DESIGN, MANUFACTURE, AND INSTALLATION GUIDELINES

OF

PRECAST CONCRETE SEGMENTED PILES

FOR

FOUNDATION UNDERPINNING

by

The Structural Committee

of

The Foundation Performance Association

Houston, Texas

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PREFACE

This document was written by the Structural Committee and has been peer reviewed by the Foundation Performance Association (FPA). This document is published as FPA-SC-08 Revision 0 and is made freely available to the public at www.foundationperformance.org so all may have access to the information. To ensure this document remains as current as possible, it may be periodically updated under the same document number but with higher revision numbers such at 1, 2, etc.

The Structural Committee is a permanent committee of the Foundation Performance Association. At the time of writing this document, the Structural Committee was chaired by Ron Kelm, P.E. and 20 to 25 members were active on the committee. The committee sanctioned this paper and formed a subcommittee to write the document. The subcommittee chair and members are listed on the cover sheet of this document.

Suggestions for improvement of this document shall be directed to the current chair of the Structural Committee. If sufficient comments are received to warrant a revision, the committee will form a new subcommittee to revise this document. If the revised document successfully passes FPA peer review, it will be published on the FPA website and the previous revision will be deleted.

The intended audiences for the use of this document are engineers, foundation repair contractors, segmental pile manufacturers, builders, owners, and others that may be involved in the design, manufacture, and installation of foundation underpinning and underpinning components.

This document was created with generously donated time in an effort to improve the performance of foundations. The Foundation Performance Association and its members make no warranty, expressed or implied, regarding the accuracy of the information contained herein and will not be liable for any damages, including consequential damages, resulting from the use of this document. Each project should be investigated for its individual characteristics to permit appropriate application of the material contained herein.

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1.0 INTRODUCTION

The scope of this document is to provide guidance and information for projects that use precast concrete segmented piles for underpinning the foundations of existing residential and other low-rise structures. This type of foundation underpinning system is usually not suitable for high-rise buildings or other similarly heavily loaded structures due to the limited load capacity of the pile sizes commonly used and the driving depths typically achieved. Most applications involve lifting existing foundations, but some only intend to stabilize a foundation from future downward movements.

The foundation underpinning system is also known by generic names such as precast concrete piles, pre-cast pilings, hydraulically driven concrete piling, pressed piles, pressed pilings, driven cylinders, and others. Most of the available segmented pile systems utilize cylindrical concrete segments, but rectangular and other shapes may be used.

Piles consist of precast concrete segments, usually manufactured cylinders, which are installed one by one on top of one another, pressed into the ground by hydraulically jacking against the underside of the existing structure. The weight of the structure is used to create the reactive force that allows the pile segments to be driven into the soil. These piles may be categorized as driven displacement piles, which displace and force aside the surrounding soil as they are driven. The piles transfer load to the foundation soils primarily through skin friction along the length of the pile, although some end-bearing load transfer also occurs.

This system is mainly utilized in clay soils where the driving resistance is small enough to allow the weight of the structure to be used to develop the driving force necessary to obtain sufficient pile penetration. Dense granular soils may offer too much driving resistance, making the piles more difficult to install with the available weight of the structure as the driving force. For similar reasons, precast concrete segmented piles are also difficult to install in clay soils with stiff sandy clay or clayey sand layers. However, a high-pressure water injection technique, called jetting, or other methods, such as pre-drilling, may be used to break up the soil and allow additional pile penetration.

This document addresses both interconnected and non-interconnected precast concrete segmented piles. Means of interconnection may consist of steel bar(s), threaded rod, or cable that is inserted into a hole preformed through the center of each of the concrete segments along their longitudinal axis. These elements are typically used to align and/or hold the segments together. An alternative method of interconnection may be to bond the segment ends using epoxy or other adhesive. It is recommended that interconnected piles be used.

2.0 GENERAL DESIGN CONSIDERATIONS

In deciding which type of foundation underpinning system to specify, consider the following in using interconnected and non-interconnected precast concrete segmental piles:

1. Non-interconnected precast concrete segmental piles without reinforcement are typically less expensive.

2. Precast concrete segmental piles are not able to resist significant bending moments due to lateral loads.

3. Depending on the type of interconnecting system used and when the interconnecting element is installed, the interconnection may help to avoid detrimental vertical misalignment of the pile while being driven.

4. When interconnected, a properly designed and installed concrete segmental pile is more likely to resist the uplift forces due to swelling of expansive soils transmitted via friction along the shaft. A pile will not resist the uplift forces to the foundation.

5. Depending upon the soil uplift forces, interconnected precast concrete segmental piles that are connected to the existing foundation system may not be able to provide resistance against foundation uplift if the soil is in contact with the existing foundation system.

6. For most projects, the final depth of each pile will vary from pile to pile. As a result of using only the weight of the structure to drive the pile, the precast concrete segmental pile system has a depth of refusal that varies depending upon the tributary weight and stiffness of the structure above the pile being driven. If the pile cannot attain sufficient penetration into stable soils, then it may not be anchored against potential movements that occur due to swelling or shrinking of the soils in the moisture active zone.

7. Should a void exist under the slab subsequent to the lifting process, treatment of the void should be determined on an individual basis.

8. Geotechnical investigation and structural analysis could be of value for the design of the foundation repair.

3.0 FOUNDATION UNDERPINNING REPAIR GUIDELINES

The purpose of this section is to provide a guideline to specifying foundation underpinning repair, including remedial precast concrete segmental piles for foundation repair, foundation stabilization against movements, and foundation lifting.

3.1 DEFINITIONS

Segment: Precast concrete units that are typically cylindrical in shape and about one-foot long, although other shapes and lengths may be used.

Reinforced Precast Concrete Segments: Precast concrete pile Segments reinforced with steel, fiberglass, or other materials.

Pile: The Pile or Piling includes the following elements: multiple Segments that are driven into the ground, Pile Head, Shims, and Interconnections (if specified).

Pile Head: The uppermost section of the Pile. The Pile Head typically consists of a rectangular or trapezoidal shaped concrete block placed on top of the last driven Segment along with two additional Segments or other spacer elements placed on top of the rectangular or trapezoidal shaped concrete block.

Foundation Underpinning: The process of adding additional supporting elements under an existing foundation system.

Shim: Metal or other material used to fill the space between the Pile Head and the bottom of the foundation system.

Precast Concrete Segmented Pile: The installed assembly of Segments, Pile Head, Shims, and interconnection system (if applicable).

Non-Interconnected Precast Concrete Segmented Pile: Precast concrete segmented piles that are driven into the ground without any physical connecting elements between the pile segments.

Interconnected Precast Concrete Segmented Pile: Precast concrete segmented piles, with a center hole in the longitudinal axis, held together by a central steel reinforcing bar, a steel rod or rods, threaded ends and coupling nuts, steel cable, or other similar reinforcement. The Segments may be interconnected by inserting the connecting element through the center hole of each Segment. An alternative method of interconnection may be with adhesives, such as epoxy, between the ends of the Segments.

Foundation Elevation Adjustment: The process of raising or lowering the foundation elements in order to obtain a new vertical position in an effort to reduce distress, deflection, and/or tilt to the superstructure.

Foundation Stabilization: The process of underpinning the foundation to help prevent future downward foundation movement without appreciably performing Foundation Elevation Adjustment.

Refusal: Refusal is defined as the point when the structure is lifted 1/4 inch to 1/2 inch above its elevation at the location of the pile during the driving process. The Pile is said to reach refusal and the driving operation is stopped before the occurrence of significant vertical movement of the building that may cause damage to the superstructure.

3.2 REFERENCES AND STANDARDS

The contractor shall follow all applicable codes and standards. The following standards are identified by issuing authority, authority abbreviation, designation number, title or other designation established by the issuing authority. The contractor shall follow the current version of the applicable standards from the American Society for Testing and Materials (ASTM) list below :

ASTM A29/A29M Steel Bars, Carbon and Alloy, Hot-Wrought and Cold Finished.
ASTM A36/A36M Carbon Structural Steel.
ASTM A153 Zinc Coating (Hot Dip) on Iron and Steel Hardware.
ASTM A416 Steel Strand, Uncoated Seven-Wire for Pre-stressed Concrete.
ASTM A615 Deformed and Plain Billet-Steel Bars for Concrete Reinforcement.
ASTM A706 Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement.
ASTM A767 Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement.
ASTM A775 Epoxy-Coated Reinforcing Steel Bars.
ASTM A992 Structural Steel.
ASTM C33 Concrete Aggregates.
ASTM C39 Test Method for Compressive Strength of Cylindrical Concrete Specimens.
ASTM C150 Portland Cement.
ASTM C494 Chemical Admixtures for Concrete.

3.3 DESIGN REQUIREMENTS

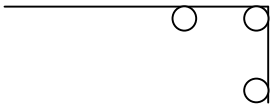
The owner shall have direct involvement in specifying the project objective. Design of the precast concrete segmented pile for commercial applications shall be prepared by an Engineer (for the purposes of this paper, defined as “Licensed Professional Engineer”)**.** In residential projects, an Engineer should be engaged to prepare a design or analyze a pile layout that has been prepared by a contractor.

The following are general piling placement guidelines in evaluating a typical one story and two story residential structures. The purpose of these guidelines is to provide general outlines when preparing a foundation repair plan.

1. **Exterior Pilings** - Exterior piling supports shall have a maximum spacing as follows: (porches and garages see below)
    a. 8 feet center to center on a 1-story wood or brick structure.
    b. 7 feet center to center on a 1-1/2 story (i.e. a 1-story with a partial 2nd-story) and 2-story with brick on the 1st story only.
    c. 6 feet center to center on 2-story brick structures.
    d. If there is no exterior grade beam present, then a structural member designed by an Engineer shall be installed between the piling and the slab in order to reduce the punching shear stresses and to increase the pile driving force.

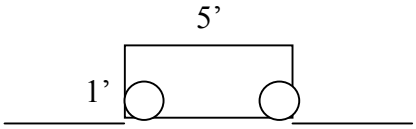
2. **Interior Pilings** - Interior pilings shall have a maximum spacing as follows:
    a. 8 feet center to center on 1-story structures.
    b. 7 feet center to center on 2-story structures.
    c. If an interior room is 16 feet wide or greater, piling supports shall be placed in the middle of the room (excluding garages). If there is no interior grade beam present then a structural member designed by an Engineer shall be installed between the piling and the slab in order to reduce the punching shear stresses and to increase the pile driving force.

3. **Corners** Piling supports shall be placed at each corner where an exterior wall changes direction. When lifting a corner provide at least one piling support on each side of the corner pile as depicted below.

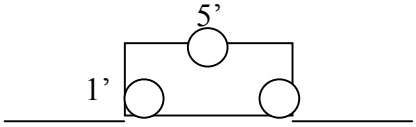


4. **Fireplaces** - The following are examples of piling support placement for fireplaces.

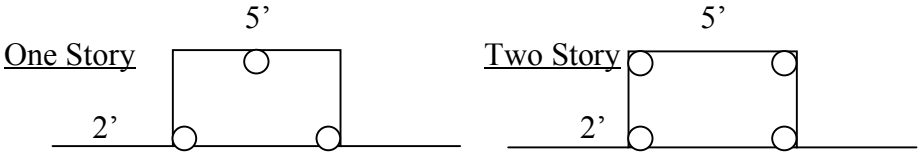
    a. 1 foot by 5 feet prefabricated fireplace with wood exterior a minimum of 2 piling supports shall be placed as shown below.



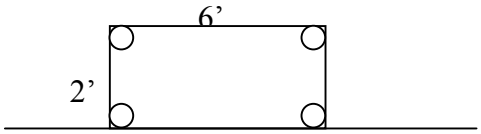
    b. 1 foot by 5 feet prefabricated fireplace with brick veneer exterior a minimum of 3 piling supports shall be placed as shown below



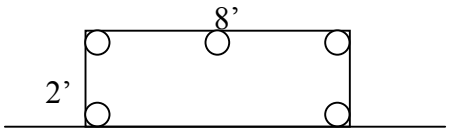
c. 2 feet by 5 feet fireplace with brick veneer exterior a minimum of 3 piling supports shall be placed as shown below for a one story and 4 pilings shall be used on a two story.



d. 2 feet by 6 feet fireplace with brick exterior a minimum of 4 piling supports shall be placed as shown below.

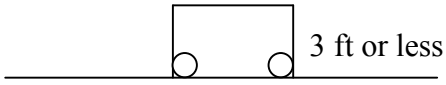


e. If the fireplace is 8 feet or greater in length then an additional piling shall be placed at the center on the exterior wall as depicted below.

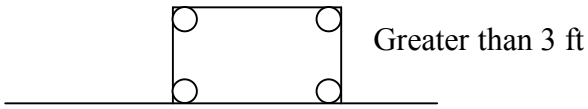


5. **Porches** - The following are examples of piling support placement for porches.

a. If the inset of the porch wall is 3 feet or less then a minimum of 2 piling supports shall be placed as illustrated below.



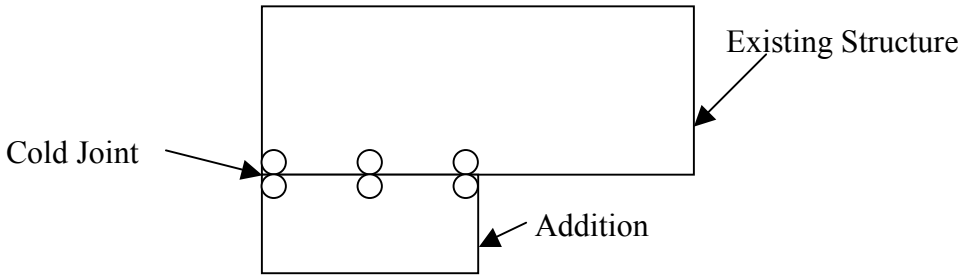
b. If the inset of the porch wall is greater than 3 feet then a minimum of 4 piling supports shall be placed as illustrated below.



c. On extended one-story porches piling supports shall be placed at a maximum distance of 12 feet center to center or shall be placed directly under the overhang column supports.

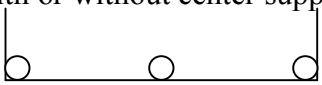
6. **Wing Walls** - If the wing wall is monolithic and greater than 3 foot in length then a piling shall be placed at the end of the wing wall.

7. **Additions** – At additions, the drawing shall show the concrete joint and separation dimensions. At the interface of the addition and the original structure double-piling supports shall be used and spaced per the exterior and/or interior requirements stated above.

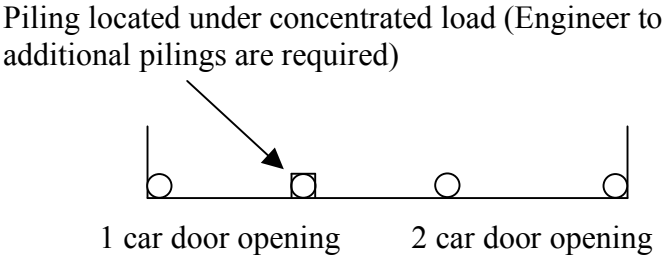


8. **Garages** – A minimum of one piling support shall be used at the mid-point of a garage door opening for a 2-car garage. A piling support shall be placed under garage support columns. Examples are illustrated below.

   a. Two car garage with or without center support.



   b. Three car garage.



3.4 SUBMITTALS

The contractor shall submit the following items to the owner or his designated representative in accordance with conditions of the contract and the applicable submittal procedures in the above References and Standards (Section 3.2):

Product Data: Submit product data for the specific type of precast concrete segmental pile used, showing pile configuration including, but not necessarily limited to, reinforcing type (if any), details of pile toe and pile head, manufacturing and fabrication details, installation instructions, product components, and related accessories.

Pile Location Drawings: Submit drawings showing the proposed location, and total number of precast concrete segmental piles.

Qualification Data: If requested, the contractor shall submit a list of completed projects with project names and addresses, names and addresses of owners, and other information to demonstrate their capabilities and experience.

Engineering Analysis: For a commercial project or if requested for a residential project, a foundation analysis and a foundation repair design shall be prepared by an Engineer. When a design is submitted by the contractor for review, it should be analyzed by an Engineer.

Pile-Driving Equipment: Submit data sheets that indicate the type, make, rated load capacity, and manufacturer's recommended calibration frequency of the hydraulic ram that will be used to drive the segmental piles. Submit the date of the ram's last calibration or purchase date of the pressure gauge. Submit data sheets that indicate the type, make, and pressure capacity of any water jetting equipment that will be used. Include a description of how the water jetting operations, (if used), will be integrated with the pile driving operations.

Foundation Lifting Equipment: Foundation lifting equipment typically consists of hydraulic jacks with a capacity in the range of 20 to 50 tons.

Pile-Driving Records: Submit to client or his representative the pile-driving records within seven days of driving the pile. The pile-driving records shall indicate depths of exterior piles from existing grade and depths of interior piles from the bottom of the slab. The submitted records shall include the force or pressure used to drive the segmental piles. Records shall indicate if water jetting was utilized and the range over which water jetting was engaged. These records shall be forwarded to the Engineer in order to verify that sufficient pile depths and other design requirements have been achieved.

Prequalification Test Reports: If a prequalification test is required to observe the behavior of the building's superstructure and the pile under actual driving conditions, then a test pile shall be driven at an outside corner of a building. If an outside corner is not available then the test pile shall be driven in another area where the driving force (structure's weight and stiffness) is minimized. Test reports for prequalification test piles shall be submitted to the Engineer for review and comment prior to the installation of additional Piles.

Safety Program: Submit Contractor's standard safety requirements for working in excavated trenches, tunnels, and confined spaces that meets the requirements of OSHA standards.

Initial Elevation Survey: Along with the Pile Location Drawings, submit the initial foundation elevation survey clearly showing the location of the reference datum. A symbol, such as a dot, shall be used to show the location of each elevation survey point.

Final Elevation Survey: After installing the Piles, submit the final foundation elevation survey. The reference datum used in the initial elevation survey shall be used for the final elevation survey.

Material Test Reports or Material Certificates: Submit material test results from a qualified testing agency, or material certificates from the manufacturer, indicating compliance with concrete and reinforcing (if applicable) materials.

3.5 QUALITY ASSURANCE / QUALITY CONTROL

The following quality assurance / quality control requirements shall be submitted to the owner or his designated representative:

Contractor Qualifications: Contractor shall submit evidence of experience in performing this type of work. Include list of completed projects with project names and addresses, names and addresses of owners, and other pertinent information.

Licensed Professional Engineer Qualifications: If an Engineer is retained for the project, evidence of experience in performing this type of work shall be submitted.

Pre-installation Meeting: If requested by the owner, contractor shall conduct a pre-installation meeting with owner or his designated representative to verify project requirements, soil conditions, contractor/manufacturer's installation plan and instructions, contractor/manufacturer's warranty, and other requirements of this document or contract.

Precast Concrete Segment Manufacturing Tolerances: Each precast concrete segment shall be within the following tolerances:

- Cylinder Diameter: Tolerance for the diameter of each of the precast concrete cylinders shall be plus or minus (±) 1/4 inch.
- Cylinder Length: Tolerance for the length of the each of the precast concrete cylinders shall be plus or minus (±) 1/2 inch.
- Segment Ends Concentricity: Tolerance for the concentricity of each of the precast concrete segment about the central axis shall be plus or minus (±) 1/16 inch per foot of segment length.
- Hole Location (if applicable): Tolerance for the location of the central hole through each segment shall be plus or minus (±) 1/8 inch from true center, and measured at each end.
- Hole Diameter (if applicable): Tolerance for the diameter of the central hole through each segment shall be plus or minus (±) 1/16 inch.
- End-Bearing Surface Flatness: Tolerance for flatness of end-bearing surfaces shall be plus or minus (±) 1/16 inch throughout the area of each end-bearing surface.
- End-Bearing Surface Cant: The cant of the end-bearing surface from a true perpendicular surface to the longitudinal axis of the cylinder shall be plus or minus (±) 1/2 degree.

Quality-Control Testing: Owner may employ, at owner's expense, an independent testing agency to evaluate the precast concrete segment manufacturer's quality control and testing methods. Owner's testing agency shall have access to material storage areas, concrete production equipment, concrete placement, and curing facilities. Contractor shall cooperate with Owner's testing agency and provide samples of materials and concrete mixes as may be requested for additional testing and evaluation. Owners testing agency shall provide contractor a written report of findings.

Defective Work: Strength of precast concrete segments will be considered deficient if units fail to comply with requirements. Discard precast concrete segments that do not comply with requirements, including strength, manufacturing tolerances, and finishes.

Verification of Equipment Performance: Calibrate hydraulic ram using method and frequency in accordance with hydraulic jack manufacturer's recommendations.

3.6 DELIVERY, STORAGE, AND HANDLING

Deliver pile components to the Project site in such quantities and at such times to ensure continuity of installation and to meet Project schedule requirements. Handle and store pile materials at the Project site to prevent breaks, chips, cracks, or other physical damage to the precast concrete segments and to any protective coating that may be used on reinforcement, if applicable.

3.7 WARRANTY

Submit contractor's standard warranty document executed by authorized company official. Contractor’s warranty is in addition to, and not a limitation of, other rights Owner may have under the contract document and / or law. The warranty period shall be a minimum of ten (10) years commencing on date when the contractor substantially completed the work. Warranties shall be transferable.

During the warranty period, if differential deflections occur due to downward movement (upward movement is not normally covered unless stated otherwise in the warranty) in any repaired area that have caused damage to the architectural finishes, then the warranty shall cover re-lifting of the foundation to as near the original as-lifted condition as possible, including any tunneling, concrete, decking, or pavement repair as required. If cosmetic repairs and landscaping were not included in the initial scope of work, they will not be covered when warranty foundation repairs are made.

3.8 PRODUCTS

Compressive Strength: The concrete shall have a minimum 28-day compressive strength of 5,000 psi in accordance with ASTM C39.

Reinforcement: The central longitudinal segmented pile reinforcement shall conform to the following, if applicable:

Reinforcing Bars: ASTM A615, Grade 60, deformed.
Low-Alloy-Steel Reinforcing Bars: ASTM A706.
Galvanized Reinforcing Bars: ASTM A767, Class II, hot-dip galvanized.
Epoxy-Coated Reinforcing Bars: ASTM A775.
Steel Cable: ASTM A416, Grade 250, galvanized, seven-wire, low-relaxation strand.
Steel Rods: ASTM F1554.

Pile Heads: Pile heads shall be precast concrete having the same strength and properties of the precast concrete pile segments.

Steel Reinforcement Corrosion Protection: The reinforcement, if applicable, shall be provided with corrosion protection as follows:

- Steel deformed bar reinforcement (rebar) shall be encased in epoxy or epoxy grout until the annulus fills.
- Steel cable reinforcement and threaded rods shall be galvanized.
- Smooth steel rod reinforcement shall be coated with epoxy paint.

Accessories: Shims shall have a minimum thickness of 1/8 inch. Shims and other accessories shall be of sufficient size, strength and durability to match the load capacity of the precast concrete segments.

3.9 INSTALLATION

Install Precast Concrete Segmental Piles in accordance with the following steps:

1. **Safety:** Meeting OSHA and other work safety requirements is the contractor's sole responsibility.

2. **Work Plan:** Contractor shall submit a work plan for excavation and backfill related to the underpinning work with a complete written description that identifies details of the proposed method of construction and the sequence of operations relative to excavation and backfill activities. The descriptions, and/or supporting illustrations, shall be sufficiently detailed to demonstrate that the procedures meet the applicable requirements.

3. **Manufacturer's Product Data:** Contractor shall comply with manufacturer's product data, including product technical bulletins.

4. **Site Examination:** Before installing any piles, the contractor shall examine the site to verify the existing conditions are as indicated on the contract drawings. Notify the owner's designated representative of any discrepancies found between the existing site conditions and the contract drawings.

5. **Piling Placement:** Use a method that will not cause damage to nearby structures. Remove concrete as required to create sufficiently sized access holes through existing slabs-on-grade. Remove and salvage any landscaping plants that occur at exterior access locations. Remove and store plants in accordance with good practice. Excavate soils as required at pile locations to obtain clearance under existing foundation elements sufficient to install piles. Provide a flat bottom surface in the excavated pit at the pile location under the existing foundation. Examine the underside of the existing foundation element, and, if required, chip concrete at bottom surface or add grout as required to provide a smooth bottom surface of the existing foundation at the pile location.

6. **Plumbing Leak Test:** Contractor should employ a licensed plumber to perform a hydrostatic leak detection test of the under-slab sanitary sewer lines and under-slab water supply lines before and after the work is performed. The plumber shall provide the results in a written report.

7. **Utilities:** Obtain utility company approvals when required before digging. When working near known buried utility lines, excavations shall be made using hand tools to avoid disturbing or damaging the utility lines.

8. **Groundwater Control:** If necessary, contractor shall provide groundwater control including dewatering of water-bearing soil layers to remove seepage water from excavations.

9. **Surface Water Control:** Contractor shall provide surface water control to divert water away from excavations through the use of dikes, ditches, curb walls, pipes, sumps, or other means.

10. **Access Holes:** Excavated holes (or pits) for precast concrete segmented piles for installation shall not be permitted beyond the depth required to obtain personnel and equipment access clearances necessary for the pile driving operation.

11. **Existing Drilled Piers:** If existing drilled piers are tied into the existing foundation, sever the top of the existing drilled piers subsequent to driving new precast concrete segmental piles from the bottom of the grade beams. When the tops of the existing drilled pier shafts are connected to the grade beams, the connection shall be severed by chipping to remove concrete and cutting reinforcement bars.

12. **Locate Piles:** Piles shall be positioned as indicated on the approved pile location drawings. Pilings shall be located not more than twelve (12) inches from design location on the Pile Location Drawing, unless approved otherwise by the contractor's design Engineer.

13. **Obstructions:** Remove any encountered obstructions, or add/relocate pile and adjacent piles as required by the pile layout designer.

14. **Stockpile Segments:** Stockpile a sufficient number of concrete segments at each pile location to obtain the anticipated pile depth, and have a sufficient number of extra segments readily available to obtain the pile length necessary to achieve the anticipated depth to refusal. The stockpiling requirement is to ensure that the anticipated pile depths can be obtained without having to stop the pile driving process to obtain more segments. Stopping the pile driving process could potentially cause early thixotropy (soil freeze up).

15. **Concrete Segment Size:** Unless approved otherwise, use the same concrete segment size for all segments within each pile. Contractors may use cylindrical concrete segments of varying diameters within a given single pile, increasing the diameter in a step-wise fashion to effectively taper the pile from bottom to top. An example would be to start

driving with 4-inch diameter segments, switching to 6-inch diameter segments, and then switching again to 8-inch diameter segments.

16. **Driving Records:** Maintain accurate driving records for each pile recording, as a minimum, the information shown on the Segmented Repair Piles checklist of FPA-SC-10 "Quality Control Checklists for Foundation Inspection of Residential and Other Low-Rise Buildings", current revision found at www.foundationperformance.org.

17. **Axial Alignment:** Establish and maintain axial alignment of all cylinders within each pile so that all cylinders remain concentric and vertical during the driving operation.

18. **Lubrication:** Water may be added to the bottom of the excavated hole (pile pit) at the pile location during pile driving for lubrication purposes. The amount of water used shall be minimized to avoid excessive water accumulation in the soils that could lead to additional swelling of expansive soils.

19. **Interruptions:** Drive each pile continuously until refusal. Avoid interruptions in the driving process that may cause soil freeze-up resulting in early refusal.

20. **Load Sharing:** Drive one pile at a time to avoid load sharing of the tributary building weight at the pile location to more than one pile. If piles are driven simultaneously the piles being driven shall be a minimum of 25 feet apart.

21. **Reinforcing:** If applicable, install steel reinforcing bars, rods, or cable through the central hole in each precast concrete pile segment during the pile installation. If steel cables are used, ensure that the cable is not slack.

22. **Epoxy:** If applicable, install epoxy or epoxy-grout to fill void around reinforcement. Some designs may also specify epoxy between the pile segments.

23. **Refusal:** Drive piles to the point of Refusal. In order to allow some time for clay soil to remold without significantly rebounding upward, at Refusal, maintain the hydraulic jack pressure for a minimum period of 5 minutes before removing the jack.

24. **Water Jetting:** Water jetting shall not be used unless specifically permitted by the Engineer and / or the building official. If used, jetting shall be carried out in such a manner that the capacity of the existing foundations and structures shall not be impaired.

25. **Pre-drilling:** Pre-drilling of holes at the pile locations will not be permitted unless otherwise approved by an Engineer.

26. **Hydraulic Jack Pressure:** Monitor the hydraulic jack pressure while driving each pile segment. If a sudden significant loss of pressure occurs along with any abnormal sound from the pile (that may indicate crushing of a concrete segment), the pile shall be considered defective and shall be abandoned and a new pile shall be added. Concrete crushing of a pile segment that occurs during the driving process is considered to result in

a defective pile since compressive load transfer between the segments can no longer be assured and further driving of the pile can result in misalignment of the pile.

27. **Pile Depth:** Install piles to the specified minimum depth if determined by a geotechnical engineer. The contractor shall provide piles capable of withstanding the pile driving stresses and design loads, and capable of being driven to refusal at or below a minimum design depth if specified by the Engineer. Piles that reach refusal before attaining the minimum required depth as specified shall be subject to the following:

    a. Terminate pile at depth obtained with approval of Engineer, or
    b. Replace pile with pile having a smaller cross sectional area, installed at a location at least 6 pile diameters from the terminated pile, or
    c. Implement water jetting or pre-drilling with approval of Engineer.

    If more than three consecutive piles cannot be driven to the minimum specified depth, notify the Engineer and obtain further instructions from the Engineer as to how to proceed. Do not drive any more piles until receiving instructions from the Engineer.

28. **Cap Pile:** Immediately after removing the hydraulic ram, and after completion of the driving process, temporarily cap and shim off the pile to prevent pile rebound. Install specified pile cap horizontally on top of the driven pile segment and install shims.

29. **Adjacent Piles:** Proceed to drive adjacent piles using the same steps as outlined above. Do not over-lift (See "Refusal") the structure during the underpinning process since it may cause damage to the structure and / or architectural finishes.

30. **Defective Pile Segment:** Withdraw damaged or defective pile segment and reinstall new pile segment.

31. **Defective Pile:** Abandon damaged or defective pile and install new pile in alternate location (See "Locate Piles"). Fill hole left by abandoned pile using the excavated soils or alternate fill materials. Place and compact in lifts not exceeding 8 inches. Record locations of abandoned pile on the as-built drawings.

32. **Adjust Pile Caps:** After all piles are installed, adjust all pile caps and shims as required to correct any shims that may have been dislodged during the driving of adjacent piles to provide full contact bearing at pile locations. Maintain horizontal alignment of the pile cap on top of the driven pile segments.

33. **Foundation Lift:** Lift foundation system in a systematic manner using jacks. The lifting process shall be performed in a manner that curtails damage to the structure. Attempt to close any masonry and / or drywall cracks as much as possible. Test doors and windows to ensure they operate as intended. If a primary structural member, such as a grade beam, is damaged during driving or lifting, an Engineer must be consulted for its repair and the member shall be repaired in accordance with the Engineer's repair specification, at the contractor's expense.

34. **Reinforcement Splices:** Splices in the pile's central steel reinforcing, if used, shall not be permitted except as approved by an Engineer.

35. **Final Elevation Survey:** After the installation is complete, the contractor shall perform a final elevation survey of existing foundation floor twelve feet beyond all locations where piles were installed. This will establish a benchmark survey that may be used for warranty purposes. The results of the survey shall be documented on a sketch of the foundation repair plan, showing the location of the reference datum, and a symbol, such as a dot, indicating the location of each elevation survey point and submitted to the Engineer and / or owner for review.

36. **Restore Landscaping:** Contractor shall restore any landscaping plants that were salvaged during the preparation stage to their original locations and restore lawn to its original condition. Owner shall be responsible for replacement of landscaping that was not salvageable. After backfilling, restore building interior slab and exterior pavement where access holes were required. Match finishes as close as possible.

37. **Excess Material:** Haul off excess excavated materials and clean finished surfaces.