.5	4.5	4.5	-.20	(9, 21)	1.62	(2, 12)	11.7	55.3
175.0	24.0	4.8	4.7	-.11	(10, 21)	1.73	(2, 12)	10.1	53.8
250.0	37.3	5.0	5.1	-.19	(9, 30)	1.82	(2, 12)	8.8	52.4
300.0	47.0	5.4	5.3	-.28	(8, 29)	1.90	(2, 12)	8.8	50.9
400.0	102.2	5.6	5.7	-.41	(5, 28)	1.96	(2, 12)	8.1	49.5

G R L W E A P - Federal Highway Admin.

S&F STUDENT EXERCISE HAMMER APPROVAL 01/29/93



BRMNGHMR B400/5.0

Efficiency	.720	
Helmet	2.14	kips
H Cushion	20705	k/in
P Cushion	511	k/in
Q = .100	.100	in
J = .050	.100	s/ft
Pile Length	60.00	ft
P-Top Area	196.00	in2