This article describes an innovative type of mechanical splicer for extending the length of precast, prestressed concrete piles. The splicer was developed, tested, and manufactured in Israel. Recently, it has been used successfully to obtain 45 m (147 ft) long piles for the foundations of highway and railway bridges constructed at the Ayalon Project in the city of Tel Aviv. Details of the new splicing method are given, which are used for the fabrication of 500 mm (20 in.) octagonal precast, prestressed concrete piles. Experimental tests have demonstrated the excellent behavior of the splicer when subjected to tensile tests, and that the tensile failure occurred in the anchoring rods away from the pile heads. The splicer can be easily modified and applied to splicing square piles of various sizes.

Poor loadbearing soils and high water levels in the foundations of some highway and railroad bridges along the Ayalon River in Tel Aviv, Israel, have required the use of very long precast, prestressed concrete piles [about 45 m (147 ft)].

Due to practical considerations, it is not always possible to fabricate, store, transport, and drive such long piles. Therefore, it is common practice to use piles of medium length [up to 25 m (82 ft)], and to join them to form long units during the driving stage.

This article describes a new type of mechanical pile splicer with the capability of joining two segments of precast, prestressed concrete piles, about 25 m (82 ft) long, to form piles with lengths up to 50 m (164 ft). The splicer is very versatile and widely applicable.

LITERATURE SURVEY

The use of splicing units for extending the lengths of precast concrete piles during the driving process has been studied for more than 30 years. Several surveys have examined the various methods for joining and extending piles, including different splicing units that are used around the world for that purpose. These sources give information about mechanical splicers as well as the use of cement.
mortars or polymers (epoxy resins) for joining or bonding together pile segments to form extended piles.

In 1974, Bruce and Hebert,\(^1\) in the first part of their study, presented a comprehensive review of the engineering details and performance of 20 types of pile splicers. In the second part of their investigation,\(^2\) they examined pile sections joined together with steel bars embedded in holes drilled at the ends of the piles and bonded with a plasticized cement.

In a subsequent study, Venuti\(^3\) reviewed previous research on pile splicers and reported the results of an investigation on the behavior of 605 mm (12 in.) square piles joined with wedge type splicers. These piles were subjected to compression, tension, bending, and torsion loadings. Venuti found that the strengths of the splicers exceeded the respective strengths of the individual piles.

In 1990, Gamble and Bruce\(^4\) investigated the mechanical splicer known as the ABB splicer, in which splicing units were used to extend the lengths of 610 mm (24 in.) square piles. The behavior of the extended piles was experimentally studied under different loading conditions. It was found that the ABB splicer, which previously had been used to extend the lengths of smaller piles, could be also used for 610 mm (24 in.) square piles.

In 1995, Cousins and Brown\(^5\) presented the results of bending tests on 406 mm (16 in.) square piles spliced with chemical agents. The study investigated the effect of anchoring lengths of protruding reinforcing bars [457 to 1220 mm (18 to 48 in.)] on the behavior of the joints. A minimum anchorage length of 840 mm (33 in.) was found necessary to ensure the required capacity of the joints is reached.

**THE MECHANICAL SPLICER**

The latest mechanical splicer, which is the subject of this paper, was developed, tested, manufactured, and applied in Israel.

The design and details of the splicer were developed by SADNAT G. Y. A. Kalman Ltd, a consulting firm in Haifa Bay, in accordance with criteria specified by J. Shimoni, an Israeli engineering consultant. The major reason for developing this splicer was to extend the length of precast, prestressed concrete piles required for the foundations of some bridges crossing the Ayalon River in Tel Aviv as well as for other projects in Israel.

The main advantages of the mechanical splicer are that the splicer can handle predetermined penetration depths of various projects and that connections between pile segments can be made quickly. Also, with a mechanical splicer, the curing time required to allow the setting of the epoxy resins or cement mortars of the chemical splicers is eliminated. A detailed schematic drawing of the splicing unit is given in Figs. 1 and 2.

The geometry of the splicers and the mechanical capacity of the connecting system were designed to meet the re-
quirements of locally available pre-
cast, prestressed concrete 500 mm (20
in.) octagonal piles. The piles are pre-
stressed by ten prestressing strands
with a diameter of 12.7 mm (1/2 in.).
The maximum length of the pile seg-
ments is about 25 m (82 ft), and the
segments can be joined to a driven pile
length of up to 50 m (164 ft).

The principle of the splicer is that
loads are transferred between the two
halves of the connected pile by
grooved steel round pins protruding
from the ends of the two connected
segments. The pins penetrate matching
holes in the opposite ends of the seg-
ments, and are locked in their position
by locking forks.

Four steel pins, each with a diameter
of 50 mm (2 in.), protrude from the
drive of the segments. Thus, tensile loads
acting in one segment of the connected
piles are transferred to the matching
segment by a total of eight pins, locked
in their position by eight locking
forks.

The head of each of the two halves
of the splicing unit is connected to the
precast pile by eight anchors made of
25 mm (1 in.) diameter reinforcing
bars. These bars, which can be welded,
conform to the requirements of Israeli
Standard SI 4466, Part 3.6

Four of the anchors are located as an
axial extension to the protruding pins,
and the other four are located as an
axial extension to the anchorage block
built at the back of the holes for the
purpose of locking the pins protruding
from the other segment of the pile. The
length of the reinforcing bar anchors is
about 1000 mm (40 in.). Each of the
splicing units comprises two comple-
mentary parts (top of first pile seg-
ment, start of second pile segment).
They have a somewhat different geo-
metrical structure, which can be con-
ected to form a complete splicing
unit.

At this stage, the components of the
splicing units are fabricated in marked
matching pairs, which cannot be inter-
changed.

The steel pile heads of the splicer
contain matching holes to enable the
threading of prestressing strands along
the prestressing bed. The geometrical
location of the holes for the passage of
the prestressing strands is one of the
important design features of the com-
ponents of the splicing unit.

Each splicing unit is furnished pre-
assembled, comprising two pile heads,
welded to each other by 200 mm (8
in.) spacers (see Fig. 3). Anchoring
rods protrude from the back side of the
pile heads, and are intended for em-
bedding in the respective ends of the
individual piles (see Fig. 4).

The splicing units can be easily in-
stalled during the preparation stage of
a prestressing line intended for fabri-
cating several piles that comprise the
entire length of the casting bed (see
Figs. 5 and 6).

After the fresh concrete has hard-
ened (see Fig. 7), the spacers of the
preassembled splicing units are cut.
The removal of the prestressed piles
from the casting bed is performed ac-
cording to common practice in a pre-
casting plant. Because a pair of piles is needed, it is important to mark the ends of the matching pile ends very clearly (see Fig. 8). The pile heads themselves are marked with a clear serial number welded on the side of the pile heads during the fabrication process.

THE AYALON RAILWAY BRIDGE

The splicing units were recently used for the foundations of a number of bridges in the integrated highway and railway complex along the Ayalon River project at the junction of the Ayalon and Yarkon rivers in the City of Tel Aviv. The bridges are under the jurisdiction of The Israeli Ports and Railway Authority. The project was completed at the end of the year 2000.

In preparing the piles for driving, initial 400 mm (16 in.) borings, 16 m (52 ft) deep, were drilled into the soil. The drilling passed through layers of soft clays containing layers of sand and maritime sandstone. A layer of hard, heavily compacted clay was located above the underground water level.

The first segments of the precast piles were driven into the initial borings. In order to safely drive the piles into the ground, a special “hat” was mounted over the pile head and over the pins protruding from the first segment of the piles. With this protection, the impact of the hammer did not cause any damage to the protruding pins.

The second segment of the piles was mounted as an extension at the end of the first segment, which remained above ground. To align the slight mismatch between the two adjoining pile heads, a thin layer of epoxy paste was applied over the upper surface of the first segment of the pile prior to mounting the second segment.

The pile driving proceeded immediately, with the epoxy paste serving as a filler between the two segments of the pile. During the hammering operation, it was found that the epoxy layer prevented undesirable vibrations of the pile segment heads.

After the protruding pins were inserted into the opposite sockets, the
splicer was locked by inserting eight locking forks into the grooves of the pins of the splicer. To avoid any accidental displacement of the forks during the hammering operation, the forks were fixed in their position in the pile heads by welding.

The pile driving process continued until the bottom end of the piles reached the required bearing layer of the clay-sand median in the ground. The final penetration resistance was about 1 mm (0.04 in) per blow using a Delmag 46 hammer.

A total of 160 spliced piles, in lengths between 40 to 43 m (131 to 141 ft), were used for the foundation of the bridge. All the piles were safely driven into the ground without any problems.

The total cost of the bridge was $6.5 million and the cost of the foundation was $850,000 (in U.S. dollars).

TEST PROGRAM

Prior to the application of the new mechanical splicer, a comprehensive test program was carried out to verify the strength and performance of the splicer.

Pile Design Data

The piles were designed to withstand the following loads:

- Compression load: 1690 kN (380,700 lbs)
- Compression load for earthquake conditions: 1730 kN (389,700 lbs)
- Pullout load: 765 kN (172,300 lbs)
- Pullout load for earthquake conditions: 1050 kN (236,500 lbs)
- Bending resistance: 157 kN-m (116,000 lb-ft)
- Bending resistance for earthquake conditions: 176 kN-m (130,000 lb-ft)

Fabrication of Splicers

All the components of the splicers were assembled and welded together by using continuous electrode wire E71 – T1 with a surrounding atmosphere of carbon dioxide under strict welding standards. The components of the splicer head were milled from mild carbon steel, ST 37 [360 MPa (52,540 psi) tensile strength].

The anchoring bars were made of

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**Fig. 8.** Identification marks at ends of each pile segment.

**Fig. 9.** Mechanical tests of splicer anchors.

**Fig. 10.** Piles stacked at prestressing plant ready for delivery to bridge site.
weldable 25 mm (1 in.) carbon steel reinforcing bars, W400 [400 MPa (57,940 psi) characteristic strength], meeting the requirements of Israeli Standard SI 4466, Part 3, Paragraph 206.4

The following tests were carried out on the fabrication of the splicing units:
- Dimensional tests (geometry) of the splicer heads
- NDT tests of the welded seams
- Compliance tests of the carbon steel components

**Tensile Tests of Welded Joint Between Connection Pins and Ribbed Anchors**

This test demonstrated that the failure of the assembly was developed in the ribbed anchors away from the welded joints and that the welded joints remained intact. The anchors failed in a ductile mode, and the fracture elongation was relatively high as expected for the W400 reinforcing bars, according to the standard requirements.

**Pullout Tests of Connecting Pins from Opposite Pile Heads**

Tensile loads were applied to the connecting pins welded to the ribbed anchors. They were then locked into opposite pile heads by the locking forks. It was found that the assembly failed in the ribbed anchors as originally intended.

No signs of failure were observed in the grooved pins, locking forks, or lock anchorage block of the pile heads. The reinforcing bars also failed in a ductile manner and away from the welded joint.

Load-strain curves of the most recent tests are given in Fig. 9. The yield tensile load of each of the loaded anchors was 225.4 kN (50,800 lbs). The breaking tensile strength of the anchors reached 312.1 kN (70,300 lbs).
4. The prestressing strands are threaded through the aligned holes of the splicing units and the stoppers.

5. After initial tensioning of the strands, the stirrups are inserted and tied around the prestressing strands. The steel forms are closed and fastened, and the location and alignment of the pile heads and splicing units are checked and adjusted as needed to achieve perpendicularity of the pile heads to the pile axis.

6. The strands are tensioned to the full prestressing loads.

7. The concrete [specified compressive strength of 50 MPa (7240 psi) at 28 days] is cast into the forms (see Fig. 6) where it is properly vibrated and compacted. The upper face of the concrete is carefully troweled to obtain a smooth surface. The concrete is moist-cured until the required prestress transfer strength is obtained.

8. The temporary spacers are released, and then the prestressing force is transferred to the piles. This is followed by the required curing and finishing, which include the cutting off of the protruding strands from the pile ends and the proper marking of the matching pile segments. This will enable easy identification of the piles and avoid mismatching of piles during storage, hauling (see Figs. 11 to 13), and driving (see Figs. 14 and 15).

**CLOSING REMARKS**

This article describes the details of an innovative type of splicer for the connection of medium length precast, prestressed concrete piles to make very long piles. This splicer enables the driving of piles to depths of about 45...
m (147 ft). Thus far, about 500 splicing units have been fabricated and used for the foundations of highway and railroad bridges in Israel.

All the units have performed successfully without any malfunctioning during the pile fabrication stage and through the penetration process. The bridges have been completed and are now serving the transportation needs of the public.

At this point in time, the splicing units are made for 500 mm (20 in.) octagonal piles. However, there are plans for fabricating splicing units for the extension of square piles in different sizes, to meet the demands of the infrastructure for deep foundations. The experience gained so far shows that the pile splicer is very versatile and widely applicable.

CREDITS

The structural designer of the bridge was Yaron, Shimoni, Shacham, Consulting Engineers Ltd.

The foundation consultant for the project was Prof. A. Komornik of Soil Engineering Ltd.

The general contractor was the construction company Elgad Ltd, which was also responsible for installing the piles of the project.

The precast, prestressed concrete piles were fabricated by the precasting firm of Ashbat Ltd in Ashdod.

The splicing units were manufactured by SADNAT G. Y. A. Kalman Ltd, a firm providing a mechanical workshop in Haifa.

The authors wish to express their gratitude to the PCI JOURNAL reviewers for their constructive comments.