CORRELATION OF CAPWAP WITH STATIC LOAD TESTS

Garland Likins[1] and Frank Rausche[2]

ABSTRACT

Signal matching analysis such as CAPWAP is considered a standard procedure for the capacity evaluation from high strain dynamic pile testing data. Using one pile top measurement, like the downward stress wave, CAPWAP iteratively alters the soil model to calculate and obtain a best match with the complimentary wave, such as the measured upward traveling wave. Previous studies of databases, and individual experience, have demonstrated generally good correlation of CAPWAP signal matching results on dynamic restrike tests with static load tests. The Proceedings of all six previous Stresswave conferences were reviewed to extract correlation cases which included both CAPWAP restrike results and static load tests. Results are summarized in a database and also presented separately for both 119 driven piles and for 23 cast-in-situ foundations such as drilled shafts and augercast-CFA piles. A statistical evaluation of results categorized by pile type is presented with a discussion of noted differences. Combined with previous studies in 1980 and 1996, the database now contains 303 case histories. The statistical results are valuable for future research into the reliability evaluation of safety and resistance factors of dynamic methods.

Keywords: CAPWAP, signal matching, static test, dynamic test, correlation, piles, drilled shafts

1. INTRODUCTION

Although there are many applications for dynamic pile testing, bearing capacity being the main one. The ability to accurately predict static capacity from dynamic pile testing has resulted in many studies, and has been the focus of dynamic pile tests on many project sites. Standard practice requires performing signal matching on the data to more accurately determine capacity from the dynamic tests.

Reliable correlations for long term capacity from dynamic tests with static load tests require simple guidelines. For driven piles, dynamic tests should be performed during a restrike after a sufficient wait period to allow soil strength changes to stabilize. Ideally, the time after installation for the dynamic test should be similar to that of the static test, and preferably as soon as possible after the static test completion. However, time pressures in the construction schedule often require dynamic testing after a limited wait time, and the full "setup" increase is then not achieved. Testing of drilled shafts or augercast piles requires the concrete or grout to achieve a sufficient strength, which indirectly allows the soil to recover from the drilling process. The driven or drilled pile must also experience a reasonable net set per blow (typically 2 mm or more) to mobilize the full capacity. Since dynamic testing of drilled shafts often results in a small set per blow, the capacity predicted would be biased on the conservative side.

Often the project engineer has then reported results for a particular project, or from a study of a series of projects, in the six previous Stresswave Conference Proceedings. While these papers are individually interesting and informative, this paper summarizes the two previous major studies (Goble et al 1980, Likins et al 1996) and a compilation of these individually reported results from previous Stresswave Conferences into a single research document. The data can then be viewed statistically for trends and to allow for computation of rational resistance factors for LRFD (load-resistance factor design) applications.

Based on the original research work at Case Western Reserve University under the direction of Dr. G. G. Goble, the CAPWAP analysis procedure was both developed and reported (Goble et al 1980). The

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[1] President, Pile Dynamics, Inc., 4535 Renaissance Pkwy, Cleveland OH 44128 USA
[2] President, GRL Engineers, Inc., 4535 Renaissance Pkwy, Cleveland OH 44128 USA

CAPWAP model for soil resistance is similar to the classical Smith model (Smith 1960), but with extensions to account for unloading behavior not originally considered by Smith, and have little effect on total capacity. Most data in the Goble et al (1980) database was from closed end steel pipe piles, predominant in Ohio, reflecting the sponsored research goals. Additional tests performed in cooperation with Federal Highway Administration (FHWA) and other state agencies demonstrated similar accuracy on H, timber, and concrete piles. The scattergraph of CAPWAP (CW) results versus static load test (SLT) is shown in Figure 1.

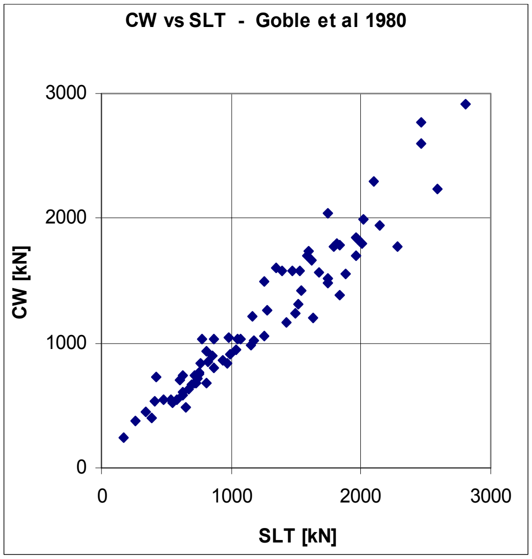

Figure 1: correlation of Goble's 1980 study

The authors subsequent experience and a research project sponsored by FHWA led to a correlation database, including additional data received from an open call for data from several dynamic testing firms; all data received was included without regard to correlation results, provided it had good quality dynamic data from restrike, a measured blow count with sufficient set per blow, a static test to failure (Davisson interpretation), a soil boring, and known dates of both restrike and static test relative to installation. In contrast to the original 1980 study, only 36 of the 83 piles were steel, and only 19 were pipes. The results of both the usual "Best Match" and the extended "Radiation Damping" solutions (Likins et al 1996) are shown in Figure 2.

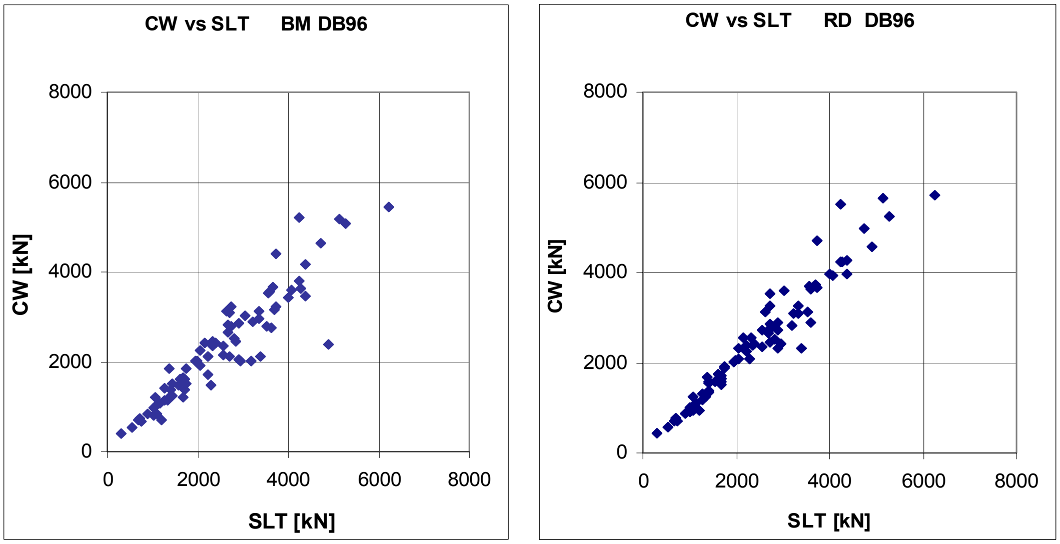

Figure 2: correlation of the 1996 database (left: Best Match, right: Radiation Damping)

In both the original study (Goble et al 1980) and the subsequent effort (Likins et al 1996), the data (from driven piles only) was analyzed by the then state-of-the-art CAPWAP analysis. The 1996 study included investigation of the fully automatic CAPWAP method which performs all calculations without any human interaction; correlation results are very good, demonstrating the inherent reliability for capacity evaluation from dynamic testing. A statistical overview of past and current studies is given in Table 1. Average CAPWAP to SLT ratio is given, with coefficient of variation (COV), the number of sample data points (N), and the Correlation coefficient (Correl). The improvement in the results for the Radiation Damping (RD) model is obvious for the 1996 data. This RD model is most helpful for higher blow count situations (low set per blow), but is not recommended for very easy driving (Likins et al 1996).

Study	CW/SLT	C.O.V.	N	Correl	notes	note2
1980	1.010	0.168	77	0.960	Goble et al 1980 study	
1996	0.964	0.223	83	0.861	automatic only	BOR = begin of restrike
1996	0.955	0.197	51	0.902	automatic only	BOR = 6+ days
1996	0.931	0.166	83	0.927	Best match	
1996	0.920	0.177	51	0.951	Best match	BOR = 6+ days
1996	1.012	0.097	83	0.967	radiation damping	
1996	1.009	0.081	51	0.971	radiation damping	BOR = 6+ days
SW	0.993	0.165	143	0.984	all piles:	“SW” from 6 “Stress Wave” Conferences
SW	0.983	0.156	119	0.987	all driven piles	
SW	0.987	0.161	70	0.968	all driven concrete	
SW	0.974	0.149	46	0.990	all driven steel	
SW	1.037	0.199	23	0.981	all drilled and cfa	
SW	1.028	0.164	65	0.990	BOR 5+ days	
SW	0.972	0.147	45	0.989	BOR/slt > 0.25	
SW	1.039	0.200	49	0.933	all piles	cw/Davisson
SW	0.982	0.139	15	0.982	all piles	cw/D10
SW	0.910	0.183	96	0.981	all piles	cw/max
SW	0.968	0.101	24	0.989	all piles	C20/u20
All	0.980	0.169	303	0.983	1980, 1996 using best match data, plus SW	
	0.888	0.184	179	0.977	1996 plus SW	Cw/max
2000	0.930	0.146	75		Static versus static - Paikowsky slow MLT (Dav.) versus cyclic capacity	

Table 1: Statistical summary of the correlation studies

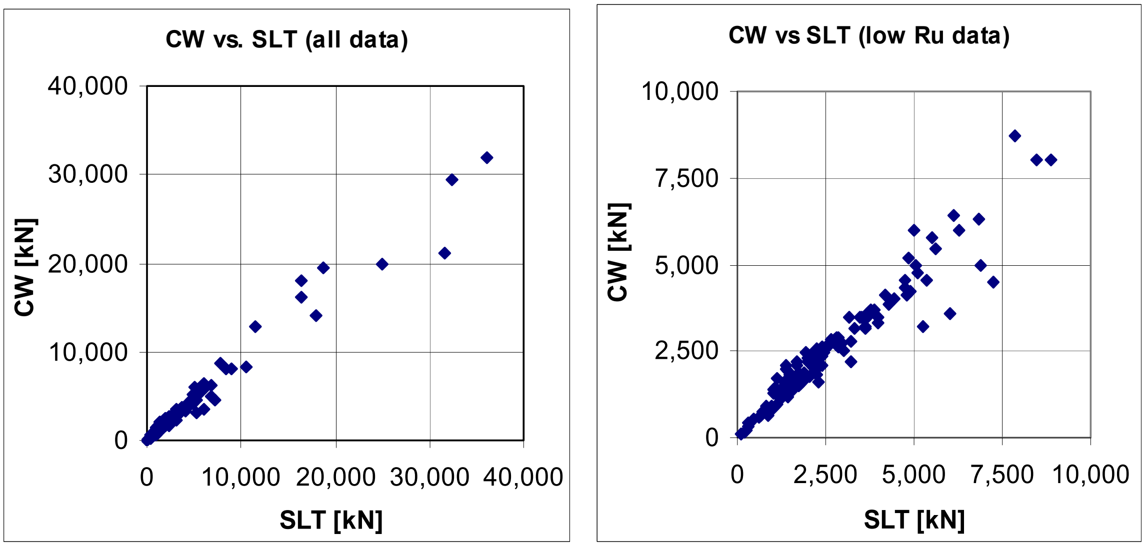

Figure 3: Compilation of correlations from previous Stresswave Conferences (N= 143)

2. STRESSWAVE CONFERENCE PROCEEDING RESULTS

Numerous papers in the previous six Stresswave conference proceedings report correlations of CAPWAP analyses by various authors on restrikes with static load tests. A total of 143 results were identified, compiled and presented in Table 1 (marked SW), Figure 3a and Appendix A. Capacity was determined dynamically from restrike testing of 119 driven piles, and also for 23 cast-in-situ piles (e.g. drilled shafts and augercast –CFA piles) following a sufficient curing time for the concrete. Many papers contained only numerical results for either CAPWAP or SLT. In all cases, the author's determination of the static load test result was used. For example, Seidel and Rausche (1984) present a CW prediction of 21,200 kN for the Chin SLT projection of 31,700 kN, even though the maximum applied load for that test was only 20,000 kN (the plotted static test curve was flat at the max 20,000 kN). Where different evaluations of the static load test were presented, the method selected for correlation was the Davisson method. Most papers included a basic description of the soil conditions, but many papers failed to identify the blow count (set per blow). Because of the recent trend toward increased design loads and more frequent use of dynamic load testing for high capacity drilled shafts, Figure 3b also shows only the results below 10,000 kN in more detail.

Because pile capacity generally changes over time, proper evaluation of capacity must consider time dependent effects. Unfortunately, only slightly less than half of the cases contained information on dates of dynamic testing and static testing relative to installation date. Inclusion of dates allows computation of the "Time Ratio", defined as the time of the dynamic test divided by the time of the static test, both relative to the installation date. So that time dependent soil strength changes after installation are minimized, a Time Ratio of 1.0 is usually ideal (except for extremely sensitive soils). Restrike tests after a very brief time (e.g. one day) often resulted in relatively low prediction (compared with a much later SLT) since the typical strength gains from setup were not fully realized in the dynamic test. Dates of tests, relative to date of installation, should be included in future reporting of results.

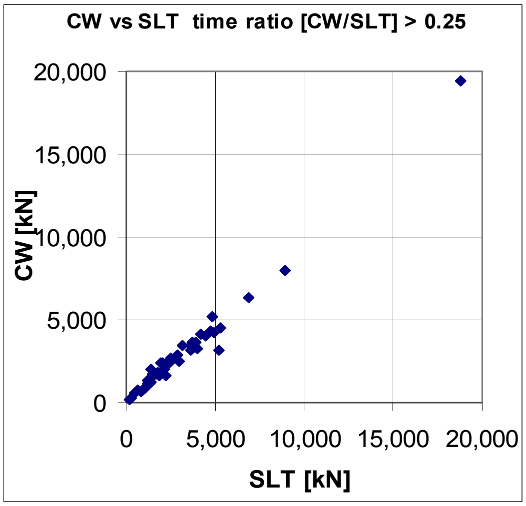

Figure 4: Correlation for Time Ratio > 0.25

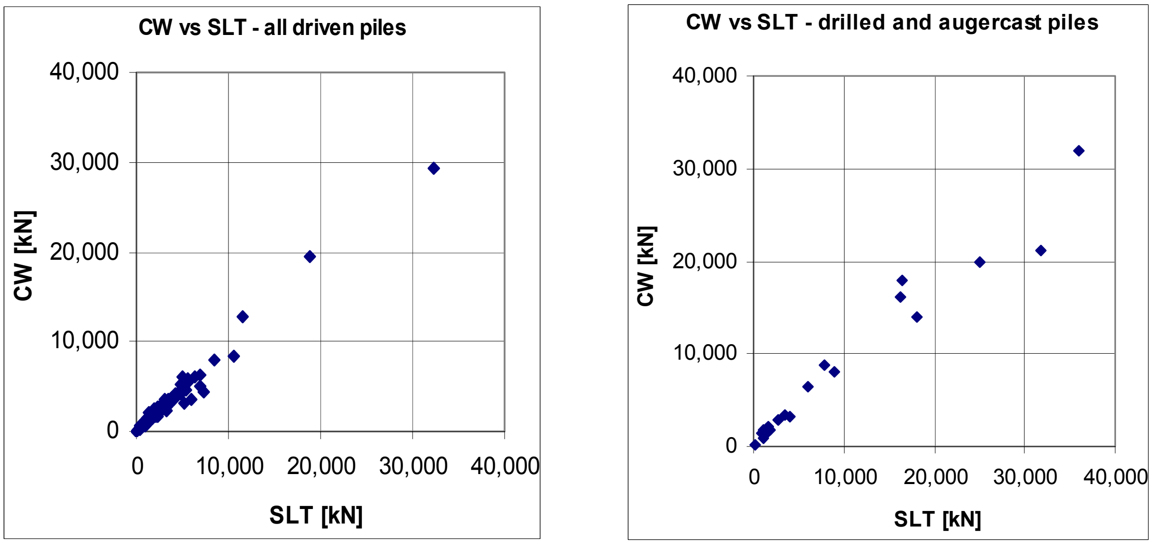

Figure 5: Stresswave Correlations for driven and cast-in-situ piles

As shown in Figure 4 and confirmed by statistics in Table 1, restrikes after longer waiting periods (e.g. 6 days) or with Time Ratios greater than 0.25 result in significant reduction of the coefficient of variation, and are therefore desirable.

Figure 5 presents the results separately for driven piles and for cast-in-situ drilled and augered piles. Table 1 shows a lower coefficient of variation for driven piles. This is perhaps due to more reliable information for driven piles of both the shape (e.g. cross section area versus pile length) and modulus of elasticity (used to calculate force from the measured strain), which are well known or easily determined. For drilled shafts, and especially CFA piles, the pile cross sectional area varies with the length.

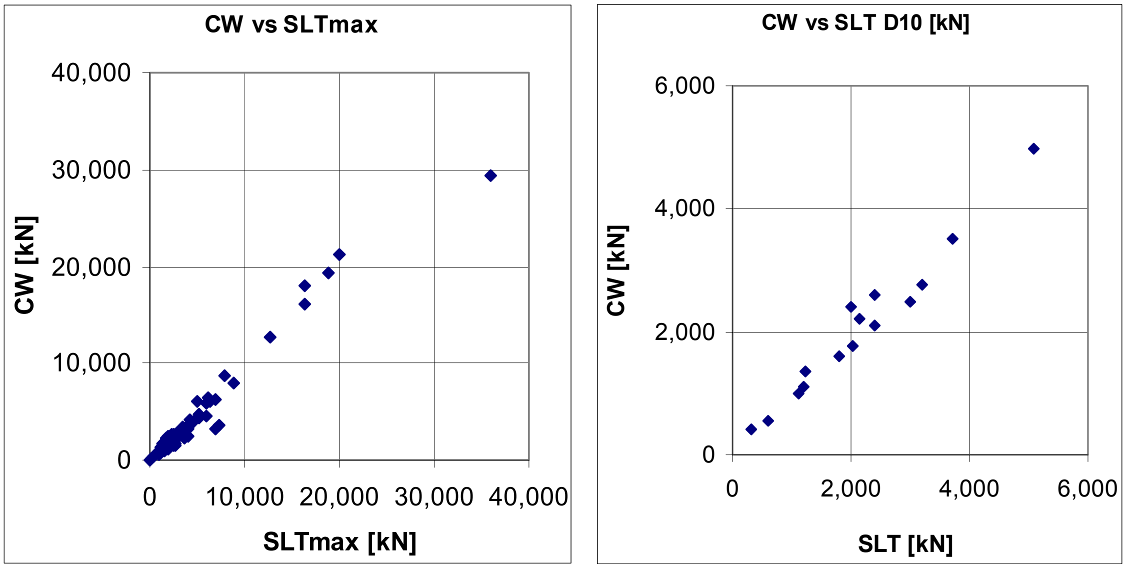

Figure 6: Stresswave Correlations for other definitions of SLT "failure" (left, maximum; right, D/10)

Because the interpretation of the SLT failure load is subjective, Figure 6 presents the CW results relative to other SLT interpretations (where available), namely the maximum applied load and the D/10 criterion which is popular for assessing drilled shaft capacity (D/10 results were all from small diameter piles, and conclusion may not extrapolate to larger shafts). The value of comparing these other failure definitions is illustrated by Lee et al (1996) who presented 8 of the 12 highest CW/SLT ratios for Davisson method, while most of Lee's reported CW results were actually very comparable to his reported SLT maximum load. Of course, the maximum SLT load is related to the applied maximum displacement. All methods are sensitive to measurement errors (SW papers usually did not report if a load cell was used to measure force). For both alternate methods (max and D/10), the coefficient of variation was reduced and the correlation coefficient improved.

TEST TYPE	**Avg.**	**COV**	**Correl**	**N**
DeBeer	0.768	0.210	0.842	24
Housel	0.822	0.120	0.872	22
Corps of Engineers	0.913	0.095	0.882	24
Davisson	**0.945**	**0.092**	**0.915**	17
Tangent Intersection	0.998	0.086	0.872	24
Shen-Niu	1.008	0.086	0.939	23
Butler-Hoy	1.025	0.081	0.925	24
Brinch-Hansen 90%	1.075	0.044	0.960	15
Fuller-Hoy	1.091	0.067	0.950	24
Mazurkiewicz	1.153	0.072	0.932	24
Brinch-Hansen 80%	1.240	0.176	0.796	20
Chin-Kondner	1.511	0.326	0.515	23

Table 2: Correlations of different failure criteria (after Duzceer & Saglamer, 2002)

At the 2000 Stresswave conference, Paikowsky correlated one SLT type with another SLT method on the same pile; interestingly, the statistics (Table 1) for these 75 cases of Davisson versus cyclic SLT interpretation are comparable to the restrike CAPWAP to SLT result. Duzceer (2002) compared 12 different failure criteria on 24 piles (14 driven and 10 drilled). Because there is no universal consensus as to a definite preferred criteria, the "average" failure load from all Duzceer tests (but ignoring Chin result) was taken as the "correct" answer. In comparing the ratio of individual criteria to this "average", Table 2 shows a wide difference in SLT failure loads for the different criteria and considerable scatter (COV), especially for methods with very low or high average ratios. Some failure definitions are relatively conservative (e.g. DeBeer, Housel); others are non-conservative (e.g. Mazurkiewicz, Brinch-Hansen 80%, Chin). The other seven methods fall within an 18% range (±9% of the average). The average Davisson result, used for the 1980 and 1996 studies and by many SW authors, was about 5% below the "average". Since the range of results in Table 1 of CAPWAP to SLT ratios is smaller than even the 18% range for the middle seven SLT failure definitions, CAPWAP is about as reliable for determining the ultimate capacity as any SLT definition of failure. The CAPWAP result is generally conservative since, statistically, it is less than Davisson, and Davisson is less than the average interpreted failure load.

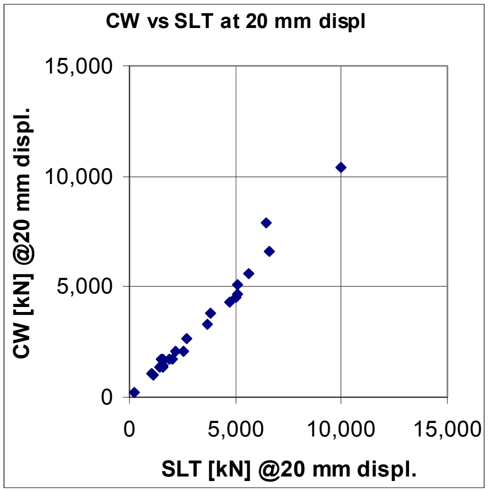

Fig 7: Comparison at 20 mm displacement

A comparison of the CAPWAP result with SLT load, both for a displacement of 20 mm, is shown in Figure 7. Correlation of results, as confirmed by the statistics in Table 1, is excellent and reflects the accuracy and precision of the CAPWAP calculated stiffness of the pile and soil system, and soil resistance distribution.

Combining the 1980 Goble study and the 1996 Likins study (using the "best match" method) with the review of previous Stresswave conferences (SW), the 303 cases are then presented in Figure 8 (lower capacity result detail is presented in Figure 8b). For the 303 cases, Table 1 shows an average CW/SLT ratio of 0.98 with COV of 0.169.

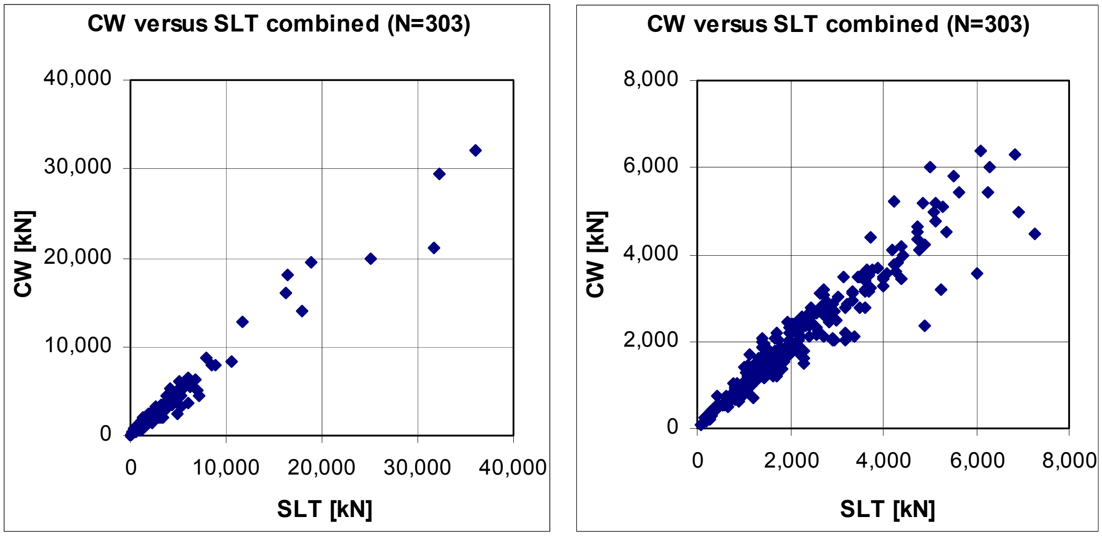

Figure 8: Combined results of previous and current correlation studies of CAPWAP versus SLT

Figure 9 presents the correlation of CAPWAP to the maximum applied static load for 179 cases combined from the 1996 and SW database. The average ratio is only 0.888 (Table 1), showing CAPWAP to be conservative, but with a COV of 0.184.

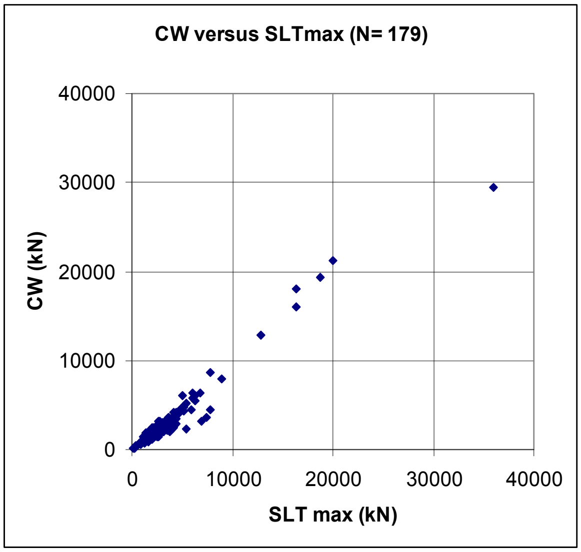

Figure 9: Correlation of CW with max SLT for SW and 1996 database studies

While the results from Figure 8 suggest good correlation, they also point out that there are some cases where CAPWAP overpredicts. Using the author's definition for the SW database and Davisson for the 1996 database, Figure 10 shows a histogram for the ratios of CAPWAP to static load test result. Clearly, results are normally distributed and few cases exceed a ratio of 125%. The selection of static test failure load, being somewhat arbitrary, comparison of the CAPWAP result to the maximum applied load for the same combined database is shown in Figure 11 for the 179 cases where the static load test curve is available. In this view, only for 1% of the combined data does the ratio of CAPWAP to maximum applied load exceed 125%. Such relatively small overprediction is not likely to cause problems for the foundation as it is well within the usual safety factor applied. Less than 9% of the cases exceed a ratio of 110%. It should be further noted that the applied maximum static load is also probably not the true maximum reserve strength of the pile. If the SLT were carried to larger applied displacements, then the maximum applied loads would also increase in many cases, and the CAPWAP to SLT ratio would be further reduced. It is suspected that many of the very low ratios include either cases with substantial setup where the restrike was performed very early, or where the blow count was near refusal and did not activate the full capacity.

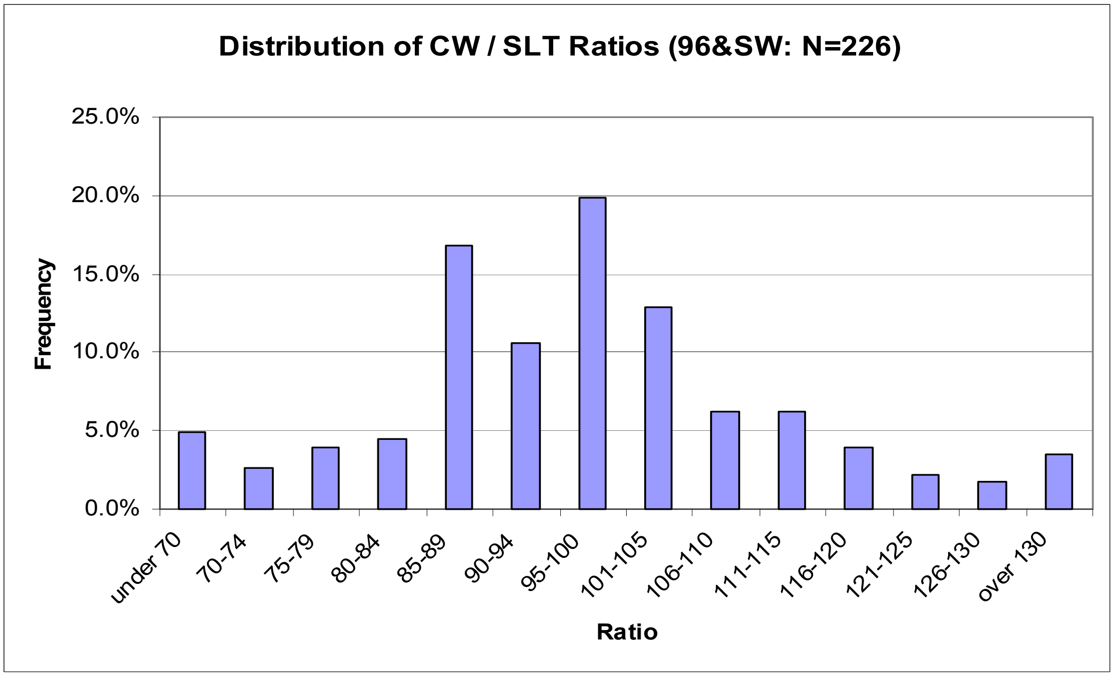

Figure 10: Distribution of CAPWAP to SLT ratios for 1996 and SW database studies

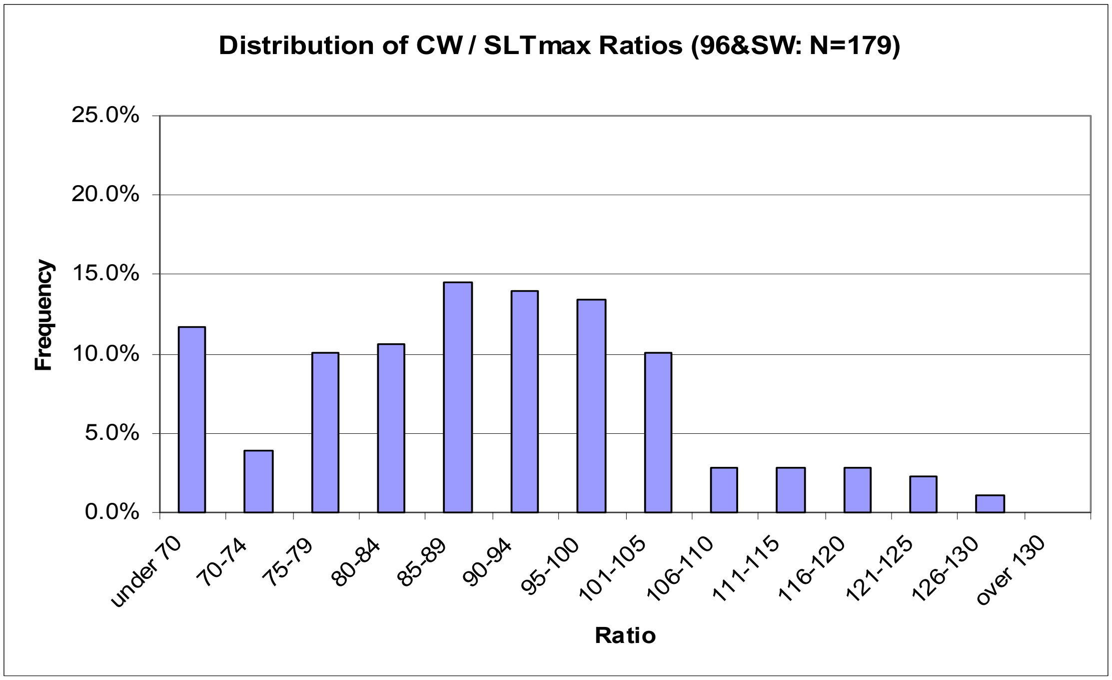

Figure 11: Distribution of ratios of CAPWAP to SLT (max applied load)
for 1996 and SW database studies

3. CONCLUSIONS

Statistical evaluation of previous studies and the current compilation of results from previous Stresswave conferences show the CAPWAP analysis of dynamic pile testing data for restrikes to be very reliable in determination of ultimate capacity of both driven piles and cast-in-situ piles (e.g. drilled shafts and augercast-CFA piles). Accuracy is slightly better for driven piles than for cast-in-situ piles. Comparison of CAPWAP results with static load tests on the same piles shows excellent agreement.

Differences between CAPWAP and SLT results are generally well within the range of SLT failure loads by different evaluation methods, and are comparable to the statistics of different static tests on the same piles. For the 303 cases in the combined database, the average CAPWAP/SLT ratio was 0.98 with COV of 0.169. Since the average CAPWAP to SLT ratio is less than unity, and the often used Davisson evaluation is less than the average failure definition, CAPWAP is statistically generally conservative. Less than 9% of the cases result in a ratio of CAPWAP to the maximum applied static load exceeding a ratio of 110%. Thus, CAPWAP is usually a conservative result compared to the reserve strength of the pile.

Accuracy of prediction by CAPWAP of long-term service load is improved by requiring at least 6 days before the dynamic restrike test to allow soil strength changes with time to stabilize. Based on results from the 1996 study, accuracy of capacity prediction would probably be improved further by use of the radiation damping model, particularly for cases of moderate to small set per impact. Considering the low cost of dynamic testing and the relatively good accuracy of the CAPWAP capacity prediction, further application of the CAPWAP method for capacity evaluation is justified both economically and technically for both driven and cast-in-situ piles.

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APPENDIX A - THE DATABASE

Previous Stresswave Proceedings contain a wealth of correlation cases for high strain dynamic testing in individual papers. To evaluate the method's accuracy, individual case histories containing restikes and CAPWAP analysis have been herein combined into a single database. The restrike criteria is essential since it is well known that pile capacity varies with time (usually due to set-up, caused by recovery of the soil structure due to the installation process). CAPWAP is an essential component of proper evaluation of capacity. The individual detailed data are presented in Table A1 (data excludes other large studies in 1980 by Goble et al. and 1996 by Likins et al.) The authors and page number for each Conference Proceeding is shown with a description of the pile (e.g. name, diameter, and pile type: cep-closed end pipe; oep-open end pipe; psc- prestressed concrete; rc-reinforced concrete; h- H pile; ds- drilled shaft; cfa- continuous flight augercast). Due to the importance of the date of testing on soil strength and thus pile capacity, Table A1 shows the number of days after installation (if revealed by the author) for both the restrike and the static test. The CAPWAP (CW) and static load test (SLT) capacities as determined by the author, and the method of static test evaluation (when known: e.g., D/10, Chin, Dav-Davisson, BH-Brinch Hansen, VV-Van der Veen) are included. In cases where the author lists the maximum applied load, or where the static load test curve is included, the maximum applied static load is also included (SLTx). This table serves as an index to the previous Stresswave Proceedings.

Table A1: Compilation of CAPWAP and Static test correlations from previous SW conferences

author	**Page**	**pile**	**Pile**	**dia mm**	**CW days**	**SLT days**	**CW kN**	**SLT kN**	**SLTx Max**
1980 SW Proceedings									
Gravare	99	Grvsnd	Rc	275		1	1560	1770	1770
Thompson	163	TP1	h	300	3		3200	3605 Dav	3605
Thompson	163	TP2	cep	300	3		1780	2000 Dav	2680
Thompson	163	TP3	psc	300	3		2310	2225 Dav	2870
Thompson	163	P1	h	300	1		1160	1420 Dav	2000
Thompson	163	P4	cep	300	1		1600	1335 Dav	1820
Thompson	163	P5	h	300	1		2890	2800 Dav	3120
Thompson	163	P6	cep	300	1		2580	2450 Dav	2880
Thompson	163	P7	timber		1		620	670 Dav	884
Thompson	163	P10	psc	300	1		1510	1740 Dav	2500
Authier	197	1	psc	305	0.05	2	2200	3200	2800
1984 SW Proceedings									
Seitz	201	IV	ds	1500	60		16100	16300	16300
Sanchez	221	1	psc	900			3500	3500	3500
Sanchez	221	1	psc	900			6000	5000	5000
Holm	240	P1	rc	270	28	21	535	460 Dav	
Holm	240	P2	rc	270	28	21	310	300 Dav	
Holm	240	P3	rc	270	28	21	1210	1390 Dav	
Holm	240	P4	rc	270	28	21	820	990 Dav	1060
Holm	240	P5	rc	270	28	21	750	690 Dav	
Seidel	313	302/1	ds	1500			20000	25000 Chin	
Seidel	313	303/1	ds	1500			21200	31700 Chin	20000
Seidel	313	403/2	ds	1500			32000	36000 Chin	
Seidel	313	204/2	ds	1300			18000	16400	16400
Seidel	313	3385/1	ds	1100			14000	18000 Chin	
1988 SW Proceedings									
Nguyen	353	fittja	cep	90			90	90	90

author	Page	pile	pile	dia mm	CW days	SLT days	CW kN	SLT kN	SLTx Max
Nguyen	353	hallsfj..	cep	812	50	50	3200	5250 Dav	6900
Cheng	477	A5	cep	298	1		2183	2170 Dav	2240
Cheng	477	B13	cep	244			880	1020 Dav	1620
Cheng	477	C-TP1	cep	244			2375	2400 Dav	2650
Cheng	477	C-TP2	cep	244			1527	1630 Dav	1995
Cheng	477	D24	cep	324			921	1080 Dav	1200
Cheng	477	E-C-60	cep	324			2710	2935 Dav	3200
Holeyman	542	7	psc	320			1640		
Holeyman	542	11	psc	320	11	41		2800	3130
Thompson	555	A5	psc	400	1		1390	1420 Dav	
Thompson	555	C2	psc	610	1		1760	1760 Dav	
Thompson	555	G1	psc	500	1		1920	2180 Dav	
Thompson	555	G2	psc	500	1		930	800 Dav	
Thompson	555	J1	cep	335	1		2670	2580 Dav	
Bustamante	579	KP1	h	350		28	2777	3200 D/10	3500
Bustamante	579	KP2	h	350		28	3513	3700 D/10	
Bustamante	579	KP3	h	350		28	4966	5075 D/10	
Bustamante	579	MP1	h	350	1	42	1759	2020 D/10	
Bustamante	579	MP2	h	350	1	42	2107	2400 D/10	
Bustamante	579	MP3	h	350	1	42	1591	1800 D/10	
Chow	626	28/E7	rc	280		21	1373	1600	1600
Huang	635	Shang.	h	350	1.7	30	4485	7250	
Plesiotis	668	br.river	rc	355	47	92	1200	1270 BH	1280
Plesiotis	668	Bar. 1	rc	450			3166	3333 BH	
Plesiotis	668	Bar. 2	rc	450			3666	3777 BH	
Plesiotis	668	Bar. 3	rc	450			4111	4777	
Hunt	689	2A'A'-10	cep	355			2669	2802	
Hunt	689	2N32-17	cep	355			3576	3648	
Seidel	717	1	rc	450	540	100	3700	3900	
Seidel	717	2	rc	450	540	100	4118	4200	4200
Seidel	717	3	rc	450	540	100	3416	3600	
Yao	805	PC1	psc	600	10	35	6301	6840 Dav	6840
Yao	805	PC2	psc	600	10	35	4533	5341 Dav	5962
Yao	805	PC3	psc	600	10	35	4340	4724 Dav	5171
Fellenius	814	AM	cep	245	14	13	1807	1810	1890
Skov	879	P9/1	rc	250	52	29	1335	1250	
Skov	879	4A	cep	762	30	7	5170	4850	
Skov	879	case3	rc	300	11	14	640	880	
Skov	879	D2	rc	350	23	19	2450	2450	
Holloway	889	TP1	psc	350	12	5	2050	2180	2243
1992 SW Proceedings									
Likins	117	case 1	psc	600	6	11	2310	2270 Max	2270
Likins	117	CT1	psc	450	21	21	1702	1666 Ult	
Likins	117	CT2	psc	450	11	21	2668	2540	
Likins	117	CT3	psc	600	8	22	2615	2869	
Likins	117	CT4	psc	600	10	22	3617	3724	

author	**Page**	**pile**	**pile**	**dia mm**	**CW days**	**SLT days**	**CW kN**	**SLT kN**	**SLTx Max**
Likins	117	CT5	psc	900	6	20	4210	4900	
Likins	117	CT6	psc	900	3	17	4994	6905	
Riker	143	Alsea	psc	510	2	12	3580	6000 Dav	7400
Seidel	153	A	psc	600	11	61	3830	4300	4300
Seidel	153	B	psc	600	58	50	4000	4420	4600
Hartung	259	sheet	sheet				1344	1100	1300
Dai	271	1	ds	800	25	33	2822	2750	3000
Dai	271	2	ds	800	22	40	3290	4000	4000
Shioi	325	T	oep	2000	2	52	29400	32340	36000
Fellenius	401	247	cep	244	26	22	2390	2070	2090
Bustamante	531	1	h	350	5	69	2600	2400 D/10	2400
Bustamante	531	2	h	350	5	75	2400	2000 D/10	2000
Chapman	537	case5	rc	350	3		3486	4000	4000
Seidel	619	C8Z	rc	350	13	6	3160	3600	3600
Stuckrath	645	Laus.	ds	240	82	22	186	190	220
Geerling	55	1	rc	250	3	17	565	595 D/10	600
Geerling	55	2	rc	250	3	18	421	324 D/10	400
Geerling	55	3	rc	250	3	20	989	1117 D/10	1360
Geerling	55	5	rc	250	3	26	1365	1215 D/10	1360
1996 SW Proceedings									
Klingberg	290	TP3	cep	219	24	217	1493	1350	1350
Cody	350	P-2	h	350	1	8	1802	2220	2390
Cody	350	P-5	h	350	1	11	1629	1837	2109
Lee	409	SIP02	ds	600	6+	5+	2811	2668 Dav	2813
Lee	409	SIP06	ds	500	4-	5+	1392	1001 Dav	1373
Lee	409	SIP07	ds	500	20+	5+	1934	1422 Dav	2090
Lee	409	SIP08	ds	500		5+	1712	1128 Dav	1766
Lee	409	SIP10	ds	600	27-	5+	1710	1570 Dav	2354
Lee	409	CON01	psc	400	6+		1294	1040 Dav	1570
Lee	409	CON03	psc	400	13-		2091	1393 Dav	1717
Lee	409	CON04	psc	350	3+		1415	1099 Dav	1177
Lee	409	CON05	psc	400	2-		1551	1393 Dav	1766
Lee	409	CON06	psc	400	4-		1449	1079 Dav	1766
Lee	409	CON07	psc	400	1-		1174	1177 Dav	1295
Lee	409	CON08	psc	450	16-		2062	1668 Dav	1962
Lee	409	CON09	psc	450	1+		2306	1972 Dav	2207
Lee	409	STL03	cep	508	3-		2625	2374 Dav	2551
Lee	409	STL04	cep	609	4-		2586	2256 Dav	2747
Rausche	435	case1	h	350			1480	1420	1420
Rausche	435	case2	psc	600			4750	5120	5120
Mukaddam	805	211/125	ds	750			3466	3466	
Mukaddam	805	17/56	ds	500			1463	1448	
Wu	991	34/E6	oep	900	12	74	12784	11607	12768
Yong	1159	case 1	ds	1000			8733	7836	7836
2000 SW Proceedings									
Svinkin	35	1	psc	1370	2	2	2450	1935	
Svinkin	35	2	psc	1370	9	9	2880	2840	

author	**Page**	**pile**	**pile**	**dia mm**	**CW days**	**SLT days**	**CW kN**	**SLT kN**	**SLTx Max**
Svinkin	35	3	psc	1370	22	22	3480	3160	
Svinkin	107	TP3	psc	610	18	31	1672	1841 Dav	
Svinkin	107	TP4	psc	762	18	32	1601	2273 Dav	
Svinkin	107	B-2	h	310	7	16	1512	1400 Dav	2675
Svinkin	107	B-2	h	310	16	16	2002	1400 Dav	2675
Kirsch	249	Hambrg	conc				6000	6275	6275
Seidel	267	TP1	oep	1200			5800	5500	6000
Seidel	267	307	oep	1200	25	52	19400	18800	18800
Matsumoto	335	Michi	oep	800	5.5	29	4530	4725	
Matsumoto	335	Shibata	pipe				2040	2165	
Xi	369	DH	ds	700			6398	6100	6100
Lima	375	E23	rail		600	600	1110	1200 D/10	1200
Cannon	393	B19	screw	850			1809	1500	1500
Cannon	399	68B	cfa	600			2200	1700	1700
Shibata	583	D/S	oep	400	6	6	2200	2150 D/10	3675
Shibata	583	D/S	oep	400	30	30	2500	3000 D/10	4130
Zheng	651	33	psc	300			1863	1900	1930
Zheng	651	76	psc	300			1881	1900	2100
Zheng	651	85	psc	300			2188	1980	2170
Zheng	651	113	psc	400			2051	2160	2360
Zhou	673	T2	oep	910			8303	10567	
Zhou	673	B3a	psc	600			8001	8453	
Zhou	673	B3b	psc	800			5448	5636	
Albuquerq.	677	Camp.	psc	180			216	262	262
Liu	683	T2	ds	800			12175		
Liu	683	T4	ds	800			11838		
Kormann	707	CFA1	cfa	350	130	90	877	1006 VV	986
Kormann	707	CFA2	cfa	350	130	90	1700	1473 VV	1380
Klingberg	715	TP	cfa-d	450			1797	1800	1800
Holeyman	725	Long	psc	350			1779	1657	1657
Holeyman	725	Short	psc	350			919	965	965
Baycan	751	T5	cfa	750	100	90	8000	8900	8900