LAPORAN

PENGUJIAN DINAMIS TIANG PONDASI

MENGGUNAKAN PILE DRIVING ANALYZER (PDA)

PROJECT : Golf Simprug

Jakarta

PT. LTS Geoinves

Desember, 2020

Jakarta , 29 Desember 2020

No : 29-12.2/PDA-SIMPRUG/GI/XII/2020

KEPADA YTH.

PT. Dayacipta Anekareksa

Di

Tempat

Perihal : Laporan Pile Driving Analyzer (PDA) Test pada Project Golf Simprug, Jakarta

Dengan hormat,

Bersama ini kami sampaikan laporan Pile Driving Analyzer (PDA) Test yang dilaksanakan pada Project Golf Simprug, test berlangsung pada tanggal 21 Desember 2020.

Test ini dilakukan sesuai dengan prosedur internasional (ASTM D 4945 – 12). Hasil yang didapat dilaporkan seperti apa adanya dengan catatan penjelasan seperlunya.

Demikian kami sampaikan, atas kerjasamanya kami ucapkan terima kasih.

Hormat kami,

Idrus Muhammad Ir. M.Sc Ph.D
Ahli Geoteknik Utama G2
Reg LPJK No: 1.2.216.1.031.09.1002930

Singgih Setiyadi, ST
Testing Engineer

DAFTAR ISI

DAFTAR SINGKATAN PADA PRINT OUT PDA

CSX tegangan tekan maksimum

TSX tegangan tarik maksimum

RSU daya dukung tiang berdasarkan metode CASE untuk tiang dengan tahanan kulit *(friction)* tinggi

RMX daya dukung tiang maksimum berdasarkan metode Case – Goble

RA2 daya dukung tiang berdasarkan metode CASE untuk tiang dengan tahanan kulit *(friction)* sedang dan tahanan ujung *(toe)* sedang

RAU daya dukung tiang berdasarkan metode CASE (tidak tergantung factor damping, JC) untuk tiang dengan tahanan ujung besar

EMX energi maksimum yang melewati sensor

STK tinggi jatuh hammer

DMX penurunan maksimum tiang pada level sensor

BTA faktor keutuhan tiang pondasi

LP panjang tiang tertanam (pada saat pengujian PDA)

LE panjang tiang di bawah *gages* (pada saat pengujian PDA)

AR luas penampang tiang pondasi pada level sensor

EM modulus elastisitas material tiang pondasi pada level sensor

SP berat jenis material tiang pondasi pada level sensor

WS kecepatan gelombang dalam material tiang pondasi pada level sensor

I. PENDAHULUAN

Laporan ini menyajikan hasil yang diperoleh dari pengujian dinamis terhadap 2 (dua) buah tiang pancang beton yang dilakukan pada :

Tanggal : 21 Desember 2020,

Proyek : Golf Simprug, Jakarta.

Pengujian di lapangan dilakukan dengan menggunakan alat Pile Driving Analyzer (PDA). Hasil dari pengetesan meliputi evaluasi tegangan pada tiang akibat tumbukan yang dilakukan oleh hammer, energi yang ditimbulkan oleh hammer dan perlawanan arah yang ter-aktif-kan pada saat pengetesan berlangsung, sedangkan hasil utama dari pengetesan adalah memperoleh Daya Dukung Ultimate Aksial tiang pada saat pengujian.

Analisa dinamis terhadap rekaman data lapangan juga dilakukan dengan program CAPWAP (**CA**se **P**ile **W**ave **A**nalysis **P**rogram). Hasil lengkap PDA dan CAPWAP dapat dilihat pada Lampiran – A, sedangkan penjelasan tentang pengujian dinamis serta prosedurnya terdapat pada lampiran – B.

II. DETAIL-DETAIL PENGUJIAN

II.1. TIANG PONDASI

Pengujian dinamis dilakukan terhadap 2 (dua) buah tiang pancang beton dengan spesifikasi seperti terlihat pada Tabel – 1.

Tabel 1. Spesifikasi Tiang*

No. Tiang	Dimensi Tiang (cm)	Panjang Tiang (m)	Panjang di bawah gages (m)	Panjang Tertanam (m)	Tanggal Pancang	Tanggal Pengetesan
Pile No.80	□ 25 x 25	9.60	9.00	8.60	18-12-2020	21-12-2020
Pile No.129	□ 25 x 25	9.80	9.30	8.80	14-12-2020	21-12-2020

II.2. HAMMER DAN SISTEM PEMBEBANAN

Jenis hammer yang dipergunakan adalah Drop Hammer dengan berat hammer 0.86 ton. Hammer dilengkapi dengan cushion dari plywood dengan ketebalan ±5cm.

II.3. INSTRUMENTASI

Pengujian dinamis ini dilakukan dengan 2 (dua) pasang sensor, yang terdiri dari pengukur regangan (strain transducer) dan pengukur percepatan (accelerometer) yang dipasang didekat kepala tiang (minimum jarak dari kepala tiang ke transducer = 1.5 – D, dimana D adalah diameter tiang, sehingga ada jarak bebas pada saat tumbukan.

Akibat tumbukan pada kepala tiang, sensor akan menangkap gerakan yang timbul dan mengubahnya menjadi signal listrik yang kemudian di-kondisioning-kan, direkam dan diproses dengan Pile Driving Analyzer (PDA) model PAX.

Sensor yang ditempatkan pada tiang akan menghasilkan besaran kecepatan partikel (particle velocity) sebagai hasil integrasi terhadap besaran percepatan terukur dari akselerometer (accelerometer) serta besaran gaya (force) sebagai hasil perkalian besaran regangan terukur dari transducer regangan (strain transducer) dengan **EA** (sesuai hukum Hooke).

Penyetaraan kecepatan partikel (V) terhadap gaya (F) dilakukan dengan mengalikannya dengan Z, yaitu impedansi/kekakuan dinamis. Hasil rekaman F dan V dapat dilihat pada Lampiran – A.

Berdasarkan hasil rekaman F dan V inilah PDA melakukan analisa dan perhitungan serta evaluasi kualitas data, integritas tiang sertaaspek perlawanan tanah akibat tumbukan. Rekaman data-data hasil PDA INI juga yang menjadi dasar dan masukan bagi analisa dengan menggunakan program CAPWAP yang tersaji pada laporan ini.

II.4. HASIL PENGUJIAN

Hasil lapangan dari pengujian dinamis disajikan pada Bab IV.3. DAYA DUKUNG TIANG.

III. <u>ANALISA</u>

III.1. LATAR BELAKANG

CAPWAP adalah program aplikasi analisa numeric yang menggunakan masukan data gaya *(force)* dan kecepatan *(velocity)* yang diukur oleh PDA. Kegunaan program ini adalah untuk memperkirakan distribusi dan besaran gaya perlawanan tanah total sepanjang tiang berdasarkan modelisasi system tiang-tanah yang dibuat dan memisahkannya menjadi bagian perlawanan dinamis dan bagian statis.

Program ini menggunakan model matematis system tiang-tanah dengan elemen diskrit massa dan pegas seperti pada analisa dengan Persamaan Gelombang *(Wave Equation)*, dengan tanah dikondisikan dalam keadaan pasif, jadi hanya merupakan fungsi dari perherakan tiang saja. Sehingga parameter tanah yang perlu diketahui adalah : Ru (tahanan batas); perpindahan elastis dari tahanan tanah statis *(quake)*; serta Jc, factor redaman tanah.

Analisa CAPWAP ini dikerjakan dengan cara mencocokkan kurva (F dan V) simulasi, yang karakteristiknya diketahui, dengan kurva hasil rekaman PDA secara iterasi *(trial and error)*. Bilamana belum mendapatkan suatu kecocokan, dapat di-iterasi lagi dengan mengubah parameter tanahnya. Bila sudah cocok, artinya model tanah yang dicari sudah sesuai; maka perlawanan tanah, Ru, dapat dipisah menjadi bagian dinamis dan statis sehingga karakteristik bagian statisnya dapat didefinisikan.

Termasuk hasil dari CAPWAP adalah perilaku system tiang-tanah dibawah pembebanan (kurva simulasi hubungan beban dengan penurunan kepala tiang/load-settlement curve) seperti yang akan didapat dari uji beban statis *(static loading test)* biasa.

III.2. HASIL ANALISA DENGAN PROGRAM CAPWAP

Hasil analisa CAPWAP dapat dilihat pada BAB IV.3 DAYA DUKUNG TIANG, sedangkan keluaran analisa CAPWAP termasuk distribusi tahanan kulit dan tegangan maksimum pada tiang dapat dilihat di Lampiran – A.

IV. DISKUSI TENTANG HASIL PENGUJIAN

IV.1. TRANSFER ENERGI TUMBUKAN

Transfer energi tumbukan ke tiang selama pengujian, menggunakan Drop Hammer dengan berat hammer 0.86 ton terlihat pada Tabel – 2 berikut.

Tabel 2. Energi Tumbukan dan Efisiensi Hammer

No. Tiang	Tinggi Jatuh / STK (m)	Energi Tumbukan/ EMX (ton-m)	Effisiensi Hammer (%)
Pile No.80	0.50	0.36	83.72
Pile No.129	0.50	0.31	72.09

IV.2. TEGANGAN PADA MATERIAL TIANG

Tegangan Tekan Maksimum terukur pada level sensor akibat tumbukan serta Tegangan Tarik Maksimumnya dapat dilihat pada Tabel – 3 berikut ini.

Tabel 3. Tegangan Tekan Maksimum dan Tegangan Tarik Maksimum Pada Tiang

No. Tiang	Tegangan Tekan Maksimum / CSX (MPa)	Tegangan Tarik Maksimum / TSX (MPa)
Pile No.80	14.20	3.50
Pile No.129	13.50	6.20

Catatan : *Lihat juga nilai CSX (tekan) serta nilai TSX (tarik) pada print out PDA di Lampiran – A*

Tegangan rekomendasi **FHWA*** yaitu 35.2 MPa untuk tegangan tekan serta 1.61 MPa untuk tegangan tarik (batas untuk tiang pancang beton dengan mutu material K-500).

*Federal Highway Administration
Reference : Vanikar, S.N. 1986. Manual on design construction of driven pile foundations. U.S. Department of Transportation, Federal Highway Administration, Demonstration Project Division, Washington, D.C.

IV.3. DAYA DUKUNG TIANG

Dari rekaman tumbukan yang ada, daya tiang aksial dapat diperkirakan dengan menganalisa rekaman tumbukan mula-mula, yaitu rekaman saat perlawanan tanah masih dalam kondisi awal tidak terganggu *(undisturbed)*.

RSU, yaitu daya dukung tiang berdasarkan metode CASE untuk tiang dengan tahanan kulit *(friction)* tinggi, digunakan dalam menganalisa tiang yang diuji.

Kapasitas ultimate yang diperoleh dari pengujian PDA dan CAPWAP selanjutnya dapat dilihat pada Tabel – 4 berikut.

Tabel 4. Daya Dukung Ultimate Tiang Pondasi Hasil PDA dan CAPWAP

No. Tiang	Daya Dukung Ultimate Tiang (Ton)				Penurunan Dx
	PDA (RMX)	CAPWAP			
		Total	Tahanan Kulit	Tahanan Ujung	
Pile No.80	77	84	60	24	6.53 mm
Pile No.129	72	77	42	36	5.78 mm

IV.4. KEUTUHAN TIANG

Didapat juga informasi dari pengujian PDA mengenai keutuhan tiang pondasi yang ditunjukkan oleh nilai BTA, yaitu sebesar 100% ini berarti tiang yang diuji memiliki keutuhan yang baik. Selanjutnya, hasil PDA test dapat dipakai dan telah verifikasi dari ahli geoteknik yang memiliki sertifikat professional G-2.

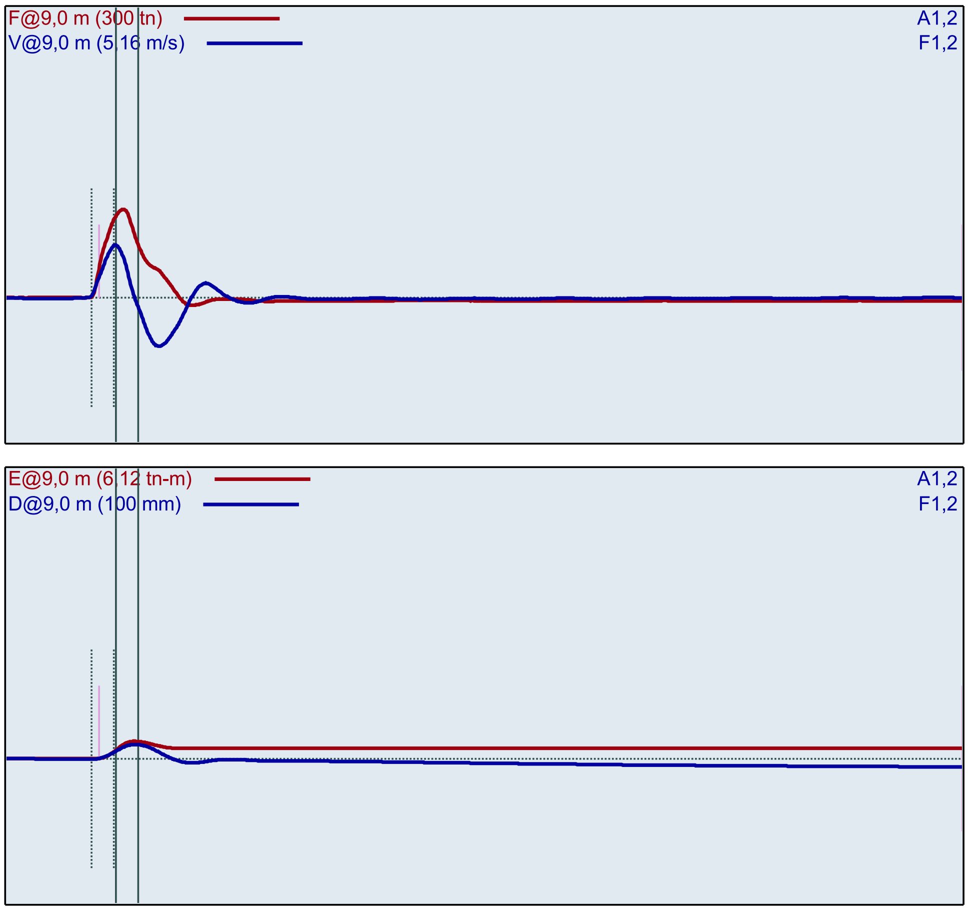
LAMPIRAN – A

HASIL PENGUJIAN DENGAN PDA DAN HASIL ANALISA

DENGAN PROGRAM CAPWAP

Pile Dynamics, Inc.
Pile Driving Analyzer ® (PDA)

GOLF SIMPRUG PILE NO.80



Project Information
PROJECT: GOLF SIMPRUG
PILE NAME: PILE NO.80
DESC: SQUARE 25x25
PDA OWNER: Unknown
SERIAL NUMBER:
OPERATOR: SGH
FILE: PILE NO80.pda
21Des2020 10.53.18 AM
Blow number 3

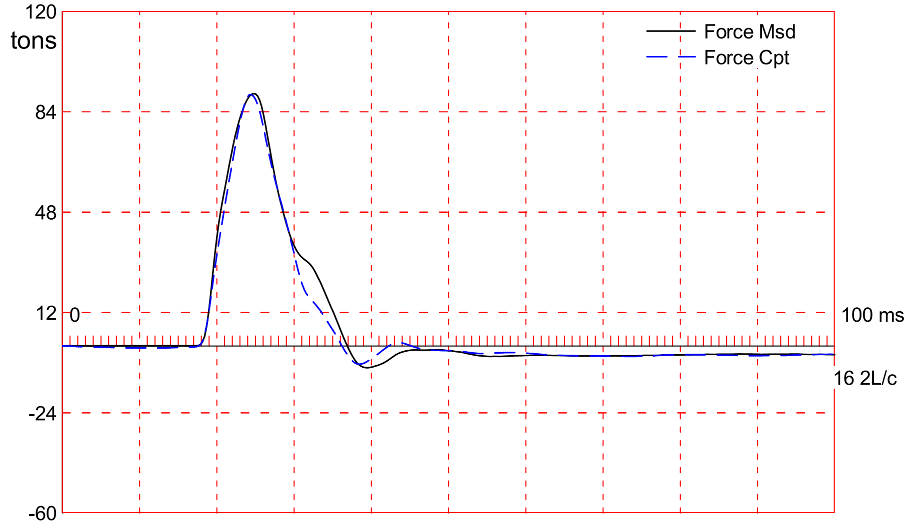
Pile Properties

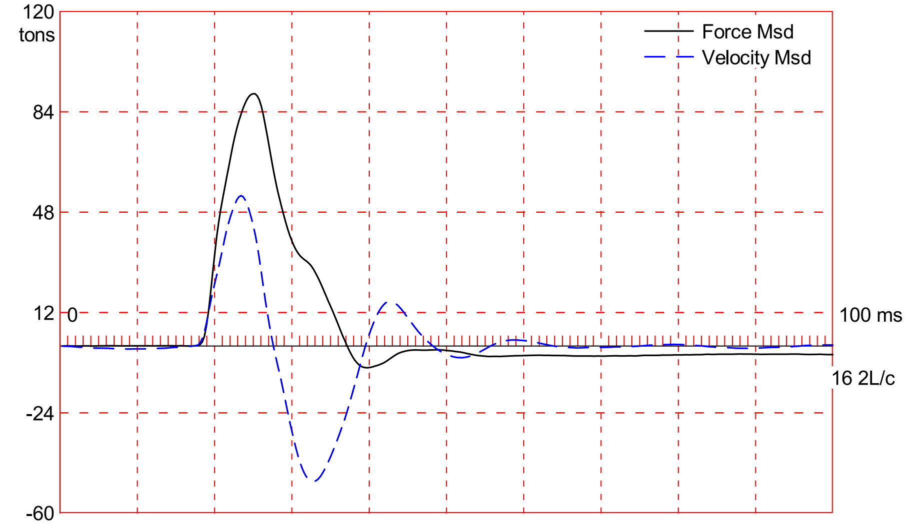
LE	9,0 m
AR	625,00 cm^2
EM	353 t/cm2
SP	2,40 t/m3
WS	3800,0 m/s
WC	3750,0 m/s
EA/C	58,1 tn-s/m
2L/C	4,80 ms
JC	0,80
LP	8,6 m

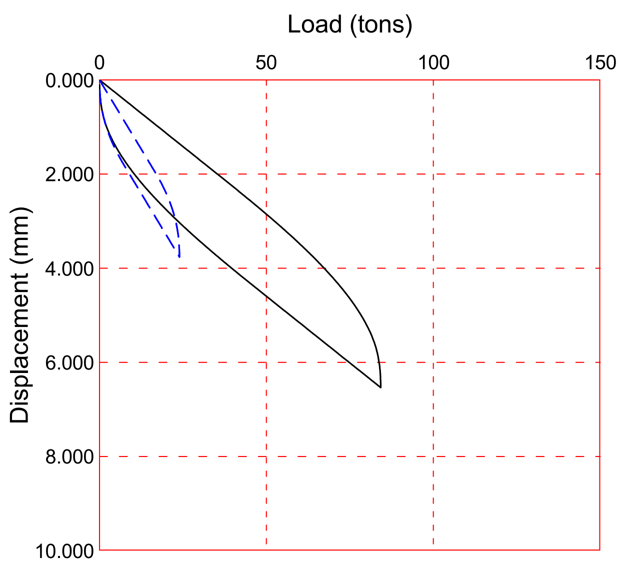
Quantity Results

CSI	19,4 MPa
CSX	14,2 MPa
CSB	16,0 MPa
TSX	3,5 MPa
EMX	0,36 tn-m
ETR	24,3 %
BPM	0,0 bpm
FMX	91 tn
RMX	77 tn
BTA	100,0 %
RX9	78 tn
RUC	0 tn
SFC	0 tn
MQ	0,00

Sensors
A1 (PE): [44865] 1190 g's/volt (1,1) VF6
A2 (PE): [52354] 1081 g's/volt (1,1) VF6
F1 : [R167] 142,8 PDICAL (1,1) FF6
F2 : [R168] 149,7 PDICAL (1,1) FF6
CLIP: OK

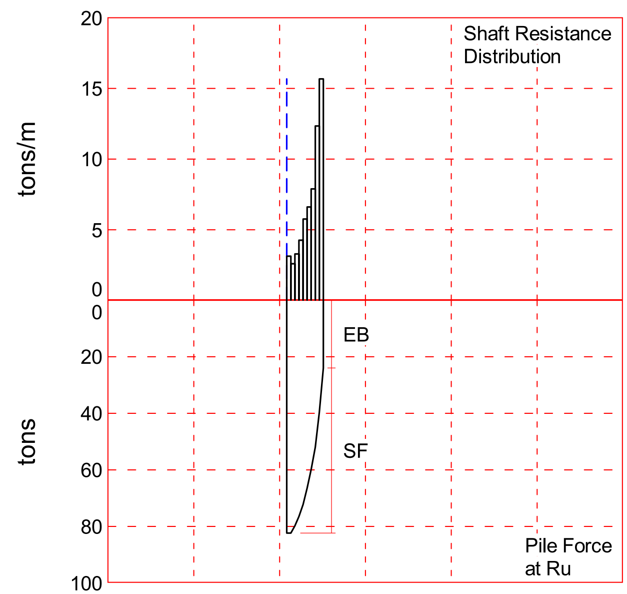






Pile Top
Bottom

RU =	84 tons
SF =	60 tons
EB =	24 tons
Dy =	6.442 mm
Dx =	6.536 mm
SET/Bl =	0.100 mm



Length b. Sensors	9.0 m
Embedment	8.6 m
Top Area	625.0 cm^2
End Bearing Area	625.0 cm^2
Top Perimeter	1.00 m
Top E-Modulus	353 tons/cm^2
Top Spec. Weight	2.4 tons/m^3
Top Wave Spd.	3800 m/s
Overall W.S.	3800 m/s
Match Quality	4.98
Top Compr. Stress	0.1 tons/cm^2
Max Compr. Stress	0.1 tons/cm^2
Max Tension Stress	-0.01 tons/cm^2
Avg. Shaft Quake	2.510 mm
Toe Quake	2.817 mm
Avg. Shaft Smith Dpg.	1.03 s/m
Toe Smith Damping	0.08 s/m

About the CAPWAP Results

The CAPWAP program performs a signal matching or reverse analysis based on measurements taken on a deep foundation under an impact load. The program is based on a one-dimensional mathematical model. Under certain conditions, the model only crudely approximates the often complex dynamic situations.

The CAPWAP analysis relies on the input of accurately measured dynamic data plus additional parameters describing pile and soil behavior. If the field measurements of force and velocity are incorrect or were taken under inappropriate conditions (e.g., at an inappropriate time or with too much or too little energy) or if the input pile model is incorrect, then the solution cannot represent the actual soil behavior.

Generally the CAPWAP analysis is used to estimate the axial compressive pile capacity and the soil resistance distribution. The long-term capacity is best evaluated with restrike tests since they incorporate soil strength changes (set-up gains or relaxation losses) that occur after installation. The calculated load settlement graph does not consider creep or long term consolidation settlements. When uplift is a controlling factor in the design, use of the CAPWAP results to assess uplift capacity should be made only after very careful analysis of only good measurement quality, and further used only with longer pile lengths and with nominally higher safety factors.

CAPWAP is also used to evaluate driving stresses along the length of the pile. However, it should be understood that the analysis is one dimensional and does not take into account bending effects or local contact stresses at the pile toe.

Furthermore, if the user of this software was not able to produce a solution with satisfactory signal "match quality" (MQ), then the associated CAPWAP results may be unreliable. There is no absolute scale for solution acceptability but solutions with MQ above 5 are generally considered less reliable than those with lower MQ values and every effort should be made to improve the analysis, for example, by getting help from other independent experts.

Considering the CAPWAP model limitations, the nature of the input parameters, the complexity of the analysis procedure, and the need for a responsible application of the results to actual construction projects, it is recommended that at least one static load test be performed on sites where little experience exists with dynamic behavior of the soil resistance or when the experience of the analyzing engineer with both program use and result application is limited.

Finally, the CAPWAP capacities are ultimate values. They MUST be reduced by means of an appropriate factor of safety to yield a design or working load. The selection of a factor of safety should consider the quality of the construction control, the variability of the site conditions, uncertainties in the loads, the importance of structure and other factors. The CAPWAP results should be reviewed by the Engineer of Record with consideration of applicable geotechnical conditions including, but not limited to, group effects, potential settlement from underlying compressible layers, soil resistances provided from any layers unsuitable for long term support, as well as effective stress changes due to soil surcharges, excavation or change in water table elevation.

The CAPWAP analysis software is one of many means by which the capacity of a deep foundation can be assessed. The engineer performing the analysis is responsible for proper software application and the analysis results. Pile Dynamics accepts no liability whatsoever of any kind for the analysis solution and/or the application of the analysis result.

CAPWAP SUMMARY RESULTS

Total CAPWAP Capacity: 84.26; along Shaft 60.30; at Toe 23.96 tons

Soil Sgmnt No.	Dist. Below Gages m	Depth Below Grade m	Ru tons	Force in Pile tons	Sum of Ru tons	Unit Resist. (Depth) tons/m	Unit Resist. (Area) tons/m²
				84.3			
1	1.0	0.6	1.88	82.4	1.88	3.13	3.13
2	2.0	1.6	2.60	79.8	4.48	2.60	2.60
3	3.0	2.6	3.29	76.5	7.77	3.29	3.29
4	4.0	3.6	4.26	72.2	12.03	4.26	4.26
5	5.0	4.6	5.76	66.5	17.79	5.76	5.76
6	6.0	5.6	6.61	59.9	24.40	6.61	6.61
7	7.0	6.6	7.89	52.0	32.29	7.89	7.89
8	8.0	7.6	12.34	39.6	44.63	12.34	12.34
9	9.0	8.6	15.67	24.0	60.30	15.67	15.67
Avg. Shaft			6.70			7.01	7.01
Toe			23.96				383.36

Soil Model Parameters/Extensions		Shaft	Toe
Smith Damping Factor		1.03	0.08
Quake	(mm)	2.510	2.817
Case Damping Factor		1.07	0.03
Damping Type		Viscous	Sm+Visc
Reloading Level	(% of Ru)	100	100
Unloading Level	(% of Ru)	94	
Soil Plug Weight	(tons)		0.427

CAPWAP match quality = 4.98 (Wave Up Match) ; RSA = 0
Observed: Final Set = 0.100 mm; Blow Count = 10000 b/m
Computed: Final Set = 1.104 mm; Blow Count = 906 b/m
Transducer F1 (R167) CAL: 142.8; RF: 1.10; F2 (R168) CAL: 149.7; RF: 1.10
A1 (44865) CAL: 1190; RF: 1.10; A2 (52354) CAL: 1081; RF: 1.10

max. Top Comp. Stress = 0.1 tons/cm² (T= 24.7 ms, max= 1.000 x Top)
max. Comp. Stress = 0.1 tons/cm² (Z= 1.0 m, T= 24.7 ms)
max. Tens. Stress = -0.01 tons/cm² (Z= 2.0 m, T= 38.7 ms)
max. Energy (EMX) = 0.37 tons-m; max. Measured Top Displ. (DMX)= 4.905 mm

EXTREMA TABLE

Pile Sgmnt No.	Dist. Below Gages m	max. Force tons	min. Force tons	max. Comp. Stress tons/cm²	max. Tens. Stress tons/cm²	max. Trnsfd. Energy tons-m	max. Veloc. m/s	max. Displ. mm
1	1.0	91.9	-8.6	0.1	-0.01	0.37	0.9	5.260
2	2.0	89.7	-8.6	0.1	-0.01	0.35	0.8	4.975
3	3.0	86.8	-8.1	0.1	-0.01	0.32	0.8	4.691
4	4.0	83.4	-7.3	0.1	-0.01	0.29	0.8	4.416
5	5.0	78.8	-6.2	0.1	-0.01	0.26	0.7	4.154
6	6.0	72.2	-4.7	0.1	-0.01	0.23	0.7	3.921
7	7.0	64.8	-3.4	0.1	-0.01	0.19	0.7	3.726
8	8.0	56.4	-2.1	0.1	-0.00	0.16	0.7	3.563
9	9.0	42.2	-0.3	0.1	-0.00	0.05	0.6	3.441
Absolute	1.0			0.1			(T =	24.7 ms)
	2.0				-0.01		(T =	38.7 ms)

CASE METHOD

J =	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
RP	100	96	93	89	85	81	78	74	70	66
RX	102	98	94	91	87	84	81	79	78	78
RU	103	100	96	93	90	86	83	79	76	72

RAU = 76 (tons); RA2 = 102 (tons)

Current CAPWAP Ru = 84 (tons); Corresponding J(RP)= 0.42; J(RX) = 0.50

VMX m/s	TVP ms	VT1*Z tons	FT1 tons	FMX tons	DMX mm	DFN mm	SET mm	EMX tons-m	QUS tons	KEB tons/mm
0.9	23.42	54	84	91	4.905	0.097	0.100	0.37	147	9

PILE PROFILE AND PILE MODEL

Depth m	Area cm²	E-Modulus tons/cm²	Spec. Weight tons/m³	Perim. m
0.0	625.0	353.4	2.400	1.00
9.0	625.0	353.4	2.400	1.00

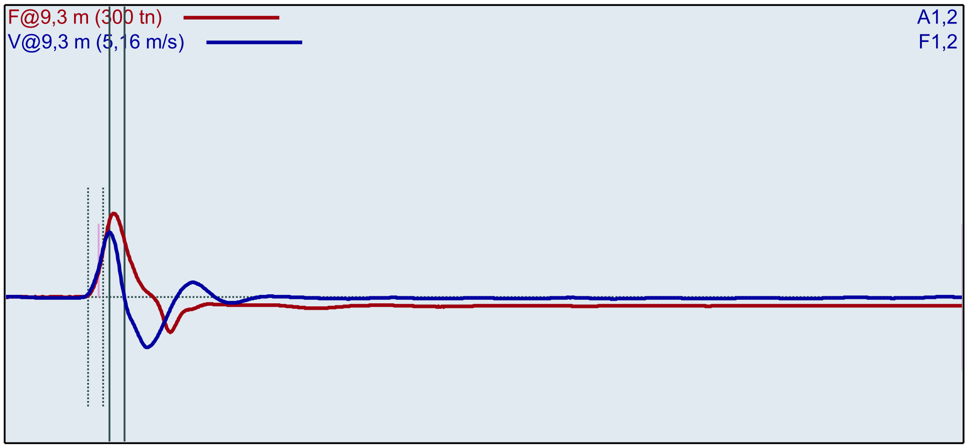
Toe Area 625.0 cm²

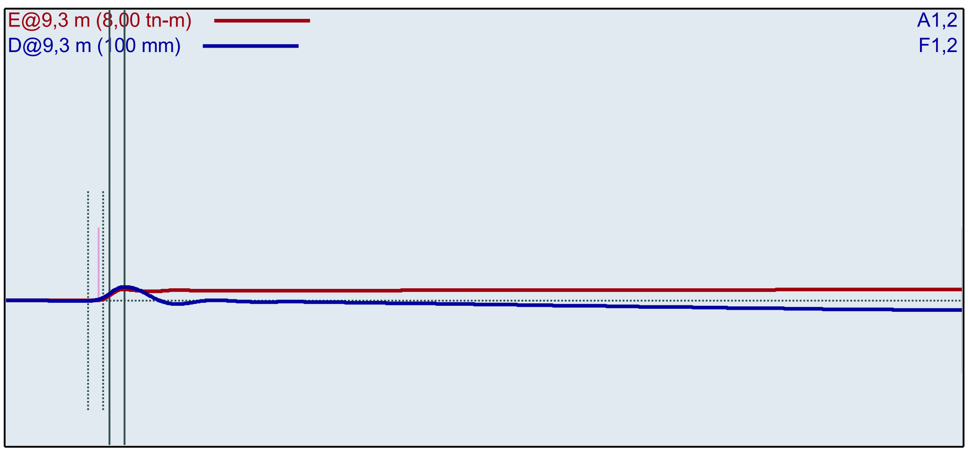
Top Segment Length 1.00 m, Top Impedance 58 tons/m/s

Wave Speed: Pile Top 3800.0, Elastic 3800.0, Overall 3800.0 m/s
Pile Damping 2.00 %, Time Incr 0.263 ms, 2L/c 4.7 ms
Total volume: 0.562 m³; Volume ratio considering added impedance: 1.000

Pile Dynamics, Inc.
Pile Driving Analyzer ® (PDA)

GOLF SIMPRUG PILE NO.129





Project Information
PROJECT: GOLF SIMPRUG
PILE NAME: PILE NO.129
DESC: SQUARE 25x25
PDA OWNER: Unknown
SERIAL NUMBER:
OPERATOR: SGH
FILE: PILE NO129.pda
21Des2020 11.41.03 AM
Blow number 3

Pile Properties

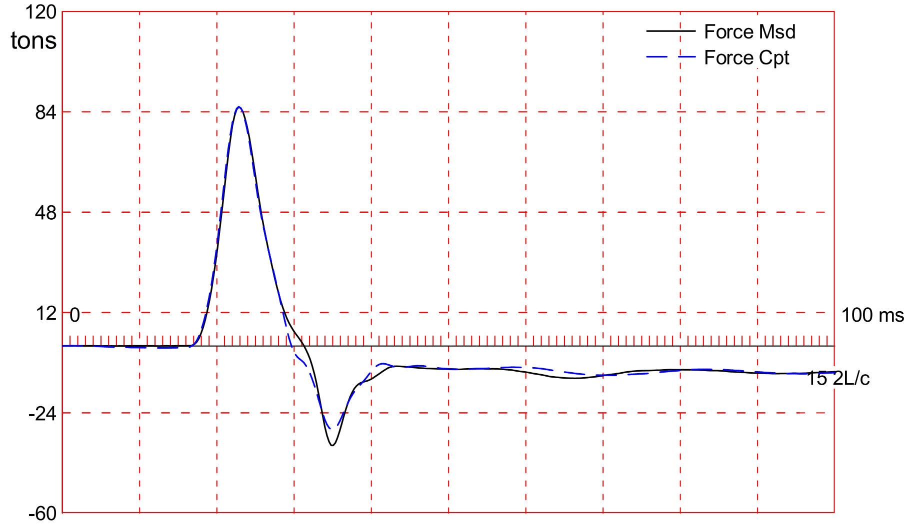
LE	9,3 m
AR	625,00 cm^2
EM	353 t/cm2
SP	2,40 t/m3
WS	3800,0 m/s
WC	5645,4 m/s
EA/C	58,1 tn-s/m
2L/C	3,29 ms
JC	0,80
LP	8,8 m

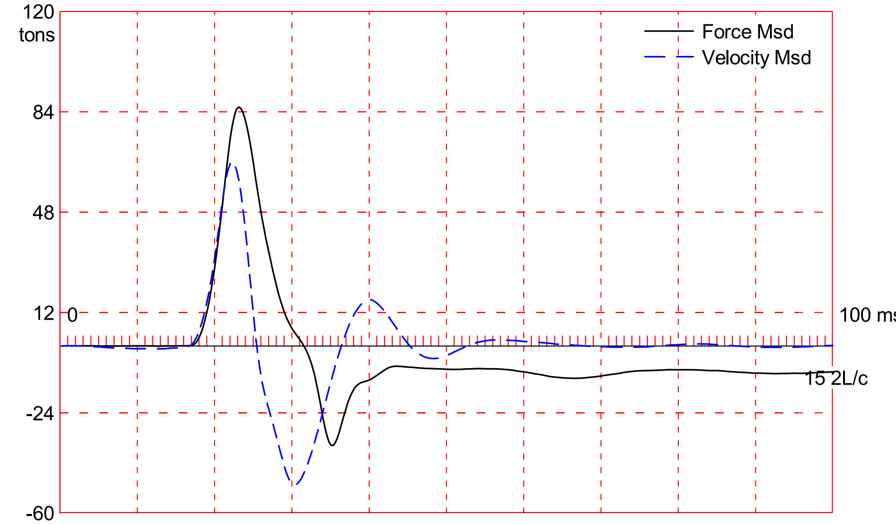
Quantity Results

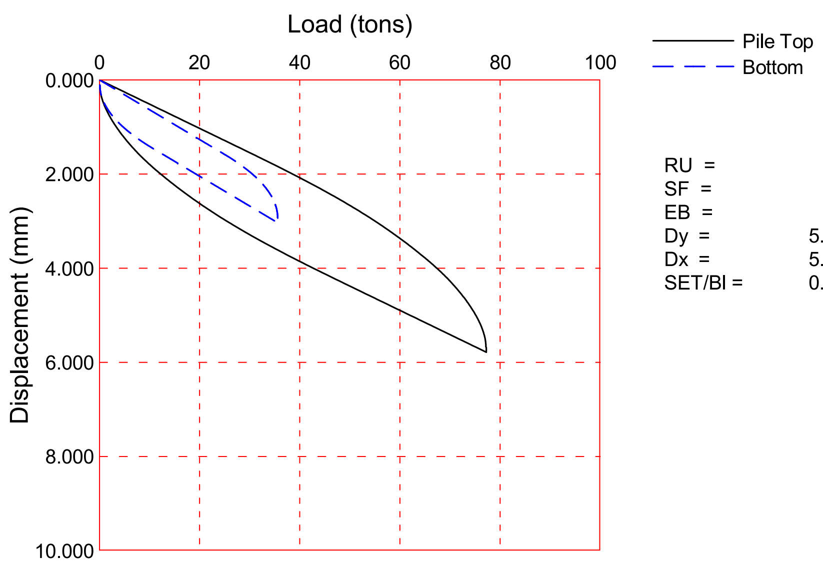
CSI	14,4 MPa
CSX	13,5 MPa
CSB	16,4 MPa
TSX	6,2 MPa
EMX	0,31 tn-m
ETR	20,3 %
BPM	0,0 bpm
FMX	86 tn
RMX	72 tn
BTA	100,0 %
RX9	65 tn
RUC	0 tn
SFC	0 tn
MQ	0,00

Sensors
A1 (PE): [44865] 1190 g's/volt (1,2) VF6
A2 (PE): [52354] 1081 g's/volt (1,2) VF6
F1 : [R167] 142,8 PDICAL (1,2) FF6
F2 : [R168] 149,7 PDICAL (1,2) FF6
CLIP: OK

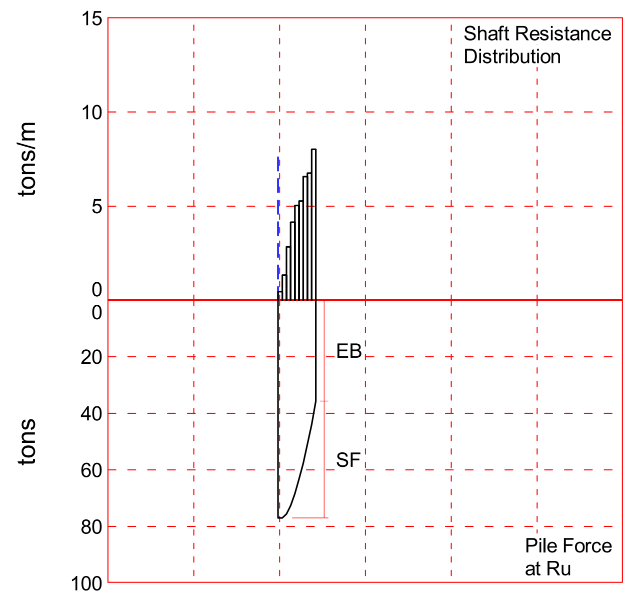
Version 2018.30







RU =	77 tons
SF =	42 tons
EB =	36 tons
Dy =	5.687 mm
Dx =	5.784 mm
SET/Bl =	0.100 mm



Length b. Sensors	9.3 m
Embedment	8.8 m
Top Area	625.0 cm²
End Bearing Area	625.0 cm²
Top Perimeter	1.00 m
Top E-Modulus	353 tons/cm²
Top Spec. Weight	2.4 tons/m³
Top Wave Spd.	3800 m/s
Overall W.S.	3800 m/s
Match Quality	3.53
Top Compr. Stress	0.1 tons/cm²
Max Compr. Stress	0.1 tons/cm²
Max Tension Stress	-0.06 tons/cm²
Avg. Shaft Quake	1.586 mm
Toe Quake	2.260 mm
Avg. Shaft Smith Dpg.	1.31 s/m
Toe Smith Damping	0.71 s/m

About the CAPWAP Results

The CAPWAP program performs a signal matching or reverse analysis based on measurements taken on a deep foundation under an impact load. The program is based on a one-dimensional mathematical model. Under certain conditions, the model only crudely approximates the often complex dynamic situations.

The CAPWAP analysis relies on the input of accurately measured dynamic data plus additional parameters describing pile and soil behavior. If the field measurements of force and velocity are incorrect or were taken under inappropriate conditions (e.g., at an inappropriate time or with too much or too little energy) or if the input pile model is incorrect, then the solution cannot represent the actual soil behavior.

Generally the CAPWAP analysis is used to estimate the axial compressive pile capacity and the soil resistance distribution. The long-term capacity is best evaluated with restrike tests since they incorporate soil strength changes (set-up gains or relaxation losses) that occur after installation. The calculated load settlement graph does not consider creep or long term consolidation settlements. When uplift is a controlling factor in the design, use of the CAPWAP results to assess uplift capacity should be made only after very careful analysis of only good measurement quality, and further used only with longer pile lengths and with nominally higher safety factors.

CAPWAP is also used to evaluate driving stresses along the length of the pile. However, it should be understood that the analysis is one dimensional and does not take into account bending effects or local contact stresses at the pile toe.

Furthermore, if the user of this software was not able to produce a solution with satisfactory signal "match quality" (MQ), then the associated CAPWAP results may be unreliable. There is no absolute scale for solution acceptability but solutions with MQ above 5 are generally considered less reliable than those with lower MQ values and every effort should be made to improve the analysis, for example, by getting help from other independent experts.

Considering the CAPWAP model limitations, the nature of the input parameters, the complexity of the analysis procedure, and the need for a responsible application of the results to actual construction projects, it is recommended that at least one static load test be performed on sites where little experience exists with dynamic behavior of the soil resistance or when the experience of the analyzing engineer with both program use and result application is limited.

Finally, the CAPWAP capacities are ultimate values. They MUST be reduced by means of an appropriate factor of safety to yield a design or working load. The selection of a factor of safety should consider the quality of the construction control, the variability of the site conditions, uncertainties in the loads, the importance of structure and other factors. The CAPWAP results should be reviewed by the Engineer of Record with consideration of applicable geotechnical conditions including, but not limited to, group effects, potential settlement from underlying compressible layers, soil resistances provided from any layers unsuitable for long term support, as well as effective stress changes due to soil surcharges, excavation or change in water table elevation.

The CAPWAP analysis software is one of many means by which the capacity of a deep foundation can be assessed. The engineer performing the analysis is responsible for proper software application and the analysis results. Pile Dynamics accepts no liability whatsoever of any kind for the analysis solution and/or the application of the analysis result.

CAPWAP SUMMARY RESULTS

Total CAPWAP Capacity: 77.26; along Shaft 41.59; at Toe 35.67 tons

Soil Sgmnt No.	Dist. Below Gages m	Depth Below Grade m	Ru tons	Force in Pile tons	Sum of Ru tons	Unit Resist. (Depth) tons/m	Unit Resist. (Area) tons/m^2
				77.3			
1	1.0	0.5	0.25	77.0	0.25	0.47	0.47
2	2.1	1.6	1.39	75.6	1.64	1.35	1.35
3	3.1	2.6	2.94	72.7	4.58	2.85	2.85
4	4.1	3.6	4.29	68.4	8.87	4.15	4.15
5	5.2	4.7	5.21	63.2	14.08	5.04	5.04
6	6.2	5.7	5.45	57.7	19.53	5.27	5.27
7	7.2	6.7	6.79	50.9	26.32	6.57	6.57
8	8.3	7.8	6.98	44.0	33.30	6.75	6.75
9	9.3	8.8	8.29	35.7	41.59	8.02	8.02
Avg. Shaft			4.62			4.73	4.73
Toe			35.67				570.72

Soil Model Parameters/Extensions		Shaft	Toe
Smith Damping Factor		1.31	0.71
Quake	(mm)	1.586	2.260
Case Damping Factor		0.94	0.43
Damping Type		Viscous	Sm+Visc
Unloading Quake	(% of loading quake)	100	75
Reloading Level	(% of Ru)	100	100
Resistance Gap (included in Toe Quake) (mm)			0.001
Soil Plug Weight	(tons)		0.449

CAPWAP match quality = 3.53 (Wave Up Match) ; RSA = 0
Observed: Final Set = 0.100 mm; Blow Count = 10000 b/m
Computed: Final Set = 0.608 mm; Blow Count = 1644 b/m
Transducer F1 (R167) CAL: 142.8; RF: 1.20; F2 (R168) CAL: 149.7; RF: 1.20
A1 (44865) CAL: 1190; RF: 1.20; A2 (52354) CAL: 1081; RF: 1.20

max. Top Comp. Stress = 0.1 tons/cm^2 (T= 23.4 ms, max= 1.039 x Top)
max. Comp. Stress = 0.1 tons/cm^2 (Z= 3.1 m, T= 23.9 ms)
max. Tens. Stress = -0.06 tons/cm^2 (Z= 2.1 m, T= 35.6 ms)
max. Energy (EMX) = 0.31 tons-m; max. Measured Top Displ. (DMX)= 4.721 mm

EXTREMA TABLE

Pile Sgmnt No.	Dist. Below Gages m	max. Force tons	min. Force tons	max. Comp. Stress tons/cm²	max. Tens. Stress tons/cm²	max. Trnsfd. Energy tons-m	max. Veloc. m/s	max. Displ. mm
1	1.0	89.8	-32.7	0.1	-0.05	0.31	1.1	4.450
2	2.1	92.9	-34.6	0.1	-0.06	0.30	1.0	4.179
3	3.1	93.2	-34.5	0.1	-0.06	0.29	0.9	3.915
4	4.1	90.2	-32.2	0.1	-0.05	0.26	0.9	3.663
5	5.2	84.3	-28.4	0.1	-0.05	0.22	0.8	3.428
6	6.2	76.6	-23.5	0.1	-0.04	0.19	0.7	3.213
7	7.2	68.3	-19.1	0.1	-0.03	0.16	0.7	3.023
8	8.3	58.6	-14.0	0.1	-0.02	0.13	0.7	2.864
9	9.3	49.8	-9.2	0.1	-0.01	0.08	0.6	2.728
Absolute	3.1			0.1			(T =	23.9 ms)
	2.1				-0.06		(T =	35.6 ms)

CASE METHOD

J =	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
RP	102	97	93	88	84	80	75	71	66	62
RX	104	99	95	90	86	81	77	72	68	63
RU	102	97	93	88	84	80	75	71	66	62

RAU = 52 (tons); RA2 = 92 (tons)

Current CAPWAP Ru = 77 (tons); Corresponding J(RP)= 0.55; J(RX) = 0.59

VMX m/s	TVP ms	VT1*Z tons	FT1 tons	FMX tons	DMX mm	DFN mm	SET mm	EMX tons-m	QUS tons	KEB tons/mm
1.1	22.30	66	79	86	4.721	0.098	0.100	0.31	128	16

PILE PROFILE AND PILE MODEL

Depth m	Area cm²	E-Modulus tons/cm²	Spec. Weight tons/m³	Perim. m
0.0	625.0	353.4	2.400	1.00
9.3	625.0	353.4	2.400	1.00

Toe Area 625.0 cm²

Top Segment Length 1.03 m, Top Impedance 58 tons/m/s

Wave Speed: Pile Top 3800.0, Elastic 3800.0, Overall 3800.0 m/s
Pile Damping 2.00 %, Time Incr 0.272 ms, 2L/c 4.9 ms
Total volume: 0.581 m³; Volume ratio considering added impedance: 1.000

LAMPIRAN – B

PENGANTAR KE METODE PENGUJIAN DINAMIS

TIANG PONDASI

BACKGROUND

Since the mid-1960s research has been conducted at Case Institute of Technology in Cleveland. Ohio with the objective of improving pile installation and construction control methods using electronic measurement and modern analysis methods. This work had been supported by the Ohio Department of Transportation and the Federal Highway Administration.

In 1973, the research results were introduced into practice. Professor G. G. Goble, who had been the principal investigator at Case, founded Pile Dynamics, Inc. a company which manufactures – among other devices – the Pile Driving Analyzer™ (PDA). Together with his former research assistants he also founded Goble Rausche Likins and Associates. Inc. (GRL) a consulting engineering firm specialized in the dynamic measurement and analysis methods of piles.

Pile Dynamics gradually improved the PDA technology, always searching for and utilizing advances in electronic and computer technology. In addition, new devices were built and introduced into the market. GRL. on the other hand, developed methods and software for the analysis of the measured quantities. It is the intent of this paper to summarize both analytical and measurement tools available to the civil engineer.

RESULTS FROM DYNAMIC TESTING

The following are the main objectives of dynamic pile testing (or monitoring).

- Bearing Capacity at the time of testing. For the prediction of a pile's long term bearing capacity, measurements are taken during testing.
- Dynamic Pile Stresses during pile driving. In order to limit the possibility of pile damage, stresses must be kept within certain bounds. For concrete piles both tension and compression stresses are important.
- Pile integrity often must be checked both during and after pile installation.
- Hammer performance must be checked for productivity and construction control.

MEASUREMENTS

The basis for the results calculated by the PDA are pile top force and velocity signals, obtained using piezoelectric accelerometers and bolt-on strain transducers attached to the pile near its top. The PDA conditions and calibrates these signals and velocity. Using Case Method solutions, the PDA calculates the results described in the following section.

Other measurements are sometimes also required. The ram velocity may be directly obtained using radar technology in the Hammer Performance Analyzer™ (HPA). For open end diesel hammers, the time between two impacts indicates the magnitude of the fall height. This information is measured and calculated by the Saximeter™. Furthermore, the combustion pressure may be measured in diesels for proper wave equation modeling. Acceleration measurements taken on a helmet in addition to standard pile top force and velocity measurements yield pile top cushion stiffness information.

The Pile Integrity Tester (P.I.T.) can be used to evaluate damage to piles which may have occurred during driving or casting. It should also be mentioned that this so-called "Low Strain Method" of integrity testing requires only the measurement of acceleration at a pile top. The stress wave producing impact is then generated by a small hand-held hammer.

ANALYTICAL SOLUTIONS

BERAING CAPACITY

Wave Equation

GRL has prepared a program, GRLWEAP, which provides for a truly analytical solution, *i.e.* it does not require measurements and provides the user with a functional relationship between both bearing capacity and pile stress and the blow count. These results can be adjusted or calibrated if measurements of pile top quantities are available. However, the real strength of the traditional wave equation approach lies in a prediction of driving behavior and in the selection of an optimal driving system.

Case Method

The Case Method is a closed form solution based on a few simplifying assumptions such as ideal plastic soil behavior and an ideally elastic and uniform pile. Given the measured pile top force F(t) and pile top velocity v(t), the total soil resistance is

$$R(t) = \tfrac{1}{2}\{[F(t) + F(t_2)] + Z[v(t) + v(t_2)]\} \quad (1)$$

where

- Z EA/c is the pile impedance,
- t_2 time t + 2L/c
- L pile length below gages
- C $(E/\rho)^{1/2}$ is the speed of the stress wave
- E elastic modulus of the pile
- ρ pile mass density
- A pile cross sectional area

The total resistance consists of a dynamic and a static component. Thus

$$R_s(t) = R(t) - R_d(t) \quad (2)$$

The static resistance component is, of course, the desired pile bearing capacity. The dynamic component may be computed from a soil damping factor, J, and a pile toe velocity, $v_t(t)$ which is, conveniently calculated for the pile toe. Using wave considerations, this approach leads immediately to the dynamic resistance.

$$R_d(t) = J[F(t) + Zv(t) - R(t)] \quad (3)$$

and finally to static resistance by means of Equation 2. This solution is simple enough to be evaluated "in real time". *i.e.* between hammer blows, using the PDA. However, the assumption of a soil damping constant must be made and the time, t, has to be selected. Often, t, is selected such that the maximum static resistance, RMX, is calculated. The damping constant, J, may not be needed if the time, t, is chosen such that the $R_d(t)$ term vanishes. One calls the resulting capacity value RA2.

CAPWAP

This method (Case Pile Wave Analysis Program) combines the wave equation pile and soil model with the Case Method measurements. Thus, the solution includes not only the total and static bearing capacity values but also the skin friction, end bearing, damping factors and soil stiffness. The method iteratively determines a number of unknowns by signal matching. While it is necessary to make hammer performance assumptions for a GRLWEAP analysis, the CAPWAP® program works with the pile top measurements. Furthermore, while GRLWEAP and Case Method require certain assumptions regarding the soil behavior, CAPWAP calculates these soil parameters.

STREESSES

The wave equation and CAPWAP solutions include stresses along the pile. For the PDA, field results include the pile top stress directly from the measurement and, for concentrated end bearing, the stress at the pile toe from Equation 1.

For concrete piles the maximum tension stress is also of great importance. It occurs at some point below the pile top. The maximum tension stress can be computed from the pile top measurements by considering the magnitude of both upward and downward traveling waves, W_u and W_d.

$$W_u = ½[F(t) - Zv(t)] \quad (4)$$

$$W_d = ½[F(t) + Zv(t)] \quad (5)$$

If any one of these waves is negative, a tension wave exists. It must be checked whether the wave traveling in the opposite direction is sufficiently compressive to reduce the net tension to allowable levels. The PDA also performs this calculation.

PILE INTEGRITY

High Strain Tests

Stress waves in a pile are reflected wherever the impedance (Z=EA/c) changes. The reflected waves arrive at the pile top at a time which depends on the location of the change. The reflected waves cause changes in both pile top force and velocity. The magnitude relative change of the pile top variables allows to determine the extent of the cross sectional change. Thus, with β_i being a relative integrity factor which is unity for no impedance change and zero for the pile end, the following can be calculated by the PDA.

$$\beta_i = (1 - \alpha_i)/(1 + \alpha_i) \quad (6)$$

with

$$\alpha_i = ½(W_{ur} - W_{ud})/(W_{di} - W_{ur}) \quad (7)$$

where

- W_{ur} is the upward traveling wave at the onset of the reflected wave. It is caused by resistance.
- W_{ud} is the upward traveling wave due to the damage reflection.
- W_{di} is the maximum downward traveling wave due to impact.

Low Strain Tests (P.I.T.)

The pile top is struck with a held hand hammer and the resulting pile top velocity is measured, displayed and interpreted for signs of wave reflections. In general, a comparison of the reflected acceleration leads to a relative measure of extent of damage, again the location of the problem is indicated by the arrival time of the reflection. An approximate pile profile can be calculated from low strain records using the P.I.T.WAP.

HAMMER PERFORMANCE

The PDA can very simply calculate the energy transferred to the pile top.

$$E(t) = \int_0^t F(t)v(t)dt \quad (8a)$$

The maximum of the E_t curve is the most important information for an overall evaluation of the performance of a driving system. This EMX or ENTHRU value allows for a classification of the hammer's performance, using :

$$E_t = EMX/E_r \quad (8b)$$

where E_r is the hammer's rated energy.

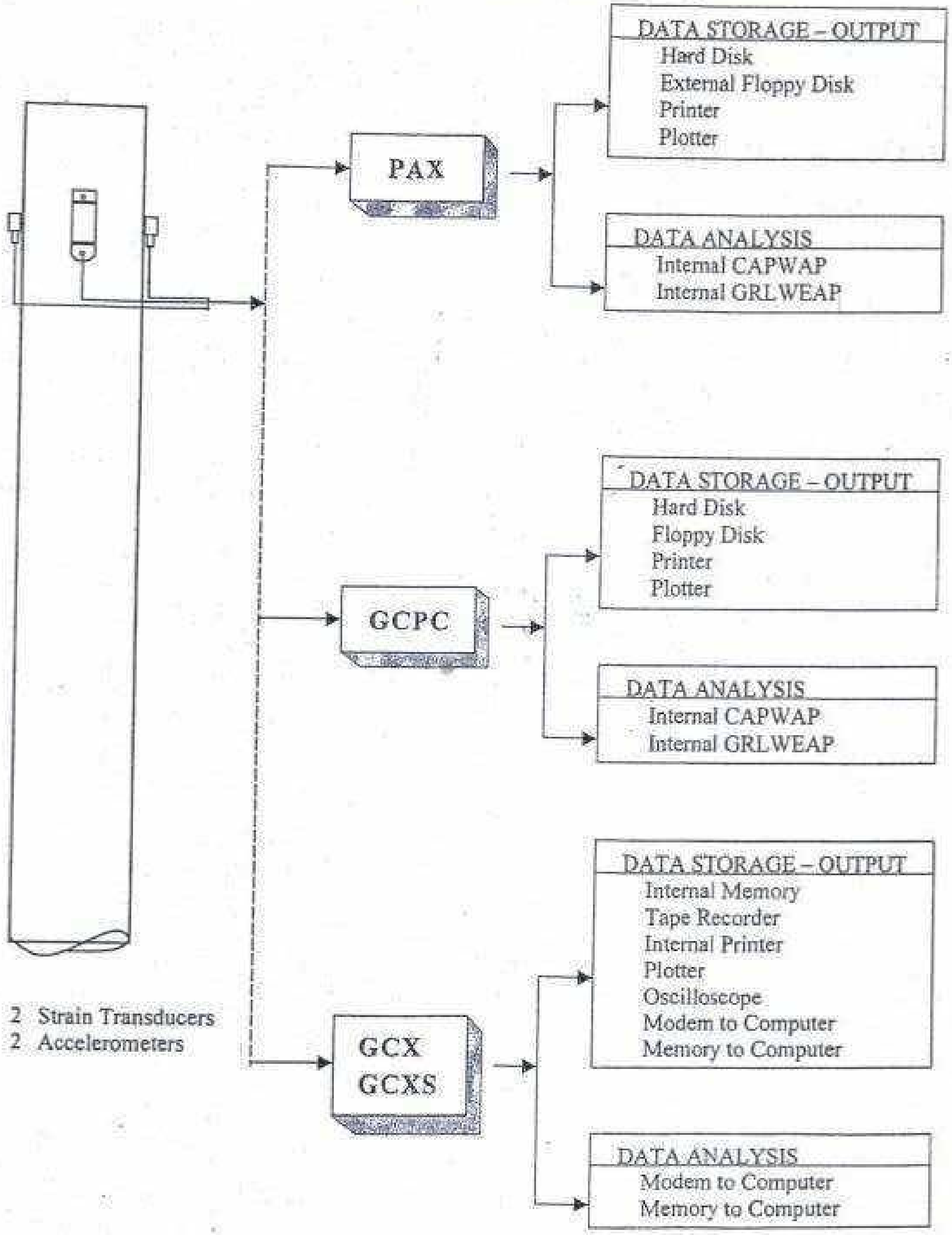
The Saximeter™ calculates the stroke from an open end diesel using

$$H = (g/8)\,T^2 - h_l \quad (9)$$

Where

- g earth gravitational acceleration,
- T time between two blows,
- h_l a stroke loss value due to gas compression and time losses during impact (usually 0.3 ft or 0.1 m).

Pile Driving Analyzer System



LAMPIRAN – C

ASTM D 4945 - 12

Designation: D4945 – 12

Standard Test Method for High-Strain Dynamic Testing of Deep Foundations[1]

This standard is issued under the fixed designation D4945; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This dynamic test method covers the procedure for applying an axial impact force with a pile driving hammer or a large drop weight that will cause a relatively high strain at the top of an individual vertical or inclined deep foundation unit, and for measuring the subsequent force and velocity response of that deep foundation unit. High-strain dynamic testing applies to any deep foundation unit, also referred to herein as a "pile," which functions in a manner similar to a driven pile or a cast-in-place pile regardless of the method of installation, and which conforms with the requirements of this test method.

1.2 This standard provides minimum requirements for dynamic testing of deep foundations. Plans, specifications, or provisions (or combinations thereof) prepared by a qualified engineer may provide additional requirements and procedures as needed to satisfy the objectives of a particular test program. The engineer in responsible charge of the foundation design, referred to herein as the "Engineer", shall approve any deviations, deletions, or additions to the requirements of this standard.

1.3 The proper conduct and evaluation of high-strain dynamic tests requires special knowledge and experience. A qualified engineer should directly supervise the acquisition of field data and the interpretation of the test results so as to predict the actual performance and adequacy of deep foundations used in the constructed foundation. A qualified engineer shall approve the apparatus used for applying the impact force, driving appurtenances, test rigging, hoist equipment, support frames, templates, and test procedures.

1.4 The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard. The word "shall" indicates a mandatory provision, and the word "should" indicates a recommended or advisory provision. Imperative sentences indicate mandatory provisions.

1.5 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.6 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.7 The method used to specify how data are collected, calculated, or recorded in this standard is not directly related to the accuracy to which the data can be applied in design or other uses, or both. How one applies the results obtained using this standard is beyond its scope.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For a specific precautionary statement, see Note 4.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C469 Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression

D198 Test Methods of Static Tests of Lumber in Structural Sizes

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D1143/D1143M Test Methods for Deep Foundations Under Static Axial Compressive Load

D3689 Test Methods for Deep Foundations Under Static Axial Tensile Load

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology

3.1 *Definitions*—For common definitions of terms used in this standard, see Terminology D653.

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[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.11 on Deep Foundations.

Current edition approved May 1, 2012. Published June 2012. Originally approved in 1989. Last previous edition approved in 2008 as D4945 – 08. DOI: 10.1520/D4945-12.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *cast in-place pile, n*—a deep foundation unit made of cement grout or concrete and constructed in its final location, for example, drilled shafts, bored piles, caissons, auger cast piles, pressure-injected footings, etc.

3.2.2 *deep foundation, n*—a relatively slender structural element that transmits some or all of the load it supports to the soil or rock well below the ground surface, that is, a driven pile, a cast-in-place pile, or an alternate structural element having a similar function.

3.2.3 *deep foundation cushion, n*—the material inserted between the helmet on top of the deep foundation and the deep foundation (usually plywood).

3.2.4 *deep foundation impedance, n*—a measure of the deep foundation's resistance to motion when subjected to an impact event. Deep foundation impedance can be calculated by multiplying the cross-sectional area by the dynamic modulus of elasticity and dividing the product by the wave speed. Alternatively, the impedance can be calculated by multiplying the mass density by the wave speed and cross-sectional area.

$$Z = (EA/c) = \rho c A \quad (1)$$

where:

Z = impedance,
E = dynamic modulus of elasticity,
A = cross-sectional area,
c = wave speed, and
ρ = mass density.

3.2.5 *driven pile, n*—a deep foundation unit made of preformed material with a predetermined shape and size and typically installed by impact hammering, vibrating, or pushing.

3.2.6 *follower, n*—a structural section placed between the impact device and the deep foundation during installation or testing.

3.2.7 *hammer cushion, n*—the material inserted between the hammer striker plate, and the helmet on top of the deep foundation.

3.2.8 *impact event, n*—the period of time during which the deep foundation is moving due to the impact force application. See Fig. 1.

3.2.9 *impact force, n—in the case of strain transducers*, the impact force is obtained by multiplying the measured strain (ε) with the cross-sectional area (A) and the dynamic modulus of elasticity (E).

3.2.10 *mandrel, n*—a stiff structural member placed inside a thin shell to allow impact installation of the thin section shell.

3.2.11 *moment of impact, n*—the first time after the start of the impact event when the acceleration is zero. See Fig. 1.

3.2.12 *particle velocity, n*—the instantaneous velocity of a particle in the deep foundation as a strain wave passes by.

3.2.13 *restrike, n or v*—the redriving of a previously driven pile, typically after a waiting period of 15 min to 30 days or more, to assess changes in ultimate axial compressive static capacity during the time elapsed after the initial installation.

3.2.14 *wave speed, n*—the speed with which a strain wave propagates through a deep foundation. It is a property of the deep foundation composition and for one-dimensional wave propagation is equal to the square root of the quotient of the Modulus of Elasticity divided by mass density: $c = (E/\rho)^{1/2}$.

4. Significance and Use

4.1 Based on the measurements from strain or force, and acceleration, velocity, or displacement transducers, this test method obtains the force and velocity induced in a pile during an axial impact event (see Figs. 1 and 2). The Engineer may analyze the acquired data using engineering principles and judgment to evaluate the integrity of the pile, the performance

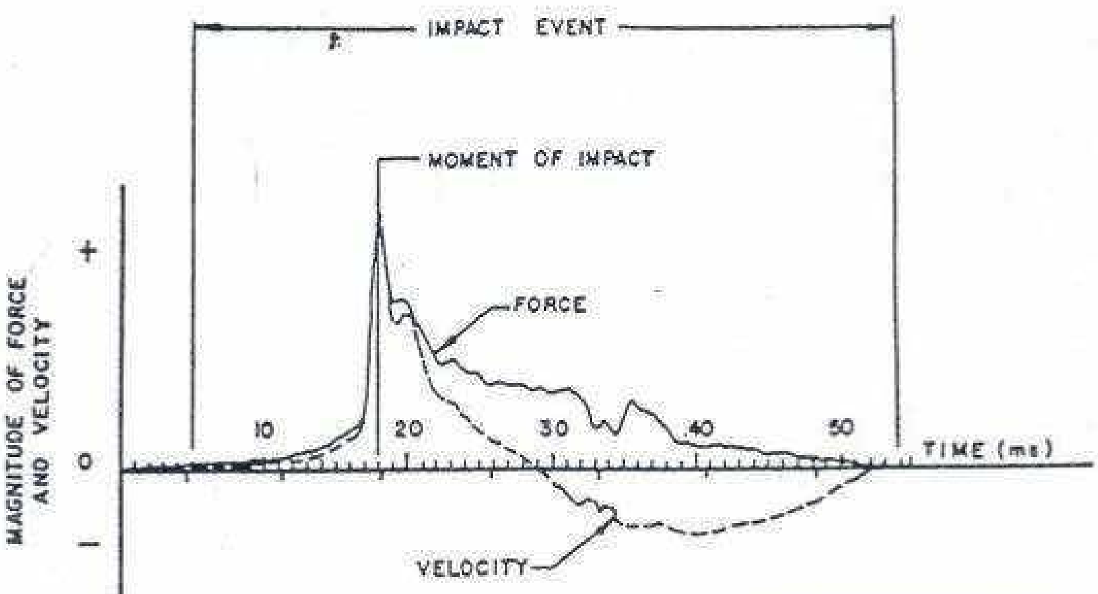


FIG. 1 Typical Force and Velocity Traces Generated by the Apparatus for Obtaining Dynamic Measurements

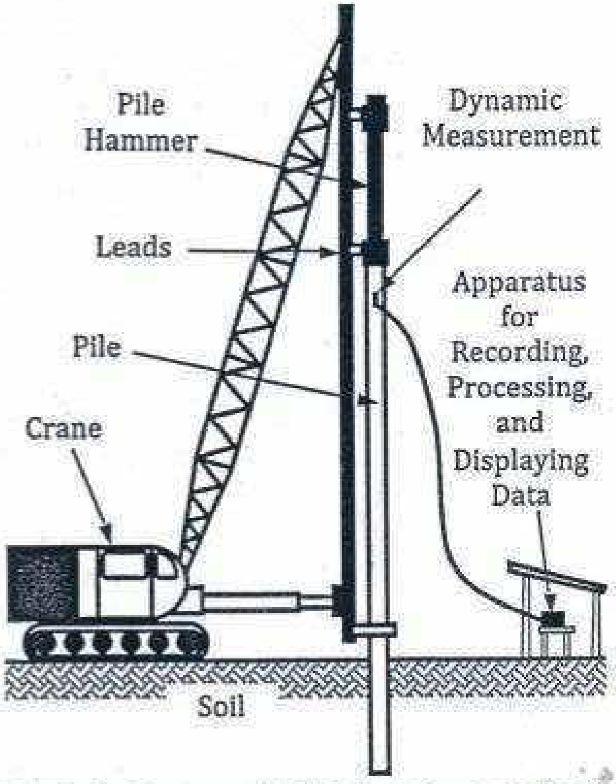


FIG. 2 Typical Arrangement for High-Strain Dynamic Testing of a Deep Foundation

of the impact system, and the maximum compressive and tensile stresses occurring in the pile.

4.2 If sufficient axial movement occurs during the impact event, and after assessing the resulting dynamic soil response along the side and bottom of the pile, the Engineer may analyze the results of a high-strain dynamic test to estimate the ultimate axial static compression capacity (see Note 1). Factors that may affect the axial static capacity estimated from dynamic tests include, but are not limited to the: *(1)* pile installation equipment and procedures, *(2)* elapsed time since initial installation, *(3)* pile material properties and dimensions, *(4)* type, density, strength, stratification, and saturation of the soil, or rock, or both adjacent to and beneath the pile, *(5)* quality or type of dynamic test data, *(6)* foundation settlement, *(7)* analysis method, and *(8)* engineering judgment and experience. If the Engineer does not have adequate previous experience with these factors, and with the analysis of dynamic test data, then a static load test carried out according to Test Method D1143/D1143M should be used to verify estimates of static capacity and its distribution along the pile length. Test Method D1143/D1143M provides a direct and more reliable measurement of static capacity.

NOTE 1—The analysis of a dynamic test will under predict the ultimate axial static compression capacity if the pile movement during the impact event is too small. The Engineer should determine how the size and shape of the pile, and the properties of the soil or rock beneath and adjacent to the pile, affect the amount of movement required to fully mobilize the static capacity. A permanent net penetration of as little as 2 mm per impact may indicate that sufficient movement has occurred during the impact event to fully mobilize the capacity. However, high displacement driven piles may require greater movement to avoid under predicting the static capacity, and cast-in-place piles often require a larger cumulative permanent net penetration for a series of test blows to fully mobilize the capacity. Static capacity may also decrease or increase over time after the pile installation, and both static and dynamic tests represent the capacity at the time of the respective test. Correlations between measured ultimate axial static compression capacity and dynamic test estimates generally improve when using dynamic restrike tests that account for soil strength changes with time (see 6.8).

NOTE 2—Although interpretation of the dynamic test analysis may provide an estimate of the pile's tension (uplift) capacity, users of this standard are cautioned to interpret conservatively the side resistance estimated from analysis of a single dynamic measurement location, and to avoid tension capacity estimates altogether for piles with less than 10 m embedded length. (Additional transducers embedded near the pile toe may also help improve tension capacity estimates.) If the Engineer does not have adequate previous experience for the specific site and pile type with the analysis of dynamic test data for tension capacity, then a static load test carried out according to Test Method D3689 should be used to verify tension capacity estimates. Test Method D3689 provides a direct and more reliable measurement of static tension capacity.

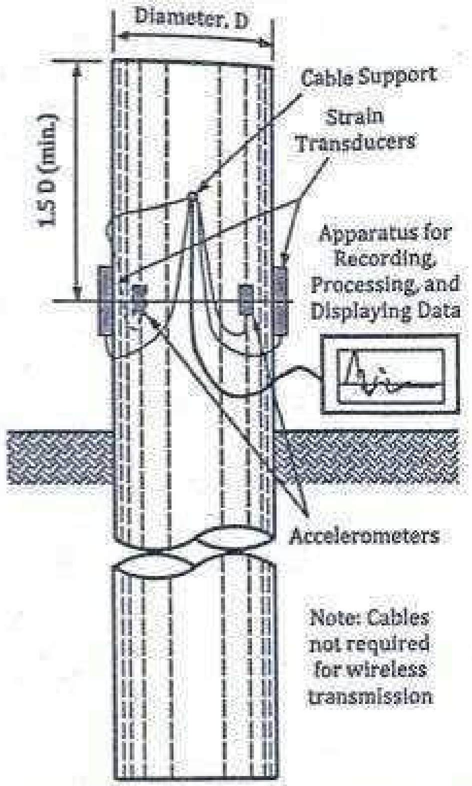
NOTE 3—The quality of the result produced by this test method is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this test method are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

5. Apparatus

5.1 *Impact Device*—A high-strain dynamic test measures the pile response to an impact force applied at the pile head and in concentric alignment with its long axis (see Figs. 2 and 3). The device used to apply the impact force should provide sufficient energy to cause pile penetration during the impact event adequate to mobilize the desired capacity, generally producing a maximum impact force of the same order of magnitude, or greater than, the ultimate pile capacity (static plus dynamic). The Engineer may approve a conventional pile driving hammer, drop weight, or similar impact device based on predictive dynamic analysis, experience, or both. The impact shall not result in dynamic stresses that will damage the pile, typically less than the yield strength of the pile material after reduction for potential bending and non-uniform stresses (commonly 90 % of yield for steel and 85 % for concrete). The Engineer may require cushions, variable control of the impact energy (drop height, stroke, fuel settings, hydraulic pressure, etc.), or both to prevent excessive stress in the pile during all phases of pile testing.

5.2 *Dynamic Measurements*—The dynamic measurement apparatus shall include transducers mounted externally on the pile surface, or embedded within a concrete pile, that are capable of independently measuring strain and acceleration versus time during the impact event at a minimum of one specific location along the pile length as described in 5.2.7.

5.2.1 *External Transducers*—For externally mounted transducers, remove any unsound or deleterious material from the pile surface and firmly attach a minimum of two of each of type of transducer at a measurement location that will not penetrate the ground using bolts, screws, glue, solder, welds, or similar attachment.



NOTE 1—Strain transducer and accelerometer may be combined into one unit on each side of the deep foundation.

FIG. 3 Schematic Diagram of Apparatus for Dynamic Monitoring of Deep Foundations

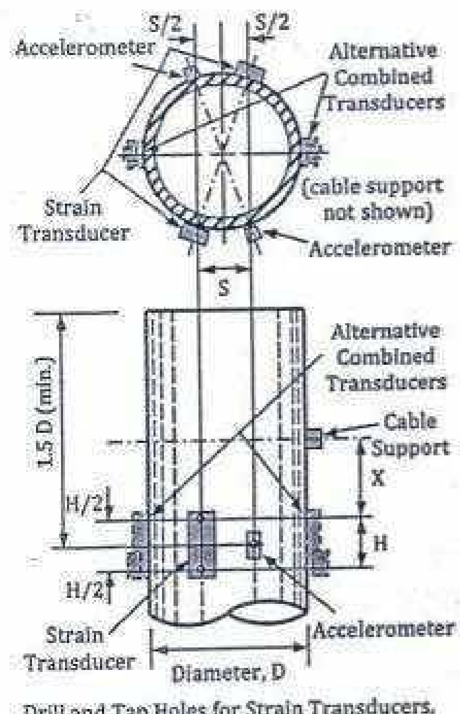
5.2.2 *Embedded Transducers*—Position the embedded transducers at each measurement location prior to placing the pile concrete, firmly supported by the pile reinforcement or formwork to maintain the transducer location and orientation during the concrete placement. When located near the pile head, one of each type of embedded transducer located at the centroid of the pile cross-section should provide adequate measurement accuracy, which may be checked by proportionality (see 6.9). Embedded transducers installed along the pile length and near the pile toe help define the distribution of the dynamic load within the pile, but usually require data quality checks other than proportionality, such as redundant transducers (see 6.9). Embedded transducers shall provide firm anchorage to the pile concrete to obtain accurate measurements; the anchorage and sensors should not significantly change the pile impedance.

5.2.3 *Transducer Accuracy*—The transducers shall be calibrated prior to installation or mounting to an accuracy of 3 % throughout the applicable measurement range. If damaged or functioning improperly, the transducers shall be replaced, repaired and recalibrated, or rejected. The design of transducers, whether mounted or embedded as single units or as a combined unit, shall maintain the accuracy of, and prevent interference between, the individual measurements. In general, avoid mounting or embedding acceleration, velocity, or displacement transducers so that they bear directly on the force or strain transducers, and place all transducers so that they have immediate contact with the pile material.

5.2.4 *Strain Transducers*—The strain transducers shall include compensation for temperature effects, and shall have linear output over the full operating range (typically between –2000 and +2000 microstrain plus an additional allowance for possible strain induced by mounting on a rough surface). Attachment points shall be spaced (dimensions S and H in Figs. 4-7) no less than 50 mm and no more than 100 mm apart. When attached to the pile, their natural frequency shall be in excess of 2000 Hz.

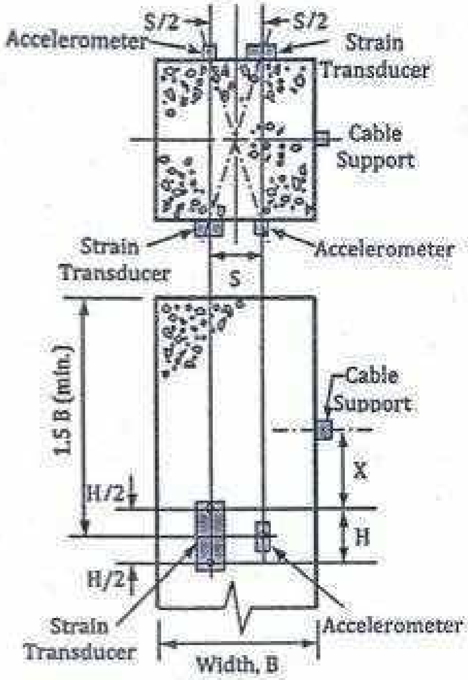
5.2.4.1 As an alternate to strain transducers, axial force measurements can be made by force transducers placed between the pile head and the impact device, or affixed in the pile cross-section, although such transducers may alter the dynamic characteristics of the driving system, the dynamic pile response, or both. Force transducers shall have impedance between 50 and 200 % of the pile impedance. The output signal shall be linearly proportional to the axial force, even under eccentric load application. The connection between the force transducers and the deep foundation shall have the smallest possible mass and least possible cushion necessary to prevent damage.

5.2.5 *Acceleration, Velocity, or Displacement Transducers*—Velocity data shall be obtained by using the dynamic measurement apparatus to integrate the acceleration



NOTE 1—Shown as separate transducers or alternative combined transducers.

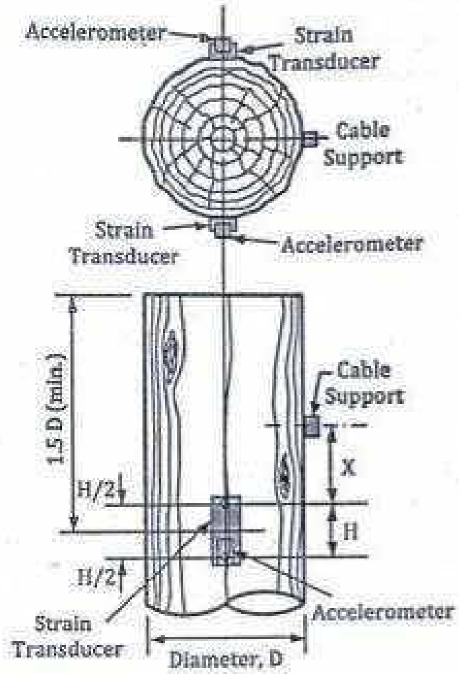
FIG. 4 Typical Arrangement for Attaching Transducers to Pipe Piles



Set Bolt Anchors or Studs for Strain Transducers, Accelerometers, and Cable Supports as Shown. Typically use 6 mm Bolt

NOTE 1—Shown as separate transducers.

FIG. 5 Typical Arrangement for Attaching Transducers to Concrete Piles



Use Lag Bolts for Strain Transducers, Accelerometers, and Cable Supports as Shown. Typically use 6 mm Bolt Size.

NOTE 1—Shown as combined transducers.

FIG. 6 Typical Arrangement for Attaching Transducers to Wood Piles

signals from accelerometers. The accelerometers shall be directly attached to the pile surface, mounted to the pile with small rigid (solid, nearly cubic shape) metal blocks, or embedded in the pile. Do not use overhanging brackets or plastic mounting blocks that can deform during impact. Accelerometers shall be linear to at least 1000 g and 1000 Hz for concrete piles. For steel piles, it is advisable to use accelerometers that are linear to at least 2000 g and 2000 Hz. For piezoelectric accelerometers using an AC coupled signal path, the resonant frequency shall be above 30 000 Hz when rigidly mounted, or above 10 000 Hz if the mounting is damped, and the time constant shall be at least 1.0 s to preserve the low frequency signal content. If piezoresistive accelerometers are used, then they should have a resonant frequency of at least 2500 Hz and a damped mounting. Alternatively, velocity or displacement transducers may be used to obtain velocity data, provided they are equivalent in performance to the specified accelerometers.

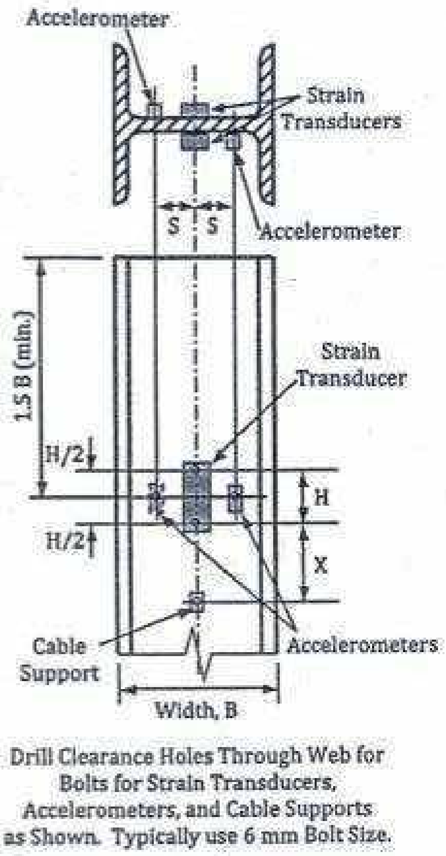
5.2.6 *Combined Transducers*—Force and velocity instrumentation may use individual transducers connected separately to the pile, or transducers connected together and attached to the pile as a combined unit.

5.2.7 *Placement of Transducers*—To avoid irregular stress concentrations at the ends of the pile, locate transducers a distance of at least 1.5 times the pile width from the top (or bottom) of pile as illustrated in Figs. 4-7. (These figures are typical, but not exclusionary.) Align transducers with their sensitive direction parallel to the long axis of the pile. Arrange strain transducers so that when averaged their measurements cancel axial bending stresses. Arrange accelerometers so that when averaged their measurements cancel movements due to bending. Unless located at the pile centroid, place similar types of transducer so that they are symmetrically opposed and equidistant from the pile centroid in a plane perpendicular to the pile axis. Verify the final position, firm connection, and alignment of all transducers, both external and embedded. Section 6.9 describes an important proportionality check required for both external and embedded transducers that helps verify measurement accuracy.

5.3 *Signal Transmission*—The signals from the transducers shall be transmitted to the apparatus for recording, processing, and displaying the data (see 5.4) by means of a cable or wireless equivalent. An intermediate apparatus may be used for initial signal processing prior to transmission of the signal data to the apparatus for recording, processing, and displaying the data if the processing functions it provides meet the requirements of 5.4. Cables shall be shielded to limit electronic and other transmission interference. If wireless transmission is used, the signals arriving at the apparatus shall accurately represent the continuity and magnitude of the transducer measurements over the frequency range of the dynamic measurement apparatus.

5.4 *Recording, Processing, and Displaying Data:*

5.4.1 *General*—The signals from the transducers (see 5.2) shall be transmitted during the impact event to an apparatus for



NOTE 1—Shown as separate transducers.

FIG. 7 Typical Arrangement for Attaching Transducers to H-Piles

recording, processing, and displaying the data. The apparatus shall include a visual graphics display of the force and velocity versus time, non-volatile memory for retaining data for future analysis, and a computational means to provide results consistent with Engineer's field testing objectives, for example, maximum stresses, maximum displacement, energy transferred to the pile, etc. The apparatus for recording, processing, and displaying data shall include compensation for temperature effects and provide a self-calibration check of the apparatus for recording, processing and displaying. No error shall exceed 2 % of the maximum signal expected. Fig. 3 shows a typical schematic arrangement for this apparatus.

5.4.2 *Recording Data*—The raw data from the transducers shall be recorded on site, electronically in digital form, with a minimum of 12 bit ADC resolution and including at most only the minimal processing required to obtain the force and velocity. Transducer data recorded after minimal processing shall also record the information required to recover the raw data signals for later reprocessing as needed, for example, calibrations, wave speed, mass density, pile area, etc. When determining velocity by analog integration of acceleration, or analog differentiation of displacement, use a minimum sample frequency for each data channel of 5000 Hz for concrete piles and 10 000 Hz for timber or steel piles. When determining velocity by digital integration of acceleration, or digital differentiation of displacement, use a minimum sample frequency for each data channel of 10 000 Hz for concrete piles and 40 000 Hz for timber or steel piles. Both analog and digital processing shall include signal conditioning that retains the frequency content appropriate to the sampling rate of the interpreted velocity signal. The minimum total time sampled for each impact event shall be the greater of 100 milliseconds or $3L/c$ (where L is the pile length and c is the pile material wave speed) with most of this time following the moment of impact as shown in Fig. 1.

5.4.3 *Processing Data*—As a minimum, the apparatus for processing signals from the transducers shall provide the following functions:

5.4.3.1 *Force Measurements*—The apparatus shall provide signal conditioning for the force measurement system. If strain transducers are used (see 5.2.4), the apparatus shall compute the net axial force on the cross-section of the pile. The force output shall be balanced to a reference level (for example, zero) prior to the impact event.

5.4.3.2 *Velocity Data*—If accelerometers are used (see 5.2.5), the apparatus shall integrate the acceleration over time to obtain velocity. If displacement transducers are used, the apparatus shall differentiate the displacement over time to obtain velocity. If required, the apparatus shall zero the velocity between impact events and shall adjust the velocity record to account for transducer zero drift during the impact event.

5.4.3.3 *Signal Conditioning*—The signal conditioning for force and velocity shall have equal frequency response curves to avoid relative phase shifts and relative amplitude differences and retain all frequency components in the data below at least 2000 Hz.

5.4.4 *Display of Data*—For each impact event, the raw or processed signals from the transducers specified in 5.2 shall be displayed during data acquisition or replay as a function of time, such as on a digital graphics display.

5.4.5 *Field Supervision*—A qualified engineer shall directly supervise all field testing and assess data quality and reliability for later detailed evaluation (see 6.9). Alternatively, field personnel may transmit the data concurrently as acquired to a qualified engineer supervising the testing from a remote location.

6. Procedure

6.1 *General*—Allow sufficient time for driven and cast-in-place deep foundations constructed of concrete to gain adequate structural strength prior to testing. Record applicable project information (Section 7). Attach the transducers (Section 5) to the deep foundation, perform any calibration checks recommended by the equipment manufacturer, and take the dynamic measurements for the impacts during the interval to be monitored together with routine observations of number of blows per unit penetration ("blow count") or set per blow. Determine the pile response to the high-strain dynamic test from a minimum of ten impact records during initial driving and, when used for soil resistance computations, normally from one or two representative blows at the beginning of a restrike.

NOTE 4—**Warning**—Never approach a deep foundation being tested while the hammer or large drop weight is operating as materials or appurtenances may break free and jeopardize the safety of persons in the vicinity. Preferably the contractor crew will attach the transducers to the pile.

6.2 *Determination of Wave Speed for Deep Foundations*—The wave speed of concrete or wood piles should preferably be determined from an early impact event if a tensile reflection from the pile toe is clearly identified. Divide two times the length of pile below transducers by the observed time between start of the impact (for example, initial sharp rise of the signal) and the start of the tensile reflection (for example, later relative velocity increase) to obtain the wave speed. For piles with instrumentation at both the head and near the toe, the wave speed can be calculated from dividing the distance between these locations by the time between impact arrivals at these locations. Alternatively, place the pile on supports or level ground free and clear from neighboring piles and obstructions. Then attach an accelerometer to the pile and strike the end of the pile with a sledge hammer of suitable weight. Take care not to damage or dent the pile. Record (see 5.4.2) and display (see 5.4.4) the accelerometer signal. Measure the total time between acceleration peaks for at least three cycles of reflection or $6L/c$ (where L is the pile length and c is the pile material wave speed). Divide the product of the number of cycles and twice the total pile length by this total time to determine the wave speed. The wave speed of structural steel piles can be assumed as 5123 m/s. Assumed wave speed values, and those determined during a low strain event, should be verified directly or indirectly if possible. The overall wave speed observed during a high-strain event as described above may differ (typically slower) from the local wave speed used to compute impedance because of variability in pile properties, degradation of pile material during repeated hammer blows, or splices in the pile length.

6.3 *Determination of Mass Density of Deep Foundations*—The density of each wood pile shall be determined from the total weight of the pile, or a sample of the pile, the corresponding volume, and the gravitational constant. The density of concrete or grout can be measured in a similar manner. Alternately, the density of concrete piles is often assumed to be 2450 kg/m^3 and the density of grout used for auger-cast or similar types of piles is often assumed to be 2150 kg/m^3. The mass density of structural steel piles can be assumed as 7850 kg/m^3. The mass density of composite deep foundations, such as concrete filled steel pipes, can be computed from a weighted average of the areas of the materials at each differing cross-section. Assumed and computed values of mass density should be verified directly if possible, or indirectly through their effect on impedance and proportionality (see 6.9).

6.4 *Determination of Dynamic Modulus of Elasticity of Deep Foundations*—The dynamic modulus of elasticity (E) for concrete, wood, steel, or composite piles can be computed as the product of the square of the wave speed (determined as indicated in 6.2) times the mass density ($E = \rho c^2$). The dynamic modulus of elasticity may be assumed as 207 × 10^6 kPa for structural steel. Assumed and computed values of the dynamic modulus of elasticity should be verified directly if possible, or indirectly through their effect on impedance and proportionality (see 6.9).

NOTE 5—Alternatively, the static modulus of elasticity for concrete piles and wood piles may be determined from measurements made during a compression test performed in accordance with Test Methods C469 or D198 respectively. The Engineer should then estimate the dynamic modulus (typically assumed 10 % greater) from this measurement.

6.5 *Preparation*—Mark the pile clearly at appropriate unit intervals to prepare for recording blow counts. Attach the transducers as described in Section 5. Determine the pile wave speed (see 6.2) and density (see 6.3). For concrete piles or concrete filled pipe piles, place a pile cushion made of plywood or other material with similar stiffness on top of the pile. For concrete filled pipe piles, the concrete must completely fill the pile top so that the impact is transferred through the pile cushion to the concrete. Position the impact device on the pile head to apply the impact force concentric with the long axis of the pile. Prepare the apparatus for recording, processing, and displaying data to receive the dynamic measurements and balance the strain (or force) and acceleration signals to their respective reference levels (for example, zero).

6.6 *Recording Hammer Information*—Record the mass of the hammer ram or drop weight. For drop hammers and single acting diesel and air/steam/hydraulic hammers, record the drop height of the ram or the ram travel length. For double acting diesel hammers, measure the bounce pressure, and for double acting steam or compressed air hammers, measure the steam or air pressure in the pressure line to the hammer. For hydraulic hammers or any of the previously listed hammer types, record the kinetic energy from the hammer readout when available. Record the number of impact blows per minute delivered by the hammer.

6.7 *Taking Measurements*—Take, record, and display force and velocity measurements for each impact event. Compare the force and the product of velocity and impedance at the moment of impact (see 6.9). Obtain the net permanent displacement per impact from the pile driving blow count record, or from marks placed on the pile prior to and after the test using the same reference, directly from the displacement transducers (if used), or by integration of the velocity versus time record (typically less reliable). Obtain the maximum energy transferred to the location of the transducers from the integral over time of force multiplied by velocity.

6.8 *Time of Testing*—Dynamic tests performed during the initial installation of a driven pile typically monitor the performance of the impact device, the driving stresses in the pile, the pile integrity, and relative changes in capacity. If the test results are used for static capacity computations, then dynamic measurements should (also) be performed during restrikes of the deep foundation, after waiting a period of time following the initial installation sufficient to allow pore water pressure and soil strength changes to occur. (See Note 1.)

6.9 *Data Quality Checks*—Confirm the accuracy of dynamic measurements obtained near the pile head by periodically checking that the average of the measured force signals and the product of the impedance and the average of the measured velocity signals agree proportionally at the moment of impact.

Do not expect proportionality when reflections occur from pile impedance changes nearby and below the transducers or from soil resistance, such as for transducers near the pile bottom or, depending on the rise time to the initial force peak, transducers located between the pile head and the bottom. Reject non proportional data. Two velocity signals should generally agree well at a particular measurement location, even though the two force signals may indicate significant bending. Two embedded strain measurements made in close proximity to the pile axis at the same location, or at adjacent locations on the pile axis, can provide a consistency check of each other. For piles with a high percentage of end bearing, analysis of measurements made near the pile head may provide confirmation of measurements near the pile bottom. For an impact device delivering relatively similar impacts, the force and velocity versus time over a series of consecutive impact events should be relatively consistent. Consistent and proportional signals of (average) force versus (average) velocity times pile impedance are the result of the transducer systems performing properly and the apparatus for recording, processing, and displaying data being properly calibrated. If the signals are not consistent, or are not in proportionality agreement, investigate the cause and correct as necessary. If the cause is loose or misaligned instrumentation, then correct the problem prior to continuing the test. If the cause is determined to be a transducer malfunction, it must be repaired or recalibrated, or both, before further use. If the cause cannot be determined and rectified, then the test is to be rejected. Perform self-calibration checks of the apparatus used for recording, processing, and displaying data periodically during testing as recommended by the manufacturer, and recalibrate before further use if found to be out of manufacturer's tolerance.

NOTE 6—It is generally recommended that all components of the apparatus for obtaining dynamic measurements and the apparatus for recording, processing and displaying data be calibrated at least once every two years to the standards of the manufacturer.

6.10 *Followers and Mandrels*—If a follower is used for installing and testing cast-in-place concrete deep foundations, this follower should have an impedance between 80 and 150 % of that of the deep foundation. However, additional caution and analysis may be required if the impedance is not within 10 % of that of the deep foundation. For mandrel-driven piles, the mandrel may be instrumented in a similar way to a driven pile provided that the mandrel is constructed of a single member with no joints.

6.11 *Testing Cast-in-Place Deep Foundations*—For testing cast-in-place piles it is often advantageous to build up the top of the pile to encase protruding reinforcement, to strengthen it for the impact using a steel shell, or to eliminate excessive excavation (sensors must be mounted at least 1.5 diameters below the impact location). The pile top should be flat and square to the longitudinal pile axis, and should be protected with plywood cushions, or other cushion material of uniform thickness. A thick steel plate may also be placed on top of the plywood to distribute the impact. Preferably apply a series of single impact blows using a drop mass having a weight of at least 1 to 2 % of the desired ultimate test capacity, beginning with a low drop height to check transducer function and pile stresses and then progressing to greater drop heights to mobilize additional pile capacity. For externally mounted transducers, carefully select transducer locations having sound concrete, and grind or sand the pile as necessary to obtain a smooth, flat, clean surface on which to mount the transducers parallel to the pile axis. Because cast-in-place piles may have non uniform material properties and a variable, irregular cross-section, when using externally mounted transducers consider placing four strain transducers equally spaced around the perimeter and as described in 5.2.7. The average force determined from each diametrically opposed pair of transducers can then be compared together, and with the average velocity as in 6.9, to assess the data quality of all force measurements.

NOTE 7—The strength and dynamic modulus of elasticity for cast-in-place deep foundations depends on the quality and the age of concrete, and can vary considerably over the cross-section and along the length of the deep foundation. The dynamic modulus of elasticity as calculated from the wave speed (see 3.2) will therefore be an average value which may differ from the modulus at the transducer location. If the cast-in-place deep foundation is encased in a steel shell, then use a composite mass density and composite dynamic modulus of elasticity.

7. Report

7.1 The report of the load test shall include any information required by the Engineer plus the following information when applicable and as available.

7.2 *General:*

7.2.1 Project identification and location, and

7.2.2 Log(s) of nearby or typical test boring(s).

7.3 *Deep Foundation Installation Equipment:*

7.3.1 For driven piles: description of driving methods and installation equipment used for driving piles, testing piles, or both as appropriate, for example, make, model, and type of hammer, size (ram weight and stroke), manufacturer's energy rating, capabilities, operating performance levels or pressures, fuel settings, hammer cushion and pile cushion descriptions with cushion exchange details, and description of lead type and any special installation equipment such as a follower, mandrel, punch, pre-drill or jet.

7.3.2 For cast-in-place concrete piles: description of construction methods, drilling or augering equipment, and concrete or grout placement, for example, type of drill rig, type and dimensions of drill tool(s), auger(s), and cleanout tool(s), tremie, concrete or grout pump, and casings.

7.4 *Test Pile(s):*

7.4.1 Identification (name and designation) of test pile(s),

7.4.2 Required ultimate axial static compressive capacity,

7.4.3 Type and dimensions of deep foundation(s) including nominal or actual cross-sectional area, or both, length, wall thickness of pipe or casing, and diameter (as a function length for tapered or composite deep foundations),

7.4.4 For driven or cast-in-place concrete piles: date(s) test pile constructed or cast, design and measured concrete cylinder strengths and date of test(s), density, effective prestress, and description of internal and external reinforcement (type, grade, size, length, number and arrangement of prestress wire, longitudinal bars, lateral ties, and spiral stiffeners; casing or shell size and length), 7.4.5 For steel piles: steel designation, grade, minimum yield strength, and type of pile (for example, seamless or spiral weld pipe, H section designation),

7.4.6 For timber piles: length, straightness, preservative treatment, tip and butt dimensions (and area as a function of length), and measured density for each pile,

7.4.7 Description and location of splices, special pile tip protection, and any special coatings applied if applicable,

7.4.8 Inclination angle from vertical, design and installed, and

7.4.9 Observations of deep foundations including spalled areas, cracks, head surface of deep foundations.

7.5 *Deep Foundation Installation :*

7.5.1 For cast-in-place piles, include the volume of concrete or grout placed in deep foundation (volume versus depth, if available), and a description of installation procedures used, such as casing installation or extraction,

7.5.2 For driven piles, include date of installation, driving records with blow count, and hammer stroke or operating level for final unit penetration,

7.5.3 Elevations of the pile top, pile bottom, and ground surface referenced to a datum, and

7.5.4 Cause and duration of installation interruptions and notation of any unusual occurrences.

7.6 *Dynamic Testing:*

7.6.1 Description of the dynamic test apparatus, including make, model, analog or digital velocity integration, sampling rate, transducers, measurement location(s), etc.,

7.6.2 Date of test(s), sequence of testing (for example, "end of driving" or "beginning of restrike"), and elapsed time since end of initial driving for restrikes,

7.6.3 Density, wave speed, and dynamic modulus of elasticity of the test deep foundation, reporting each quantity with three significant digits, but not to exceed the precision of the measurement,

7.6.4 Penetration resistance (blows per unit penetration, or set per blow) and embedment depth,

7.6.5 Graphical presentation of velocity and force measurements in the time domain for representative blows,

7.6.6 Analysis method(s) used to interpret or evaluate test measurements,

7.6.7 Interpretation of the test measurements, including measurements down the pile if applicable, to estimate as appropriate the overall magnitude of the dynamic and static axial compressive capacity mobilized at the time of testing, the distribution of the dynamic and static axial compressive capacity along the pile length, and the engineering properties of the pile and the soil or rock adjacent to the pile as used in the interpretation,

7.6.8 Comments on the performance of the impact device as measured by the energy transferred into the deep foundation with comparison to manufacturer's rating or ram weight and drop height,

7.6.9 Comments on the driving stresses within the deep foundation, and whether measured or estimated through analysis,

7.6.10 Comments on the integrity of the deep foundation, and

7.6.11 Numerical summary of measured and interpreted results, with statistical analysis as appropriate, reporting time in milliseconds at the rate digitized, and other quantities with three significant digits, but not to exceed the precision of the measurement.

8. Precision and Bias

8.1 *Precision*—Test data on precision is not presented due to the nature of this test method. It is either not feasible or too costly at this time to have ten or more agencies participate in an in situ testing program at a given site. The inherent variability of the soil, or rock, or both surrounding the pile, the pile driving apparatus, and the pile itself adversely affect the determination of precision.

8.1.1 The Subcommittee D18.11 is seeking any data from the users of this test method that might be used to make a limited statement on precision.

8.2 *Bias*—There is no accepted reference value for this test method, therefore bias cannot be determined.

9. Keywords

9.1 augered piles; deep foundations; drilled shafts; driven piles; driving stresses; dynamic testing; pile bearing capacity; pile driving hammer performance; pile integrity

LAMPIRAN – D

DOKUMENTASI

Dokumentasi PDA Test : Golf Simprug
Jakarta

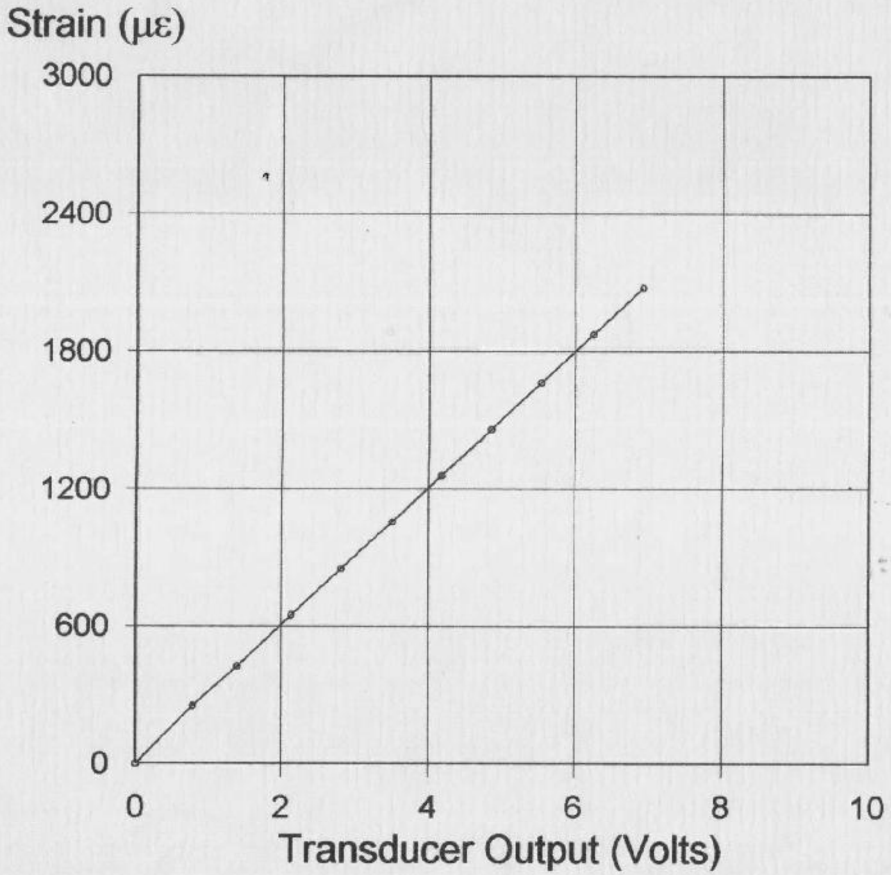
Pile No.80

Pile No.129

Pile Dynamics, Inc.

GEOTECH CALIBRATION

Transducer R168



PDA Cal Factor (5.0 V) 149.7με/V

Applied Strain (με)	Transducer Output (Volts)
0	0.00
253	0.79
424	1.39
646	2.13
850	2.80
1053	3.49
1258	4.17
1460	4.84
1663	5.53
1876	6.24
2077	6.92

Shunt (60.4 KΩ) 2.5 V

General Factor 519.6με/mV/V

Traceable to N.I.S.T.

Calibrated by: Dennis Rio Perdana

Calibrated on: 09-Nov-2020

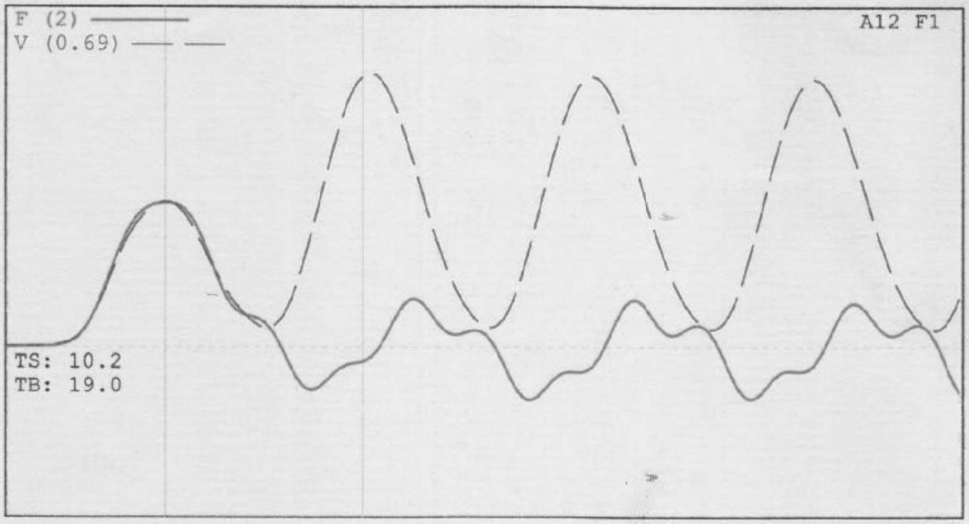
Strain Transducer Calibrator System 2011 Version 1.5

GEOTECH CALIBRATION

Pile Driving Analyzer ®

GEOCAL

52354



Project Information

PROJECT: GEOCAL
PILE NAME: 52354
DESCR: HOPKINSON BAR
OPERATOR: DNS
FILE: 52354.W01
09/11/2020 15:13:51
Blow Number 7

Pile Properties

LE	5.4 m
AR	7.04 cm^2
EM	2109 t/cm2
SP	7.88 t/m3
WS	5123.0 m/s
EA/C	2.9 tn-s/m
2L/C	2.11 ms
JC	0.60 []

Quantity Results

RMX	0 tn
RSU	0 tn
EMX	0.00 tn-m
ETR	0.0 (%)
CSX	11.8 MPa
TSX	11.9 MPa
DMX	19 mm
DFN	19 mm
CSI	11.8 MPa

Sensors

F1: [H118] 94.99 (1)
A1: [34906] 1080 g's/v (1)
A2: [52354] 1081 g's/v (1)
CLIP: OK

Version 2016.125

Pile Dynamics, Inc.

Contact PDI- GEOCAL
Tel USA 216-831-6131
Tel INA 62-21-658-35493

Accelerometer Calibration N.I.S.T. Traceable

Serial Number	: 52354
Calibration	: 1081 g's/V
Date	: 09- November - 2020
PDA Operator	: Dennis Rio Perdana