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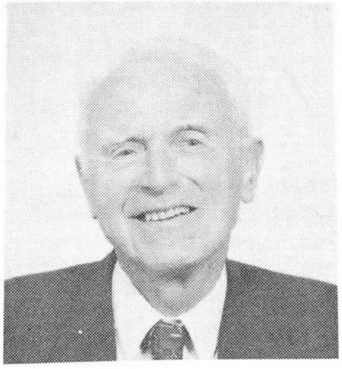
Large Diameter Steel Tubular Piles for Optimum Seismic Performance



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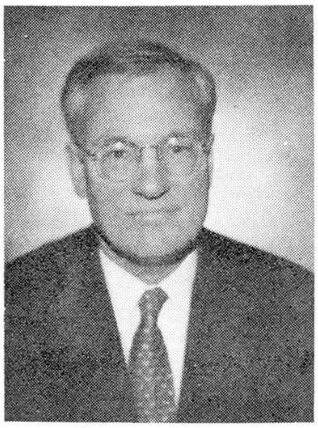

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Summary

Large diameter steel tubular piles, installed vertically or on a slight rake, offer many advantages as the foundations of major overwater bridge in regions of high seismicity. By proper selection of diameter and wall thickness, an optimum balance between stiffness and strength can be achieved. Under strong seismic motion, the piles will deflect and bend so as to reduce the acceleration forces transmitted to the superstructure, while still limiting drift.

A major advantage of this concept is that the mass of the footing block is significantly reduced from that of the conventional pier. The design of the footing block requires great care in order to transfer the high shears and moments.

Where the soils consist of significant depths of sediments, the kinematic interaction of soils, piles and structures must be considered. Moments will be a maximum just under the footing block. Filling the top portion of the pile with concrete will prevent local buckling and assure ductile behavior even under overload.

Typically the piles will be long, with most or all of their support furnished by friction and will require the use of very large pile hammers to achieve the required capacities. Where the piles are founded on rock or in hardpan, sockets will be drilled and filled with reinforced concrete. For these piles, high moments can occur both at the head and just below the rock surface, so the concrete infill should extend the full length.

The paper will describe the use of tubular piles driven through the deep silty sands of the Jamuna River, Bangladesh, and also where socketed into the near-surface rock for the main pylon pier of the new San Francisco-Oakland East Bay Bridge in California.

Introduction

1.1 Steel tubular cylinder piles with diameters of one to two meters have been previously employed for a number of major bridges, including the Rio Niteroi Bridge in Brazil, the Parana Bridges in Argentina, and on the new bridge across the Tagus River in Portugal. They have proved to be an efficient and economical solution for the foundations, because they enabled the footing block to be constructed near the waterline, thus obviating the need for a deep cofferdam or caisson.

In recent years it has been recognized that tubular piles of even greater diameter, 2.5 to 4.0 meters, have the ability to provide lateral stiffness to the pier along with ductility for overload events such as earthquakes, sea ice, and ship collision. (Fig.1) Combined with an efficiently designed footing block that develops both moment and shear, they can be optimized for drift (lateral deflection), and strength.

These piles are typically thick-walled so as to enable effective driving to deep penetrations, as well as to provide moment resistance and stiffness. The wall thickness can be varied along the length to suit the demands of both driveability and in-service stresses. Where piles are driven into deep sediments, the highest bending moment occurs in the 1 to 1 ½ diameters just below the footing block. Filling the upper part of the pile with concrete, locked to the steel pile by means of shear rings, will give the pile increased stiffness and ductility. Stable hysteresis responses have been obtained in laboratory tests up to a ductility factor of 4.

As a result of the failure of many raked piles in wharves during earthquakes, the current trend has been to use only vertical piles in seismic zones. Vertical piles respond well to excitation from all directions. However, it has been recently realized that in soft sedimentary soils or deep water, a slight rake can be utilized and still not result in excessive moment, shear or axial forces during earthquake. The benefits are greater lateral stiffness under serviceability environmental loadings, reduced drift during the seismic event and especially reduced residual displacement.

1.2 Design of these piles for lateral forces such as those of earthquake, requires a full analysis of the soil-structure interaction. The free-field motions are modified by the kinematic interaction of the pile with the soil due to the pile's stiffness. In layered sediments, the load-deflection performance can be determined by the finite element method with soil springs input along the pile length.

Group effects due to "shadowing" must be considered. For extreme deflections, the moments and deformations resulting from eccentric loading may be important.

1.3 Installation of these large piles requires the use of very large crane barges and very heavy pile hammers. Templates are usually employed to position the piles accurately, especially when the piles are battered (raked). See Fig. 2. Because there will be only a few such piles in a footing, each will be highly loaded e.g. to several thousand tons. Tolerances in pile head location are very critical.

1.4 Design of the footing blocks requires consideration of the demands for moment, shear and axial force transfer and also the practicality of construction. Precast concrete shells are often employed, temporarily supported on the piles. Both circumferential and axial shear keys are employed. Because of the high forces in moment and shear, post-tensioning may also be required.

It should be noted that if the piles are slightly battered, the footing block can be reduced in size, thus reducing the mass which is subject to high accelerations under earthquake. It has been found that the largest contributor to the shear under earthquake is usually the mass of the footing block. Piles are usually designed for essentially elastic behavior under the design earthquake, with ductility employed for possible overload during a few cycles.

1.5 Large diameter steel tubular piles were utilized for the recently completed Jamuna River Multipurpose Bridge in Bangladesh, where very deep and unstable sediments, combined with variable river depths due to shifting channels as well as high Monsoon floods, demanded an unique solution. The piles varied from 2.5 to 3.15m in diameter. They were 80m in length, with wall thicknesses up to 65mm. They were driven in three sections, using a Menck hydraulic hammer developing 1800 KN-m of energy per blow. The piles were driven through medium dense to very dense sand, and founded in a gravel stratum at a depth of 80m below normal water level. Up to 12,000 blows per pile were required. Splicing of three sections was by full-penetration welding.

The 300 ton pile hammer and the pile sections were handled by a large offshore-type crane barge. Piles were installed at a rate up to 5 per week and the work was completed on schedule.

1.6 Tubular piles are also an excellent solution for overwater bridge piers founded in rock or hardpan. In this case, vertical piles will usually prove best. They are cleaned out and a socket drilled into the rock.

Past practice has then been to install a reinforcing steel cage and to fill the pile with concrete. However, if there is inadequate overburden, the pile may develop high moments at or just below the rock line. In such cases, an oversize socket is drilled and the tubular pile lowered or driven into it, assuring that full moment capacity is provided at this critical region. The annular space is then grouted and the pile filled with concrete.

This concept has been adopted for the seismic retrofit of the several major bridges across San Francisco Bay, in order to develop greater stiffness and thus reduce drift deflection to acceptable values. Steel tubular piles, socketed into rock, have been selected as the probable design for the major pylon pier suspension span of the new San Francisco-Oakland East Bay Bridge while driven tubular piles, 2.5m diameter and up to 100m in length will support the long approach viaduct.

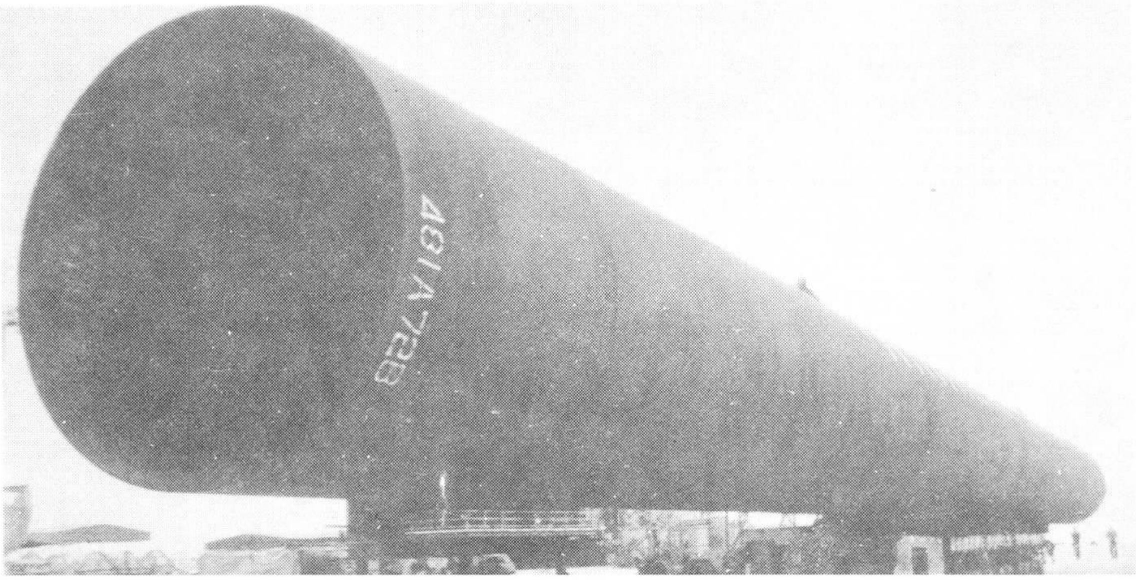

Fig. 1 – 3m dia x 80m long piles were used to support the piers of the Jamuna River Multipurpose bridge in Bangladesh

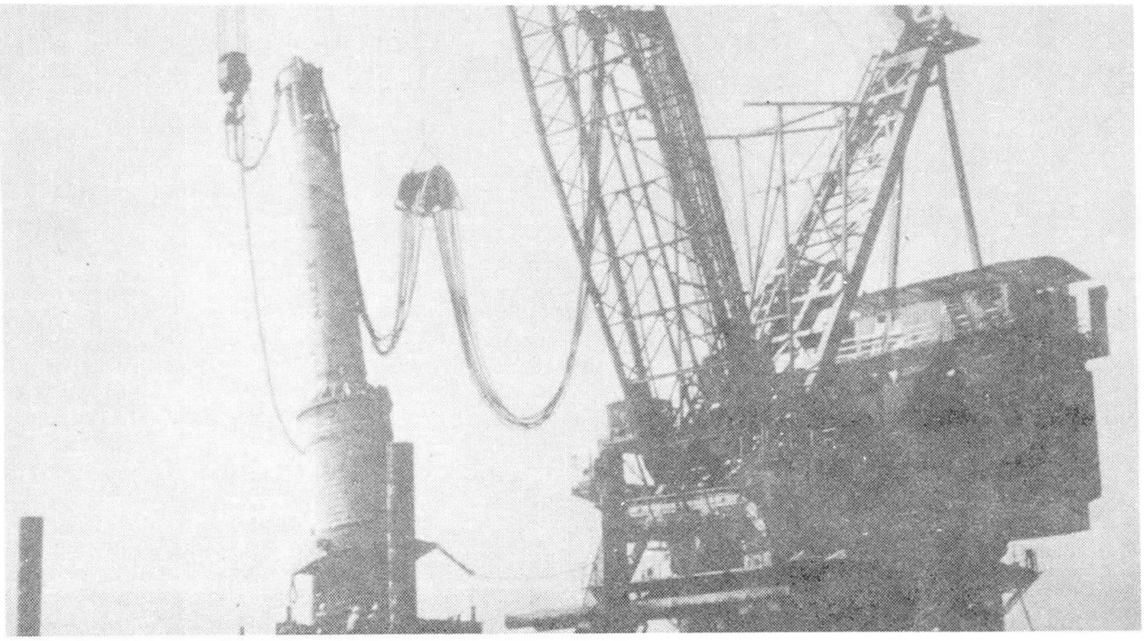

Fig. 2 - Installation of these large piles requires very heavy pile hammers

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