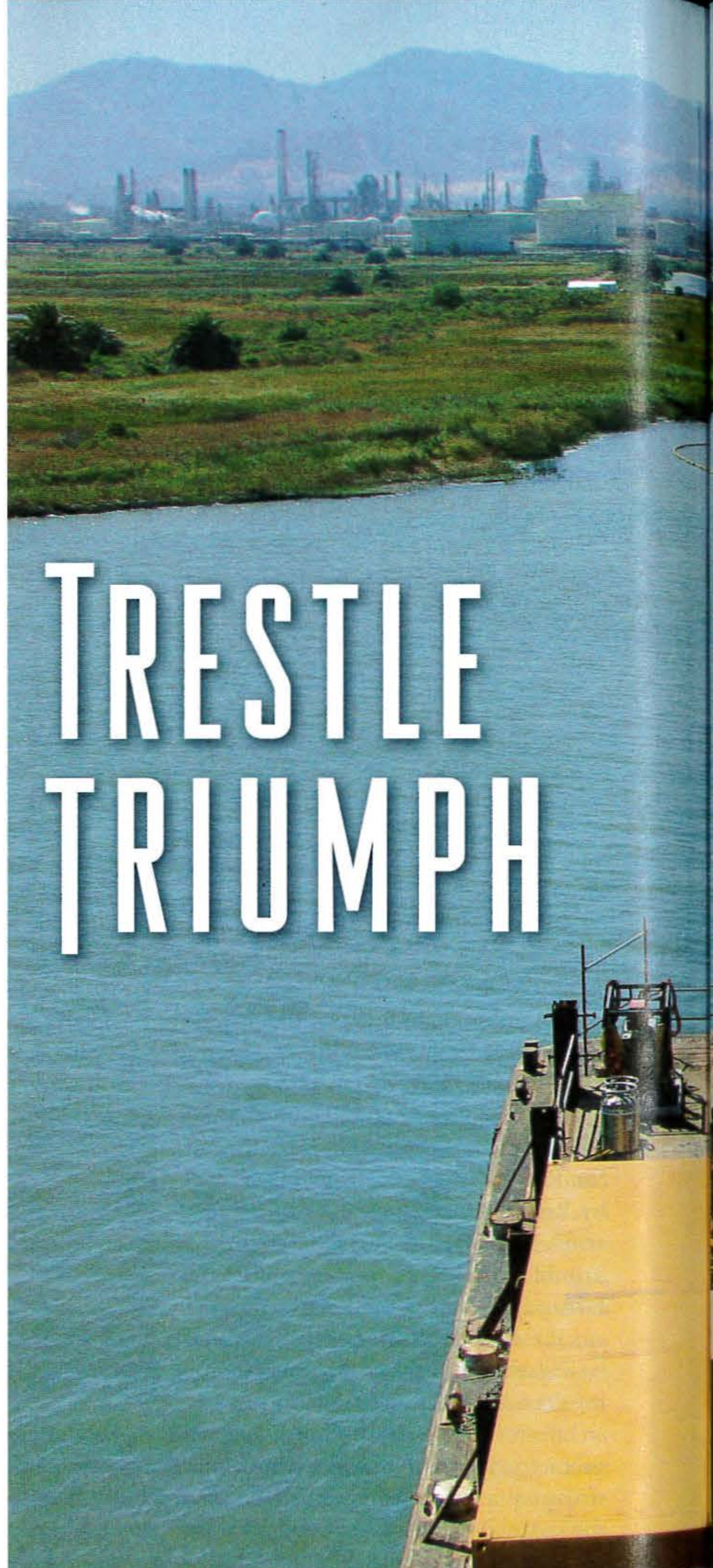

Trestle Triumph

As part of improvements to a marine oil terminal in California, the design team had to ensure that a nearly century-old timber trestle met contemporary requirements related to operations, seismic activity, and anticipated rises in sea level. Completed this past May, the timber structure is the first in the San Francisco Bay Area to be upgraded to meet such requirements.

By Ted W. Trenkwalder, P.E., S.E., M.ASCE, Sandy Yee, S.E., and Andres Espinoza, Ph.D., P.E.

MARINE OIL TERMINALS in California must comply with the state's Marine Oil Terminal Engineering and Maintenance Standards (MOTEMS). Promulgated in 2006, the standards include requirements for the review, assessment, and rehabilitation of marine oil terminals in the state. Recently, the owner of a marine oil terminal in Martinez, California, opted to achieve compliance by replacing and repairing portions of a more than 90-year-old timber trestle and the "pipeway," that is, the conveyance for the piping, that serve the terminal. The strengthened structures meet current operational and seismic demands as well as anticipated changes associated with climate change. This is the first timber structure in the San Francisco Bay Area to be upgraded to satisfy contemporary design requirements related to operations, seismic activity, and expected rises in sea level.

The oil company maintains the marine oil terminal on the Bulls Head Channel, which is within Suisun Bay near Martinez, in Contra Costa County. Consisting of two berths and a 1 mi long trestle, the marine oil terminal supports the company's adjacent refinery by facilitating the export of petroleum products. Extending from the refinery to the terminal, the timber trestle traverses a wildlife marsh and connects to a timber berth, Berth 1, located in water approximately 45 ft deep. The other berth, Berth 5, is a concrete structure immediately to the west of Berth 1. Located immediately east of Berth 1 is a new berth, 1A, that was commissioned this year. (See the figure on page 79.)

Berth 1 and the timber trestle were built in 1925, and Berth 5 and a connecting timber structure were added in 1954. A timber pile-and-deck structure, Berth 1 is protected by timber piles and a steel-spring fender system along the channel side and by timber fender piles on the land side. A system of timber piles and steel-spring fenders protects the channel side of Berth 5. The original mile-long timber trestle that connected Berth 1 to the shore supported the pipeway and a railway system to facilitate personnel access. Berth 1 and Berth 5 have been decommissioned and are no longer being used for vessel mooring or product transfer.

The terminal has been maintained and repaired over the years. In 1998 and 2010 steel monopile dolphins 7 ft in diameter were added to Berth 1 to improve mooring and berthing capacity. In late 2008 the terminal owner was advised that the waterside structures were susceptible to

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liquefaction during a seismic event and presented a collapse hazard. Beginning in 2009, the owner conducted the engineering studies necessary to ensure that Berth 1 and the trestle complied with MOTEMS.

In 2011 the owner hired a team to design a new berth and trestle that would meet the MOTEMS requirements. The team consisted of the Oakland, California, office of COWI Marine North America; the Anvil Corporation, of Bellingham, Washington; and Langan, which has its headquarters in Parsippany, New Jersey. In 2014 the owner requested bids for the construction of a new berth, to be called Berth 1A and located next to Berth 1. The project also included replacing the timber approach trestle from Berth 1 to the point onshore at which dry land begins and upgrading the trestle south of

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The trestle extends in a largely south to north orientation from the refinery to the berths. The upgrade of the trestle was subdivided into four areas based on water depth, tides, potential liquefaction, and permit restrictions. Area A, the southernmost section of the trestle, begins at the refinery and extends north to bent 262. Area B continues from bent 262 to bent 163. Area C extends from bent 163 to bent 68, which is located at the shoreline. Area D extends from the shoreline to Berth 1 and Berth 1A (see the figure on page 79). For each area, the selected trestle upgrade alternatives adhere to the most recent edition of MOTEMS from the California State Lands Commission and incorporate input from the owner.

The berth and trestle design included repair and replacement options developed on the basis of requirements pertaining to performance and cost. Portions of the trestle deemed capable of meeting the performance requirements would be repaired, while portions unable to do so would be replaced. The portion of the trestle forming areas A and B was found to be in fair condition. Located behind an earthen berm, this portion is not susceptible to liquefaction or tidal inundation. In an effort to reduce initial capital costs, the design included an approach in which minimum repairs would be carried out to ensure that the existing trestle in areas A and B met MOTEMS requirements.

However, the remainder of the trestle, that is, areas C and D, is subjected to tidal action and could experience flooding during the structure's design life. In area D the existing berths and trestle are susceptible to liquefaction and kinematic loading on the structure's pilings. Because of soil deposition in the vicinity of the wharf, the existing berths have mounds of soil beneath them, making the structures susceptible to liquefaction and, possibly, collapse. Therefore, the design called for the replacement of the trestle in areas C and D to meet permitting requirements associated with seismic activity and potential rises in sea level.

The project's design life varies between the new and the repaired structures. New structures have a 50-year design life, while repaired structures have an assumed 25-year design life. The repaired trestle sections have a shorter design life because of the assumed condition below the mud line of the existing timber pilings, which, as mentioned above, are more than 90 years old. The existing pilings will require regular inspections and maintenance to achieve the 25-year design life. By contrast, the new structures have epoxy-coated steel pilings and a $^1/_8$ in. steel corrosion allowance to ensure that they meet or exceed their 50-year design life. Because MOTEMS requires periodic inspections, depending on the inspection findings and the actual demands, the new pilings could exceed their 50-year design life with proper inspection and maintenance.

As defined by MOTEMS, the design criteria for the berth and trestle included dead loads, vehicle and equipment loads, and seismic loading. The berth design also included loads associated with the control room constructed as part of Berth 1A. The trestle in areas C and D was designed for dead loads, standard truck loads, and piping loads. In areas A and B, some portions of the trestle can accommodate vehicle access, while others are restricted to pedestrian or bike traffic. To this end, the trestle design included a new section to the west of the pipeway on which refinery staff may walk or cycle. Separating the walkway and bikeway section from the pipeway helped to improve the performance of the latter. The walkway and bikeway section was designed for dead and live loads. The pipeway, however, was designed for dead loads and piping loads and if necessary can be expanded in the future. To resist the operational and seismic loads of the piping, five new anchor stations are located along the length of the trestle and the manifold of the new berth. All structures were designed for seismic loads in accordance with MOTEMS.

The berth and trestle operational design loads included the following:

• Dead load, including the weight of the structure itself and any superimposed dead loads;

• Live load, which includes 100 psf for the roadways and walkways, standard truck loading for the roadway, loading from a septic truck that is used for transferring wastewater between the terminal and the onshore facilities, and loading from a forklift that operates between Berth 1A and the trestle roadway;

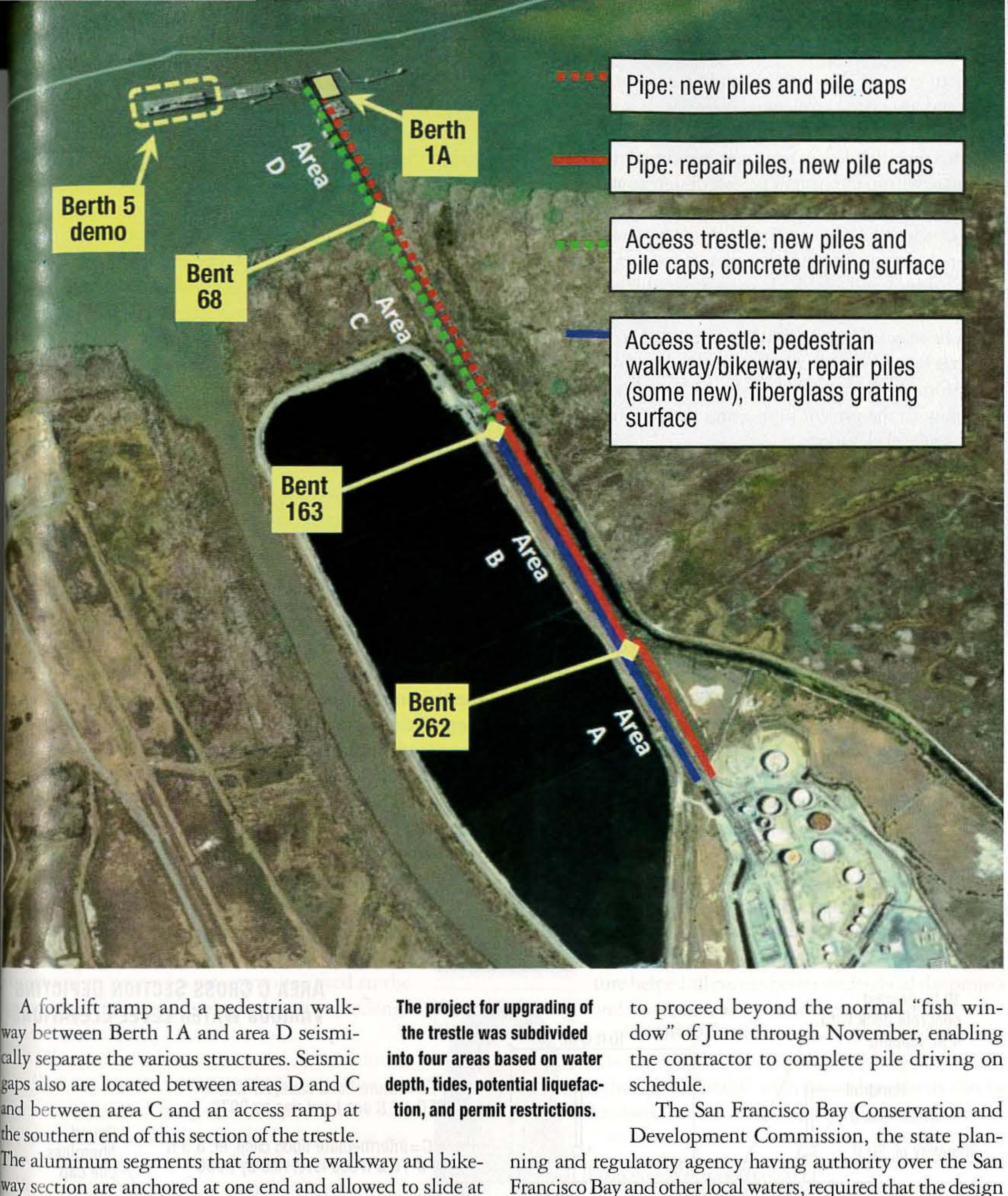
• Wind loads in accordance with MOTEMS and ASCE's standard 7-10 (*Minimum Design Loads for Buildings and Other Structures*);

• Tides (+7 ft and –2 ft), currents (5 ft/s), and waves (2 ft), including the effects on these from tsunamis, floods, sea level changes, and storm surges.

Langan conducted the geotechnical investigation and developed design seismic response spectra for the performance-based design of this project. In accordance with the MOTEMS requirements for the soft soils at the site, the response spectra are intended to ensure that the facility remains operational after what is known as a level 1 earthquake, which has a return period of 72 years. In the event of a level 2 earthquake, which has a return period of 475 years, the facility is designed to sustain repairable damage but to prevent a major spill.

The piping designer provided the operational and hydrostatic test loads, the seismic guide loads, and the piping anchor loads. The seismic piping loads, either longitudinal or transverse, were superimposed on the structure seismic loading, and an assessment of the structural system was then completed for both levels of earthquakes. Allowable displacements for the existing piping were taken into account in the design of the pipeway anchor stations.

The seismic performance requirements are specified in MOTEMS and depend on whether the structural material is timber, concrete, or steel. Although the piping is supported vertically at each bent, it is anchored laterally only at the five anchor stations located along the trestle. Between the anchor stations, the piping is allowed to slide laterally on top of polyethylene pads of ultrahigh molecular weight supported by steel cap beams. The pads have a specified coefficient of friction that allows greater sliding while imposing less load on the structures located between the anchor stations.



A forklift ramp and a pedestrian walkway between Berth 1A and area D seismically separate the various structures. Seismic gaps also are located between areas D and C and between area C and an access ramp at the southern end of this section of the trestle. The aluminum segments that form the walkway and bikeway section are anchored at one end and allowed to slide at the other.

The project for upgrading of the trestle was subdivided into four areas based on water depth, tides, potential liquefaction, and permit restrictions.

The project had to comply with restrictions related to the installation of piles in the water. Two regulatory agencies, the California Department of Fish and Wildlife and the National Oceanic and Atmospheric Administration, were concerned that the noise levels associated with pile installation might have untoward effects on the habitat and migratory patterns of fish and pinnipeds. The owner and the design team discussed with the agencies how best to mitigate sound levels during pile installation. The regulatory agencies agreed to the use of a bubble curtain to attenuate the expected noise levels. To confirm that sound attenuation was maintained during pile installation, the pile driving was monitored. Regulators allowed the work to proceed beyond the normal "fish window" of June through November, enabling the contractor to complete pile driving on schedule.

The San Francisco Bay Conservation and Development Commission, the state planning and regulatory agency having authority over the San Francisco Bay and other local waters, required that the design team consider a rise in sea level of approximately 2 ft over the 50-year design life of the new structures. The rise expected to occur during the project life was determined using the medium trajectory estimates developed by the Coastal and Ocean Working Group of California's Climate Action Team, a body comprising state agencies, boards, and departments that works with the California Environmental Protection Agency to mitigate the effects of climate change throughout the state.

Because it was in good condition, the existing piping was to remain in place, and the new structure was to be constructed around the existing piping and eventually support the piping once the existing structure had been demolished. Because it is not located on an elevated pipeway, the southern edge of the piping could be susceptible to wave loads and associated accelerated corrosion as a result of rises in sea level in 15 years.

Therefore, the design team was asked to develop and incorporate within the current project design an adaptive measure that would enable the pipe to rise as sea level rises. The team developed a means to install a new pipeway beam at a higher elevation. A traveling trolley supported from the existing roadway and guardrail can be used to lift and place piping for the elevated pipeway in area C. Piping in areas A and B can be relocated to the newly constructed access roadway, which is located well above the estimated sea level elevations in the future. The figure below shows the typical area C cross section with the present piping and the current and anticipated sea level elevations.

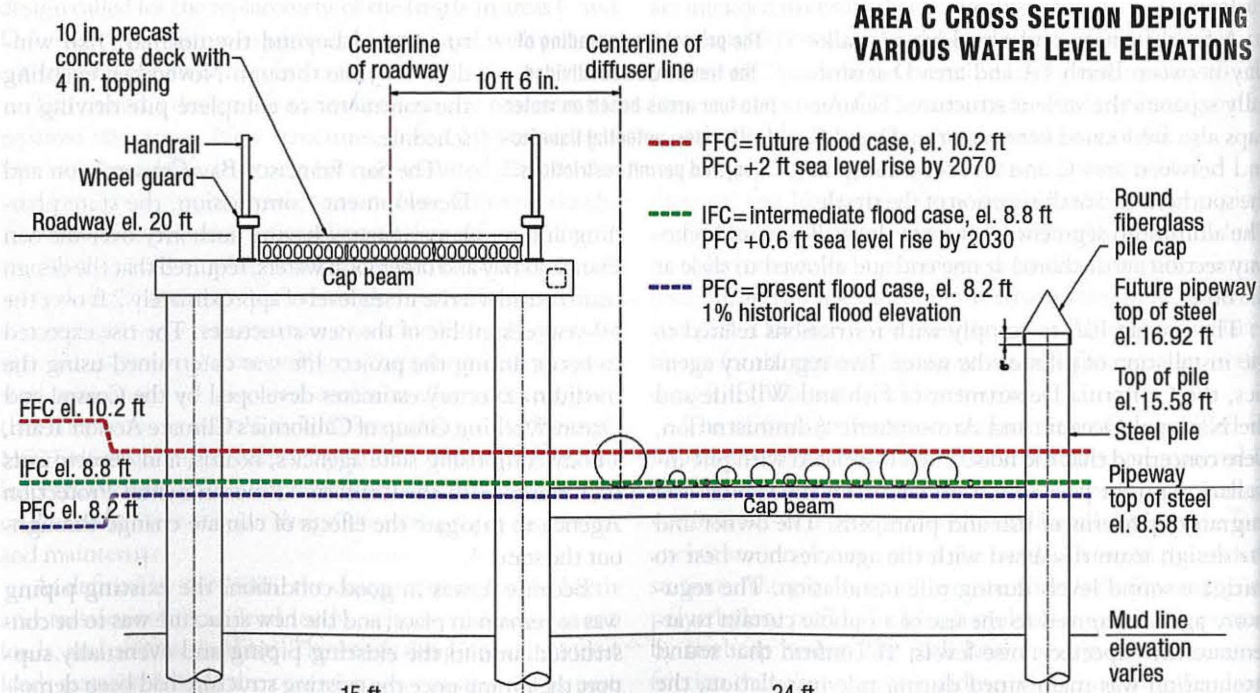
Because the replacement and repair work on the trestle was to occur within a marshland, the design team developed means to minimize the use of permanent and temporary fill. The agencies granting the necessary permits would not allow a construction trestle or other temporary structures to be erected in marshland within areas A through C. In areas A and B, the proposed repairs were conducted by means of heavy equipment operating from a newly constructed roadway or from small, temporary crane platforms located outside of the designated marshland areas. In area C an "over-the-top" construction method would be required to build the replacement trestle. The design team considered the optimum crane size that could be used to lift and drive the heaviest pile or place the heaviest cap beam for the permanent trestle. The contractor would need to install the permanent piles and ensure that its crane could be adequately supported by the permanent piling within the limited setup time available to achieve the necessary production rates.

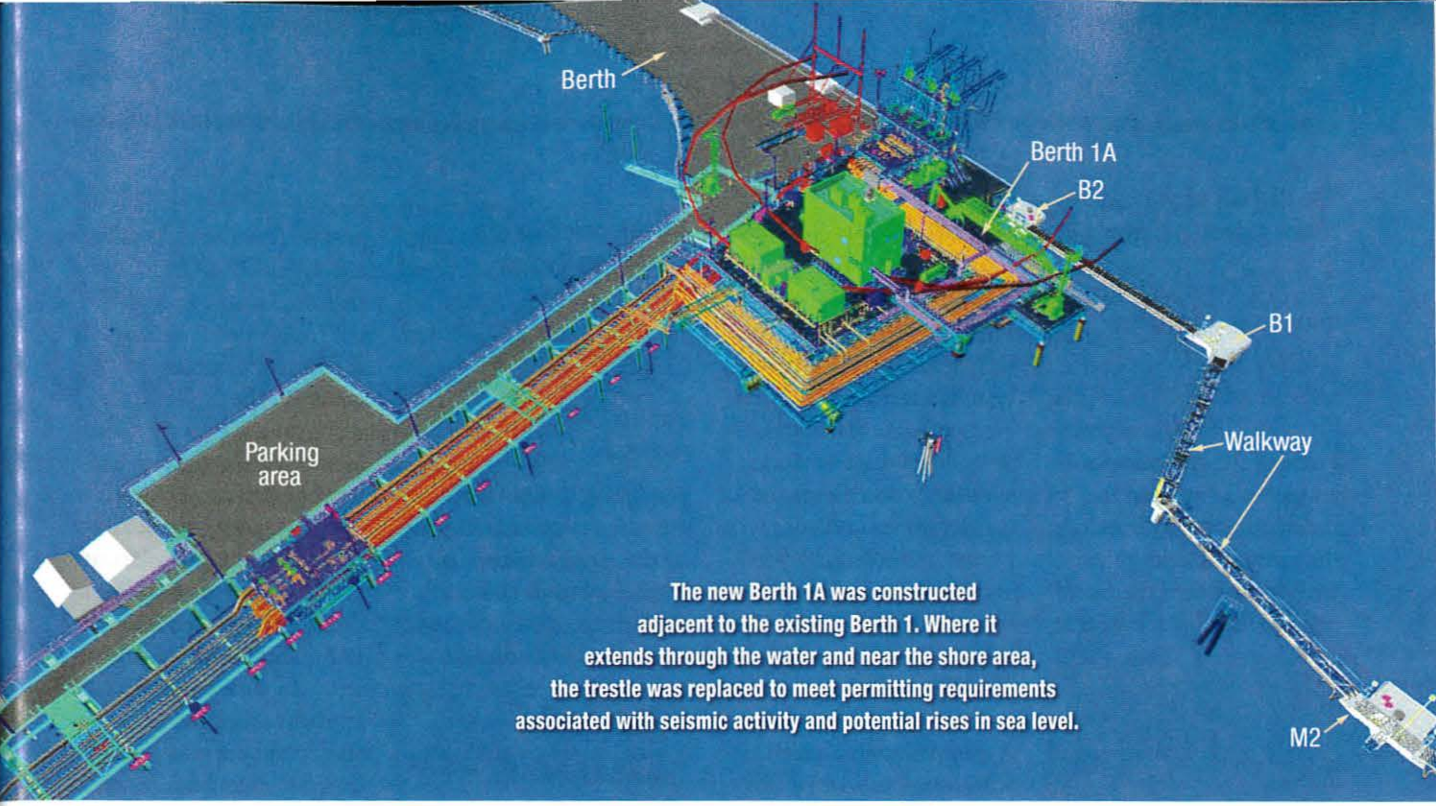
Crane selection was of paramount importance for the trestle construction. The selected contractor—Cherne Contracting Corporation, of Eden Prairie, Minnesota—proposed a 200-ton crane, which required longer piling but afforded greater flexibility for the contractor's proposed means and methods. Beginning in 2014, the contractor worked from both ends of area C to complete the work within the fish window, that is, the four months during which construction could occur in the tidal areas. The contractor drove piling, erected temporary trestle support beams, and worked toward the middle of the new trestle in area C. After completing the pile installation, the contractor worked backwards, removing falsework and placing new steel caps and decking. Because it occurred above the water, this work could be conducted outside of the fish window.

Another challenge for the trestle construction involved the need to keep the trestle piping operational so as to meet the refinery's various shipping schedules. This requirement meant that the new trestle piling had to be installed among existing timber piling and piping in a way that would not affect existing pile capacities or product deliveries. Because the existing trestle piling is spaced approximately 16 ft apart on center, the design team arranged the new piles to be spaced approximately 24 ft apart on center. In this way the new piling is staggered by a minimum of four pile diameters from the existing timber piling to avoid down drag and settlement of the existing timber piling that supports the piping. The design team also had to ensure that pile-driving equipment remained at least 2 ft away from live product lines at all times. This precaution was taken to avoid damaging the existing pipeline and risking an oil spill into the water or marshland.

Construction of the new trestle and Berth 1A was completed this past May. With the completion of Berth 1A and the upgrades to the trestle, loading operations were discontinued at

AREA C CROSS SECTION DEPICTING VARIOUS WATER LEVEL ELEVATIONS





The new Berth 1A was constructed adjacent to the existing Berth 1. Where it extends through the water and near the shore area, the trestle was replaced to meet permitting requirements associated with seismic activity and potential rises in sea level.

Berth 1 and now occur at Berth 1A. Ultimately, the design and construction of this project succeeded as a result of the ability of the owner, its consultants, and the contractor to quickly grasp the critical items of the project and keep them firmly in mind through construction.

Lessons Learned

• Good communication with end users and agencies is necessary in the design process. For example, educating the agencies on the safety and operational benefits associated with the newer terminal proved helpful. The schedule and the various steps of the construction process were communicated to the agencies and community through public meetings and news articles.

• The goals of the project need to be defined, detailed, and understood by all parties. The design team defined the project requirements and approach in a report (*Basis for Design*) that was approved by the refinery staff. The owner's team excelled at outlining and communicating the project requirements with corporate stakeholders and regulatory agencies so that all parties would have a sound understanding of the costs and scheduling effects of the proposed improvements. This communication enabled the refinery to move forward with the project while adhering to its financial guidelines.

• Understaffed regulatory agencies require a longer time to review, assess, and approve projects. Fortunately, the owner already had an internal department dedicated to environmental compliance, and its members involved the agencies early on and navigated the project thorough the approval process.

• Early contractor involvement exposed potential construction problems that could have arisen as a result of the contractor's means and methods. For example, the contractor proposed heavier and wider cranes, which then led to changes to the steel caps and piles on the project.

• MOTEMS, an accepted design standard, proved beneficial because some agencies with the best of intentions proposed requirements that would not have improved structural performance. MOTEMS will help in formulating design criteria for marine oil terminals and waterfront structures sufficient to meet operational and extreme events.

• Detailed modeling for portions of the structure helped all parties better understand the project and keep goals and cost restrictions in mind.

• Geotechnical recommendations should include studies of alternatives for pile support so that other geotechnical analyses and methods can be explored. **CE**

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PROJECT CREDITS **Structural engineering:** COWI Marine North America, Oakland, California, office **Mechanical, electrical, and piping design:** Anvil Corporation, Bellingham, Washington, office **Geotechnical engineering:** Langan, Parsippany, New Jersey **Construction management:** Eichleay, Inc., Concord, California **General contractor:** Cherne Contracting Corporation, Eden Prairie, Minnesota