San Francisco Floating Fire Station 35: Overview and Lessons Learned

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ABSTRACT

The San Francisco Fire Department acquired a new floating fire station at Pier 22 ½ for their fireboat fleet. The station is built on a 9 ft x 95 ft x 173 ft (2.7 m x 29 m x 53 m) steel float that is moored with four 60 inch (1.52 m) diameter steel piles. A new pile-supported steel pier structure connects to the float via a steel access ramp. The floating station design is unique, having a steel float with an attached building that houses personnel at the station full time, accommodating sea-level rise, and designed as an essential facility with a 50-year design life. Even though this project was unusual, many of the items to consider and lessons learned can be applied to improve designs on more typical projects, such as ferry terminals. This paper will discuss some of those items.

INTRODUCTION

The new floating fire station (SFFD35) is an important addition to the San Francisco waterfront. It will allow fire fighters ready access to fire boats, improving the ability to reach parts of the city that could otherwise be inaccessible after a major disaster. It is also resilient to sea level rise, severe storms, flooding, and earthquakes.

Given its use and need for resiliency, the design had to meet many challenging requirements. It is the only floating building of its kind along the San Francisco waterfront and needed to meet permitting requirements by many entities. It is an essential facility and therefore is designed to remain operational with controlled and repairable damage after a 100-year Design Storm or ASCE 7 Design Earthquake. It is difficult to dry dock it for periodic maintenance as would typically be done for a steel float, so it is designed for a 50-year life without dry docking. It is designed to be accessible to ambulances and trucks, and certain areas are accessible to the public.

ITEMS TO CONSIDER AND LESSONS LEARNED

Though the station has more design requirements and is more robust than many other waterfront structures, many design and construction considerations can be applied to other marine structures and facilities. This section presents several of those items. See Figure 1 for a plan view of the facility.

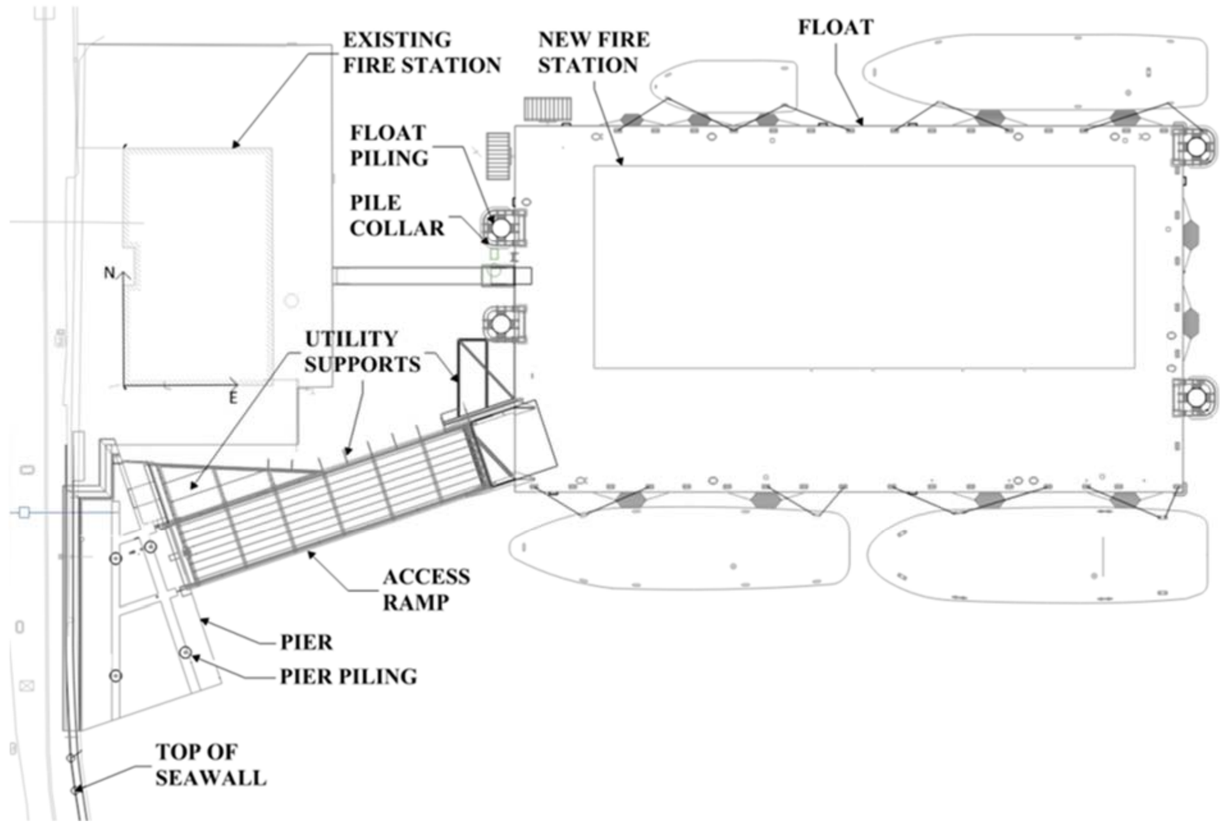


Figure 1. Plan view of facility.

Corrosion Design Approach

Corrosion is a significant concern in marine environments. Steel structures are typically protected with coatings and cathodic protection, such as anodes. This is reasonable since most floats can be dry docked periodically to repair coatings and replace below-water anodes. However, it would be difficult to dry dock the SFFD35 float due to the attached building. Given that, combinations of coatings, zinc and magnesium anodes, and sacrificial steel thicknesses were used on the float, access ramp, pier, and piling to meet the 50-year design life with minimal maintenance. Providing sacrificial steel thickness was found to be more economical than providing 50 years of anodes. Anodes can still be maintained to limit corrosion.

Pier Design Approach

Two important requirements for the facility were that it integrate well with the existing San Francisco Embarcadero and original Fire Station 35, including providing additional public access, and that it be resilient to sea level rise. To accomplish the former, the pier is mostly accessible to the public and the pier deck is at the same elevation as an adjacent sidewalk and timber pier. However, that elevation is below the design sea level rise elevation, so the pier may need to be raised in the future. This can be accomplished relatively easily because the pier was prefabricated as a single structure that can be disconnected from the piles, lifted, and reset on extensions welded to the top of the piles as shown in Figure 2.

Figure 2. Pier connection to pier piles.

Tsunami Design Loading

This location has a design tsunami height of about 8 ft (2.5 m). The float guide piles extend far enough above the water to prevent the float from rising above the piles and floating away. The piles are also designed for lateral loads from the float rising to the design tsunami elevation. The pier is designed for lateral and vertical loads due to the tsunami water levels, including the uplift from buoyancy.

Pier Piling Design Approach

The pier is just waterside of the San Francisco seawall concrete bulkhead. Figure 3 shows the limited clearance between the seawall and the pier, where the top of the seawall is shown on the right side under the railing, and the edge of the pier is shown on the left side. This photo was taken during construction before removal of the railings and installation of the transition plates from the pier to embarcadero. Figure 4 shows the pier piles in the seawall rock embankment.

Figure 3. Pier and top of seawall.

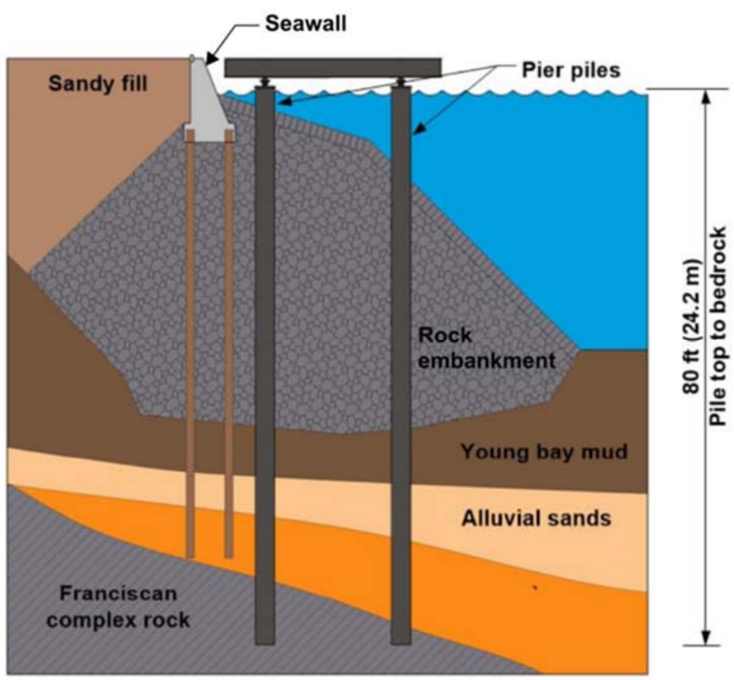


Figure 4. Elevation of pier and seawall.

The piles are designed to accommodate seawall lateral movement in the design earthquake. This pile design included an involved analysis of the rock seawall embankment sliding on the relatively weak 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 on the project is that it is reasonable to design such a piling system with a "fitness for purpose" approach. Even if plastic hinges develop in the piling, the piles still provide adequate vertical support due to the lateral support of the surrounding soil as shown in Figure 5.

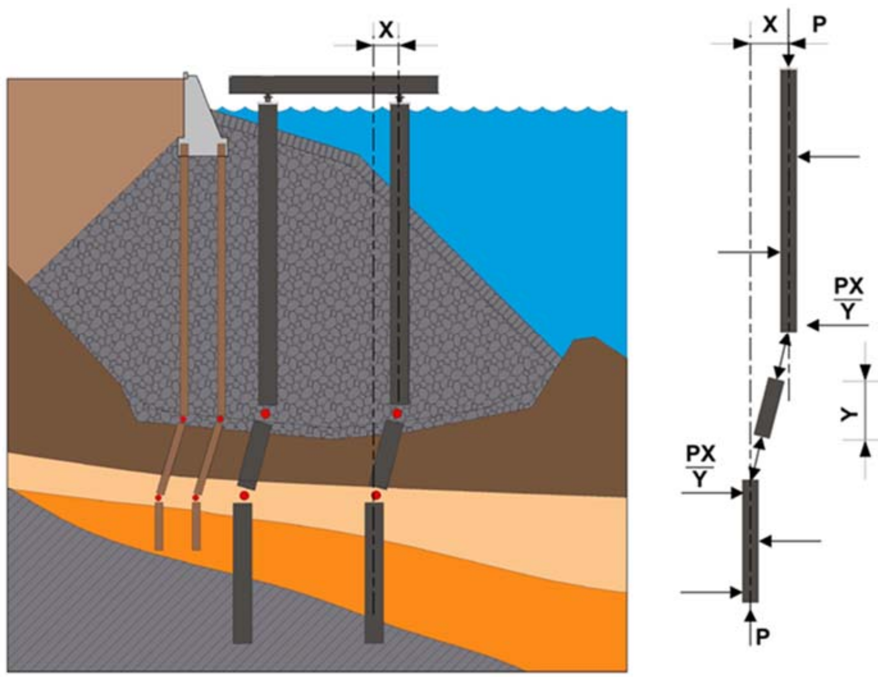


Figure 5. Pier piling plastic hinging and free body diagram.

Utility Relative Motions

The utilities run from the land, under the pier, along the access ramp, and into the float. Each of these structures can experience relative movement due to the seismic and storm loads, where some of the relative movements between components are several feet. Flex conduit is used at multiple locations so the utilities can accommodate these large relative movements. Additional structure is provided at multiple locations to support and protect the flex conduit. For example, the corner of the float near the access ramp has a large cantilever platform to support the conduit where it enters the float, as shown in Figure 6.

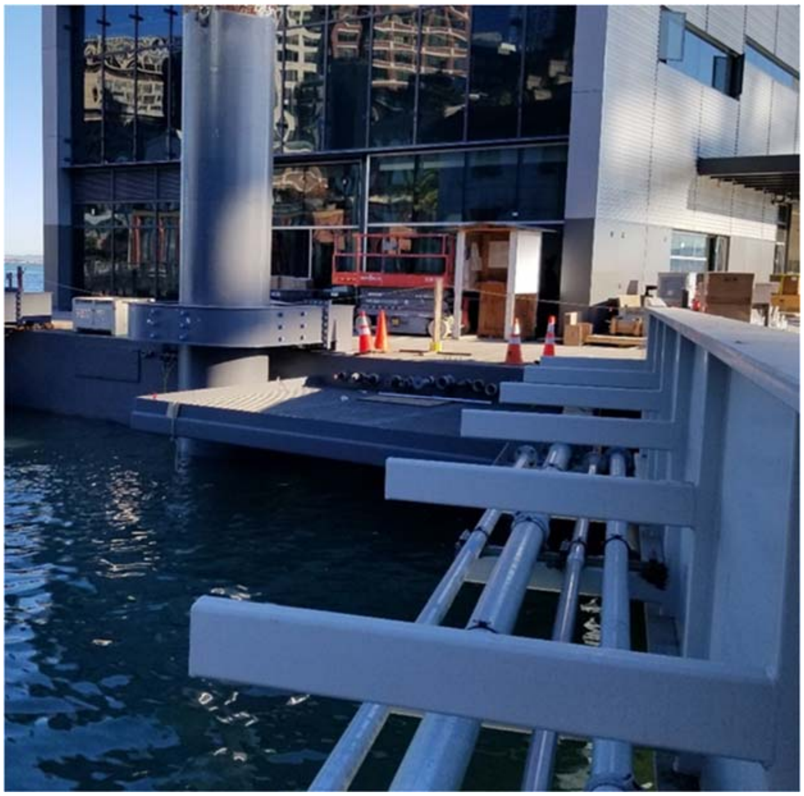


Figure 6. Utility supports on access ramp and float.

One lesson learned is that designing a facility with large relative movements and large diameter conduit is a significant undertaking, and large supports can be required for the flexible lengths of connections between the various components.

Float Design Storm and Design Earthquake Motions

The float pile design included analyses indicating the 100-year design storm loads will control over the Design Earthquake loads. This is mostly due to the lengthy period of the float-pile system decreasing 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 pier-to-land interface includes a seismic joint. The pier-to-access-ramp interface includes a kingpin and sliding feet (see Figures 7 and 8). The access ramp to the float includes rollers. The access ramp supports can accommodate significant continual movement due to low-friction, self-lubricating marine bearings. All interfaces have transition plates.

Figure 7. Pier kingpin sleeve and slide bearing supports.

Figure 8. Interface of access ramp sliding foot and pier (Teflon bearing).

Float Pile Cyclic Loading and Reliability

Structural reliability of the float piles due to the cyclic lateral loading over the 50-year design life was evaluated. A wave loading spectrum based on past wave data was applied and the stresses and fatigue life were calculated. 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 (see Figure 9). A series reliability of greater than 0.977 was achieved for the 50-year design life. Series reliability is the reliability of a series of details, or the product of the reliability of each detail in the series. This provides the total reliability. For example, if a pipe has ten transverse welds with a calculated reliability at each weld of 99.6%, the series reliability or total reliability of the pipe is only 96.1%, or 0.996^{10}.

BS 7608:2014

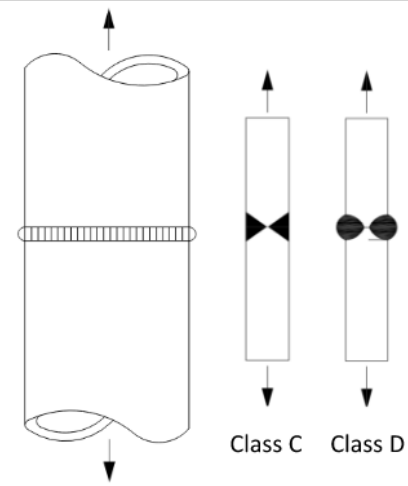
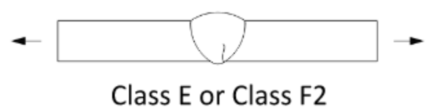
Class: Nominal stress	Class: Hot-spot stress	Thickness and bending correction (see 16.3.2)	Notes	Sketch
C	Not applicable	Not applicable	NDT technique capable of ensuring the detection of significant flaws should be selected (see **14.3.4** and **B.5.2.**	
D	D	Applicable assuming b = 0.2 and $t_{eff} = t$		
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)	
F2	F2		Weld root condition not assessed directly by appropriate NDT	

Figure 9. Excerpt from BS 7608 – select fatigue detail classes.

The following were determined from this analysis:

1. Fatigue damage from wave loads is significant. It is not surprising that 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.

Pile Collar Damper

The fire station needed to meet cruise ship comfort criteria due to the fire fighters living on the station during their shifts. It was a significant challenge to design a robust float system with strong and stiff piles able to resist wind, wave, and berthing loads while also mitigating the float movements. It was practical to integrate a dampener in the pile collar composed of reinforced rubber pads between steel plates to cushion the motions (see Figure 10), reducing the accelerations and float impact on the piling by up to 90%.

Figure 10. Pile collar damper.

Construction Approach and Results

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 (see Figure 11). This was a valuable exercise, as a few 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 (see Figure 12). This construction approach provided significant cost savings to the team.

The building was erected on the float at Treasure Island and the piling and pier installed at Pier 22 ½ in San Francisco. The float with building was then pulled to Pier 22 ½ and the access ramp was installed.

Figure 11. Test assembly at the fabrication yard.

Figure 12. Delivery of structures to San Francisco Bay. [Photograph from Argonautics Marine Engineering, Inc. with permission.]

CONCLUSION

This paper presented several important design and construction factors that were used to help ensure the success of the new San Francisco floating fire station. Though this is a unique facility, these factors can also be considered in other marine projects with similar constraints.

REFERENCES

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