Marine Oil Terminal Engineering and Maintenance Standards (MOTEMS) Structural Analysis, Design & Performance Requirements

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Introduction

Most of the existing Marine Oil Terminals (MOT's) in California were built before today's more stringent seismic code requirements and before today's much larger oil carrying vessels. Due to general population growth it has become increasingly difficult if not almost impossible to build MOT's at new locations around the main metropolitan areas. Most existing MOT's have therefore not been moved over the years but rather been upgraded and rehabilitated to be able to handle the ever increasing demand for oil.

Following the passing of the Lempert-Keene-Seastrand Oil Spill Prevention and Response Act of 1990, the Marine Facilities Division (MFD) was created under the California State Lands Commission (CSLC). This Act provided the MFD with the specific task of developing rules, regulations and guidelines for performance standards of MOT's such that the facilities provide the best achievable protection of the public health and safety, and the environment.

The MOTEMS (Ref /1/) document is a direct result of this Act. The guidelines are comprised of the following sections:

1. Introduction
2. Audit and Inspection
3. Structural Loading Criteria
4. Seismic Analysis and Structural Performance
5. Mooring and Berthing Analysis and Design Criteria
6. Geotechnical Hazards and Foundations
7. Structural Analysis and Design of Components
8. Fire Prevention, Detection, and Suppression
9. Piping and Pipelines
10. Mechanical and Electrical Equipment
11. Electrical Systems

Each MOT operator is required to inspect, audit and evaluate the structural, electrical and mechanical components of the facility. Part of the audit requires that mooring and berthing analysis as well as a seismic analysis be carried out in accordance with the MOTEMS guidelines. This paper discusses these requirements and the general philosophy behind them.

Existing Characteristics of Marine Oil Terminals in California

There is approximately 45 active MOT's along the coast of California. While they vary greatly in size, vessel calls and oil thru-put, almost all of them have one thing in common, they are old. About two-thirds of all MOT's in California were built before 1960 and approximately forty percent were built before 1940.

The terminals are dominated by pile-supported concrete and timber structures and hybrids of the two where a few steel structures are the exception. The MOTEMS document therefore provides extensive guidelines on the analysis of terminals supported by concrete and/or timber piles.

The layout of the MOT's vary greatly even though the traditional loading platform/access trestle configuration dominates.

Seismic Performance Requirements

One of the requirements of the new audit is a seismic analysis of the structural system. Following a string of serious earthquakes along the Pacific Rim in the late 1980'ies and early to mid 1990'ies the seismic design codes have undergone major changes. Prior to these events, the seismic codes had only seen minor revisions of which the most significant was minor increases in the lateral design accelerations. As an example, major transportation structures in the 1950'ies were designed for approximately 0.1g lateral acceleration whereas today the seismic upgrade projects are designed for up to 1.5g lateral acceleration.

One could easily fear that the large increase in lateral design acceleration would have a detrimental effect on the existing aged MOT's that are designed for hardly any lateral acceleration. The objective of the MOTEMS guidelines is not to force all MOT operators into closure, relocation or construction of replacement structures.

Using state-of-the-art seismic performance standards that optimizes the capacity of the existing structures is therefore of paramount importance. MOTEMS is based on such performance standards that allow the engineer to utilize the full capacity of each component of the structure.

MOT's typically have an advantage over other waterfront berthing facilities such as container wharves and U.S. Navy type piers. MOT's often consist of a loading platform with an access trestle and breasting and mooring dolphins. These independent structures carry little live load and are typically connected through catwalks. These characteristics result in structures with little seismic mass, which in turn limit the seismic force they will attract. This will most likely reduce any required seismic upgrades and help the old structures withstand today's modern seismic demands.

Not all MOT's have such a light configuration. The importance of a performance based analysis methodology that can minimize the required improvements is therefore obvious.

The main features of the seismic performance standards are as follows:

- Analysis is displacement based. This allows for much better tracking of internal demands, which in turn allows for greater capacity of the entire structure.
- Moment-curvature analysis of sectional members is used for input into the displacement based analysis. This moment-curvature analysis allows for greater concrete and steel strains than typically used in ACI 318. This increases the deformation characteristics.
- Higher damping values may be allowed when a refined analysis is used. This will reduce the overall displacement demand of the structure.
- Risk Classification. MOT's are subject to varying seismic demands depending on the exposed oil on the terminal, the number of transfers per year and the size of vessels calling at the terminal. The classification is as follows:

MOT Risk Classification			
Risk Classification	Exposed Oil* (bbls)	Transfers per Year/Berthing System	Max Vessel Size (DWTx1000)
High	1200	N.A.	N.A.
Moderate	< 1200	90	30
Low	< 1200	< 90	< 30

* Exposed oil is defined as the sum of all stored and flowing volumes, prior to Emergency Shut Down (ESD) stopping the flow of oil.

The effect of using performance/displacement based analysis is illustrated in the following example:

The key for the survival of any marine oil terminal subjected to seismic forces is its ability to undergo lateral deformations. For pile-supported structures the lateral displacement capacity is typically controlled by the piling and pile/deck connection. Consider two pile/deck connection configurations:

1. New 24-inch octagonal prestressed/precast concrete pile connected to the deck through 8 - #10 dowels
2. Old (pre 1930) 20-inch square precast concrete pile connected to the deck through 4 - 1" square dowels

While the newer pile has much greater strength than the old pile, both pile connection details have similar moment-curvature/rotation capacities and thereby same overall lateral deformation capacity, unless shear controls. Figure 1 illustrates this concept. Traditional analysis methods based on force demands would not have captured this "hidden" beneficial behavior of old structures.

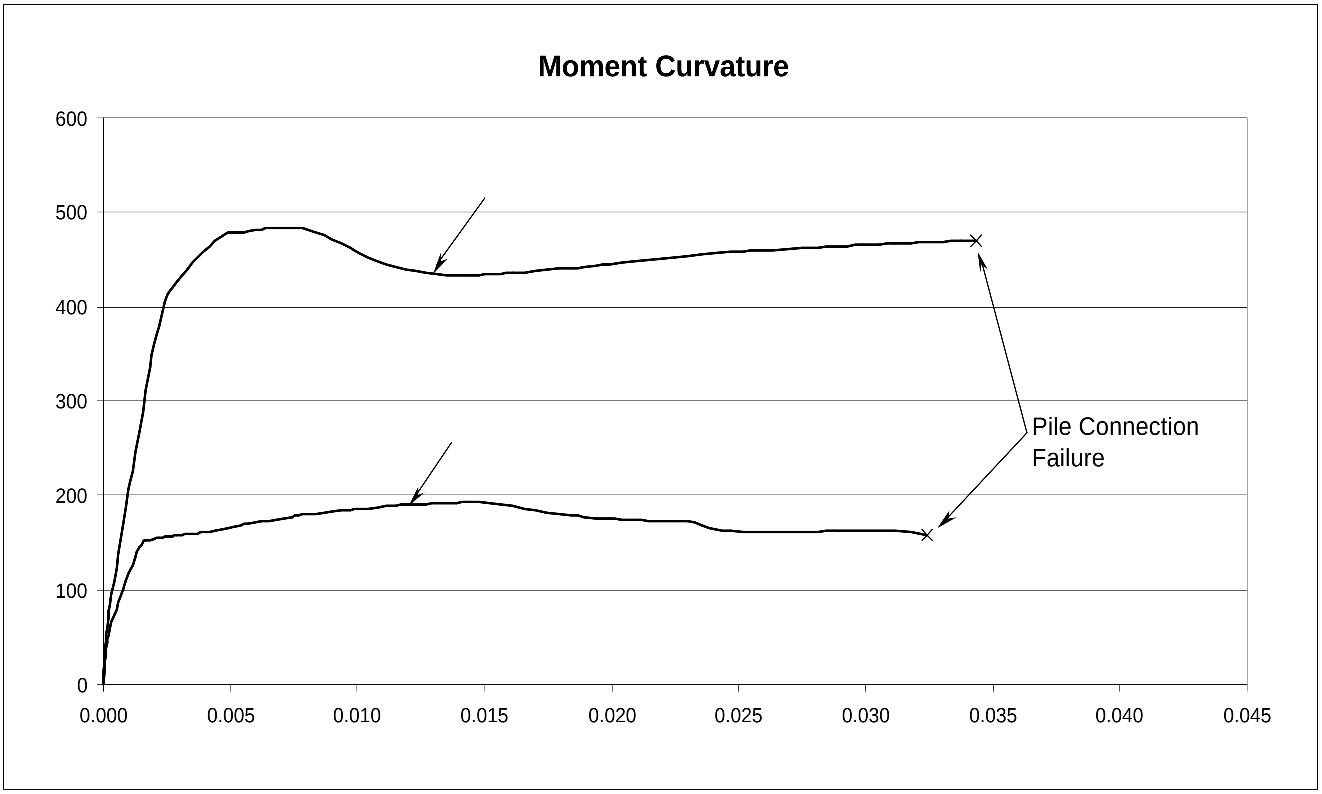

Figure 1

Mooring and Berthing Requirements

Oil carrying vessels have undergone the same development as most ocean going vessels over the last fifty years - they have become larger. Berthing of large vessels at MOT's designed for much smaller vessels typical result in problems meeting the code requirement of mooring line angles and spacing of breasting dolphins as well as existing bollards and platform decks being capable of handling the larger mooring forces.

The environmental conditions at the MOT during berthing operations are also of concern. The most critical conditions include:

- Wind
- Current
- Change in vessel draft
- Passing vessel effects

The impact of the berthing of large vessels at old existing MOT's is reflected in the environmental demands that will increase as well. MOTEMS therefore uses a MOT Mooring/Berthing Classification that divides MOT's into three risk categories depending on the environmental conditions at the particular facility (for higher risk classification more detailed analysis is required):

MOT Mooring/Berthing Classification				
Risk Classification	Wind (knots)	Current (knots)	Passing Vessel Effects	Change in Draft (ft)
High	> 50	> 1.5	Yes	> 8
Moderate	30 to 50	1.0 to 1.5	No	6 to 8
Low	< 30	< 1.0	No	< 6

It is important to notice that a facility can experience winds that exceed 50 knots yet still be classified as being moderate. As part of the new audit, each MOT operator is required to identify the operating conditions for oil transfer. If the wind, current, passing vessel effects and change in draft all are less than the requirements of the high classification for the operating window then the terminal can be classified as moderate.

When the maximum wind condition defined by the operator is exceeded at an existing MOT a vessel is required to cease transfer operations.

Once the operational window has been established by the MOT operator, a mooring and berthing analysis shall be conducted to verify that the mooring and berthing system is adequate for the given conditions.

In addition to the operating condition, the moored vessel shall also be checked for the survival condition. For new MOT's the vessels shall be able to remain safely moored during a maximum wind condition, which is obtained from historical data for a 30 second gust and a 25 year return period. Existing MOT's, which may have difficulties meeting this requirement, are allowed to use a reduced survival condition, above which the vessel must leave berth within 30 minutes or less. This reduces the burden of existing MOT's trying to meet modern code without increasing the risk of accidents since the vessels are required to leave berth.

Some of the highlights of the mooring/berthing analysis requirements are:

- Passing vessels effects. It is a well known phenomenon that passing vessels can interfere significantly with a moored vessel under certain circumstances. These circumstances are in the MOTEMS document defined as three conditions that all need to exist: 1) passing vessel size greater than 25,000 dwt and 2) distance between vessels less than 700 feet and 3) vessel speed greater than a critical vessel speed defined as $1.5 + ((L-2B)/(700-2B))*4.5$ (knots), where B is the beam of the moored vessel at berth and L is the distance between the vessels. If these conditions all exist one is required to establish the surge and sway forces and yaw moment using simplified methods. Methods by Wang (Ref /2/), Flory (Ref /3/) or Seelig (Ref /4/) are recommended. Only if the demands calculated using such simplified methods are greater than 75% of the mooring system capacity, is a more sophisticated dynamic analysis required.
- For vessels classified as low a manual procedure may be used to determine the mooring forces (when certain line angle limitations are met).
- For vessels classified as moderate or high, a numerical method is required to determine the mooring forces.

Under rare circumstances, a number of additional analyses may be required to verify safe behavior of the moored vessel. These rare circumstances involve the following additional environmental loads:

- Wind Waves

  MOT's are generally located in sheltered waters such that typical wind waves can be assumed not to affect the moored vessel if the significant wave period T_s is less than 4 seconds. However, if the period is equal to or greater than 4 seconds, then a simplified dynamic analysis is required. The method by Froude-Krylov (Ref /5/) or an equivalent method is recommended.

- Seiche

  A seiche analysis is generally required for an existing MOT located within a harbor basin which has historically experienced seiche. For new MOT's, a seiche analysis is required inside a harbor basin prone to penetration of ocean waves. The methodology in the Navy's Design Manual 26-1 (Ref /6/) combined with methods outlined in a paper by F.A. Kilner (Ref /7/) to calculate vessel motion, are recommended for a simplified seiche evaluation. In more complex cases dynamic methods are required.

- Tsunami

  A tsunami may be generated by an earthquake or a subsea or coastal landslide, which may induce large wave heights and excessive currents. While approximate tsunami run-up values have been estimated along the coast of California, most recently by USC (Ref /8/), little documentation exist on how best to analyze the effect on waterfront structures. It is impossible to protect an MOT against a large tsunami. MOTEMS therefore require that each MOT have a plan with specific actions for responding to tsunami events. For smaller events and run-up values it is recommended that uplift and other tsunami induced loads be considered. Camfield (Ref /9/) provides guidelines on these issues.

References

/1/ “Marine Oil Terminal Engineering and Maintenance Standards” (MOTEMS), published by the California State Lands Commission, May 2002.

/2/ Shen Wang, "Dynamic Effects of Ship Passage on Moored Vessels", Journal of the Waterways WW3, 1975.

/3/ Flory, J.F., "A Method for Estimating Passing Ship Effects," Proceedings, Ports 2001, ASCE Conference April 29-May 2, 2001.

/4/ Seelig, William N., "Passing Ship Effects on Moored Ships," Technical Report TR-6027-OCN, NFESC, November 2001.

/5/ Chakrabarti, S. K., "Hydrodynamics of Offshore Structures," Computational Mechanics, 1987.

/6/ Dept. of the Navy, "Harbors Design Manual 26.1," NAVFAC 26.1, Alexandria, VA, 1984.

/7/ Kilner F.A. "Model Tests on the Motion of Moored Ships Placed on Long Waves." Proceedings of 7th Conference on Coastal Engineering, The Haque, Netherlands, 1960.

/8/ Synolakis, C., “Tsunami and Seiche,” Chapter 9 in the Earthquake Engineering Handbook, Chen, W. and Scawthorn, C., editors, CRC Press, Boca Raton, Fl (expected publication date 9/25/02).

/9/ Camfield, F. E., "Tsunami Engineering," U.S. Army, Corps of Engineers, Coastal Research Center, Special Report No. 6, 1980.