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Seismic Assessment of Chemical Facilities under California Risk Management and Prevention Program

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INTRODUCTION

In recognization of the potential for explosion, fires or release of toxic chemicals into the environment, the California Health and Safety Code (Section 25534 of Chapter 6.95) requires that a business which handles significant amount of acutely hazardous material (AHM) should develop a comprehensive Risk Management and Prevention Program (RMPP). The purpose of the RMPP is to systematically identify hazards and operability problems of a facility, assess the potential consequences posed by hazards, and examine the means of detecting and correcting potential off-site release of AHM. Seismic events are capable of simultaneously inflicting substantial damage to several components and systems in a facility that may have a significant impact on public safety and financial health of the business and are therefore required to be examined in an RMPP of the facility.

SEISMIC ASSESSMENT

The general requirements for seismic assessment in an RMPP are available in the Los Angeles City Fire Department's "Seismic Assessment Guidelines" and in "Proposed Seismic Assessment Guidelines for RMPP Studies" developed by the ad hoc Committee of the RMPP Subcommittee of California Fire Chiefs Association [1].

The elements of seismic assessment are a site specific geologic (i.e. seismic hazard and geotechnical evaluation) evaluation and an engineering review of the facility. The site specific geologic evaluation includes the consideration of all active faults in the region for their impact on the facility in terms of ground motion, potential for liquefaction, landslide potential and tsunami; potential for surface faulting and ground breaking are also investigated. Local site amplification effects are evaluated.

The seismic engineering review of AHM components consists of a review of the existing design and performance of a detailed walkdown to verify as-built condition and assess relative seismic vulnerabilities. For critical items of equipment with AHM inventory, seismic capacities are calculated using the RMPP guidelines cited above and probabilistic procedures. If earthquake ground motions should occur exceeding these capacities, the equipment is assumed to fail. Depending on the failure mode of the particular equipment, the consequential release of AHM is estimated using engineering judgment. In the following, the seismic assessment approach is described using a case study [2, 3].

Seismic Hazard Analysis

A probabilistic assessment of the seismic ground motion hazard at a site in Southern California was performed taking into consideration all potential seismic sources that may affect the site, their activity rates and potential earthquake magnitudes (Figure 1). A site specific seismic hazard curve representing the frequencies of exceeding different levels of peak ground acceleration at the site was developed (Figure 2). The peak ground accelerations at mean return periods of 100, 500 and 2500 years were estimated to be 0.28g, 0.44g and 0.60g, respectively. Maximum acceleration at the site from postulated earthquakes on different faults were estimated and a fault close to the site was found to yield the largest value of 0.42g. Alternatively, peak ground acceleration values at the site from two scenario earthquakes [4] were estimated. The scenario earthquakes, viz. a magnitude 7.0 event on the Newport-Inglewood fault and a magnitude 8.0 event on the San Andreas fault resulted in peak horizontal ground accelerations at the site of 0.31g and 0.12g, respectively.

Based on a review of Special Publication 42 [4], it was concluded that there is no potential for surface faulting and ground breaking at the site. Special Publication No. 99 [5] discounts the potential for tsunami occurring due to local off-shore earthquakes. Because of the topography and local sea-floor physiography it was also concluded that the Southern California coast is immune to the tsunami waves generated from distant earthquakes (e.g., Chile).

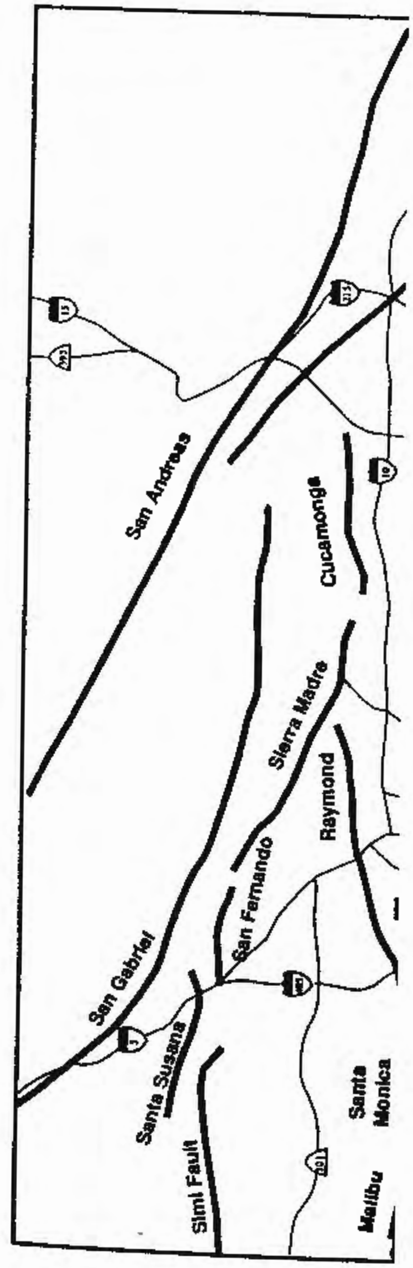
The local soil profile consists of silty sand and sand. They are firm to very firm throughout the site; soil settlement as a result of strong seismic shaking was considered to be unlikely.

Geotechnical Evaluation

A deconvolution study was conducted using selected time histories of earthquake ground motion as appropriate to the site. These time histories were input at the rock outcrop at elevation zero and propagated up to the surface near the site. ,This analysis was performed using SHAKE and FLUSH computer codes developed for the soil structure interaction analysis. The soil profile and soil property data were derived from a previous investigation. It was found that the local amplification of ground motion from the bed rock to the surface is minimum. Therefore, it was concluded that the local soil amplification is not a concern at this site.

For several locations in the site, a slope stability analysis was performed using the modified Bishop method. The analysis showed that slope failure will not occur until the peak ground acceleration exceeds 0.62g. Therefore, it was concluded that the instability of slopes in the site is not a concern.

The water table at the site is at depths greater than 75 feet from the surface. The soil layer above the water table is firm to very firm silty sand and not susceptible to liquefaction. Therefore soil liquefaction affecting foundations and buried piping at the site is not likely.



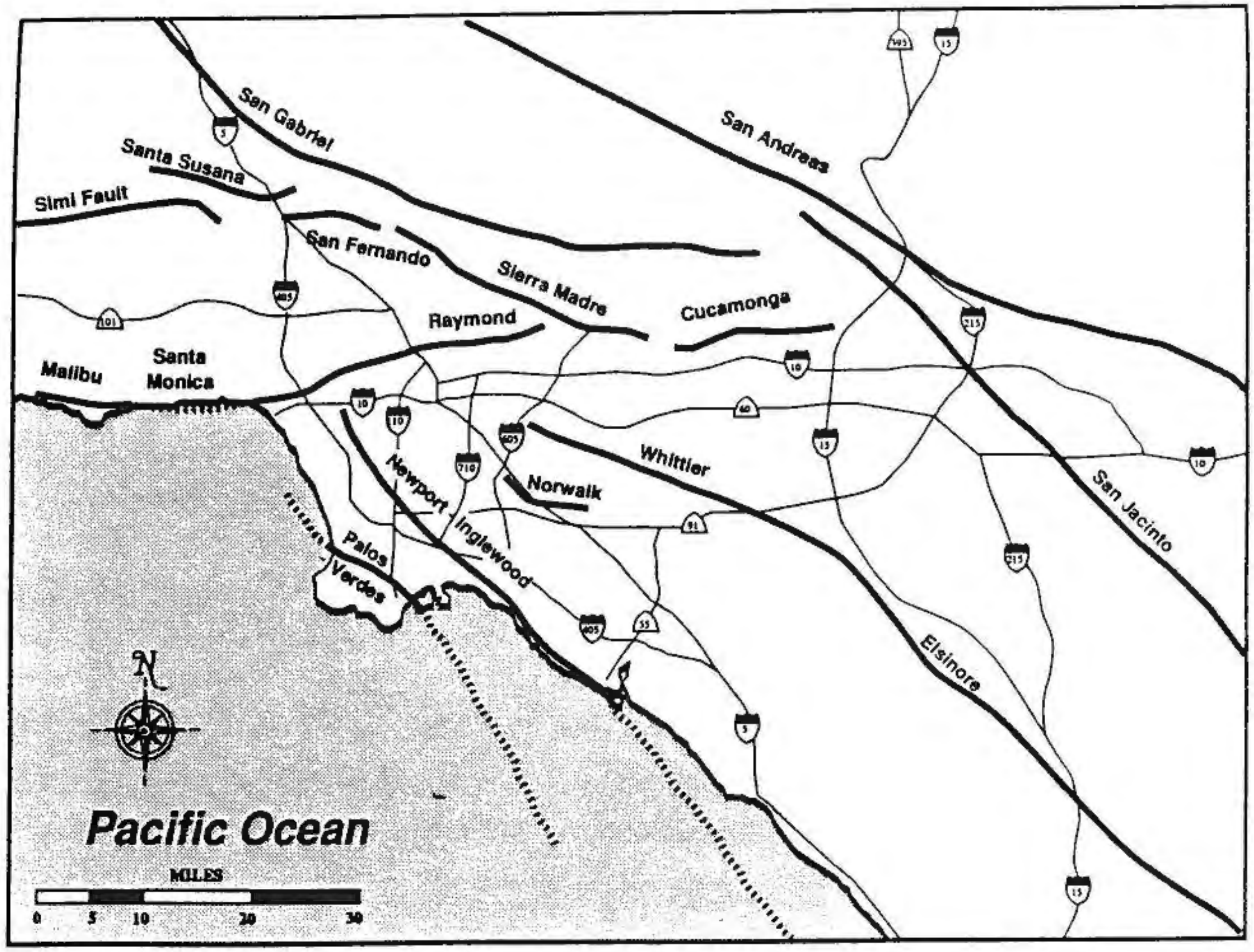


Figure 1: Major Earthquake Faults in Southern California Region

Engineering Assessment

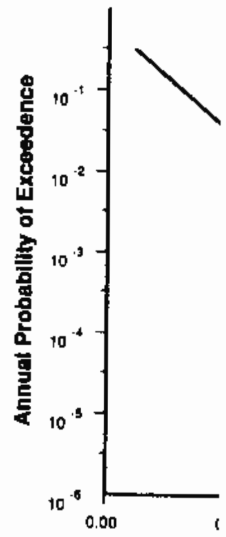
The equipment items that contain AHM were identified by the RMPP consultant. A review of the design codes used and the design drawings was conducted to obtain relevant information for calculating the seismic capacities. Detailed walkdowns of components and systems in the facility were performed to obtain additional data and to identify any potential seismic weaknesses. The components examined included vessels, reactors, heat exchangers, compressors, pumps, and associated piping, etc. The focus of the walkdown was on the anchorage of the equipment, lateral seismic supports, and potential effects of failure of non-AHM components on the AHM components. The EQE experience data on the performance of industrial facilities during major earthquakes and the insights gained in the seismic risk studies of critical facilities were used in this review and walkdown. EQE has collected a proprietary database on the performance of structures and equipment in industrial facilities, chemical plants, oil refineries, and power plants subjected to major earthquakes throughout the world. Data have been collected from the investigation and review of over 100 industrial and power plant facilities. Major earthquakes of which on-site investigations were conducted include: Chile, 1985 [6], Mexico, 1985 [7], Whittier, California 1987 [8], Loma Prieta, CA 1989 [9], etc.

Some components (e.g., compressors and pumps) could be assigned high seismic capacities based on the experience database. For the remaining components, seismic capacity evaluation was conducted. The relevant failure modes were identified and the capacity in the critical failure mode was calculated. The median capacity, A_m and a logarithmic standard deviation reflecting the uncertainty in the capacity, ß, were estimated. A deterministic estimate of the capacity using RMPP guidelines [1] was also derived. Figure 3 shows the failure probability of a component obtained using A_m and ß as a function of the peak ground acceleration. This is called a "fragility curve". For each component, the consequences of failure in terms of the release area were estimated by examining the attached piping, nozzles, and the connection details. Table 1 gives a condensed list of the component name, description, critical failure mode, seismic capacities estimated using the RMPP guidelines and the realistic median failure capacities, and a description of the consequence of failure in terms of release. This table shows that there are some components with relatively low seismic capacities because of marginal anchorage and which could be upgraded with minimal cost. Any decision on upgrading has to come only after the importance of the upgrading is evaluated in the context of the overall risk mitigation plan.

From the review of design documents, it was noted that some components were designed for a static seismic acceleration of 0.2g per local building code. This equivalent static force method for seismic design is similar to that in the *Uniform Building Code*. A detailed evaluation identified vulnerabilities of these components even though they were designed to building code requirements. Potential seismic vulnerabilities of equipment components are:

- The seismic response of the equipment could be underestimated by not considering the dynamic characteristics of the equipment and its supports. This was observed for vessels mounted on tall flexible concrete piers.

- The base shear equation in the UBC has implicitly reduced the elastic earthquake response load to take credit of the inelastic energy absorption capability of building structures beyond yielding. However, the energy absorption capability of the equipment is



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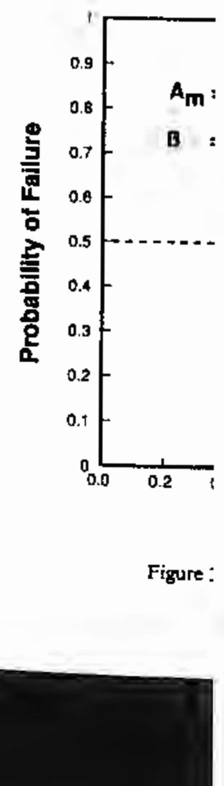

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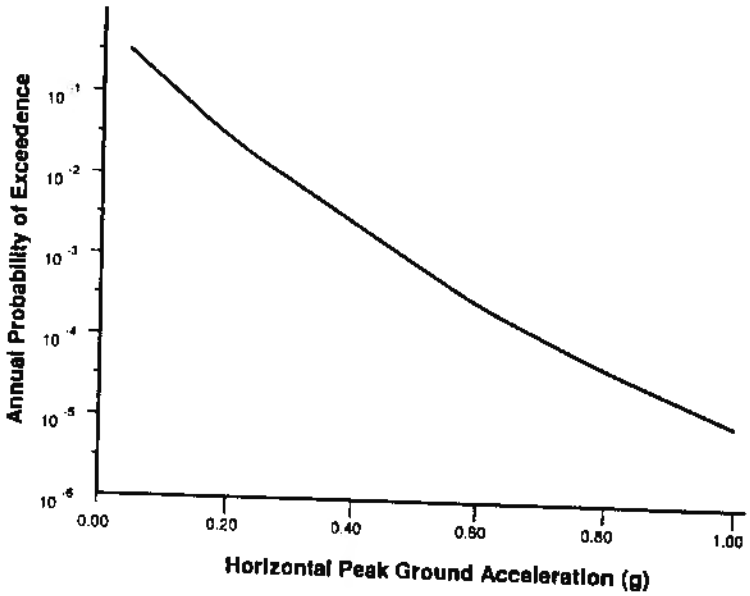

Figure 2: Seismic Hazard Curve for the Site

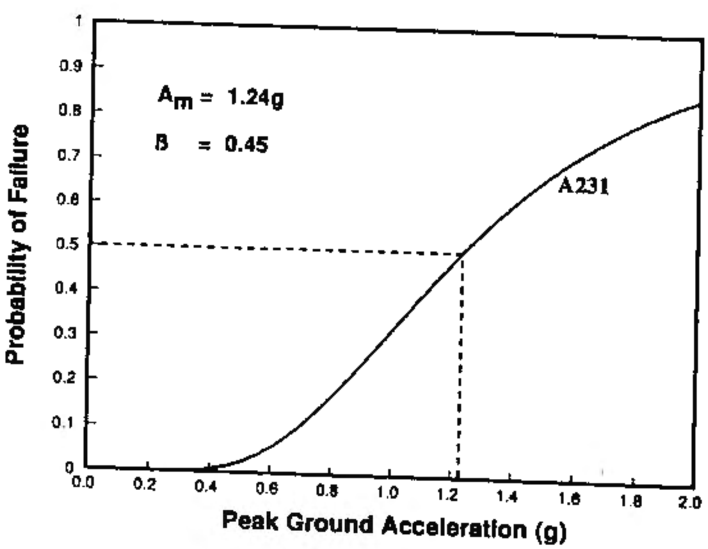

Figure 3: Absorber Column Seismic Fragility Curve

Table 1:

Component Seismic Evaluation Results

Item	Component Description	RMPP Capacity (g)	Median Capacity (g)	β	Failure Mode	Consequence of Failure	Remarks
G-201	Recycle Gas Heater	0.45	0.40	0.35	Support Legs	Tube rupture and pipe failure	Vertical vessel
A-231	Absorber Column	1.11	1.24	0.45	Anchor Bolts	Severe failure of connected piping	Tall columns
HX2D1	Heat Exchanger	0.16	0.32	0.38	Bolts	Rupture of connecting pipe	Stacked heat exchanger
D-202	Low Pressure Flash Drum	0.34	0.72	0.38	Anchor Bolts	Leakage at connected piping	Horizontal vessel
P-234	Pump	0.80	0.80	0.40	Anchorage	Severe failure of connected piping	Ground mounted equipment
C-256	Compressor	0.80	0.80	0.40	Anchorage	Severe failure of connected piping	Ground mounted equipment

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Consequence Analysis

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CONCLUSIONS

From a number of seismic as
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1. A detailed walkdown of the
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2. Further guidance on the en
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3. The acceptable level of safe
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limited due to its lack of redundant load paths and lower damping. Thus, the equipment may potentially fail in a brittle fashion due to its limited or total lack of ductility due to improper structural detailing. This was observed for the anchor bolts of some horizontal vessels mounted on concrete piers. The capacities of the vessels were judged to be governed by the concrete failure of the anchor bolts due to inadequate edge distance.

Consequence Analysis

An earthquake could cause damage to one or more components in the facility. Each combination of component damage, herein called sequence, may have different consequences in terms of different AHM releases including their possible reactions and synergestic effects. The consequence evaluation is typically done using a dispersion analysis considering the types and rates of AHMs released.

By combining the seismic fragility of components with the seismic hazard for the site, we could obtain the annual frequency of occurrence of different sequences. Table 2 shows representative sequences and their frequencies. Of the sequences comprising of single component failures, the heat exchanger HX2D1 failure is seem to dominate since its seismic capacity is relatively low. It is also observed that HX2D1 failure dominates the frequency of sequences consisting of two component failures. However, any decision to upgrade HX2D1 should consider the consequence of its failure by itself or in conjunction with other component failures. This upgrading decision is also made by comparing the seismic sequence frequencies with those of internal and other external events.

CONCLUSIONS

From a number of seismic assessments conducted as part of RMPP of oil refineries and chemical plants, the following conclusions are drawn:

1. A detailed walkdown of the facility is an essential element of the seismic assessment. The walkdowns are able to identify potential seismic vulnerabilities that could not be seen on the design documents. For older facilities, design information in terms of drawings and calculations are generally not available making the data collected in the walkdown invaluable for estimating the seismic capacities. Walkdown would identify the "house keeping" issues e.g. nuts on anchor bolts not replaced after maintenance, corroded anchor bolts, cracked concrete pedestals exposing the bolts etc. Some of these items could be fixed with minimum cost.

2. Further guidance on the engineering assessment is needed. The applicability of the Uniform Building Code provisions developed for buildings should be assessed for components in oil refineries and chemical plants; the equipment may not possess the amount of inelastic energy absorption capacity assumed to be present.

3. The acceptable level of safety depends on the consequence of AHM release. If a quantitative analysis is performed for seismic events along with internal and other external events, the relative contribution of the seismic events to the overall AHM risk could be assessed. If a deterministic evaluation is conducted for seismic events, the choice of earthquake level used in judging the adequacy of AHM components and systems becomes crucial. This level should reflect the type and potential amount of AHM release and the mitigation measures available within the facility and local region. It should acknowledge the possibility that a large earthquake could affect a number of such facilities in the region posing a severe challenge to the emergency response systems.

Table 2:

SEISMIC-INDUCED FREQUENCIES OF DIFFERENT SEQUENCES

Sequence	Component Failures	Annual Frequency
1	G 201	5.5 E-03
2	A231	1.8 E-04
3	HX2D1	1.1 E-02
4	D202	7.5 E-04
5	P234	5.4 E-04
6	C256	5.4 E-04
7	G201, HX2D1	3.3 E-03
8	A231, C256	4.0 E-05
9	G201, HX2D1, D202	4.4 E-04
10	A231, HX2D1, C256	3.9 E-05
11	G201, A231, D202, C256	1.9 E-05
12	HX2D1, D202 P234, C256	4.2 E-05

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