Historical Application of Screw-Piles and Screw-Cylinder Foundations for 19th Century Ocean Piers

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ABSTRACT

Iron Screw-Pile foundations were first introduced by Alexander Mitchell in the middle of the 19th Century for support of offshore lighthouses in shallow water ocean environments. Large diameter Screw-Piles with helical blades ranging from 2.5 ft. to 4 ft. in diameter were routinely used during this period and were constructed with either a solid iron central shaft (Screw-Pile) or a large diameter hollow cylindrical pipe shaft (Screw-Cylinder). Soon after their introduction, Screw-Piles and Screw-Cylinders were being used in pier construction, to allow ocean front piers to be constructed quickly and economically in many parts of the world, while at the same time providing adequate support for loads. A brief summary of this technology is presented and several examples of the variety of Screw-Piles and Screw-Cylinders that were used to construct ocean front piers are presented. Several examples of the application of Screw-Piles and Screw-Cylinders at specific sites are described using available historic records demonstrating that this foundation technology was well developed and well accepted by engineers.

INTRODUCTION

Screw-Pile foundations were the invention of an Irish brickmaker turned engineer named Alexander Mitchell (1780-1868). In 1838, Mitchell used screw-piles consisting of a solid wrought iron shaft 5 in. in diameter with a cast-iron helical blade having a diameter of 4 ft. installed to a depth of 12 ft. below the mudline to support a lighthouse at Maplin Sands off the coast of England near the mouth of the Thames estuary, as seen in Figure 1.

With time, as applications progressed to other Civil Engineering projects around the globe, engineers replaced the solid central shaft of Screw-Piles with a hollow iron pipe shaft. In this paper, a Screw-Pile will be defined as a helical element having a solid central shaft and a Screw-Cylinder will be defined as a helical element having an open hollow central pipe shaft. By comparison, most modern Screw-Piles have an open pipe central shaft and very few exceptions are currently found where the central shaft consists of a solid round shaft. In most cases, the term Screw-Pile is used for both.

Figure 2 shows Mitchell's patent drawings that were used to describe the application of Screw-Piles for foundations and for mooring of ships in shallow water harbors. Mitchell constructed a number of lighthouse and other structures supported on Screw-Piles (Lutenegger 2011).

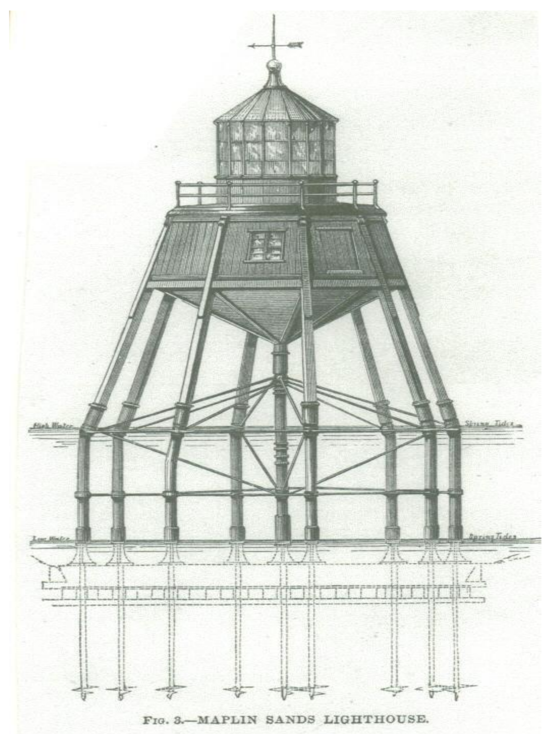


Fig. 1. Drawing of the Maplin Sands Lighthouse.

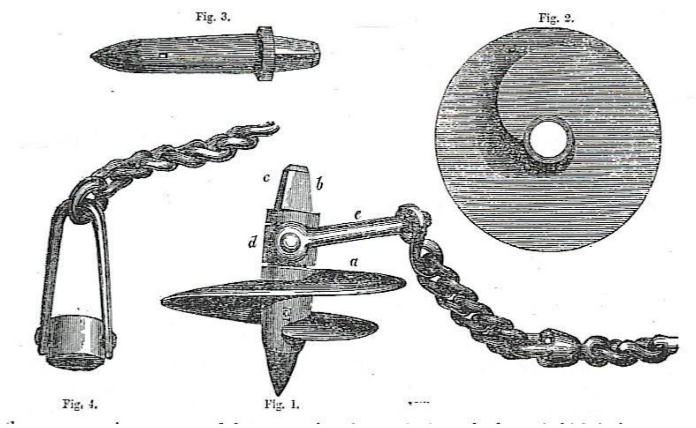


Fig. 2. Mitchell's Patent Drawings.

The helical plate or blade serves two purposes: 1) it facilitates installation by rotation of the central shaft with the pile ideally advancing into the soil one blade pitch for each full revolution; and 2) it provides increased load capacity in both compression and tension as a result of the increased cross sectional area of the blade.

Mitchell (1848) gave a detailed account of the work at Maplin Sands:

> "In fixing the foundation piles for the Maplin Sands Lighthouse, a raft of 36 feet square was used as a stage, or platform, upon which the men worked, as barges would have been too high from the surface, and it was necessary to ground the raft itself, before the piles could be screwed down to the required depth, their heads being only a short distance above the bank. The raft was constructed of balks of American timber bolted together, leaving an aperture of 2 feet in width from one side to the centre, by which the pile was brought to its position. About forty men, furnished by the Corporation of the Trinity House, were employed on the work; their wages and the cost of the raft amounted to about 300 pounds. The contract for the screw-piles and the Author's professional charges for superintendence, was 900 lbs., making the total coast of the foundation for the lighthouse, 1200 lbs."

Figure 3 shows a period engraving of workers using a capstan to install a Screw-Pile from a raft. It appears that the supervisor (perhaps Mitchell?) is standing in the lower right hand corner of the raft. This was dangerous work to be sure, especially at a time when most construction projects were completed without the aid of large-scale power equipment. This was a period in which projects were performed largely by hand labor.

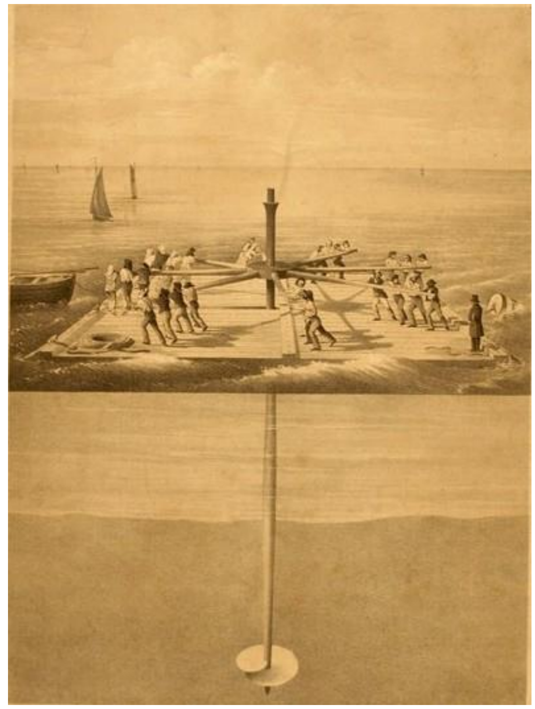


Fig. 3. Engraving of Workers Using a Capstan to Install Screw-Pile from a Raft.

One of the most interesting aspects of the work at Maplin Sands performed by Mitchell is given in his account (Mitchell 1848) of the field testing that was performed to test the bearing capacity of the Screw-Piles:

> "Before determining the length of the piles and the area of the screws necessary to be employed, a careful examination of the ground was made… The instrument used in trying the nature of the ground, was also employed in testing its holding power. It consisted of a jointed rod 30 feet long, and 1 ¼ inch in diameter, having at its foot a spiral flange of 6 inches diameter. It was moved round by means of cross levers, keyed upon the boring rod; and upon these levers, when the screw was turned to the depth of 27 feet, a few boards were laid, forming a platform sufficiently large to support twelve men. A bar was then driven into the bank at some distance, its top being brought to the same level as that pf the boring-rod. Twelve men were then placed upon the platform to ascertain if their weight, together with the apparatus, in all about one ton, sufficed to depress the screw. After some time, the men were removed, and the level was again applied; but no sensible depression of the screw could be observed.
>
> This experiment was made in the presence of Sir John Henry Pelly, the Deputy Master, and some of the Elder Brethren. The inference from it was, that if a screw of 6 inches in diameter could support one

ton, one of 4 feet diameter was capable of supporting at least 64 tons, the comparative area of their surfaces being as the square of their diameters; but this experiment was nothing more than an approximation to the truth, a continuous surface possessing a much greater sustaining power than the same area in detached portions."

The application of Screw-Piles and Screw-Cylinders for ocean piers allowed extensive economic expansion in areas where it might not have been possible for another 40 years had not these foundations been used. It is accurate to say that Screw-Piles and Screw-Cylinder foundations were the most important Civil Engineering technological foundation development of the mid to late 19th Century, at a time when formal Soil Mechanics had not yet been introduced. Most designs were by trial and error and previous contractor experience. Ocean piers were built around the cost of England for both pleasure piers at seaside resorts and for commerce. In other parts of the world, including the U.S., Australia, Europe, South America, India and Africa, piers were built primarily to service the growing market for import/export of raw materials and manufactured goods. The scale of most of these historic foundation elements relied on the use of Screw-Piles and Screw-Cylinders that were much larger than has generally been used in modern times, except for a few very recent large-scale projects.

OCEAN FRONT PIERS

Even while construction of Screw-Pile lighthouses was perhaps in the forefront of his Screw-Pile work, Mitchell's success with Screw-Moorings and Screw-Piles allowed him to expand his contracting activities into other areas and develop other applications for Screw-Piles. This work was initiated even while lighthouse construction was still being performed.

One of the earliest pier structures to be built was the pier extension at Courtown, Wexford in England. The construction of this pier in 1847 would set the stage and successfully demonstrate that Screw-Piles could be used to support large ocean front piers with great speed, efficiency and cost savings. This would be a concept taken up by several of the great pier builders right through the end of the 19th century. In addition, this project would demonstrate a new method of Screw-Pile installation specifically suited to this type of work. Mitchell's account of the work (1848; 1849) is given as follows:

> "In the summer of 1847, the screw-pile was subject to a new trial, in the construction of a pier or jetty, near the village of Courtown, about twelve miles south of Arklow, on an open and exposed part of the coast of Wexford. On its commencement, a startling difficulty presented itself. Barges, or strongly-constructed rafts, had previously found sufficiently steady to act as stages for the workmen, when screwing down either piles or moorings; but the coast at Courtown being unprotected nearly from north to south, with an open sea of 70 miles in front, a surf of great height and force beats almost without intermission upon the shore, preventing the use of any floating body in the construction of the works. As a steady footing for the men is to a certain extent essential, it became indispensable that the screwing down of the piles should be effected from the work itself. The method of construction that was adopted was very cheap and simple. The piles were placed 17 feet apart, in a direct line outwards; a projecting stage was therefore rigged, extending that distance forwards, with the other end resting upon and temporarily attached to the solid part of the pier. The screw-pile was then run forward upon rollers, lifted by tackle, and placed vertically in the situation it was intended to occupy. A wheel, 32 feet in diameter, formed of capstan-bars lashed together at their ends, with a deeply-grooved end to each, was keyed upon the body of the pile, and an endless rope-band was passed through it, and held in tension round a smaller grooved pulley, fixed about 150 feet back towards the shore."

Mitchell (1848;1849) also described the overall scope of the project and the geometry of the Screw-Piles used:

> "The new part of the Courtown jetty is 260 feet in length beyond the solid stone part of the old jetty. The main roadway is 18 feet 6 in. wide with a line of railway laid upon each side, leaving a space for passengers in the centre between the lines. It is terminated by a cross-head or platform, 54 feet long by 36 feet wide, with a landing stage at each end, which can be raised or depressed, to suit the convenience of the vessels loading or discharging… The bottom into which the piles were inserted consisted of an average depth of about 8 feet of sand and gravel, upon a firm blue clay. Screws of 2 feet diameter were therefore sufficient, with wrought-iron plies of 5 inches diameter, inserted in the ground to a depth varying between 11 feet and 15 feet."

> "These preparations being made, a number of men hauling upon the endless band gave a rotary motion to the large wheel, and screwed the pile down to its place with great ease. The same operation was repeated for the next pile laterally, - the cross beams were laid on, the overhanging platform was pushed forward, and two more piles were inserted. During this time the cross-braces were applied, and the permanent platform was finished. The works were by this means conducted with such facility and regularity, that, in spite of rough weather, one bay of 17 feet in advance was generally completed in a day; …"

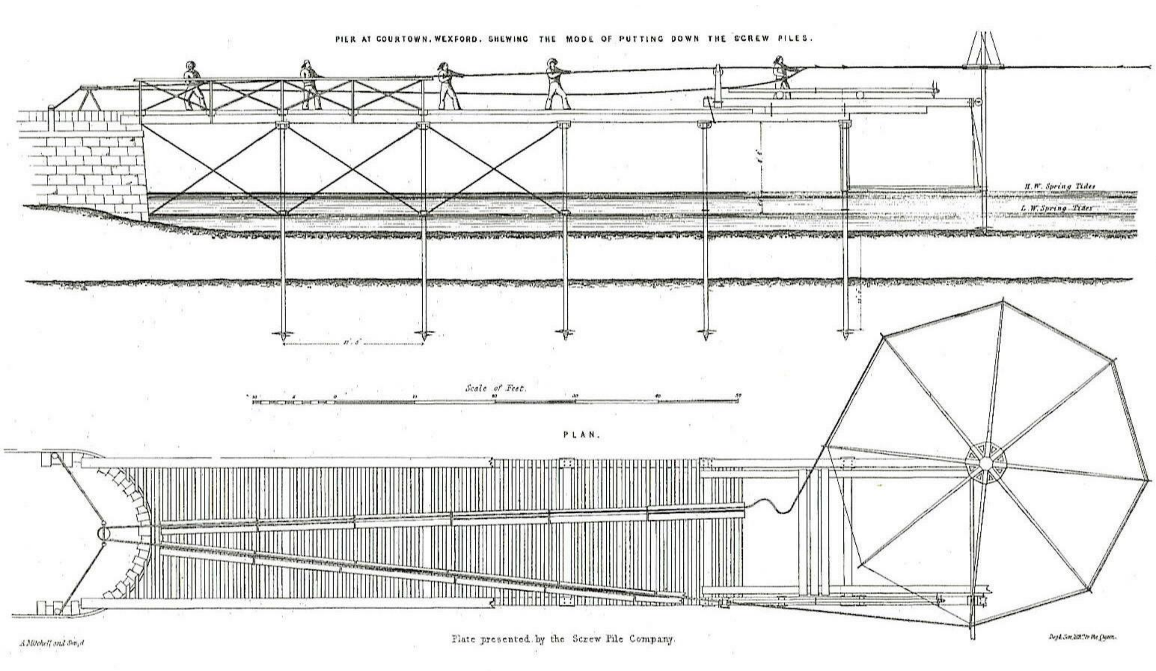


Fig. 4. Diagram of Construction of the Pier at Courtown.

The use of Mitchell's endless rope provided a practical solution of being able to construct a pier sequentially, from the land outward into the open sea. The wheel allowed the workers to stand on the competed portion of the pier as construction progressed. This allowed both a safer work area and a much shorter construction period. Figure 4 shows and engraving giving plan and profile views of the Screw-Pile work in progress at Courtown. At the bottom of the page it is indicated that the plan was presented by "The Screw Pile Company" presumably set up to operate under that name by Mitchell. A similar note is indicated at the bottom of the plates showing the Belfast Lough and Wyre lighthouses given in Mitchell's paper (1848) published in the ICE Journal.

In effect, the pier construction at Courtown not only served as a model demonstration of the feasibility of using Screw-Piles to support on ocean front pier, but the pier is effectively a bridge so that that the most natural extension of this work would be the future use of Screw-Piles and Screw-Cylinders in bridge construction.

Not long after the successful completion of the pier at Courtown, additional opportunities arose to build piers at a number of locations around the coast of England and Wales and in other parts of the world. In general the piers were of one of two types: 1) pleasure piers which were developed to satisfy the new Victorian pastime of spending leisure time at the beach; and 2) commercial piers to facilitate the shipping industry and the export/import trade being expanded throughout the British Empire.

A flurry of construction activity associated with work on ocean front piers started not long after the success at Courtown and was lead largely by perhaps the most famous of pier builders during this period, Eugenius Birch (1818-1884). However, before most of the pier construction was to take place around the English coast, Mitchell undertook to build a substantial pier at Madras, India in 1859. Johnson (1862) who was an agent for Mitchell and the Mitchell Screwpile and Mooring Co., described the work:

> "The Madras Pier, designed by Messrs. Saunders and Mitchell, was commenced in the latter part of the year 1859 by Mr. F. Johnson, their successor, and is now nearly completed. This pier is 1080 feet in length, and its width 40 ft. 6 in. It terminates in a cross-head 160 feet long by 40 ft. 6 in. wide. The piles are of solid wrought-iron, the screws of which are inserted to a depth varying from 11 ft. to 19 ft. 6 in. in the ground. The pier extends about 40 feet beyond the water line of surf. When it is considered that several attempts have been made to erect piers at Madras, all of which proved impracticable, it will be readily understood the situation is one of great exposure… during the course of construction of this pier not the slightest vibration has been perceptible, a convincing proof of the great advantages of screw-pile structures over any other, - a great base or supporting surface being obtained without the necessity of exposing a large body to the action of either wind or wave."

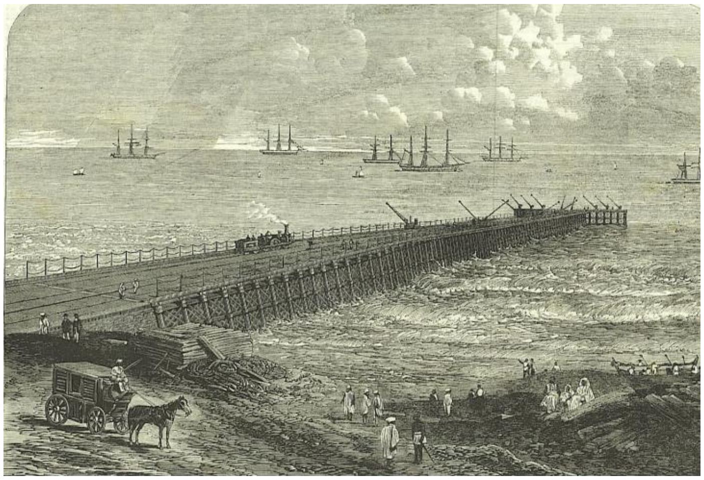


Fig. 5. Engraving of the Madras Screw-Pile Pier – 1862.

Figure 5 Shows and engraving of the Madras Pier that appeared in the Illustrated London News. The caption accompanying the engraving reads:

"Madras Pier, On Screw-Piles, The Invention Of Mr. Alexander Mitchell, C.E."

OCEAN FRONT PLEASURE PIERS IN THE UK

Among the most famous of engineers to design piers using Screw-Piles and Screw-Cylinders was Eugenius Birch, a practicing Civil Engineer and Member of the ICE. Birch's first use of Screw-Pile was at Margate Jetty on the eastern shore in 1853. It may be that Birch recognized the potential for using Screw-Piles from his work in India around 1845-1847 where he and his brother John Bannis Birch worked on the East Indian Railway from Calcutta to Delhi, (ICE 1884) and may have seen Screw-Piles being installed in that country for bridge foundations (Lutenegger 2011).

Fig. 6. Period Postcard of Margate Jetty.

Since Mitchell had received only a seven year renewal of his 1833 patent in 1847, by the time Birch began construction at Margate, it is likely that the patent had run out and there would have been no royalties to pay to Mitchell. Figure 6 shows a period postcard of the completed Margate Jetty.

The use of Screw-Piles was now an open playing field and any engineer could incorporate the use of Screw-Piles for their projects without requiring Mitchell's involvement. Birch would use Screw-Piles at several other locations, including Blackpool North, Deal, West Pier at Brighton, Aberystwyth, and others. Examples of other completed Screw-Pile piers at Hastings and Birnbeck are shown in Figure 7. Note that the general scheme of most piers was very similar, the use of both vertical and battered Screw-Piles at different locations is evident.

Table 1. Partial List of Screw-Pile & Screw-Cylinder Pleasure Piers.

Pier	Date	Style	Geometry
Margate	1853	N/A	N/A
Blackpool	1863	N/A	N/A
Deal	1864	N/A	N/A
Lytham	1865	N/A	N/A
Aberystwith, Wales	1865	N/A	N/A
Teignmouth, South Devon	1867	N/A	N/A
Birnbeck	1867	N/A	N/A
Clevedon	1868	SP	Shaft – 5 in. Blade – 2 ft. Pitch – 5 in.
New Brighton, Liverpool	1868	SC	Cylinder – 12 in. Blade – 2 ft. 6 in.
New Ferry, Liverpool	1868	SC	Cylinder – 12 in. Blade – 2 ft. 6 in.
Scarborough	1868	N/A	N/A
Saltburn-by-the-Sea	1869	N/A	N/A
Eastbourne	1870	N/A	N/A
Hastings	1872	N/A	N/A
Milford Haven	1874	SP	Shaft - 5 & 6 in. Blade 2 ft. 3 in.
Birkenhead	1877	SC	Cylinder – 1 ft. 7 in. Blade – 2 ft. 7 in. Pitch – 8 in. + Spiral Tip Piles
Bournemouth	1880	N/A	N/A
Hornsea	1880	N/A	N/A

Skegness, Lincolnshire	1881	N/A	N/A
Ramsgate	1882	N/A	N/A
St. Leonards-On-Sea	1888	SC	Cylinder – 12 in. Blade – 2 ft. 6 in. & 3 ft. Pitch – 6 in.
Southend-On-Sea	1890	N/A	N/A
Bangor, Wales	1896	N/A	N/A
Colwyn Bay, Wales	1900	N/A	N/A
Pince-of-Wales Pier, Dover	1902	N/A	N/A

There is limited detailed information on the geometry of the Screw-Piles and Screw-Cylinders used at many of these pier locations, however, it appears that most screw blades were in the range of 0.9 to 1.2 m in diameter. The pitch of the screw blade mostly varied from about 6 in. to 8 in.

Fig. 7. Ocean Front Piers at Hasting and Birnbeck.

The longevity of many of these ocean front piers was considerable, many lasting well into the mid 19th century and few right up to the present day. The most common cause for ruin was being struck by a ship or fire at the pavilion. In 2011, the author visited the piers at Weston-Super-Mare and Clevedon on the west coast of England, Figure 8. The iron was in remarkably good shape and there was no visible signs of distress in the members.

Fig. 8. 2011 Photos of the Piers at Weston-Super-Mare (upper) and Clevedon (lower).

Fig.8. Work in progress at Weston Pier.

Figure 8 shows a period photograph of work at the Weston Pier with Screw-Cylinders off to the side, ready for installation. Note that the top of the shaft section is equipped with a hexagonal section which was used to attach tools for installation and for connecting extension sections.

OCEAN FRONT PIERS IN THE US

With the success of Screw-Pile and Screw-Cylinder piers in England and other parts of the world, the use of Screw-Piles for pier/wharf foundations also found its way to the U.S. In the U.S. one of the most notable structures supported on Screw-Piles was the government pier built in 1871 at Lewes, Delaware, described by Stierle (1877). The foundations were described as follows:

> "There are altogether 297 piles, placed in 81 cross-rows, 21 feet apart from center to center, and measured along the axis of the pier. The piles in each row stand 10 feet 6 inches apart from center to center. Fifty-four rows of piles, those under the narrow part of the pier, have 3 piles each and the 27 rows supporting the pier head have 5 piles in each row… From the first to the forty-ninth row, the diameter of the pile is 5 ¼ inches; the length increasing, more or less, from 16 to 25 feet. For the next five rows, from the fiftieth to the fifty-fourth inclusive, the diameter is 5 ¾ inches; the length as the water is now getting deeper, rapidly increasing from 25 feet to 29 feet 6 inches. The next row, the fifty-fifth, is the first row of the pier-head. In this and the two following rows, the fifty-sixth and fifty-seventh, the diameter of the piles is 6 ¾ inches; their length, for the rows named, being respectively, 31, 32 ½ and 33 ½ feet."

Figure 9 shows a diagram of a portion of the Lewes pier. All of the Screw-Piles were installed vertically in the sand and gravel and had a blade diameter of 2 ft. 6 in.

Another notable Screw-Cylinder pier was built in the U.S. at Fort Monroe, Virginia in 1888. Open Screw-Cylinders were installed and then wooden piles were driven through the open cylinder to a depth several feet below the blade. Duncklee (1892) described the geometry of the Screw-Cylinders:

> "The lower section, which rests on and encases the wooden bearing pile, is 8 feet long and 13 inches in interior diameter, the iron being 1 inch in thickness… About 1 foot above the lower end of this section of pile are two screw-pile blades, with a maximum diameter of 32 inches. The blades are 2.5 inches thick at the junction with the cylindrical pile, this thickness diminishing to three-eigths of an inch at the edge of the blade."

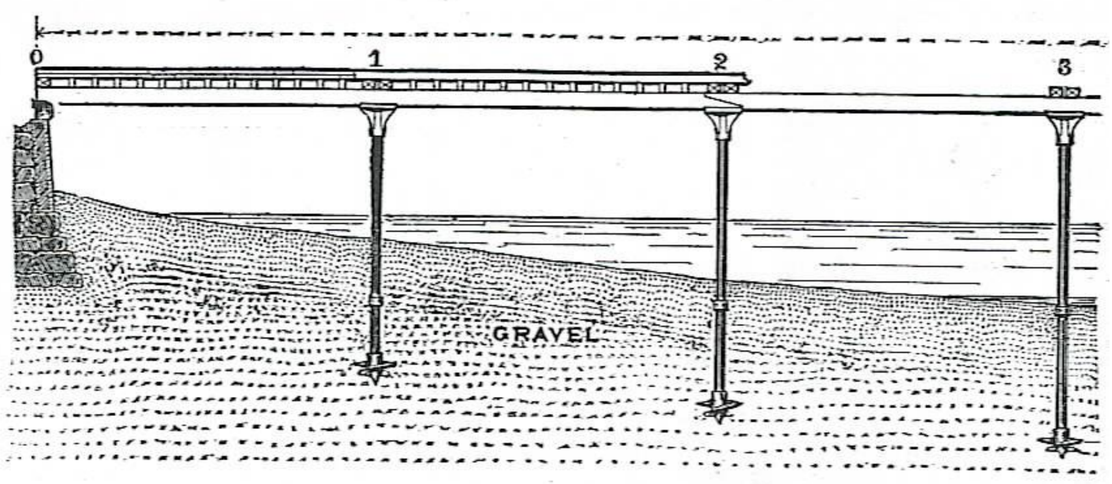
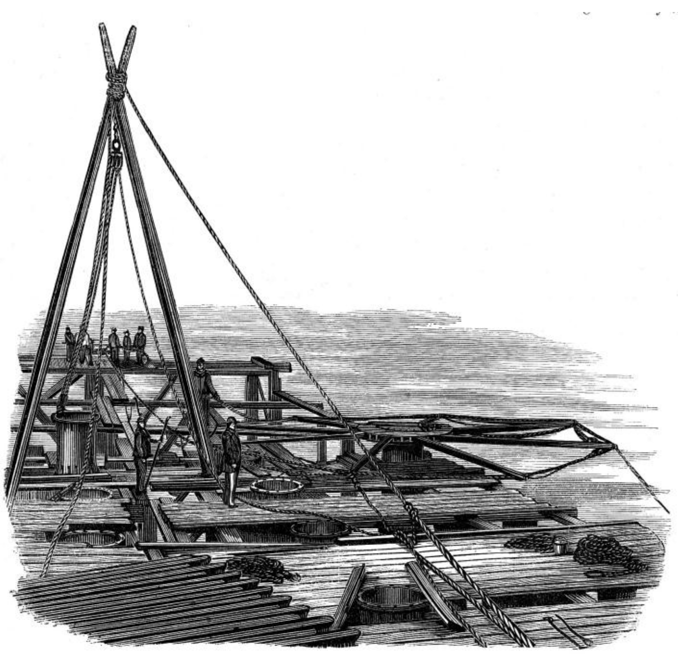


Fig. 9. Partial Drawing of Pier at Lewes, Delaware.

WORLDWIDE SHIPPING PIERS

A wide variety of Screw-Pile and Screw-Cylinder ocean front shipping piers were constructed at various ports around the world. The geometry, length, and height of the pier depended on the local conditions and the tidal fluctuations. The primary usage of these structures was for the loading and unloading of both raw materials and finished trade goods as well as for the convenience of passengers traveling to/from various ports. Table 2 gives a partial list of known Screw-Pile and Screw-Cylinder shipping piers from around the world.

One of the most remarkable uses of Screw-Cylinders for the construction of ocean front shipping piers during this period was the Royal Arsenal Pier in Woolrich, England. The pier was used for the loading and unloading of heavy guns from naval warships and was actually short by many standards, with a total length of only 328 ft. The principal part of the pier was founded on cast-iron Screw-Cylinders with a diameter of 2 ½ ft. and a screw blade diameter of 3 ft. 11 in. At the pier head, an 80 ton crane was supported by twelve 5 ft. diameter Screw-Cylinders and a central Screw-Cylinder with an outer diameter of 7 ft. and a blade diameter of 9 ft. 6 in. All of the Screw-Cylinders were installed with the capstan wheel similar to that which had been used by Mitchell at Courtown., and shown in Figure 10. A plan view of the pier is shown in Figure 11.



SHEAR LEGS AND CAPSTAN, NEW PIER WORKS, WOOLWICH.

Fig. 10. Installation of Screw-Cylinders at Woolrich.

Table 2. Partial List of Screw-Pile & Screw-Cylinder Shipping Piers.

Pier	Date	Style	Geometry
Glenelg, South Australia	1856	N/A	Cylinder – 8 in. Blade – 2 ft. Pitch – 6 in.
Madras, India	1862	N/A	N/A
Mazagon Pier, Bombay, India	c. 1870	N/A	N/A
Punto Avenas, Costa Rica	c. 1870	SP	Shaft - 4 in. & 5 in. Blade – 2 ft. 3 in.
Royal Arsenal Pier, Woolrich, England	1870	SC	Cylinder - 2 ½ ft Blade – 3 ft. 11 in. Pitch – 7 ½ in. Cylinder – 5 ft. Cylinder – 7 ft. Blade 9 ½ ft.
Milford Haven, England	1874	SP	Shaft - 5 & 6 in. Blade 2 ft. 3 in.
Callao, Peru	1874	SP	Shaft – 5 in. Blade – 2 ft. Pitch – 7 ½ in.
Portsmouth Harbor Pier and Railway Station	1875	SC	Cylinder – 18 in. Blade – 4 ft. Pitch – 8 in.
Huelva – Rio Tinto Railway, Spain	1878	SC	Cylinder – 16 in. Blade – 5 ft. Pitch – 6 in.
Salto, Uruguay	1887	SC	Cylinder – 2 ft.
Kurrachee, India	1887	SP	Shaft – 5 in. Blade – 3 ft. Pitch – 6 in.
Koto Nou, Gulf of Benin, Africa	1892	SP	Shaft – 5 3/8 in.
Cienfuegos Pier – Cuban Central Railways, Cuba		SC	Cylinder – 30 in.

NOTES

It should be noted that Screw-Piles and Screw-Cylinders were not the only type of foundation used to construct 19th Century ocean front iron piers. There are reported cases of timber piles being used, mostly during the first half of the 19th Century, but these were soon replaced by iron piles as iron became more available. The construction of these piers predates the use of concrete piles and steel piles that might be seen on more

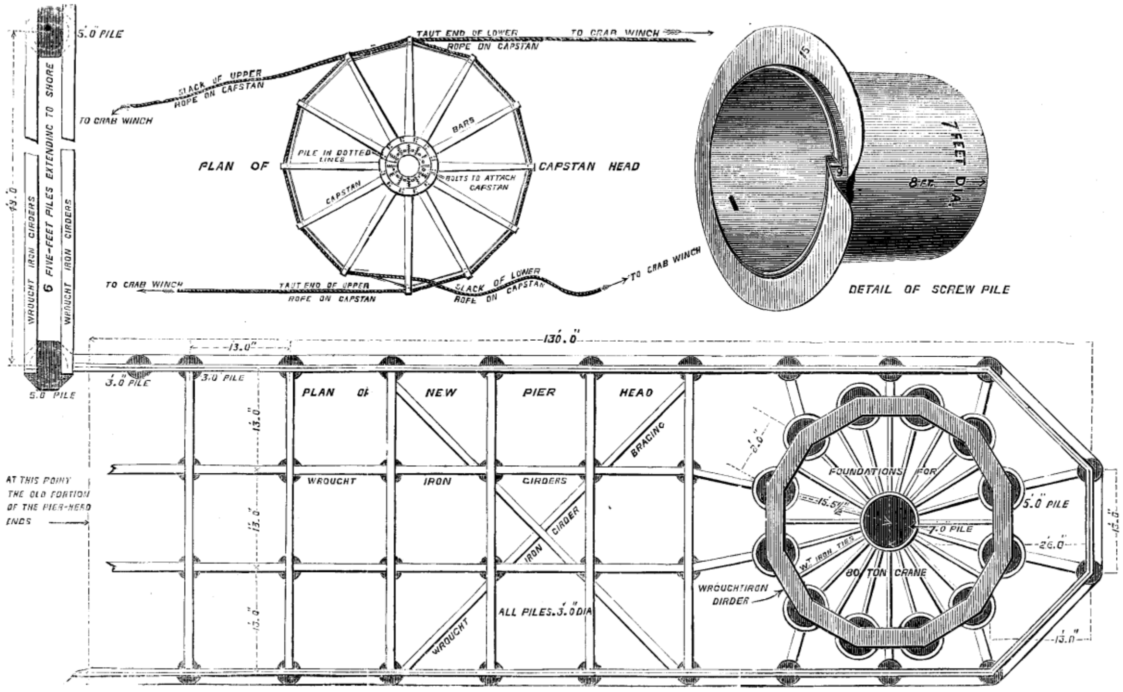


Fig. 11. Plan View of Woolrich Pier.

modern structures. However, perhaps the largest rival to Screw-Piles and Screw-Cylinders was the so-called Jetted Disc Pile, shown in Figure 12. In this case, a disc was attached to

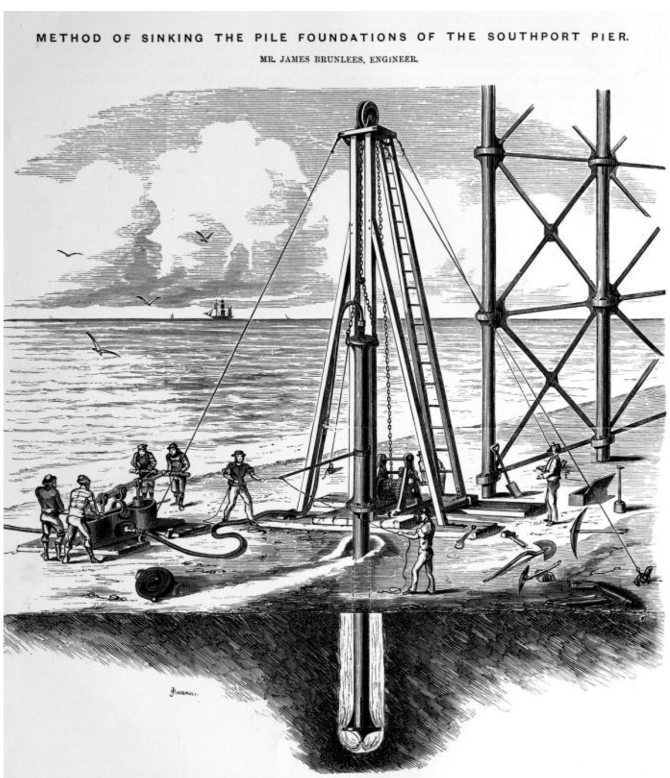


Fig. 12. Installation of Jetted Disc Pile at Southport Pier.

a hollow pipe and water was pumped through the pipe exiting through holes in the disc. The weight of the pile allowed the disc and shaft to sink as soil was washed away. After sufficient embedment, the water jetting was stopped and soil was allowed to run back in over the disc providing embedment. A number of such installations were apparently made and it appears that they were directly implemented to compete with Screw-Piles.

SUMMARY

Screw-Pile and Screw-Cylinder foundations were used extensively to construct ocean front iron piers throughout the mid to late 19th Century. The size of central shaft and screw blades used varied widely and depended in local site conditions, bay spacing and anticipated loading. Shortly after the beginning of the 20th Century, there was a decline in the use of Screw-Piles and Screw-Cylinders as other modern pile materials became available and, perhaps more importantly, the steam powered pile hammer was developed. For nearly 80 years this technology was largely dormant but since the late 1980s and early 1990s it has seen a resurgence in use for a variety of projects.

The most likely reason for this is the development of large hydraulic torque heads capable of performing rapid installation when attached to conventional construction equipment, such as a track mounted excavator. This trend is likely to continue as engineers once again become familiar with this technology and take advantage of the capability of developing substantial load capacity and rapid installation.

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