

# Design and Construction of Driven Timber Piles and Foundations

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**Abstract:-** Timber piles can also be driven for ground improvement, to densify loose granular soils. Although timber piles are rarely used on shore in the UK, in other countries notably the United States, Canada and Australia, they are used widely. For many structures, timber piles are a highly suitable choice of foundation, given appropriate ground conditions. They are economical, easy to transport, handle, cut to length and work with on site; and particularly suited for locations with access difficulties, or where excavations and the delivery of concrete would pose problems. Short, driven timber piles can be the solution for foundations in ground with a high water table, and where firm strata exists below surface material of loose sand, soft clays, or organic soils. In deep silt deposits, where the capacity of the pile is determined by shaft friction, timber piles are especially suitable being tapered and easy to splice. In Sweden and the Netherlands, timber piles are used below the water table, where they have proved practically invulnerable to decay, and extended to the surface using concrete sections. One of the suggested methods of reducing global warming has been to bury timber to create carbon dumps. Using timber for piled foundations would effectively achieve this.

**Keywords:** Design, durability, Engineering News ,Formula, environmental, factor of safety, timber piling.

## 1. INTRODUCTION

Pile foundations are used extensively for the support of buildings, bridges, and other structures to safely transfer structural loads to the ground and to avoid excess settlement or lateral movement. They are very effective in transferring structural loads through weak or compressible soil layers into the more competent soils and rocks below. A "driven pile foundation" is a specific type of pile foundation where structural elements are driven into the ground using a large hammer. They are commonly constructed of timber, precast prestressed concrete (PPC), and steel (H-sections and pipes).

Historically, piles have been used extensively for the support of structures in Boston, MA. This is mostly a result of the need to transfer loads through the loose fill and compressible marine clays that are common in the Boston area. Driven piles[1], in particular, have

been a preferred foundation system because of their relative ease of installation and low cost.

## 1.2 ROLE OF DRIVEN PILE FOUNDATIONS ON THE CA/T PROJECT

The CA/T project is recognized as one of the largest and most complex highway projects in the United States. The project involved the replacement of Boston's deteriorating six-lane, elevated central artery (Interstate (I) 93) with an underground highway; construction of two new bridges over the Charles River (the Leverett Circle Connector Bridge and the Leonard P. Zakim Bunker Hill Bridge); and the extension of I-90 to Boston's Logan International Airport and Route 1A. The project has been under construction since late 1991 and is scheduled to be completed in 2005. Driven pile foundations were used on the CA/T for the support of road and tunnel slabs, bridge abutments, egress ramps, retaining walls, and utilities. Because of the large scale of the project, the

construction of the CA/T project[2] was actually bid under 73 separate contracts. Five of these contracts were selected for this study, where a large number of piles were installed, and 15 pile load tests were performed.

**1. Contract C07D1** is located adjacent to Logan Airport in East Boston and included construction of a part of the I-90 Logan Airport Interchange roadway network. New roadways, an egress ramp, retained fill sections, a viaduct structure, and retaining walls were all constructed as part of the contract. Driven piles were used primarily to support the egress ramp super structure, abutments[3], roadway slabs, and retaining walls.

**2. Contract C07D2** is located adjacent to Logan Airport in East Boston and included construction of a portion of the I-90 Logan Airport Interchange. Major new structures included highway sections, a viaduct structure, a reinforced concrete open depressed roadway (boat section), and at-grade approach roadways. Driven piles were used to support the boat section, walls and abutments, and portions of the viaduct.



**Fig1. Locations of selected contracts from the CA/T project.**

**3. Contract C08A1** is located just north of Logan Airport in East Boston and included construction of the I- 90 and Route 1A interchange. This contract involved new roadways, retained fill structures, a

viaduct, a boat section, and a new subway station. Both vertical and inclined piles were used to support retaining walls and abutments.

**4. Contract C09A4** is located just west of the Fort Point Channel in downtown Boston. The contract encompassed construction of the I-90 and I-93 interchange, and the northbound section of I-93. Major new structures included surface roads, boat sections, tunnel sections, viaducts, and a bridge. Piles were used to support five approach structures that provide a transition from on-grade roadways to the viaduct sections. Piles were also used to support utility pipelines.

**5. Contract C19B1** is located just north of the Charles River in Charlestown. The contract included the construction of viaduct and ramp structures forming an interchange connecting Route 1, Storrow Drive, and I-93 roadways. Major new structures included roadway transition structures, boat sections, retaining walls, and a storm water pump station.

## 2. DRIVEN PILE DESIGN CRITERIA AND SPECIFICATIONS

The physical properties and geological origin of the soils encountered at the contract sites are described below.

### Bedrock:

The bedrock in the area consists of argillite from the Cambridge formation. The condition of the bedrock varies considerably with location, even within a given site. Evaluation[4] of rock core samples indicates that the rock is typically in a soft and weathered condition and contains a significant amount of fracturing. However, hard and sound bedrock was found at some locations.

### Glacial Soils:

The glacial soils were deposited during the last glaciation approximately 12,000 years ago. These deposits include glacial till, and glaciomarine, glaciolacustrine, and glaciofluvial soils. Till is characterized by a mass of unsorted debris that contains angular particles composed of a wide variety

of grain sizes, ranging from clay-sized particles to large boulders. Glaciomarine or glaciolacustrine deposits generally consist of clay, silt, and sand, whereas glaciofluvial deposits contain coarser grained sand and gravel. The glacial soils are typically dense in nature as indicated by high standard penetration test (SPT) [5] resistance, and the piles were typically terminated in these deposits.

#### **Marine Soils:**

Marine soils were deposited over the glacial soils during glacial retreat in a quiescent deepwater environment.

The clay is generally over consolidated in the upper portions of the layer and is characterized by relatively higher strengths. The over consolidation is a result of past desiccation that occurred during a period of low sea level.

#### **Inorganic Soils:**

Inorganic silts and sands are typically encountered overlying the marine soils. These soils were deposited by alluvial processes.

#### **Organic Soils:**

The organic soils that are encountered below the fill generally consist of organic silt and may contain layers of peat or fine sand. These soils are the result of former tidal marshes that existed along the coastal areas.

#### **Fill Soils:**

Fill material was placed in the more recent past to raise the grade for urban development. The fill layer is highly variable in its thickness and composition, ranging from silts and clays to sands and gravels. The consistency or density is also variable as indicated by the SPT blow counts. The variability in the fill is attributed to the characteristics of the particular borrow source material and the methods of placement. The required depth of preaugering [6] varied depending on the contract and pile location, but ranged from 7.6 to 32.0 m below the ground surface.

### **3. Pile driving and design**

Timber piles support loads by end bearing, shaft friction or combined end bearing and friction depending on the nature of the strata into which they are inserted. Most timber piles are displacement piles,

although occasionally they are installed into pre-augered holes and set in concrete sockets. Timber piles are not suitable for driving through firm strata such as dense sand or gravel. Timber can be used as end bearing piles on rock, provided care is taken to avoid damaging the pile during insertion. Tapered timber piles are particularly suited for use as friction piles in sands, silts and soft clays where the pile capacity is determined by shaft friction. Driven thin end down, trees make natural tapered piles[7].

Timber is resilient to impacts and drives well. A helmet or cap protects the pile head from fracturing or brooming during insertion, and in addition the pile may be banded to prevent splitting. Conventional pile drivers are used to insert timber piles with the normal weight of a drop hammer being 1.5 times the weight of the pile. Typically for softwood piles a 0.5 tonne hammer is used, whereas for hardwood piles the hammer weights vary from 1 to 4 tonnes with a drop height not greater than 1.5 m. A long narrow drop hammer increases the chance that the pile is hit axially, avoiding damage to the pile and maximising the downward impulse. Diesel hammers are sometimes used for driving hardwood piles in stiff soils, but are not suitable for softwoods. Care must be taken with all hammers not to overstress the pile or to cause splitting of the pile toe.

Groups of timber piles inserted into soft clays and silts may need to be loaded temporarily to prevent the effect on soil pore water pressures causing buoyancy. Timber piles[8] can be extended in length by splicing, using short sections of steel tube, angle or plates, to reach load bearing strata or to develop sufficient shaft friction. Timber piles can also be coupled to concrete or steel sections to avoid exposure above the water table. Timber has a high strength to weight ratio, and is particularly strong in compression parallel to grain. Piles are designed as columns, and consideration should be given to cross-bracing for unsupported lengths above ground level. Typical axial design loads are in the range 100 to 500 kN for softwood piles. Hardwoods piles are normally used for marine applications where either marine borer or high abrasion resistance is required. BS 5268 may be used to calculate the axial capacity of timber piles, including those which extend above ground level.



Failure in buckling should be also considered for the pile section in weak soils with an un drained shear strength of less than 15 kPa.

#### **4. GEOTECHNICAL USES FOR TIMBER**

Timber is a natural and attractive material that can be used for earth retaining structures such as bridge abutments and crib walls. It can be easily combined with soil anchors and geotextiles in the same way as concrete or steel. Round timber and sheet piles can provide an economical wall for moderate heights of retained material. Examples of interlocking timber sheet piles are given in BS 6349-2. Further demonstration of the suitability of treated timber as foundation material is provided by the Permanent Wood Foundation. All connectors are corrosion resistant. A polyethylene moisture barrier (DPM)[9] extends over the outside of the walls below ground level terminating at the top of the drainage layer. A separate moisture barrier is placed under the floor of the basement usually a suspended timber floor. Timber foundations make excellent use of material that is often locally produced and renewable. They can also take the form of embedded poles with concrete pads and collars.

#### **5.CONSTRUCTION EQUIPMENT AND METHODS**

Impact hammers were used to drive all of the piles for the CA/T project. An impact hammer consists of a heavy ram weight that is raised mechanically or hydraulically to some height (termed "stroke") and dropped onto the head of the pile. During impact, the kinetic energy of the falling ram is transferred to the pile, causing the pile to penetrate the ground. Many different pile driving hammers are commercially available, and the major distinction between hammers is how the ram is raised and how it impacts the pile. The size of the hammer is characterized by its maximum potential energy, referred to as the "rated energy." [10] The rated energy can be expressed as the product of the hammer weight and the maximum stroke. However, the actual energy transferred to the pile is much less a result of energy losses within the driving system and pile. Three types of hammers were used on the selected contracts: (1) a single-acting diesel (2) a double-acting diesel, and (3) a single-acting hydraulic.

A single-acting diesel hammer works by initially raising the hammer with a cable and then releasing the ram. As the ram free-falls within the cylinder, fuel is injected into the combustion chamber beneath the ram and the fuel/air mixture becomes pressurized. Once the ram strikes the anvil at the bottom of the cylinder, the fuel/air mixture ignites, pushing the ram back to the top of the stroke. This process will continue as long as fuel is injected into the combustion chamber and the stroke is sufficient to ignite the fuel.

A double-acting diesel hammer works like the single-acting diesel hammer except that the system is closed at the top of the ram. As the ram rebounds to the top of the stroke, gasses are compressed in the bounce chamber at the top of the hammer. The bounce chamber temporarily stores and redirects energy to the top of the ram, allowing the stroke height to be reduced and the blow rate to be increased. Bounce chamber pressure is monitored during pile driving because it is correlated with hammer energy. The stroke of the hammer, and thus the energy, is controlled using the fuel pump.

An advantage of hydraulic hammers is that the free-fall height, and thus the energy delivered to the pile, can be controlled more accurately. In preparation for driving, a pile is first hoisted to an upright position using the crane and is placed into the leads of the pile driver. The leads are braces that help position the piles in place and maintain alignment of the hammer-pile system so that a concentric blow is delivered to the pile for each impact. Once the pile is positioned at the desired location, the hammer is lowered onto the pile butt. A pile cushion consisting of wood, metal, or composite material is placed between the pile and the hammer prior to driving to reduce stresses within the pile during driving.

Once the pile is in position, pile driving is initiated and the number of hammer blows per 0.3 m of penetration is recorded. Toward the end of driving, blows are recorded for every 2.5 cm of penetration. Pile driving is terminated when a set of driving criteria is met. Pile driving criteria are generally based on the following:

- (1) the minimum required embedment depth
- (2) the minimum number of blows required to achieve capacity

(3) the maximum number of blows to avoid damage to the pile.

### 5.1 Pile Heave

Pile heave is a phenomenon where displacement of soil from pile penetration causes vertical or horizontal movement in nearby, previously driven piles. Pile heave generally occurs in insensitive clays that behave as incompressible materials during pile driving. (17) In these soils, the elevation of adjacent piles is often continuously monitored during driving to look for heave. If a pile moves in excess of some predetermined criterion, the pile is redriven to redevelop the required penetration and capacity. From a cost perspective, pile heave is important because redriving piles can require significant additional time and effort.

### 5.2 Pile Layout and Soil Conditions

Of the contracts reviewed, pile heave was an issue during construction of the arrivals tunnel at Logan Airport (contract C07D2). The tunnel structure is approximately 159 m in length and is located where ramp 1A-A splits from the arrivals road. The tunnel [11] was constructed using the cut-and-cover method, and thus a portion of the overburden soil was excavated prior to pile driving.

## 6. ENVIRONMENTAL CONSIDERATIONS

According to the Environmental Protection Agency, round timber piling, properly treated with creosote or CCA [12], or dual treated with both, has no harmful effect on the environment. Creosote is biodegradable and CCA, when fixed to the wood, does not leach out. National Geographic published an article titled, Pillar of Life, showing how marine life attaches to timber piling to help the environment. The following is a quote from the Grail article: "When a piling is driven into the bottom of the bay, life takes up residence almost immediately. Bacteria, algae, and protozoans cover the submerged surface. This "slime" provides a foothold for larger creatures to attach themselves in succession. In the summer young ivory barnacles [15] are among the first to appear. With them come sun sponges and mosslike bryozoans, which spread over the piling by budding. Bright patches of algae such as

sea lettuce soon arrive, followed by hydroids and bulbous sea squirts. Mussels use byssus threads to anchor themselves. Tube builder amphipods construct tunnels of mud and detritus for protection and for a niche on the crowded piling. Still others affix themselves to the shells of animals already attached. Almost every underwater part of the piling is covered with sessile species, each looking for food, shelter, and a place to propagate."

## 7. CONCLUSION

Treated round timber piling have been successful for the past 130 years in the United States as deep foundations for highway bridges and other structures. Based on the Engineering News formula driving criteria, timber piles were installed to a safety factor averaging 4.0, with a mean of 3.5. Design has been based on the local Geotechnical Engineers knowledge and experience of site-specific soil and rock conditions. Engineers refer to ASTM D 25 for timber and AWWA C 3 [13] for preservative specifications. Piling sizes are usually Class B or 203.2 mm (8 inch) diameter tip natural taper. Durability of treated timber piles has been determined for foundation, land and fresh water, and marine conditions. Creosote and CCA were approved for use by the Environmental Protection Agency in 1986. Creosote is biodegradable and CCA [14], when fixed to the wood, does not leach. National Geographic published a paper showing how treated round timber piles help the marine environment.

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