STRUCTURAL DESIGN

design issues for structural engineers

Rational Approach to Design and Analysis of Piers and Marginal Wharves

Part 1

By Vitaly B. Feygin, P.E.

Vitaly B. Feygin, P.E. is a Marine Structural Engineer. He is a Principal Structural Engineer with Marine and Industrial Consultants, Tampa and Jacksonville offices. He is an author of two patents related to Sea Walls, Composite Cofferdams, Bridge Fenders and Port Structures and author of multiple professional publications related to Marine, Port and Waterfront projects. Mr. Feygin can be contacted at ***vfeygin.mic@gmail.com****.*

This three part article is a tribute to my mentor and friend, Mr. Ron J. Mancini, P.E., and my wife Margaret who illustrated this manuscript.

Design of a new waterfront project is a challenging task. Waterfront tenants expect highly competitive designs that shorten construction time and save material resources. Global competition coupled with a tight design market demand innovative approaches incorporating modern modeling, utilization of new construction materials and use of advanced construction technologies. Efficient design is always economical and practical. However, practicality of the design is determined by the single but most important criteria – compatibility of design complexity and ability of a qualified contractor to complete the project within the budget. Finally, successful and competitive design is always based on accumulated experience and solid engineering judgment.

Piers and Wharves are the most commonly used waterfront Port structures. A **Pier** is a docking structure that typically projects seaward at an angle to the shoreline. Both sides of the pier are normally used for mooring and berthing operations. A **Wharf** is a docking structure oriented parallel to the shore. A wharf built as a continuation of the shoreline is known as a Marginal Wharf. When water along the shore has inadequate depth for a deep water terminal, and dredging is costly or not feasible, the wharf structure can be moved seaward. Such wharves are connected to the land by pile supported trestles. This arrangement allows ships to be berthed on both sides of the wharf. However, within the context of this series, both structures are reviewed under the generic term of **Pier**.

Load Selection

One of the most challenging tasks of Pier design is the selection of realistic loads. Proper selection of loads and load combinations is the most critical part of the Waterfront project. In recent years, codes and criteria for the design of Marine structures have changed. Today, a Waterfront Engineer must rely on his/her solid judgment dealing with codes. Some of the design loads and load combinations prescribed by current design codes are extremely conservative. Some have zero probability, and some are grossly overrated. The dynamic impact requirement for vehicular traffic prescribed by UFC 4-152-01 was a carryover from the AASHTO Specifications. Such an approach does not differentiate between traffic pattern and speed of train traffic on the bridge or pier deck. Impact from container crane operation was similarly overrated. Recent research data, along with load combinations suggested by practicing engineers, indicated that revising the allowance for impact was long overdue. Unrealistic and/or overrated loads and load combinations can be excluded by an educated facility owner during design criteria review. The objective of this article is to give the Waterfront Structural Engineer and facility operator valid arguments for educated decision making.

Computer Modeling of Pier Structure

Analysis Assumptions

It is commonly accepted that a Pier behaves as a space structure, reacting to different combinations of horizontal loads applied along the structure length. On the other hand, each bent of the Pier reacts to the attributed gravity load independently of adjacent bents. This commonly accepted assumption allows a designer to resolve complicated 3-D framing into a sequence of planar computer models with highly accurate boundary conditions.

Building the Computer Model

Modeling of the Pier begins with a review of all reasonable load cases. All loads, for that purpose, are separated into two load categories:

- *Lateral loads* are used to calculate horizontal reactive forces attributed to pile bents. Each pile bent is modeled as an elastic support for pier deck horizontal diaphragm action. The reactive forces determined from the horizontally loaded diaphragm

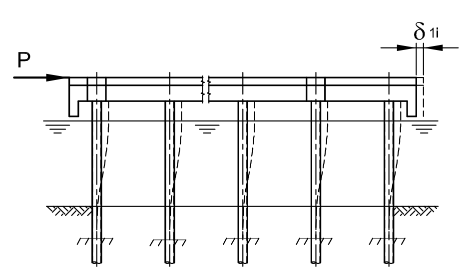

Figure 1: Transverse bent spring model.

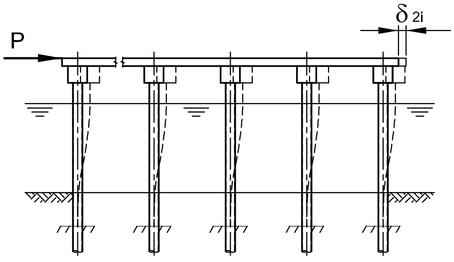

Figure 2: Longitudinal bent spring model.

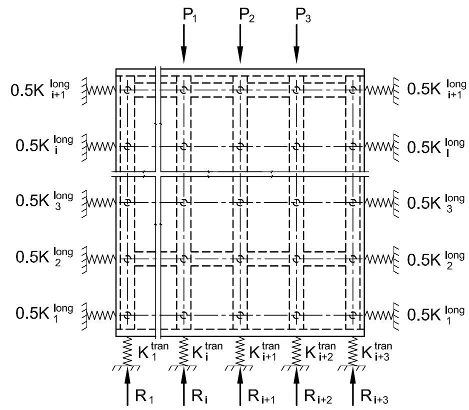

Figure 3: 2-D Deck model with local transverse loads.

model are applied to two-dimensional pile bent models at the level of the pier deck, and combined with gravity forces acting simultaneously with the horizontal forces. The degree of load sharing between pile bents is highly dependent on the stiffness of the deck diaphragm and relative stiffness of each pile bent. Variations in the soil strata along and across the pier length greatly influence the stiffness of the pile bent, and consequently affect horizontal load redistribution. The following lateral loads are normally considered in diaphragm lateral analysis:

- berthing load;
- mooring forces;
- seismic force;
- ice pressure;
- wind; and
- wave-induced forces.

All these forces shall be treated as distributable loads. In some cases, when soil strata variation along the pier is negligible, seismic force, ice, wind and wave-induced pressures can be treated as non-distributable loads.

- *Gravity loads* can include several sets of loads. Selected load combinations must be realistic, and shall induce the most critical forces in designed element.

The advanced Pier modeling technique can be described as a sequence of several design steps:

Step 1. Find the fixity point of each pile in the bent. Model the pile using appropriate boundary conditions and estimated lateral load on the pile head.

Step 2. Develop a 2-D model of each transverse bent and apply a unit force to each transverse bent at the level of deck diaphragm. Calculate the bent spring value $K\,i^{tran} = 1/\delta_{1i}$ where δ_{1i} is the bent horizontal displacement (*Figure 1*).

Step 3. Determine the equivalent stiffness of the longitudinal bent horizontal members. Repeat Step 2 for modeling each longitudinal bent, and determine the longitudinal bent spring value $K\,i^{longit} = 1/\delta_{2i}$, where δ_{2i} is the bent horizontal displacement (*Figure 2*).

Step 4. Calculate the spring value of the bent supplemental support, and combine it with the bent spring value.

Step 5. Apply transverse spring supports to each transverse bent and ½ of longitudinal spring support values to each side of longitudinal bents in the 2-D deck diaphragm model. Run the deck diaphragm model with different sets of applicable horizontal forces (*Figure 3*). Find reactions at each transverse spring support.

Step 6. Create load combinations, and apply loads to each critical planar bent model. Some of the gravity load combinations will include horizontal reactive forces predetermined in Step 5.

Step 7. Determine the critical set of forces for each bent element, and design the bent elements for these critical forces.

Some marginal wharf structures are designed with ancillary lateral load resisting mechanisms such as A-frames integrated into the sheet pile wall, or Tie Backs. In that case, both springs shall be combined as springs in series. The combined spring constant of that system shall be determined using the following formula:

$$1/K_{comb} = 1/K\,i^{tran} = 1/K_{bent} + 1/K_{suppl.}$$

Where (K_{bent}) is a bent spring value and ($K_{suppl.}$) is a spring value of a supplemental reaction mechanism.

A sheet pile wall with properly designed backfill can be used as an elastic foundation (EF) for forces directed landward. However, retaining structures of marginal wharves shall be checked for slope stability in circular slip surface failure. Such failure can greatly endanger the general stability of the whole wharf.▪