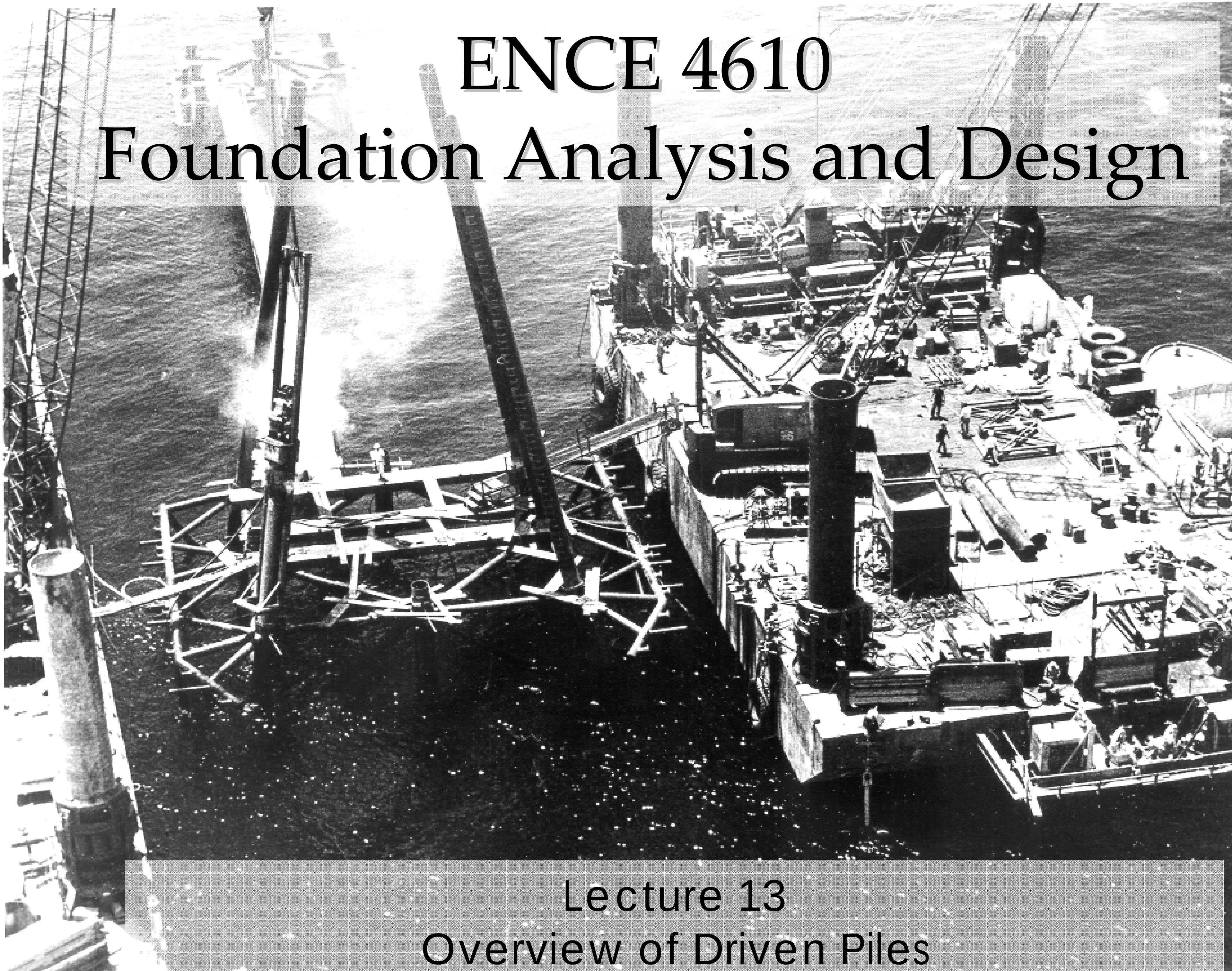
ENCE 4610
Foundation Analysis and Design



Lecture 13
Overview of Driven Piles

Credits for Slides and Graphics

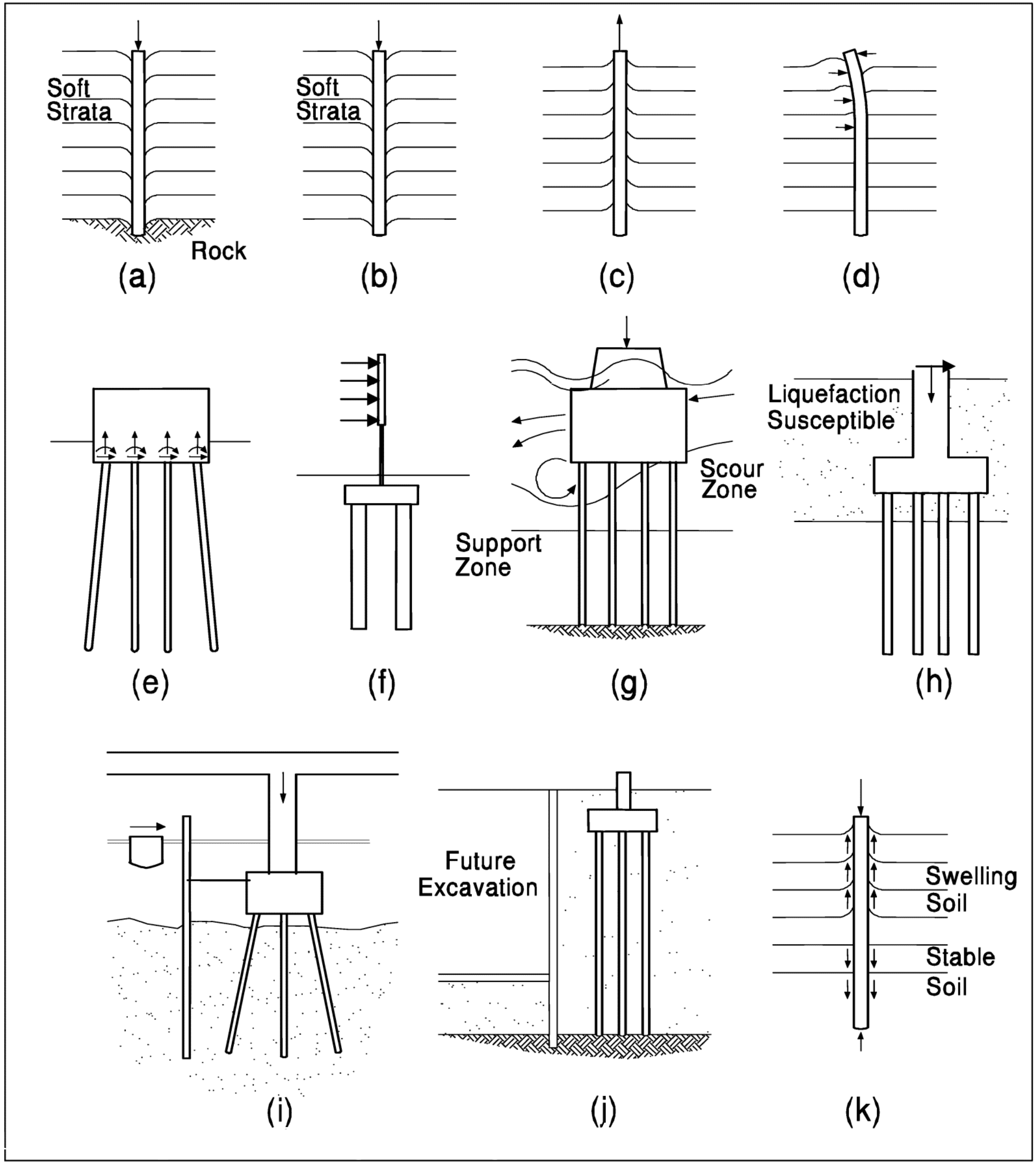
Some of the slides and graphics for this and the following lectures courtesy of

GRL

Goble Raushe Likins & Associates

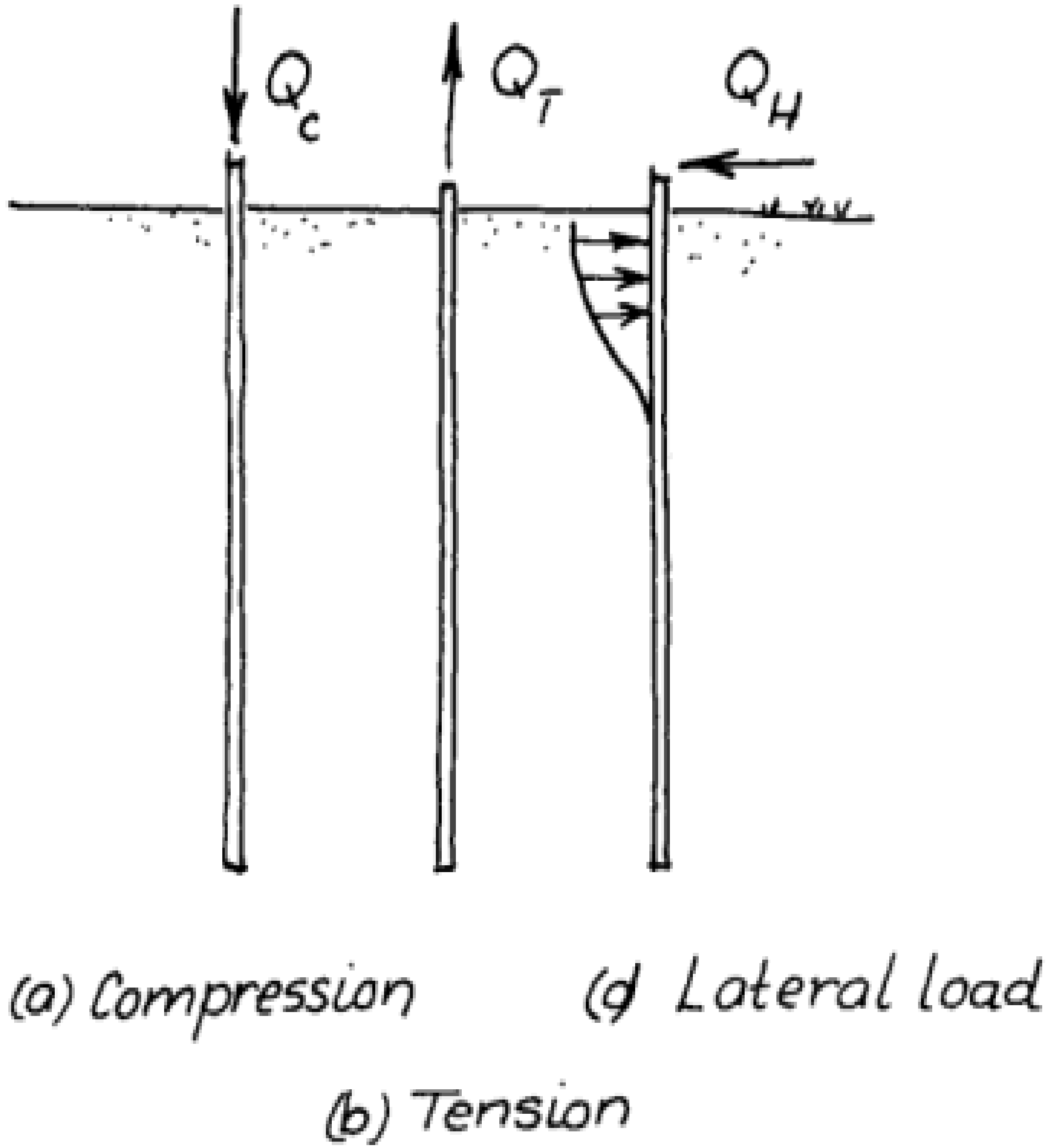
Pile Dynamics, Inc.
Cleveland, Ohio

Reasons for Deep Foundations



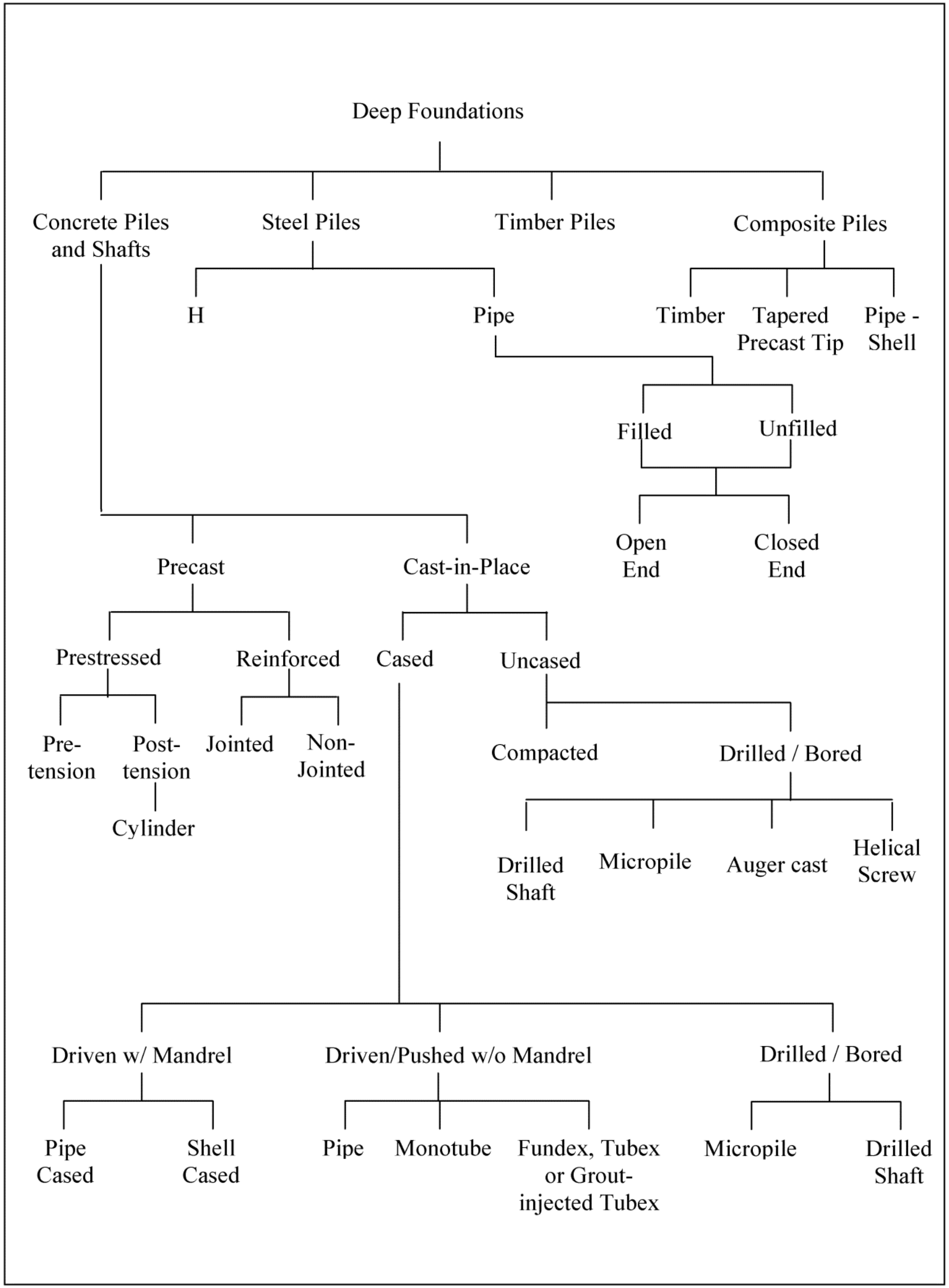
- Also: Foun

Loading of Deep Foundations



- One of the main reasons for deep foundations is the ability of deep foundations to bear loads that shallow foundations cannot
  - Lateral Loads
  - Tension Loads
  - Compression Loads in Soft Soils

Types of Deep Foundations

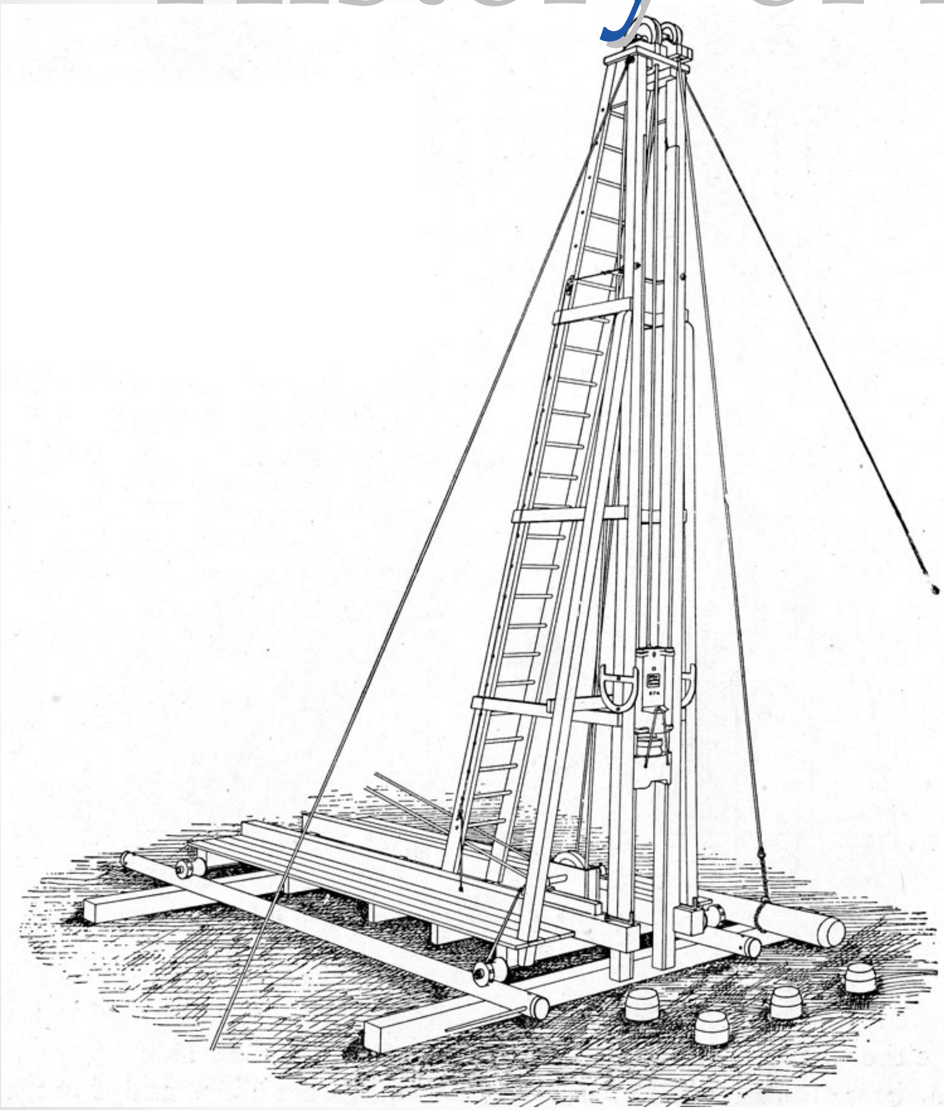


Driven Piles

- A long, slender, prefabricated structural member driven or otherwise inserted into the ground

•

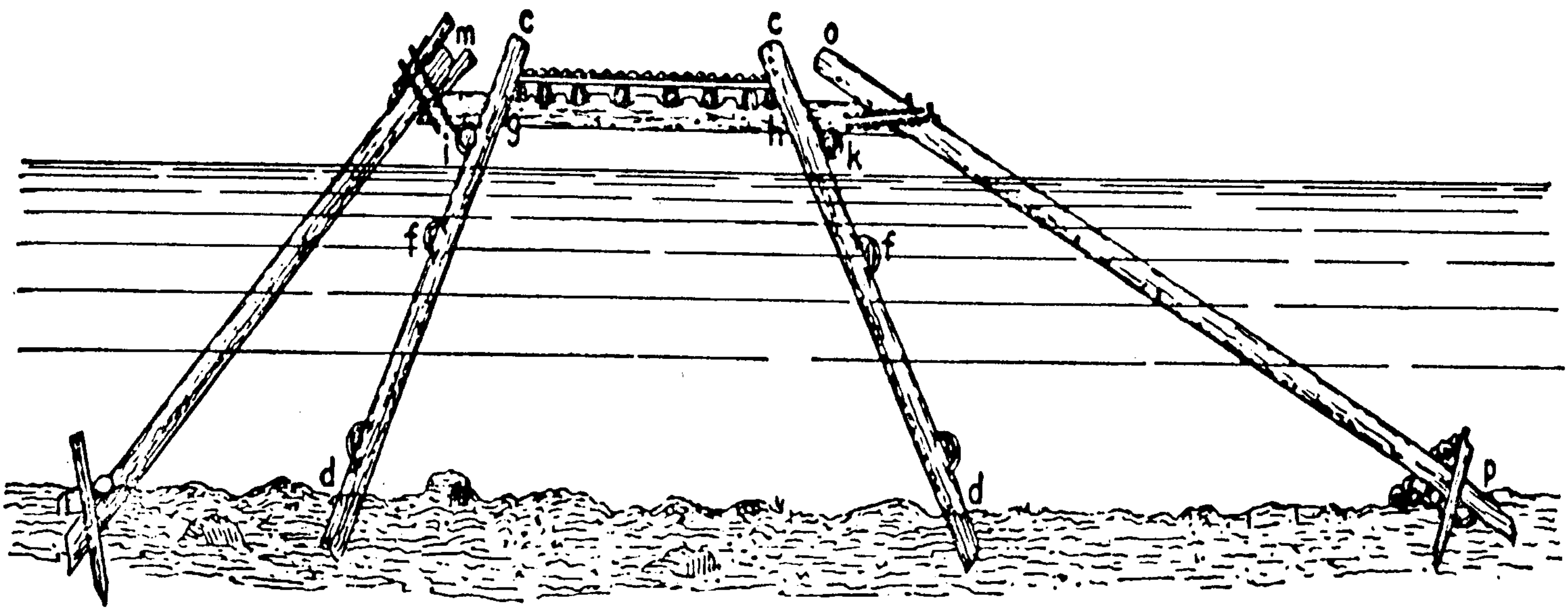
History of Driven Piles



- The oldest form of deep foundation in existence
- All ancient civilzations (Greek, Roman, Chinese) used driven piles to support structures in poor soils
- Driving equipment involved positioning, raising and lowering the driver by hand

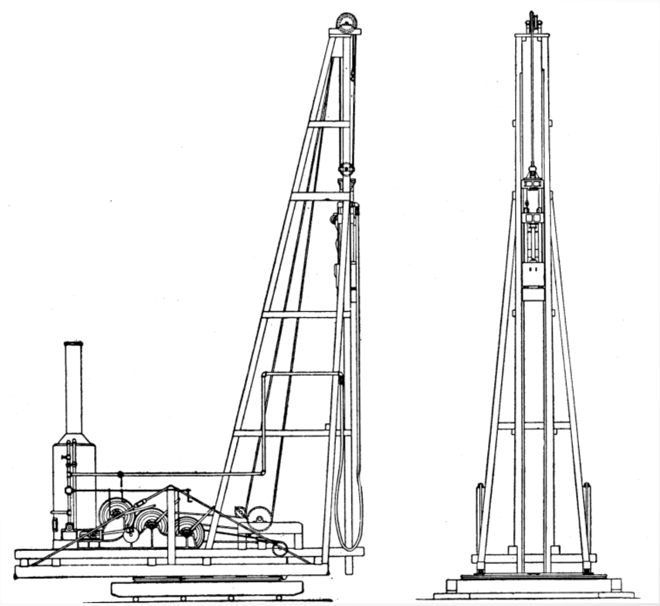
Caesar's Bridge over the Rhine

- Built in a span of ten days
- Consisted of batter piles for the lateral loads of the river



Advances in Driven Piles and Pile Drivers

- Hammers
  - Steam Hammers
    - Naysmith (1845) – related to forging hammers
    - Vulcan (1887), MKT, etc.
  - Pile Driving Rigs
    - Rotating Skid Rigs
    - Crawler mounted rigs
- Piles
  - Steel Piles
    - H-Piles – addressed problems of bridge scour in the Midwest
    - Pipe Piles
  - Precast Concrete Piles
    - François Hennebique (1897) – first use
    - A.A. Raymond (1901) – built with it Raymond Concrete Pile Company



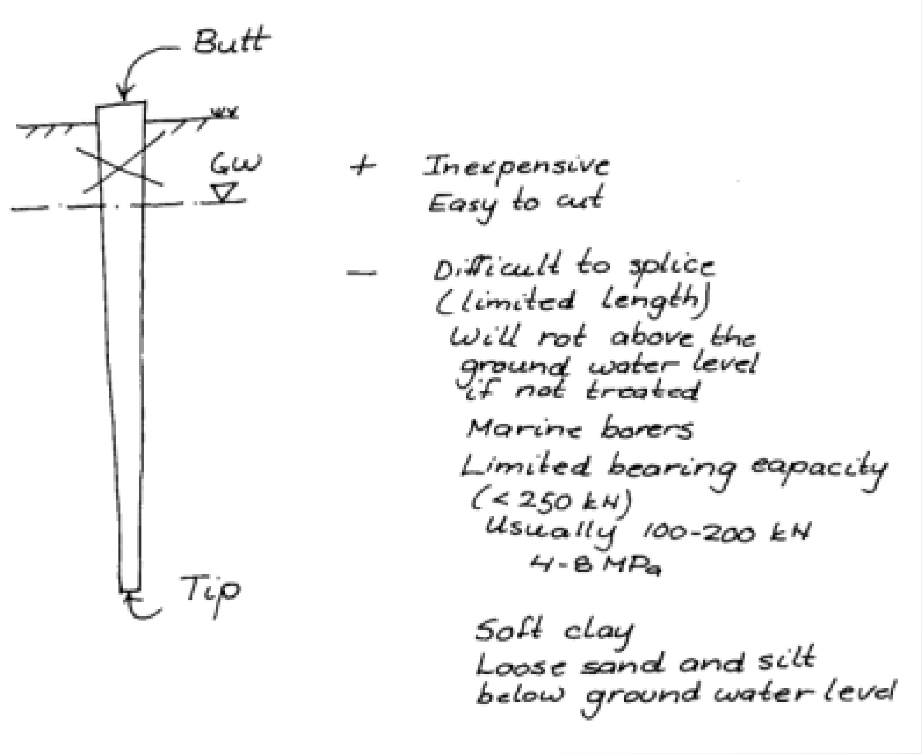
Types of Piles

- Types of Piles Used
  - Timber Piles
  - Steel Piles
    - H-Beams
    - Pipe Piles
  - Concrete Piles
    - Precast Piles
    - Prestressed Piles
  - Other Types of Piles
    - Plastic-Steel Composites
    - Sheet Piling

- Selection of Pile Type
  - Applied Loads
  - Required Diameter
  - Required Length
  - Local availability of each pile type
  - Durability of the pile material in a specific environment
  - Anticipated driving conditions

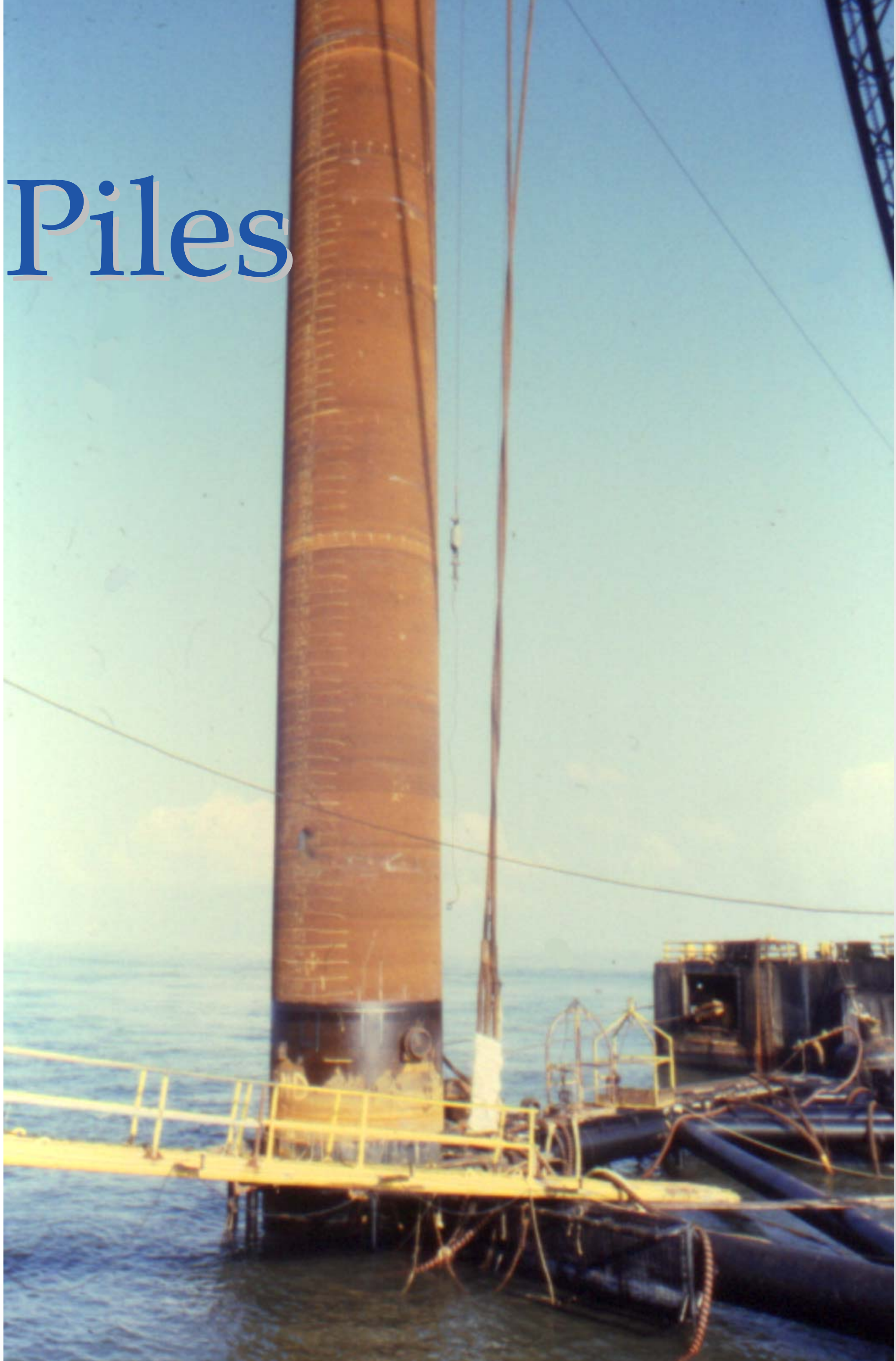
Timber Piles

- The oldest type of pile in use
- Most used today are Southern Pine or Douglas Fir

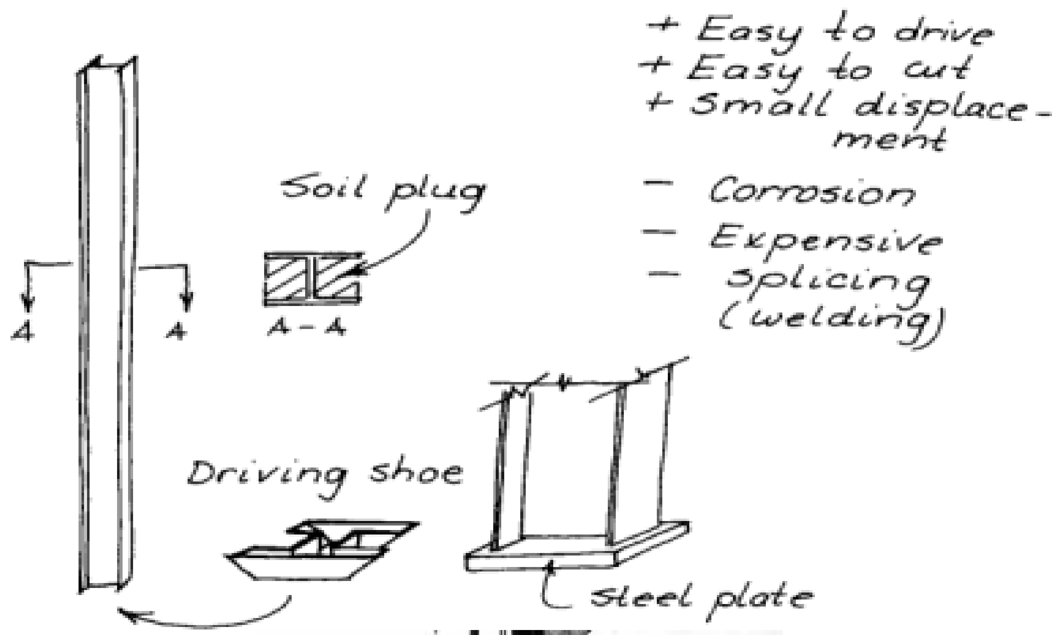


Steel Piles

- Steel piles first came into use in the 1890's
- Can be driven through hard soils and carry large loads
- Especially useful for tension and uplift loads
- Easy to splice and add onto
- Expensive compared to other piles
- May be subject to corrosion, depending upon soil and water conditions



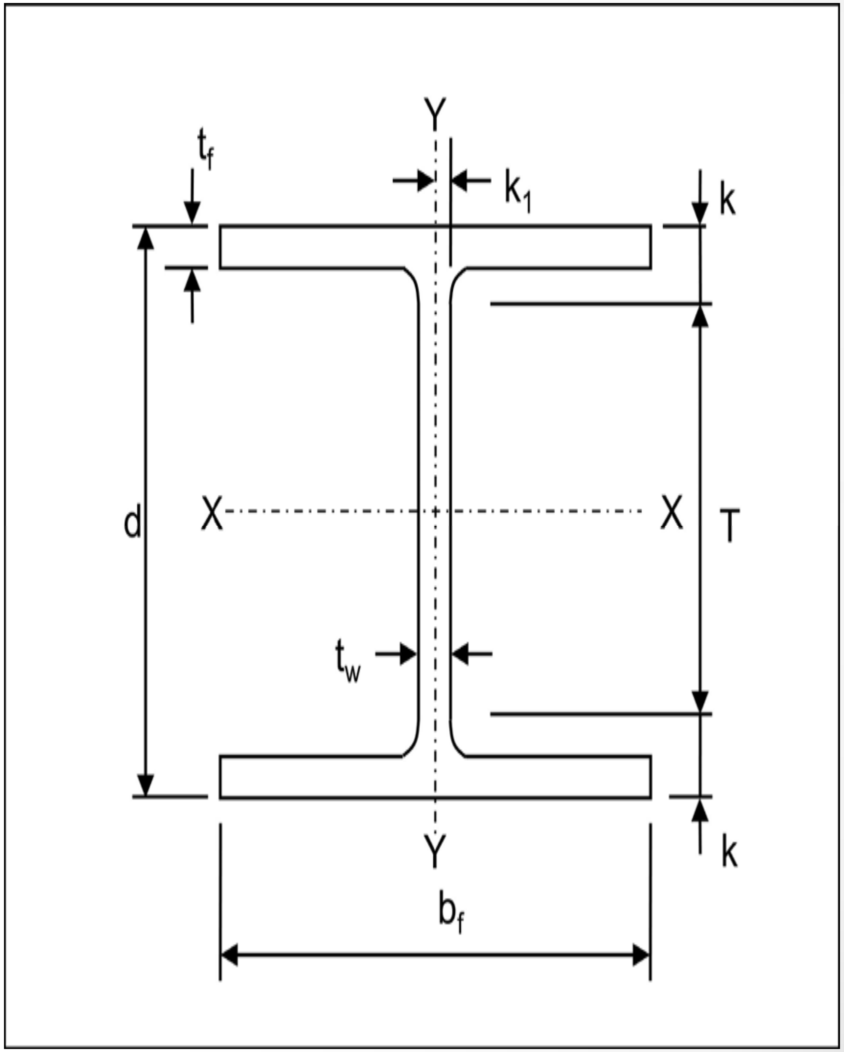
H-Piles



- Similar to WF beams used in structural applications but flanges and webs are of equal thickness with H-beams
- Often used as end bearing piles in rock

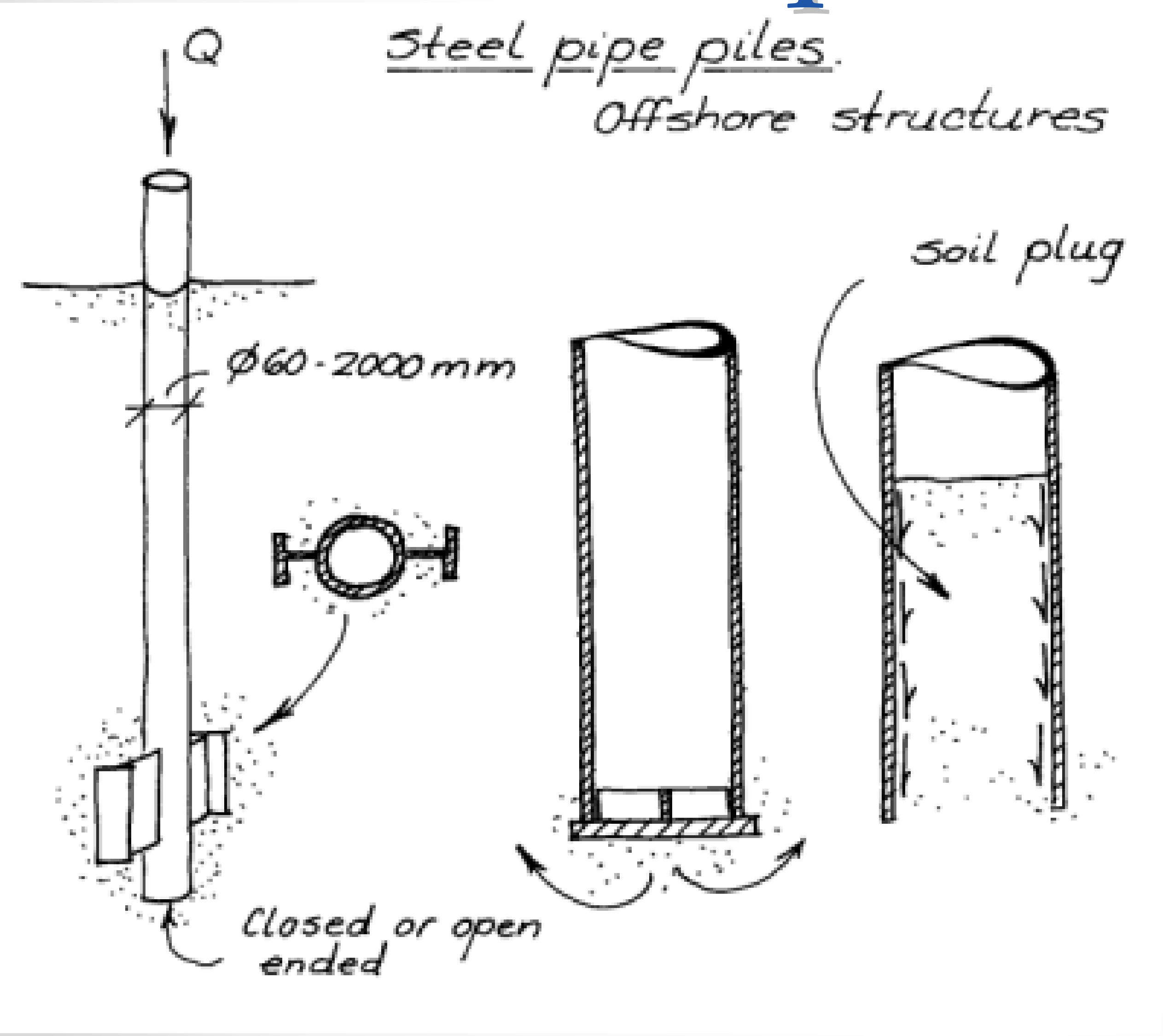
H-Pile Chart

Section	Weight	Area	Depth	Flange Width	Thickness		Properties							
							X- Axis				Y-Axis			
			d	b_f	Web t_w	Flange t_f	I	Z	S	r	I	Z	S	r
	lb/ft	in^2	in	in	in	in	in^4	in^3	in^3	in	in^4	in^3	in^3	in
HP8X36	36	10.6	8.02	8.16	0.445	0.445	119	33.6	29.8	3.36	40.3	15.2	9.9	1.95
HP10X42	42	12.4	9.70	10.10	0.420	0.415	210	48.3	43.4	4.13	71.7	21.8	14.2	2.41
HP10X57	57	16.7	9.99	10.20	0.565	0.565	294	66.5	58.8	4.18	101	30.3	19.7	2.45
HP12X53	53	15.5	11.80	12.00	0.435	0.435	393	74.0	66.7	5.03	127	32.2	21.1	2.86
HP12X63	63	18.4	11.90	12.10	0.515	0.515	472	88.3	79.1	5.06	153	38.7	25.3	2.88
HP12X74	74	21.8	12.10	12.20	0.610	0.605	569	105.0	93.8	5.11	186	46.6	30.4	2.92
HP12X84	84	24.6	12.30	12.30	0.685	0.685	650	120.0	106.0	5.14	213	53.2	34.6	2.94
HP12x89	89	25.9	12.36	12.32	0.720	0.720	689	126.3	111.6	5.16	225	56.2	36.5	2.94
HP12X102	102	29.9	12.56	12.64	0.819	0.819	811	147.6	129.3	5.20	276	67.1	43.7	3.04
HP12X117	117	34.4	12.76	12.87	0.929	0.929	946	170.8	148.2	5.24	331	79.3	51.4	3.11
HP14X73	73	21.4	13.60	14.60	0.505	0.505	729	118	107	5.84	261	54.6	35.8	3.49
HP14X89	89	26.1	13.80	14.70	0.615	0.615	904	146	131	5.88	326	67.7	44.3	3.53
HP14X102	102	30.1	14.00	14.80	0.705	0.705	1050	169	150	5.92	380	78.8	51.4	3.56
HP14X117	117	34.4	14.20	14.90	0.805	0.805	1220	194	172	5.96	443	91.4	59.5	3.59
HP16X88	88	25.8	15.30	15.70	0.540	0.540	1110	161	145	6.56	349	68.2	44.5	3.68
HP16X101	101	29.9	15.50	15.80	0.625	0.625	1300	187	168	6.59	412	80.1	52.2	3.71
HP16X121	121	35.8	15.80	15.90	0.750	0.750	1590	226	201	6.66	504	97.6	63.4	3.75
HP16X141	141	41.7	16.00	16.00	0.875	0.875	1870	264	234	6.70	599	116.0	74.9	3.79
HP16X162	162	47.7	16.30	16.10	1.000	1.000	2190	306	269	6.78	697	134.0	86.6	3.82
HP16X183	183	54.1	16.50	16.30	1.130	1.130	2510	349	304	6.81	818	156.0	100.0	3.89
HP18X135	135	39.9	17.50	17.80	0.750	0.750	2200	281	251	7.43	706	122.0	79.3	4.21
HP18X157	157	46.2	17.70	17.90	0.870	0.870	2570	327	290	7.46	833	143.0	93.1	4.25
HP18X181	181	53.2	18.00	18.00	1.000	1.000	3020	379	336	7.53	974	167.0	108.0	4.28
HP18X204	204	60.2	18.30	18.10	1.130	1.130	3480	433	380	7.60	1120	191.0	124.0	4.31



From Skyline Steel

Pipe Piles


Q
Steel pipe piles.
Offshore structures
Ø60-2000mm
soil plug
Closed or open ended

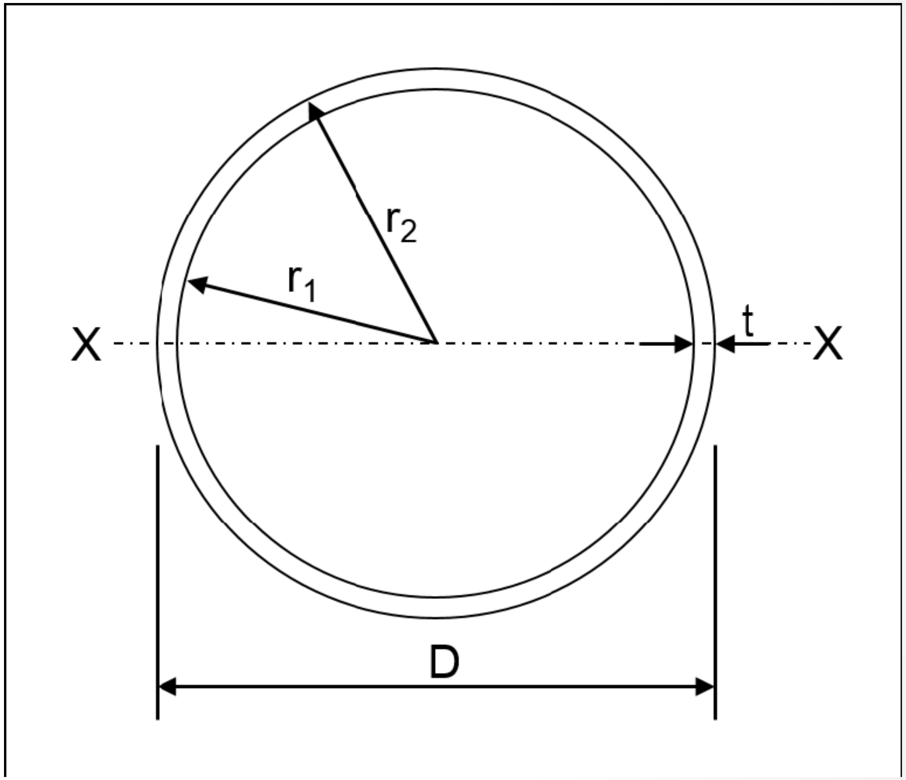
Pipe Piles and Steel Pile Materials

Table 8-1 Common Steel Pipe Pile Grades and Yield Stress

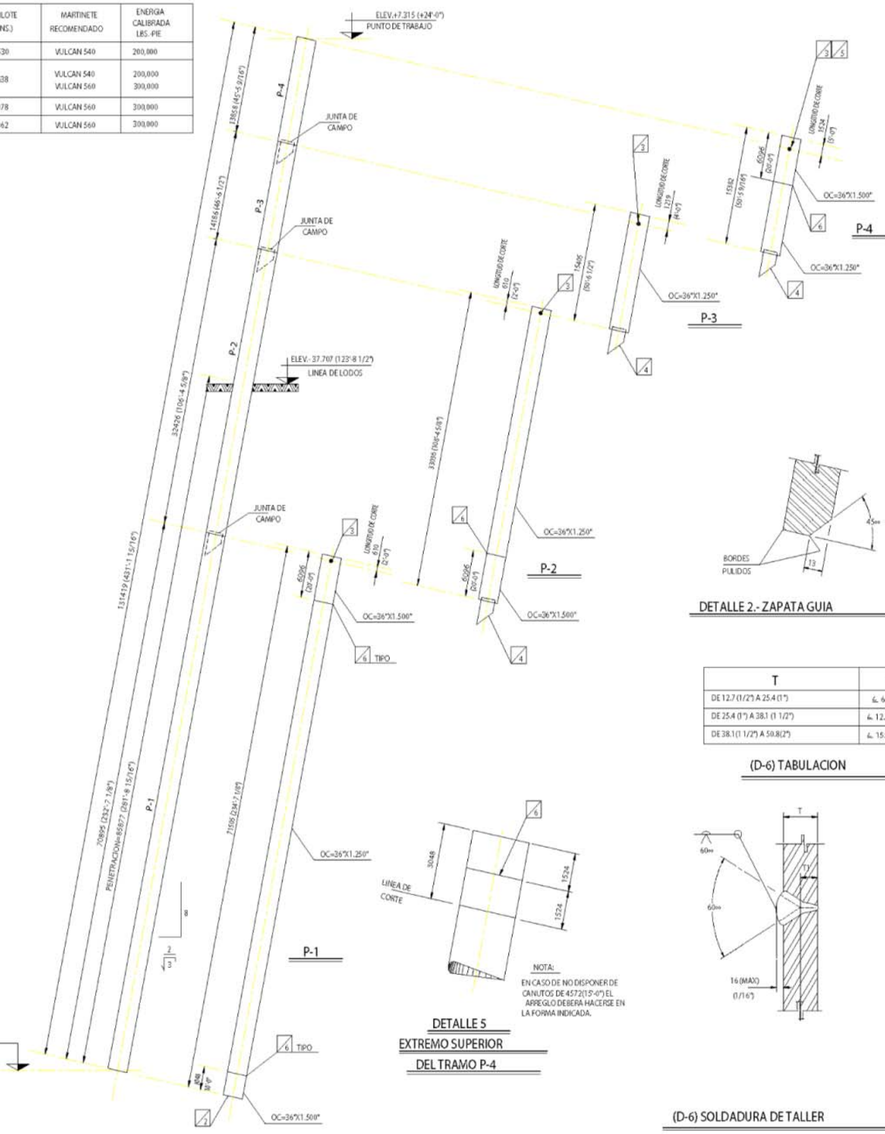
Designation/Grade	Yield Stress, F_y, ksi
ASTM A-252 Grade 2	35
ASTM A-252 Grade 3	45
ASTM A-252 Grade 3 (Mod)	50-80

Table 8-2 Common Steel H-pile Grades and Yield Stress

Designation/Grade	Yield Stress, F_y, ksi
A-36	36
ASTM A-572-50	50
ASTM A-572-60	60



TRAMO	PESO PILOTE (TONS.)	MARTINETE RECOMENDADO	ENERGIA CALIBRADA LBS.-PIE
P-1	51.530	VULCAN 540	200,000
P-2	27.638	VULCAN 540 VULCAN 560	200,000 300,000
P-3	11.078	VULCAN 560	300,000
P-4	11.062	VULCAN 560	300,000



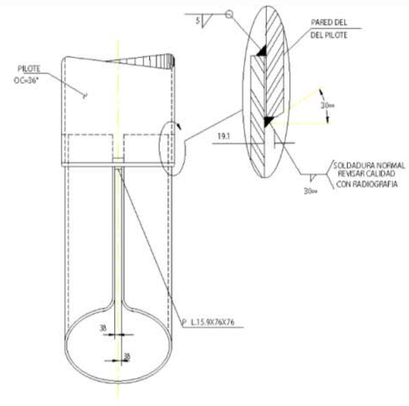
(D-1) ELEVACION

DETALLE 1-. ARREGLO DE PILOTE EN EJES ①, ②, ③

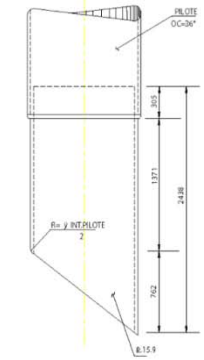
DETALLE 2.- ZAPATA GUIA

NOTA:
EN CASO DE NO DISPONER DE CANUTOS DE 4572(15'-0") EL ARREGLO DEBERA HACERSE EN LA FORMA INDICADA.

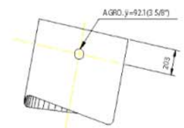
DETALLE 5
EXTREMO SUPERIOR
DEL TRAMO P-4



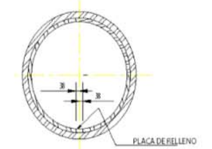
(D-4) ELEVACION



(D-4) VISTA LATERAL

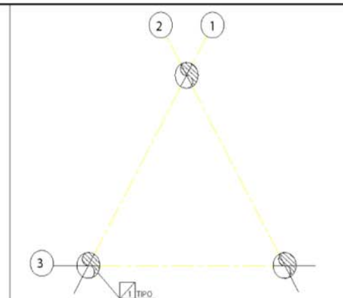


DETALLE 3.- AGUJERO
PARA IZAJE



(D-4) PLANTA

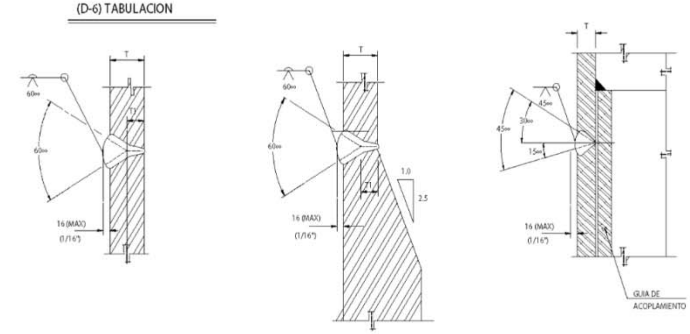
DETALLE 4.-GUIA DE ACOPLAMIENTO



PLANTA DE LOCALIZACION

T	T1
DE 12.7 (1/2") A 25.4 (1")	6.3 (1/4")
DE 25.4 (1") A 38.1 (1 1/2")	12.7 (1/2")
DE 38.1 (1 1/2") A 50.8 (2")	15.9 (5/8")

(D-6) TABULACION



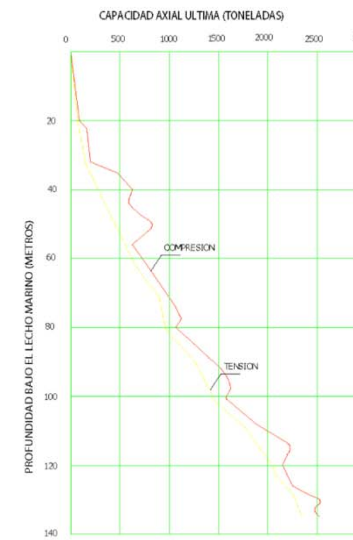
(D-6) SOLDADURA DE TALLER
PARA ESPESORES IGUALES

(D-6) SOLDADURA DE TALLER
PARA ESPESORES DIFERENTES

(D-6) SOLDADURA DE CAMPO
PARA ESPESORES IGUALES

DETALLE-.6 PREPARACION DE JUNTAS DE CAMPO PARA PILOTES

SIMBOLOGIA
(TIPOS DE ACERO)
A.S.T.M. A-36



CURVA DE CAPACIDAD AXIAL ULTIMA
DIAMETRO DEL PILOTE 36"

(ESTUDIO GEOESTADISTICO ELABORADO Y CORRELACIONADO CON ESTUDIO GEOTECNICO ABKATUN B)

NOTAS:

1.- PARA OTRAS NOTAS GENERALES Y LISTA DE MATERIALES VER DIB. 00196 M
2.- EN CADA UNO DE LOS TRAMOS DE PILOTE SE DEBERA INDICAR EL NUMERO DE TRAMO,PESO LONGITUD Y EL PILOTE AL QUE CORRESPONDE.
3.- EL IZAJE DEL TRAMO DEL PILOTE P-1 DURANTE LA INSTALACION SE DEBERA EFECTUAR SUJETANDOLO A UNA LONGITUD DE 60' RESPECTO A LA CABEZA.
4.- EL FABRICANTE PROVEERA AL CONTRATISTA DE INSTALACION DE UNA PLANTILLA PARA CORTAR LA PARTE SUPERIOR DE PILOTE AL FINALIZAR EL HINCADO.
5.- DURANTE LA INSTALACION SE DEBERA CONTAR CON EL APOYO DE UN GEOTECNISTA PARA RESOLVER PROBLEMAS DE RECHAZO PREMATURO, DEBIDO A LA ALTA COMPACIDAD DE LAS ARENAS EN ESE CAMPO

PRELIMINAR

NUMERO	DIBUJOS DE REFERENCIA	C.P.	FECHA
00196A	ELEVACION (TIPO)		
00196F	SUBESTRUCTURA Y CENTRADORES DE PILOTES		
00196M	PREPARACION PARA JUNTAS TUBULARES SOLDADAS		

REVISIONES

MCA.	DESCRIPCION	FECHA	POR	Vo.Bo.
A	PARA REVISION Y COMENTARIOS			

A	L.F.G.	E.C.S.	V.M.F.	E.C.S.	L.P.C.
REV.	ELABOR°	REVIS°	DIBUJ°	VERIFIC°	VALID°

FECHA / FIRMA / FECHA / FIRMA

APROBADO POR:
SUBGERENTE DE MAO
SUPERINTENDENTE DE BASES EV. T.I.C., F.I.
SUPERVISOR

"INGENIERIA PARA PUENTE ENTRE PLATAFORMA ABK-A HABITACIONAL Y LA PLATAFORMA ABK-B, PARA INSTALACION EN ABK-B DE EQUIPO SUPERFICIAL PARA EL SISTEMA BEC"

PETROLEOS MEXICANOS
PROY. PEMEX No.
SONDA DE CAMPECHE — CONT. IMP. F.33771 — MEXICO

INSTITUTO MEXICANO DEL PETROLEO

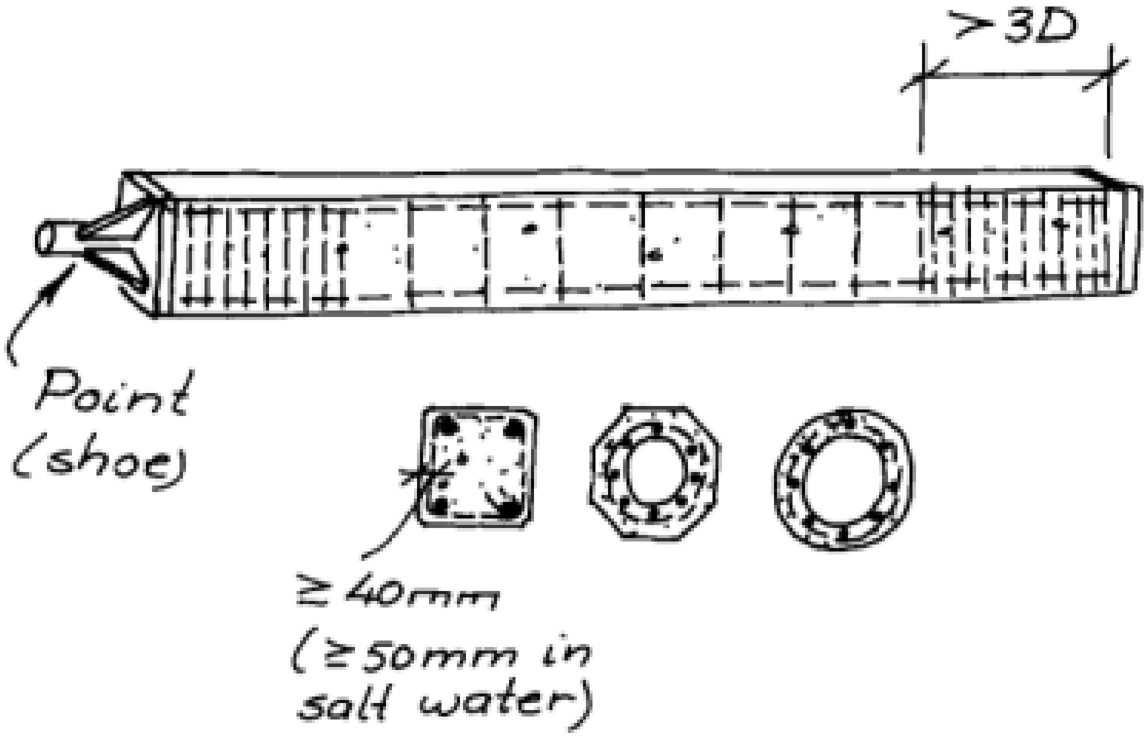
TRIPODE 1
SUBESTRUCTURA
ARREGLO GENERAL DE PILOTES

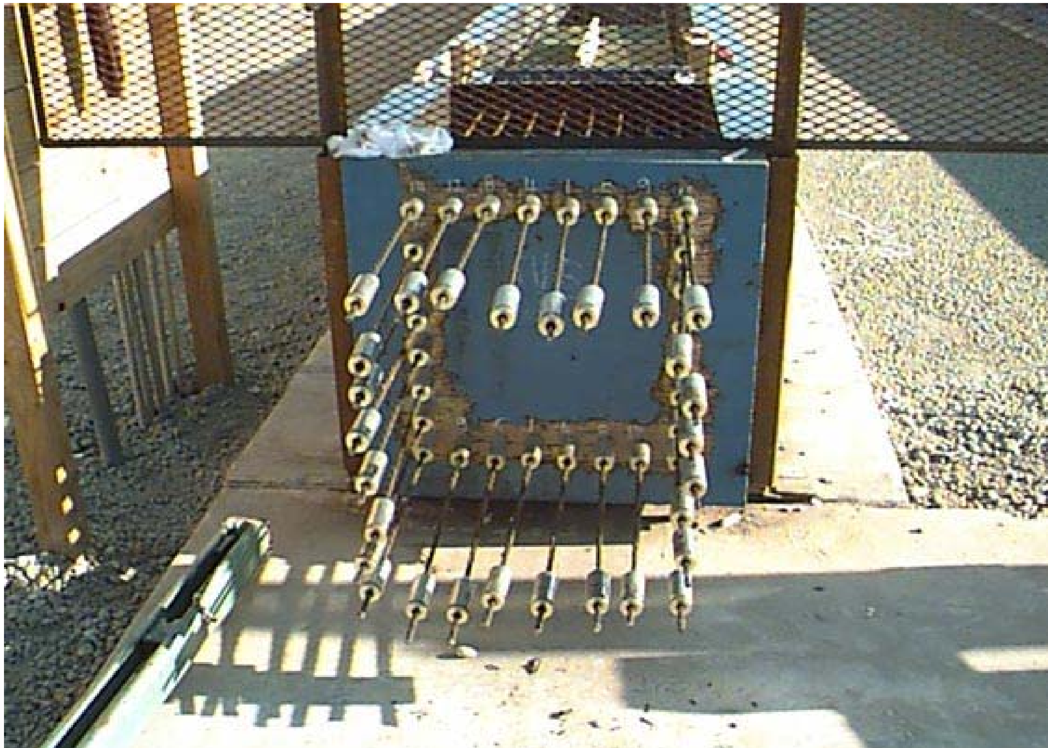
ESC.: SIN
ACOT.: mm.
Dib. No. N-F.33771-1815-00196 E
REV. A

PS-IN-F-515-1-01-08 REV. 3

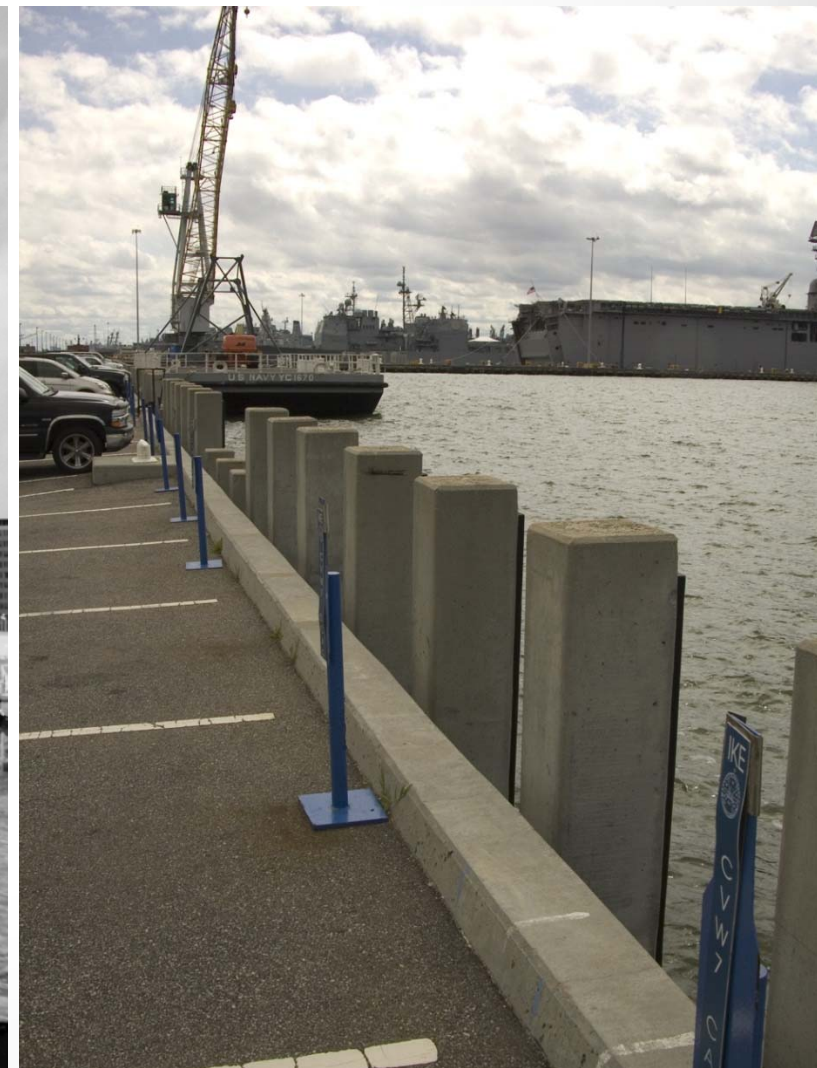
Concrete Piles

- Either precast or prestressed piles
  - Precast contain rebar similar to shallow foundations – not commonly used in North America
  - Prestressed uses cables tensioned before concrete is poured





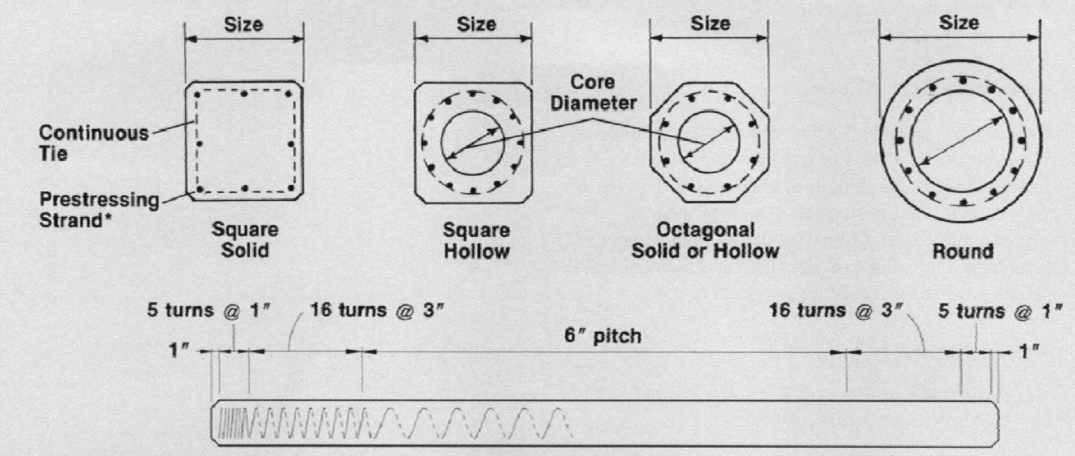
Square Concrete Piles



Concrete Cylinder Piles

Square and Cylinder Pile Specifications

Table 2.4. Section properties and allowable service loads of prestressed concrete piles.



* Strand pattern may be circular or square.

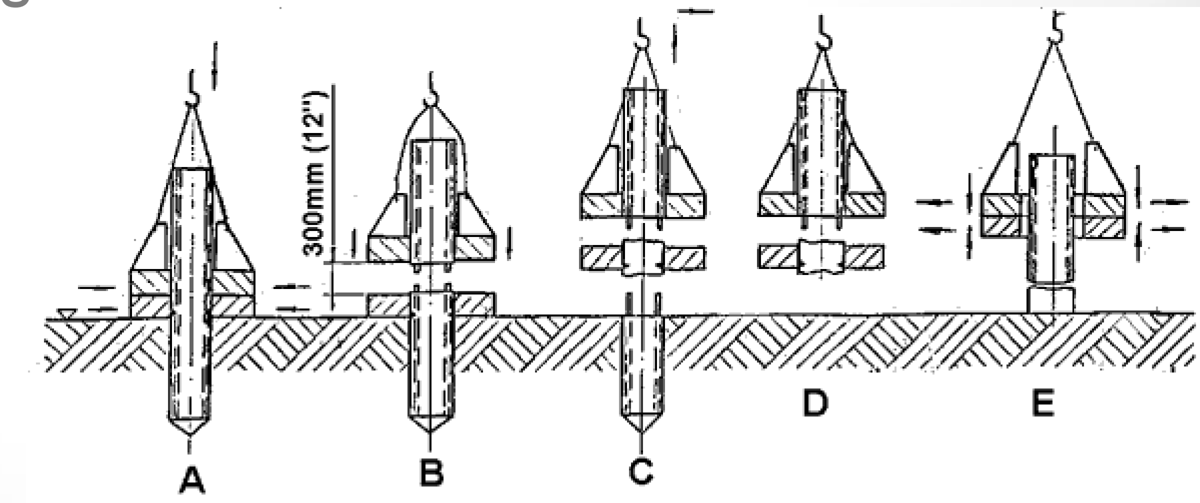
Typical Elevation

Size (in.)	Core Diameter (in.)	Section Properties(1) Area (in.²)	Weight (plf)	Moment of Inertia (in.⁴)	Section Modulus (in.³)	Radius of Gyration (in.)	Perimeter (ft)	Allowable Concentric Service Load, Tons(2) f'_c 5,000	6,000	7,000	8,000
Square Piles											
10	Solid	100	104	833	167	2.89	3.33	73	89	106	122
12	Solid	144	150	1,728	288	3.46	4.00	105	129	152	176
14	Solid	196	204	3,201	457	4.04	4.67	143	175	208	240
16	Solid	256	267	5,461	683	4.62	5.33	187	229	271	314
18	Solid	324	338	8,748	972	5.20	6.00	236	290	344	397
20	Solid	400	417	13,333	1,333	5.77	6.67	292	358	424	490
20	11 in.	305	318	12,615	1,262	6.43	6.67	222	273	323	373
24	Solid	576	600	27,648	2,304	6.93	8.00	420	515	610	705
24	12 in.	463	482	26,630	2,219	7.58	8.00	338	414	491	567
24	14 in.	422	439	25,762	2,147	7.81	8.00	308	377	447	517
24	15 in.	399	415	25,163	2,097	7.94	8.00	291	357	423	488
30	18 in.	646	672	62,347	4,157	9.82	10.00	471	578	685	791
36	18 in.	1,042	1,085	134,815	7,490	11.38	12.00	761	933	1,105	1,276
Octagonal Piles											
10	Solid	83	85	555	111	2.59	2.76	60	74	88	101
12	Solid	119	125	1,134	189	3.09	3.31	86	106	126	145
14	Solid	162	169	2,105	301	3.60	3.87	118	145	172	198
16	Solid	212	220	3,592	449	4.12	4.42	154	189	224	259
18	Solid	268	280	5,705	639	4.61	4.97	195	240	284	328
20	Solid	331	345	8,770	877	5.15	5.52	241	296	351	405
20	11 in.	236	245	8,050	805	5.84	5.52	172	211	250	289
22	Solid	401	420	12,837	1,167	5.66	6.08	292	359	425	491
22	13 in.	268	280	11,440	1,040	6.53	6.08	195	240	283	328
24	Solid	477	495	18,180	1,515	6.17	6.63	348	427	506	584
24	15 in.	300	315	15,696	1,308	7.23	6.63	219	268	318	368
Round Piles											
36	26 in.	487	507	60,007	3,334	11.10	9.43	355	436	516	596
42	32 in.	581	605	101,273	4,823	13.20	11.00	424	520	616	712
48	38 in.	675	703	158,222	6,592	15.31	12.57	493	604	715	827
54	44 in.	770	802	233,373	8,643	17.41	14.14	562	689	816	943
66	54 in.	1,131	1,178	514,027	15,577	21.32	17.28	826	1,013	1,199	1,386

(1) Form dimensions may vary with producers, with corresponding variations in section properties.
(2) Allowable loads based on $N = A_c\,(0.33 f'_c - 0.27 f_{pc})$; $f_{pc} = 700$ psi. Check local producer for available concrete strengths.

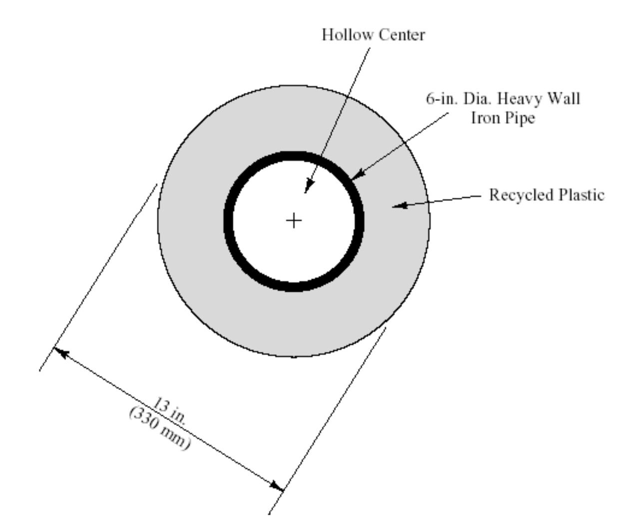
Cutting Concrete Piles

- Can be cut with concrete saws or special pile cutters
- Usually best to drive as friction piles where refusal is not as likely to take place



Composite Piles

- Two possible definitions
  - Pile made up of two other pile types, such as a concrete pile with an H-pile "stinger" on the end
  - Pile made up of two materials
- Plastic-steel composite
  - A useful substitute for wood piles in applications where wood is environmentally unacceptable



Typical Capacities and Lengths of Driven Pile Types

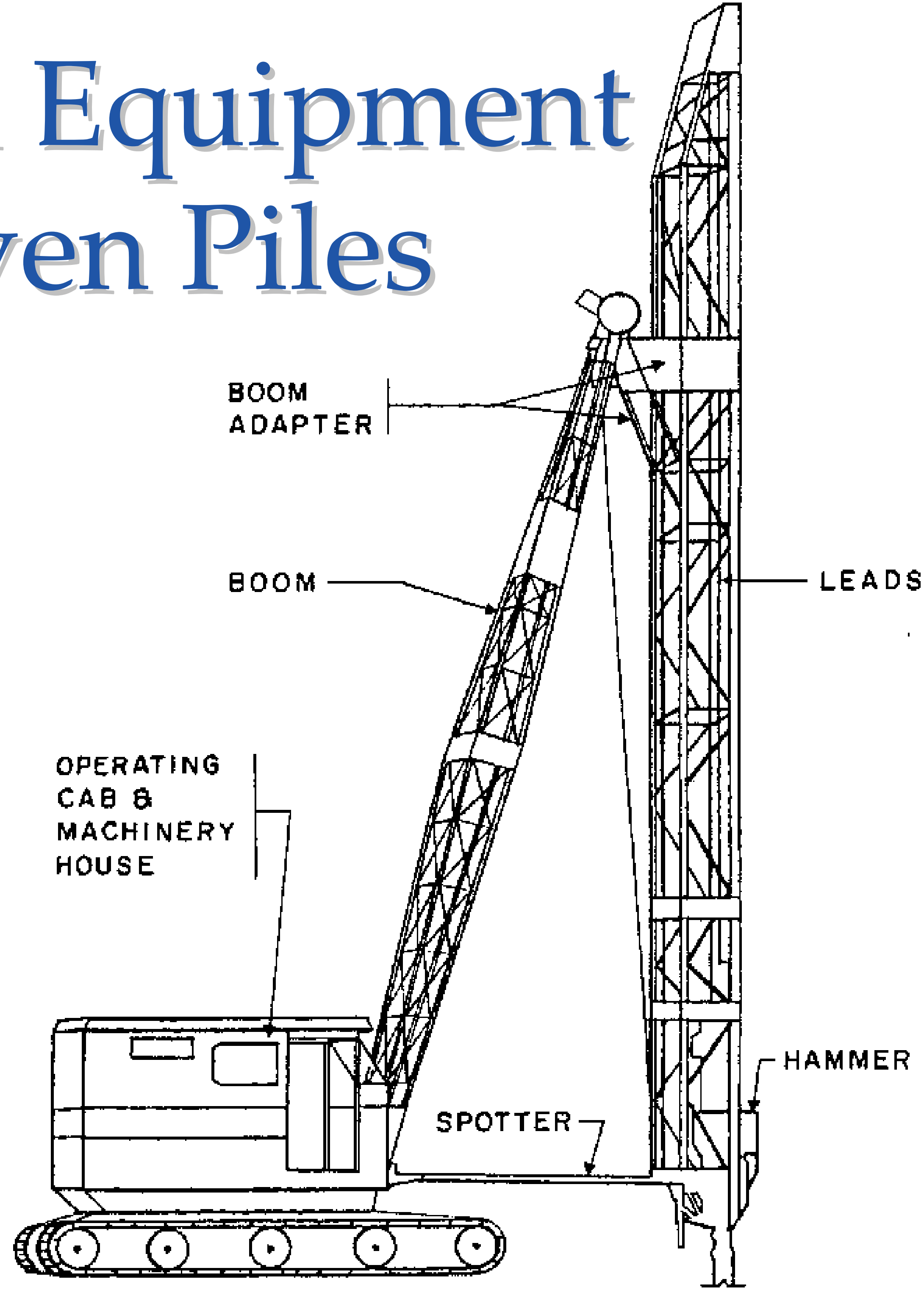
Table 9-2

Typical piles and their range of loads and lengths

Type of Pile	Typical Axial Design Loads	Typical Lengths
Timber	20-110 kips (100 – 500 kN)	15-120 ft (5-37 m)*
Precast / Prestressed Reinforced Concrete	90-225 kips (400-1,000 kN) for reinforced 90-1000 kips (400-4,500 kN) for prestressed	30-50 ft (10-15m) for reinforced 50-130 ft (15-40m) for prestressed
Steel H	130-560 kips (600-2,500 kN)	15-130 ft (5-40 m)
Steel Pipe (without concrete core)	180-560 kips (800-2,500 kN)	15-130 ft (5-40 m)
Steel Pipe (with concrete core)	560-3400 kips (2,500-15,000 kN)	15-130 ft (5-40 m)
* 15-75 ft (5-23 m) for Southern Pine; 15-120 ft (5-37 m) for Douglas Fir		

Installation Equipment for Driven Piles

- Pile Driving Rigs
- Pile Hammers
- Hammer Accessories
  - Leaders
  - Cushion Material
- Predrilling, Jetting and Spudding

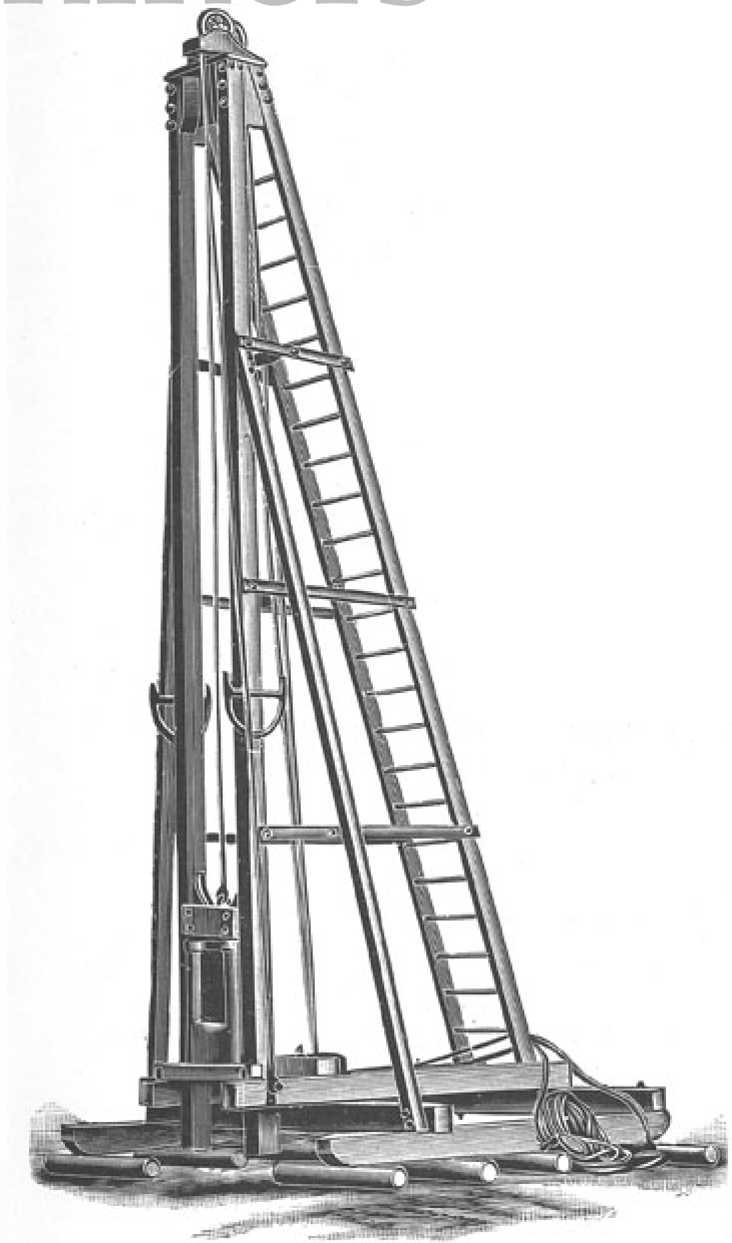


Pile Hammers

- Impact Hammers
  - Drop Hammers
  - Air/Steam Hammers
  - Diesel Hammers
  - Hydraulic Hammers
- Vibratory Hammers
- Pile Jacking Devices

Drop Hammers

- Oldest type of hammer in use
- Simply raised by the crane (or hoist) and released to impact the pile top
- A very simple hammer, yet slow and efficiency is inconsistent

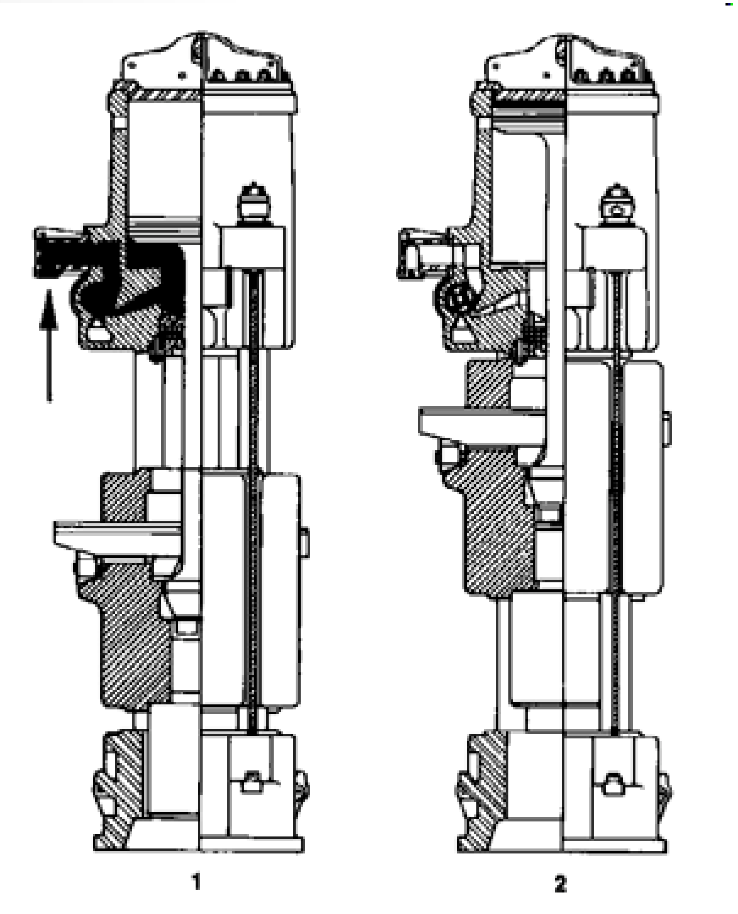


Air/Steam Hammers

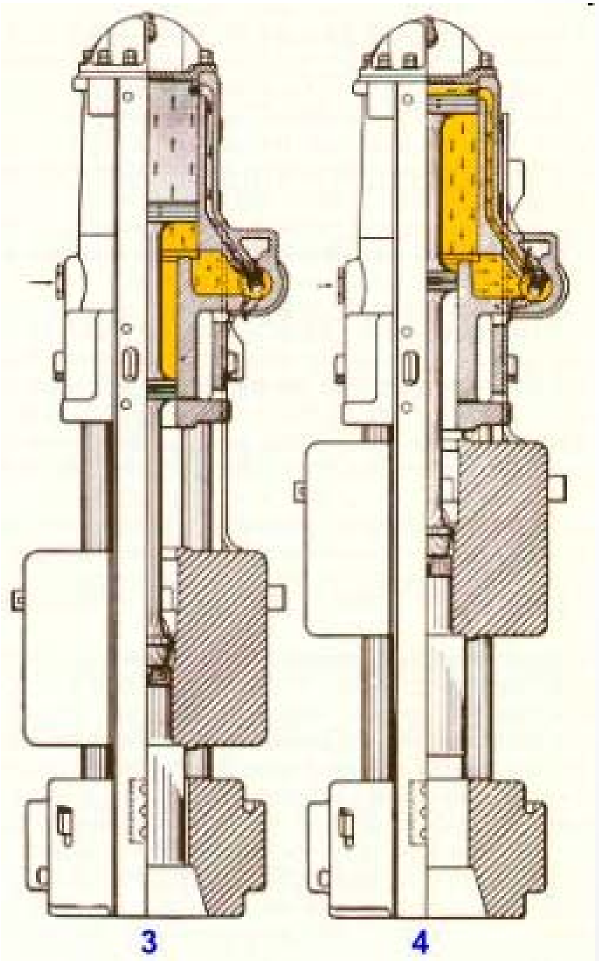
- In use since the nineteenth century
- Hammers are simple; require little maintenance and are of long duration
- Efficiency also variable due to age of hammers and conditions of operation
- Hammers can be single, double or differential acting

Air/Steam Cycles

- Single-Acting (No Downward Assist)



- Differential or Double-Acting (Downward assist)



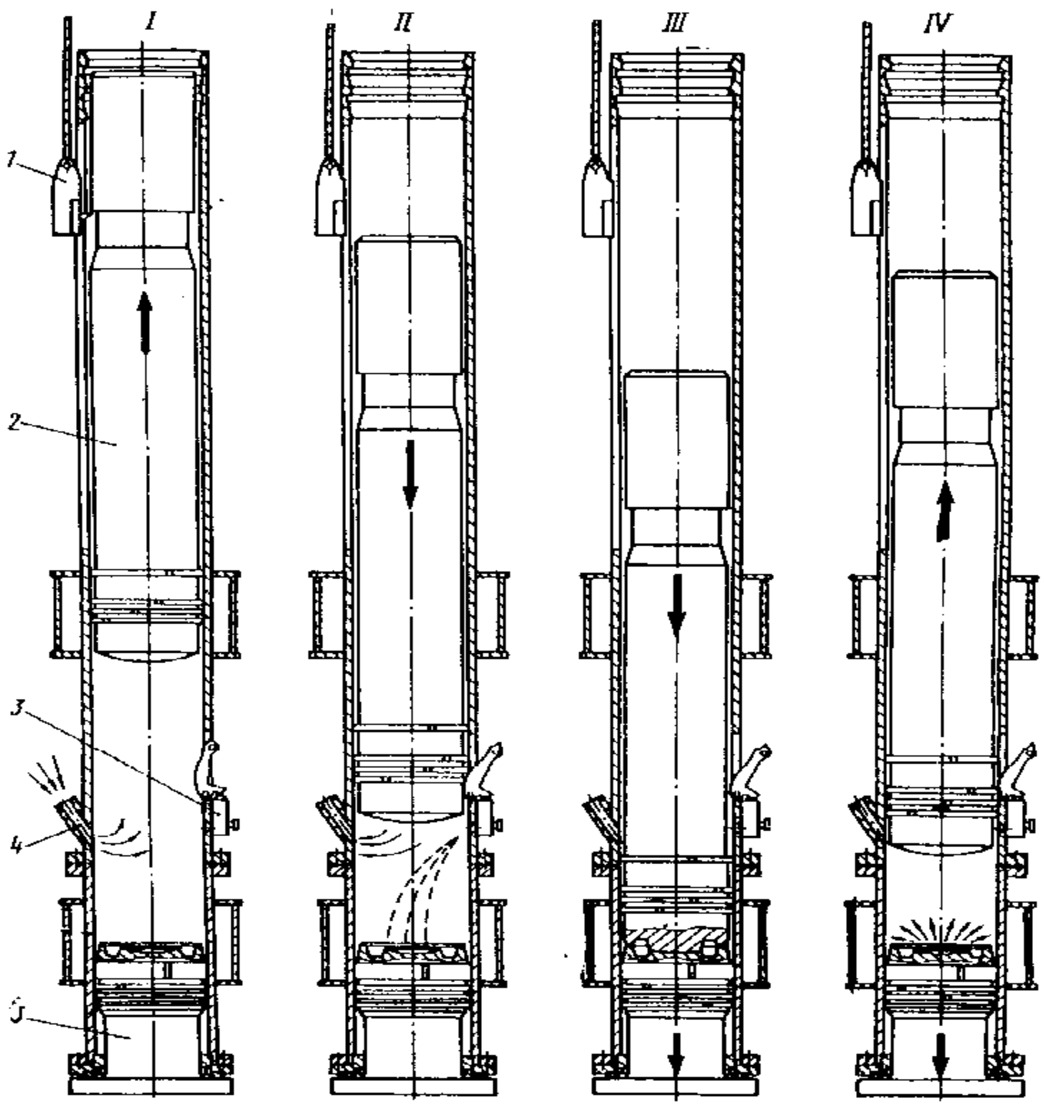
http://www.youtube.com/watch?v=eLsnYKUBgD8

Diesel Hammers

- Developed in Germany between the two World Wars
- Does not require an external power source; usually light
- Can also be single-acting or double-acting

Operating Cycle of Diesel Hammers

- Upstroke or starting of the hammer with starting device (crab)
- Lowering of ram; injection of fuel
- Combustion at bottom of stroke
- Fuel ignition and upward lifting of ram



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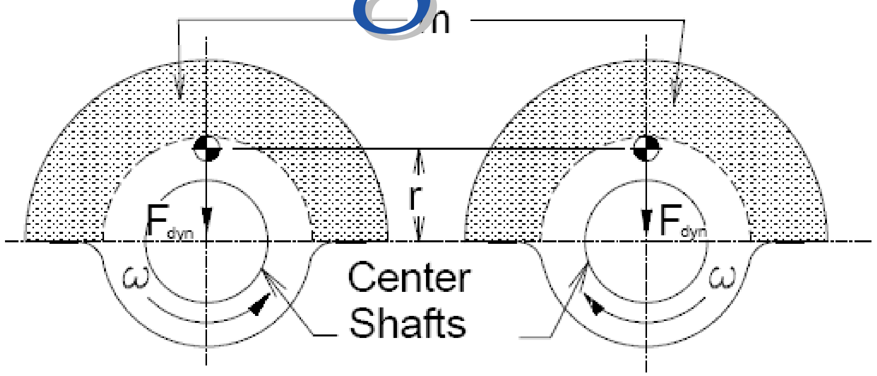
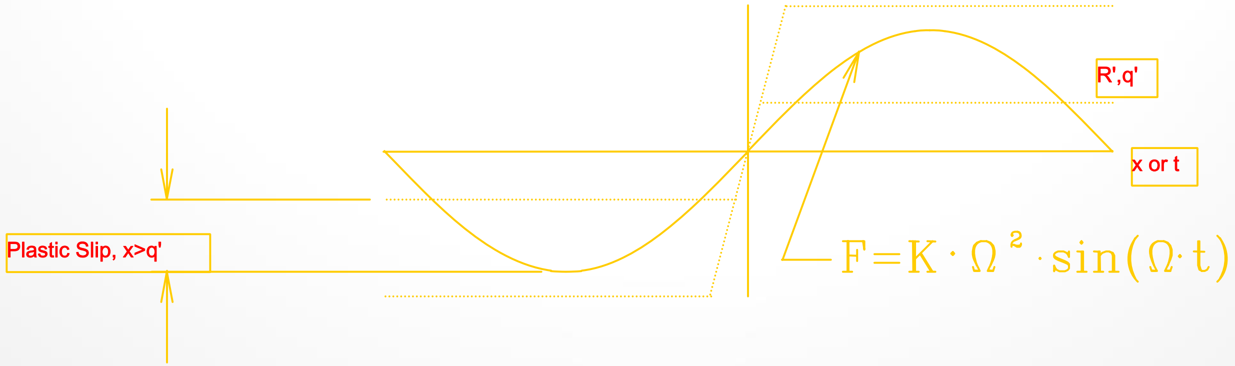
Hydraulic Impact Hammers

Vibratory Hammers

Operating Principle



- Vibratory hammers apply a rapidly alternating force to the pile by rotating eccentric weights about horizontal shafts
- Each eccentric produces centrifugal, dynamic force acting in a single plane and directed toward the centerline of the shaft
- The eccentrics are paired so the horizontal forces cancel each other, leaving only vertical force for the pile



Original Development and Soviet Equiment

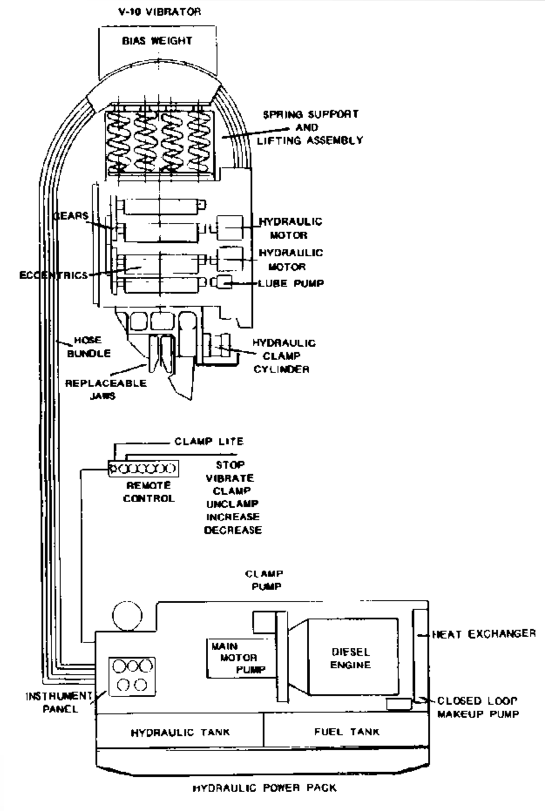
- Soviet B-402 pile driver
  - Dynamic force, 270 kN
  - Maximum eccentric moment, 12 kg-m
  - Rotation frequency, 23.8 Hz
- Driving sheet piling in Leningrad (St. Petersburg)

- First job in the USSR -- Gorki hydroelectric development, 1949
  - Model BT-5
    - Dynamic Force, 214 kN
    - Eccentric Frequency, 41.67 Hz
    - Power, 28 kW
  - Sheet Piles
    - 3700 sheet piles
    - 9-12 m long
    - 2-3 minutes driving time

Other Vibratory Hammers

- Japan
  - Nippei
  - Uraga
  - Tomen
- France
  - PTC
- Germany
  - Müller
  - MGF

- U.S.
  - MKT – first U.S. Vibratory (V-10)
  - Foster (PTC, then Nippei derived)
  - ICE (US and Europe)
  - Vulcan
  - HPSI
  - Ape

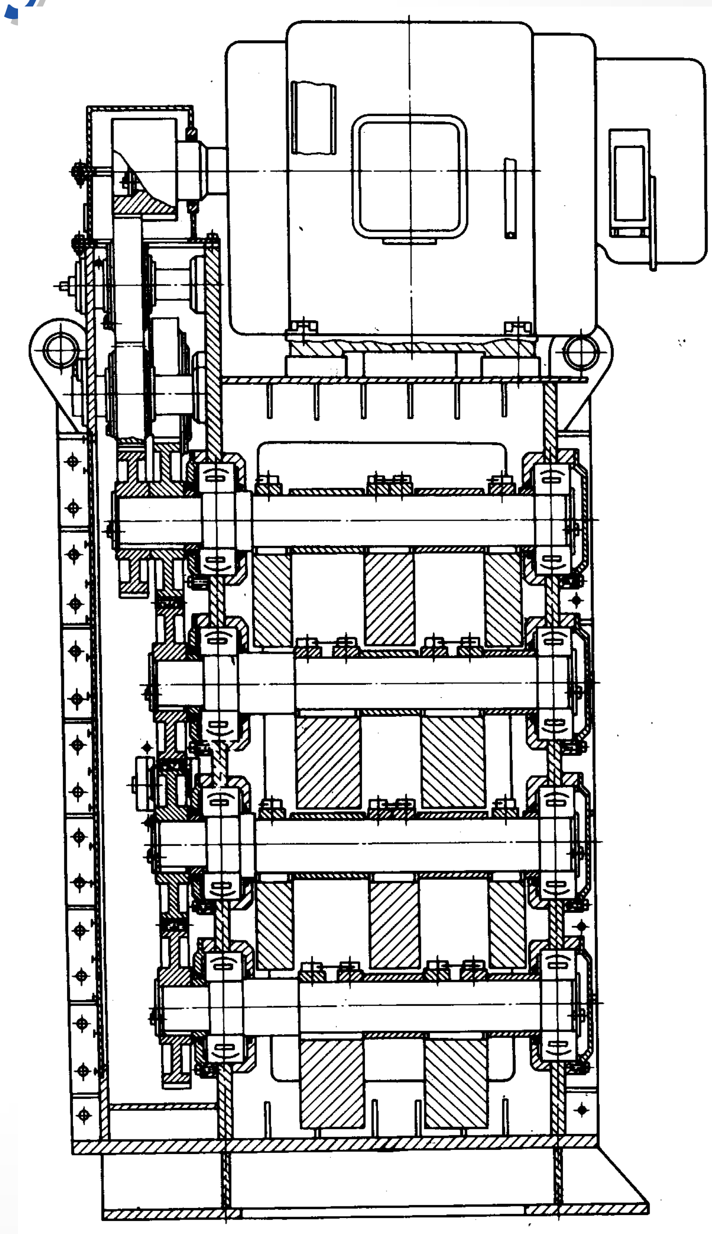


Basic Types of Vibratory Hammers

- Low frequency vibrators
- Medium frequency vibrators
- High frequency vibrators

Low Frequency Vibrators

- Characteristics
  - Vibration frequency of 5-10 Hz
  - Used with piles with high mass and toe resistance
  - Drive with high eccentric moments and amplitudes
- VPM-170
  - Dynamic force 1,700 kN
  - Frequency 9.17 hZ
  - Eccentric moment 510 kg-m



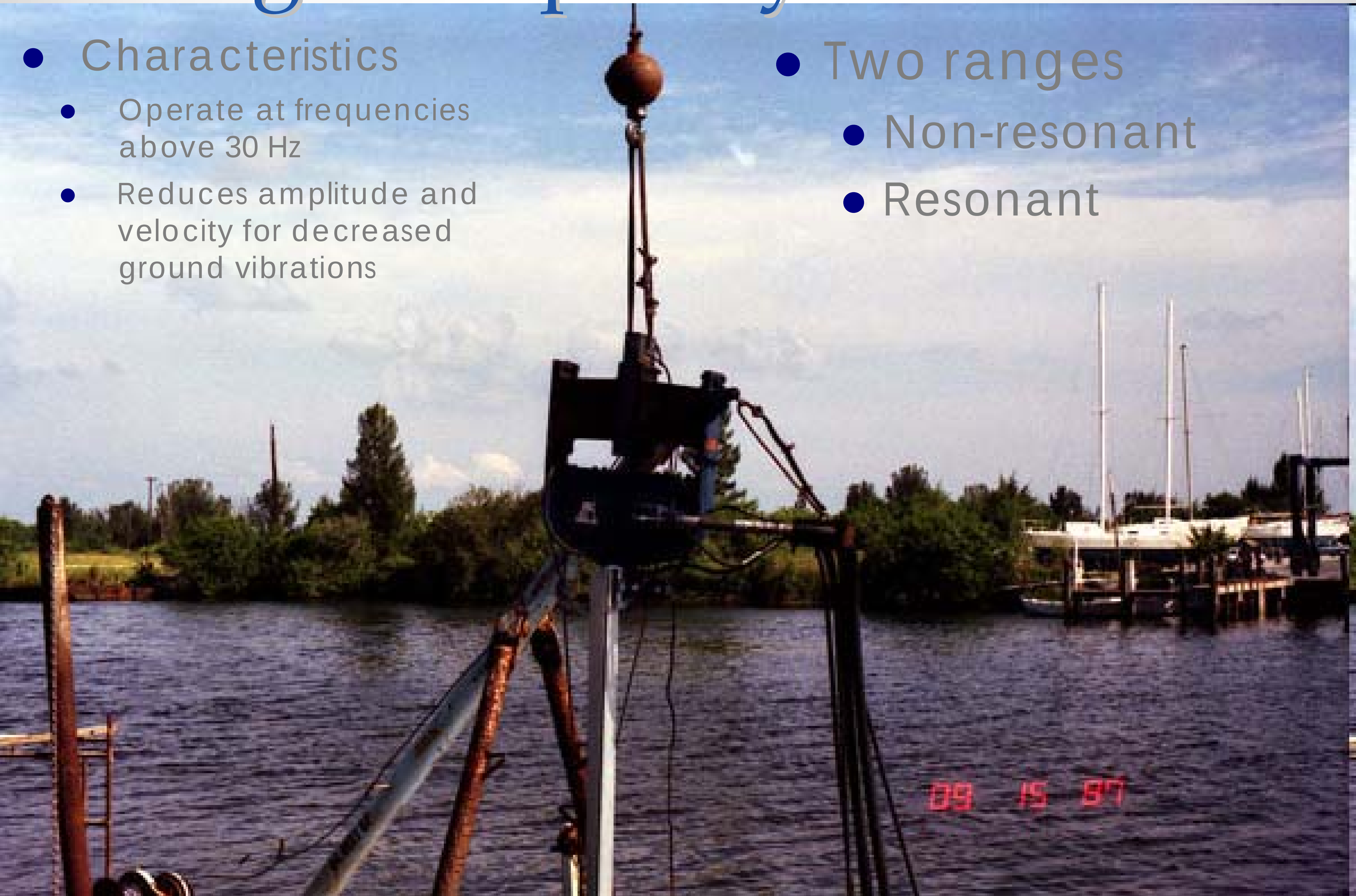
Medium Frequency Vibrators

- Characteristics
  - Frequency range – 10-30 Hz
  - Balance of frequency, eccentric moment and dynamic force needed to drive wide variety of piles
  - Most larger vibratories fall in this range

http://www.youtube.com/watch?v=L5xFptZbfTw

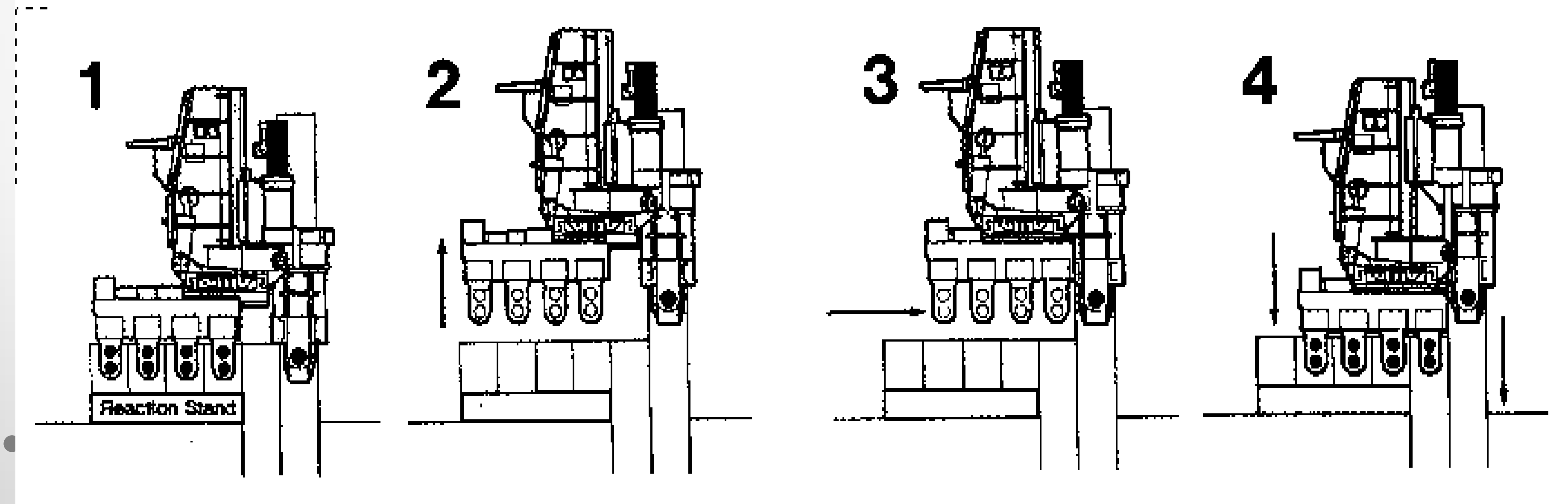
High Frequency Vibrators

- Characteristics
  - Operate at frequencies above 30 Hz
  - Reduces amplitude and velocity for decreased ground vibrations
- Two ranges
  - Non-resonant
  - Resonant

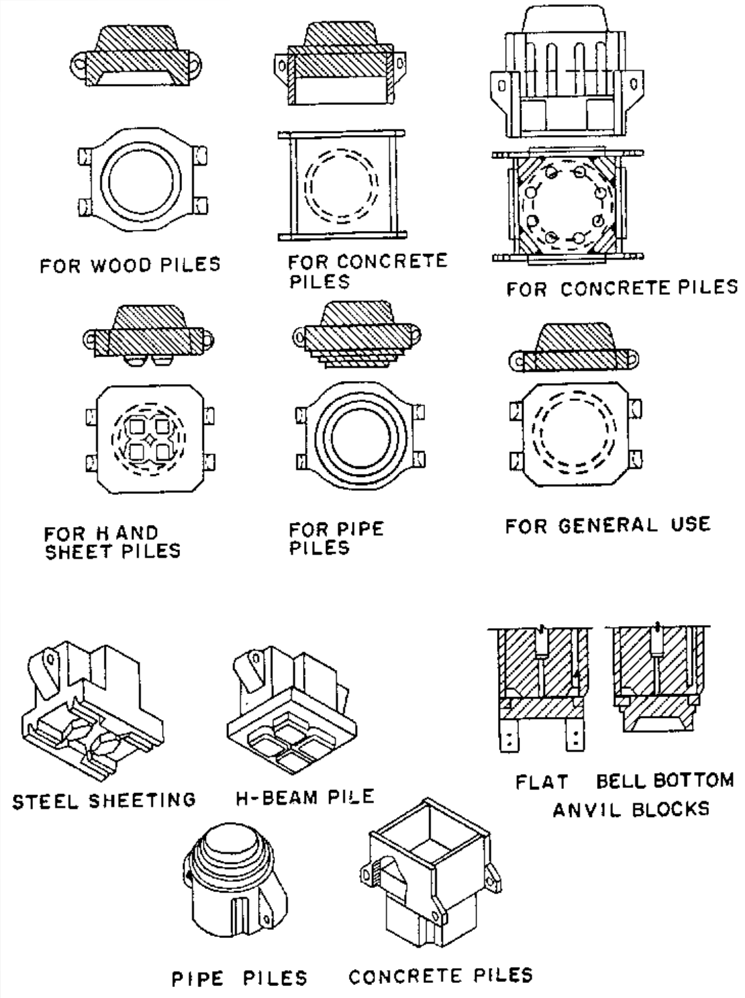


Pile Jacking Device

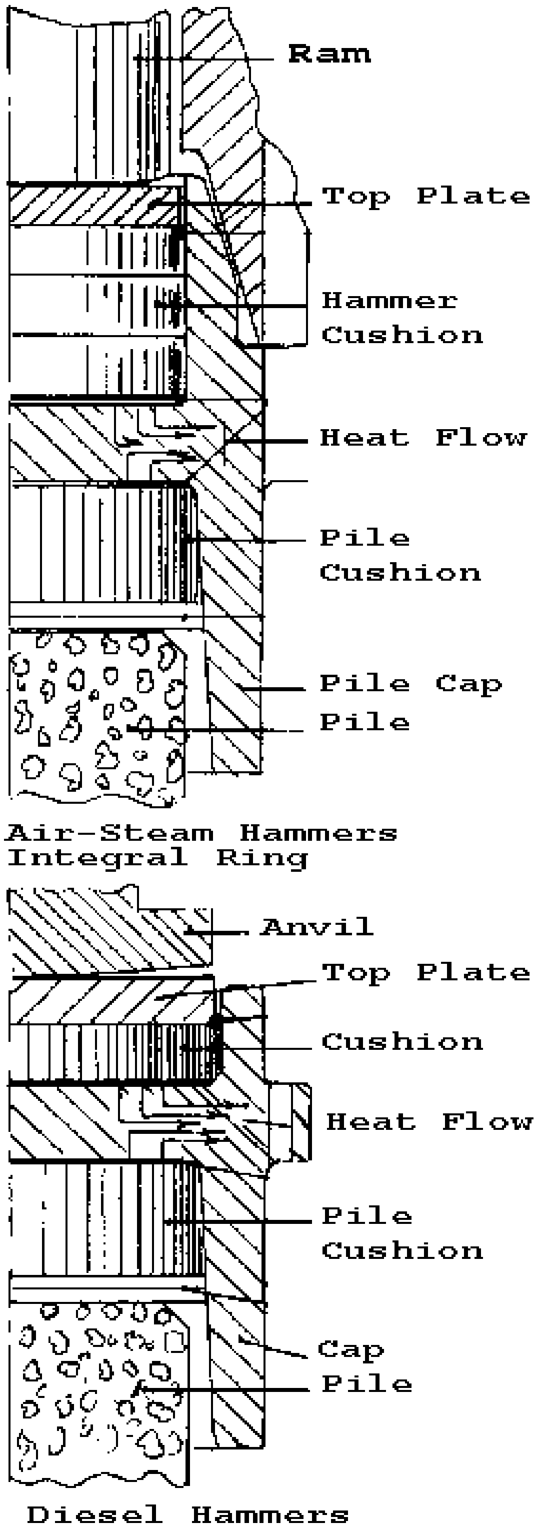
- Installs piling by pushing them into the soil, not impact
- Useful in situations where vibrations cannot be tolerated



Driving Accessories



- Drive Caps
  - Mate the hammer to the pile
  - Hold the cushion material in place
- Weight of the cap influences the energy transmission from the hammer to the pile



Cushion Material

- Hammer Cushion
  - Protects the hammer and modulates the blow
  - Usually struck via a top plate above
- Pile Cushion
  - Used only with concrete piles
  - Protects the pile from cracking and spalling

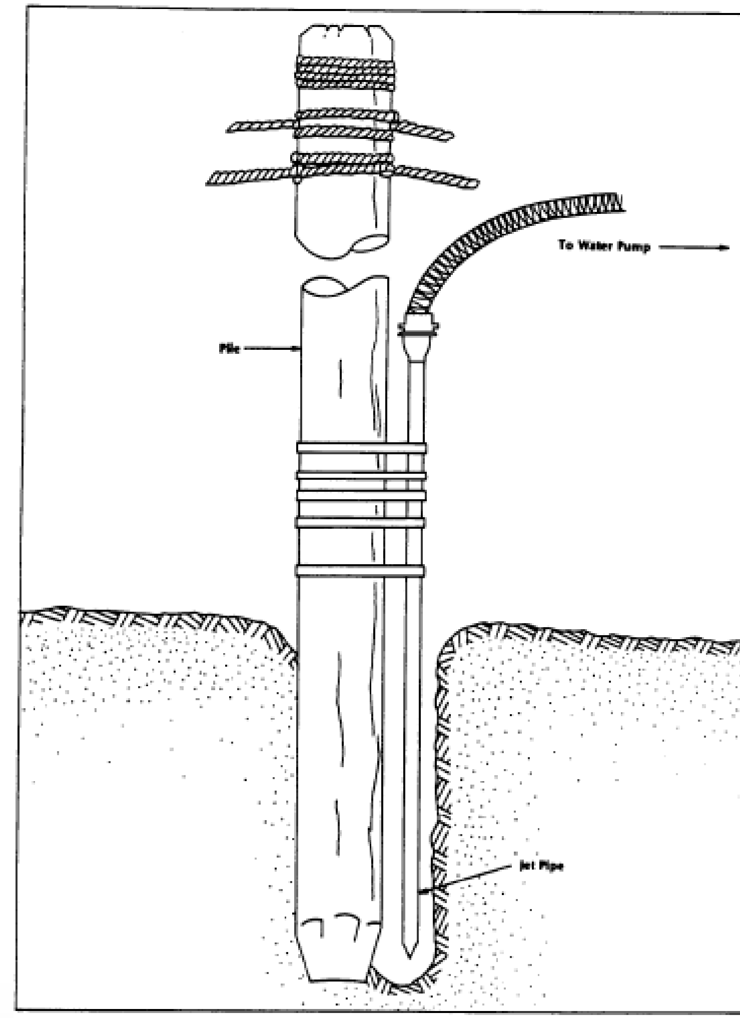
Leaders

Fixed Leaders

Swinging Leaders

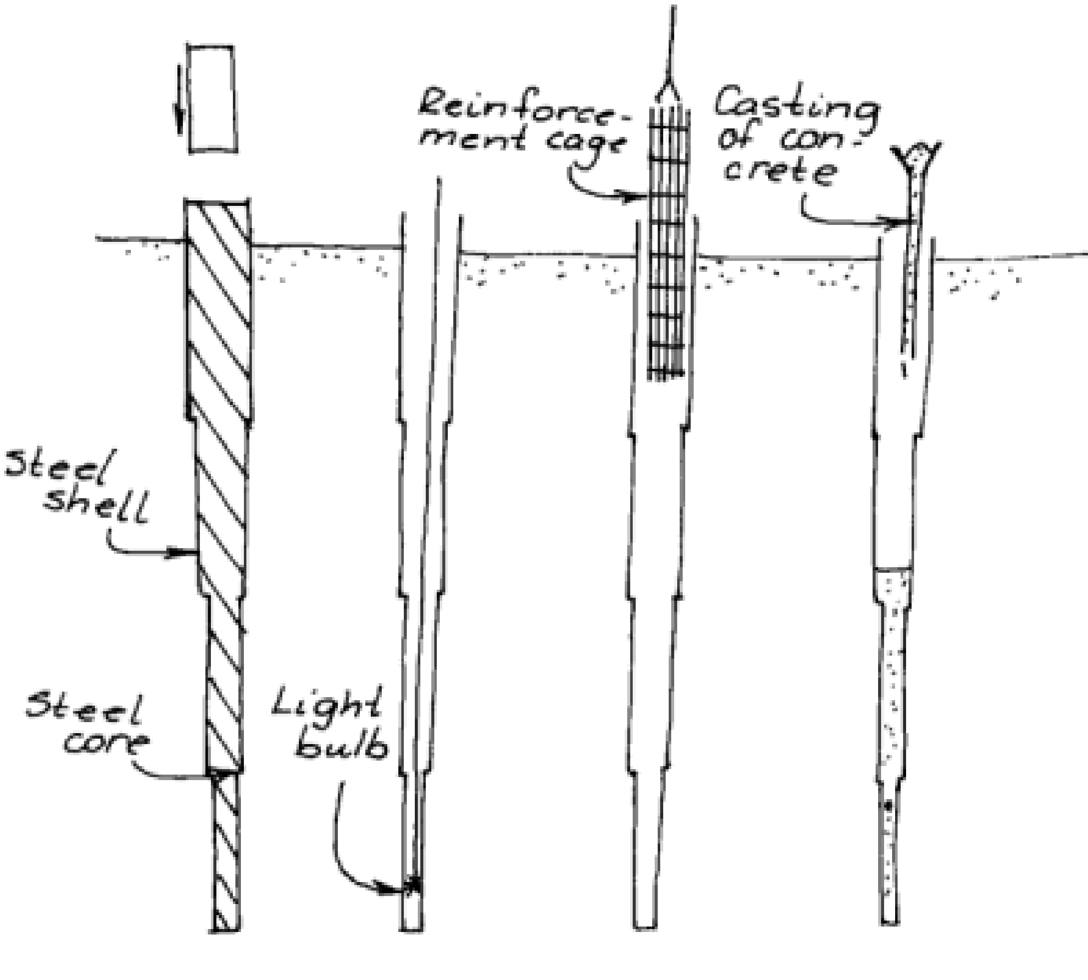
Predrilling and Jetting

- Methods of reducing the soil resistance to assist driving
  - Predrilling
    - Using an auger (usually continous flight) to drill a hole into which the pile is driven
    - Does result in loss of shaft friction
  - Jetting

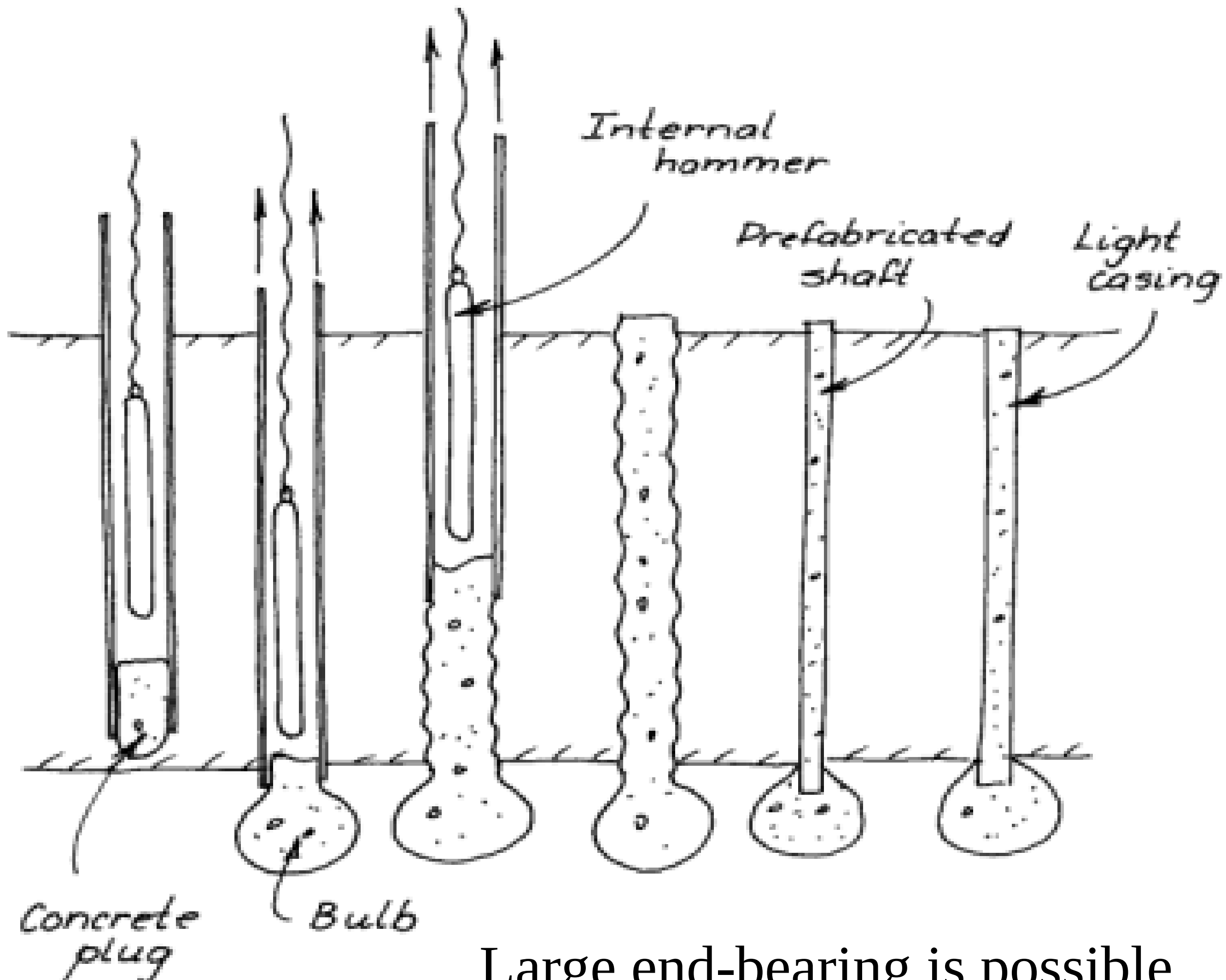


Mandrel-Driven Thin Shelled Piles

- Thin shelled steel piles which are driven with the assistance of a mandrel, as they would collapse if driven directly (as with pipe piles)
- Piles then filled with concrete and a reinforcing cage
- First widely popular mandrel driven thin shelled pile was the Raymond Step-Taper Pile, but there are many other kinds available today



Pressure-Injected Footings (Franki Piles)



Large end-bearing is possible

Design and Selection of Deep Foundations

Design Parameters

- Service loads and allowable deformations
- Subsurface investigations
- Type of Foundation
- Lateral and Axial Load Capacity
- Driveability
- Structural Design
- Seismic Design
- Verification and Redesign
- Integrity Testing

Selection and Types

- Type of Foundation is influenced by:
  - Design Loads
  - Subsurface Conditions
  - Constructibility
  - Reliability
  - Cost
  - Availability of materials, equipment and expertise
  - Local experience and precedent

Design of Deep Foundations

- Subsurface Investigations
  - For deep foundations, the subsurface investigations are generally more intensive and expensive
  - Exploratory borings must extend well below the toe elevation, which may have to be altered after initial calculations
  - Investigations assist in determining the type of foundation that should be used
  - Use data from deep foundations that have already been installed in the vicinity (capacity and drivability)

- Service Loads and Allowable Deformations
  - Most important step
  - Loads can include
    - Axial loads (live or dead, tensile or compressive)
    - Lateral loads (live or dead)
    - Moment loads
  - Should be combined both as unfactored loads (ASD) or factored loads (LRFD)
  - Allowable settlements should be determined by structural engineer

Lateral and Axial Load Capacity

- Axial loads
  - Analytic methods should be performed first, although their limitations should be understood
  - Analysis should include considerations of allowable load, allowable settlement, and group effects (including block failure)
  - Ideally, a static load test on test piles should be done; however, if economic or other factors make this impractical, other methods such as Osterberg Tests, CAPWAP, or Statnamic should be considered
  - Blow count specifications using a wave equation analysis are acceptable on smaller projects
- Lateral Loads
  - Frequently dictate the diameter (section modulus) of the foundation, so should be considered first, if present
  - p-y curves are the best way of determining lateral capacity
  - Large diameter piles may also be necessary for scour resistance
  - Batter piles are also a typical way of dealing with lateral loads, but can pose rigidity problems in seismic situations
  - Seismic retrofits are a common application of laterally loaded piles

Driveability

- Piles that cannot be driven cannot be used to support loads; thus, drivability is an important consideration with driven piles
- Wave equation methods are ideal to use for drivability studies
- Deep foundations must be designed and analysed to meet criteria for
  - Reasonable cost
  - Sufficient capacity
  - Possible drivability

Structural and Seismic Design

- Seismic Design
  - In seismically active areas, earthquake occurrence must be taken into consideration
  - Liquefaction of soils is a major cause of failure during seismic events
    - Deep foundations can be installed beyond liquefying soils in some cases
    - Soil improvement is necessary in others
  - Most direct seismic loads on foundations are lateral ones so lateral load analysis is important for seismic resistance
  - Batter piles tend to be too rigid for seismic loads
- Structural Design
  - Once the geotechnical analysis is done, the structural engineer can proceed with the structural design
  - Structural design involves both the structural capacity of the deep foundations themselves and the pile caps and connecting members that are above these members
  - Plans and specifications presented for bid should be complete and unambiguous

Other Considerations

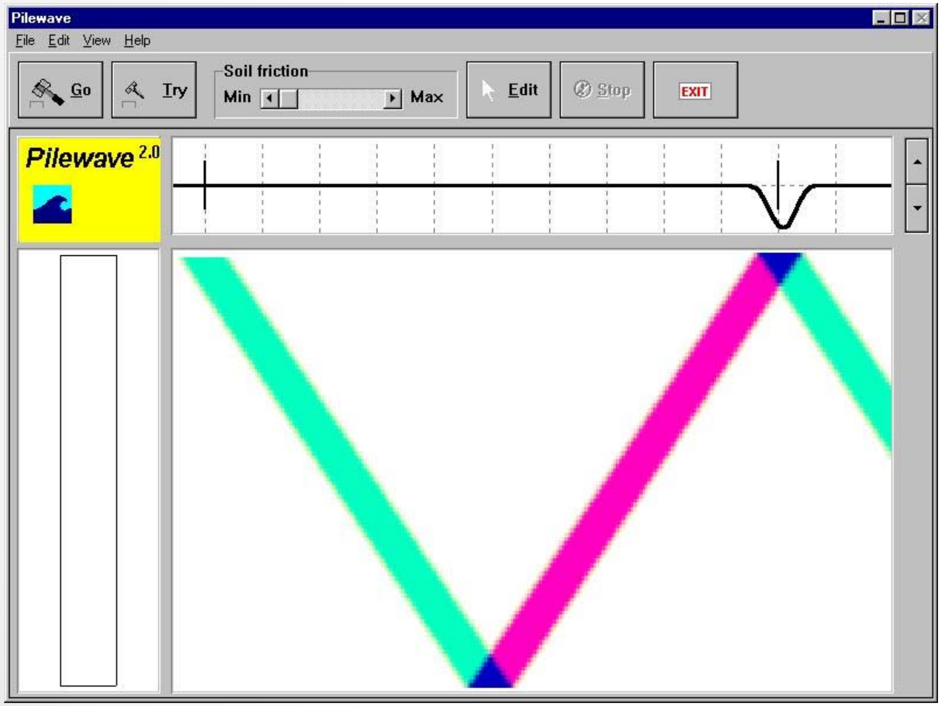
Scour and Downdrag

- Scour
  - Scour is an important consideration for bridges over rivers or other bodies of water with consistent currents
  - Loss of supporting soil at the head of the deep foundation must be considered when designing for scour
- Downdrag
  - Compression of soil by overburden around piles creates downdrag on piles
  - This is dealt with either by design or by treatment of the surface of the pile

Verification and Redesign

- Redesign during construction is to be avoided but is sometimes necessary due to differences in the subsurface conditions between what was estimated and what actually takes place
- Dynamic testing (Case Method, CAPWAP) is a useful tool to evaluate the need for redesign but must be used with good judgement
- Drilled shafts and the cuttings from boring should be inspected before and during the placement of concrete

Integrity Testing



- Integrity testing includes methods such as
  - Sonic logging
  - Nuclear logging
  - Vibration analysis
  - Stress-wave propagation (PIT)
  - Tomography
- Especially important with drilled shafts where quality control is critical

Questions?