SPLICING OF PRECAST PRESTRESSED CONCRETE PILES: PART I—REVIEW AND PERFORMANCE OF SPLICES

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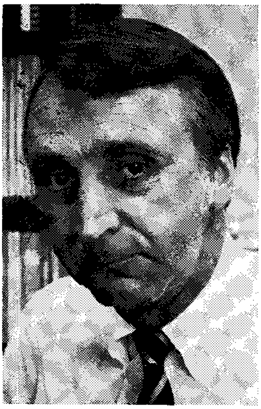
Effective splicing of prestressed concrete piles can reduce or eliminate many problems associated with the installation of long piles.
Proper splicing methods eliminate the need to predict precise pile lengths, and allow extensions of piles when necessary. This report presents the results of an investigation into existing methods presently used in the splicing of prestressed concrete piles.
The first part of this report constitutes a review and evaluation on splicing methods developed and used in several areas of the world.
The second part of the report, to be published in the next issue of the PCI JOURNAL, describes actual tests and analyses of one of the splices described in this article.



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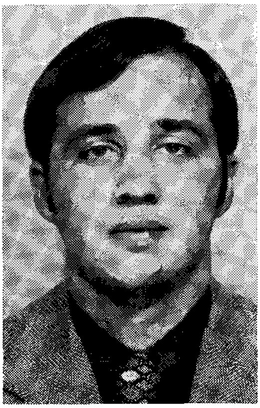

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BACKGROUND

Effective pile splicing can reduce or eliminate many problems associated with the installation of precast prestressed concrete piles. Among these problems are the:[1]

1. Need to forecast pile lengths accurately, eliminating waste
2. Extension of piles cast short of the length found to be necessary from field results
3. Cost and difficulty of handling and transporting long piles
4. Tremendous weight of long piles, and
5. Increased cracking incurred with excessive handling of long piles.

Proper splicing of prestressed piling eliminates the need to predict the precise pile lengths and allows extensions of piles when necessary. Splicing enables the use of shorter pile sections; thereby reducing the weight and length of pile that is handled and reducing the danger of cracking due to excessive handling.

This report represents the results of an investigation into the present methods of splicing prestressed concrete piling, and the results of actual tests of certain splices. Each splice included in the investigation was studied to determine the performance of the spliced section compared to the unspliced continuous pile.

The overall effectiveness of a given splice is dependent upon several factors. Those factors used in evaluating the splices examined in this investigation were as follows: size range, field time for splicing, approximate cost of splice, availability, construction usage, structural integrity, and structural performance.

The data used in the evaluation of the splices was generated by the authors for the most part. However, some of the data was furnished by the designers and fabricators of a given splice.

The investigation was limited to those splices commonly used and was limited to splices capable of being driven by pile driving equipment.

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PILE SPLICES PRESENTLY IN USE

Introductory Remarks

Twenty pile splices are discussed in this section. Though each splice has unique and distinct characteristics, the splices investigated could be categorized generally as follows:

1. Welded Splices
2. Bolted Splices
3. Mechanical Locking Splices
4. Connector Ring Splices
5. Wedge Splices
6. Sleeve Splices
7. Dowel Splices
8. Post-Tensioned Splices

Those specific splices that form the basis of this investigation included:

1. Marier Splice (Canada)
2. Herkules Splice (Sweden)
3. ABB Splice (Sweden)
4. NCS Splice (Japan)
5. Tokyu Splice (Japan)
6. Raymond Cylinder Splice (USA)
7. Bolognesi-Moretto Splice (Argentina)
8. Japanese Bolted Splice (Japan)
9. Brunspile Connector Ring (USA)
10. Anderson Splice (USA)
11. Fuentes Splice (Puerto Rico)
12. Hamilton Splice (USA)
13. Dowel Splice (USA)
14. Macalloy Splice (Great Britain)
15. Mouton Splice (USA)
16. Raymond Wedge Splice (USA)
17. Pile Coupler Splice (USA)
18. Nilsson Splice (Sweden)
19. Wennstrom Splice (Sweden)
20. Pogonowski Splice (USA)

Description of Individual Splices

The purpose of this section is to provide specific information concerning each individual splice. This information includes the origin, fabrication, construction, and use of the splice. Each of the above splices was analyzed and evaluated and compared in terms of several parameters. Basic considerations included size range, field time for splicing, approximate cost, availability, and construction usage.

The evaluation based on performance data included driving performance; compression, tension, and flexural resistance; fatigue; and corrosion resistance. The evaluation was based on actual experimental data obtained from tests on specific splices. Where no test data was available (as was the case with a few splices), theoretical analyses were made.

The tests included driving tests under variable conditions, extractions of piles, and flexural and shear testing of the full-sized extracted piles. Drawings of each splice are provided to show the basic concept of the splice, but are not intended to describe particular engineering details.

The data used to establish the evaluation of individual splices was furnished, for a considerable part, by fabricators, designers, and proponents of a given splice. Most of the splices were proprietary, having one or more patents, United States or otherwise. The data furnished was generally favorable.

Data reflecting unsatisfactory performance was difficult to obtain. A status report of the investigation was presented to the 1973 Regional Meetings of the Committee on Bridges and Structures of the American Association of State Highway Officials, in an attempt to uncover any problem areas with given splices, or with splices in general. Although some general comments were made by the bridge engineers present, no specific unsatisfactory performance was reported.

PILE SPLICES INVESTIGATED

Marier Splice

The Marier splice is a mechanical splice and is shown in Fig. 1. Small flexible pins are inserted circumferentially into the splice, locking the sections together. Small tolerances must be met in the fabrication of this splice as exact fits of the locking pins are necessary for good performance of the splice.

The Marier splice requires anticipation in the preparation of the pile sections. Male and female steel caps are cast into the ends of the piles. Holes in the caps allow prestressing strands to pretension the piles. The prestressing strands are not mechanically connected to the pile caps. The cap is secured to the piling by use of dowel bars. The number and length of dowels required to anchor the cap to the pile is dependent on the size of the pile and the structural capacity of the pile section. The steel caps are circular in shape; the piles need not be circular. The Marier splice has been successfully used with octagonal piles.

The female section is driven in the field with the use of a driving shoe. The shoe fits in the female end and is locked to the bottom section with a locking pin. When driving is completed, the driving shoe is removed by pulling the locking pin from the bottom splice cap. The top section is then set into position. Four flexible locking pins are driven circumferentially into the splice to complete it. The male cap is a tighter fit than the driving shoe because the pins are not to be withdrawn.

The splice was patented in 1969 by Gaston Marier of Princeville, Quebec.[2] The time required to complete the splice is minimal. Reports indicate that the Marier splice has been successfully used in Canada.

Herkules Splice

The Herkules splice is a mechanical splice and is shown in Fig. 2. The splice is available for hexagonal, round, or square sectional shapes. It is presently used for reinforced concrete piling, but can be adapted for prestressed concrete piling as well. The manufacturers design the spliced Herkules pile to develop the same flexural capacity as that of the unspliced pile, and report that joint strength in compression and tension is designed to withstand all conditions of hard or soft driving.

The Herkules splice requires prior preparation of the concrete piling. Steel male and female caps are cast into the ends of the piles. The female cap is driven down with the bottom pile section. A special driving shoe is required to prevent damage to the female cap. The top pile section, with the male end attached to it, is then stabbed into the female cap.

As shown in Fig. 2, the male cap has a steel pin which protrudes at the tip. This pin acts as a stabbing guide and aids in the alignment of the male and female caps during splicing operations. The top section is rotated, locking the piles together mechanically. Two locking pins are inserted into the splice, maintaining the locked position. The field time required to complete the splice is minimal and the procedure simple.

The Herkules splice is manufactured by A. B. Scanpile, Gothenberg, Sweden. The splice is patented and may be used apart from the Herkules pile. A. B.

Scanpile reports 30 million ft of Herkules piles have been used with the Herkules splice over the past 10 years.[3]

ABB Splice

The ABB splice, shown in Fig. 3, is a mechanical splice. It is used primarily for square piling but may also be used with round, hexagonal, octagonal, or hollow cross sections. The ABB splice is used on conventionally reinforced piling, but it can be adapted to prestressed concrete piles.

The upper and lower pile sections are identical. The splice consists of lock-blocks welded to the reinforcing rods and cast with the piles. Reports indicate that the reinforcing rods are not weakened by the weld, and the joint is at least as strong as the reinforcement. The block is coated with a corrosive protective material to insure long life of the pile.

A special driving shoe is required to protect the protruding joint block during driving. The top section is aligned properly and lowered into the bottom pile section. The splice is completed by driving special locking pins into the joint blocks, which remain in place. When in position, the locking pins exert stresses in the joint blocks which draw together the ends of the pile sections. The face of the splice is prestressed to some extent. The time required to complete the splice is minimal, and the procedure is simple.

The ABB splice is manufactured and patented by the Stabilator firm of Sweden.[4] According to reports, the ABB and Herkules splices cover the need of pile joints on the Scandinavian and Western European markets. Stabilator reports the strength and rigidity of their joint is equal to that of a continuous pile.

NCS Splice

The Nippon Concrete Systems (NCS) splice is a welded splice shown in Fig. 4. The splice is manufactured in conjunction with the NCS prestressed concrete piles. These piles are prestressed by the pretensioning method. The prestressing strands are tensioned; then the piles are centrifugally spun.

The NCS splice consists of two steel caps cast into the ends of the sections to be spliced. The caps are connected to the pile tips in two ways. First, the caps have dowel bars attached to anchor the cap to the pile. The number and length of the dowels is a function of the pile dimension and strength. Secondly, the prestressing strands are mechanically fastened to the steel cap by use of a buttonhead. The buttonhead can be seen in Fig. 4 at the tip of the pile section. This procedure is unique in that the full prestress of the pile is carried into the end of the pile section.

The bottom section is driven down, and the top section is properly aligned on it. The sections are then welded together with a groove weld. Nippon Concrete Systems has developed three methods of welding the joint: (1) hand operated, (2) semi-automatic, or (3) full-automatic joint welding. Corrosion is accounted for by increasing the size of the groove weld.

The Nippon Concrete Industries reports excellent performance of the splice.[5] The company has constructed a plant in Everett, Washington, for the manufacture of the NCS piles and splices. Acceptance and usage of the NCS splice is anticipated in the Pacific Northwest.

Tokyu Splice

The Tokyu splice is a welded splice used in conjunction with piles prestressed with steel bars instead of strands. Seventy percent of the bars are low carbon steel hardened by high frequency electricity; the remaining 30 percent are high carbon steel bars hardened by drawing. This splice is shown in Fig. 5.

The splice itself consists of male and female steel caps cast into the piles. The male and female caps are fitted through the prestressing bars. These bars are threaded at the ends, enabling bolts to fasten the cap to the end of the pile securely. The tightening of the bolts is, in effect, carrying the prestressing to the tips of the pile, similar to the NCS splice. The male cap has stabilizing guides to help align the two sections during construction.

The bottom section is driven in the field with the aid of a special driving shoe to protect the splice. The top section is stabbed into the bottom section and positioned. Fig. 5 shows how the stabbing guides are helpful during stabbing and alignment of the sections. The splice is completed by butt welding the pieces together.

The Tokyu welded splice is manufactured and patented by the Tokyu Concrete Industry Co., of Tokyo, Japan, and it is used in conjunction with their prestressed concrete piles. The splice can be used on various sizes of cylinder piles. It is reported that the Tokyu splice develops the full bending strength of the unspliced section.[6] Tests reported indicate that the temperatures reached during the welding of the splice are not detrimental to the concrete or the prestressing bars.

Raymond Cylinder Pile Splice

The Raymond cylinder pile splice is a welded splice, as shown in Fig. 6. The inability to handle long sections of prestressed cylinder piling on land induced development of this splice.

The cylinder pile splice consists of two steel ring caps which are cast into the ends of the spun concrete piles. The steel caps are connected directly to the piling by use of dowel bars threaded into the cap. The cap is designed with openings to allow the post-tensioning of the pile.

The post-tensioning is performed by the threading of the prestressing strands through the cast holes in the piling and the steel splice cap. The strands are stretched and grouted to apply the prestress to the pile. The prestressing cables are not intended to anchor the cap to the pile.

In the field, the bottom section is driven with the aid of a special driving shoe. The shoe fits over the splice cap and is tack welded to allow driving of the bottom section without damage to the splice. After the bottom section is driven, the driving shoe is removed and the two sections are then butt-welded together. If stability problems exist, leads are used to aid the alignment procedures. Tests of the splice indicate total time required to complete the splice to be 1½ hours.

The cast steel driving splice was designed by Walter E. Blessey for Raymond Concrete Pile Co., with Shell Oil Company as cosponsor. As a result of tests performed at Tulane University, the dowel bars were lengthened from 18 to 36 in.

Bolognesi-Moretto Splice

The Bolognesi-Moretto splice is a welded splice illustrated in Fig. 7. It is presently used in the splicing of reinforced concrete piles and is included in the investigation because of its adaptability to prestressed piles.

The lower pile section is cast with a ½-in. plate anchored to the pile tip by means of dowels. Four steel angles are welded to the plate and extended in varying lengths into the pile. The splice is unique in that the dowels are angles rather than bars.

The top pile section is cast in much the same manner; however, the base plate in the top section is somewhat smaller in size than the bottom plate. This enables the two plates to be welded together by a fillet weld. Fig. 7 shows the alignment of the plates and the fillet weld required to make the splice.

The bottom section is driven down to a splicing position. The top section is set on the bottom plate and aligned. The two plates are then welded together with a fillet weld. An epoxy cover protection is spread over the weld and splice area. This is done to protect the splice from corrosion. Driving is then resumed.

Bolognesi-Moretto Consulting Engineers of Buenos Aires, Argentina, designed and patented the splice. Reports indicate the the splice can be completed within 30 to 40 minutes.[8] Drawings illustrate the splice used for 15-in. square reinforced concrete piles. Test data as to the performance of this splice were not available at the time of this report.

Japanese Bolted Splice

The Japanese bolted splice is shown in Fig. 8. It is presently used in the splicing of reinforced concrete piling. It is included in this study because of its adaptability to prestressed concrete piling. The principle of the bolted splice is simple, but the details are relatively elaborate.

Preparations for the bolted splice involve the casting of two steel pieces into the ends of the piling. Both pieces are fastened to the ten reinforcing bars of the piling. The bottom splice piece also has ten dowel bars attached which serve as additional anchorage for the splice. The upper splice section has eight dowel bars which provide additional anchorage to the pile section. Eight bolts, which are extensions of the eight dowel bars, protrude from the splice section.

The field work involves the driving of the bottom pile section in place. Tests performed on this splice emphasize the care necessary in choosing a cushion material and in driving the pile sections. The top pile is guided into place over the lower section. The eight bolts act as stabbing guides during splicing. The eight bolts are then fastened, locking the two sections together in preparation for additional driving. Reports indicate that the tightening of the bolts prestresses the face of the splice to some extent.[9]

The bolted splice is made in Japan and can be used for various sizes of piling. Nippon Concrete Industries, Co., Ltd., produces the bolted splice in conjunction with its precast reinforced concrete piles. Consideration should be given to corrosive effects, since the steel in the splice is exposed.

Brunspile Connector Ring

The Brunspile connector ring is a wedge splice used to join prestressed concrete piles.[10] Prior preparation of the Brunspile consists of casting a round steel ferrule at the end of the pile. Small tolerances must be met in the fabrication of the connector ring. A good fit of the ring to the steel ferrules is necessary for the proper performance of the splice.

The Brunspile connector ring acts as a wedging sleeve, as shown in Fig. 9. In the field, the bottom pile section is driven down, leaving the steel ferrule exposed. The wedge connector is then tapped onto the steel ferrule. A 1-in. impact plate is placed between the pile sections within the connector ring. The top pile section is guided into the seated connector ring. At this point, driving is begun. Initial blows of the pile driver wedge the sections together, completing the splice.

The Brunspile connector ring is distributed by the Associated Pile and Fitting Corporation and Belden Concrete Products Co., Inc. Both the Brunspile and the Brunspile connector ring are covered by United States patents. The connector ring has been used extensively and satisfactorily by Associated Pile and Fitting Corporation with steel pipe piles. Its use has not been as extensive with prestressed concrete piles. The connector ring was not designed as a tension splice for prestressed concrete piles.

Anderson Splice

The Anderson splice is a sleeve splice developed for prestressed concrete piles. The steel sleeve is made to fit tightly around the pile, as shown in Fig. 10. Fabrication requires small tolerances to assure the tight fit of the sleeve on the piles. The friction between the piles and the sleeve is required for proper alignment and performance of the piling. It can be fabricated for various sizes and shapes of piling, with the thickness of the sleeve as a function of the diameter of the pile. The pile itself requires no special preparation for splicing.

The installation of this splice in the field is simple. First, the steel sleeve is driven over the head of the bottom pile. A plywood pad, cut to the shape of the piling, is placed between the bottom and top pile sections. This acts as a cushion during driving.

The top pile is driven into the sleeve with a tight fit. If this is not possible, two halves of the sleeve may be welded together over the pile. If the splice must develop tension, it is reported that epoxy resin can be injected into the space between the piles and the splice sleeve. The friction between the piles and the sleeve is not enough to develop significant tensile forces.

The Anderson sleeve splice was developed by Dr. A. R. Anderson of Tacoma, Washington. It has been used by state agencies and various architects and engineers in the state of Hawaii. Approximately 120,000 ft of prestressed concrete piles have been driven on state and private projects in Hawaii in the last 5 years with the use of the Anderson sleeve splice.[11]

Fuentes Splice

The Fuentes splice is a sleeve splice, as shown in Fig. 11. It is presently used to splice 10-in. diameter reinforced concrete piles. Modifications in the splice could enable the Fuentes splice to be used on prestressed concrete piles.

The Fuentes sleeve splice does require prior preparation of the concrete piles. A steel band is first welded to the pile reinforcement. The weld is made 18-in. from the splice on both the bottom and top pile sections. The amount of welding required to connect the band to the pile reinforcement is dependent on the tensile forces expected in the pile.

The steel band is cast with the pile, exposing its outer surface. A thin steel sleeve is then placed on the bottom section and welded to the steel band. This completes the prior preparation necessary in the splice.

The bottom pile section is driven with a special mandrel. This mandrel protects the sleeve section that is to receive the male end of the next pile section. The top pile is inserted into the sleeve, and the sleeve is welded to the top pile. The only work required in the field to make the splice is the welding of the sleeve to the top pile section. Driving is then resumed.

The Fuentes sleeve splice is used in conjunction with the Fuentes Concrete Pile. It was developed by Gabriel Fuentes, Jr., of Puerto Rico.[12] The pile and splice are patented in the United States and abroad. Shorter pile sections can be handled more easily and do not require large pile driving rigs.

Hamilton Form Company Splice

The Hamilton Form Company splice, shown in Fig. 12, is a sleeve splice. It was designed specifically for 36-in. outside diameter cylinder piles with 4-in. thick walls.

Unlike most other splices, no prior preparation of the piles is necessary. The splice consists of two semi-circular sleeve sections 8 ft in length. Small steel extensions are secured to the sleeves by the welding of gusset plates. These extensions are used to receive the bolts which clamp the semi-circular sections together. This arrangement is shown clearly in Fig. 12.

In the field, the lower pile section is driven in a normal procedure. The top section is lowered into position and then properly aligned. The sleeve sections are positioned around the joint. Bolts are threaded through the holes and are tightened with torque wrenches. Time required to complete the splice is one hour to ninety minutes.

The Hamilton Form Company of Fort Worth, Texas, designed the splice for the piles of the McBride Bridge in British Columbia, Canada. The original design called for a ¼-in. thick sleeve, but this was increased to ⅜ in. at the request of the British Columbia Department of Highways. The piles were driven in −30 F temperatures.

Reports point out the fact that the pile withstood an axial pull of 550 kips and was tested in flexure until visible cracking of the pile occurred.[13] A patent was never applied for, so the splice is public domain.

Cement-Dowel Splice

The cement-dowel splice is shown in Fig. 13. A variation of this splice is the epoxy-dowel splice. The concept of the splice is simple. The choice of materials used to anchor the dowels to the pilings is of prime importance. Some materials are effective in anchoring the dowels, but require an excessive setting time, therein disrupting driving. Other materials set quickly but are ineffective in anchoring the dowels or withstanding driving forces.

The cement-dowel splice in this investigation was made using Florok Plasticized Cement, manufactured by the Chargar Corporation of Hamden, Connecticut.

The bottom section of the splice has holes which receive the dowels. These holes may be cast with the pile or drilled in the field if necessary. The top section is cast with the dowel bars in the end of the pile, as shown in the figure. The number and length of dowel bars is dependent on the pile size and structural capacity.

The bottom section is driven with no special consideration. The top section, with the dowels protruding from the end, is guided and set in position over the bottom section. The dowels act as stabbing guides. Once in position, a thin sheet metal form is placed around the splice. The cementing material is then poured, filling the holes of the bottom section and the small space between the piles. The form can be removed after 15 minutes and driving resumed.

The splice is not patented. It has been used in New York[14] and Florida.[15]

Macalloy Splice

The Macalloy splice is a post-tensioned splice,[16] applied to prestressed and reinforced concrete piling. Macalloy prestressing bars are coupled continuously across the joint, fully prestressing it.

Preparation is extensive. The lower section is cast with 1½-in. grouting ducts to contain the Macalloy bars and with holes at the pile ends to receive the dowels from the top section. The bars are anchored to the bottom section by a sleeve at the ends of the bars, and they extend out from the top of the pile. The top section is cast with 1½-in. grouting ducts and high-tensile strength dowels. Macalloy bars are then threaded through these ducts. Details of the splice are shown in Fig. 14.

A special driving helmet is needed to protect the protruding Macalloy bars in the bottom section. After driving the bottom section, the top section is positioned over the bottom; and threaded Macalloy bars are then screwed into mechanical couplers. A jointing compound is spread over the head of the bottom pile and into the holes which receive the dowels, taking care to keep the grouting ducts clear. The top section is lowered and seated.

The Macalloy bars are stressed with hydraulic jacks, post-tensioning the piling. The bars are wedged and driving resumed. Top sections of 40 ft and piles up to 185 ft in length have been successfully installed with this splice.

The Macalloy splice is patented and is used in Great Britain.[17] The structural capacities of the spliced section are virtually the same as those of an unspliced section. Tests of the Macalloy splice indicate that this method of splicing is practical.

Mouton Splice

The Mouton splice is a combination splice. It is illustrated in Fig. 15. It is completed by wedging a pin connector into connector sleeves which are cast into the ends of the pile sections. The pin connector is mechanically wedged into position when the splice is made.

The connector sleeve is cast into the end of the pile along with a cast iron head. A ½-in. layer of insulation material surrounds the connector sleeve. This allows the pin to expand and wedge itself into position without crushing the concrete surrounding the sleeve. Reports indicate that the fabrication and casting of the connector sleeves is critical for proper performance of the splice.

In the field, the bottom section is driven down and the top section set into position over the driven pile. The pin connector is placed within the connector sleeves of the pile sections. The top pile is then rotated for proper alignment with the bottom section. As the top section is lowered onto the lower section, the wedges in the tips of the pin connector are activated and expand transversely. The wedging action is complete when the sections are touching. The pin connector is now wedged, and the splice is complete. Field time required to complete the splice is minimal and the procedure is simple.

The Mouton splice was developed by William J. Mouton, Jr., and patented in 1972.[18] It may be employed with various shapes of piling and is presently used in conjunction with the Tri-Pile, a triangular prestressed concrete pile which is patented.

Raymond Wedge Splice

The Raymond wedge splice is a combination sleeve and wedge splice. It is illustrated in Fig. 16. The splice is similar to a "mortise and tenon" splice[19] and is used with prestressed concrete piles.

Preparation of the piles for this splice is necessary. The end of the bottom pile section is cast with a pipe sleeve. The top section is also cast with a pipe sleeve, but this sleeve is constructed differently. A portion of the sleeve is imbedded in the tip of the pile, while the end of the sleeve is not filled with concrete. This sleeve has square holes cut out for the insertion of the steel wedges during splicing. Fig. 16 shows the construction of the pile tips clearly.

The lower section is driven into position for the splice to be made. The top pile section is lifted into position. The pipe sleeve of the top section is lowered over the smaller pipe sleeve of the bottom section. After proper alignment, steel wedges are driven through the holes of the outer sleeve. This produces a tight fit between the pipe sleeves. Once in position, the wedges are welded in place to prevent movement during driving.

This splice was developed and patented by Raymond International, Inc., which has used the splice with 16½-in. octagonal prestressed piles.[20] This splice can be adapted for use with other sizes and shapes of prestressed concrete piles. Prestressed concrete piles 175 ft long were successfully spliced in Seattle, Washington, using this splice.

Pile Coupler Splice

The Pile Coupler Splice shown in Fig. 17 was developed and tested in 1974, and consists of a steel split ring connector which is used to join two lengths of prestressed concrete piling. Prior preparation of the Pile Coupler Splice includes the casting and anchoring of steel plates into the ends of the sections to be connected. Studs are used to anchor the splice plates.

The tension band split ring connector can be in one piece, or it can be fabricated in two pieces. The connecting band is C-shaped and fits into grooves in the steel plates. A good fit of the connecting band to the steel plates is necessary for the proper performance of the splice.

In the field, the bottom pile section is driven, leaving the steel plate exposed. The top pile section is guided onto the bottom section by a dowel, and the connecting band is fitted to the bottom and top pile sections. The connector band is then closed with a double beveled weld.

The Pile Coupler Splice was developed and tested by Marine Concrete Structures, Inc.; and a United States patent has been applied for. Tests indicate that the splice, if properly anchored, is effective in developing the strength of the prestressed concrete pile.

Nilsson Splice

The Nilsson Splice was developed and patented by Jan Nilsson and Sten Nilsson, and is illustrated schematically in Fig. 18. It consists of two steel plates which are mutually similar and complementary to each other in such a manner that each one of the plates can be fitted and engaged to the corresponding plate on the end of the other pile section. Since the two fittings forming the joint are mutually alike, the jointing work is simplified, and economies can be realized in the cost of production of the fittings.

The portions of the fitting which accomplish the interlocking are provided with undercut edges which engage each other by means of a sliding ability.

The jointing plates are provided with recesses which, in interlocked position, are so located that they face each other for the purpose of forming a channel into which a locking bar is placed to lock the two sections together.

The Nilsson Splice is capable of developing the strength of the prestressed concrete pile, provided that it is properly anchored to the pile section by means of the steel sleeve shown in the figure. The field time required to make the splice is approximately 20 minutes.

The splice is shown for circular piles, but can be adapted for piles of other cross section configurations.

Wennstrom Splice

The Wennstrom Splice is a wedge splice which was invented by Elof Algot Wennstrom of Orebro, Sweden, and is schematically illustrated in Fig. 19.

Opposing steel plates are anchored into the pile section to be spliced. These steel plates are provided with registering grooves which extend inwardly from the edges of the steel plate members and are of dovetailed cross section. The grooves are designed to accomodate the locking wedges shown, which are of double dovetail configuration in cross section. At their inner ends, the wedges have projections which cooperate with curved recesses at the inner ends of the grooves. As a result, the wedges when driven into the grooves will be reliably anchored to the plate-shaped members.

It is reported that the driven wedges are so anchored that there is no possibility of the wedges coming loose and sliding out.

The analysis of this splice indicates that it is effective in developing the strength of the prestressed pile, if the splice plates are properly anchored. The time required to make the splice is approximately 20 minutes.

Pogonowski Splice

The Pogonowski Splice illustrated in Fig. 20 was invented by Ivo C. Pogonowski, Paul D. Carmichael, and Edward E. Bodor. The patent assigns the splice to Texaco Inc.

This mechanical locking splice was designed to be particularly adapted for use in offshore or similar applications, where a hostile environment or a severe corrosion problem is a pertinent factor. The pile comprises an elongated member formed essentially of a series of concrete pile sections.

A metallic cap carried at each pile section end is adapted to engage and be fixed to a corresponding cap on the next succeeding pile end thus forming a rigid connection between the two sections. The metal joint thus formed between the concrete sections is then isolated from its surroundings by means of an enclosing barrier formed on the pile to protect the joint from corrosion.

The splice is especially applicable to prestressed concrete cylinder piles.

ANALYSIS OF SPLICES

There is a variation of the behavior of the various splices under field conditions. Some may fail directly in the joint, while in other cases failure results from bond failure of the dowels anchoring the splice to the piles. Lack of ability to anchor and develop the dowels causes the latter problem. In some instances, failure occurs completely outside of the spliced region. Splice systems that develop strengths greater than the piles themselves are usually costly.

Each splice in this report was analyzed to determine its structural capacity as compared to that of the unspliced pile. The piles are evaluated as structural members, even though the piles are just one part of a soil-structure interaction. Capacities of pile-supported structures are often governed by soil conditions, and not by the structural capacities of the piles.

The comparative strengths of the spliced and unspliced sections were measured in terms of compression, tension, and flexure. The efficiency of any particular splice was computed to be the strength of the spliced section compared to the strength of the unspliced section; and is represented as a percentage. The strength of the spliced section was considered to be the strength of the splice in compression, or in tension, or in flexure. The strength of the unspliced section was considered to be the strength of the section in compression, or in tension; or the strength at which flexural cracking occurred. Piles are usually designed to prevent undesirable cracking. Those splice systems, in which cracking of the fully prestressed pile sections occurred before distress in the splice, were considered to be 100 percent effective in developing the cracking load for the spliced pile.

Individual costs of the splices are not dealt with directly in this report, but information supplied by this investigation will give some indication as to the relative costs involved. Knowledge of the preparation of piles, the availability of the piles, field time required for the splice, and fabrication of the splice are all beneficial in determining costs. A detailed account of the actual costs incurred in the utilization of each splice was beyond the scope of this investigation.

(Text continued on p. 93)

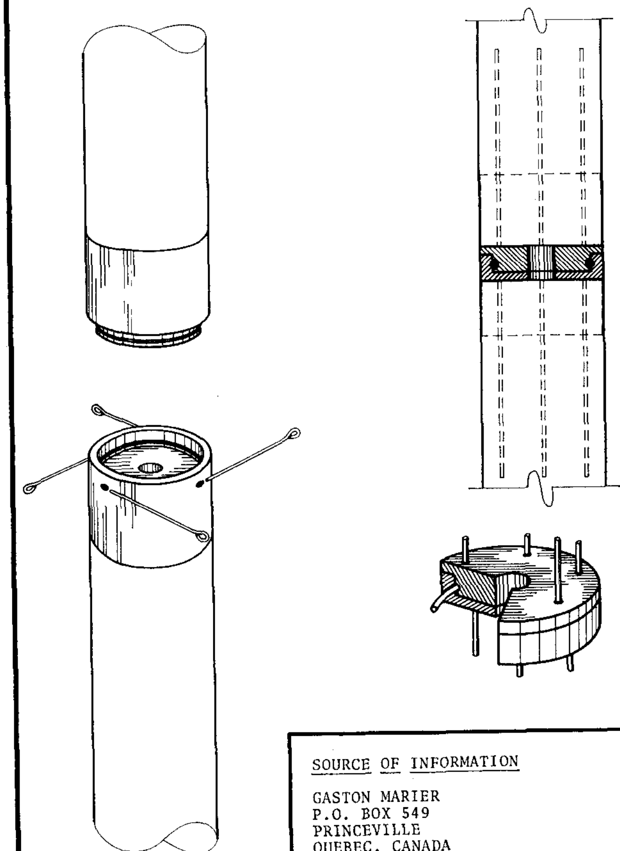


FIG. 1 MARIER SPLICE

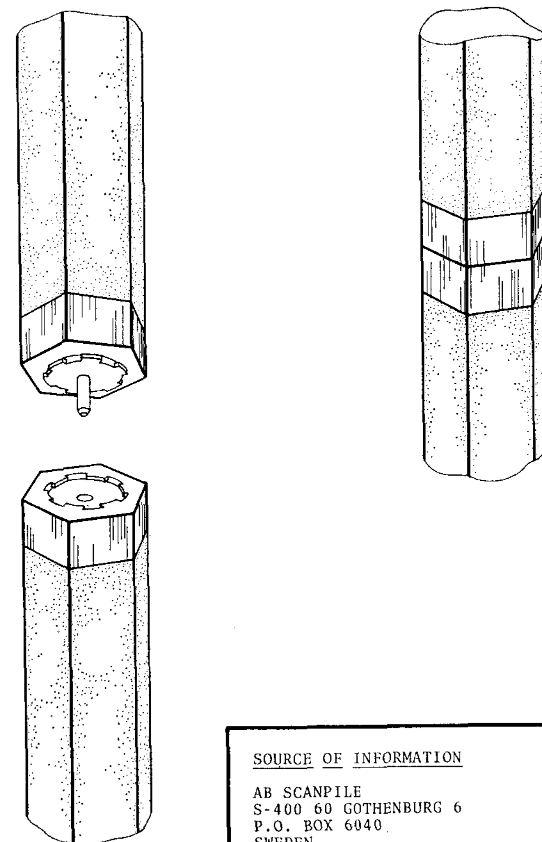
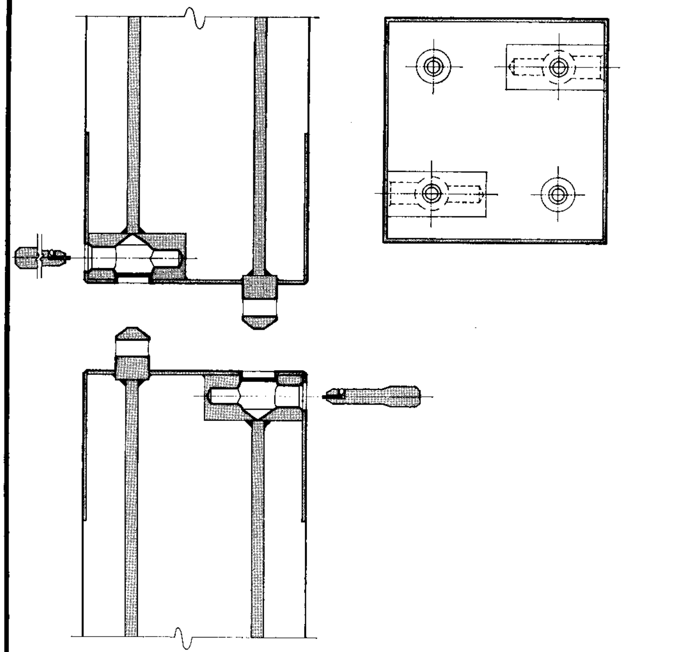


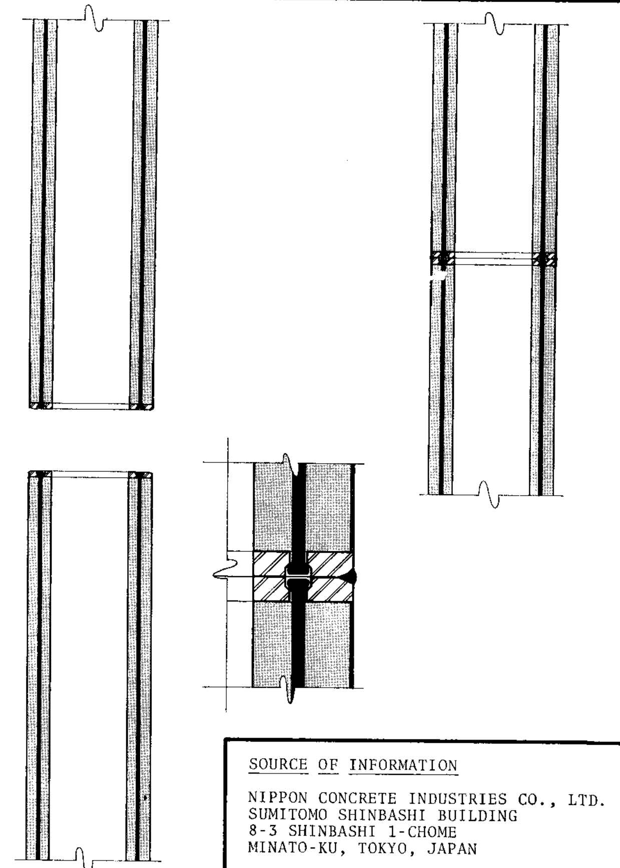
FIG. 2 HERKULES SPLICE



SOURCE OF INFORMATION

STABILATOR AB
BOX 46
BROMMA 1
SWEDEN

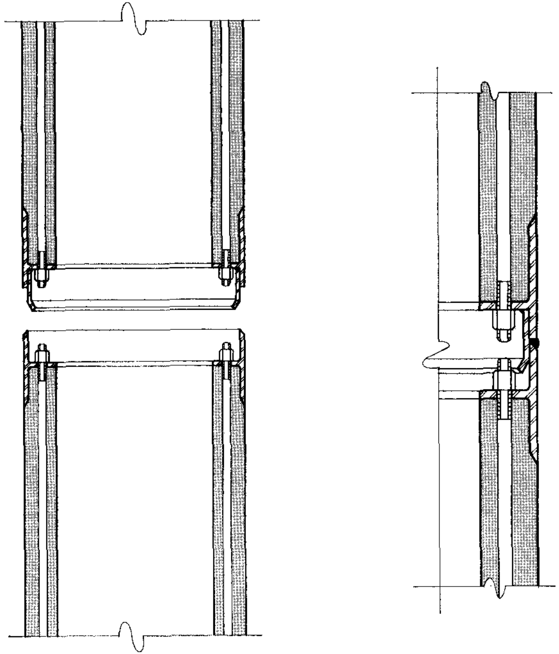
FIG. 3 ABB SPLICE



SOURCE OF INFORMATION

NIPPON CONCRETE INDUSTRIES CO., LTD.
SUMITOMO SHINBASHI BUILDING
8-3 SHINBASHI 1-CHOME
MINATO-KU, TOKYO, JAPAN

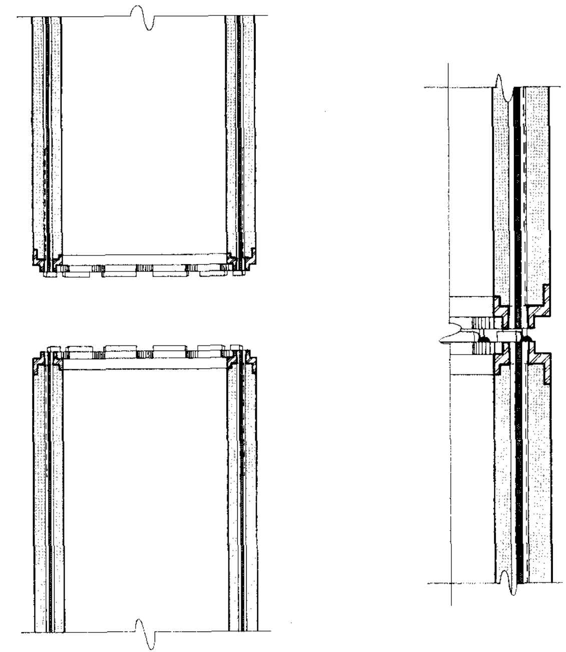
FIG. 4 NCS SPLICE



SOURCE OF INFORMATION

TOKYU CONCRETE INDUSTRY CO. LTD.
TAMEIKE - TOKYU BUILDING
NO. 1-1-14, AKASAKA,
MINATO-KU, TOKYO, JAPAN

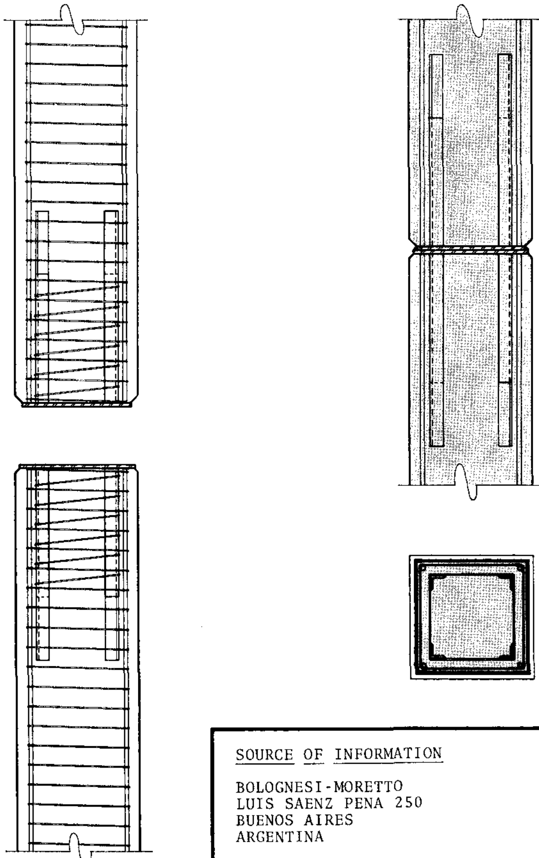
FIG. 5 TOKYU SPLICE



SOURCE OF INFORMATION

WALTER E. BLESSEY
TULANE UNIVERSITY
NEW ORLEANS
LOUISIANA

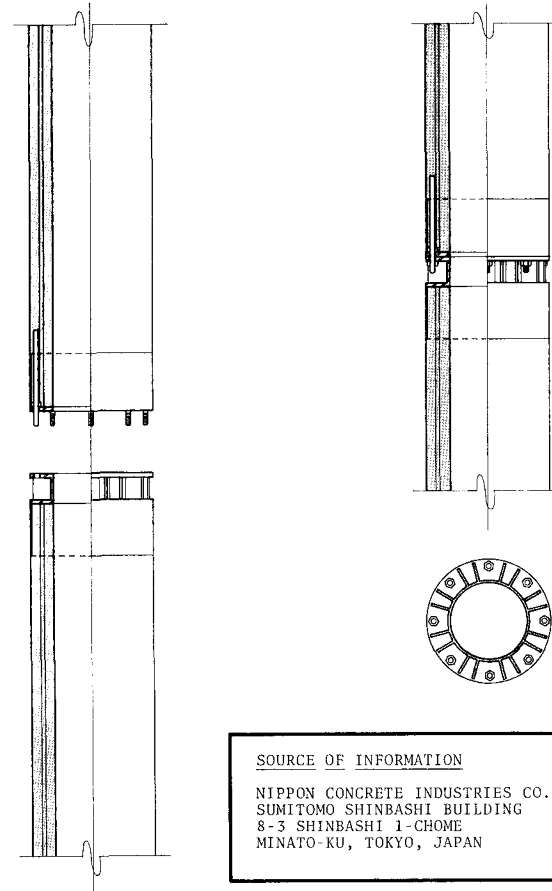
FIG. 6 RAYMOND CYLINDER PILE SPLICE



SOURCE OF INFORMATION

BOLOGNESI-MORETTO
LUIS SAENZ PENA 250
BUENOS AIRES
ARGENTINA

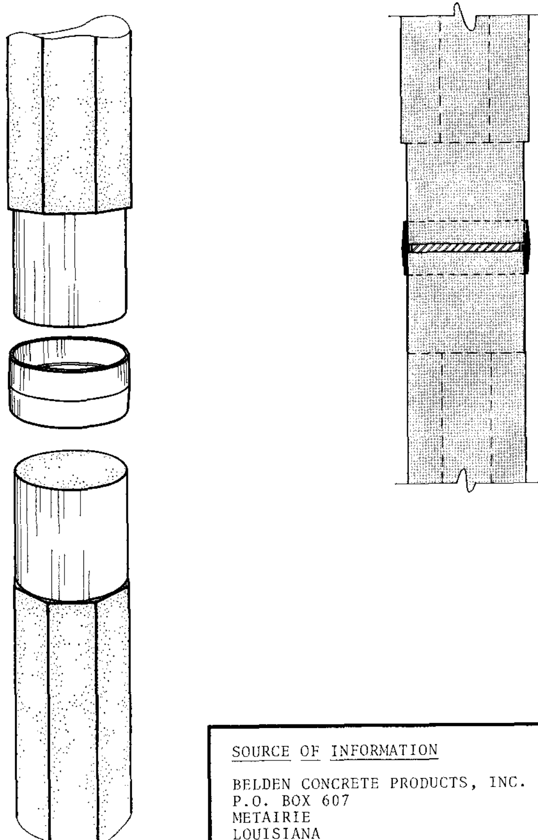
FIG. 7 BOLOGNESI-MORETTO SPLICE



SOURCE OF INFORMATION

NIPPON CONCRETE INDUSTRIES CO., LTD.
SUMITOMO SHINBASHI BUILDING
8-3 SHINBASHI 1-CHOME
MINATO-KU, TOKYO, JAPAN

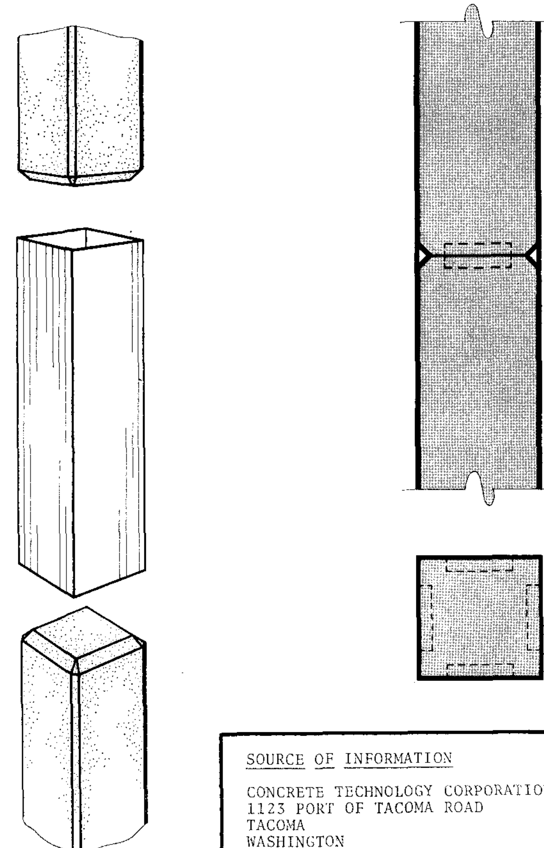
FIG. 8 JAPANESE BOLTED SPLICE



SOURCE OF INFORMATION

BELDEN CONCRETE PRODUCTS, INC.
P.O. BOX 607
METAIRIE
LOUISIANA

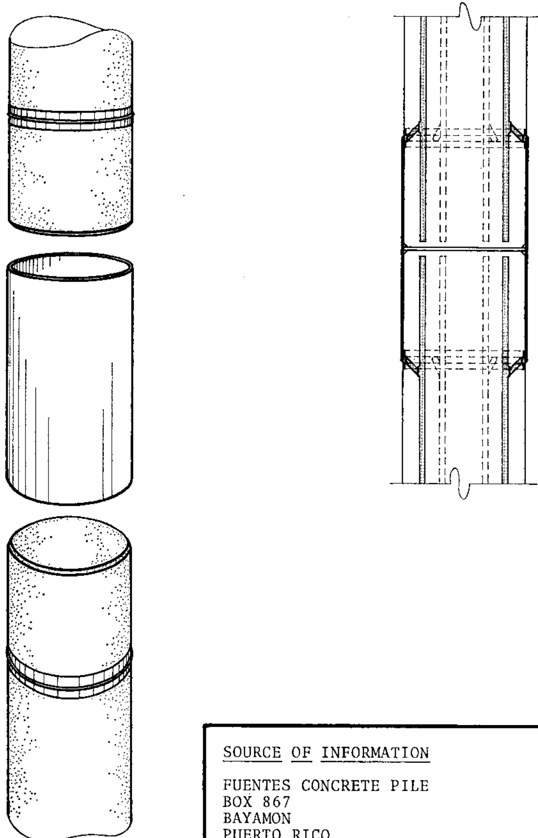
FIG. 9 BRUNSPILE CONNECTOR RING



SOURCE OF INFORMATION

CONCRETE TECHNOLOGY CORPORATION
1123 PORT OF TACOMA ROAD
TACOMA
WASHINGTON

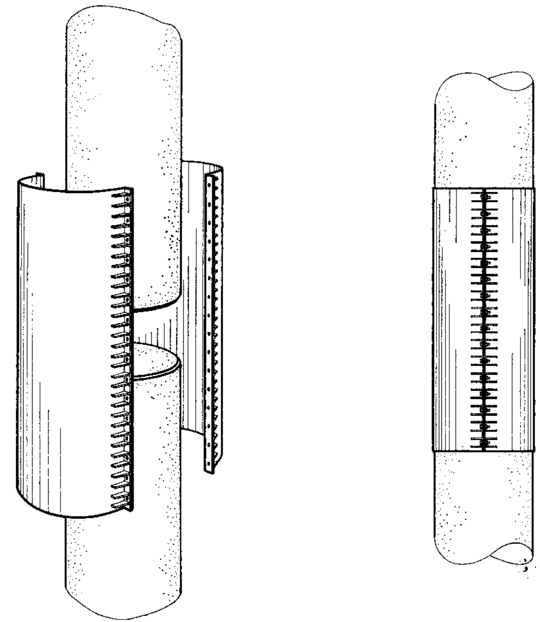
FIG. 10 ANDERSON SPLICE



SOURCE OF INFORMATION

FUENTES CONCRETE PILE
BOX 867
BAYAMON
PUERTO RICO

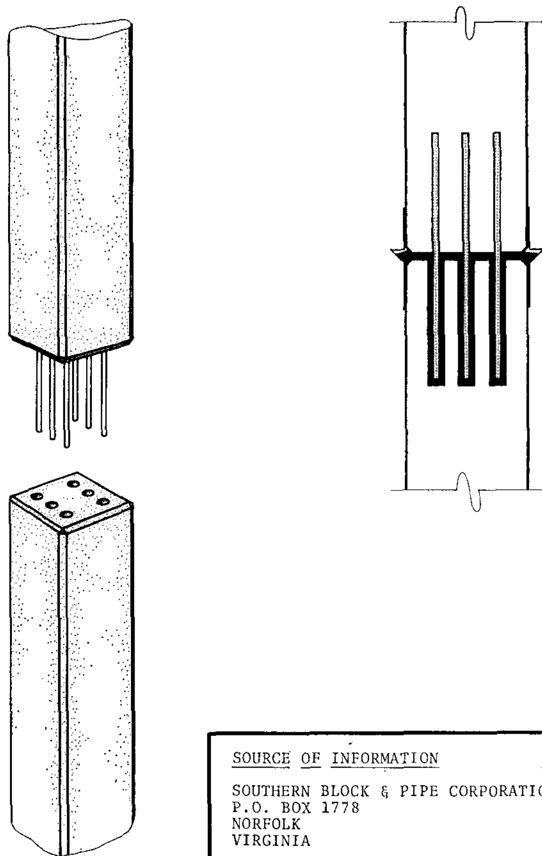
FIG. 11 FUENTES SPLICE



SOURCE OF INFORMATION

HAMILTON FORM COMPANY, INC.
P.O. BOX 13466
FORT WORTH
TEXAS

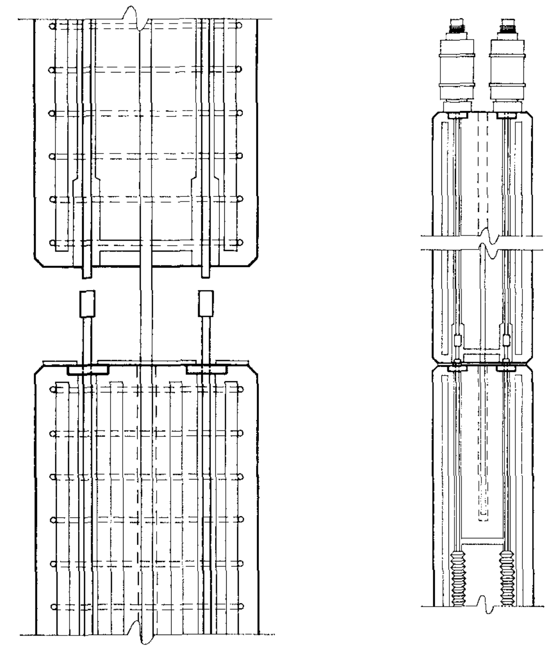
FIG. 12 HAMILTON FORM COMPANY SPLICE



SOURCE OF INFORMATION

SOUTHERN BLOCK & PIPE CORPORATION
P.O. BOX 1778
NORFOLK
VIRGINIA

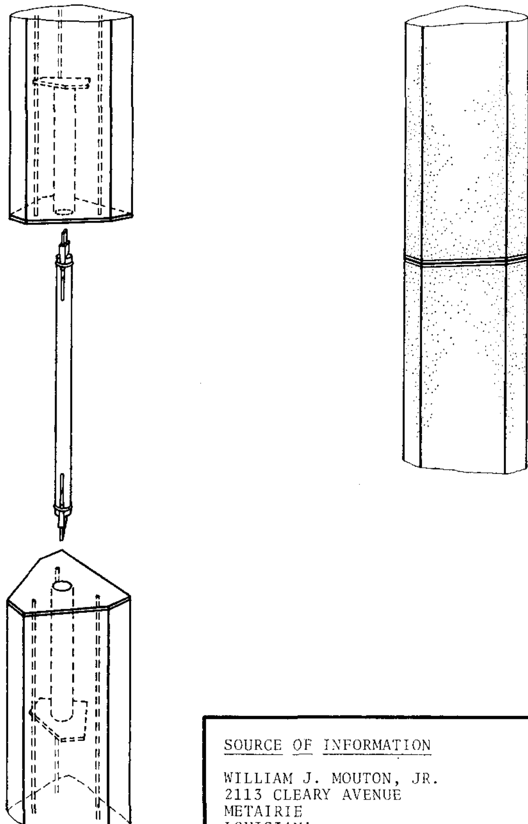
FIG. 13 CEMENT-DOWEL SPLICE



SOURCE OF INFORMATION

THE CONCRETE SOCIETY
TERMINAL HOUSE
GROSVENOR GARDENS
LONDON, ENGLAND

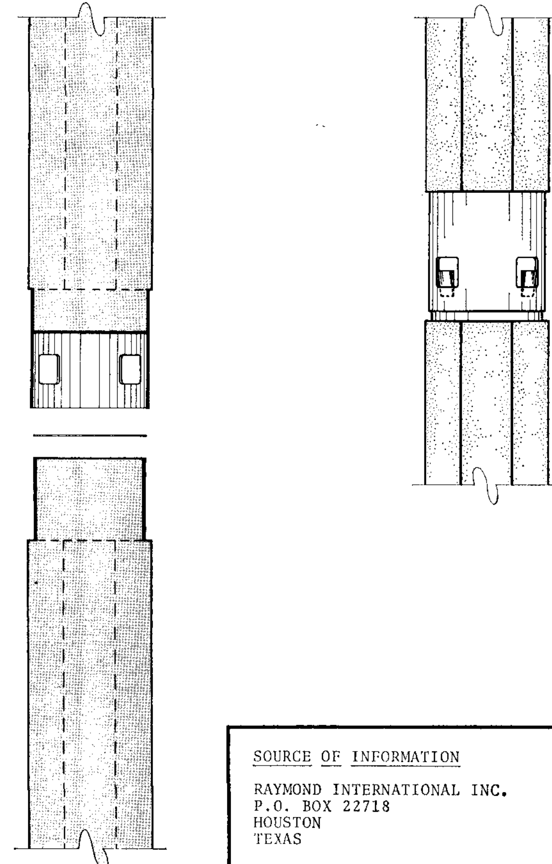
FIG. 14 MACALLOY SPLICE



SOURCE OF INFORMATION

WILLIAM J. MOUTON, JR.
2113 CLEARY AVENUE
METAIRIE
LOUISIANA

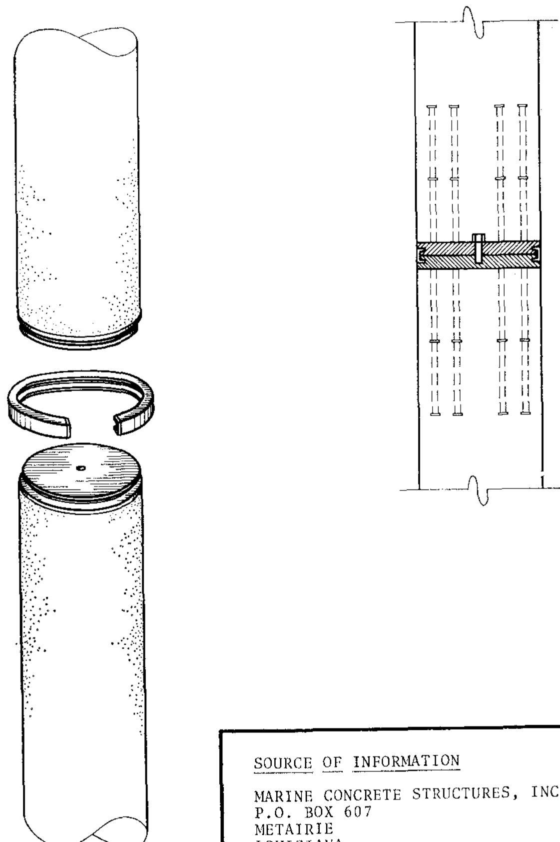
FIG. 15 MOUTON SPLICE



SOURCE OF INFORMATION

RAYMOND INTERNATIONAL INC.
P.O. BOX 22718
HOUSTON
TEXAS

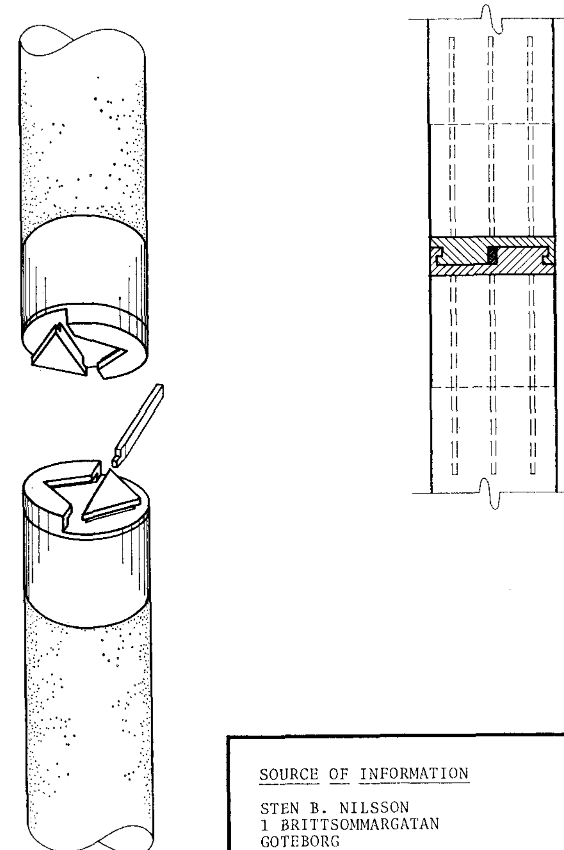
FIG. 16 RAYMOND WEDGE SPLICE



SOURCE OF INFORMATION

MARINE CONCRETE STRUCTURES, INC.
P.O. BOX 607
METAIRIE
LOUISIANA

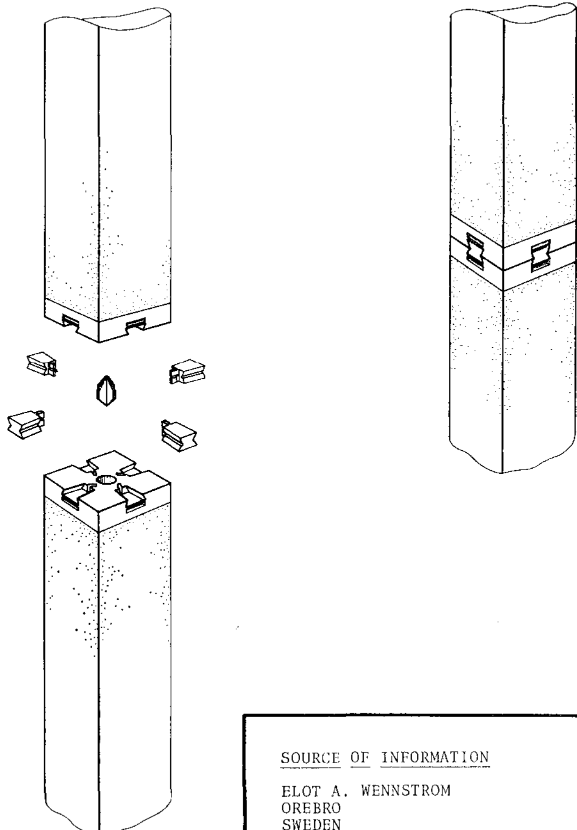
FIG. 17 PILE COUPLER SPLICE



SOURCE OF INFORMATION

STEN B. NILSSON
1 BRITTSOMMARGATAN
GOTEBORG
SWEDEN

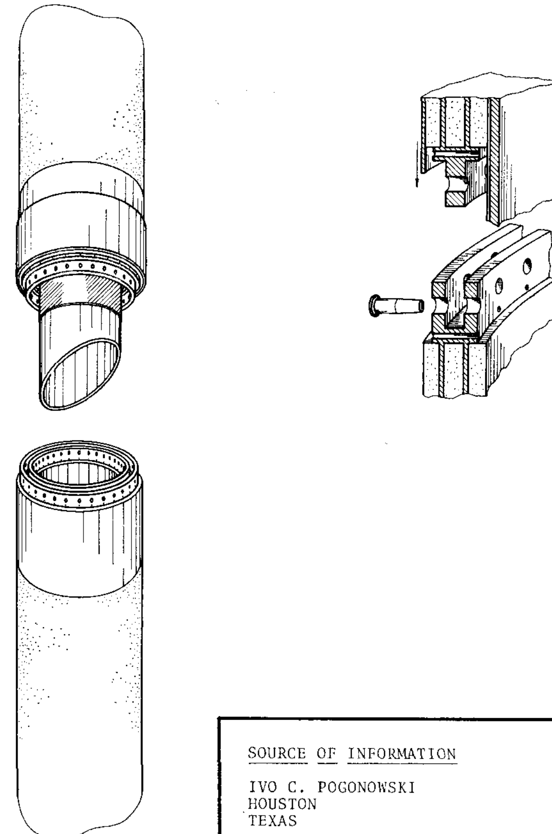
FIG. 18 NILSSON SPLICE



SOURCE OF INFORMATION

ELOT A. WENNSTROM
OREBRO
SWEDEN

FIG. 19 WENNSTROM SPLICE



SOURCE OF INFORMATION

IVO C. POGONOWSKI
HOUSTON
TEXAS

FIG. 20 POGONOWSKI SPLICE

SUMMARY OF SPLICES

Table 1 contains information on each splice. The sources of the information are varied. Most of the data was gathered from general correspondence with the manufacturer or designer of the splice. Data on the strength of the splices was obtained in three ways: from tests conducted during this investigation; from experience and tests conducted by others; and from theoretical and analytical studies.

Information gathered on the splices studied during this investigation was for the most part favorable. There was little difficulty in obtaining favorable results. Unfavorable results, however, were not as readily available and were difficult to obtain.

With reference to those splices listed in Table 1, all are patented with three exceptions. Those splices not patented include the:

—Anderson Splice
—Hamilton Form Splice
—Cement Dowel Splice

Prior preparation is required for all splices with two exceptions. Those splices not requiring advance preparation of the pile sections include the Anderson Splice and Hamilton Form Splice. Other data is as tabulated.

It is of importance to note that the strengths indicated for individual splices are dependent on close control and proper procedures in making the splice. Careless workmanship or improper field procedures can result in significant deviations from the strength levels indicated.

CONCLUSIONS AND RECOMMENDATIONS

Marier Splice

Care and precision in the fabrication of the male and female caps and the locking pins are necessary for proper performance of the splice. Any slight variation in the tolerances may result in the failure of the splice. The use of the splice must be anticipated so the caps may be cast with the piles.

Herkules Splice

This has been found to be an effective method of splicing reinforced concrete piles. It is felt that only minor modifications would be necessary to adapt the Herkules splice to prestressed concrete piles. Anticipation of the use of this splice is necessary because the male and female caps cannot be installed in the field.

ABB Splice

The ABB splice can be used with various shapes of piles. It can be adapted to prestressed concrete piles. The steel caps cast in the ends of the pile sections are symmetrical, thus eliminating any confusion in identifying the sections. Extensive use of the splice in Western Europe is an indication of this effective splicing technique.

NCS Splice

Analysis and extensive tests of this splice point out the excellent performance of the splice. The buttonhead process is important in carrying the full prestress into the splice region. The construction of a plant in Everett, Washington, should make the NCS pile and splice a competitive one in the Pacific Northwest. Modern welding techniques reduce the time normally required by hand welding.

TABLE 1. SUMMARY OF SPLICES

Name of Splice	Type	Origin	Approximate Size Range, in. (cm)	Approximate Field Time, min.	Strength		
					Percent Compressive	Percent Tensile	Percent Flexural Cracking
Marier	Mechanical	Canada	10-13 (25-33)	30	100*	100*	100*
Herkules	Mechanical	Sweden	10-20 (25-51)	20	100**	100**	100**
ABB	Mechanical	Sweden	10-12 (25-30)	20	100**	100**	100**
NCS	Welded	Japan	12-47 (30-119)	60	100**	100**	100**
Tokyu	Welded	Japan	12-47 (30-119)	60	100**	100**	100**
Raymond Cylinder	Welded	USA	36-54 (91-137)	90	100**	100**	100**
Bolognesi-Moretto	Welded	Argentina	Varied	60	100*	55*	100*
Japanese Bolted	Bolted	Japan	Varied	30	100**	90**	90**
Brunsplice	Connector ring	USA	12-14 (30-36)	20	100**	20*	50*
Anderson	Sleeve	USA	Varied	20	100*	0*	100*
Fuentes	Welded sleeve	Puerto Rico	10-12 (25-30)	30	100**	100*	100*
Hamilton Form	Sleeve	USA	Varied	90	100*	75**	100**
Cement Dowel	Dowel	USA	Varied	45	100**	40**	65**
Macalloy	Post-tensioned	England	Varied	120	100*	100*	100*
Mouton	Combination	USA	10-14 (25-36)	20	100*	40*	100*
Raymond Wedge	Welded wedge	USA	Varied	40	100*	100*	100*
Thorburn	—	Scotland		No information available on this splice			
Pile Coupler	Connector ring	USA	12-54 (30-137)	20	100**	100**	100**
Nilsson	Mechanical	Sweden	Varied	20	100*	100*	100*
Wennstrom	Wedge	Sweden	Varied	20	100*	100*	100*
Pogonowski	Mechanical	USA	Varied	20	100*	100*	100*

* and ** based on data furnished by proponent   *Calculated   **Observed

Tokyu Splice

Tests performed in Japan indicate that the Tokyu splice is effective in splicing prestressed concrete cylinder piles. Temperatures due to welding do not heat the concrete as greatly as the NCS splice. It is significant that prestressing bars rather than strands are used with the splice because some test failures have occurred where these bars were threaded at the tips of the bars at the splice cap.

Raymond Cylinder Pile Splice

This pile splice was effective in splicing cylinder piles, but not to the same extent as the NCS or Tokyu splices. Extensive preparations were necessary to splice the piles. A driving shoe was tack welded to the bottom section, increasing the splicing time somewhat. The weakness of the splice was in the dowels and not in the weld.

Bolognesi-Moretto Splice

Analysis of the Bolognesi-Moretto splice reveals one possible weakness. It is felt that the dowels attached to the plates and the weld connecting the plates may cause warping of the plate and damage the splice. An eccentricity is present in the splice. Without further test data available, it is difficult to determine actual strength levels.

Japanese Bolted Splice

It is felt that this splice is susceptible to corrosion because of the large area of exposed steel. Some protective coating should be used to insure long life of the splice and safe performance of the splice.

Brunspile Connector Ring

This splice has performed well in various load tests. It is felt, however, that it is not a tension splice, and should not be used where tension is expected in the piles. It is felt that the high level of field control necessary for the effective performance of this splice is not easily obtained.

Anderson Splice

One advantage of the Anderson splice is that no preparation of the piles is necessary prior to splicing. Waste of splice sections cast with piles is eliminated. Piles may be extended easily when splicing was not anticipated. The splice can be constructed to fit a variety of pile shapes and sizes. The weakness of the splice is in the tensile capacity of the connection. Extra steps must be taken to develop significant tensile resistance in the pile. The splice is not patented.

Fuentes Splice

This splice has been used successfully in Puerto Rico for splicing reinforced concrete piles. Present design of the splice restricts the use of the splice to circular piles. Adapting the splice technique to prestressed concrete piles may require some alterations in the splice concept. Presently, the tensile capacity of the splice is obtained by welding the splice collars to the reinforcing bars. This would be undesirable with the use of prestressing strands.

Hamilton Form Company Splice

It is felt that cost and time of fabrication for this splice make it impractical for mass production. However, job considerations, such as structural performance and integrity, may warrant the use of the Hamilton splice in some cases. A patent was not applied for, so the use of the splice is not restricted.

Macalloy Splice

Though this splice develops structural capacities virtually the same as those of an unspliced section, it is felt that the Macalloy splice is time-consuming and expensive. Judgment on the part of the engineer is necessary to determine whether the structural effectiveness of the splice is more importance than the cost and time aspects.

Mouton Splice

The fabrication and placing of the connector sleeves is critical to the performance of the splice because the connector pin is the only piece which keeps the sections together. The location of the connector pin in the center of the piles hinders the development of the full flexural capacity of the pile section because of the reduced lever arm. Rigid field control is necessary for the effective performance of this splice.

Raymond Wedge Splice

The wedges used in this splice are necessary for the completion and performance of the splice. Installation of these wedges in the field is critical. The fit of the sleeves is not as critical with the use of the wedges.

Pile Coupler Splice

The effective performance of this splice depends on a proper fit of the connecting band to the steel plates, and proper anchorage of the steel plates into the prestressed concrete pile. It is desirable that the finished splice be flush with the longitudinal surfaces of the pile. It is felt that this splice can be utilized effectively and economically, but that more experience in the field is required.

Nilsson Splice

As with other splices utilizing steel plates, it is imperative that the plates be properly anchored into the concrete for effective performance of the splice. The interlocking principle requires proper tolerances and good field alignment, but once accomplished, an effective splice should result. It is essential, of course, that the locking bar remain in position and not become dislodged.

Wennstrom Splice

The effective performance of this splice depends among other things on the wedges being reliably anchored to the plate-shaped members. Proper alignment of the pile sections is required in order to make the splice. The wedges must be protected against deterioration, corrosion, or dislodging; for the splice would be lost without the wedges.

Pogonowski Splice

It is felt that the complexities of this splice demand constant attention and rigorous control in the field. The embedding material, introduced in a liquid state into the void spaces in this splice, must be properly placed if effective corrosion control is to be accomplished, for the hostile environment anticipated.

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Discussion of this paper is invited.
Please forward your discussion to PCI Headquarters by February 1, 1975, to permit publication in the March-April 1975, PCI JOURNAL.