#17

ICC EVALUATION SERVICE

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JUN - 4 2009

ICC-ES Evaluation Committee

To: ICC-ES Evaluation Committee

From: David Zhao, P.E., S.E.

Date: May 29, 2009

Subject: Proposed ICC-ES Acceptance Criteria for Mechanical Pinned Splices (MPSs) for Precast Prestressed Concrete Piles, Subject AC414-0609-R1 (DZ/BG)

MEMO

The following revisions to AC414-0609-R1, posted on the ICC-ES website, are proposed based on further discussion with the report applicant, to address the issue raised in our staff letter dated April 30, 2009 concerning axial stiffness of piles. The underlined text reflects changes to the previously proposed criteria posted on the ICC-ES website.

1. Revise lines 215 through 219 of Section 3.3.1 as follows: The rational engineering analysis employed shall determine the pile stiffness and deformation capacity for vertical and lateral loads taking into account the contributions of the MPS so as to demonstrate compliance with Sections 1808.2.7, 1808.2.8.2, 1808.2.8.3, 1808.2.12, and 1808.2.9.3 of the IBC. The results from the rational engineering analysis shall be verified by test data complying with Section 4.0. To assess the contribution of MPSs to axial tension and compression stiffness, analytical and/or experimental evidence shall be submitted to ICC-ES for approval in order to demonstrate that axial stiffness contributions by MPSs are negligible. Otherwise, a test proposal which is based upon Sections 4.5 and 4.6 of this criteria, with additional provisions for axial stiffness of MPSs, shall be submitted by the report applicant to ICC-ES for approval prior to testing.

2. Add the following statements at the end of Section 4.2.6, after line 289: In addition, the contributions of MPSs to axial tension and compression stiffness shall be modeled in the impact test described in Section 4.2 and in the in-situ testing described in Section 6.5 for piles under driving conditions, unless substantiating data is provided, which demonstrates that the contributions of MPSs to pile axial tension and compression stiffness are negligible.

Thank you for consideration of above items.

PILE **ADVISORY & CONSTRUCTION COMPANY**
264 Fisher Place, Princeton, New Jersey 08540

May 25, 2009

#17- AC414-0609-R1

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JUN - 4 2009
ICC-ES Evaluation Committee

ICC Evaluation Services, Inc.
Los Angeles Business/Regional Office
5360 Workman Mill Road
Whittier, California 90601

Attention: Mr. David Zhao, P.E., S.E.
Senior Staff Engineer

Subject: Comments Regarding Requirement for Stiffness Model for Mechanical Pinned Splices (MPSs) for Work Involving Dynamic Pile Analysis

INTRODUCTION

This report presents Pile Advisory & Construction Company's comments to the request by ICC Evaluation Services (ICC-ES) staff as to whether the axial tension and compression stiffness of MPSs should be modeled in numerical analysis involving Wave Equation Analysis Program (WEAP) and dynamic pile testing using the Pile Driving Analyzer (PDA) and Case Pile Wave Analysis Program (CAPWAP). The request was announced by ICC-ES in its document of April 30, 2009, titled "Proposed Acceptance Criteria for Mechanical Pinned Splices (MPSs) for Precast Prestressed Concrete Piles, Subject AC414-0609-R1 (DZ/BG)."

Pile Advisory & Construction Company has had extensive engineering experience with the subject splices. We have been in design role on numerous projects for which long precast concrete piles of multiple sizes have been jointed using the subject MPSs, with total number of combined project piles in excess of seven thousands. Our specific experience with MPS-jointed piles have included numerical modeling of pile-soil response to impact driving using WEAP, PDA and CAPWAP along with overall Quality Control/Quality Assurance (QA/QC) inspection and certification.

Technically, consideration for stiffness modeling of the MPSs can be attributed to two physical properties of the MPS; namely, the non-uniformity associated with its higher density of longitudinal steel reinforcement in the anchor zone in comparison to the rest of the pile shaft and the seemly presence of discontinuity at the MPS joint interface. We have endeavored herein to provide comprehensive evaluation as the whether there is significant merit for modeling stiffness variation in the MPSs as part of the engineering evaluation of pile-soil response of impact driving using WEAP, PDA and CAPWAP software, and present herein the results of our evaluation.

DESCRIPTION OF WEAP, PDA AND CAPWAP EVALUATION METHODS

The WEAP is a computer software for numerical simulation of the pile driving process. In the WEAP, the hammer, helmet and pile are modeled by a series of rigid mass elements connected by weightless springs, each defined by stiffness quantity equal to EA/L, where E is the Elastic Modulus, A is the cross-sectional area and L is the length of the mass element. In this way, the computer model accounts for the mass and flexibility of the hammer-helmet-pile system. Soil resistance forces and the energy damping capacity of the soil are modeled by a combination of springs and dashpots attached to each embedded pile element. While the springs model the soil resistance, the dashpots model soil damping. The analysis is performed over a small incremental time step, with each time step roughly equal to one half the travel time of the stress wave through the length of one pile segment. The results of the WEAP analysis includes energy delivered to the pile, hammer blow count resistance, mobilized pile capacity, pile driving stresses (tension and compression). Please note that the WEAP is a predictive tool, usually performed based on assumed soil properties, typically prior to the actual pile driving.

The PDA is a field digital computer that processes the strain and acceleration signals from instrumentation hardware connected to the pile during driving. For each hammer blow, the PDA collect the data at the rate of about every 2 milliseconds, and converts the analog strain into digital force and the analog acceleration into digital velocity. The plots of these resultant digital parameters versus time are referred to as wave traces. The wave traces are plotted on the PDA computer screen during pile driving so that the quality of the data can be evaluated in real time. The data is store on the computer hard drive, and are used for calculation of quantities relating to the hammer-pile-soil response during driving. These parameters include transferred energy from hammer to pile, mobilized total static pile capacity and maximum pile driving stresses (tension and compression).

The CAPWAP method is a wave equation-type computer analysis of pile driving, performed using the PDA data. Later versions of the CAPWAP program utilize a state-of-the-art continuous segment pile model rather than the older lumped mass approach of the WEAP. Each pile segment is defined by its impedance, EA/c, where E and A remain as defined before and c is the wave speed through the segment. The results of the CAPWAP evaluation represent typically a refinement of the PDA field measurements. To start the analysis, a complete set of WEAP-type soil constants (boundary conditions) is assumed and entered into the computer model along with the pile profile model. Then, in a dynamic analysis, the hammer model is replaced by the velocities, which were measured using the PDA, and CAPWAP calculates the forces necessary to match on a lot with those forces measured using the PDA. If the computed and the measured forces do not agree, the soil model is changed and the analysis is repeated. This interactive process is repeated until no further improvement can be obtained in the force match. Alternatively, the forces measured by the PDA may be imposed as the boundary conditions and the velocities computed and matched by CAPWAP. The results of the CAPWAP evaluation include refined total static pile capacity, shaft and toe pile capacity components, precise distribution of the soil shaft resistance, and refined dynamic soil properties.

STIFFNESS MODELING FOR NON-UNIFORM MPS ANCHOR ZONE

Both WEAP and CAPWAP programs have capabilities for modeling profiles of dimensional and material properties of non-uniform piles, based on segmental increments, from top to bottom. On the other hand, the PDA has capability for input of pile dimension and material properties only at the location of the strain gage and accelerometer instrumentation. While, non-uniformity of a pile is not modeled for PDA testing, it can be modeled in WEAP and CAPWAP. In reference to the subject MPS piles with uniform cross sections, the characteristic mechanical parameters for modeling a pile segment would be E for WEAP and E and c for CAPWAP.

The question that remains is whether there is significant merit to model the anchor zone of an MPS pile with different mechanical parameters due to presence of more longitudinal steel within the zone for WEAP and CAPWAP. The 14-inch square pile has additional eight #5 rebars in the anchor zone, and the 12-inch square pile has additional eight #4 rebars in the anchor zone. The anchor zones for both piles sizes extend about 30 to 60 inches into the pile from the interface. Our calculated increases in composite elastic modulus due to additional steel reinforcement in the anchor zone for the 14-inch and 12-inch square piles were based on method of weighted cross-sectional areas of steel and concrete, and indicate an increase of 6 percent for the 12-inch pile and an increase of 7 percent for the 14-inch pile. Intuitively, the relative increase in wave speed within the anchor zone would be in the same order of magnitude, less than 10 percent. We believe that these estimated increases in modulus and wave speed are small, and that the effort to model such minor change in stiffness in either WEAP or CAPWAP would not provide commensurate significance in the result. Moreover, conventional precast prestressed concrete piles without splices often have higher density of spiral core reinforcement at the ends, and are not traditionally differentiated with respect to stiffness in WEAP and CAPWAP models.

STIFFNESS MODELING FOR MPS INTERFACE

The WEAP and the CAPWAP programs have capabilities for splice modeling, each being somewhat different from the other. The WEAP uses a splice model similar to that used for cushions, helmet and pile top. This model has three parameters, a slack, a coefficient of restitution and a round-out deformation. The CAPWAP splice model is more sophisticated, and hence more realistic for modeling steel-reinforced concrete piles. The CAPWAP splice model is actually two models in one. The first model is a partial or full slack, which means that the downward travelling wave is at least partially reflected upwards and the upward wave is at least partially reflected downwards, as long as the slack is open. The quantity, r, is a user specified slack efficiency, which ranges from 0 to 1. For a non-spliced pile, r is 0, and for a full slacked splice, r is 1. In the second CAPWAP splice model, there are compressive and tensile "slack inputs," Sc and St, which are displacements. When these parameters exceed a certain value, they are interpreted as maximum slack force, Fs (tensile or compressive, depending on the specified slack type). In the English system of units, the limiting slack value is 4 inches; an input value of 5 would be interpreted as maximum slack force of 5 kips.

As can be observed, modeling the stiffness of a splice amounts to modeling the slack (if any), and the degree to which the waves are transmitted across the interface of the splice joint. By design, the diameters of the locking pins of the subject MPSs are slightly larger than those of the side holes. As a result, when driven into the side holes, the pins induce some compression loading on the adjoining base plates. By virtue of this ever-present positive compression, the two spliced segments are always in contact and foster reasonably a continuum behavior of the MPS pile, with respect to transfer of stress waves across the splice interface. We believe that the subject MPSs lack slack to require modeling in the WEAP program because:

1. The WEAP slack input value would be zero.
2. The coefficient of restitution input would be 1.0 (steel-to-steel striking).
3. The round-out input value would be infinitesimal (insignificant) due to lack of slack.

A consideration to model the stiffness of the MPSs in the CAPWAP program would require reasonable definition of the model parameters in relation to the actual performance of the MPSs under real driving conditions. Attachment A presents actual CAPWAP data and model for a 100-foot long 12-inch square test pile spliced at the 50-foot mid-point using 12-inch square MPS. The MPS is located at the depth of 48 feet below the PDA instrumentation. Page A-1 of the attachment shows the PDA screen for the blow record No. 1 being evaluated. The pile integrity factor, BTA, is 100 percent, indicative of a pile of relative continuum. In practice, BTA value of less than 80 would be associated with a pile of questionable integrity. Page A-2 shows the Wave Up and Wave Down traces with identification of the splice effect. Page A-3 presents plots of profiles of calculated and measured CAPWAP parameters verses depth. Visual inspection of these parameters shows expected segmental imprint in the calculated profiles for force, transferred energy, compressive stress and tension stress. On the other hand, the measured velocity and displacement profiles lack segmental imprints. Noteworthy is the fact that the profile for velocity (which was input from the PDA data) shows a consistent gradient through the zone of the MPS location at 48 feet. We believe that the absence of apparent distortion of the velocity profile in the zone of the MPS demonstrates that the locking mechanism of the MPS adequately fostered continuum behavior of the jointed pile, and as such should preclude any requirements for reduced stiffness modeling of the subject MPSs. Pages A-4 through A-7 of the attachment present the rest of the CAPWAP evaluation results for completeness of the records.

CONCLUSION

In response to a public request by the ICC-ES, Pile Advisory has presented herein comment as the whether the tensile and compressive stiffnesses of the MPSs should be modeled for numerical analysis of pile driving using WEAP, PDA and CAPWAP. Based on our experience and knowledge working with the WEAP, PDA and CAPWAP methods, we have presented in detail the capabilities and limitations of the methods in modeling non-uniform properties of a pile and splice behavior in a pile. We have also defined the physical parameters required by the methods for modeling non-uniformity and splices. We described the ever-presence of positive compression of the adjoining base plates of the MPSs due to over-sizing of the locking pins per design. We presented results of an actual test pile jointed with an MPS and analyzed using PDA and CAPWAP methods. The results showed that there was total absence of distortions in the measured velocity profile at the location of the MPS. Ordinarily, the velocity profile would have been distorted had there been inadequate structural continuity through the MPS. Based on the details and data presented herein, Pile Advisory & Construction Company concludes that the MPS fosters adequate continuum behavior with respect to transmission of impact wave between adjoining pile segments and that there should be no requirement to model the MPSs for WEAP, PDA and CAPWAP analyses.

We appreciate the opportunity to submit these comments to ICC Evaluation Services, Inc. Please contact the undersigned should you have any questions regarding this submittal.

Very truly yours,

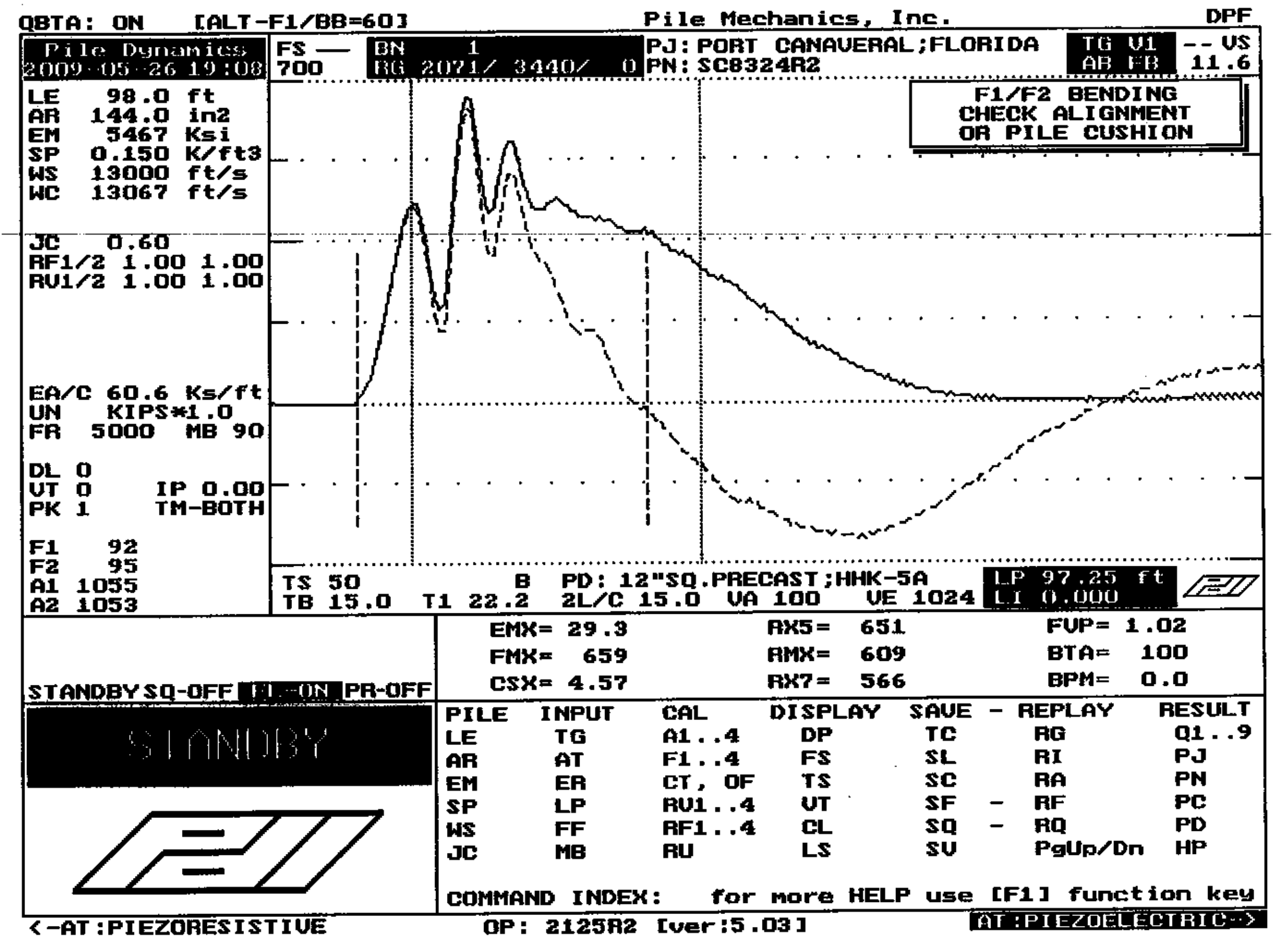
PILE ADVISORY & CONSTRUCTION COMPANY

Cyril N. Okoye, P.E.
Principal

Attachment:

ATTACHMENT A

RESULTS OF PDA AND CAPWAP FOR MPS TEST PILE



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QBTA: ON    [ALT-F1/BB=60]                Pile Mechanics, Inc.                 DPF
Pile Dynamics     FS ——  BN        1         PJ: PORT CANAVERAL;FLORIDA   TG V1  -- VS
2009-05-26 19:08  700    RG 2071/ 3440/   0  PN: SC8324R2                 AR FB  11.6

LE     98.0 ft                                          F1/F2 BENDING
AR    144.0 in2                                        CHECK ALIGNMENT
EM     5467 Ksi                                        OR PILE CUSHION
SP    0.150 K/ft3
WS    13000 ft/s
WC    13067 ft/s

JC    0.60
RF1/2 1.00 1.00
RV1/2 1.00 1.00

EA/C 60.6 Ks/ft
UN    KIPS*1.0
FR   5000   MB 90

DL 0
VT 0      IP 0.00
PK 1      TM-BOTH

F1     92
F2     95
A1   1055   TS 50          B   PD: 12"SQ.PRECAST;HHK-5A    LP 97.25 ft
A2   1053   TB 15.0   T1 22.2  2L/C 15.0   VA 100   VE 1024  LI 0.000

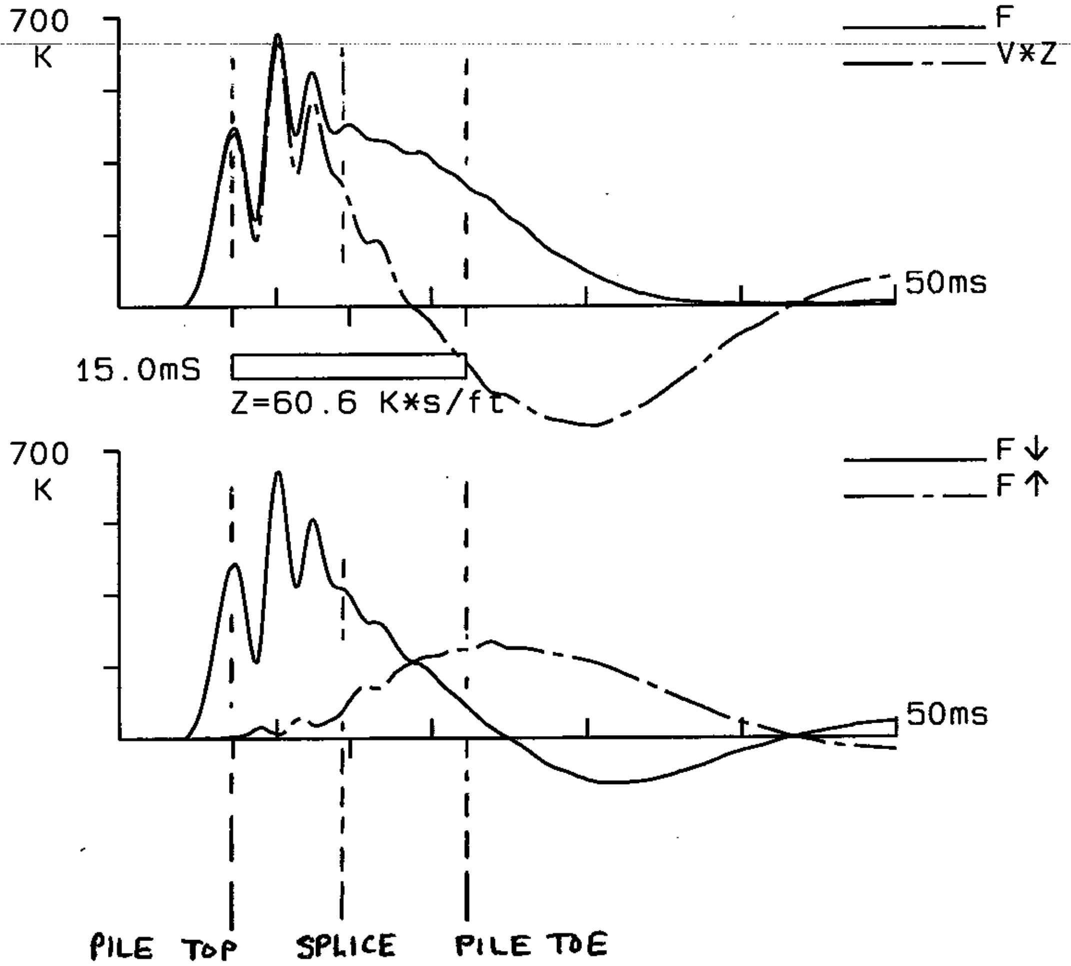
                                   EMX= 29.3          RX5=   651          FVP= 1.02
                                   FMX=  659          RMX=   609          BTA=  100
STANDBY SQ-OFF FL-ON PR-OFF        CSX= 4.57          RX7=   566          BPM=  0.0

                                   PILE   INPUT   CAL      DISPLAY  SAVE - REPLAY     RESULT
        STANDBY                    LE     TG      A1..4    DP       TC     RG         Q1..9
                                   AR     AT      F1..4    FS       SL     RI         PJ
                                   EM     ER      CT, OF   TS       SC     RA         PN
                                   SP     LP      RV1..4   VT       SF  -  RF         PC
                                   WS     FF      RF1..4   CL       SQ  -  RQ         PD
                                   JC     MB      RU       LS       SV     PgUp/Dn    HP

                                   COMMAND INDEX:   for more HELP use [F1] function key
<-AT:PIEZORESISTIVE              OP: 2125R2 [ver:5.03]                  AT:PIEZOELECTRIC->
```

Pile Mechanics, Inc.
PORT CANAVERAL; FLORIDA
PDA OP: 2125R2

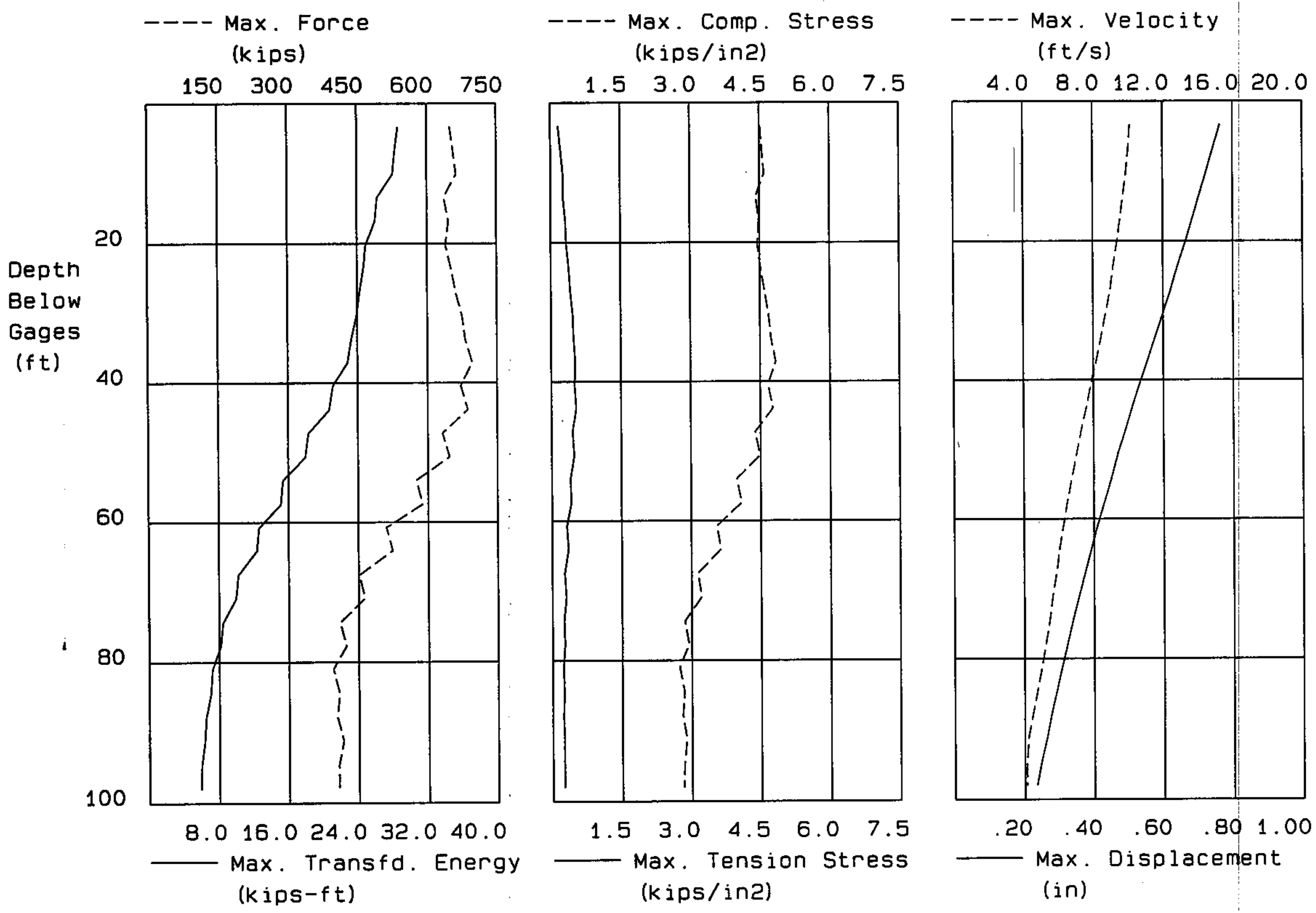
PDI PILE DRIVING ANALYZER® v5.03
SC8324R2 2008-05-19
W



BN	1	
EMX	29.30	Kip-ft
FMX	659	Kips
CSX	4.57	Ksi
RX5	651	Kips
RMX	609	Kips
RX7	566	Kips
FVP	102	%
BTA	100	%
BPM	0.0	BPM
LP	97.25	ft
LE	98.00	ft
AR	144.00	in2
EM	5467	Ksi
SP	0.150	K/ft3
WS	13000	ft/s
F12	A12	

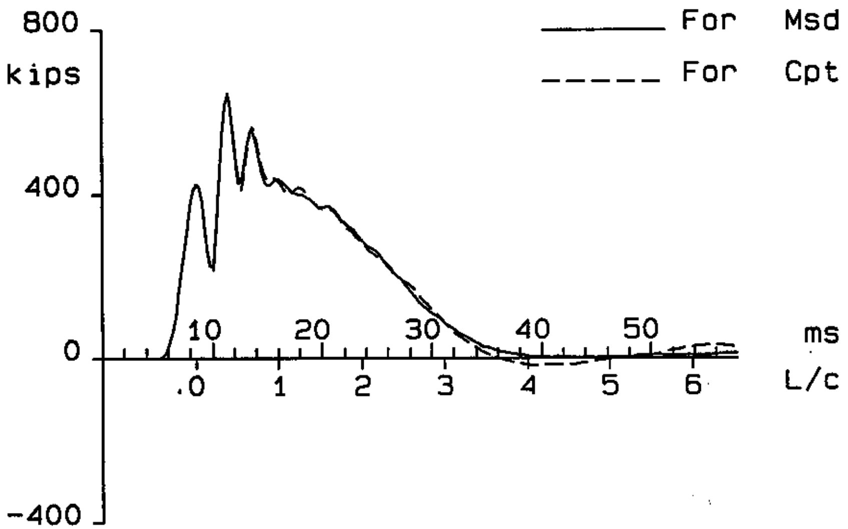
PORT CANAVERAL; FLORIDA, SC8324R2, BN: 1
Pile Mechanics, Inc.

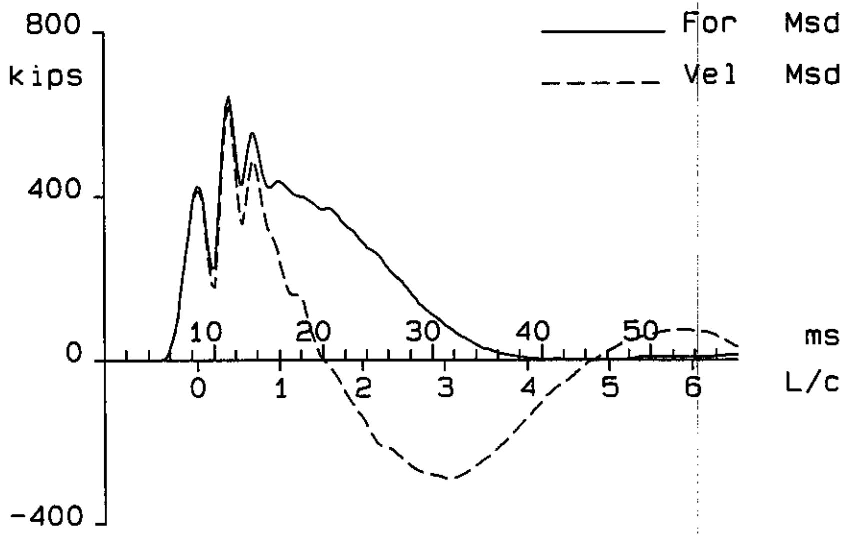
26-May-2009
CAPWAP (R) Version 1997-1

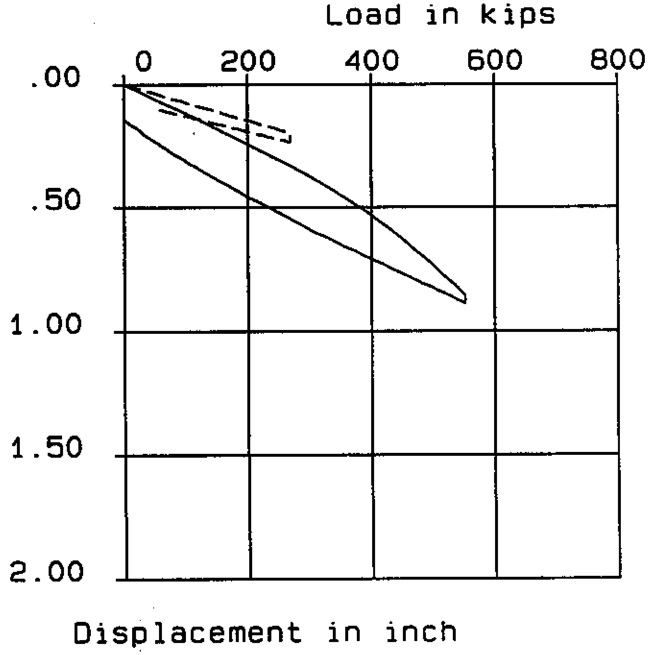


PORT CANAVERAL; FLORIDA, SC8324R2, BN: 1
Pile Mechanics, Inc.

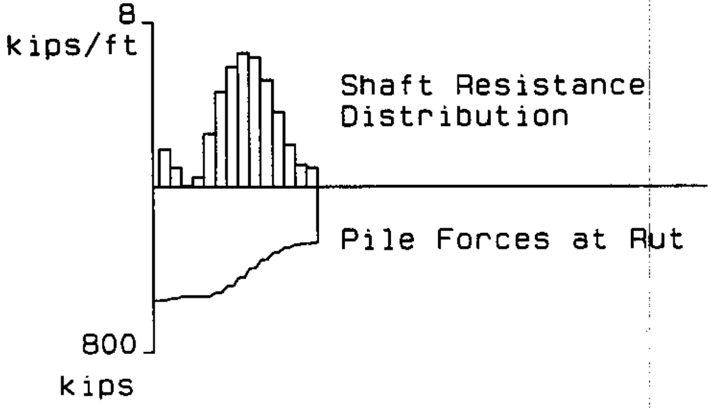
26-May-2009
CAPWAP (R) Version 1997-1







Ru = 552.4 kips
Rs = 282.1 kips
Rb = 270.4 kips
Dy = .86 inch
Dmx = .89 inch



```
Pile Mechanics, Inc.                                       26-May-2009

PORT CANAVERAL;FLORIDA
Pile: SC8324R2          Blow: 1           Data: 12"SQ.PRECAST;HHK-5A
Collected: 08-05-19      Operator: 2125R2          CAPWAP(R) Ver. 1997-1
----------------------------------------------------------------------------
                         CAPWAP FINAL RESULTS

Total CAPWAP Capacity:     552.4; along Shaft   282.1; at Toe   270.4 kips
==========================================================================

 Soil   Dist.  Depth       Ru   Force      Sum  Unit  Resist.   Smith  Quake
Sgmnt  Below  Below             in Pile   of Ru  w. Respect to Damping
  No.  Gages  Grade              at Ru           Depth    Area  Factor
          ft     ft      kips    kips     kips kips/ft kips/f2    s/ft   inch

                                 552.4
    1   10.1    9.4      12.2   540.3     12.2    1.80     .45    .177   .188
    2   16.9   16.1       6.2   534.0     18.4     .92     .23    .177   .188
    3   23.7   22.9        .1   534.0     18.5     .01     .00    .177   .188
    4   30.4   29.7       3.1   530.8     21.6     .47     .12    .177   .188
    5   37.2   36.4      17.3   513.5     38.9    2.56     .64    .177   .188
    6   43.9   43.2      31.3   482.2     70.2    4.64    1.16    .177   .188
    7   50.7   49.9      39.3   442.9    109.5    5.81    1.45    .177   .188
    8   57.4   56.7      43.7   399.3    153.2    6.46    1.61    .177   .188
    9   64.2   63.5      42.4   356.8    195.6    6.28    1.57    .177   .188
   10   71.0   70.2      34.8   322.0    230.4    5.15    1.29    .177   .188
   11   77.7   77.0      24.3   297.7    254.8    3.60     .90    .177   .188
   12   84.5   83.7      13.8   283.9    268.6    2.04     .51    .177   .188
   13   91.2   90.5       7.4   276.5    275.9    1.09     .27    .177   .188
   14   98.0   97.3       6.1   270.4    282.1     .91     .23    .177   .188

Average Skin Values      20.1                     2.90     .75    .177   .188

      Toe               270.4                           270.36    .210   .200


Soil Model Parameters/Extensions                    Skin      Toe

Case Damping Factor                                 .825     .939
Unloading Quake      (% of loading quake)            100       83
Reloading Level      (% of Ru)                       100      100
Unloading Level      (% of Ru)                        23
Soil Plug Weight     (kips)                                   .13
```

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 Pile Mechanics, Inc.                                           26-May-2009

 PORT CANAVERAL;FLORIDA
 Pile: SC8324R2          Blow: 1          Data: 12"SQ.PRECAST;HHK-5A
 Collected: 08-05-19     Operator: 2125R2           CAPWAP(R) Ver. 1997-1

                                EXTREMA TABLE

 Pile    Dist.      max.      min.      max.     max.      max.    max.    max.
Sgmnt    Below     Force     Force     Comp.  Tension   Trnsfd.  Veloc.  Displ.
 No.     Gages                        Stress   Stress    Energy
            ft      kips      kips  kips/in2 kips/in2   kips-ft    ft/s      in

    1      3.4     651.2     -25.0     4.523    -.174     28.75    10.2    .766
    2      6.8     656.8     -32.3     4.561    -.224     28.43    10.1    .746
    4     13.5     638.1     -40.1     4.431    -.279     26.39     9.8    .706
    7     23.7     651.9     -56.0     4.527    -.389     24.71     9.2    .644
   10     33.8     682.5     -71.4     4.740    -.496     23.31     8.5    .580
   13     43.9     687.9     -77.7     4.777    -.539     20.78     7.6    .513
   16     54.1     575.4     -57.8     3.996    -.401     15.46     6.8    .452
   19     64.2     523.8     -51.6     3.638    -.358     12.37     6.1    .394
   22     74.3     410.8     -36.2     2.852    -.252      8.48     5.5    .342
   25     84.5     410.0     -37.4     2.847    -.260      7.08     4.8    .294
   28     94.6     408.2     -36.3     2.835    -.252      5.99     4.1    .251
   29     98.0     406.9     -36.9     2.826    -.256      5.87     4.2    .236

Absolute  37.2                         4.843               (T=     27.8 ms)
          43.9                                  -.539      (T=     53.3 ms)

                                CASE METHOD

        J=0.0  J=0.1  J=0.2  J=0.3  J=0.4  J=0.5  J=0.6  J=0.7  J=0.8  J=0.9
RS1      637.   617.   596.   575.   555.   534.   514.   493.   472.   452.
RMX      852.   811.   769.   728.   686.   644.   603.   561.   520.   481.
RSU      652.   632.   613.   594.   575.   556.   537.   517.   498.   479.

RAU      436.    RA2   478.

Current CAPWAP Ru=   552.4;    Corresponding J(Rs)= .41;    J(Rx)= .72

   VMX     VFN  VT1*Z    FT1    FMX    DMX    DFN    EMX    EFN    RLT    REN
 10.27     .54  416.5  426.9  645.4   .783   .094   29.1   21.4   768.  1542.

                        PILE PROFILE AND PILE MODEL

      Depth          Area       E-Modulus    Spec. Weight    Circumf.
         ft           in2       kips/in2         kips/ft3          ft

        .00        144.00         5467.0             .150       4.000
      98.00        144.00         5467.0             .150       4.000

 Toe Area   1.000 ft2

 Top Segment Length     3.38 feet, Top Impedance   60.57 kips/ft/s

 Pile Damping   2.0 %, Time Incr  .260 ms, Wave Speed 12996.8 ft/s
```

```
                          CAPWAP ANNOTATIONS

 Notes for PORT CANAVERAL;FLORIDA
 Records:     1/    1 for PDA Temporary File: C:\CAPDATA\SC8324R2.000

  QSkn    UNld    CSkn    LSkn    JSkn    SSkn    REss    SKdp    MSkn    PIld
  .188    .240   1.000   1.000    .825    .177    .000    .000    .000    .020
  QToe    TGap    CToe    LToe    JToe    SToe    OPtd    BTdp    MToe    PLug
  .200    .000    .838   1.000    .939    .210    .000    .000    .000    .126

  FOsc    VEsc    DIsc    TIsc    FDsc    DFsc    RSsc    FPsc
  800.   20.00   1.000    7.50  800.00   2.000    8.00  800.00
  STcw    RUcw    BLcw
 40.00    800.   1200.

  TVpk    ACas    T1ad    T2ad     A12    T3ad    T4ad     A34
  22.1     .00    13.5    22.1     .00    22.1    27.0     .17
  VCal    VPcl    FCal    FZcl    FPcl    TBeg    TEnd
  3.28   1.000    3.28   651.8   1.000    13.5    71.5
  VAsh    FAsh    VTsh    FTsh    VFil    FFil
    .0      .0       0       0       0       0

  PEnt  M-BLct  C-BLct    CIrc    BTar    MQno    Freq    J-Rx    J-Rs     RSA
  97.3    95.0   135.6   4.000   1.000    3.25   5000.     .72     .41       0

 Added            Cut-Off            E-Modul  Toe Quake and  Uplift Frictn
 Quake                            Multiplier   Damping Optn  Reduct. Factr
   .00                .00               1.00              0            .80

Added Impedance
None

Added Damping
None

Damping Multipliers
All ones

Capacity Reduction Factors
All ones
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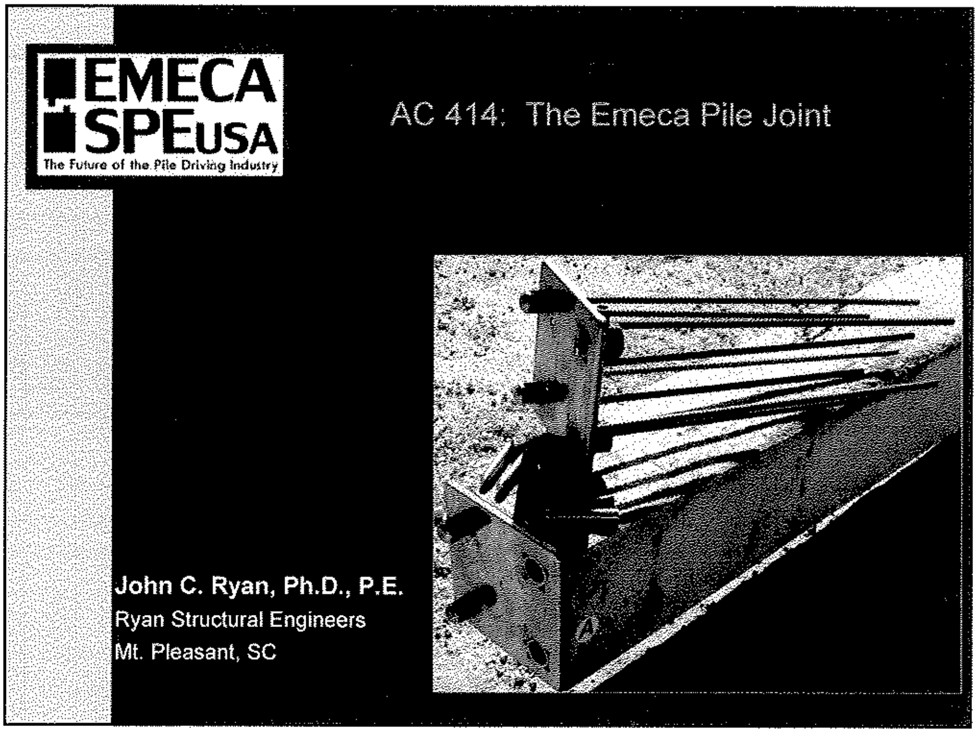
JUN - 4 2009

ICC-ES Evaluation Committee

17

AC414-0609-R1



EMECA SPEUSA
The Future of the Pile Driving Industry

AC 414: The Emeca Pile Joint

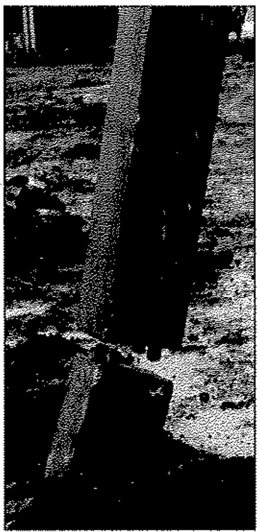
John C. Ryan, Ph.D., P.E.
Ryan Structural Engineers
Mt. Pleasant, SC

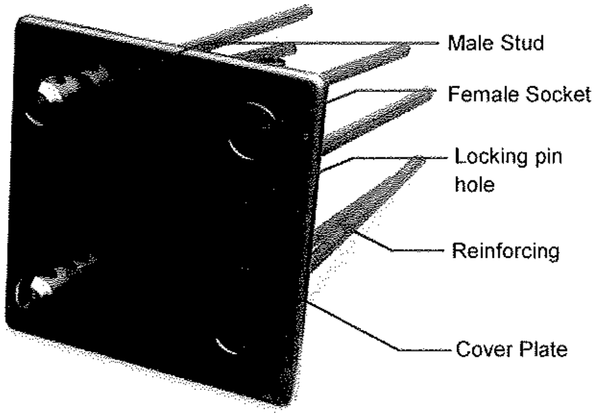
Overview

- The Emeca Joint and Locking Mechanisms
- Casting the Emeca Joints
- Pile Installation
- Structural Analysis
- AC 414 & IBC Provisions for Splices

EMECA SPEUSA

Emeca Pile Joint





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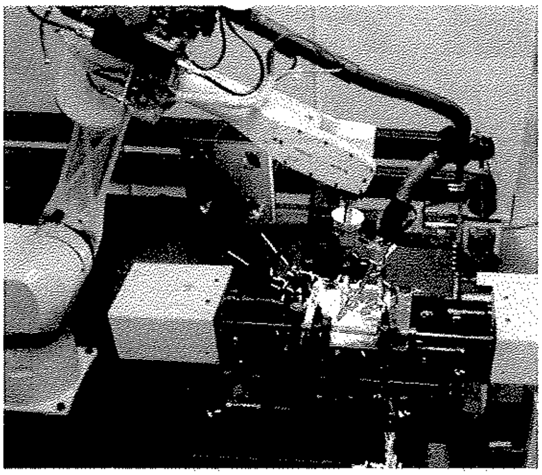
Emeca Pile Joint



Automated Robotic Fabrication

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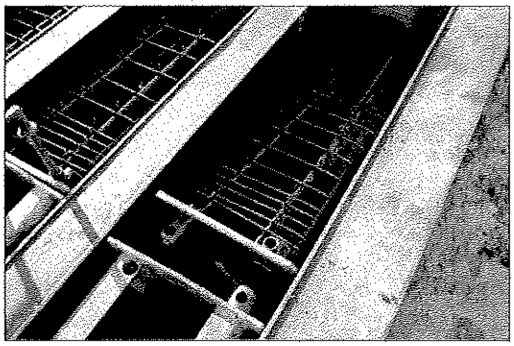
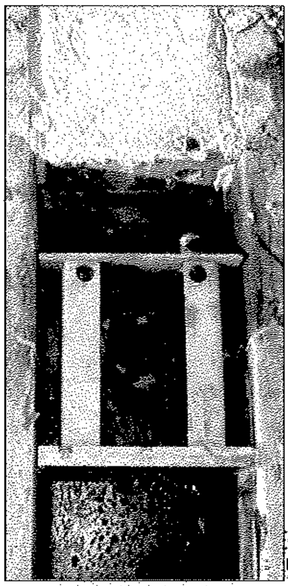
Casting Splices

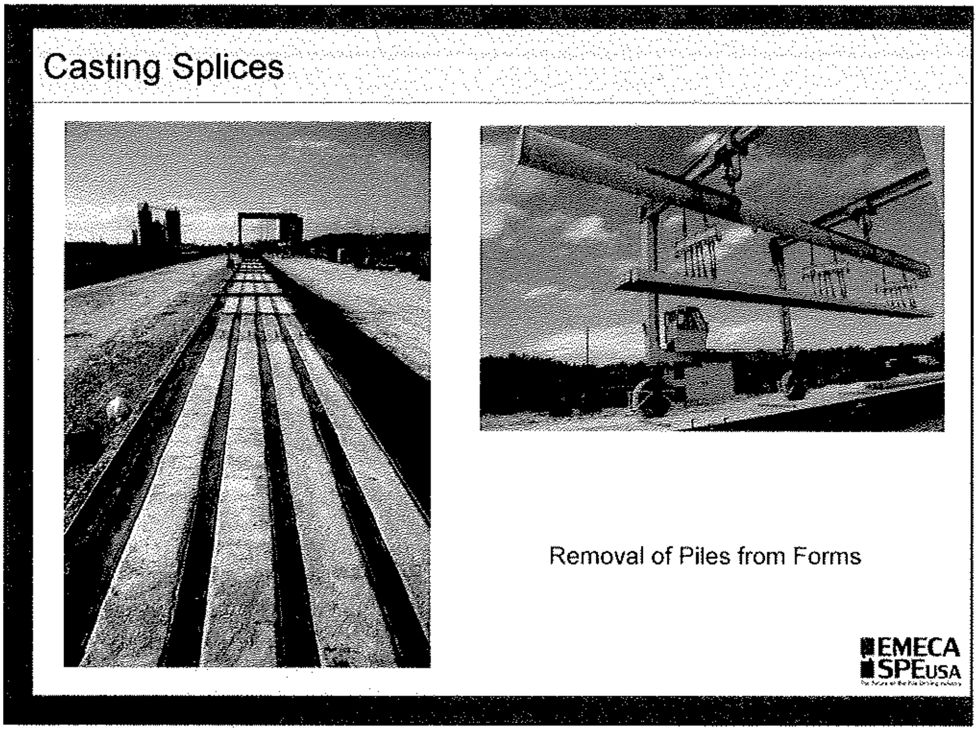
Casting for Vitol Oil

Casting Splices



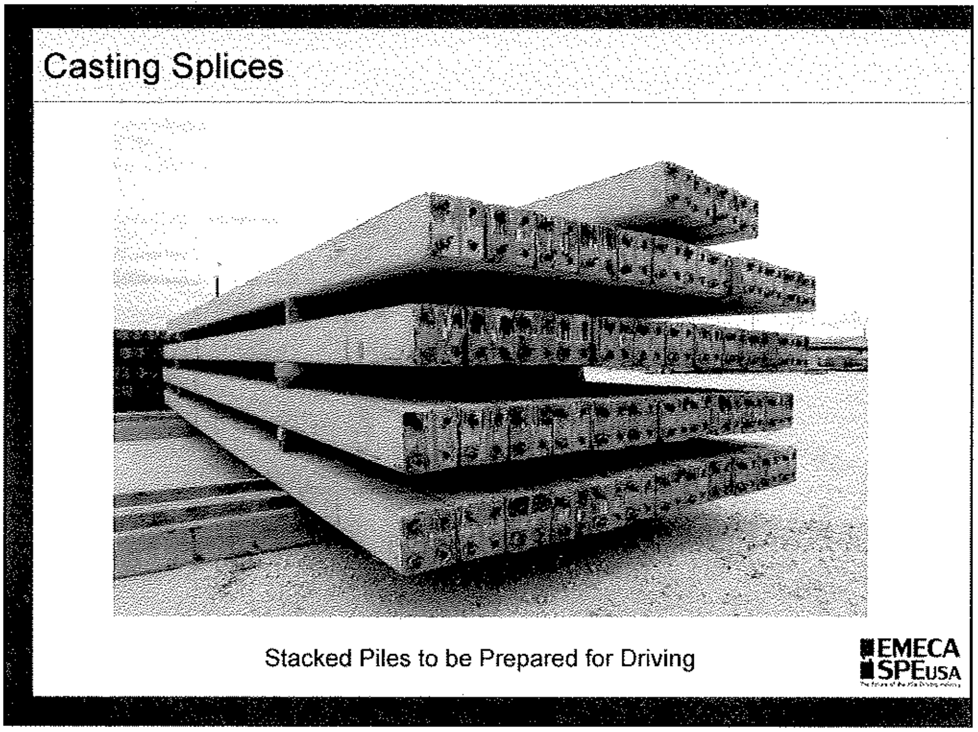
Casting Guides Provide Square Ends





Casting Splices

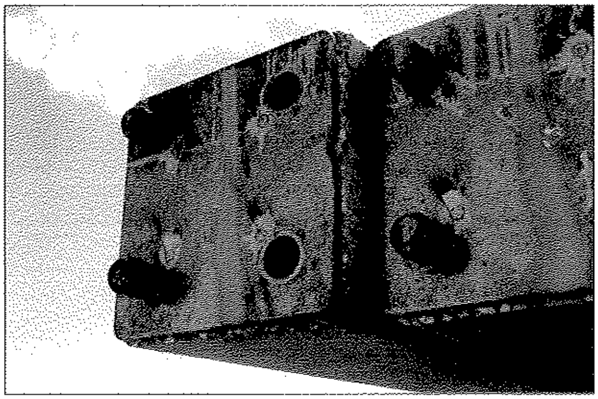
Removal of Piles from Forms



Casting Splices

Stacked Piles to be Prepared for Driving

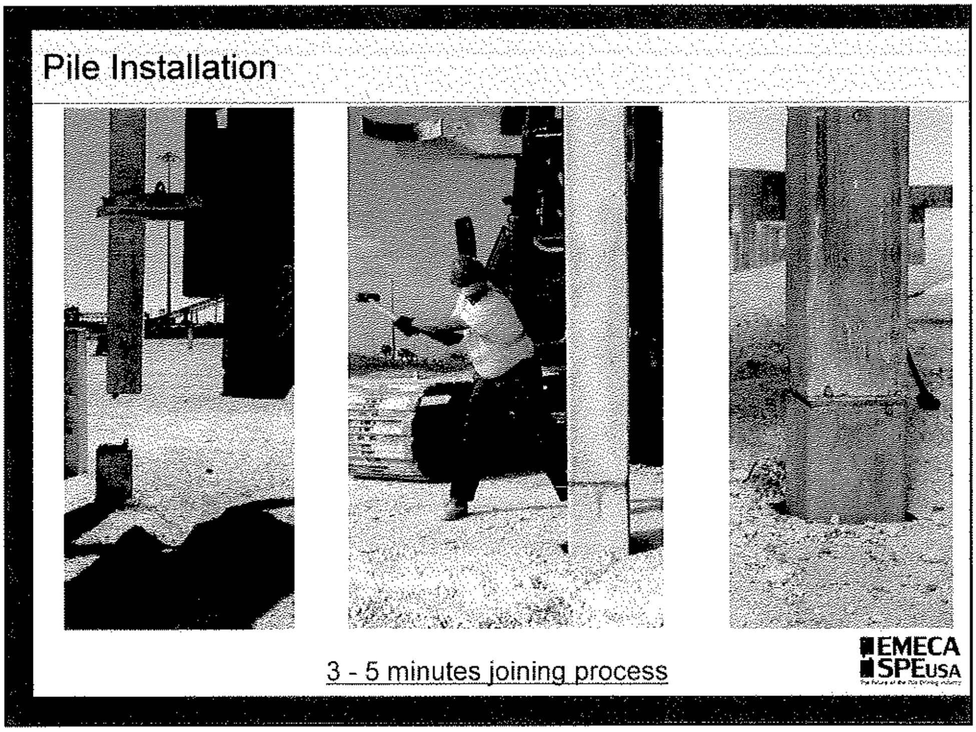
Casting Splices



Prestressing Strands Ground Flush

Pile Installation

Driving Production Piles



Pile Installation

3 - 5 minutes joining process

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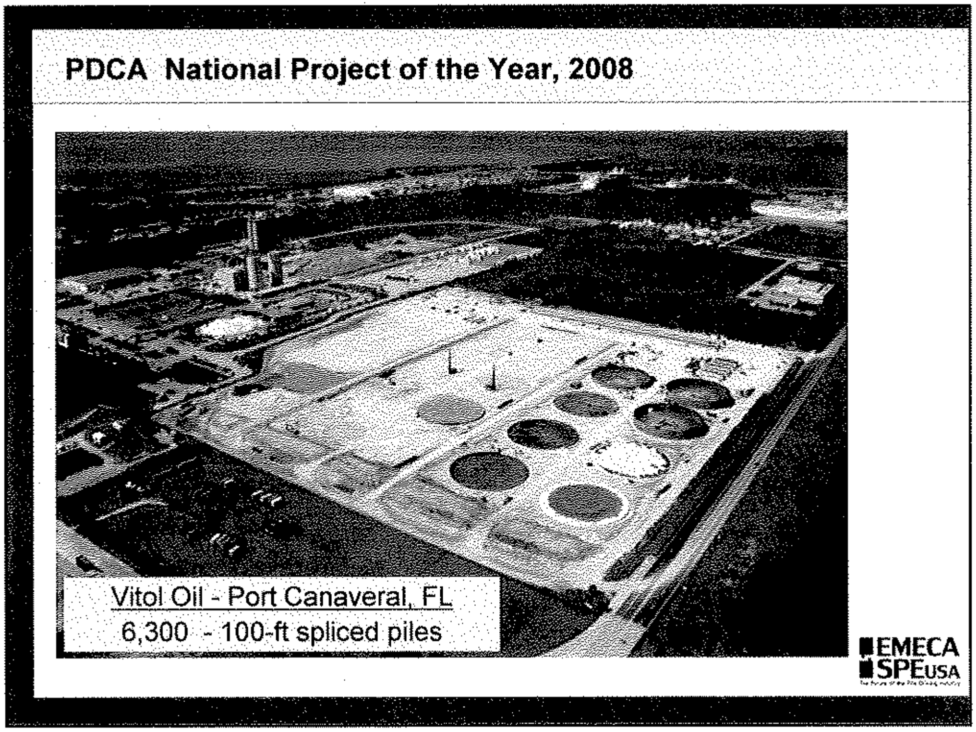

PDCA National Project of the Year, 2008

Vitol Oil - Port Canaveral, FL
6,300 - 100-ft spliced piles

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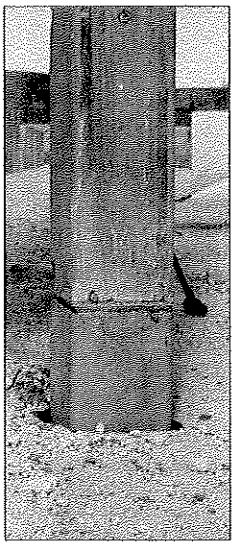
Structural Analysis

Establish capacity for transfer

- Compression
- Shear
- Tension
- Bending



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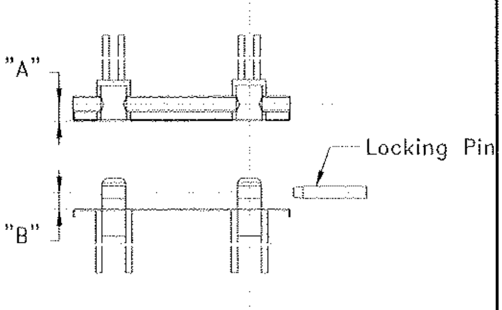
Compression

- "A" > "B"
- Faying surfaces are drawn together when pins are driven
- Compression is transferred through bearing of faying surfaces



Assembly Diagram of Emeca Joint

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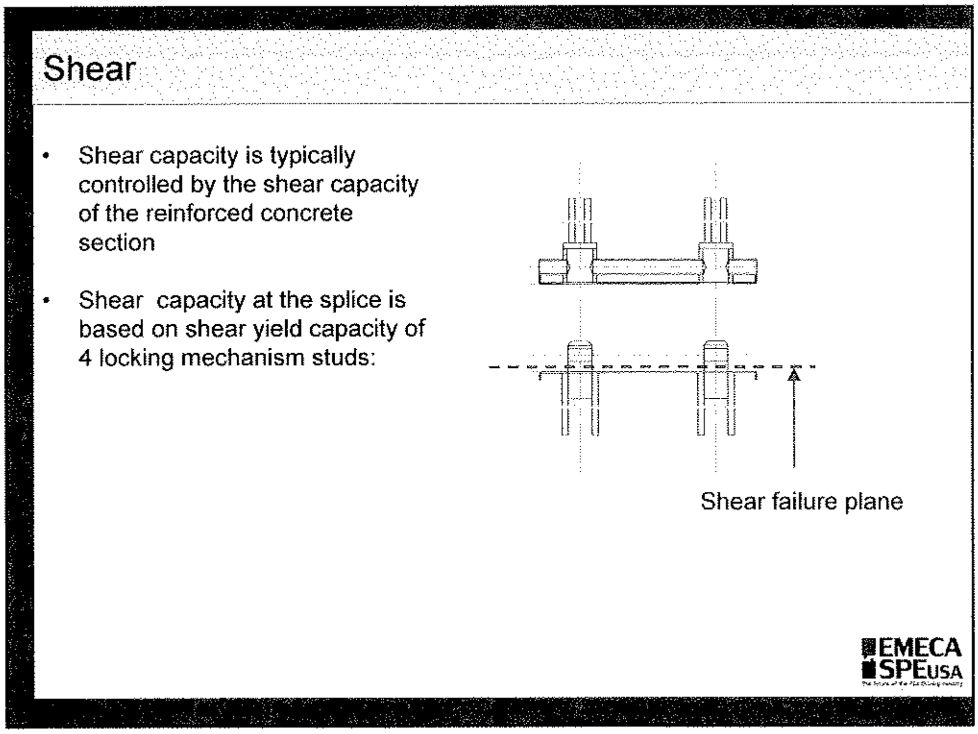
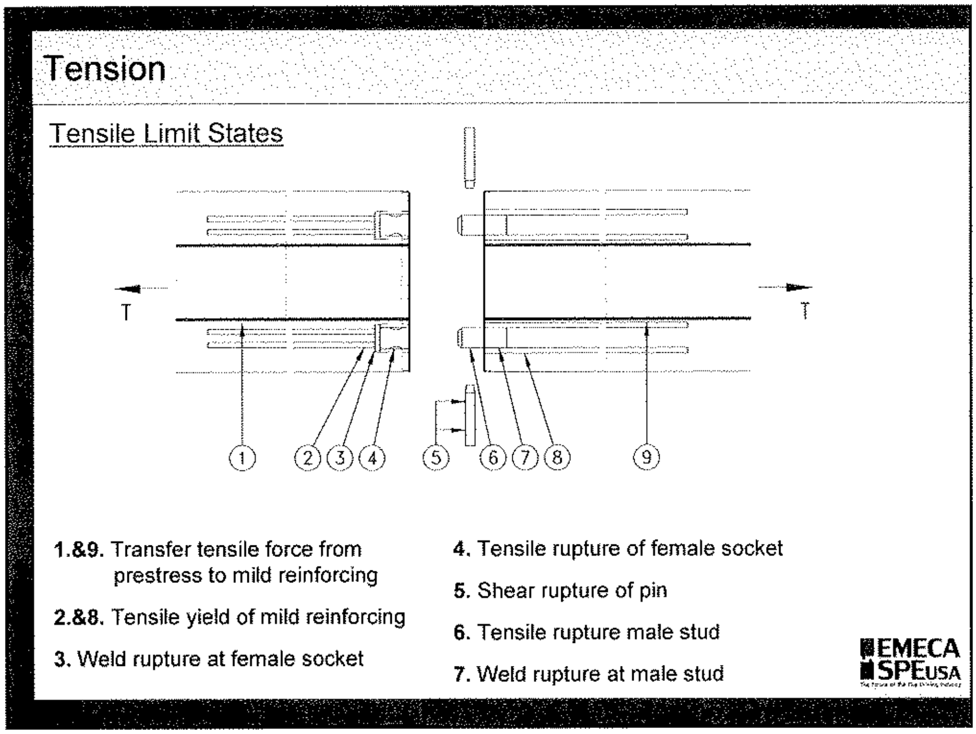


Shear

- Shear capacity is typically controlled by the shear capacity of the reinforced concrete section
- Shear capacity at the splice is based on shear yield capacity of 4 locking mechanism studs:



Tension

Tensile Limit States

1.&9. Transfer tensile force from prestress to mild reinforcing

2.&8. Tensile yield of mild reinforcing

3. Weld rupture at female socket

4. Tensile rupture of female socket

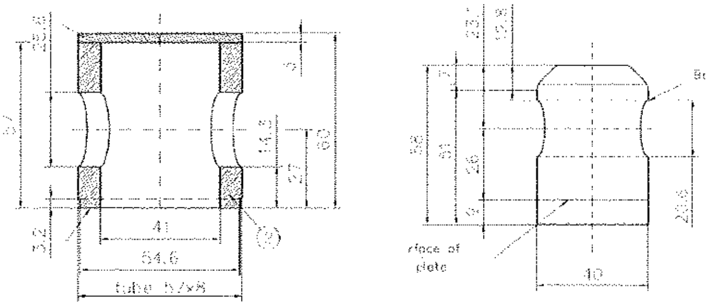
5. Shear rupture of pin

6. Tensile rupture male stud

7. Weld rupture at male stud

Tension

Limit States 4., 5. & 6.: Locking Mechanism Limit States



- Design is the result of optimization through finite element analysis
- Double shear across the locking pin controls tensile capacity
- Proof testing was done at VTT testing laboratory in Finland

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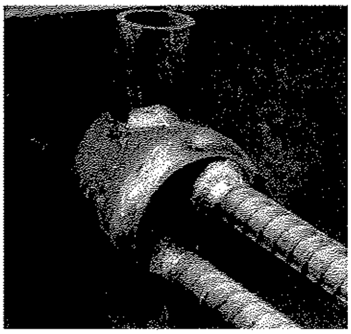
Tension

Limit States 3. & 7.: Weld rupture at reinforcing/locking mechanism interface



Butt-Joint at female socket

Lap-Joint at Male Stud

Note: Welds are designed to develop reinforcing

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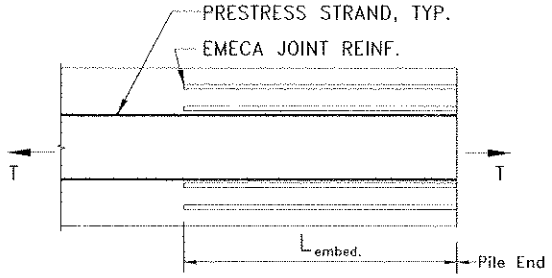
Tension

Limit States 1. & 9.: Transfer tensile force from prestress strand to mild reinforcing



CASE 1: $L_{embed.} \geq L_d$ for strand:

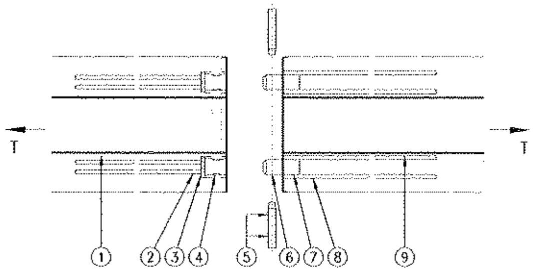
- Failure mechanism is strand rupture
- $f_{ps} = F_u$

CASE 2: $L_{embed.} < L_d$ for strand:

- Failure mechanism is strand slip
- Max stress based on underdeveloped strand, $f_{ps} < F_u$
  (Ref: PCI Figure 4.12.4 / ACI 12.9.1)

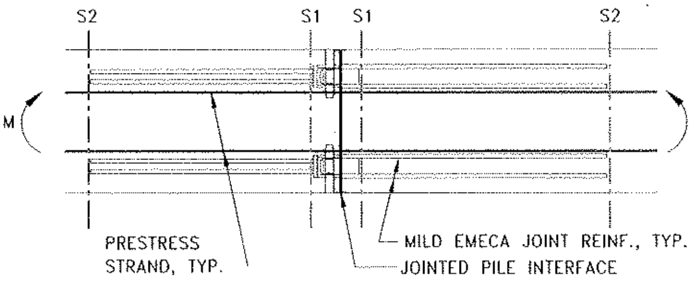
Tension

Summary:

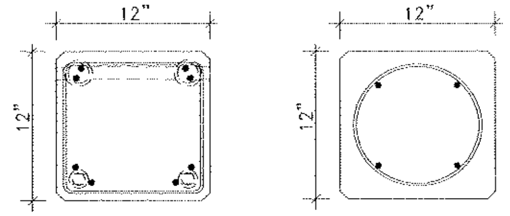


- Welds and locking mechanism are designed to develop reinforcing
- (1) Strand slip, (2) strand rupture **OR** (3) yield of reinforcing will control over all tensile limit states
- The limits states of the tension component of the bending couple are analogous

Bending Analysis at Joint



Critical Sections:



S1-Section at Joint

S2-Prestress Section

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AC 414 – General Criteria

Determination of Reported Splice Capacity

1. Design values for the transfer of the following force components across the splice are calculated using rational analysis: (1) Compression, (2)Tension, (3) Shear, and (4) Moment
2. Quasi-static Compression, Tension, Shear, and Moment Tests are conducted to failure for 3 specimens, each. (12 tests total)
3. All tests specimens are subjected to Impact Tests, using state-of-practice driving practices prior to quasi-static tests.
4. Experimental results are subject to acceptance criteria, based on tested material properties for each specimen and rational analysis.
5. Analytical values calculated per item "1." using nominal specified material properties and rational analysis are reported.

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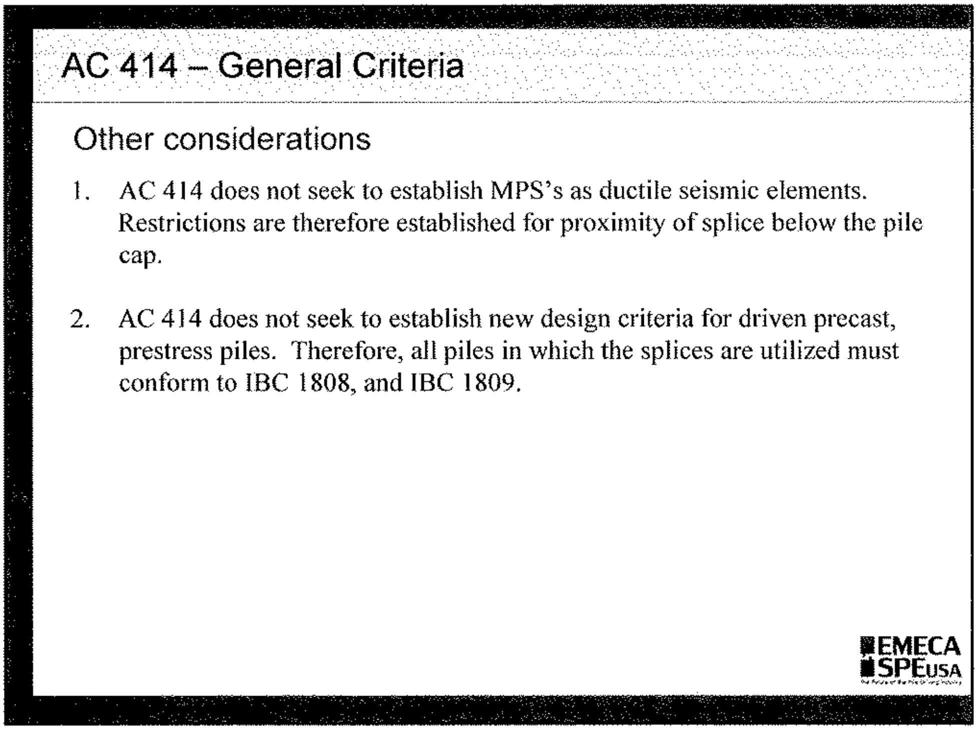

AC 414 – General Criteria

Other considerations

1. AC 414 does not seek to establish MPS's as ductile seismic elements. Restrictions are therefore established for proximity of splice below the pile cap.

2. AC 414 does not seek to establish new design criteria for driven precast, prestress piles. Therefore, all piles in which the splices are utilized must conform to IBC 1808, and IBC 1809.

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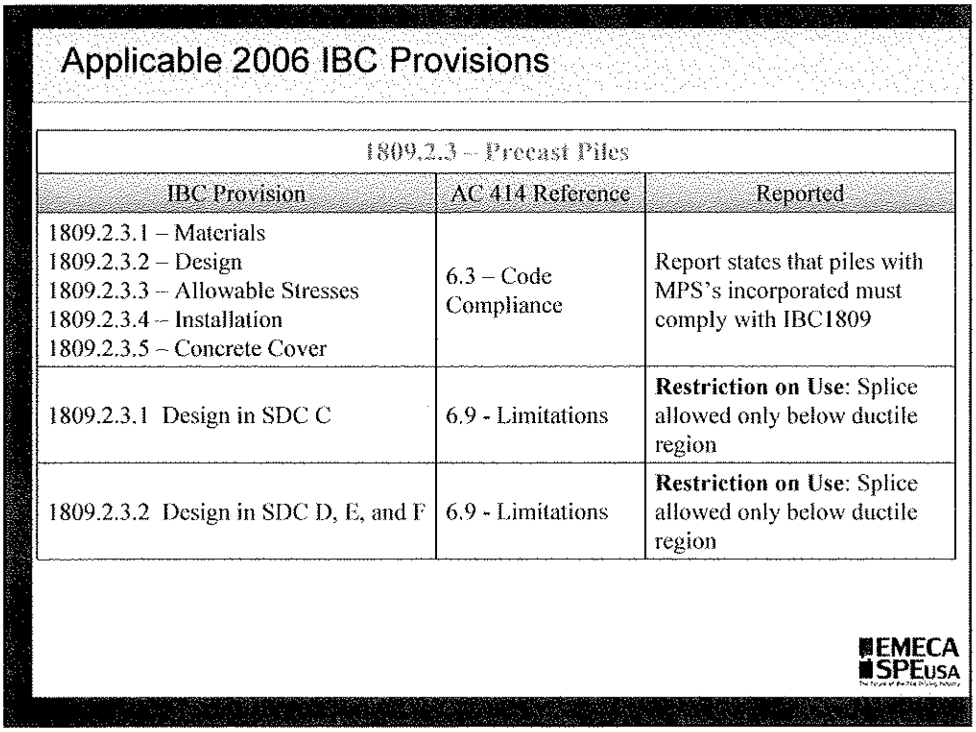

Applicable 2006 IBC Provisions

1809.2.3 – Precast Piles		
IBC Provision	AC 414 Reference	Reported
1809.2.3.1 – Materials 1809.2.3.2 – Design 1809.2.3.3 – Allowable Stresses 1809.2.3.4 – Installation 1809.2.3.5 – Concrete Cover	6.3 – Code Compliance	Report states that piles with MPS's incorporated must comply with IBC1809
1809.2.3.1 Design in SDC C	6.9 - Limitations	**Restriction on Use**: Splice allowed only below ductile region
1809.2.3.2 Design in SDC D, E, and F	6.9 - Limitations	**Restriction on Use**: Splice allowed only below ductile region

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Applicable 2006 IBC Provisions

1808.2.7 – Splices

IBC Provision	AC 414 Reference	Reported
(1) Provide and maintain true alignment	4.2.6 (2) - angular deviation limited subsequent to impact tests	Measured angular deviation
(2) Must have adequate strength for driving and service loading	3.0 - Test and Performance Requirements	Design values for each limit state and interaction of limit states, calculated using rational analysis
(3) Shall develop not less than 50% of the least pile capacity in bending	6.3 – Code Compliance	Moment capacity of joint reported
(4) Special consideration for splices occurring in the upper 10 ft. of the pile	6.9 - Limitations	**Restriction of use**: Splices are not to be installed in upper 10 ft. of pile

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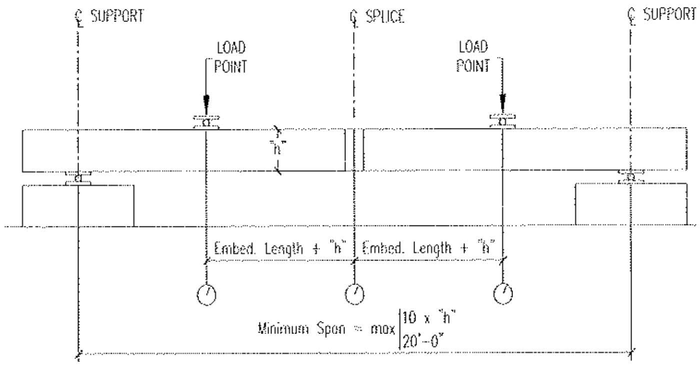
Applicable 2006 IBC Provisions

IBC Provision	AC 414 Reference	Reported
1808.2.9.2– Lateral Support	6.9 - Limitations	**Restriction of use**: Splices are not permitted in un-braced section of pile
1808.2.9.3– Lateral Stiffness	4.3.7 – Flexural Stiffness	Flexural stiffness, calculated using rational analysis
1808.2.17– Protection of Materials	6.4 - Geotechnical Investigation	States that geotechnical report shall provide guidance regarding corrosive potential of soil at the depth of the splice

Bending Tests



Ⓘ INCIATES LOCATION OF MEASURED DEFLECTION

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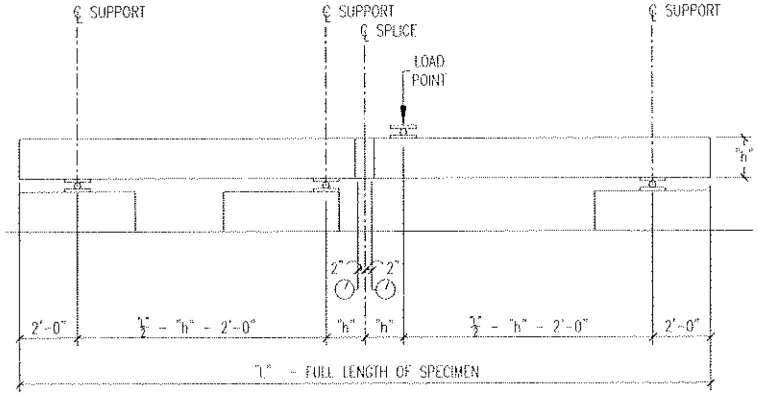
Shear Tests



Ⓘ INCIATES LOCATION OF MEASURED DEFLECTION

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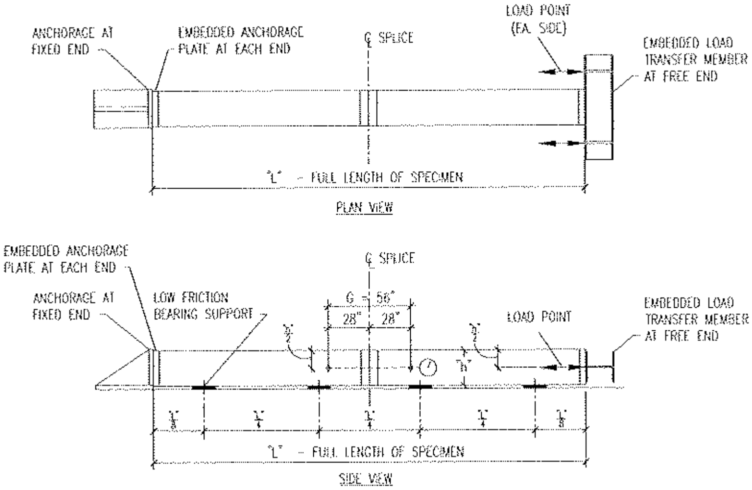
Axial Tests



⊘ INCIATES LOCATION OF MEASURED DEFLECTION, EACH SIDE OF SPECIMEN

G.L. REFERENCE GAGE LENGTH ACROSS WHICH RELATIVE AXIAL DISPLACEMENT IS MEASURED

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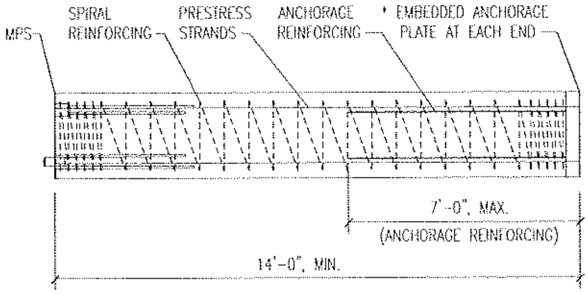
Axial Test Specimen



* EMBEDDED ANCHORAGE IS TO BE INSTALLED
IN SPECIMENS TO BE TESTED FOR
AXIAL TENSION AND COMPRESSION ONLY

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