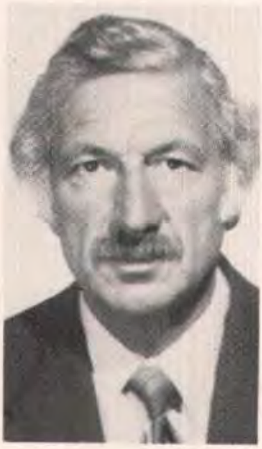
Efficient Splicing Technique for Precast Prestressed Concrete Piles



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Frequently it is necessary, or at least desirable, to splice precast prestressed concrete piles. The advantages of reducing the lengths of long piles into shorter sections are that it:

1. Results in easier handling during transportation and in the pile driver leads.
2. Minimizes the chance of cracking during handling.
3. Permits greater flexibility in determining required length of pile.
4. Allows extensions of piles when necessary.
5. Reduces cost in transportation.
6. Simplifies storage at the precasting yard and at the construction site.

These advantages can only be achieved if the splice is economical, can develop the structural capacity of the pile section and the connection can be made quickly and without the requirements of special trade skills in the field.

This report presents the results of an extensive investigation of the structural capacity of a wedge-type splice for 12-in. (305 mm) square precast prestressed concrete piles.[1]

Literature Review

Only a limited number of references on prestressed concrete pile splices have appeared in the literature in the past decade, a few of which have dealt with laboratory or field testing of splices.

In June 1968, Gerwick[2] presented a review which includes historical information and the utilization, design, manufacture, and installation of prestressed concrete piles. Problem areas and failures are discussed. Epoxy-dowelled splices were mentioned as being the most desired type in meeting the necessary requirements of high flexure resistance, although mechanical splices were considered to be the most economical. An account of the entire presentation appeared in a subsequent PCI JOURNAL.[3] Kilbridge[4] later summarized Gerwick's presentation in *Concrete* (London).

An excellent state-of-the-art report on design practice and recommendations of prestressed concrete piling was presented by Li and Liu[5] in 1970. The paper first reviews major factors inherent in prestressed concrete piles. It discusses required concrete strengths for splices and build-ups for conditions with and without driving. Included are considerations of pile prestress levels, driving stresses, head and tip design practice, and requirements for an ideal splice.

Alley[6] discusses the successful use of a combination sleeve and wedge splice which was developed and patented by Raymond International, Inc. It was used for splicing 16½-in. (420 mm) octagonal piles for a cement plant in Seattle, Washington. The splice consisted of an outer and inner steel sleeve connected with four steel wedges which were driven and welded to form piles with a total length of 175 ft (53.4 m).

A technique of splicing piles, whereby high strength steel bars are embedded in the driven pile with sleeve anchorages, is discussed by Britt.[7] Since the bars extended beyond the top of the driven pile, a special helmet was required during driving. The upper pile section, with high strength bars threaded through its entire length, is then lowered into position over the driven pile. The bars of the two pile sections are then coupled. After hardening of an epoxy at the end surfaces of the connected piles, the high strength (Macalloy) bars are post-tensioned, after which the extended pile is then ready for further driving.

An excellent textbook[8] on the construction of prestressed concrete structures devotes an entire chapter to prestressed concrete piling. Discussed are typical details of prestressed concrete pile splices used in the United States, Norway, Sweden, Great Britain, and Japan.

An example of a special pile splicing technique used for the construction of a Florida expressway is discussed by Cook.[9] Due to the very severe foundation problems, piles with

Synopsis

This paper summarizes the results of a comprehensive laboratory investigation of the structural integrity of a wedge-type splice for prestressed concrete piles.

A series of tests were conducted in tension, compression, bending, and shear. In addition, tests were made to determine the corrosion rate of the splice.

Conclusions from the test results indicate that the splice has the structural characteristics required for spliced precast concrete piles. Design recommendations are made for the use of the splice in buildings and bridges.

total lengths ranging up to 355 ft (108 m) were used. The splices for the 36-in. (914 mm) diameter hollow-core precast prestressed concrete pile sections utilized a 10-ft (3.05 m) long external splicing collar which was clamped to the upper and lower pile sections. The collar remained in place while an epoxy, which enveloped reinforcing bars inserted into the pile sections, hardened overnight.

In 1973, ACI Committee 543[10] published recommendations for the design, manufacture and installation of concrete piles. The objective of the report is to assist the design engineer, the manufacturer, the field engineer, and the contractor in the design and utilization of various types of concrete piles. Although only a minimal reference is made to splices, it does recommend that epoxies and other quick-setting compounds used for splices should have strength and durability at least equivalent to that of the concrete materials in the pile. Regrettably, the extensive revisions[11] to this committee report, which were published the following year, do not refer to splices.

A comprehensive review and evaluation of prestressed concrete pile splices were made in 1974 by Bruce and Hebert of Tulane University.[12,13] Twenty splices used in various parts of the world are discussed. They include welded, bolted, mechanical locking, connector ring, wedge, sleeve, dowel, and post-tensioned splices. Excellent details of the splices and a summary of the splice strengths are presented. The second part of the report gives the results of the testing and analysis of a cement-dowel splice.

The S-M splice, which consists of a male-female connection, was tested by Houde[14] for Western Caissons (Quebec) Limited. The two parts are locked together with a circular locking bar after they are brought together. The male and female plates, which are cast on the ends of the pile sections, are anchored with deformed bars which are welded to the plates and embedded in the concrete. This report gives the results of push-out, torsion, compression, and bending tests made on a 14-in. (356 mm) square pile splice.

Gamble[15] made similar but more extensive tests on the same splice as part of an acceptance requirement for piles to be used in the foundation of a sewage treatment plant in Syracuse, New York.

The PCI Committee on Prestressed Concrete Piling[16] published a useful report on recommendations for the design, manufacture, and installation of prestressed concrete piles in 1977. Included is a discussion on considerations that should be made in selecting a splice.

A practical manual by Hunt[17] presents information on pile foundations and various kinds of pile accessories. It also includes a brief description of some prestressed concrete pile splices.

Regrettably, current codes and specifications lack detailed requirements for the design, manufacture, and installation of prestressed concrete pile splices; hence, there is a pressing need for the ACI and PCI recommendations to be fully recognized. As an example, the current AASHTO[18] specifications for bridges merely indicates that full-length piles shall be used where practicable, but in exceptional circumstances, splicing of piles may be permitted.

The Uniform Building Code[19] contains no reference to pile splices. In fact, the first research report to be issued for a pile splice by the International Conference of Building Officials is for the Dyn-A-Splice, the test results for which are presented here.

The Swedish Building Code[20] requires that a driving test of a spliced

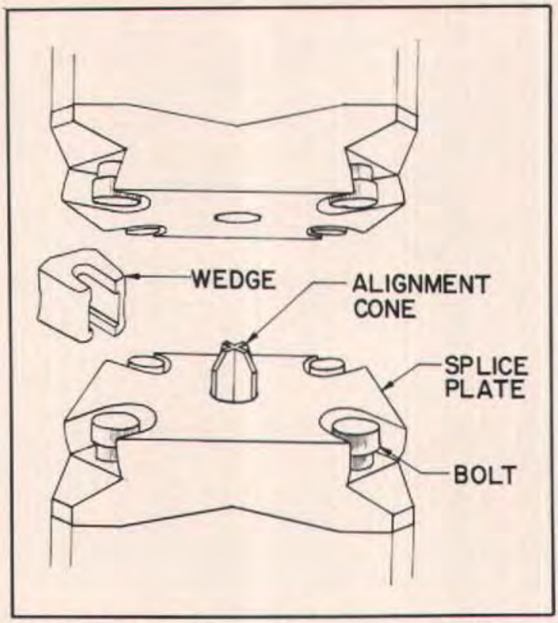

Fig. 1. Major components of wedge-type splice.

pile be made prior to approval. The number of blows, as well as the size of the pile hammer, is specified. Subsequent to the driving, the pile is extracted, the splice examined, and then subjected to a standardized bending test.

Description of Splice

The mechanical wedge splice tested is used primarily for square piling but may also be used with round, octagonal, and hollow cross sections. The splice is currently being used successfully with precast reinforced concrete piles in Scandinavia and Western Europe but has been adapted to precast prestressed concrete piles for the purpose of this investigation.

The parts of the splice in the upper and lower pile sections are identical, as shown in Fig. 1. Only one of the four wedges is shown.

During fabrication, the splice is assembled by placing the four internally threaded bolts into the holes of the splice plate. Reinforcing bars are then threaded into the bolts and positioned into place (Fig. 2). Preformed holes in the splice plate allow for placement of the prestressing strands. The ends of the splice are shown in Fig. 3.

In the field, the splicing procedure is quite simple. The alignment cone is first placed into the centering hole of the lower pile section. The upper pile section is then lowered onto the lower pile section until the splice plates are in direct contact. (See Fig. 4; note that the cone had not been installed at this point.) This is followed by driving a wedge into each of the four corners of the splice with a sledge hammer (Fig. 5). The tapered wedge then becomes locked in the splice plate with each protruding bolt. This operation pulls the two pile sections towards each other and forms a tight connection. The splice is completed by tapping down splice plate tabs over the outside face of the wedge to assure that

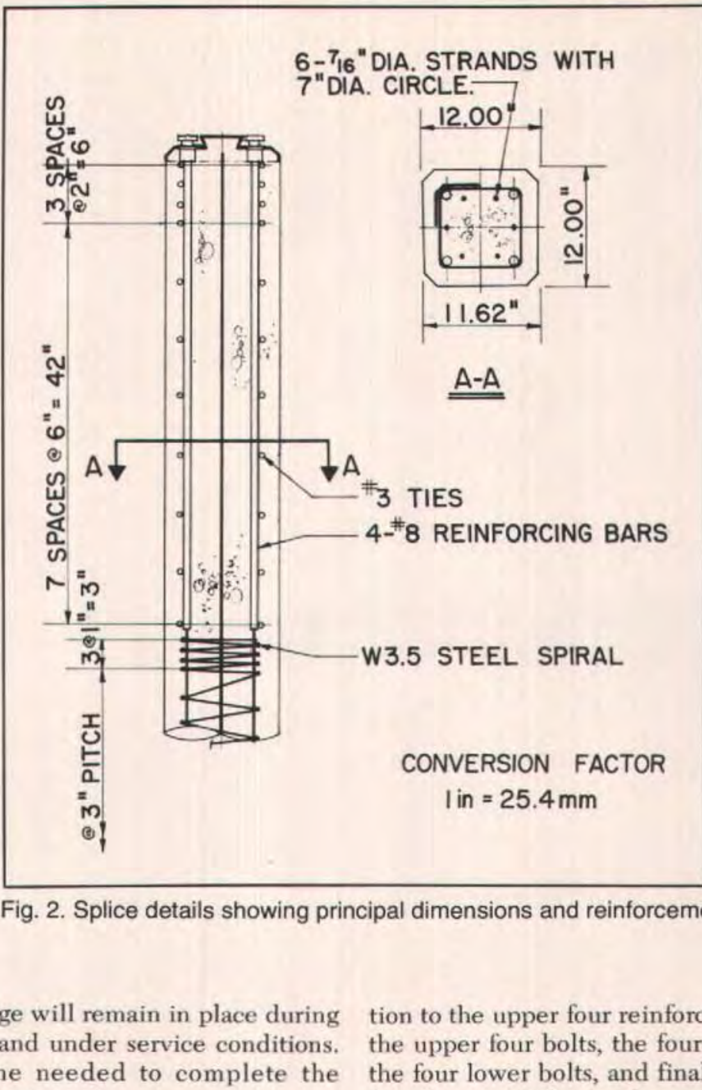

Fig. 2. Splice details showing principal dimensions and reinforcement.

the wedge will remain in place during driving and under service conditions. The time needed to complete the splice is minimal.

Force Paths

The splice is designed to transmit the full capacity of the pile section in compression, tension, bending, shear, and torsion.

Compressive forces are transmitted from the upper pile section to the upper splice plate, the lower splice plate, and then to the lower section of pile. No contact is made between mating bolts. Tensile forces are transmitted from the upper pile section to the upper four reinforcing bars, the upper four bolts, the four wedges, the four lower bolts, and finally to the four lower reinforcing bars which are bonded to the lower pile section. Shearing forces are transmitted by means of the four wedges at the splice interface. The forces are in turn transmitted to the bolts, reinforcing bars, and then to the concrete.

Although torsion tests were not conducted on the splice, it does have the capability of transmitting torsion in either rotational direction about the longitudinal axis of the pile. Torque is transmitted by means of the wedges at each of the four corners of the splice.

Fig. 3. Piles with wedge-type splice.

Fig. 4. Positioning of upper pile section.

Fig. 5. Workman driving in splice wedge.

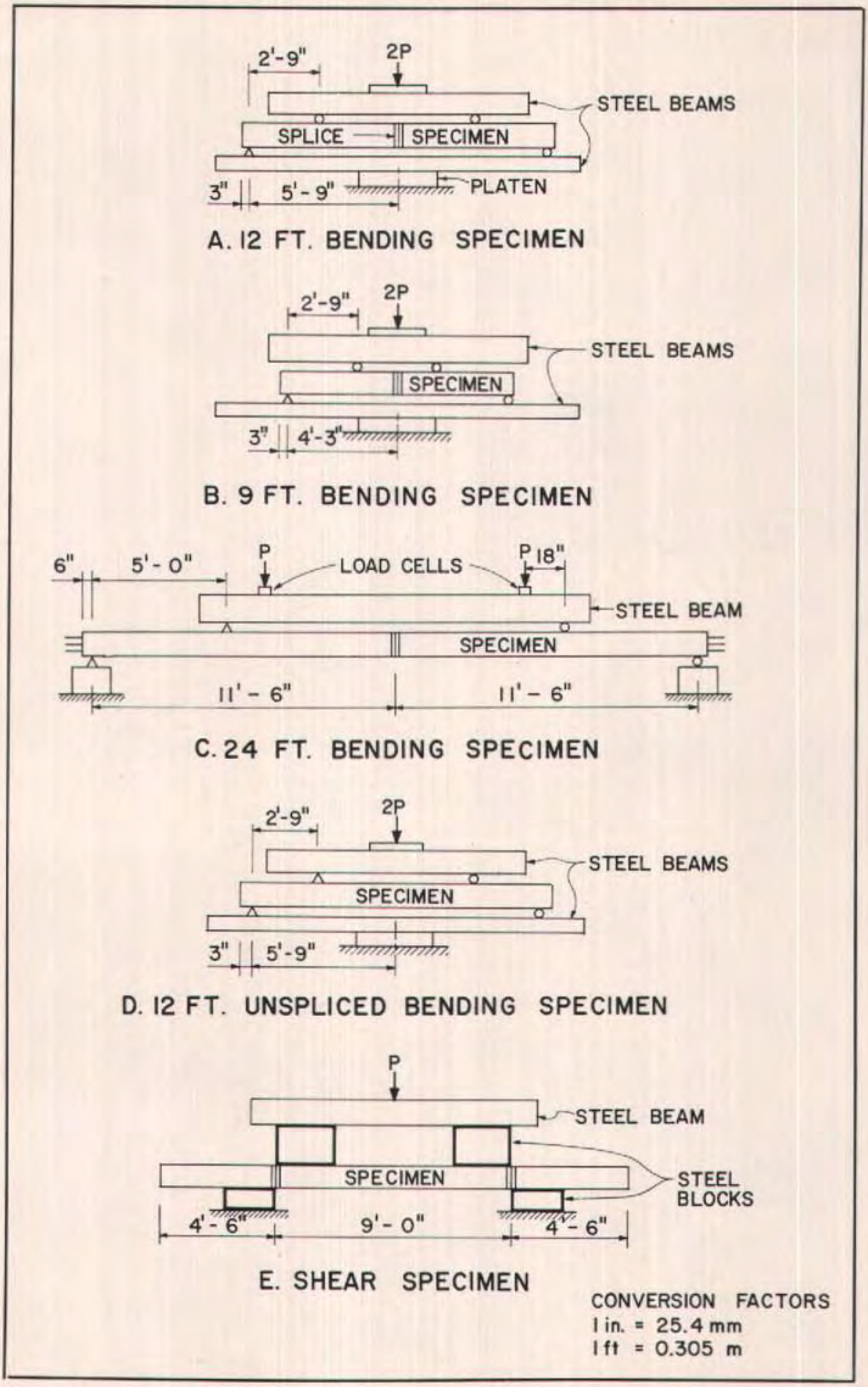

Fig. 6. Loading arrangements of specimens.

Test Specimens

Inasmuch as the splice was originally designed for precast reinforced concrete sections, it was considered essential that the splice be modified and subjected to various tests prior to its use in precast prestressed concrete piles. Consequently, the newly designed splice was incorporated into piles of various lengths and subjected to tests in tension, compression, bending, and shear.

The bending specimens were of 12, 9, and 24 ft (3.66, 2.75, and 7.32 m) as shown in Figs. 6A, 6B, and 6C, respectively. Unspliced pile specimens [12 ft (3.66 m) long], (see Fig. 6D) were also tested for comparison purposes. Tension specimens were of the same length and type as shown in Fig. 6C. Shear specimens included two splices (see Fig. 6E).

Fabrication of Specimens

The specimens were cast at the prestressing plant of Santa Fe-Pomeroy, Inc., Petaluma, California. The specimens were cast in steel forms along with a normal production run of 12-in. (305 mm) square piles, using the long line method for pretensioning. Fig. 7 shows the splice plate, reinforcing bars, ties and spiral in place prior to casting of the concrete.

The cement content of the concrete mix was 7 sacks per cu yd (389 kg of cement per m^3). The concrete mix was proportioned for a compressive strength, f'_c, of 6000 psi (41.4 MPa) at 28 days. Type II prestress Kaiser Permanente cement was used and the 1-in. (25.4 mm) maximum size aggregates were Russian River run obtained from the Kaiser Sand and Gravel Co. in Windsor. The admixture used was supplied by Zeecon.

For prestressing, the initial tensioning force was 22,600 lbs (101 kN) per strand. After prestress losses, the total working force of 111,600 lbs (496 kN) for the six strands provided an effective prestress of 785 psi (5.41 MPa) in the concrete.

The average compressive strength of the concrete at 30 days, based on three cylinder tests, was 7560 psi (52.1 MPa). The average split cylinder tensile strength, based on two cylinder tests, was 670 psi (4.62 MPa).

Testing Program

As previously stated in the literature review, there is virtually no published guidance for the design of prestressed concrete pile splices. Nor are there any specific requirements in national codes or specifications. In the absence of such references, a designer either establishes his own requirements for

Fig. 7. Splice assembly of specimen prior to casting.

the performance of a prestressed concrete pile splice or conservatively specifies that the splice should have an ultimate capacity in tension, compression, bending, shear, and torsion equivalent to the unspliced pile. Other considerations must also be made such as excessive relative movements, possible corrosion, induced brittleness due to welding, installation method, cost, behavior under impact loads due to driving, and other criteria.

Another consideration is the effect of a splice on the curvature of a pile when subjected to bending in a seismic zone. Margason and others[21-24] discuss the basic assumption that piles generally move with the surrounding soil during an earthquake and that if no soil failure occurs, a rational prediction of the pile curvature can be made for a given site and specific earthquake. It is stated that the pile bending problem is one of ductility rather than of strength with resulting radii of pile curvatures ranging from 200 ft (61 m) for strong earthquakes to 1000 ft (305 m) for small to moderate earthquakes.

However, the introduction of a splice in a pile should have a minimal effect on pile curvature because any increase in flexural stiffness due to the presence of reinforcing bars in the splice would be small considering the splice length of about 8 ft (2.44 m) in a total length of spliced pile of approximately 100 ft (30 m).

Because of these various considerations, the objective of the tests was to determine if the splice had structural characteristics equivalent to those of the unspliced pile. Therefore, tests were made in tension, compression, bending, and shear. No torsional tests were made because torsional loading on a pile foundation does not appear to be critical even under extreme conditions such as seismic loading. However, because of the mechanical features of the splice, it is believed that the ultimate torsional moment is greater than that of a typical 12-in. 305 mm) square prestressed concrete pile.

Fig. 8. Test bed for tension testing.

Test Results

In this section a summary is given of the results of tension tests of the splice and assembly parts, bending tests of spliced and unspliced beams, and shear, compression and corrosion tests.

Tension Tests of Bars, Bolts, and Wedges

In order to estimate the tensile and flexural capacity of the splice, five specimens, each consisting of two reinforcing bars, two bolts and a wedge, were tested in tension. Each assembly was put together in a manner similar to how it would be arranged within a splice, with the exception of the splice plate. The average tensile strength of the five specimens was 54.8 kips (244 kN). In each case, failure was in the wedge.

Tension Tests of Splice

The tension specimens were tested in a prestressing concrete bed while in a horizontal position, as shown in Fig. 8. No longitudinal displacement measurements were made during the tests. At increments of 25 kips (111 kN), the specimen was examined for cracks.

Table 1. Tensile capacity and type of failure of tensile specimens.

Specimen	Age, days	Tensile capacity, kips	Type of failure
T1	26	165.0	Splice*
T2	29	180.0	Strands
T3	32	186.0	Strands

* Failure of three wedges and one bolt.
Note: 1 kip = 4.448 kN.

The tensile strengths of the tensile specimens (Specimens T1, T2, and T3) are tabulated in Table 1.

Specimen T1 was gradually loaded and inspected for cracks periodically. No cracks were visible at 115 kips (512 kN), the last load at which crack examinations were made. The splice failed at a tensile force of 165 kips (734 kN).

Specimen T2 did not experience a splice failure. At 150 kips (667 kN), transverse cracks, spaced at approximately 2 ft (0.6 m), were observed.

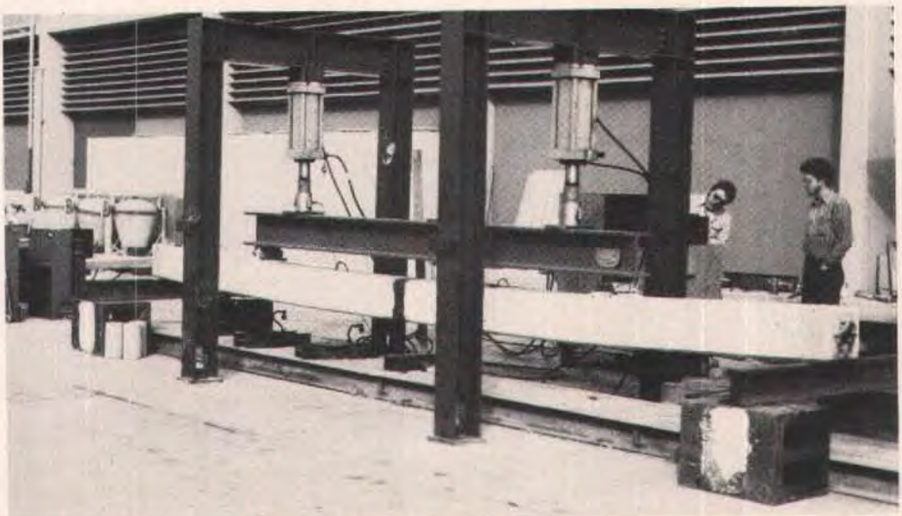

Fig. 9. Arrangement for bending tests of 24-ft (7.32 m) long specimens.

Fig. 10. Splice of Specimen T2 after flexural failure.

Many of the tensile cracks in the concrete closed after release of the tensile force at failure.

Specimen T3 likewise did not experience a splice failure. As with Specimen T2, the six strands failed without causing any structural distress in the splice. An examination of the splice after the strand failure of 186 kips (827 kN) indicated that the splice was completely intact with no evidence that it had been loaded. As with the other tensile specimens, transverse cracks developed before failure. The estimated breaking strength of six strands, based on the mill test reports, is 191.8 kips (853 kN).

Bending Tests of 24-ft (7.32 m) Beams

Specimens T2, T3 (which had been tested in tension but did not experience a splice failure), T4 and T5, were tested in bending, as shown in Fig. 6C. Hydraulic rams were used to apply the load and SR-4 strain gage load cells were utilized to measure the load at each of the two load points, as shown in Fig. 9. Deflection readings at the ⅛, ¼, and midpoints of the left half of the specimen were re-

Table 2. Summary of test data and type of failure for bending specimens.

Specimen	Age, days	P_{cr}, kips	M_{cr} kip-ft	P_u, kips	M_u, kip-ft	Type of failure
T2	50	—	—	23.0	127.6	Compressive
T3	48	—	—	16.5	95.1	Compressive
T4	49	6.0	42.6	17.1	98.1	Compressive
T5	49	4.5	35.1	21.8	121.6	Compressive
B1S	26	14.0	41.0	32.5	91.9	Wedges
B2S	29	15.0	43.8	25.1	71.4	Wedges
B3S	32	16.2	47.2	34.0	96.0	Compressive
B4S	35	13.8	40.3	22.5	64.4	Bolts
B5S	37	13.8	40.3	32.5	91.9	Wedge and bolt
B6S	40	12.5	35.8	38.3	106.6	Compressive
B7S	40	13.8	39.1	38.1	106.2	Wedges
B8S	40	13.8	39.1	24.1	67.7	Bolts
B1U	30	15.0	43.8	30.3	85.7	Compressive
B2U	31	16.5	47.9	28.9	82.0	Compressive
B3U	34	15.0	43.8	29.0	82.2	Compressive
B4U	37	16.2	47.2	30.0	85.0	Compressive
B5U	39	16.2	47.2	31.1	88.0	Compressive

Symbols: P_{cr} = cracking load; P_u = ultimate load; M_{cr} = cracking moment; and M_u = ultimate moment.
Note: 1 kip = 4.448 kN; 1 kip-ft = 1.356 kN • m.

corded at load increments of 2 kips (8.9 kN) (on one ram). Deflections were read to the nearest 0.001 in. (0.025 mm).

The load at the appearance of the first crack, P_{cr}, the corresponding moment, M_{cr}, the ultimate load, P_u, and the ultimate moment, M_u, for Specimens T2, T3, T4, and T5 are tabulated in Table 2. The tabulated loads are those read directly from the load cell. The tabulated moments include the bending moment due to the application of the external loads and the bending moment due to the beam's own weight [12.6 kip-ft (17.1 kN • m)].

Specimen T2, although previously loaded in tension to 165.0 kips (734 kN), displayed the maximum bending strength, failing in flexural compression at 52 in. (1.32 m) from the splice plate, within the zone of constant moment, but beyond the end of the splice reinforcing bars. Fig. 10 shows the excellent condition of the splice after flexural failure of the beam. A plot of deflection curves for load increments of 2 kips (8.9 kN) up to P = 20 kips (89 kN), is shown in Fig. 11.

Specimen T3 also failed in flexural compression in the zone of constant bending moment. Subsequent to the compressive failure in the top fibers at 45 in. (1.14 m) from the splice, some strands ruptured. The diagonal crack at failure, as shown in Fig. 12, extended to 62 in. (1.58 m) from the splice, at the bottom surface. The splice was in excellent condition after failure.

Specimens T4 and T5 were the two 24-ft (7.32 m) long flexural specimens

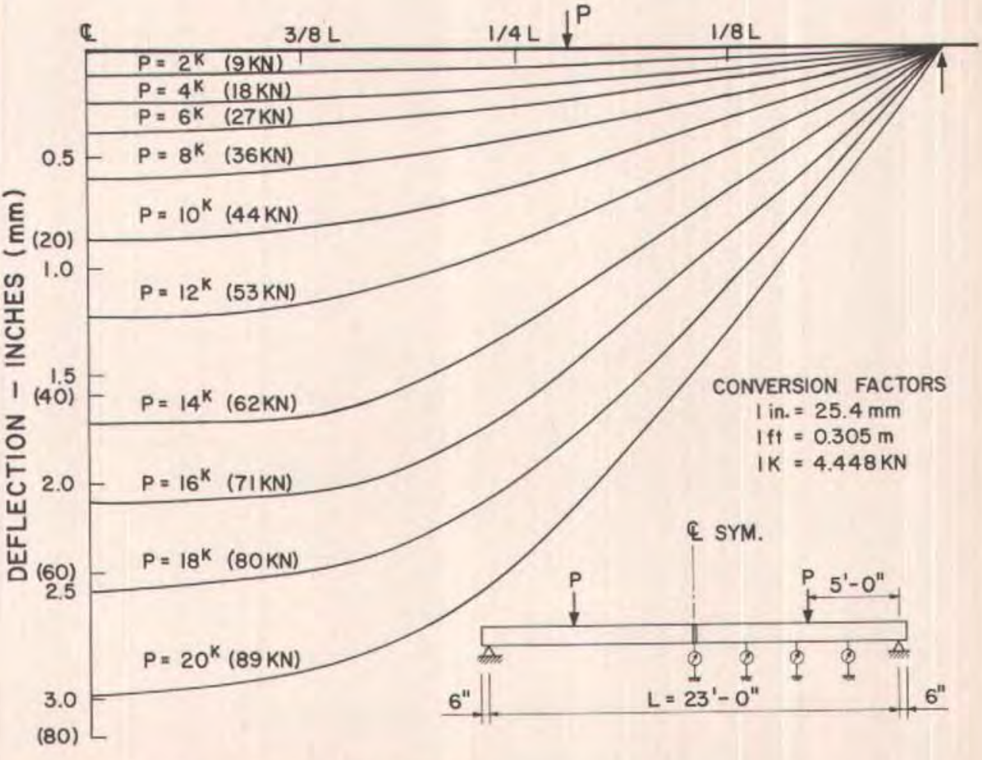

Fig. 11. Load vs. deflection (Specimen T2).

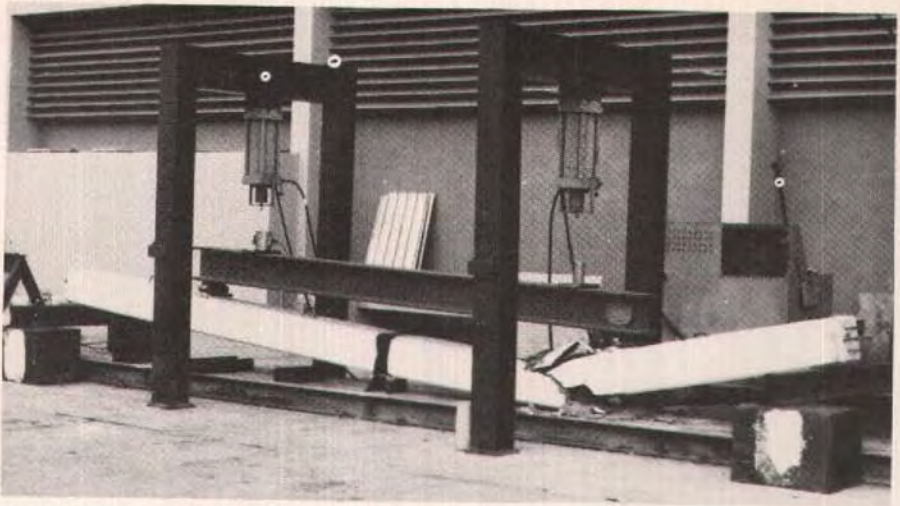

Fig. 12. Specimen T3 after flexural failure.

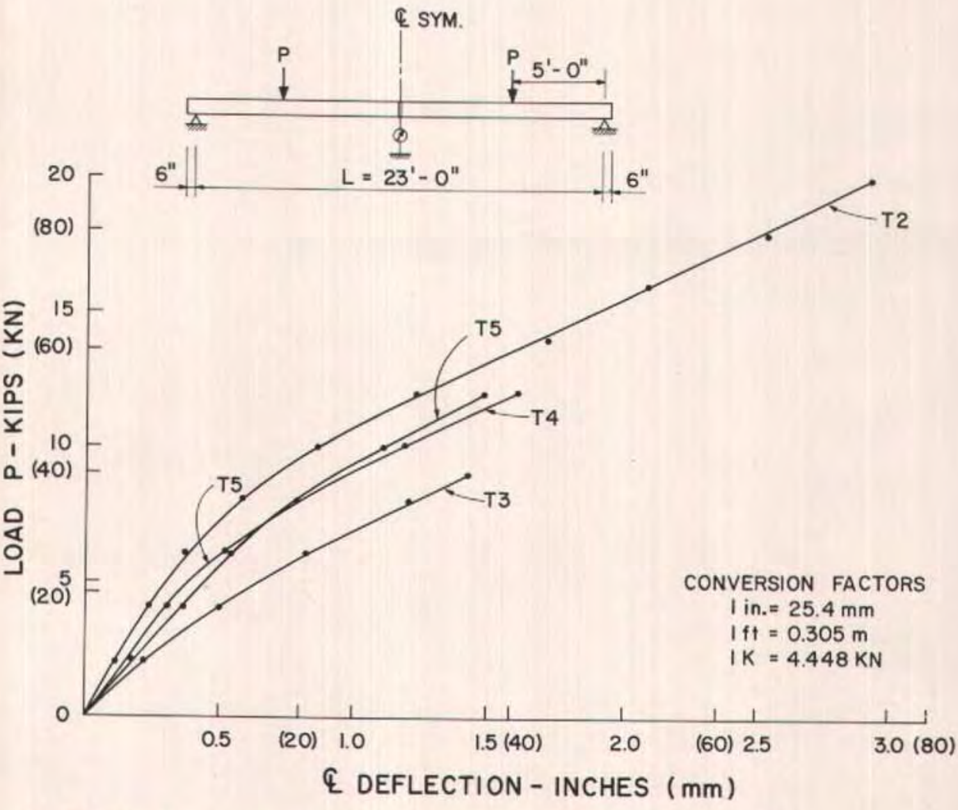

Fig. 13. Load vs. centerline deflection (Specimens T2, T3, T4, and T5).

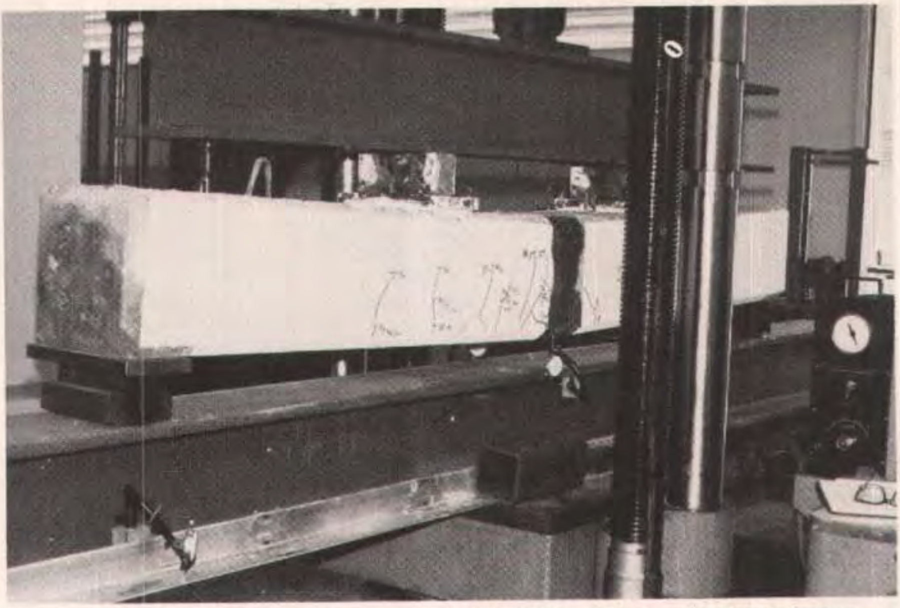

Fig. 14. Testing arrangement for testing of 12-ft (3.66 m) long spliced specimens.

which were not previously loaded in tension. Both specimens experienced a flexural compressive failure with no damage to the splices.

It should be noted that in all four cases, the unspliced section of the pile failed while the splice retained its structural integrity. This would infer that the splice capacity of these specimens was in excess of the average ultimate moment capacity of 110.6 kip-ft (150 kN • m).

A plot of load, P, vs. centerline deflection for all four test specimens (Specimens T2, T3, T4, and T5) is shown in Fig. 13. (Note that deflection readings were not taken to ultimate load.)

Bending Tests of Shorter Specimens

Specimens B1S, B2S, B3S, B4S, and B5S were tested in bending on a 11 ft 6 in. (3.51 m) span, as shown in Fig. 6A.

Specimens B6S, B7S, and B8S were tested in bending on an 8 ft 6 in. (2.59 m) span, as shown in Fig. 6B. With a shear span of 2 ft 9 in. (0.84 m), the maximum moment for a given load is the same as for the 12-ft (3.66 m) long beams.

Specimens B1U, B2U, B3U, B4U, and B5U (pile specimens without splice) were tested in the same manner as the 12-ft (3.66 m) long spliced specimens, as shown in Fig. 6D. Beams were loaded in the same position as they were cast.

Bending Test Results of 12-ft (3.66 m) Spliced Beams (Fig. 14)

The values of P_{cr}, M_{cr}, P_u, and M_u for Specimens B1S, B2S, B3S, B4S, and B5S are tabulated in Table 2. The listed moments include the bending moment due to the application of the machine load and that due to the beam's own weight of 2.5 kip-ft (3.4 kN • m).

The failure of Specimen B5S is attributed to rupture of one bolt and the opposite wedge at the bottom of the splice. A view of a splice and some

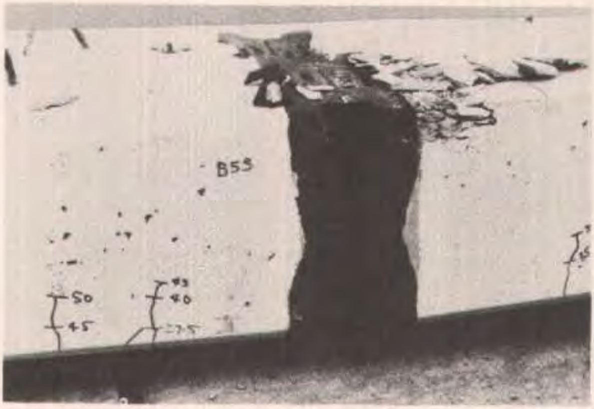

Fig. 15. Flexural failure of Specimen B5S.

concrete crushing at the top adjacent to the splice is seen in Fig. 15.

The mean ultimate moment for the five 12-ft (3.66 m) specimens is 83.1 kip-ft (113 kN • m).

A plot of moment at the splice vs. beam rotation is shown in Fig. 16 for the five 12-ft (3.66 m) specimens. In these tests deflection readings were terminated prior to reaching ultimate moment.

Specimens B6S, B7S, and B8S were tested in bending as shown in Fig. 6B. The values of P_{cr}, M_{cr}, P_u, and M_u are tabulated in Table 2. The listed moments include the additional moment due to the beam's own weight of 1.4 kip-ft (1.9 kN • m). The mean ultimate moment for the three 9-ft (2.75 m) specimens is 93.5 kip-ft (127 kN • m). The mean ultimate moment for all twelve spliced specimens is 94.9 kip-ft (129 kN • m). Note that in six of the twelve specimens, the splice did not fail at ultimate moment.

Bending Tests of 12-ft (3.66 m) Unspliced Beams

The values of P_{cr}, M_{cr}, P_u, and M_u for Specimens B1U, B2U, B3U, B4U, and B5U are tabulated in Table 2. The moments M_{cr} and M_u include the moment due to the machine load and the specimen's own weight of 2.5 kip-ft (3.4 kN • m).

All specimens failed due to crushing of the concrete fibers in the zone of maximum moment. A typical failure is shown in Fig. 18.

The mean ultimate moment of the unspliced specimens is 84.6 kip-ft (115 kN • m). This compares with a recommended allowable moment of 32 kip-ft or 384 kip-in. (43.4 kN • m) for a permissible concrete tensile stress of 600 psi (4.14 MPa).[25] The theoretical ultimate moment of the unspliced 12-in. (305 mm) square pile without an axial load, using a strength reduction factor, ϕ, 0.90, is 55 kip-ft (74.6 kN • m).[26]

The actual pile capacity of 84.6 kip-ft (115 kN • m), based on the test results, is 54 percent greater than the theoretical value. It is also to be noted that the mean ultimate moment of the twelve spliced specimens of 94.9 kip-ft (129 kN • m) is 73 percent greater than the theoretical pile capacity and 12 percent greater than the actual pile capacity.

A plot of moment at the splice vs. beam rotation for the five unspliced specimens is shown in Fig. 17. A comparison of Fig. 16 with Fig. 17 shows that the flexural stiffness of the

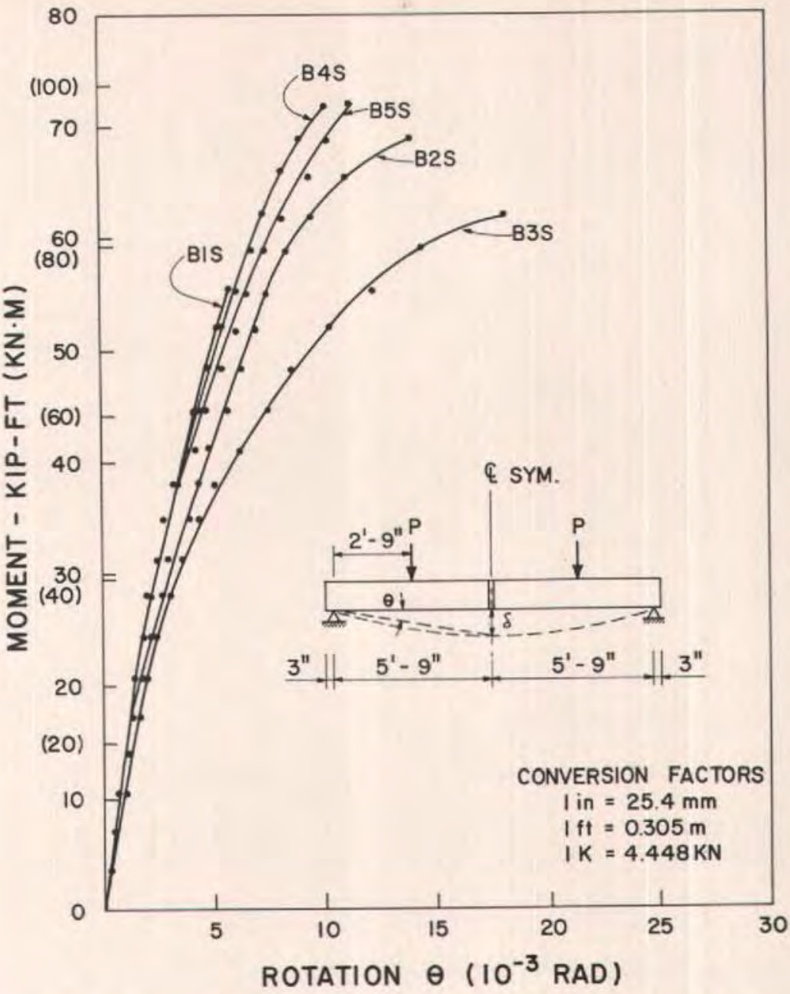

Fig. 16. Moment vs. rotation of 12-ft (3.66 m) specimens with splice.

spliced specimens is approximately equivalent to that of the unspliced specimens. This is probably attributed to the fact that the elastic movement of the splice components due to tension is balanced by the increased flexural stiffness of the pile section in the vicinity of the splice owing to the presence of the No. 8 (25 mm) reinforcing bars.

Shear Tests

Two complete shear specimens were tested in shear as shown in Fig. 6E. With this arrangement, two splices were tested simultaneously.

Due to the capacity of the loading beams and a desire to later reuse the shear specimens for flexural or compression tests, each test was stopped at a total load of 225 kips (1000 kN), or with 112.5 kips (500 kN) of shearing force on each splice. The splices were found to be in excellent condition at the conclusion of the tests, as shown in Fig. 19.

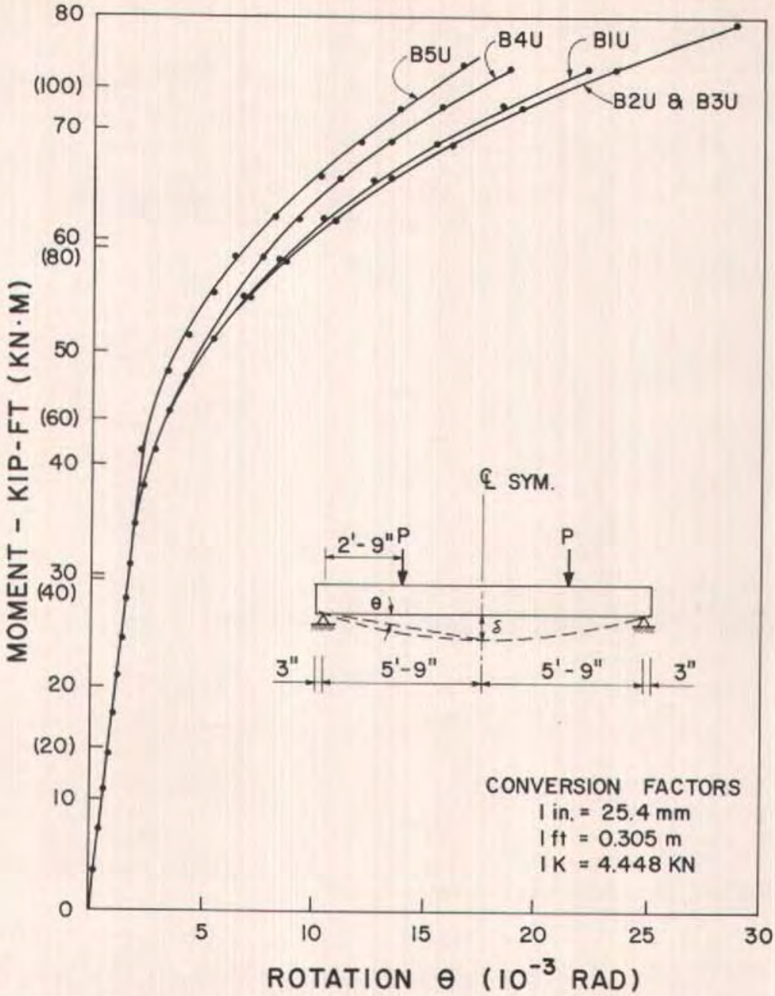

Fig. 17. Moment vs. rotation of 12-ft (3.66 m) specimens without splice.

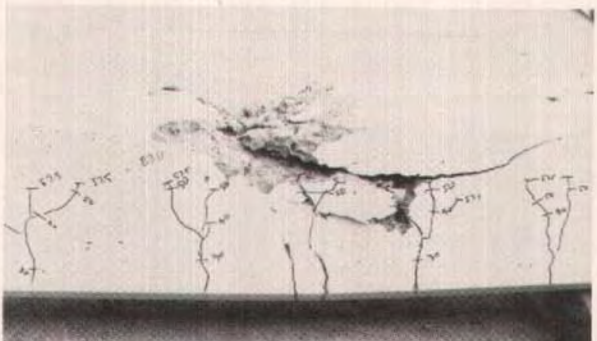

Fig. 18. Flexural failure of Specimen B3U.

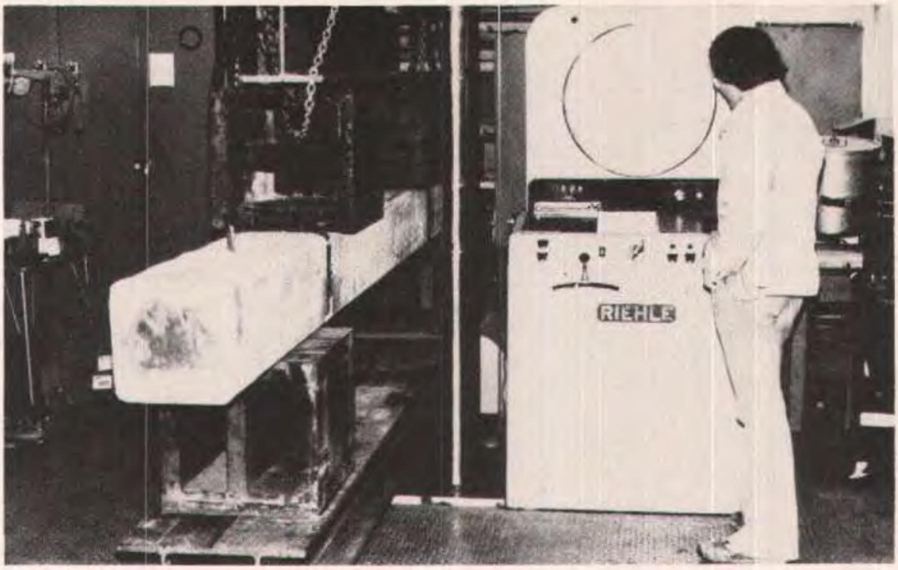

Fig. 19. Arrangement for shear tests.

Compression Tests

Three compression specimens, similar to the 9-ft (2.75 m) long bending specimen as shown in Fig. 6B, were tested in axial compression as shown in Fig. 20. The average ultimate load was 877 kips (3900 kN),[27] which corresponds to a compressive stress of 6180 psi (42.6 MPa). There were no failures of the splice. All specimens failed due to concrete crushing in the upper section just beneath the machine loading head.


Fig. 20. Arrangement for testing of compression specimens.

Corrosion Tests

In order to assess the corrosion resistance of the splice when subjected to a harsh environment, corrosion tests were conducted on the individual parts of the splice and on a complete 9-ft (2.75 m) specimen with the splice at mid-length. The 9-ft (2.75 m) specimen was subjected to a sustained compressive loading of 150 kips (667 kN), the magnitude of which represents a reasonable level of sustained force that a 12-in. (305 mm) pile will be subjected to in a building or bridge and is equal to 60 percent of the recommended allowable compressive force. The load was sustained for a period of three days prior to the corrosion test and during the entire period of the corrosion test (approximately 10 hours). The reason that the corrosion readings were taken under loading is that it is recognized that the corrosion rate increases with increased stress of the component.

The technique involved taking a series of potentiostatic measurements of the complete splice while immersed in a saline solution. A second method involved subjecting the splice to an aggressive environment for a given period of time and then measuring the weight of the corrosion products formed during this time.

The results[28] indicate that the splice exhibited negligible corrosion and is serviceable for use in most soils without restrictions. This low corrosion rate is attributed to the presence of the zinc alloy alignment cone which serves as a sacrificial part.

Conclusions

The following conclusions are based on the experimental data obtained from this project.

1. The minimum ultimate moment capacity of the splice is 95 kip-ft (129 kN • m). Since one-half of the flexural specimens failed outside the pile splice region, the actual mean ultimate moment capacity of the splice was not attainable.

2. The ultimate moment capacity of the splice is greater than that of a typical unspliced pile [85 kip-ft (115 kN • m)].

3. The negligible movement between two pile sections at the splice and the presence of the reinforcing bars of the splice do not significantly alter the moment-curvature or load-deflection characteristics of the pile.

4. The tensile strength of the splice is greater than that of the pile. The 48-in. (1.2 m) embedment length of the reinforcing bars is more than adequate in developing the tensile capacity of the pile or splice.

5. Under an axial compressive force, the splice is capable of developing the compressive strength of the pile.

6. The splice has a shear capacity which is in excess of that required for most severe loading conditions.

7. The splice should exhibit negligible corrosion and is serviceable for use in most soils without restrictions.

Design Recommendations

The design requirements for a precast prestressed concrete pile should apply equally to splices. The splice should be capable of resisting forces induced during handling and driving and when subjected to design loads. Inasmuch as the splice is equally as strong as the pile, the design of the pile need not be limited by the installation of a splice.

Pile design recommendations[25] given by Santa Fe-Pomeroy, Inc., manufacturers of the piles which were tested with the splice, allow an axial compressive force of 250 kips (1112 kN) for a 12-in. (305 mm) square pile. This allowable load is based on the commonly accepted building code formula[29] for concentrically loaded short column prestressed piles. With a pile capacity of 877 kips (3900 kN) in compression, the safety factor of 3.50 is more than adequate.

The theoretical ultimate moment of the 12-in. (305 mm) pile with no axial force is 55 kip-ft (74.6 kN • m).[26] Using a load factor of 1.7, the design allowable moment is 32 kip-ft (43.4 kN • m). With a splice ultimate moment capacity of 95 kip-ft (129 kN • m), the safety factor is 3.0, which is much higher

Table 3. Summary of recent applications of pile splice.

Structure	Location	Pile Driving Contractor
Liberty House—Department Store	Sacramento, California	Jensen & Reynolds Benicia, California
Golden Gateway III—Condominiums	San Francisco, California	Santa Fe-Pomeroy, Inc. Petaluma, California
Hines Building—High-rise office building	San Francisco, California	Santa Fe-Pomeroy, Inc. Petaluma, California
San Francisco International Airport—Central Terminal modernizations	San Francisco, California	Kie-Con, Inc. Pleasanton, California
Bridge	Hayward, California	Kie-Con, Inc. Pleasanton, California

than normally required. For higher strength 12-in. (305 mm) piles, an allowable moment in the splice of 47 kip-ft (63.7 kN • m) (50 percent of the ultimate moment) should be permissible.

For combined axial and flexural loading, an interaction formula should be used to check the adequacy of the pile and splice, due to the infinite number of combinations of loadings that could exist.

The details of the splice (Fig. 2) should be kept the same for all 12-in. (305 mm) piles. Although the 48-in. (1.2 m) long reinforcing bars are longer than required to develop the tensile capacity of the pile, the additional length assists in extending the high impact forces near the pile head, due to driving, over a greater length.

To date, three agencies have given their acceptance or approval of the splice.

In a report[30] of the Technical Director of the International Conference of Building Officials to its Research Committee, it was stated that "the Dyn-A-Splice device for splicing prestressed concrete piles is an alternate method of design to that required by the 1979 Uniform Building Code,[19] Section 2909 (e)."

A recently published ICBO Research Report states that the assembled Dyn-A-Splice is capable of transmitting the following design loads and bending moments:

Compression: 525 kips (2335 kN)

Tension: 100 kips (445 kN)

Shear: 70 kips (311 kN)

Bending: 32 kip-ft (43.4 kN • m)

These limiting values are primarily based on the test results of the experimental investigation of the splice.

The City of San Francisco has granted approval[31] for the use of the 10, 12, 14, and 16 in. (254, 305, 356, and 406 mm) square splice in the construction of pile foundations in the city. No design values for the various size splices are specified. However, one condition is that special inspection shall be required for installation of the wedges.

The State of California Department of Transportation (Caltrans) has also granted approval of the splice for use in pile foundations of bridges. The ultimate design loading requirements[32] for a 12-in. (305 mm) square splice are as follows:

Tensile force: 115 kips (512 kN)

Compressive force: 500 kips (2224 kN)

Shearing force: 70 kips (311 kN)

Bending moment: 75 kip-ft (102 kN • m) (with zero axial load).

To date, the splice has been used in the projects shown in Table 3.

Advantages and Disadvantages of Splice

Based on the results of the experimental program and observation of the fabrication and installation of the splice, the advantages of the splice are as follows:

1. The splice can develop the full capacity of the pile in tension, compression, and bending.

2. The shear and torsional strengths are the same in all directions. The splice cannot unlock due to torsion.

3. Prior to fabrication, the reinforcing bars, bolts, and splice plates can be stored separately thus requiring a minimum of storage space.

4. Parts of the splice are identical in each pile section which simplifies handling and avoids errors in the manufacture of the piles.

5. The splice is installed easily and quickly with unskilled labor and a sledge hammer. No welding or epoxy materials are needed.

6. The pile head with an installed splice needs no special helmet during driving. Only normal pile cushioning materials or other cushioning devices[33] are required.

7. There are only two kinds of components to install in the field: four wedges and an alignment cone.

8. Plate-to-plate contact of the splice assures longitudinal alignment.

9. The zinc alloy alignment cone serves as a sacrificial element in the event of corrosion thus prolonging the life of the structural components of the splice.

The only apparent disadvantage of the splice is that careful fabrication at the prestressing plant is required to insure longitudinal alignment of the reinforcing bars. However, this is easily accomplished by use of specially designed jigs.

Further Research

Plans are currently being made to extend the structural testing program to include:

1. Bending about a diagonal (45 deg) axis.

2. Response of the splice when subjected to combined axial compression and bending.

3. Structural behavior of 16-in. (406 mm) square splices.

4. Structural behavior of spliced octagonal piles.

5. Torsional capacity of the splice.

6. Dynamic response of the splice and pile during driving.

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* * *

Discussion of this paper is invited. Please forward your comments to PCI Headquarters by May 1, 1981.

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NOTE: Further information on the patented Dyn-A-Splice may be obtained from the author or Bengt O. Cardell, President, A-Joint Corporation, 335-D Turtle Creek Court, San Jose, California 95125.