Marine Oil Terminal Engineering and Standards (MOTEMS)
An Overview

Martin L. Eskijian, P.E.
Supervisor, Engineering Branch
Marine Facilities Division
California State Lands Commission
eskijim@slc.ca.gov

Introduction

For the past twelve years, the California State Lands Commission (CSLC) has been involved in the operational monitoring, structural inspection and requalification of 45 marine oil terminals (MOTs) along California's coast. The average age of these structures is about 50 years, and operators plan to keep many of these pier/wharf structures in service for another 20 to 40 years. Having seen the port and harbor damage from the 1995 Kobe, Japan and 1999 Izmit, Turkey earthquakes, the potential for a major disruption in petroleum product production is real. California imports about 1 million barrels of oil a day, over wharves or piers, and about 1 million barrels a day from pipeline sources to provide refinery feedstock. All of the major marine oil terminals in California are very near major active earthquake faults, similar to Izmit, Turkey. Losing the daily gasoline production for a period of weeks or months could significantly affect the economic well being of California and much of the Western United States. In addition, a major oil spill associated with an earthquake or other metocean event could cause the closure of a major port for days or even weeks. Such a closure would also affect the economy of California and the United States.

Most of these facilities were designed to very primitive seismic standards and for vessels much smaller than those currently moored. Many of these structures have never had a comprehensive underwater inspection. Wind and current forces on large tank vessels can cause mooring lines to break or cause serious structural damage to supporting structures. Having a large tanker drift away from a wharf can be a very serious problem. In almost every case in California, the facilities were not designed to operate with the current sized vessels calling at the terminals.

In order to protect the public health, safety and the environment, the California legislature passed the Lempert-Keene-Seastrand Oil Spill Prevention and Response Act of 1990. The Act defines specific tasks for the CSLC (the commission), in part stating:

> *"…the commission shall adopt rules, regulations, guidelines and commission leasing policies for reviewing the location, type, character, performance standards, size and operation of all existing and proposed marine terminals within the state, whether or not on lands leased from the*

commission, and all other marine facilities on land under lease from the commission to minimize the possibilities of a discharge of oil…" (Public Resources Code Section 8755 (a))

"The commission shall periodically review and accordingly modify its rules, regulations, guidelines and commission leasing policies to ensure that all operators of marine terminals within the state and marine facilities under the commission's jurisdiction always provide the best achievable protection of the public health and safety, and the environment…" (PRC Section 8756).

As a result of the above mandate, the CSLC created the Marine Facilities Division (MFD) in 1990. The MFD is responsible for oversight of 45 MOTs throughout California.

Because of these issues, the CSLC developed engineering and maintenance standards for marine oil terminals in California. This effort is now complete, and the guidance document, Marine Oil Terminal Engineering and Maintenance Standards (MOTEMS, Ref. 1), is now available. The remaining task, currently in progress is to convert the guidance document into statewide CSLC regulations.

Overview of MOTEMS

The Marine Oil Terminal Engineering and Maintenance Standards (MOTEMS) were initiated by the MFD to develop comprehensive engineering standards for the analysis, design and inspection/maintenance of MOTs. These new standards define criteria for both new and existing facilities. Funding for this project was from a hazard mitigation grant from the Federal Emergency Management Agency (FEMA) through the Governor's Office of Emergency Services, as a result of the Northridge earthquake of 1994, and also from the California State Lands Commission.

The MOTEMS were developed under the direction and active participation of the MFD. The prime consultant for the development of these standards is a joint venture of Han-Padron Associates of Long Beach, California and Ben C. Gerwick, Inc. of San Francisco, California.

The U.S. Navy's Facilities Engineering Service Center (NFESC), through a "Cooperative Research and Development Agreement" has also been an active participant through funding provided by the CSLC. The NFESC has provided extensive input to the seismic, mooring and structural inspection sections (Ref. 2). The Civil Engineering Department of the University of Southern California participated in the work by providing research and criteria in the area of tsunami risk assessment (Ref. 3) and also has contracted for the offshore seismic hazard risk assessment to Lawrence Livermore National Laboratory (Ref. 4). The Civil

Engineering Department of the University of California, San Diego contributed to the structural performance criteria for seismic loading.

The process has included strong participation by the regulated community of marine oil terminal owners and operators. The standards development process has included a series of workshops in which all areas of the MOTEMS were discussed in detail. The workshops have involved experts from facility owners and operators, as well as from the consulting community, academia, and the Navy. Participation by industry has been very strong and encouraging; the Western States Petroleum Association (WSPA) has been very active in leading the industrial review of the MOTEMS.

The Engineering Standards

The MOTEMS will require each MOT to conduct an audit to determine the level of compliance and an evaluation of the continuing fitness-for-purpose of the facility. Depending on the results, operators must then determine what actions are required, and provide a schedule for implementation of deficiency corrections and/or rehabilitation. The standards define criteria in the following areas:

- Audit and Inspection
- Structural Loading
- Seismic Analysis and Performance Based Structural Design
- Mooring and Berthing Analysis and Design
- Geotechnical Hazards and Foundations
- Structural Analysis and Design of Components
- Fire Prevention, Detection and Suppression
- Piping and Pipelines
- Electrical and Mechanical Equipment

Audits and Inspections

The standards define three distinct types of audits and inspections that are required. The first is the annual inspection, which is a walk-down of the facility conducted by the MFD, along with the operator. This follows the current practice of the MFD.

A second type, called the Audit, is the primary focus of the standards. It consists of a comprehensive evaluation of all structural, mooring, electrical and mechanical systems relative to specific criteria defined throughout the MOTEMS. The Audit is conducted every three years for above water structure components, as well as electrical and mechanical systems. The frequency for underwater inspection varies with the condition of the facility, but may range from one to six years. The underwater inspection procedures are consistent with the new ASCE Underwater Investigations – Standard Practice Manual (Ref. 5).

The third type of inspection or audit is conducted following a significant event, such as an earthquake, flood, fire, or vessel impact. The goal of the Post-Event Inspection is to determine if the facility is safe to continue operations and to determine if remedial action is necessary.

The audit and inspection standards also define the scope of the evaluation, minimum qualifications for audit personnel, evaluation and rating criteria, follow-up action guidelines, and reporting requirements. Following the detailed inspection, a structural condition assessment rating is assigned to the facility.

Loading Criteria

Loading criteria are defined for both new and existing MOTs. The requirements for existing MOTs are lower than for new facilities, and rehabilitation may be required. In addition to defining loading criteria for dead loads, live loads, earthquake loads, mooring loads, and berthing loads, the MOTEMS also define required loading combinations and associated safety factors.

Seismic Analysis and Design Criteria

The seismic analysis requirements of the MOTEMS differentiate facilities into high, moderate and low risk classifications as shown in Table 1, below. These risk classification levels are used to define the earthquake ground motion to be applied to the facility, as well as to determine the level of sophistication required for the structural analysis.

TABLE 1 EXISTING FACILITY CLASSIFICATION

Classification Level	Exposed Oil (bbl)	Transfers per Year/Facility	Vessel Size (DWTx1000)
High	≥ 1200	N.A.	N.A.
Moderate	< 1200	≥ 90	≥ 30
Low	< 1200	< 90	< 30

Two different levels of design earthquake motion are defined for each risk classification as shown in Table 2. The spectral acceleration, peak ground acceleration may be determined, once the return period of the event is established. The Level 1 and Level 2 performance criteria are defined below:

Level 1 Earthquake: No or minor structural damage without interruption in service or with minor temporary interruption in service.

Level 2 Earthquake: Controlled inelastic behavior (prevention of structural collapse) with repairable damage resulting in temporary closure, service restorable within months, and the prevention of a major spill, defined as 1200 barrels of a petroleum product.

TABLE 2
DESIGN EARTHQUAKE MOTIONS

Classification		Probability of Exceedance	Return Period
High	Level 1	50% in 50 years	72 years
	Level 2	10% in 50 years	475 years
Moderate	Level 1	64% in 50 years	50 years
	Level 2	14% in 50 years	333 years
Low	Level 1	75% in 50 years	36 years
	Level 2	19% in 50 years	238 years

The recurrence interval varies for different levels of risk and performance, as shown in Table 2. The procedure to get spectral maximum accelerations is similar to that provided in the FEMA 356 guideline (Ref. 6). Currently, the initial earthquake parameters are taken from the USGS web site, http://geohazards.cr.usgs.gov/eq/html/canvmap.shtml. They are available as peak ground acceleration and spectral acceleration values at 5 percent damping for 10, 5, and 2 percent probability of exceedance in 50 years, which correspond to Average Return Periods of 475, 975, and 2,475 years, respectively. The spectral acceleration values are available for 0.2, 0.3, and 1.0 second spectral periods. In obtaining peak ground acceleration and spectral acceleration values from the USGS web site, the site location can be specified in terms of site longitude and latitude or the zip code when appropriate. Once peak ground acceleration and spectral acceleration values are obtained for 10, 5, and 2 percent probability of exceedance in 50 years, the corresponding values for other probability levels may be obtained by interpolation or extrapolation. As a result of the Lawrence Livermore National Laboratory study, specific response spectra are provided for the ports of Los Angeles and Long Beach. It should be noted that for existing facilities located on weak soils, a site-specific hazard assessment is required.

For new marine oil terminals, the same criteria as the "high" classification is used for all cases (50% probability in 50 years and the 10% probability in 50 years). A site-specific seismic hazard assessment is required.

The performance-based design criteria is incorporated into the MOTEMS and allows for limiting values of strain (or displacement) to determine whether or not a specific structural component is fit-for-purpose. This criteria is consistent with the new PIANC (Permanent International Association of Navigation Congresses) seismic guidelines (Ref. 7).

Mooring of Tank Vessels

Since its inception in late 1990, the MFD has been concerned about the mooring of tank vessels at marine oil terminals. Most of these facilities were designed and built long ago, for much smaller vessels. Larger vessels have greater sail areas resulting in greater wind loads, as well as larger hull areas below the water line resulting in higher current loads transferred to the terminal structure. Aging structures with older design fender types may not be adequate for these types of loads and higher impact loads. The problem is further complicated by the new generation of double-hulled vessels, which have even larger sail and hull areas.

Mooring and berthing analysis/design criteria are also provided in the MOTEMS. As in the seismic criteria, facilities are grouped into three risk classifications to determine the level of sophistication of the analysis required.

Mooring and berthing loads are consistent with industry accepted recommendations (Ref. 8). Two load cases involving wind are specified for both new and existing facilities:

(1) Survival Condition:

> 25 year return period wind, with a 30 second duration
>
> For a new MOT, this condition is defined as the state wherein a vessel can remain safely moored at the berth during severe winds. This survival condition threshold is the maximum wind velocity with a 25 year return period, for a 30 second gust.

(2) Operating Condition:

> The operating condition is the safe wind envelope derived from the mooring analysis. This is the maximum wind velocity below which a vessel may conduct transfer operations. When this maximum velocity is exceeded, the vessel is required to cease transfer operations. An operational wind rose is required.

Wind velocity data from nearby sources is “corrected” for height (10m), duration (30 seconds) and “over water” conditions.

For high velocity current areas, a current meter is required to determine maximum values for analysis. For berthing forces, the kinetic energy method is to be used, with coefficients considering eccentricity, configuration, geometry, deformation and virtual mass. The arrival vessel mass is used for the impact calculations.

Tsunami and Seiche

The MOTEMS also provides requirements for determining loads due to tsunamis and seiche. As part of a collateral grant from FEMA/OES, new information and a new methodology were employed to develop the seismic and tsunami risk assessments for the ports of Southern California. In order to develop the tsunami hazard model, offshore seismic hazards had to be determined. The seismic hazard information is completely new, and is based on the data and methodology of the Lawrence Livermore National Laboratory, under the direction of Dr. Jean Savy. The seismic information was then used to obtain the tsunami run-up heights. The tsunami work was performed by Professor Costas Synolakis at the University of Southern California. The tsunami information includes the potential for a near-field event triggering a subsea landslide, and its resulting tsunami. Tabular results are provided in MOTEMS for the 100 and 500 year return period tsunami event. The threat of a near-field generated tsunami would leave no time for a vessel to depart the MOT. However, for a tsunami generated by a distant source (far-field event), there would be time for vessels to depart the terminal and transit into deep water.

Seiche analysis is required for MOTs in harbors subject to penetration by ocean waves.

Fire, Mechanical and Electrical Systems

MOTEMS also provides standards for fire prevention, detection, and suppression. The fire standards incorporate the minimum requirements of the industry-accepted guidelines of the Oil Companies International Marine Forum (Ref. 9). Specific firewater requirements are based on vessel size and oil at risk (both stored and flowing). Details of the required fire plan are reviewed as part of the audit process. Mechanical and electrical systems, including piping are also included in the MOTEMS and are consistent with industry-accepted recommended practices as presented in various API documents.

Issues

Some of the issues in MOTEMS that often stir debate and will require additional effort and resources (i.e. expense) from the marine oil terminal owners and operators include:

a. The criteria for the dive team requires that a registered civil or structural engineer to be in the water for 25% of the total dive time. The new ASCE standard practice (Ref. 5) requires this and the MOTEMS concurs.

b. “Grandfathering” of terminals will end. Up to now, the MFD has allowed facilities to continue operations, using the largest vessel described in the operations manual. To date, there has never been a requirement that any engineering justification be provided for this size vessel. The MOTEMS requires the owner/operator to provide an engineering justification, using the maximum wind and current velocities expected, that the facility can safely handle a vessel of the size anticipated to call at the terminal. Most commonly, operators and their consultants consider this to mean a "mooring analysis" which indeed is part of the process, but equally important is the structural verification that the wharf or pier is adequate for the mooring loads. In many cases the structural verification has been overlooked and the 55% of breaking strength of the mooring lines has been used to determine the maximum wind and/or current loads during operating conditions. And although this new requirement will mandate an engineering effort, it does not mean that the maximum vessel moored at a particular facility will be acceptable. It does mean that a specific operational wind rose may be required, with limiting values in some directions. In other words, the operating wind condition at a specific facility may be less than the 25-year maximum 30-second gust. Yet this operating condition may be perfectly acceptable for 50, 75 or even a higher percentage of the time during a year. It means that the wind must be monitored and that product transfer will have to be terminated if the wind exceeds that value.

c. A seismic structural analysis will be required. With the average age of marine oil terminals in California at about 50 years, the design criteria used in the 1950's is significantly less than what is required today. This analysis may require rehabilitation of the structure, so that it will be better able to withstand expected seismic loads. There are a number of reasons why the seismic rehabilitation is included in the MOTEMS. First, because of the stated age of many of the terminals the commonly accepted lifespan of a marine structure has been exceeded (Ref. 10). And in many cases, operators would like to continue operations for another 20 to 40 years. A second reason for the seismic reassessment is that the refineries must satisfy the requirements of CalARP (Ref. 11). The seismic performance criteria spelled out therein for existing petroleum refineries (i.e. 10% probability of exceedance in 50 years, with no collapse) is the same as we use in the MOTEMS. It is thus postulated that the marine oil terminal and the adjacent refinery would both achieve the same level of seismic hardness. As a third reason, the state's economy relies on the one million barrels of oil that feeds our refineries, coming through marine oil terminals. Having a major supply of refinery feedstock interrupted for weeks or months would have a significant effect on the economy of California and the United States.

d. A new pipeline analysis may be required, as a result of the updated seismic analysis. Depending on the horizontal displacement results from the seismic analysis, the petroleum pipelines may have to be analyzed to determine if they can facilitate the seismic structural displacement of the wharf. Hard points, the lack of flexibility or other impediments to horizontal motion need to be considered in the analysis. The recommended firewater volumes are consistent with the guidelines of the OCIMF. To date, there has not been a consistent and uniform fire requirement for MOTs in California. The fire risk is based on tanker size and the number of barrels of oil (or petroleum product) at risk, that is both flowing and stored in the pipelines.

e. A baseline inspection may be required. If the structural drawings, P & ID's or other logic diagrams are not available, the audit process of the MOTEMS will require "as-built" drawings. In order to perform a seismic analysis, drawings with sufficient detail to provide pile properties, depth of embedment, dowels, reinforcing bar configurations and basic structural data is required. P & ID's are necessary to perform a pipeline analysis. A comprehensive fire plan is also required, along with a layout drawing indicating the various components.

f. A geotechnical review of the facility is required. As geotechnical engineering has significantly advanced in the last 30-40 years, the potential for liquefaction and other types of soil failures can be fairly easily determined. With the recent seismic hazard information (i.e. not the original criteria of the early 1950's), and the facilities seeking to remain operational for another 20 to 40 years, soil stability should be verified. The MOTEMS requires screening and the evaluation of the liquefaction potential. The original geotechnical data may be sufficient to perform the analysis, but it is possible that new borings and soil data may also be required.

g. A schedule for rehabilitation is required. At the conclusion of the audit process, the MOTEMS requires that the repair, rehabilitation or deficiencies be corrected within a time specified by the operator and agreed upon by the MFD.

h. Subsequent audits are required at intervals ranging from one to six years. Pending the condition of a specific structure and its associated systems, subsequent audits are scheduled. However, if there are no changes in the design, vessel size or risk, then the analyses mandated by the first audit need not be repeated. Thus, the seismic analysis, pipeline assessment, geotechnical assessments, the mooring assessment, the fire plan, P & ID review, etc. may only be required for the initial audit. Of course, if there are substantial changes to the structure or systems, additionally analyses may be required.

Schedule for Audits and Rehabilitation

Based on preliminary estimates of oil volume at risk at California's MOT's, the following number of facilities fall into the "high", "medium" and "low" category for performing audits.

Risk Classification	** Number of MOTs	* Time to complete audit
High	14	30 months
Medium	12	48
Low	15	60

* Based on start time of regulations becoming effective (estimated to be mid-2003)

** Does not include offshore terminals

This means that the 14 MOTs that are rated as "high" risk would have until early 2006 to complete their initial audit, and those rated as "low" would have an additional 30 months. As the initial audit is completed, there will, no doubt be deficiencies and some rehabilitation required for most MOTs. As the MOTEMS does not set specific dates to complete the repairs, it does require the operator to provide a schedule for completion. The complete audit and the scheduled completion of rehabilitation will be tracked and monitored by the MFD.

Conclusions

The MOTEMS is the first set of comprehensive engineering standards developed specifically for MOTs in the U.S. The background for these standards is based on the MFD's experience of inspecting and reviewing mooring and structural upgrades at MOTs during the past 10 years. The MOTEMS fulfills the mandate of the law to provide regulations for the performance standards of marine oil terminals in order to minimize the possibilities of the discharge of oil. However, much of the criteria is equally applicable to other types of marine facilities.

It is expected that these standards will form the basis for similar standards developed for other state, federal, and international agencies. The seismic performance standards of the MOTEMS are now established in the PIANC text of seismic guidelines for ports (Ref. 7). In addition the seismic performance criteria is being proposed for the 2003 re-write of FEMA 368 of NEHRP (Ref 12). The potential application of this effort is worldwide, for any new or existing marine oil terminal, or other wharf/pier structure, regardless of the seismic hazard classification of the region.

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