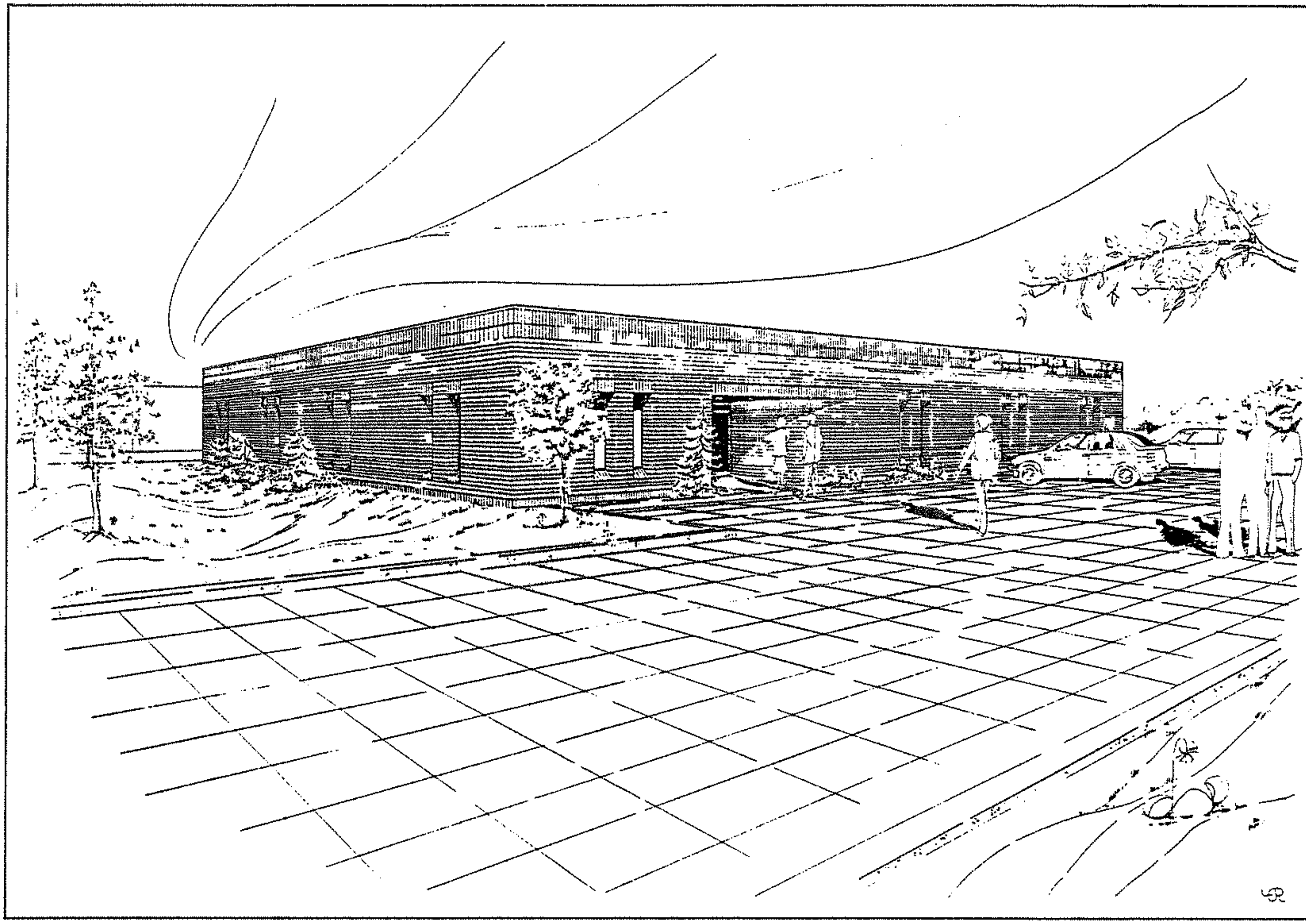
Cleveland 1991



PDA USERS DAY • CLEVELANI

August 23 and 24, 1991

ILE DYNAMICS, INC.

535 Emery Industrial Parkway ● Cleveland, Ohio 44128 ● U.S.A.
hone 216-831-6131 ● Fax 216-831-0916

PDA Users Day

1991

The 1991 CAPWAP Program

Recommended CAPWAP Matching Procedure

Remedies Against Faulty Capacity Predictions

by

Frank Rausche

Goble Rausche Likins and Associates, Inc.
4535 Emery Industrial Parkway
Cleveland, Ohio 44128

INTRODUCTION

CAPWAP of 1991 is still based on a continuous model. But it is also the one and only CAPWAP and the trailing "C" can therefore be dropped from its name. Fortunately, the 1991 version contains more than just a slight name change to distinguish it from its earlier versions. The new features will be discussed in this presentation. This paper reviews the recommended CAPWAP signal matching procedure, which is also followed by CAPWAP's automated prediction routine. Finally, critical questions are summarized which the user of any dynamic pile capacity method should ask before proceeding to use these results.

THE 1991 PROGRAM ENHANCEMENTS

The Name

The program is called CAPWAP. However, for speed, you start the 1991 version by merely typing **CW**.

The New RI Menu

The 1991 **RI** Menu shown below contains a few new entries and features.

E,0 ... Exit
T ... Toe Resistance Model
N ... Skip Auto - Numeric Manual
G ... Skip Auto - Graphic Manual
I ... Auto Skin Friction, Starting at Segment No. I
-I ... Auto Skin Friction to BM, Starting at Segment No. I
X ... Extra Toes

T will automatically search for improvements in the set of toe resistance parameters. The search has been improved compared to the previous versions.

N is the numerical resistance input option and is therefore equivalent to the previous "skip auto" option.

G allows for resistance data input in a graphical environment. This option is described below in greater detail.

I calls for the entry of a starting segment number (most often 1) for an improved resistance distribution calculation starting below segment I.

-I calls for a negative segment number input. As for I this option will attempt to improve the resistance distribution starting at segment number I and will continue to do so until a further improvement cannot be achieved.

X is a new option. It allows the user to enter additional "toe segments" anywhere along the pile. Of course, these extra segments can be added at the toe itself. A description of the Extra Toe Menu follows below.

The RI Graphics Screen (Option "G")

This is the most obvious program addition. It allows the user to accomplish static Resistance Input in a combined graphics and numerical environment where a measure of the current match differences at the time of pile top apparent resistance activation is numerically included. The screen is shown in Figure 1. For an understanding of its different components a step-by-step description now follows.

Header Lines

The first header line shows the normal CAPWAP variables with values used during the most recent analysis. The second line shows newly assigned values. All quantities shown in the header lines can be modified in the same manner in which they are modified in the CV menu. Of course, the RToe and RUlt values are modified as part of the resistance input.

The Match Graph

The match graph (either forces, velocities or waves-up, depending on the ANty option) always shows what has been calculated in the last analysis. **Changing resistance values does not affect the match graph. An analysis must be performed before the effects of a new resistance distribution on the calculated pile top quantity become apparent.**

The Cursor

The cursor consists of a vertical and slanted line intersecting the match graph and pointing to the associated segment number. The vertical cursor line intersects the resistance activation marker (static tick mark) for the associated segment. Please note that extra toes will be included in the redistribution calculations. Extra toes will, however, not appear on the RI Graphics Screen.

The vertical cursor may be moved along the match graph using the left and right arrow keys. As the cursor moves to the righthand or lefthand side of the screen, lower or higher segment numbers and associated resistance values will be shifted into the screen until the first segment or the toe segment have been moved into the screen.

Segment Numbers

Up to 11 soil segments can be displayed at one time. If there are more than 10 skin resistance segments and (plus the toe) therefore more than 11 resistance values, then the cursor movement will bring into screen segments at first not displayed.

Current Values

These resistance values most recently were analyzed.

Modified Values

Resistance values entered through I1, R1, I2, R2 (as you would in the numerical section of the RI menu) are echoed in the modified value line by replacing the original resistance values. Note that the final resistance values will only be correctly displayed after a "blank Enter" induced recalculation.

Delta Values

The Delta values are the difference between measured and last analyzed pile top quantity. They do **not** change as new R values are entered.

Modified D

This line **approximately** indicates the **predicted** Delta values expected after the next analysis due to the modified resistance values.

New Ultimate Capacity

A new ultimate capacity value can be entered after an **RU**. It is reflected in the second header line.

Unresolved: XX

The sum of all modified values minus the **RUlt** value.

Resistance Distribution Input

In the lower left hand corner of the screen, numerical resistance values are echoed as they are entered. (Resistance data entry is recognized by a leading numerical value. All other entries start with two alphabetic characters.) The same rules as in the numerical input hold, *e.g.*, the toe capacity entered will not be changed during the recalculation of the individual resistance values.

Modifications of CAPWAP Variables

The most commonly changed CAPWAP variables are included in the header lines of the graphics resistance screen. They can be changed here without the need to exit the resistance graphics screen and then enter the **CV** menu. Data entry requires the two letter identifier (*e.g.*, JT, QS, ...) and then the new value. Limitations are not checked.

Calculation of Resistance

As long as non zero unresolved resistance values exist, the new set of resistances will differ from the modified ones. To see the recalculated values type **CR.**

Begin Analysis

Without leaving the resistance screen an analysis will be started with an **SA** entry. A **CR** will be automatically performed.

Exit

The graphics screen can be exited after an **EX** entry. Control will then resume with the main menu. **EX** will automatically include the **CR** action.

The Extra Toe Menu

This menu contains the following entries:

I1 to	the pile segment number where the first extra toe occurs; $0 < I1 < NS01L+2$
I2 to	the pile segment number where the second extra toe occurs; $0 < I2 < NS01L+2$
R1 to	the capacity value of the first extra toe
R2 to	the capacity value of the record extra toe
RU lt	the total ultimate capacity should not be changed in this value
Q1 to	the quake corresponding to R1
Q2 to	the quake corresponding to R2
T1 to	the Case damping factor of extra toe No. 1
T2 to	the Case damping factor of extra toe No. 2
S1 to	the Smith damping factor of extra to No. 1
S2 to	the Smith damping factor of extra to No. 2

Additional toes allow better modeling for composite piles such as concrete piles with H pile toe extensions where the bottom of the concrete has end bearing characteristics.

Energy Formulas

Energy formulas rely on the visual observation of blow count and on the calculation of measured energy to calculate of bearing capacity based on energy principles. Two formulas are of particularly widespread use, the Hiley and the Engineering News formulas. An adoptation of these two formulas to measured quantities would yield

$$R_H = 2\ EMX / (s + s_{max})$$

and

$$R_E = EMX / [(s + s_{loss})]$$

With these formulas, ultimate capacity values are calculated. EMX is either in kip-ft or kN-m, s is the final set under a hammer blow while s_{max} is the measured, maximum displacement occurring under a hammer blow. For the EN formula a lost set, s_{loss} of usually 0.1 inches (2.5 mm) is chosen. Note that R_E is usually calculated for end of driving blow counts and that it therefore includes an estimate of set-up.

The Standard CAPWEAP Option

There are four dynamic methods for the calculation of pile bearing capacity:

Energy formula

Wave Equation

Case Method and

CAPWAP.

Both energy formulas and the wave equation approach are usually used without the measurement of pile top force and velocity. However, both can be adopted such that pile top measurements are introduced to replace assumptions about hammer performance. For the wave equation this means that a CAPWEAP analysis is performed with the measured downward wave, rather than a hammer impact, as an input and with certain assumptions about the soil response. The soil assumptions include damping and quake values. Resistance distribution may be taken from an initial CAPWAP analysis.

The wave equation analysis approach requires that the observed blow count determines the pile bearing capacity. In CAPWAP, for an automated calculation of the "Standard CAPWEAP" capacity, trial and error analyses with different capacity values are therefore automatically analyzed until a capacity value has been found whose calculated blow count matches the observed one.

Discussion of the Blow Count Dependent Methods

The blow count is an important observation and commonly only reflects an average soil resistance. Often it does not reflect the available soil strength. When a restrike is performed with varying energies and rapidly changing capacities, particular care must be exercised when applying blow count dependent methods (BCD). The advantage of BCD methods is probably that they are less likely to underpredict in hard driving. The wave equation is the most realistic BCD approach, but, of course, it requires relatively extensive calculations. The standard CAPWEAP wave equation approach allows for the introduction of standard soil dynamic parameters. For that reason four different shaft soil types may be identified which are then used to define four different damping factors:

Soil Type	Skin Damping Factor	
	s/ft	s/m
Cohesionless	.05	.16
Sand and Silt or with Clay	.10	.33
Silt and Sand or Clay and Sand	.15	.49
Cohesive	.20	.66

Similarly, for the toe different soil materials are distinguished which yield the following different toe damping factors (note that the GRLWEAP recommendations are simpler).

Soil Type	Toe Damping Factor s/ft	s/m
Hard Rock	.05	.16
Sand, Silt, or Clay	.15	.50
Weathered Shale, Silt Shales	.30	1.00

Skin quakes are always assumed to be 0.1 inches or 2.5 mm. Toe quakes are calculated by the D/120 rule, *i.e.*, it is assumed that toe quakes are only a function of pile size and not dependent on the soil type.

Naturally, the user could introduce his own thoughts on these parameters, *e.g.*, by choosing an effective diameter quite different from the actual one. But that would defeat the idea of a "standard" wave equation and therefore not add further information to the pool of available capacity values. On the other hand, it is very instructive to inspect the "match" achieved after the standard CAPWEAP has been run.

The modified Hiley formula has a definite advantage over the two other BCD methods. It recognizes the effect of capacity reduction due to larger quakes or high rebound situations. On the other hand, a soil damping parameter is not included. The Engineering News formula recognizes neither quake nor damping. Of course, the "lost set" could be easily increased to reflect large quake (or even high damping) cases. Again, the interest is to provide additional information and not a forced "good result". It also might be mentioned that the EN formula, introduced in CAPWAP, would yield a result identical to the real EN formula, if a safety factor 2 was sought against ultimate and if the transferred energy EMX happened to be 33% of the rated hammer energy.

THE RECOMMENDED CAPWAP MATCHING PROCEDURE

As the available soil model parameters become more and more numerous and as real choices have to be made between certain models and higher or lower capacity results, it may be wise to summarize the recommended CAPWAP matching procedure. In this way it may be possible to arrive at a unique CAPWAP for all parameters.

Basically, the ultimate resistance values at skin and toe, the skin and toe quakes and the skin and toe damping factors are at first the only analysis choices available. In order to avoid ambiguities as to the relative magnitudes of skin and toe damping, Smith skin and toe damping factors should be checked and modified by assigning an appropriate static resistance component to the pile skin and toe.

Unloading quakes are in general only needed for the matching of the fourth period (starting 5 ms after 2L/c). In cases with early unloading, the skin unloading quake and the negative friction level, modified through CRsk and UNld, respectively, also can have a decisive effects on the total bearing capacity. In those cases, CRsk should be limited to CRsk greater than 0.1 and the choice of these unloading factors should be based on the match quality of the fourth period and not on the magnitude or distribution of static resistance forces.

As the seven basic soil parameters are iteratively determined, toe plug and gap can always be tried. Their effect is local (around the 2L/c time) and insignificant as far as the total capacity prediction or the resistance distribution is concerned. Similarly, reloading levels hardly have a significant effect on the important CAPWAP variables.

Residual stress analyses (RSA) may always be tried. They generally do not cause major capacity increases and they yield improved resistance distributions. RSA **should** be chosen whenever resistance values start to decrease significantly near the toe.

Finally, the most important question: when should we choose the radiati on damping model. A little bit more experience has been gathered during the past year. A few rules might be formulated.

> Matches should first be attempted without radiation damping. Two situations might develop which indicate the use of these additional soil model parameters.
>
> The match shows a significant overshoot (computed higher than measured) shortly after 2L/c, then undershoot in the later record portion and the match is in general "bad" (MQ > 5).
>
> The Smith damping factors become unreasonably high, *i.e.*, greater than .3 s/ft (1 s/m).
>
> The radiation dampers may also be employed when drilled shafts with high friction or piles on rock are analyzed leading to skin and toe radiation damping, respectively. Maybe this rule can be further generalized as follows:
>
> > Radiation is indicated if the pile experiences very little set and the displacement maxima therefore do not exceed the quakes by more than a small percentage.

It should be noted that in most instances only either skin or toe radiation damping is necessary. The above rules should prevent accidental over predictions of bearing capacity through the use of the radiation soil model.

Finally, CAPWAP now offers toe models at two additional locations along the pile. The use of these parameters should be limited as follows.

> Along the skin, extra toes should only be employed if the pile is non-uniform and if therefore additional points of soil displacement are known to exist. At the last pile segment extra toes may be freely chosen to represent a more or less non-linear soil resistance *vs* pile set behavior. Those latter extra toes may receive a portion of the total toe damping.

REMEDIES AGAINST FAULTY CAPACITY PREDICATIONS

After a "Best Match" has been achieved and a CAPWAP output obtained the pile dynamicist has to compile as much information as possible to evaluate the piles actual long term capacity. Note, it is more important to judge the pile's bearing capacity than to achieve correlation with a static load test!!! The following check list is based on the PDA Users Day 1990 presentation of the potential over and under prediction by CAPWAP.

The following checks and actions are recommended to guard against most types of prediction errors. These checks apply as well to other dynamic methods. (Case Method, WEAP, formula). They are a first attempt and feed back is highly appreciated.

A. Blow count less than 24 BPF (80BPM)?

A1. Smith damping factor less recommended for soil types providing major bearing?

Suggestion: Reanalyze with higher damping.

A2. Relatively high impact force?

Note that a capacity prediction error of 5% of the maximum impact force is not uncommon. Suggest: reduce hammer energy input for the dynamic test.

B. Substantial end bearing (>33% of total capacity including bearing on last skin segment)?

B1. Does geology suggest that pile can break through thin layers? (1/10)

B2. Fine sand/silt at toe? Dense or very dense with the potential of negative pore water pressures? (1/2)

B2.1. End of driving or restrike with more than two blows prior to blow analyzed?

It is suggested to analyze an earlier restrike blow.

B3. Silt shale at toe. (1/3)

B4. Weathered rock below toe. (2/3)

B5. Soil known to exhibit relaxation at toe? (Enter factor)

It is suggested to multiply end bearing by reduction factor indicated (in B1 through B5).

C. How reliable is analysis?

C1. Has radiation damping been used with low damping factors?

C2. Are the unloading quakes less than .01" (.25 mm)?

C3. Is match quality greater 5?

C4. Is calculated blow count significantly higher than measured?

Suggestion: Run standard CAPWEAP.

C5. Are Smith damping constants reasonable?

D. How reliable is the soil?

D1. Is the soil type calcareous?

D2. Is the soil known to exhibit strain softening?

It is suggested to check the potential for a progressive failure under static loads, as pile displacements in upper layers become large enough to cause strain softening before the whole pile has reached failure. It then would be safe to reduce predicted capacity to residual values. In the future, the CAPWAP analysis will be expanded to cover this situation, however, load deformation characteristics of soil must then be known quantitatively.

E. How reliable was test?

E1. Large acceleration adjustments? (Displacement versus reasonable?)

E2. Force calibration adjustment > 1?

E3. Poor blow count information?

E4. Is sufficient waiting time after driving?

E5. How likely is it that the elastic modulus was assumed too high?

E5.1. Do we have results from other test piles?

E5.2. Do we know whether this modulus is common?

E6. How well do we know cross sectional area? Could it be (like pipe spec's) that real area is less than nominal? What likelihood?

E7. Yielding in steel possible and therefore forces computed too high? Is "force" curve reasonable, particularly in later portion of curve? (Remember we measure strain).

E8. High bending and therefore inaccurate force?

F.

G. Is the blow count greater than 100 BPF (330 BPM)?

G1. Are damping factors higher than normal?

G2. Are predicted quakes unusually high?

G3. Is calculated blow count significately lower than observed?

G4. Is soil under toe granular?

G4.1. Does soil below toe exhibit strain hardening?

G5. Is end bearing from end of drive (including last skin segment) significantly greater than from restrike?

G5.1. Is energy of restrike lower and/or friction greater than during driving?

G5.1.1. Is soil not exhibiting relaxation under toe? Suggestion: Add difference between EOD and BOR toe capacity to total restrike capacity.

H. Time of testing.

H1. Is this an end of drive analysis?

H1.1. Use skin friction reduced by that of last segment and increase by:

Sand	10%
Silty Sand	20%
More Cohesive	50%

Or apply known setup factor.

(Note: H1.1 is an **estimate** and really should be confirmed.)

H1.2. Suggest restrike tests.

H2. Is this a restrike but late blow?

H2.1. Suggestion: Analyze earlier and several blows of restrike. Is soil sensitive to dynamics?

I. Differences in Static-Dynamic failure mechanics.

I1. Open profile?

I1.1. H-Pile

I1.1.1. Granular soil with plug during driving (plug and high end bearing indicated by CAPWAP).

Suggestion: Doubled friction.

I1.1.2. Granular soil at toe no plug and low end bearing indicated.

Suggestion: Statically and conservatively calculated end bearing for full cross section be used instead of dynamic one.

I1.2 Open ended pipe.

I1.2.1. Granular soil at toe, no plug and low end bearing indicated. An increased end bearing may be estimated by static methods.

J. Residual Stresses?

Thin walled pipes particularly Monotubes;

Suggestion: Perform standard CAPWEAP with residual stress analysis.

K. Quality of test.

K1. Sufficient energy?

K2. Sufficient impact force?

Friction Piles:	R < 1.1 FMX
End Bearing Piles:	R < 1.5 FMX

K3. Sufficient waiting time for restriking (no disturbance during waiting).

L. Data Quality

L1. Wave speed possibly too low set during test and not corrected during analysis? Check overall wave speed?

L2. Proportionality "forced" by down adjusting force calibration?

L3. High bending, therefore inaccurate forces?

L4. Large acceleration adjustment?

L5. Force calibration based on 2 L/c even though wave speed could be higher at pile top than for whole pile (due to cracking, joints, etc...)?!

M. Is static soil resistance likely to change?

M1. Will overburden be added or removed?

M2. Will tide change or are other significant changes in ground water table (will points?) possible?

M3. Will pile be extended/cut-off?

M4. Will additional piles be driven nearby causing densification (loose soils) or loosening (dense soils). For example, H-Piles drive in after load test pile as reaction piles have caused cavities - relieving effective stresses. In other cases, nearby driven piles have caused heave, causing pile toe to move away from bearing layer.

M5. Will there be jetting nearby causing large cavities?

M6. Could the pile have been damaged by driving of other piles?

N. Analysis quality not satisfactory?

N1. Match quality > 5?

N2. High damping factors and <u>no</u> radiation damping?

N3. Distribution shows reduction of resistance near bottom and no residual stress?

N4. Reasonable unit friction values which are in basic agreement with soil boring.