Seismic Load on the Wharf

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Abstract. Earthquake is a natural event that shocks can cause casualties and damage public facilities or infrastructure. The wharf is an infrastructure built with large investments. The purpose of this paper is how to design an open wharf and closed wharf that can minimize the risk or prevent collapse due to earthquake. The design uses a approach or force based with reference to the Earthquake Code of the world.

1. Introduction
Earthquakes are natural events that occur not only in earthquake-prone zones but also occur in zones with less seismic activity. In addition to causing fatalities, earthquakes can cause infrastructure damage from minor damage to severe damage. The Wharf is a maritime infrastructure that has the potential to be affected by the earthquake. Damage to wharf in addition to causing loss of large investments can also have an impact on the macro economic sector, especially in the field of import trade and exports. Seismic disaster mitigation has been an interesting field of study in the past decade. One method of earthquake mitigation is the design concept of earthquake resistant structures. This method has long been developed and implemented in various Codes and Standards in many countries. This method is based on force and is the simplest among other methods. This paper will outline the earthquake resistant design concept on the wharf structure.

2. Type Wharf
Wharves are infrastructure maritime can be classified into open type and closed type. Open type wharves are constructed in such a way that sea-water can run below the platform which generally rests on piles or columns embedded in an embankment. Closed type wharves are the common construction type where the depth to firm soil is shallow as well as the depth of water which results in a limited wave action against the wharf. These conditions can be found in rivers, and shallow depth shorelines. Closed type wharves are generally made of a vertical wall which divides the sea from the shore, and backfilled with soil material and topped with a concrete deck or platform. The choice of type of wharves is influenced by geographical conditions, geology, soil conditions, economic and functional.

3. The Wharf design approach
The wharf structure design can be done with two approaches with two approaches namely; forced based design and displacement based design. Forced based design or called to seismic coefficient method or equivalent lateral. Stiffness is a design approach where the structure or components are designed to be able to withstand loads up to the allowable limit. This method is widely adopted on many codes in several countries. According to [1] this method may be used for preliminary design. Code [2] provide application conditions force based that is:
   a. Force-based design is permitted for “low” design classifications.
   b. Force-based design is permitted for all design classifications when \( S_{DS} < 0.33 \)
c. Force-based design is permitted for all design classifications where it can be demonstrated that the capacity of all primary structural members exceeds the elastic earthquake demand force when using a value of \( R = 1 \).

Displacement based design: A design approach whereby an anticipated displacement of the structure is determined for design earthquake motions and the various elements are designed to perform to certain standards under the imposed displacements. This method is known by several approaches namely: 1) Nonlinear Static Pushover, 2) Elastic Stiffness Method, 3) Substitute Structure Method, 4) Modal Response Spectra Analysis, 5) Nonlinear Time-History Analysis.

4. Seismic Mass of Wharf

Seismic mass is the mass of other structures and masses that occur in an earthquake. According to [2] and [3] the seismic mass shall include: 1) The mass of the wharf deck, 2) 1/3 of the mass of piles with the tributary length measured from the bottom of deck soffit to 5D below the surface of pile embedment, 3) The mass of any permanently attached equipment/ fixtures, 4) Mass due to the minimum of 10% of the design uniform live load or 100 pounds per square foot, 5) The hydrodynamic mass, if the pile diameter is greater than 2 feet, 6) The part of crane mass not less than \( m_{\text{crane,deck}} \) or 0.05 \( m_{\text{crane}} \), \( \text{wherem}_{\text{crane,deck}} \); Part of the crane mass positioned within 10 feet above wharf deck or \( m_{\text{crane}} \); Mass of crane.

Some researchers [4] and [5] suggest to calculate contributions from the mass of additional water for piles. Additional mass contributions are estimated at 24%.

5. Forces when an earthquake occurs

5.1. Seismic Load

Base shear earthquake load according to some Code [6], [7] and [2] is calculated as shown in Table 1. Code [6] and [7] does not account for seismic reduction factor (R) due to the influence of ductility in the wharf structural system.

| Code            | Base shear method | Equivalent seismic | R              | I              |
|-----------------|-------------------|--------------------|----------------|----------------|
| PIANC (2001)    | \[6\]             | \( \alpha = \frac{\alpha_{\text{max}}}{g} I; \alpha_{\text{max}}<0.2g \) | [1]; I = 1     |                 |
| OCDI (2002)     | \[7\]             | \( \alpha = \frac{1}{3} \left( \frac{\alpha_{\text{max}}}{g} \right)^{1.5} I; \alpha_{\text{max}} \geq 0.2g \) | [2]; I; 0.8 < I < 1.5, For high seismic, I = 1.5 |                 |
| ASCE (2014)     | \[2\]             | \( \alpha = \frac{S_{DS} I}{R} \) | Prestressed concrete and steel pipe piles; R=2, Other structures, R=1 | OC: I or II; I=1, OC: III; I=1.25, OC: IV; I=1.5 |

\( V \): The horizontal seismic force; \( \alpha \): seismic influence coefficient; \( W \): structures weight; \( \alpha_{\text{max}} \): Regional PGA at bedrock Site Category (site amplification factor) earthquake partition coefficient; I: importance factor; R: seismic response reduction coefficient; \( S_{DS} \): Structural reaction coefficient; g: gravity acceleration; OC: Occupancy Category

Structural reaction coefficient \( (S_{DS}) \) is calculated using the Spectrum Response diagram according to [8]. Periodic time is calculated by;
\[ T = 2\pi \frac{W_g}{g \sum K_{Hi}} \]  

Where  
\( T \); natural period of pile-deck system, \( W_g \); surcharger and dead weigh of deck; \( g \); acceleration of gravity; \( K_{Hi} \); equivalent spring stiffnes for lateral reaction by \( i \)th pile

5.2. Active earth pressures

In the pseudo-static approach, the earth pressures are usually estimated using the Mononobe–Okabe equation (Mononobe-Okabe, 1924) the seismic inertia angle, \( \psi \) defined by

\[ \psi = \tan^{-1} \left[ \frac{\alpha}{1 - \alpha_v} \right] \]  

![Figure 1. Hydrodynamic pressure and Active earth pressures [6]](image)

For a vertical wall having a friction angle \( \delta \), between the backfill and the wall, and retaining horizontal backfill with an angle of internal friction \( \phi \), the dynamic active earth pressure coefficient, \( K_{ae} \) is given by

\[ K_{ae} = \frac{\cos^2(\phi - \psi)}{\cos \psi \cos(\psi + \delta) \left[ 1 + \frac{\sin(\phi + \delta) \sin(\phi - \psi)}{\cos(\delta + \psi)} \right]^2} \]  

\[ P_{ae} = \frac{1}{2} K_{ae} \gamma_d (1 - k_v) H^2 \]  

Where \( \gamma_d \) is the unit weight of the dry backfill. In case of a uniformly distributed surcharge \( q \) sure, \( \gamma_d \) should be substituted with \( (\gamma_d + (1/2q_{sur}/H)) \)

The active angle of failure from the horizontal direction for a level surface condition is computed as

\[ \alpha_{ae} = \phi + \arctan \left[ \frac{\tan \phi + \sqrt{\tan \phi (\tan \phi + \cot \phi) (1 + \tan \delta \cot \phi)}}{1 + \tan \delta (\tan \phi + \cot \phi)} \right] \]  

Considering a fully saturated Coulomb wedge, the modified seismic coefficient as follows
\[ \alpha' = \frac{1}{2} q_{sw} H + \gamma_w H_{sur}^2 + \gamma_{wet} H_{sub} H_{sur} + \frac{1}{2} \gamma_{sat} \frac{H_{sub}^2}{\alpha} \] (6)

5.3. Hydrodynamic pressure

The resultant hydrodynamic thrust computed by Westergaard (1933), which acts at a height of 0.4H from the base of the wall, is given by

\[ P_{dw} = \frac{7}{12} \alpha' \gamma_w H_{w}^2 \] (7)

6. Load kombination and orthogonality effect

The combination of load must be analyzed to calculate the worst effect on the wharf. Load combinations are calculated for two conditions, namely a combination of loads for structural strength design or Load and Resistant Factor Design (LRFD) and load combinations for stability design or Allowable Stress Design (ASD).

| CODE               | D | L  | H   | E | B |
|--------------------|---|----|-----|---|---|
| PIANC,OCADI        | 1 | -  | 1   | 1 | - |
| ASCE               | 1+k| 0,1| 1   | 1 | 1.2|
|              | 1-k | - | 1 | 0.9 |
| ASD               | 1+k’| 0,1| 1   | 0.7 | 1 |
|              | 1-k’| - | 0.7 | 0.6 |

where; D=Dead loads, including all permanent fixed equipment and structures, and other items expected to be present for more than 50% of the time; L = uniform live loads; H = soil pressure loads (e.g., soil pressure on end walls, concrete cutoff walls, steel sheet pile walls on pier or wharf type structures, and/or piles); E = horizontal earthquake loads; k = 50% of Peak ground acceleration (PGA); k’ = 0.7k = 0.35PGA; B = Buoyancy load

7. Design of wharf structures.

The designed structure is an open and closed wharf structure as shown in Figures 4 and 5. The earthquake load structure is calculated based on Code ASCE (2014) and PIANC (2001) and the closed wharf structure is calculated using a combination of Code ASCE (2014) and PIANC (2001). Earthquake Load The closed wharf structure involves service load factors namely 0.7 for earthquake loads and 1.5 for vertical loads for seismic.

Structural data regarding loads, dimensions, pile parameters, property materials, geotechnical parameters and loads are presented in the following Tables and Figure 2 and 3:

| Uniform live load | = 30 kN/m²; Load seismic 10% x 30 = 3 kN/m² or 100 pounds per square foot = 4.88 kN/m² (use) |
|-------------------|------------------------------------------------------------------------------------------------|
| Detail Crane load (AS4997:2005) [9] | • Container crane on 2.5 m from the waterside  
• C.t.c. distance of crane tracks: 30.48 m  
• C.t.c. distance wheelbases: 17.25 m  
• 8 wheels per leg, c.t.c. 1.2 m, so crane loads acts on 7x1.2=8.40 m |
| Design crane load | Per wheel (kN) | Load on Corner (kN) | Load per m (kN/m) |
| Vertikal          | 750            | 6000               | 750               |
| Horisontal        | 45             | 360                | 43                |
**Figure 2.** Pile-supported wharf, (a) Plan, (b) Cross section

**Figure 3.** Cross section and dimensions of the wall

7.1. **Seismic load design for the open Wharf**

1. **Vertical forces**

   Dead Load; Plate + Cover layer + Girder + Upper edge beam + Pile Cap + Crane + (Pile + Added mass to pile) + Live load:  
   \[ W = 11363.53 \text{ kN} \]

2. **Horizontal forces**

   1) Border + Fender = 0.5 x 20 = 10 kN; 2) Crane = 0.05 x 360 = 18 kN

   Natural period; equation (2) = 1.36 s;  
   \[ V, \text{ in Table 1} = 3122.76 \text{ kN} \]

7.2. **Designed earthquake load for closed Wharf**

1. **Active earth pressures and thrust**

   \[ \alpha = \frac{S_{DS}}{R} \cdot I = 0.6 \cdot \frac{0.51}{1.5} = 0.46 \]
   \[ P_{ae \cos \delta} = 1679.53 \text{ kN/m at } 0.54 \times 12 = 5.4 \text{ m above bad} \]
   \[ P_{ae \sin \delta} = 450.03 \text{ kN/m ; 6.5 m from A} \]
(2) Hydrodynamic force $P_{dw} = 300, 84$ kN/m at 4m above bed
(3) Inertia and other driving force; cover layer, coisson, footing, the backfill inertia force, the static bollard pull (50% reducing its value during earthquake), crane.
(4) Vertical forces; crane, cover layer, caisson dry, caisson wet, footing, backfill material above water table, backfill material under water table.
(5) The hydrostatic pressure; bisade (1,8 and 60) kN, uplift (24 kN)

Figure 4. Loads acting on structure wharf during earthquake (a) Open wharf (forces are in kN), (b) Close wharf (forces are in kN/m)

8. Discussion
Base shear earthquake load according to ASCE (2014) and PIANC (2001) for open wharf structures tend to have $R = 2$ giving adjacent results. Earthquake load for closed wharf structures, ASCE (2014) tends to give results slightly larger than PIANC (2001). For an open wharf structure, it is easier to analysis using software.

References
[1] POLB 2015 Port of Long Beach Wharf Design Criteria WDC Version 4.0.
[2] ASCE/COPRI 61-14 2014 Seismic design of piers and wharves American Society of Civil Engineers
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[7] OCDI 2002 Technical Standards and Commentaries for Port and Harbor Facilities in Japan, The Overseas Coastal Area Development Institute of Japan.
[8] ASCE-7-10 2010 Minimum Design Loads for Buildings and Other Structures American Society of Civil Engineers
[9] AS 4997-2005 Australian Standard™ Guidelines for the design of Maritime Structures Committee CE-030.