# TOC ASIA
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# THE 1995 KOBE EARTHQUAKE

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## The Event

This year, January 17, five forty-six, Tuesday morning: the earth shook for 13 seconds as the Nojima fault slipped 2.5 meters, destroying weak buildings, killing 5300 men, women, and children, and disabling Japan's major container terminal at Kobe.

Kobe was struck and severely damaged by a very unlikely earthquake.

Five hundred of the 5300 died in one block. First the quake wrecked the buildings, then fires, which could not be stopped because there was no water, killed the occupants.

Many died at home. One and two story Japanese homes are designed for vertical loads. Delicate post-and-beam construction supports tile roofs. The walls are laced bamboo with mud covering or wood slats with stucco. The bamboo construction is called Shinkabe, the stucco Okabe. No attempt is made to tie the structural components together: no nails, no braces, no reinforcing, and no resistance to even moderate lateral forces. Very charming and very dangerous.

The port was never charming, but it was impressive with 8400 meters of container wharves and 60 container cranes.

WEAK STRUCTURES FAILED

THE DISABLED TERMINAL

FIVE HUNDRED DIED ON THIS BLOCK

COLLAPSED HOME

The three main islands at the Port of Kobe, Port, Rokko, and Maya Pier, are in Osaka Bay and are man made. Concrete caisson quay walls enclose hydraulically placed granular fill.

American President Lines operates a container terminal on Port Island. APL retained Liftech Consultants Inc. to assist with the recovery plans for their terminal. Liftech engineers arrived in Kobe on January 20.

This paper looks at the damage, discusses the phenomena that caused the damage, and makes some observations of measures that would have reduced the damage.

Then the paper looks at the wharf and crane design and considers, what does this catastrophe mean?

## Kobe and Japan

Kobe is a major world port handling a little less cargo than Busan, Korea and a little more than Hamburg, Germany. Kobe is the major container port in Japan.

Although Japan is a country of earthquakes, Kobe is not a city of earthquakes. In the last one hundred years, Japan has experienced 185 earthquakes greater than Richter Magnitude 7. For over one thousand years, Kobe had not experienced an earthquake greater than a Richter Magnitude of 7.0. The seismic risk at Kobe is no more than the risk in New York City.

So the moderate Richter Magnitude of 7.2 was unexpected. Moderate? Yes, moderate. The damage is major, but the earthquake is moderate.


PORT, ROKKO, AND MAYA PIER ISLANDS

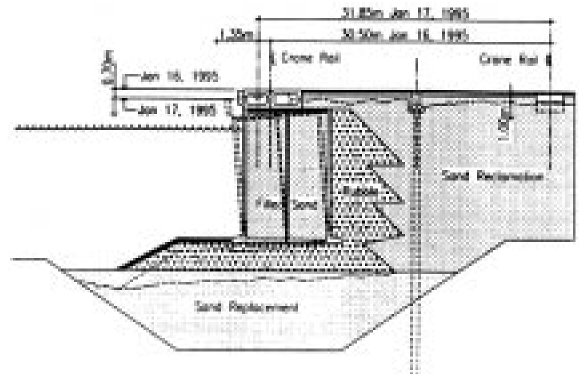
PORT ISLAND

## The Damage

This paper concentrates on the container terminals, but the port at Kobe is more than a container port. The reclaimer shown is on a portion of Rokko Island that was being expanded. This wharf was under construction when the quake struck. Notice the damage is due to the wharf failure and not the failure of the crane structure. The soil under the crane rails liquefied.

DAMAGED RECLAIMER

Throughout the port, the damage was caused by liquefaction. The concrete perimeter quay caissons settled and translated. The original and the damaged wharves at Port and Rokko Islands are shown in the section.




TYPICAL WHARF AT KOBE

### LIQUEFACTION

Notice the photo of the container next to the fractured pavement. Notice the stains on container's side. These marks are the signature of liquefaction. How did they occur?

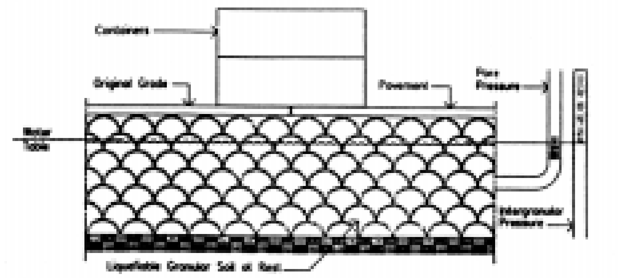
LIQUEFACTION SIGNATURE

Initially, hydraulically deposited cohesionless granular soil settles into a loose network of interconnecting fragile arches. The soil may be naturally or artificially placed. When the soil structure is shaken with sufficient intensity, the natural soil structure is disrupted. The overburden that was carried by intergranular pressure moments earlier is now carried by hydraulic pressure in the groundwater. The groundwater escapes carrying fine soil and making a spectacular fountain until the subterranean grains consolidate. There are a few common misconceptions of liquefaction: one, that the shaking increases the pore pressure, thereby decreasing the intergranular pressure, not true; another, that the large settlements are due to loss of soil particles, also not true.

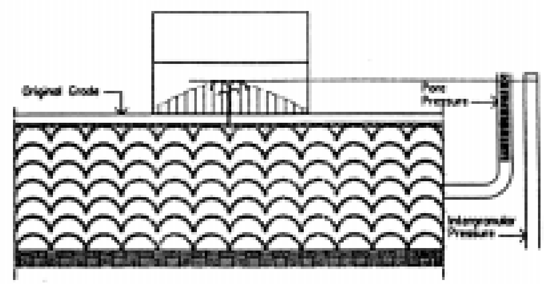
The four diagrams that follow explain the phenomena. Initially the loose soil is at rest. When the quake strikes, the soil structure is disturbed, the grains are suspended in the groundwater. The weight of the groundwater and the overburden is carried by pore pressure in the groundwater. The pressurized groundwater escapes through the pavement, bursting into fountains. These fountains marked the side of the containers.

As the groundwater escapes, the surface settles. The groundwater carries fine material to the surface. The settlement is due to loss of groundwater, only a little is due to these fines. Temporarily the water forms a pond. Notice the water line near the bottom of the container.

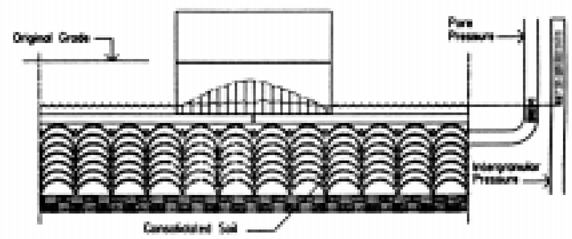
Eventually equilibrium is reached. Again the intergranular pressure supports the overburden. But the volume of the fill has been reduced, mainly due to the escaped groundwater.



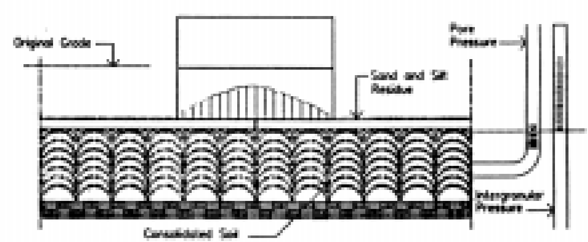

BEFORE LIQUEFACTION $T_1$




DURING LIQUEFACTION $T_2$




AFTER LIQUIFACTION $T_3$




SOMETIME LATER $T_4$

At Port and Rokko Islands, the surface settled one to three meters. The vertical motion was very gentle, like being lowered on a giant shock absorber. The fountains sometimes flow for 30 minutes. Notice that the stacks of containers were not tipped, except when liquefaction caused differential settlement.

The mud that remains on the surface after liquefaction is the fines carried with the groundwater. Remember the settlement is mostly due to the loss of groundwater, not fines. The pavement settled meters, the mud is only centimeters thick.

SOIL FINES CARRIED TO THE SURFACE

Liquefiable soils are identifiable and can be improved by the installation of stone columns. Stone columns have been used to stabilize soil in the Port of Oakland, and they are being used to stabilize the soils for the Port Authority of Guam container terminal.

## BUILDING DAMAGE

Pile supported structures did not settle and were not seriously damaged. The pile supported crane concrete girder at 50' gage that appears to have risen, in fact, did not rise or settle. The adjacent pavement settled.

THE PAVEMENT SETTLED

## WHARF DAMAGE

The caissons displaced toward the sea about one meter and settled about one meter. Each caisson moved independently. No attempt was made to key them together. Keys could have been provided at a very small cost.

The gantry rail gage increased one meter or more, causing serious damage to most of the cranes and causing one crane to collapse.

FAILED QUAY WALLS

## CONTAINER CRANE DAMAGE

Liquefaction, not lateral earthquake accelerations, damaged most of the cranes and destroyed one crane. Notice the collapsed crane fell vertically; not sideways. As the rail gage spread several meters, the legs buckled.

CRANE DAMAGE

The other cranes were seriously damaged. Notice the leg fractures above the portal and in the portal tie. The legs and portal ties are made of thin stiffened plates. Even though some local buckling occurs, the global structure remained ductile.

The damage to the cranes is very similar to that sustained when a ship collides with a crane. It appears that the designer did not anticipate an accident.

For a few dollars, the portal tie beam could have been increased and ductile joints could have been provided. The resulting ductile moment frame would have come off the rails, and the frame would have not collapsed.

### Ductile Moment Frames

Ductile moment frames are an inexpensive way of increasing earthquake resistance of any structure. Crane specifications should require ductile moment frames.

DUCTILE FRAMES PERFORMED WELL

Liftech has investigated the effects of earthquakes exceeding Richter magnitude 8, in Honduras and Guam, and of earthquakes exceeding magnitude 7, the Loma Prieta in Northern California and the Northridge in Southern California. Ductile frames can resist significant lateral displacement without failure.

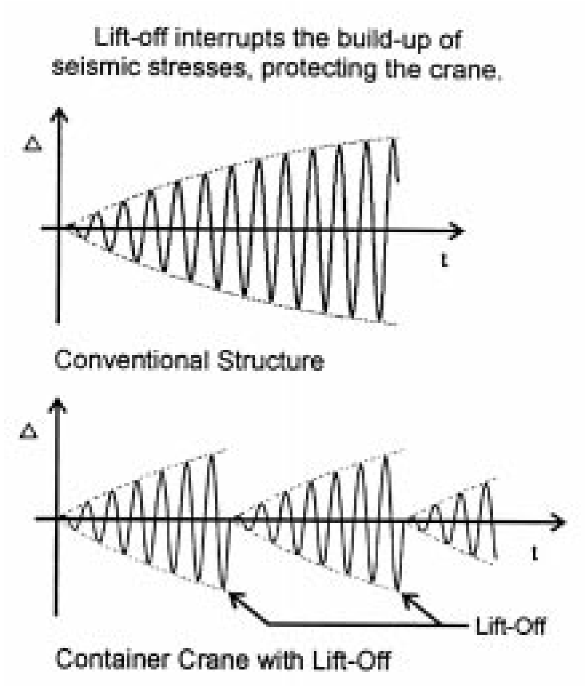
So far, no container crane having a ductile moment frame has been seriously damaged in an earthquake. Many, however, have left their rails.

### Crane Response

The seismic response of container crane is different than that of a conventional building. In 1916, when Frank Lloyd Wright designed the Tokyo Hotel, an unconventional building, he observed "Why fight the quake? Why not sympathize with it and outwit it?"

The crane naturally outwits the quake when the crane structure responds to the quake. Those vibration modes in resonance with the ground motion experience the maximum response. This response increases with time; maximum displacement is not instantaneous. If the quake is powerful enough, the forces build until one leg lifts.

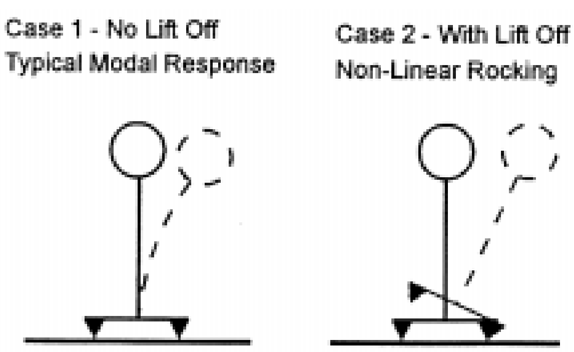
This interrupts the response, the crane settles down, and the cycle begins again. When the shaking is done, the crane may be off the rails, but it's not seriously damaged.




EARTHQUAKE RESPONSE OF A CONTAINER CRANE

## Lessons

What structural lessons did we learn from Kobe? We already knew structures with no lateral resistance will fail, that loose granular fill will liquefy, and that ductile moment frames perform well. So, structurally, we didn't learn anything new.




DYNAMIC BEHAVIOR OF A CONTAINER CRANE UNDER SEISMIC LOADING

### WHAT COULD HAVE BEEN DONE?

A number of improvements could have been made:

Tie the crane rail girders together.

Use a pile supported wharf structure with a ductile moment frame. This has been used in Oakland and is being used in Guam.

Consider the effects of liquefaction.

Improve the liquefiable soil, using stone columns.

Design the caissons to resist the pressure from the liquefied soil and the earthquake lateral

> acceleration. The structure was designed for a lateral force coefficient of 0.1g. In seismically active regions, which Kobe is not, the lateral force coefficient is usually about 0.2g.

A life line approach would seem sensible. Using the life line approach, a portion of the terminal would be designed for a large earthquake, so that after the earthquake some of the facilities would be operational.

## WHAT SHOULD HAVE BEEN DONE?

All the above could have been done. But should they have been done?

Let's think about it. First let's consider the fundamentals.

### Fundamentals

From *Fatigue of Metal Structures* by T. R Gurney: "If the designer ... is asked what life he requires from his structure, he will almost invariably reply that he wants infinite life...,.regardless of what the structure may be."

Dr. Gurney is right. Most of us do not naturally consider that there is always a chance of failure. Although structural reliability may approach one, it is never one.

*Engineering News Record,* January 30, 1995 reports a young civil engineer from Osaka, eyeing the awesome wreckage, saying, "We used to say that Japan's earthquake engineering was the best in the world. I don't think we'll be saying that anymore." The young engineer is wrong. Structural failure and design failure are not synonymous. In fact, if there is never any earthquake damage, we are spending too much preventing it.

*The Economist*, January 21, 1995, opines, "Finding the will to act and accumulating experience are the easier parts of guarding against natural disaster. Harder is knowing how to draw the line between sensible precaution and a vain quest to free the world of all risk. In making this judgment, common sense is a surprisingly unhelpful ally. ...Individuals think their lives should be secure at any price. ... No society limited in resources could afford to apply such a principle."

And the Mobil Corporation in the *New York Times* states, "One of the major steps to regulatory reform seems like such a logical one it is surprising that it has not already become part of the process. It's called risk assessment / cost benefit analysis. Perhaps the reason it has been missing over the years is that it's so, well ...businesslike."

### Design Philosophy

Life is uncertain. Resources are limited. There are no quick fixes. The design challenge is to understand and apply these truths.

We must balance our design between the damage caused by avoiding failure - the initial cost plus operating costs - and the cost of failure. We must learn to draw the line between sensible precaution and a vain quest to free the world of all risk.

Possibly the Kobe design was in balance. True, it's hard to imagine that the design was in balance. But what if the destructive quake occurred once every 10,000 years, or for the sake of clarifying the concept, what if the quake occurred once every one million years? If so, clearly, no amount could be justified to reduce the risk of earthquake damage. So what do we do?

The earthquake provisions in the new ASCE 7-93, *Minimum Design Loads for Buildings and Other Structures*, are excellent. Remember, they are based on a probabilistic approach, as they should be. But the code can become a cookbook, as it should not be. The code is a guide. In most cases, it is a minimum; in some cases, it is too restrictive.

The ASCE 7-93 commentary points out that the maximum design load has a 90% chance of not being exceeded in 50 years. I think we should say a 10% chance of being exceeded in 50 years.

The commentary also points out that the design earthquake is not the maximum that can occur. If the period is long enough, the design earthquake will probably be exceeded. It happened in Kobe.

One shortcoming of ASCE 7-93 is that the concept of cost benefit / ratio analysis is ignored. My gut feel is that a cost benefit analysis would verify the code. However, lacking any mention of cost benefit ratio tends to lead us away from the thinking I am encouraging rather than toward such thinking.

## Conclusion

We have seen the earthquake and its terrible damage. We understand what went wrong. Should we change our designs? Not much. The greater change should be in our approach.

Designers should think about failure. Almost always, a small and inexpensive improvement will increase the reliability by an order of magnitude. It's like fastening your seat belt.

Recognize that if you wait long enough, some rare event will occur, and structures will fail. We should not attempt to avoid failure at any cost. Remember, if there are never any failures, we are using too much of our resources avoiding them.

Proper designs draw the line between sensible precaution and a vain quest to free the world of all risk.