

SUPPORT OF BRIDGE PIERS BY HIGH CAPACITY PIN PILESSM

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ABSTRACT

Pin Piles are small diameter, cast-in-place, bored piles. Their performance makes them an attractive choice for underpinning bridge foundations where difficult access, restricted vertical clearance, poor ground conditions or sensitive surroundings are influential factors. Details are provided from ten case histories of bridge support using Pin Piles, and some practical constraints are defined. Data are also cited from a current test program in which several different types of piles are being tested largely for their suitability for seismic retrofit applications.

INTRODUCTION

A number of recent papers have described the state of practice in Pin Pile technology in the United States (Bruce, 1988; 1989; 1992; Bruce and Gemme, 1992). These papers demonstrated that Pin Piles - known elsewhere in the world as mini-piles or micropiles, but defined generically as small diameter, cast-in-place, bored piles - had arrived relatively late in the United States, at least 20 years or so after their European genesis in the early fifties. However, the growth in their use had been dramatic, as the specialist geotechnical construction industry responded to the demands of renovation, remediation and redevelopment, largely in urban and industrial locales. These reviews also detected that the Pin Pile market in the United States was generating a special identity for itself as

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a result of its ongoing pursuit of progressively higher unit capacities in a wide and complex range of sub-surface conditions, including:

- karstic limestone geology (including voids or clay filled cavities)
- mined rock geology (with voids or rubble filled voids)
- bouldery ground or glacial tills
- soils under a high water table making caisson construction costly
- variable and/or random urban fills
- the presence of existing foundations or other obstructions below the planned excavation.

Pin Piles are ideal in a variety of situations with physical constraints such as:

- limited overhead clearance
- vibration sensitive areas
- settlement sensitive areas
- limited access areas
- the need to install elements in close proximity to existing footings, columns, walls, or other structures.

This high degree of flexibility makes Pin Piles well suited to:

- new construction
- reconstruction on existing sites over old substructures
- underpinning of existing foundations to be undercut by other construction
- rehabilitation; which can include:
 - the replacement of deteriorated deep foundations (e.g., wood piles)
 - the increase of load capacity for bridge widening or meeting increased loading standards
 - bridge rehabilitation for scour protection
 - seismic upgrade projects where substructure units require significant increases in foundation capacity (i.e., for compression, uplift, and lateral forces).

In the last few years there has been a very rapid growth in the number of Pin Pile projects, especially in the older urban and industrial centers of the East Coast. Equally noteworthy is the routine use of individual pile working loads appreciably higher than in earlier years, or elsewhere in the world: test loads of over 400 kips in the silty sands of Brooklyn and over 750 kips in the dense alluvial gravels of Washington State compare with the 50-100 kip range commonly associated with traditional European practice.

This expansion in applications and growth in acceptable working loads has been supported by evidence from numerous exhaustive test programs, executed in a consistently routine and scientific manner as an integral part of each commercial project. In most cases the test piles have been loaded in incremental,

cyclic fashion, so permitting total pile movements to be positioned into elastic and permanent components. Analysis of the former has provided indications of load transfer mechanisms within the pile (e.g., Bruce, et al., 1992), whereas examination of the latter permits the behavior of the founding medium to be investigated. This approach has significantly aided the understanding of how the ancillary ground treatment technique of post-grouting works to enhance performance (Bruce, 1988a)

GEOTECHNICAL ASPECTS

Pin Piles derive their load carrying capacity primarily through side friction in any available suitable ground stratum. Ground types that are suitable include:

- stiff or hard non-plastic clays or silts
- sands and gravels
- rock formations
- "combination" materials such as glacial tills or fills.

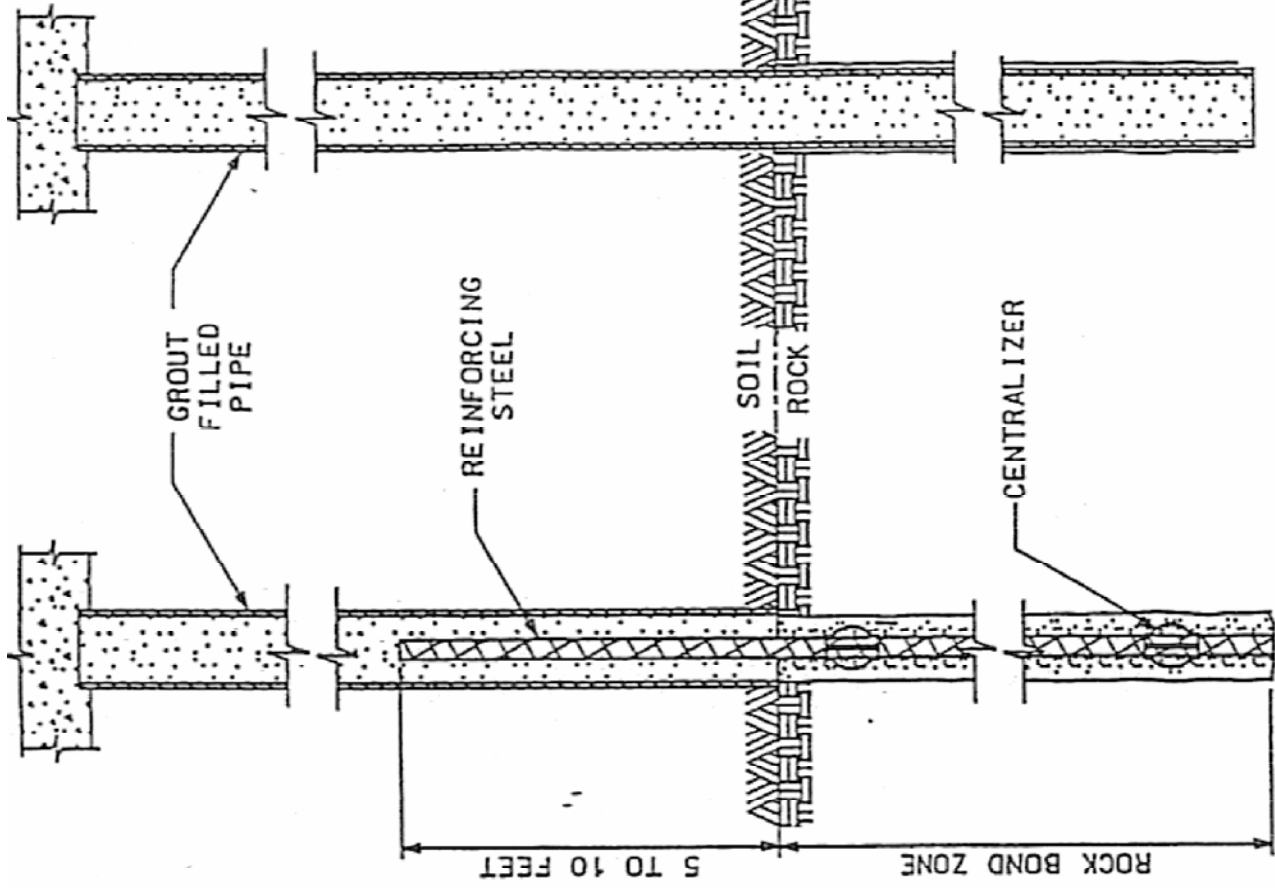
Since the primary load carrying capacity in the ground is derived from frictional bond in soil or rock, Pin Piles can develop high capacity in both compression and tension. In compression, Pin Piles typically range in working load from 100 to 300 kips, while for seismic applications under maximum load conditions, design forces may range from 200 to 800 kips. In tension, their capacity is nearly identical, being limited, however, by the amount of reinforcement placed in the elements.

When subjected to lateral loadings, the piles derive resistance from the horizontal response of the confining soils, and due to their superior structural integrity, can sustain significant lateral deflection within the available structural pile capacity. Seven inch diameter Pin Piles have been laterally tested in variable urban fills, with a free head condition, to up to 19 kips with 0.75" deflection. On a site with stiff alluvial soils, in a free head condition, a seven inch Pin Pile was tested to 24 kips with 0.3" deflection.

CONSTRUCTION ASPECTS

Due to the wide variation of ground types where piles have been installed, their ability to attain effective load carrying capacity is directly related to the installation technique that is employed. Details of the installation aspects of small diameter grouted elements are described by Bruce (1991). The four basic installation configurations (S1, S2, R1, and R2) are shown in Figures 1 and 2. The installation technique for each type is as follows:

- Type S1 - A steel pipe is rotated into the soil using water to externally flush the ground cuttings up around the pipe annulus. A neat cement grout is tremied from the bottom of

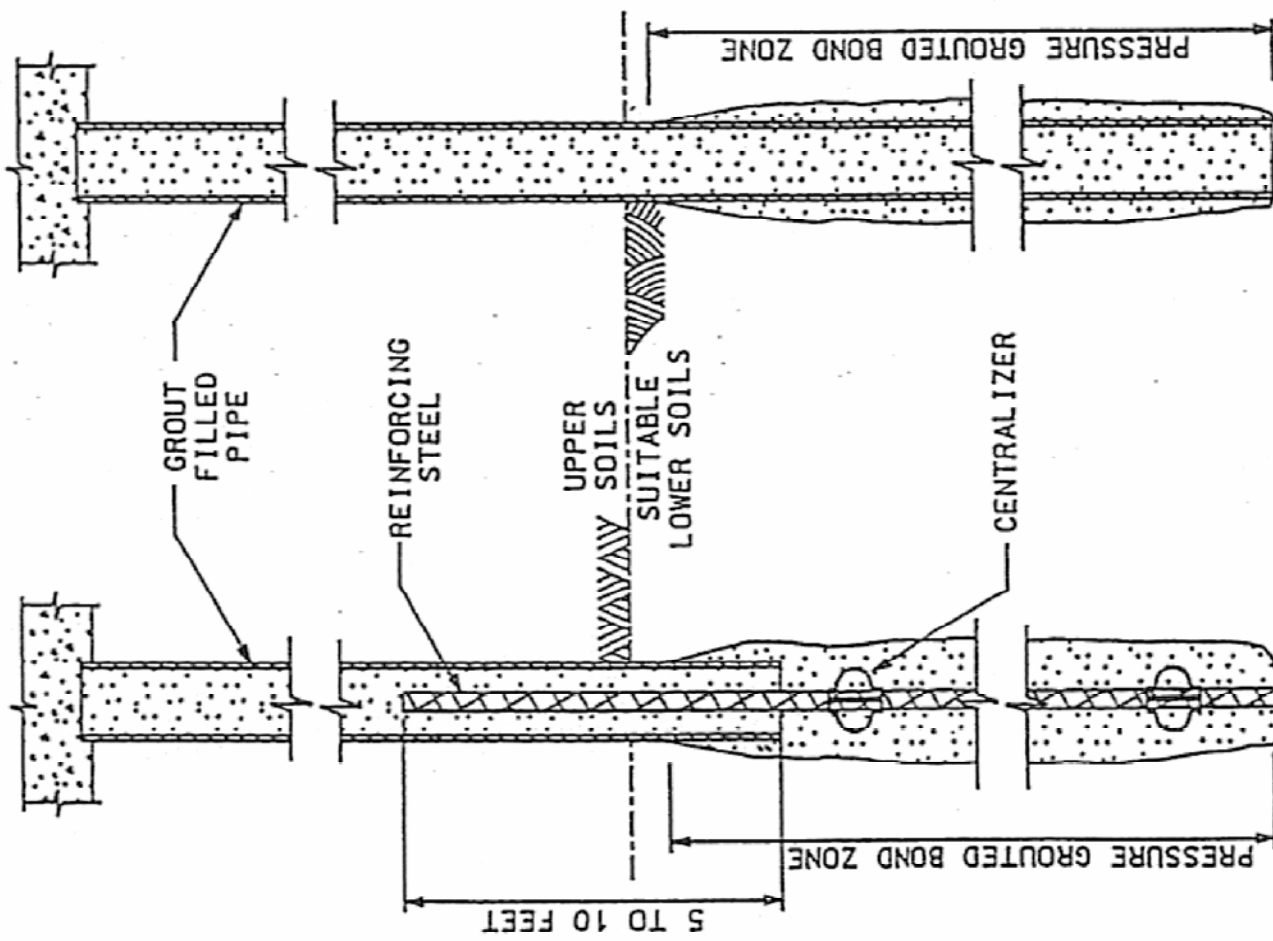


PIN PILE TYPE R1

PIN PILE TYPE R2

FIGURE 2

PIN PILE TYPES IN ROCK



PIN PILE TYPE S1

PIN PILE TYPE S2

FIGURE 1

PIN PILE TYPES IN SOIL

the hole to displace the water. The reinforcing element is then placed to the bottom of the hole. As the pipe is withdrawn over the length of the bond zone, additional grout is pumped under sufficient excess pressure to create the bond zone. The pipe is then seated into the grouted bond zone for 5 to 10'. In granular soils, a certain amount of permeation, and replacement, and compaction of loosened soils takes place. In cohesive soils, some lateral displacement or localized improvement of the soil around the bond zone is accomplished with the pressure grouting. To attain an even greater displacement effect around the bond zone, a special technique called post-grouting (Figure 3) can be used with S1 type Pin Piles. In this process, a plastic tube with drilled holes covered by a rubber sleeve (sleeved-port pipe) is placed into the pile with the reinforcement. After the initial grout has partially cured, a double packer is used to place grout at high pressures through individual sleeve ports. This process breaks the initial grout, injects additional grout, and may create higher in-situ lateral stresses around the bond zone while effectively enlarging the bond zone.

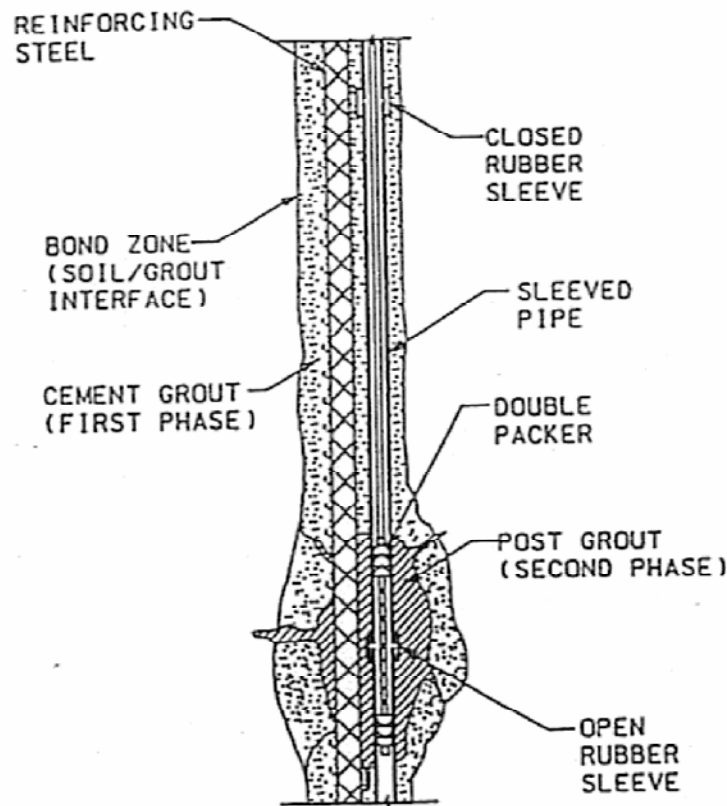


FIGURE 3
 REPRESENTATION OF TYPE S1 PIN PILE
 DURING POST GROUTING PROCEDURE

- Type S2 - The Type S2 pile is installed in the same fashion as the S1 pile except that
- the centralized reinforcing element is not needed;
 - the steel pipe is installed to the full length of the bond zone after pressure grouting is completed;
 - post-grouting is not typically used in this type of installation.

- Type R1 - The Type R1 pile uses the same technique for advancing a steel pipe as described for Type S1, except that the depth of penetration is limited to the top of rock. Once the pipe is seated into the rock, a smaller diameter drill string is advanced through the center of the pipe to drill the rock bond zone to a diameter slightly less than the inside diameter of the pipe. Once the hole has been cleaned out, neat cement grout is tremied from the bottom, and a reinforcing element is placed in the rock bond zone to complete the pile installation. A minimum transfer length is required for the reinforcing to develop inside the pipe (typically 5 to 10').

- Type R2 - The Type R2 pile differs from the R1 pile in that it uses a full length steel pipe. Centralized reinforcement is optional. In order to advance the pipe through both the overburden and the rock, a permanent drill bit is used on the end of the pipe with a diameter somewhat greater than that of the outside diameter. There are grout ports in the bit, and once the hole is advanced to the desired depth, grout is tremied from the bottom, and additional grout is pumped to assure full grouting of the rock bond zone. This grout may not flow completely to the surface in some conditions. However, once the level inside the pile has stabilized, the final grout level on the outside of the pile can be verified.

MATERIALS

Pin Piles are constructed using steel pipe with special machined threads. The pipe meets ASTM A-252 Grade 3, except that the minimum yield strength is 80 ksi. Typically this material is manufactured under API specifications. The reinforcing steel is Grade 60 rebar (ASTM A615, A616 or A617) or Grade 150 prestressing bar (ASTM A722). Grout is mixed with a high shear colloidal type mixer and typically is neat (i.e. consisting of cement and water). The grout has a fluid consistency, a water/cement ratio of about 0.45, and a typical unconfined compressive strength (from cubes) of 4000 psi in 28 days.

STRUCTURAL DESIGN

Once the maximum geotechnical capacity for the founding stratum is determined, the structural capacity for the piles is designed. All projects of any significance justify full scale testing (ASTM D1143) of at least one pile unless there is strong confidence and prior experience with the founding stratum. The purpose of the testing is to verify both the geotechnical capacity of the bond zone and the structural performance of the pile. Many tests have been run on the Pin Pile configurations discussed above. As more highly loaded Pin Piles are installed and tested, the experience and confidence with this technique will expand. Load testing to over 700 kips in dense granular soils shows that

structural bursting of the bond zone can occur prior to frictional failure of the grout to soil interface. Fundamental studies are currently underway to quantify the ultimate strength of the composite bond zone and how this is influenced by the confinement of the soil. Also, the ultimate strength of the grout filled pipe has been studied. Recent graduate studies at the University of Pittsburgh (Kenny, et al., 1992) included full scale tests of grout filled pipe sections to correlate the predicted allowable load with that of the AISC specifications. This work indicates that the yield stress of 80 ksi may be fully accounted for in the design.

CASE HISTORIES - GENERAL

Table 1 summarizes details from ten bridge related projects using Pin Piles. All except one (I-78, Delaware River Crossing) were completed since 1989. Further details of each may be found in Bruce (1988, 1989), Bruce and Gemme (1992), and Pearlman and Wolosick (1992).

CASE HISTORY - CALTRANS TEST PROGRAM

Background

The California Department of Transportation (CALTRANS) experienced some bridge failures in the 1971 Sylmar Earthquake (Zelinski, 1992). These failures were linked primarily to separations at bridge deck expansion joints and lack of ductility in the supporting columns. About 1250 state bridges were retrofitted to provide deck continuity from 1971 to 1989. Column ductility retrofiting was delayed until 1986 due to budget restraints. Such improvements, however, result in an increase of load demand on both superstructures and foundations. Investigations into various bridge foundation problems and solutions were intensified recently as a result of the increased level of funding following the 1989 Loma Prieta Earthquake.

Regarding the foundations, column yielding will exert loads up to 50% greater than normal service loads. Foundations for new structures are designed to resist these column yield loads: pre-1971 foundations do not, however, have sufficient reserve strength to resist the cyclic seismic demands. CALTRANS has developed several "standard" solutions, the two most common being 1) adding tension/compression piles around the perimeter of the existing footing, and 2) installing (passive) tiedowns through the existing footings where ultimate pile or soil compression capacities are satisfactory.

With respect to the piles, such systems are assessed on an ultimate capacity criterion. Existing piles are assessed for axial capacity based on a total ultimate of either pile structural limitations or soil resistance. When new piles are added to

LOCATION	DESCRIPTION	GROUND CONDITIONS	PHYSICAL CONSTRAINTS	PILE LOAD WORKING/TEST (TONS)	NO. OF PROD. PILES	TOTAL LENGTH INST. (ft)	TYPICAL PILE LENGTH INST. (ft)	NOM. BOND ZONE DIA. (in.)	TYPE-STRUCTURAL COMPOSITION
R. 45139 Montgomery City, PA	Foundations for new bridge abutment	Silty soil over pinnacled karstic limestone	Overhead power lines	77/235	48	1026	20-80	8 1/2	R-2 - 9-5/8" pipe to rock, 7" casing full length
Route 732 over Coosa Creek Ludleston, VA	Foundations for new river bridge	15' of alluvials and weathered rock over granite/granite	Narrow bench, unlimited headroom	70/140	72	1901	25	8	R-2 - 7" pipe full length
Route 675 over Coonoke River Coonoke City, MD	Replacement foundations for 60-yr-old delicate bascule bridge	River bed silts and clays over 30' dense fine-medium sands	Most through bridge piers, 4 from very limited access/ headroom	50/100	52	5200	100	10	S-1 - 7" pipe plus 1-3/8" high yield rebar in bond zone and airlead anchor for preloading
Brooklyn-Queens Expressway Brooklyn, NY	Temp. and Perm. piles to support overhead roadway	Fine-medium glacial sands with silts and clays	Reasonable access, 15' + headroom	60-100/ 120-250	368	20,200	50-60	10	S-2 - 7" pipe full length
Jones Falls Rd. Baltimore, MD	Foundation for temp. highway bridge	25' of alluvials and weakened material over hard schist with old footing obstructions	Unrestricted	75/N/A	12	300	25	7	R-2 - 7" pipe full length
Route 9A Millers Highway Viaduct Manhattan, NY	Foundations for new elevated structure bents and abutments	Wood cribbing manholes and obstructions 70' to schist	Unrestricted	100/N/A	93	4644	40-02	5 1/2 - 8	R-1 with 7" pipe and 2 grade 150 rebars, and R-2 with 7" pipe full length
S.R. 1003 Bridge over Mahoning Creek Armstrong City, PA	Foundations for two new abutments and long wing wall	Old sandstone foundations, alluvials, over sandstone	Tight plan area on river bank abutment	55/175	174	5140	21-25-63	8	R-2 - 7" pipe full length
U.S. Route 11 Williamsport, MD	Underpinning of existing bridge piers	Clay over calcareous shale	Tight access, 25' headroom	76/N/A	48	1379	28-32	10	R-1 - 11 3/4" pipe plus 1" 60 ksi rebar in bond zone
U.S. Route 220 Colobour City, VA	Foundations for new river bridge	Clay and alluvials over karstic limestone	Tight plan area in cofferdam	110/150	91	2905	24-83	8 1/2	R-2 - 9 5/8" pipe through overburden, 7" casing full-length
I-78 Delaware River Crossing Warren City, NJ	Foundations for new pier	Residual soils over karstic limestone	Unrestricted overhead, large voids in rock	100/224	24	2600	45-170	8 1/2	R-2 - 9 5/8" pipe to rock, 7" pipe full length

TABLE 1. SUMMARY OF CASE HISTORIES

an existing pile group, the designer must use a strain compatibility assessment to assure the structural integrity of the upgraded footing.

File Test Program

As noted above, proprietary systems such as Pin Piles, can be attractive when noise, vibrations, and space restrictions exist and foundation retrofits cannot be avoided. CALTRANS is therefore evaluating the performance of various proprietary pile systems in a unique field test program. This is a cooperative effort between the pile contractors (who have installed their piles, free of charge), FHWA, and CALTRANS (who are also conducting the loading).

The test site is beneath the I-280 elevated freeway in San Francisco, south of Evans Street, approximately one mile north of the US101/I-280 interchange. The soil conditions are distinctive and not atypical of the Bay Area: 20' of fills over 100' of soft "Bay mud", which in turn overlies dense granulars. All major damage to viaducts in the Bay area from the Loma Prieta Earthquake occurred to structures whose substructure was supported in soft soils. The displacement amplification experienced at these sites imposed large forces on the complete substructure/superstructure system. From these proof tests, the design of pile groups to resist the earthquake-induced moment/couple, amplified by deep soft soils, will be more accurately understood and modelled.

In addition to five types of typical standard plan CALTRANS piles, at least five different proprietary piling systems are also being tested, both in tension and compression. The authors' company have installed six piles, as summarized in Table 2. Preliminary loading results are shown in Table 3. These data show that even in the very soft Bay Mud, Pin Piles using appropriate drilling and grouting techniques can provide very attractive load/deflection characteristics. Such piles, therefore, have excellent potential for this vital retrofit application.

FINAL REMARKS

Throughout the United States, there has been a growing appreciation for the benefits of the Pin Pile technique to underpin existing structures threatened by foundation deficiencies. Most recently, the potential of this technique has been widened as a result of the demands made by the seismic retrofit programs. The service and test data accumulated in recent years, together with the information currently being generated by the CALTRANS program confirm that Pin Piles are technically extensively equipped to satisfy designers' criterion.

PILE #	DESIGNATION	DESCRIPTION
1	Nicholson Compressed Anchor Pile (founded in sand)	120' of 7" casing with central tendon 145' long. Lower 35' pressure grouted.
2	Nicholson Compressed Anchor Pile (founded in clay)	70' of 7" casing with central tendon 105' long. Lower 45' pressure grouted (twice).
3	Nicholson Flushed Casing Pile (founded in sand)	140' of 7" casing with central #18 Rebar. Lower 30' flush grouted.
4	Nicholson Flushed Casing Pile (founded in clay)	105' of 7" casing with central #18 Rebar. Lower 45' flush grouted.
5	Nicholson Pin Pile (founded in sand)	120' of 7" casing with central #18 Rebar. Lower 30' pressure grouted.
6	Nicholson Pin Pile (Founded in clay)	105' of 7" casing with central #18 Rebar. Lower 45' pressure grouted.

Table 2. Composition of Nicholson test piles, CALTRANS test program.

PILE NO.	FIRST TENSION TEST*	COMPRESSION TEST ⁺	SECOND TENSION TEST (to failure)
1 (NCA Long)	Failed at 420 kips	Both these piles were tested to failure in the first tension test only.	
2 (NCA Short)	Failed at 260 kips		
3 (NFC Long)	Held 200 kips	Held 400 kips	Failed at 480 kips
4 (NFC Short)	Held 200 kips	Failed at 220 kips	----
5 (PP Long)	Held 200 kips	N/A	N/A
6 (PP Short)	Held 200 kips	N/A	N/A

* Acceptance criterion: 0.500" total extension at 200 kips.

+ Acceptance criterion: 400 kips.

N/A Not available at time of writing.

Table 3. Summary of load test performance (provisional)

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