Liftech Consultants Inc. is a consulting engineering firm, founded in 1964, with special expertise in the design and procurement of dockside container handling cranes and other complex structures. Our experience includes design of wharves and wharf structures, heavy lift structures, buildings, container yard structures, and container handling equipment. Our national and international clients include owners, engineers, operators, manufacturers, and riggers. We provide structural, mechanical, and electrical engineering services.

Erik Soderberg is Liftech's president and a structural engineer with over 28 years of experience in the design, review, and modification of a variety of structural systems including hundreds of container cranes, over a dozen bulk loader structures, and over two dozen wharves and piers. Other structures include crane lift and transfer systems and concrete and steel floats.

Introduction

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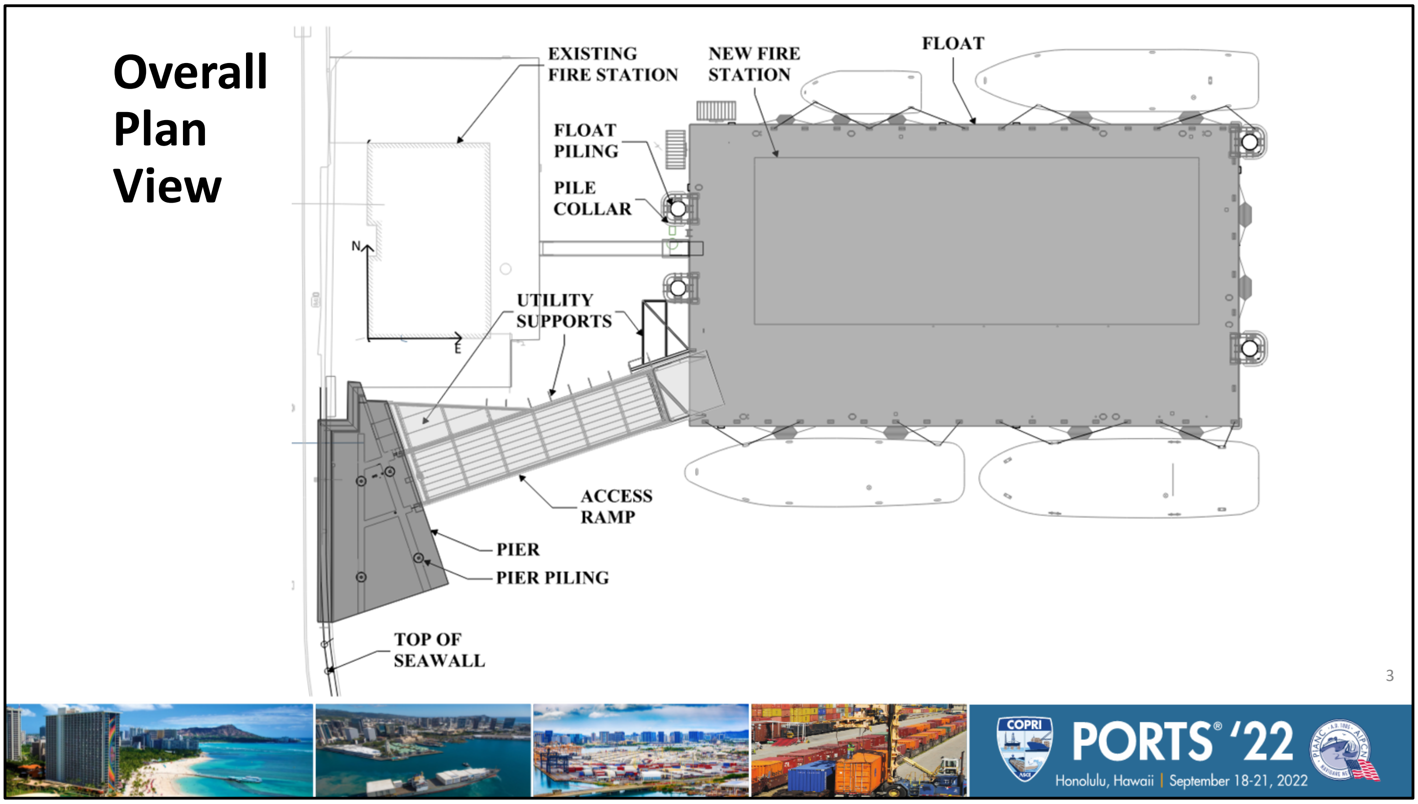
This presentation provides an overview of the design and some lessons learned about the new floating fire station at Pier 22 ½ in San Francisco. This is an important addition to the San Francisco waterfront and is one of the only floating fire stations in the world. The City of San Francisco decided to develop a floating fire station rather than placing it on a fixed pier, in large part to be adaptable to sea level rise. It also provides a fixed freeboard for easier access to the fireboats that will moor around the float.

This is an essential facility with a 50-year design life and will be integral to the city's recovery in the event of a large earthquake. The project requirements were more stringent than similar types of projects, including being designed to have better performance than required by ASCE-61, e.g., to only have controlled and repairable damage in the design earthquake (DE).

This slide shows the original fire station in back on the left, new pier, new access ramp, and new float and fire station. The Bay Bridge is in the background and to the right.

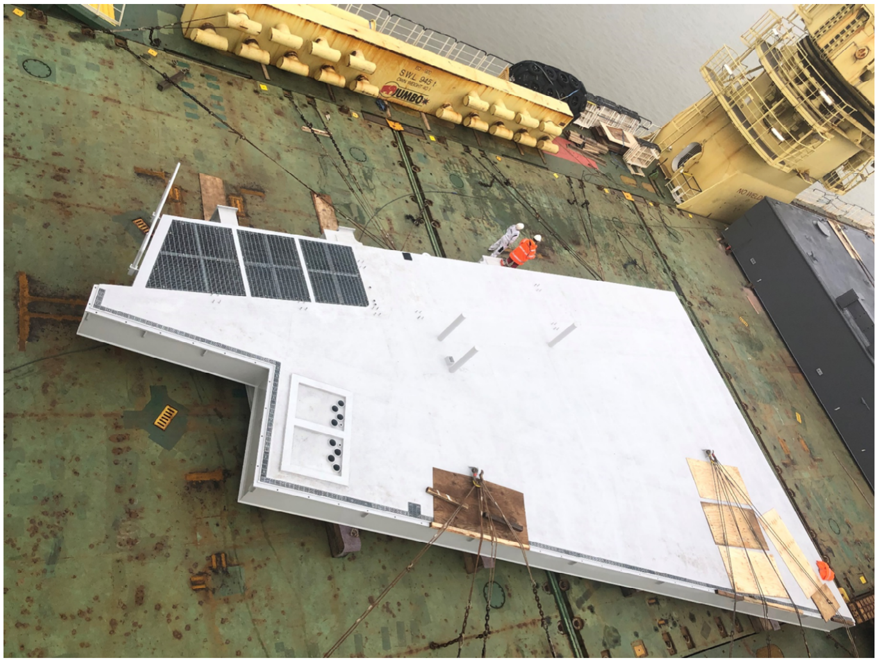


This slide presents a plan view of the facility.

The new facility components are in gray. Key components include the pier, access ramp, and float.

The main marine structural components were prefabricated in China and shipped to San Francisco.

Pier



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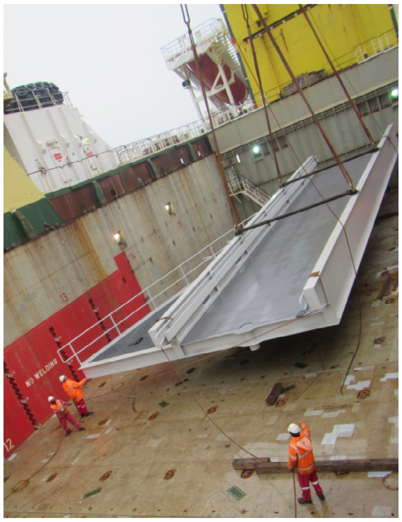
This is a photograph of the pier superstructure lashed to the delivery ship. The superstructure is mostly an enclosed steel box structure with internal beams and stiffeners. The pier superstructure was kept shallow to help limit water exposure.

Access Ramp



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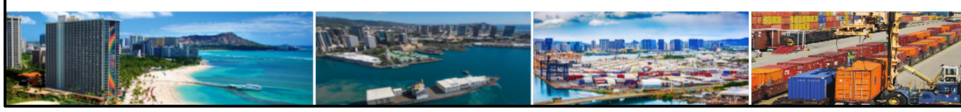
The access ramp is about 80 ft (24.4 m) long with 16 ft (5 m) of usable width, with two main girders that use 70 ksi material for the flanges. The ramp includes side brackets and a platform for supporting utilities extending to the float.

Also, hoses can be run from the fireboats along the access ramp to a manifold at land so the fireboats can pump seawater into the fire water system that extends throughout the city.

Photographs:
Left is of the access ramp being lifted onto the delivery vessel.
Top right is looking down the ramp to the fire station.
Middle is looking up the ramp from the float.
Right shows the many utility lines running along the north side of the ramp.

Float

6



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This is a photograph of the float on the delivery vessel. Notice the tube column stems for the building.

The steel float is 9 ft deep x 95 ft wide x 173 ft long (3 m x 29 m x 53 m), moored by four 5 ft (1.5 m) diameter steel piles.

Items to Consider and Lessons Learned

- Pier design approach
- Pier piling design approach
- Float pile cycle loading and reliability
- Pile collar damper
- Tsunami design loading
- Float design storm and earthquake motions
- Utility relative motions
- Corrosion design approach
- Construction approach and results

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Next I will present nine items to consider and lessons learned during the project.

Pier Design Approach

Pier in front of original fire station

Interface at seawall concrete bulkhead

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The left photograph is the completed pier with artwork. The concrete bulkhead of the original seawall is to the left of the pier. The pier steel superstructure was required to facilitate prefabrication but resulted in difficulties integrating with the existing surroundings, discussed later.

The right photograph is of the pier during construction: Standing on original Fire Station 35 timber pier deck, seawall on right with long steel transition plates to be added between the pier and seawall.

The facility had to integrate with the existing San Francisco seawall and the original fire station deck, including providing additional public access and being resilient to sea level rise.

Pier Design Approach

Integrates with the waterfront and accessible to the public

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This photograph shows integration of the pier with the landside after completion.

The pre-fabricated straight pier deck made integration more difficult than a cast deck as the seawall and original pier deck were not flat, not in the same plane, and were sloped differently.

Integration required careful measurements to determine the required pier support elevations that would result in correct slopes. Each support pile was then trimmed to that elevation and the pier installed.

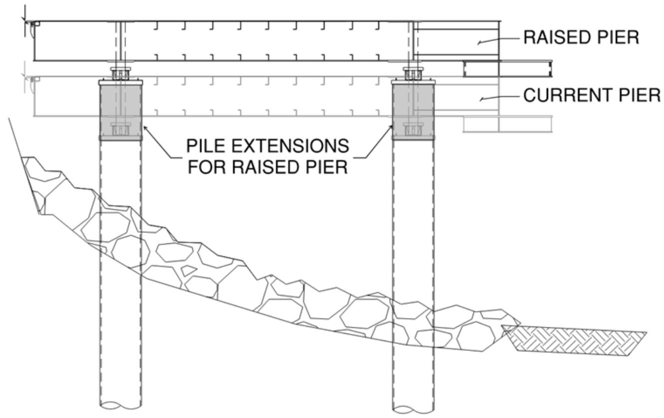
The left photograph shows how well the pier transition plates match the adjacent sidewalk.

Pier Design Approach

Resilient to sea level rise

Current pier

Raised pier (Future)



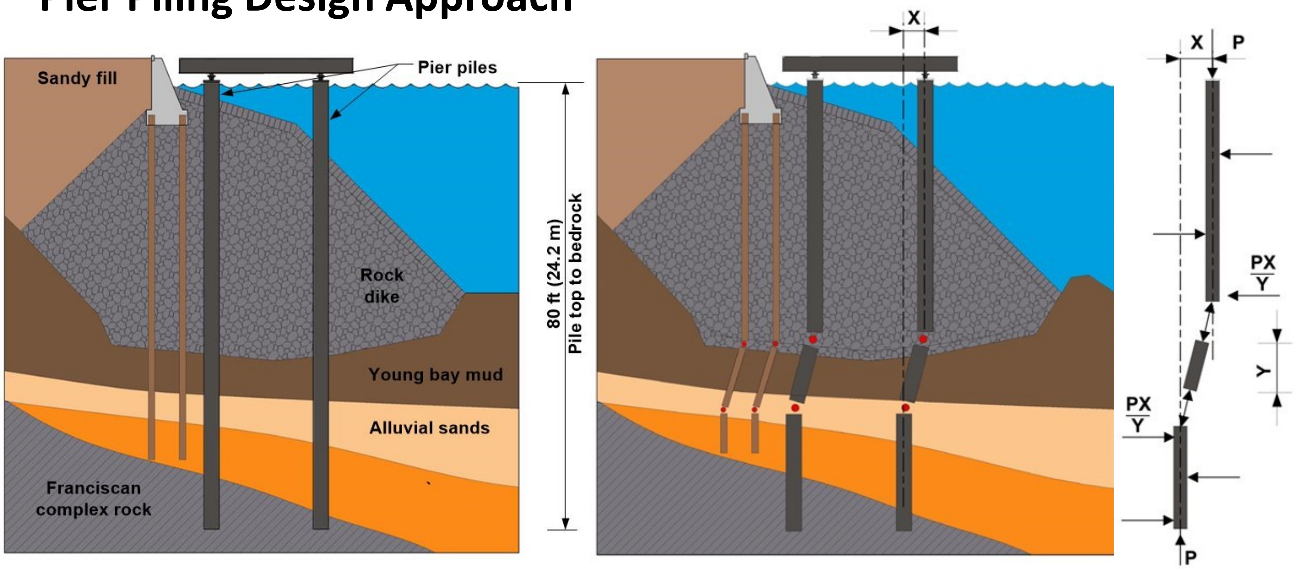
Resiliency to sea level rise was a very important part of the project.

To match current surroundings, the pier deck elevation is below the design sea level rise elevation, so the pier may need to be raised in the future.

The pier superstructure can be disconnected from the piles, lifted, and reset on pile extensions welded to the top of the current piles.

The image on the right shows the pier raised by 4.5 ft (1.4 m) based on estimated 4.5 ft of sea level rise (SLR) by year 2100 (desired by permitters).

Pier Piling Design Approach



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The piles are designed to accommodate seawall lateral movement in the controlling earthquake.

The pile design included an involved analysis of the rock seawall embankment sliding on the relatively weak Young Bay Mud soil layer beneath it. The pier piles are designed to remain within allowable strain limits and to deform plastically without buckling as the seawall shifts toward the water (Liu et al 2019, Serna et al 2019). The pier and access ramp will then move toward the float, where the access ramp support on the float is designed to accommodate the movement.

A lesson learned in the piling design is that hinges can form in the pier piling due to the differential soil layer movements, and still be acceptable, i.e., the ASCE 61 prescribed strain limits can be exceeded and the piling still perform as needed.

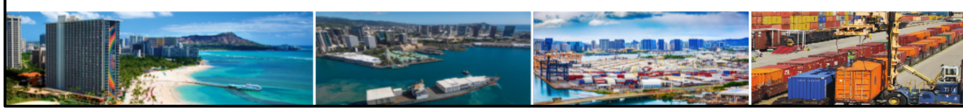
The fitness-for-purpose approach shown may be useful to other projects that have larger soil movements.

Float Pile Cycle Loading and Reliability

Significant fatigue due to wind and waves

Wave Loading based on 2014 wave data near Pier 22 San Francisco

Ave Wave Ht	Cycles per Year	Percent of Waves	Fatigue Percent	Fatigue Cumulative
0.08	12219429	71.9%	0.0%	0.0%
0.23	3258000	19.2%	1.0%	1.0%
0.47	1164800	6.9%	13.8%	14.8%
0.78	216000	1.3%	17.9%	32.7%
1.09	88800	0.5%	22.8%	55.5%
1.41	32640	0.2%	18.4%	73.8%
1.72	14400	0.08%	14.7%	88.6%
2.03	6776	0.04%	11.1%	99.7%
2.34	100	0.001%	0.2%	100.0%
2.66	10	0.0001%	0.0%	100.0%
2.97	1	0.00001%	0.0%	100.0%
	17000956	100.0%	100.0%	



We evaluated the structural reliability of the float piles due to the wave cyclic lateral loading over the 50-year design life. Stresses and fatigue life were calculated using a wave loading spectrum based on past wave data. Reliability of the pile welds was calculated using guidance from BS 7608 (Guide to Fatigue Design and Assessment of Steel Products) for different classes of fatigue details. A calculated series design reliability of greater than 0.977 was achieved for the 50-year design life. Series reliability is calculated as the product of the reliability of each detail in the series. For example, if a pipe has ten transverse welds with a calculated reliability at each weld of 99.6%, the series reliability of the pipe is only 0.961, or 96.1%.

The following were determined from this analysis:

1. Fatigue damage from wave loads is significant. It is not surprising that some mooring piles develop fatigue cracks and fail, particularly if they are undersized, use lower reliability weld details, or both.
2. Use as large a pile diameter as practical.
3. Use BS 7608 Class C or D welds. Class C, which requires grinding the welds flush, may be worthwhile over a limited length of the pile in locations of high stress.
4. Consider limiting the number of transverse welds as practical.

Float Pile Cycle Loading and Reliability

Significance of weld details

Relative Fatigue Life

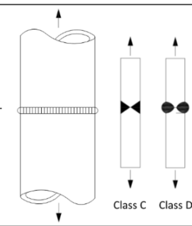
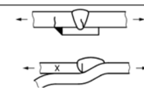
Compared to Class (columns); Considered Class (rows)

Class	D	E	F	F2	G
D	1.00	1.46	2.41	3.35	6.08
E	0.68	1.00	1.65	2.42	4.16
F	0.41	0.61	1.00	1.47	2.52
F2	0.28	0.41	0.68	1.00	1.71
G	0.16	0.24	0.40	0.58	1.00

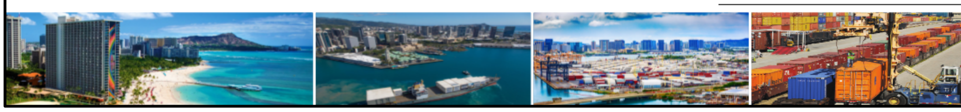
Note: Based on BS 7608:2014, and reliability of 97.8%

Example: For a given location on a crane, the fatigue life of a class F detail is expected to be 2.52 times that of a class G detail

Fatigue Detail Reliability from BS 7608:2014

Class: Nominal stress	Class: Hot-spot stress	Thickness and bending correction (see 16.3.2)	Notes	Sketch
C	Not applicable	Not applicable	NDT technique capable of ensuring the detection of significant flaws should be selected (see **14.3.4** and **B.5.2**.	
D	D	Applicable assuming b = 0.2 and $t_{eff} = t$		
E	E	Applicable assuming b = 0.2 and $t_{eff} = t$	Weld root condition assessed by appropriate NDT (see **B.5.2.4**). Without direct access to root automated ultrasonic testing (AUT) is recommended. Alternatively, class can be validated by testing (see Annex E)	
F	F		Applicable assuming b = 0.2 and $t_{eff} = t$. or thickness of member X in joggle joint	
F2	F2		Weld root condition not assessed directly by appropriate NDT	

13

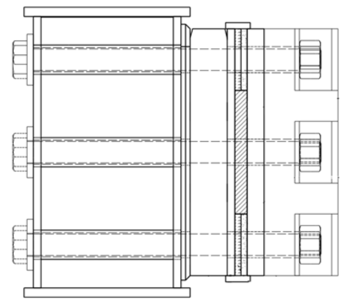


This slide is provided to show that small changes to the details can have a significant effect on reliability and fatigue life.

On the left, the 5 ft diameter float piles are shown during fabrication. Notice the large spacing of the transverse welds.
On bottom left, relative fatigue life for different details is provided.
On the right, see some fatigue details related to pile welds.

Improving the weld detail can improve fatigue life significantly, e.g., F2 to D improves life by 3.4x, E to D improves life by 1.5x.

Pile Collar Dampener



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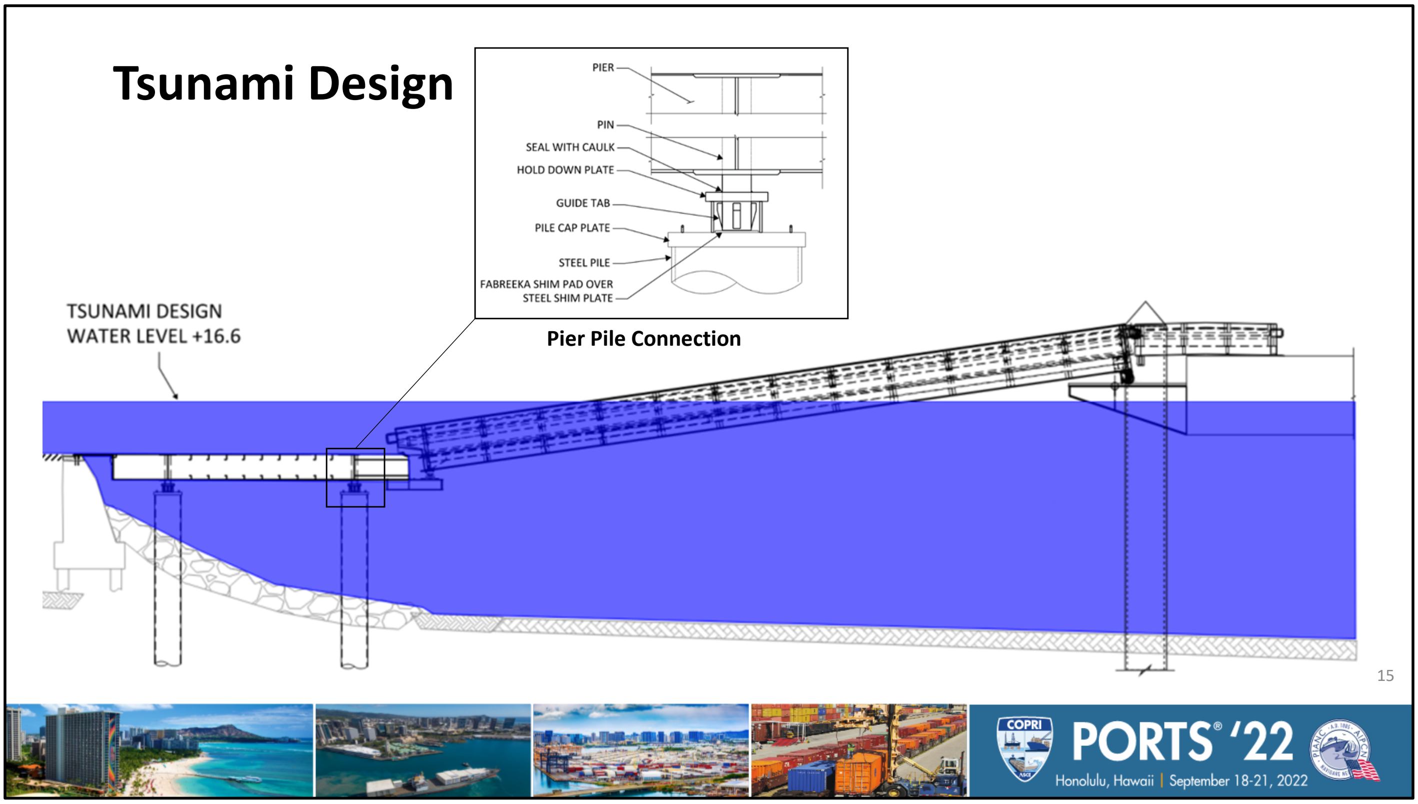
One of the design criteria was to mitigate float motions for the fire station personnel living on the float.

A very worthwhile design was integrating a dampener in the pile collar. The dampener is composed of reinforced rubber pads between steel plates to cushion the motions, reducing the accelerations and float impact on the piling by up to 90%.

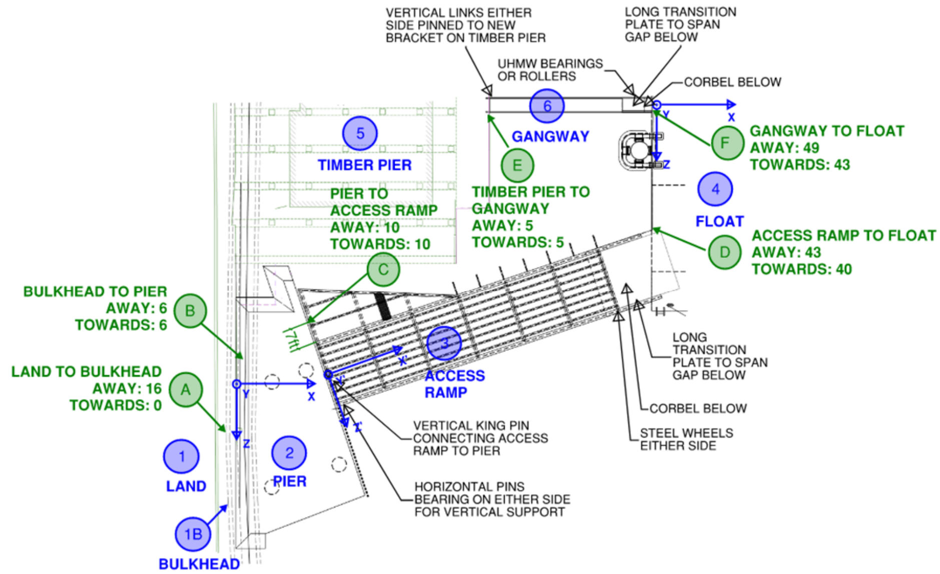
The lesson learned was that this was practical and worthwhile. There is no clanging between the float and piling with the addition of 1 in of elastomeric pads.



The tsunami design condition is shown. The float deck will be at 21.6 ft (6.6 m) NAVD88 with a design tsunami height of about 8 ft (2.4 m).

Some comments:
1. The pier is designed for large uplift. The superstructure vertical bar has guide tabs that bear against a hold down plate to transmit the large uplift loads.
2. All piles are designed for large lateral loads.
3. Float piles are tall enough to contain the float.
4. The float is designed for compartment damage and flooding – it was not practical to design for the more severe tsunami impact loading.

Float Design Storm and Earthquake Relative Motions (inches)



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This slide presents the relative design motions between components.

We found that the EQ design condition was significant, nearly as large as the design storm. EQ motions should be considered in addition to storm motions.

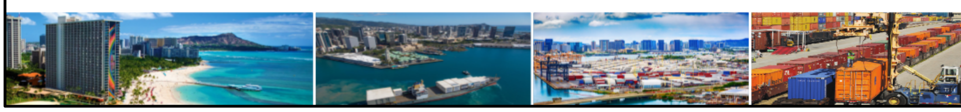
Will show locations on next slide
- Kingpin
- Slide bearing
- Steel wheels/rollers

Accommodating Relative Motions

Kingpin and sliding supports at pier to access ramp

Roller supports at access ramp to float

17



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Photographs:

Kingpin at pier-to-access-ramp interface
Low friction slide bearings at pier-to-access-ramp interface
Steel wheels/rollers at access-ramp-to-float interface

This slide shows complex bearing systems that allow for significant relative motions with little or no noise in a marine environment.

The float pile design analyses indicated the 100-year design storm loads will control over the design earthquake loads, mostly due to the long period of the float-pile system, which decreases the seismic design motions, though the water also provides limited damping (Soderberg et al 2019). Design storm and earthquake motions should typically be checked to determine which controls, since in certain locations or some designs, the design earthquake could control.

As discussed in the Pier Piling Design Approach section, the pier piling was designed for earthquake embankment design motions.

All project structures needed to accommodate significant design displacements and rotations. This was accomplished with various methods. The land-to-pier interface includes a seismic joint. The pier-to-access-ramp interface includes a kingpin and sliding feet. The access-ramp-to-float interface includes rollers. The access ramp supports can accommodate significant continual movement due to low-friction, self-lubricating marine bearings. All interfaces have transition plates.

Utility Relative Motions

Utility supports and protection

Utilities inside the float

18

Utilities run from the land, under the pier, along the access ramp, and into the float, and are protected from waterborne debris along the way.

Relative movements at component interfaces are up to several feet due to the EQ and storm loads.

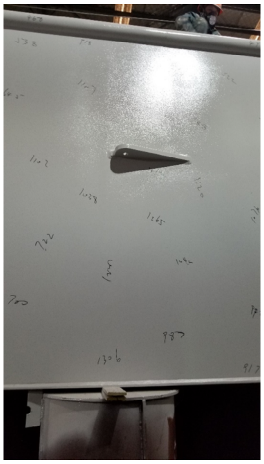
Flexible conduits are used at interfaces.

Structure was added to support and protect the flexible conduits.

Conduits inside the float are located as near the float neutral axis as practical to limit fatigue from float flexing.

Corrosion Design Approach

Marine coatings



Anodes

Sacrificial thickness (example below is based on side of float)

19

This float cannot be dry docked. We used three methods for corrosion design for 50 years:

- Marine grade coating
- Cathodic protection with sacrificial anodes (zinc and magnesium (internal))
- Sacrificial steel thickness – up to 3/8 in

Construction Approach

Test assembly at fabrication yard

Loadout and transportation to San Francisco Bay

20

The general construction approach was to construct off-site as much as practical to limit work on-site and to accelerate the construction schedule.

The float, access ramp, pier, and piles were fabricated in Nantong, China, by ZPMC, where Liftech Shanghai Limited coordinated much of the fabrication oversight.

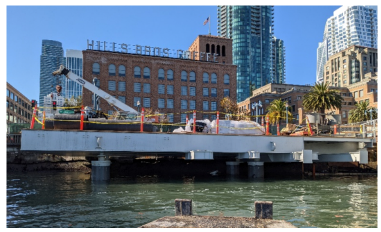
After fabrication, the structures were assembled at the yard before shipping to check for any clearance or assembly problems. This was worthwhile, as a few minor clearance issues were corrected at the yard rather than needing to be corrected during final installation on-site.

The structures were shipped to Treasure Island via barge.

Construction Approach

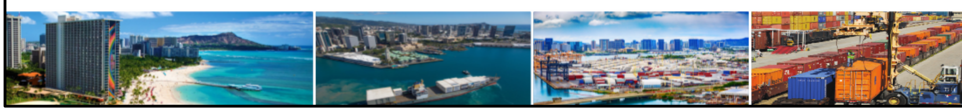
Building fabricated on float at Treasure Island

Pier unloaded to work barge and installed at Pier 22 1/2



Float piling installed at Pier 22 1/2

21



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Concurrent construction improved the construction schedule and permitted uninterrupted operations at the existing fire station.

The building was fabricated while the float was at Treasure Island. (Left photographs)

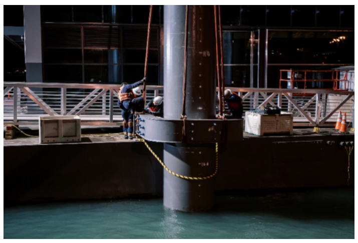
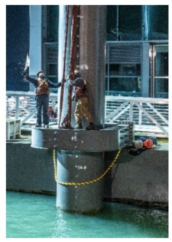
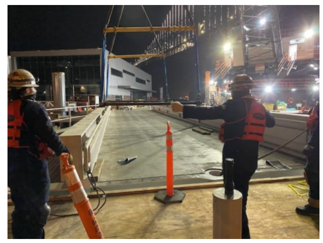
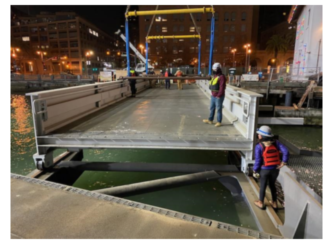
Piling was driven at the site. (Right photographs)

The pier superstructure was set onto piling at the site. (Top middle photograph: Work barge and pier superstructure. Lower middle photograph: Pier superstructure set onto the piling at the site.)

Construction Approach

Float installation at Pier 22 ½



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After the building was completed at Treasure Island, the float and access ramp were floated to the site and installed.

Installation was performed one night during calm weather and to limit wake from passing vessels.

Everything went well.

The off-site construction approach was worthwhile, saving significant cost and time with concurrent construction, and reducing construction congestion at and around the site at the busy Embarcadero.

Acknowledgements

For guidance and teamwork throughout the project

- San Francisco Public Works
- San Francisco Fire Department
- Ellen Johnck – Permitting consultant
- Power Engineering Construction Co. (PEC) – Marine contractor
- Swinerton Builders – Building contractor
- Shah Kawasaki Architects - Architect
- Liftech Team – Group Delta (geotechnical engineering), Argonautics (naval architect), Corrpro (corrosion), BKF (civil engineering), ABS Group (fabrication inspector)
- ZPMC – Chinese marine structure fabricator

Several Construction Approach photographs - PEC

We had some help throughout, so thank you to the team members above and to any others we may have missed.

Thank you!

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Thank you for attending my presentation. Let me know if you have any questions.


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