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ABSTRACT

River piers were constructed during the later part of 19th and early part of 20th centuries to handle increased marine freight traffic in the coastal regions of the United States. The sub-structure of these piers, commonly referred to as “finger-piers”, was usually constructed with a timber deck relieving- platform supported by timber piles. These platforms were used to support either earth-fill and/or concrete arch supports, which in turn provided structural support for the main floor. Most of the piers also had superstructures, usually truss-supported roof with columns, and a railroad siding. Many existing piers on the Delaware River in Philadelphia and the Hudson River in New York harbor are examples of this kind of piers. These piers are now being increasingly refurbished as site for new uses including condominiums, storage warehouses, cruise terminals and other waterfront developments. These new uses require evaluation of the available structural and soil load capacity of existing foundations. Additionally, a number of historical monuments are supported on timber piles. Current load capacity of these piles also is of interest to the engineers.

For the study presented herein, the laboratory testing program consisted of strength tests on specimens sawed from full size pile segments submerged in river water for about 100 years. Tests consisted of compression parallel to grain, compression perpendicular to grain and radial specimen. For comparison, tests were also conducted on new pile specimens. Additionally, deck and pile core samples were also tested. The specimens were prepared and tested in accordance with the provisions of ASTM D 143-52 for small clear timber specimens. Significant strength and modulus of elasticity losses were observed.

This paper summarizes the methodology of a comprehensive investigation of evaluating current condition of existing Piers, structural strength and soil capacity of pier piles, typical results and experience of the author in the Philadelphia, Pennsylvania area.

INTRODUCTION

River piers were constructed during the later part of 19th and early part of 20th centuries to handle increased marine freight traffic in the coastal regions of the United States. The sub-structure of these piers commonly referred as “finger-piers”, was usually constructed with a timber deck relieving- platform supported by timber piles. These platforms were used to support either earth-fill and/or concrete arch supports, which in turn provided structural support for the main floor. Most of the piers also had superstructures, usually truss-supported roof with columns, and a railroad siding. Many existing piers on the Delaware River in Philadelphia and the Hudson River in New York harbor are examples of this kind of piers. These piers are now being increasingly refurbished as site for new uses including condominiums, storage warehouses, cruise terminals and other waterfront developments. These new uses require evaluation of the available load capacity of existing foundations. This paper summarizes the methodology of a comprehensive investigation of evaluating structural strength of existing pier piles, typical results and experience of the author in the Philadelphia area.

FIELD INVESTIGATIONS

The field investigations included a video survey of the underside of the timber deck, inspection of piles above the mud-line and recovery of representative cores from both the timber deck and foundation piling. Large-scale timber pile samples were also obtained by sawing undamaged segment sections from piles which had become disengaged.

Video scan survey

To evaluate the condition of the timber deck a diver-operated video camera was used to conduct a survey of the underside of the timber decks. During the survey, video tapes were obtained for subsequent evaluation. Video work was very slow and tedious and was confined to the easily accessible areas of the piers.

Pile inspection

Approximately 25 percent of piles were visually inspected by divers from the mud-line to the pile cap. As part of this inspection, an evaluation was made of the condition of the pile caps and metal fastenings. As the turbidity of the water inhibited visibility, much of the inspection below water level was made by the feel of the pile surfaces. Measurements were made of the length of the piles from mud-line to pile cap and the diameter of the pile at the mud line and the pile cap. The measurements and other observations were logged for each pile inspected.

Pile condition rating

The system used to rate pile condition employed a scale from 1 to 4 in accordance with the following criteria.

Table 1: Pile Condition Rating

Ratings Category	Pile Condition	Percent of Piles
1	Sound/Intact with no visible deterioration	91.6
2	Minor splintering, chafing and/or surface deterioration	1.3
3	Significant splits/cracks or substantial reduction of cross section	4.2
4	Pile splits/cracks or damage resulting in little or no bearing capacity	2.9

Where piles were observed to be missing or disengaged, the No. 4 rating was also applied. The condition of the piles inspected was predominantly categorized by a 1 rating. More than 90 percent of the piles surveyed at each pier received a 1 rating. Only 2.9 percent of the piles surveyed were found to have little or no bearing capacity.

Pile & deck sampling

To investigate the compressive strength and load deformation properties of the timber pile and deck components of the substructure, cores 2 inch diameter by 6 inch long, were obtained from foundation piles. In addition, cores were also obtained from the timber deck. The 2 inch cores were supplemented by small diameter (3/16 inch x 4 inch "Pencil Cores") cores. These cores were obtained primarily to provide a visual evaluation of the near-surface condition of the piles and to check for creosote treatment.

In addition to the core samples, four timber piles segments were cut to prepare laboratory test specimens for evaluation of strength and load-deformation characteristics both parallel and normal to the grain of the timber.

Condition of metal fastenings

The bolts, nuts and washers connecting the clamp and pile cap members to the piles were inspected during the deck and pile survey. The condition rating system employed a scale from No. 1 to No. 3 in accordance with the following criteria.

Table 2: Hardware Rating System

Hardware Rating	Condition	Percent of Total Inspected
1	Less than 25 percent loss of section	91.8
2	Losses between 25 and 50 percent	6.0
3	Greater than 50 percent loss	2.2

As judged by the results of this survey presented in the table above, about 90 percent of the fasteners were observed to have suffered section loss of less than 25 percent. Fasteners for higher section loss should be replaced.

Marine borer potential

During the diver inspection no marine borer activity or presence of borer species were encountered. Limited research indicated that the widespread presence of borers in the Delaware River at Philadelphia is highly unlikely as marine borers require a saline environment of at least 10 parts per 1,000 for long-term survival and from 11 to 20 parts per 1,000 to cause any significant level of wood infestation. Historically, measurements in the Delaware River Port area have shown salinities of less than 0.5 parts per 1,000. Consequently, it was concluded that the current marine environment at the site is not conducive to the propagation of widespread marine borer activity. However, future changes in the river environment should be identified, evaluated and appropriate actions taken.

LABORATORY TESTING OF PILE SPECIMENS

The laboratory testing program consisted of compression strength tests on 109, 2-inch diameter pile cores, 47 deck core samples and on 42 specimens sawed from the full-size pile segments. These specimens were prepared and tested in accordance with the provisions of ASTM D 143-52 for small clear timber specimens. The following types of tests were conducted:

Scope of laboratory testing

Compression Parallel to Grain: Tests were made on 2 x 2 x 8 inch specimens obtained by sawing from full size pile segments to determine the elastic limit and crushing strength of the specimens. For all the tests, the modulus of elasticity and specific gravity were also calculated.

Compression Perpendicular to Grain: Tests were made on 2 x 2 x 6 inch specimens. The load was applied to the middle third of the area through a bearing plate. Orientation of the specimen was such that load is applied to a radial surface.

Radial Specimens: Tests were made on 2 x 2 x6 inch specimens cut such that their axis followed the radius of the pile. These specimens were prepared to be analogous to the 2-inch diameter cores obtained from the pier piles. For these tested specimens the elastic limit, modulus of elasticity and specific gravity were obtained.

Test results

Table 3 presents the data relevant to the laboratory tests conducted. For comparison, average strength parameters were calculated from ASTM D 2555-78 for the four most commonly used species of Southern Pine (Loblolly, Longleaf, Shortleaf and Slash) and are also listed. The strength data, in comparison to the small clear strength as provided by ASTM D 2555-78 for new piles, suggests that on the average the old piles have lost about 32 percent of their crushing strength parallel to the grain. The associated strength perpendicular to grain at the elastic limit indicated a loss of 12 percent. The strength reduction for radial specimens (i.e. radial loading case), based on similar strength tests on an unused Southern Pine pile, is about 60 percent. The significant reduction in the strength at the elastic limit for radial specimens is due to the fact that the test specimens are strongly influenced by the surficial softened zone of the old piles.

The conclusions regarding reduction in strength are compatible with previous studies on old marine piles. Examples of case histories are presented below.

Table 3: Strength Tests Specimens cut from Piles

	Mean	Standard Deviation
Parallel to Grain		
Marine Pile:		
Elastic Limit	1934	483
Crushing Strength	2451	476
Modulus of Elasticity	$5.8x10^5$	$1.7x10^5$
Specific Gravity	0.40	0.04
New Pile:		
Crushing Strength	3627	603
Modulus of Elasticity	$14.8x10^5$	$2.95x10^5$
Perpendicular to Grain		
Marine Pile:		
Elastic Limit	389	87
Modulus of Elasticity	$0.90x10^5$	$0.2x10^5$
New Pile:		
Elastic Limit	438	123
Specific Gravity	0.51	0.06
Modulus of Elasticity	$14.8x10^5$	$2.95x10^5$
Radial Specimens		
Elastic Limit	118	35
Modulus of Elasticity	$0.14x10^5$	$0.04x10^5$
Specific Gravity	0.38	0.01
New Pile:		
Crushing Strength	310	---

Note: All values in pounds per square inch.

COMPARISON WITH CASE HISTORIES

(a) 14th Street Bridge, Washington, DC

Timber piles at a bridge site over the Potomac River, which had been in water for 62 years, were extracted and specimens were tested for compressive strength parallel to grain (Shaffer, Duncan & Wilkinson, 1969). A total of four pile sections were tested. The piles were reported to be Southern Pine. For pile samples above mud line, the average residual strength was found to be 40 percent of the original strength. For tests of pile specimens taken from below mud line, the residual strength was found to be 80 percent. It is noted that the piles used at this site were untreated and the Potomac River at the site is not saline.

(b) Saint Francis Yacht Club, San Francisco, California

Timber piles supporting a docking facility on San Francisco Bay were driven between 1928 and 1931. These piles were creosoted before use (AE Concepts, 1978). After a fire, six piles were extracted in 1977 and specimens were evaluated for compressive strength. The piles were assessed to have an average design load capacity greater than 12 tons per pile. As additional capacity was not needed, no attempt was made to substantiate higher design loads.

(c) Pleasant Street Bridge, Milwaukee, Wisconsin

Strength tests parallel to grain were conducted on full-size sections of untreated timber piles which had remained submerged in non-saline water for over 80 years (Elyn & Clark, 1976). The average residual compressive strength for these Red Pine pile sections as compared to the original strength were reported to be:

Above mud line = 62%
Below mud line = 65%

The Milwaukee data indicated that the bridge foundation piles lost about one-third of their strength at all levels of the piling. The outer third of the pile in the radial direction was reported to have suffered the greatest strength loss.

(d) Langan Engineering tests, Delaware River

Langan Engineering (Personal Communication, 2009) conducted compression tests on specimens obtained from a Delaware River Pier and the results obtained are presented below:

Mean Compression parallel to grain	
	: 1773 psi (residual 49 percent)
New piles	: 3627 psi for Southern Yellow Pine
Residual Strength Range	: 25 to 76 percent
Specific gravity loss	: 0 to 58 percent

(e) Piers 3 & 5, Philadelphia, Pennsylvania

Compressive loading parallel to grain and perpendicular (radial) to the grain were conducted in the laboratory on small specimens cut from piles which had been in water as long as 60 years (WCC 1984). Based on the test results, the average residual compressive strength for these Southern Pine piles was expressed as a percentage of the original strength as follows:

Crushing strength Parallel to Grain	= 69%	(31% Loss)
Radial Load at Elastic Limit	= 26%	(74% Loss)

The case histories of treated marine piles documenting the loss of axial load capacity with time can be summarized in Table 4.

In summary, the results of the tests on specimens sawed from the Southern Pine pile sections show that the average of the laboratory compression tests conducted parallel to grain are about 2/3rd of the average small clear strength determined by ASTM D 2555-78.

Table 4: Residual Compressive Strength for Pine Piles

Case History	Age of piles (Years)	%Original strength
(a) Southern Pine	62	40 / 80*
(c) Red Pine	80	62 / 65*
(d) Southern Pine	60	69
Various Piers Philadelphia Area Southern Pine	60 to 80	68

*Below mud line

Compression strength tests on 2-inch cores

Cores having a diameter of 2 inches were obtained from piles and deck. The cores were, in general, 6 inches in length and included the softened portions of timber which have been in water at least 60 to 70 years. These cores were tested in the laboratory for compression strength. The strength at proportional limit was obtained as the cores included the softened part of pile and crushing strength, in most cases, was not reached even at large deformations. The data obtained showed that the softened pile cores have mean proportional limit strength of 103 psi and the deck cores have a mean strength of 158 psi. It should be noted that there was a large scatter in the data (with standard deviation to mean value ratio being 0.48 for both pile and deck cores). These values are not representative of the total pile cross section, considering that the radial cores contained the softened exterior zone of the pile.

The strength of radially oriented test specimens is not, in general, available in literature. Strength tests of horizonal specimens of new wood obtained from a dried Southern Pine untreated pile section were conducted. A mean value of 310 psi was obtained. Considering this value, substantial reductions in strength are indicated for the pile and deck cores.

It is deemed conservative to assume no strength in the much softened 1-inch outer annulus of the piles. To account for surficial softening, a complete loss of flexural strength in the top and bottom 3/8 inch of deck planks is recommended. This assumption results in a 24 and 18 percent reduction in the section modulus for the 6-inch and 8-inch deep planks, respectively.

The radial cores are easily obtained as compared to the vertical compression samples. An attempt was made to correlate the reduction in radial strength to vertical compressive strength. A statistically significant correlation could not be established due to scatter in data.

FOUNDATION PILE ASSESSMENT

Allowable compressive strength

The 5 percent exclusion limit strength (S_5) of small clear timber specimens was calculated for the lowest and the average of the four most commonly used southern Pine timber specimens in accordance with ASTM D 2555 and ASTM D 2899 procedures. The resulting S_5 values of 2499 psi and 2591 psi were converted to "new pile" working stresses of 925 and 959 psi, respectively, following procedures by the ASCE draft "Standards for Pile Foundations" (Gardner 1984). Note that compared to ASTM D 2899, which includes no formal safety factor, the ASCE method provides for a safety factor of 1.44. To estimate the allowable timber stresses for the piles supporting the old river piers, the "new pile" working stress was reduced by 40 percent. This reduction is conservative particularly for the portion of the pile embedded more than 5 ft. below the mudline. As demonstrated by the case histories, timber strengths are likely to be at least 10 to 15 percent higher in this interval. Correspondingly, the minimum allowable stress for the 40 percent reduction criteria was estimated to be 555 psi.

Available pile compressive capacity

To accommodate the effect of the softened peripheral zone of the old piles, as evaluated from the load deformation behavior of 2 inch diameter cores, a 2.0 inch reduction in the pile diameters is assumed for the exposed pile length. For the soil embedded portion of the pile, the diameter reduction is assumed to taper from 2 inches at the mud line to 1 inch at the pile tip.

The allowable compressive load at the critical section of the pile has been evaluated for a median pile butt diameter of 14 inches and a tip diameter of 7 inches. To evaluate the allowable structural capacity of the pile, it is assumed that typical No. 1 rated pile have a constant effective diameter of 12 inches down to the mud line and tapers uniformly to a tip diameter of 6 inches. By assuming a 60 ft. pile driven through soft, fine-grained river deposits and 5 ft. into dense to very dense sand, an estimate of the critical pile section and of the structural capacity of the pile was made.

Consistent with the foregoing near worst-case scenario the critical section, where the pile stresses are the maximum, is estimated to be 92 sq. in. and the allowable axial load capacity is estimated to be 50 Kips. This assumes that the pile has the required soil capacity with appropriate Factor of Safety. Soil resistance depends on subsurface conditions and should be evaluated by the Geotechnical Engineer. For the pier studied herein the No.1 rated piles are currently supporting a maximum load axial load of about 20 Kips, and the net allowable capacity of such piles is estimated as 30 Kips. As there is an uncertainty in estimating pile capacity from limited number of tests on small scale specimens, a further reduction of 15 percent was recommended, reducing the available pile capacity to 25 Kips per pile. Pile load settlement analyses were conducted and results were deemed satisfactory.

Pile soil capacity

Design pile soil capacity may be evaluated by conducting a load test on a representative pile. A disengaged pile may be used for this purpose. The pile load tests are expensive and will be more so for a marine pier pile. A pile hammer may be used to estimate the pile capacity by driving it. Assuming energy of 15000 ft-lbs for the hammer, a driving resistance of 2 blows per inch is indicated by the widely used “Engineering News” pile driving formula for a 50 Kips allowable capacity. A dynamic pile load test using the Pile Driving Analyzer (PDA) may be utilized to assess the pile compression capacities. For this project these tests were not conducted. However, for important projects it is recommended these should be carried out to assess the existing soil pile capacity

RISK MITIGATION PROGRAM

It is recommended that the foundation system of the piers supporting critical structures be inspected on a regular basis throughout the life of the development. Criteria pertaining to periodic inspection of the substructures have been developed and are recommended herein.

Visual inspection

Inspection of the pile, decking and the metal fastenings should be made, initially on an annual basis, to document any visually perceptible changes in the pile and deck system. The inspection shall be made by divers experienced and competent in this kind of work. A lengthened inspection frequency would be likely depending on accumulated experience. Alternatively, an annual inspection of a part of the piers could be made so that a complete coverage is obtained each two to three years.

Detection of leaks

To protect the timber deck and prevent loss of subfloor fill, a monitoring program should be implemented to detect leaks from subfloor utilities, swimming pools, and other potential leak sources. Causes of any subsidence or settlement and cracks in the floor slab should be promptly investigated and corrected.

Marine borers

During visual inspection special attention should be paid to detect marine borer activity, if any. If burrowing activity is suspected, specimens should be collected and identified by a qualified marine biologist.

SUMMARY

Based on the field investigations supplemented by laboratory tests and analysis of the data obtained, the following conclusions and recommendations are made:

(1) Based on the investigations described, it is judged that on the order of 60 (±5) percent of the original structural capacity is retained above the mudline and 70 (±5) percent capacity is retained within the soil embedded portion of the pile. This judgment is consistent with: (a) the strength losses commonly attributed to the long-term surficial deterioration of the portion of the untreated piles above the mudline and within the zone of oxidation below the mudline; and (b) by the long-term action of bacteria colonization on the exposed and embedded portions of the pile.

(2) The maximum allowable load increase for 14-inch diameter and 60-feet long pile Southern Pine for earth fill piers in Philadelphia area should be restricted to a maximum of 25 Kips, unless a detailed structural evaluation is accomplished. The maximum total load should not exceed 50 Kips per pile unless proved by a pile load testing program.

(3) Consideration should be given to verification of the pile soil capacity evaluation by dynamic load testing of selected piles. However, conducting a pile load test may not be financially feasible for many small renovation projects.

(4) The substructure connections (hardware), judged to have suffered a section loss of more than 25 percent, should be replaced as a minimum and are subject to evaluation by the project Structural Engineer.

(5) Horizontal and vertical control points should be established at the time of construction of the project. These control points should be monitored regularly during the construction period and at least annually thereafter. The settlement and horizontal movements should be analyzed by the Engineer and their implication relative to the safety of the structures should be assessed.

(6) All marine pilings and substructure are likely to continue to suffer a slow but progressive deterioration and require careful monitoring inspection and maintenance after the renovated structure is put in service. A recommended program of inspection and periodic testing is outlined above.

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