Chichi, Taiwan Earthquake of September 21, 1999 (M7.6)

An EQE Briefing

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General Overview

An earthquake of magnitude 7.6 occurred in Taiwan at 1:47 a.m. on September 21, 1999. The epicenter was approximately 7 km NW of Chichi, a small town bordering a mountainous resort area, located 155 km from Taipei, the capital. The duration of severe ground shaking was about 40 seconds. The earthquake was felt over the entire island. In the 5 days following the earthquake, there were many aftershocks, several from M6.0 to M6.8.

This earthquake is of particular importance because of its impact on the high-tech facilities that are a crucial part of the supply chain to the worldwide computer manufacturing industry. Business interruption in these facilities has repercussions for major computer companies in Silicon Valley and elsewhere.

Beginning the day of the earthquake, EQE International had a team of engineers on the ground in the affected area, investigating and researching the damage, providing support to our clients, and documenting lessons learned to prevent such catastrophic losses in future earthquakes. This report is a briefing of our findings on the effects of the earthquake on the people, structures, and the country of Taiwan.

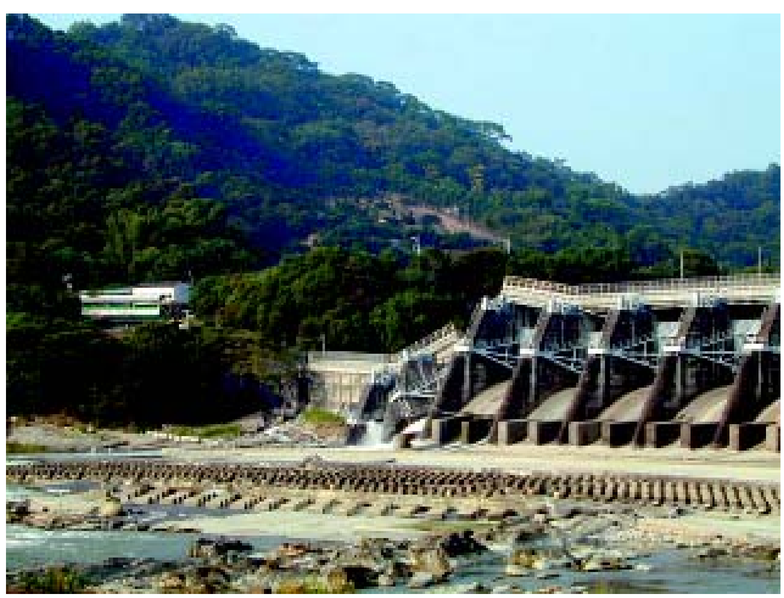
Map of Taiwan showing epicenter of Chichi earthquake and nearby cities.

The Earthquake

This was the largest earthquake to hit Taiwan in recent history. High ground accelerations on the order of 0.5g to 1.0g were recorded in the epicentral region. Significant ground failures of various types were observed. One of the most spectacular aspects of this event was the extreme amount of vertical ground offset observed along the fault rupture. Offsets measured 3m to 6m in many regions. At the dam in Shihkang, nearly 15m of vertical offset was noted, disrupting water supply to Taichung.

Taiwan is located along a zone of collisional convergence between the Eurasian plate and the Philippine Sea plate. On Taiwan, the zone of collision is marked by NE-trending zones of thrust and strike-slip faulting. A primary zone of thrust faulting follows the Western Foothills of Taiwan, in close proximity to the city of Kaohsiung on the south and the city of Taipei on the north. This earthquake occurred near the center of this zone.

Shihkang dam failure caused by vertical fault rupture of 15m through the dam (right photo). Vertical fault rupture across the main street of Fengyuan (bottom photo).



Widespread damage to quartz tubes in wafer fabs demonstrates vulnerability of wafer processing equipment to earthquakes (left photo).

Damage to typical high-tech facilities in the 1990 Philippine earthquake (bottom photo).

High-Tech Facilities

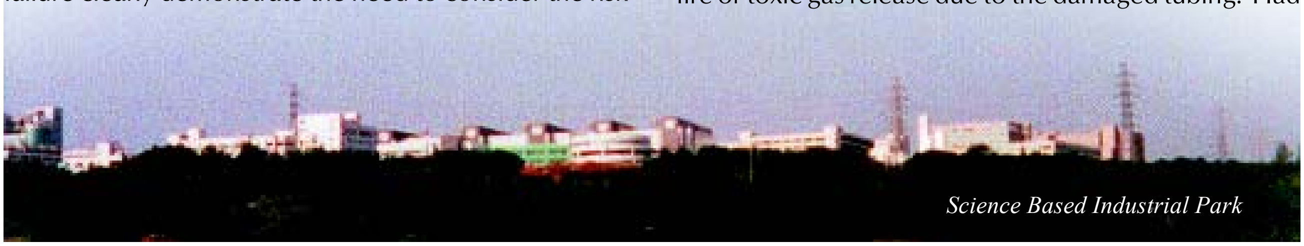
Hsinchu is located about 110 km from the epicenter and is the site of the Science Based Industrial Park, a major development where about 30 companies provide a significant percentage of the world's semiconductor manufacturing and silicon processing. Even though the facilities were a long distance away from the epicenter, there was still a major business interruption consequence from this earthquake for this key industry.

The overwhelming problem caused by the earthquake was loss of electrical power. Almost all of the Science Park was down for several days, resulting in business interruption costs of about $50 million to $100 million per day. Earthquake damage to distant 345 kV transmission towers and a switching station made it impossible for the park to receive power from the usual steady supply from the South of Taiwan. Power was slowly restored to major users in the area by rationing residential and small commercial customers in other parts of the country, including Taipei. Some facilities were able to maintain emergency power through the use of generators with varying success. One wafer fabrication company sustained a large loss when the generators burnt up after running continuously for 40 hours after the earthquake. With loss of the standby power, this facility went completely black, and lost power to fans that maintain the clean room environment.

The large business interruption costs due to this power failure clearly demonstrate the need to consider the risk not just to the facility, but also to the surrounding infrastructure.

The ground shaking intensity in the Science Park area was low, with ground accelerations of less than 0.15g. As such, damage to buildings in the Science Park was limited to minor breakage of windows and small cracks in concrete walls. Some facilities sustained partial failure of raised floors and dropped ceilings. Had the earthquake ground motion been more intense, the business interruption as a result of structural failure would have been worse. The buildings in the Science Park can be categorized according to age: mid-80s, late 80s to early 90s, and mid-to-late 90s. There are significant differences between the building codes for these three periods. Heavy concrete was used in most of the buildings, some with and some without special shear walls. Some buildings, mainly those that are newer and taller, were built with structural steel. With more intense shaking, there could have been widespread business interruption caused by structural damage to the mid-to-late 80s and early 90s buildings.

Varying equipment damage was reported in the Science Park manufacturing facilities. The worst reported damage entailed breakage of quartz tubes inside vertical diffusion furnaces. Most of the wafers contained in the quartz "boats" were also cracked when they were tossed during the shaking. There were many cases of process equipment shifting, and at least one case where a tall cabinet overturned. Fortunately, there was no report of fire or toxic gas release due to the damaged tubing. Had



Science Based Industrial Park

Fire damage due to a standby generator failure in the Hsinchu Science Park.

the shaking been even slightly stronger, damage and loss would have been much more extensive. Such damage to typical high-tech facilities occurred in the 1990 Philippine earthquake.

Despite the known seismic risk, much of the very expensive process equipment in these facilities is not designed with adequate seismic protection. Damage to this equipment can contribute greatly to business interruption, because replacement of critical tools could take several months.

Sprinkler piping leakage caused heavy damage at some facilities, including damage to steppers and large sections of clean rooms. Piping systems in Taiwan are most typically not designed for earthquakes. These are some of the easiest systems to strengthen, and such strengthening would greatly reduce both fire-following and sprinkler leakage problems.

The earthquake in Taiwan has adversely affected production of computers in Silicon Valley in California (and elsewhere), as many critical components are manufactured in Taiwan. This clearly demonstrates the need for companies to understand the risks to their own businesses through the vulnerability of other businesses in their supply chain.

Results from our investigation into the damage at the Hsinchu Science Park emphasizes two important points. First, the damage to one of the most important supply chains for the world's computer industry was limited only because of its distance from the epicenter. The business interruption could have been significantly worse. Our experience suggests that business interruption of 6 to 12 months is quite possible following high-intensity shaking. Second, the building and equipment vulnerabilities at the Science Park are not too different from those in other high-tech parks such as Silicon Valley in California, where the earthquake threat is as great and is increasing over time.

While the direct implications of the business interruption from this earthquake to the worldwide computer industry are very significant, it could have been worse. This earthquake does provide a wake up call to this industry, and to other industries that depend on key production facilities in parts of the world that are susceptible to natural disasters.

Buildings

Well over 10,000 buildings collapsed or were severely damaged. The collapsed buildings were predominately of reinforced concrete framing, with infill masonry walls or reinforced concrete walls, and ranged from older, smaller buildings to modern high-rises.

Within about 5 km of the fault line, ground accelerations approached 1.0g in the E-W direction. The "softer" first story of many older buildings collapsed as a result of severe ground shaking, especially those oriented such that E-W was their weaker direction. Most of the buildings in Chichi were destroyed by the earthquake. Other towns that were hit exceptionally hard were Chungliao, Wufeng, Tali, Takeng, Shihkang, and Tungshih.

Directly on the fault line, vertical ground offsets caused complete destruction of all buildings that straddled the fault. This was observed in Mingchien, Takeng, and Shihkang.

Collapsed 14-story condominium in Taichung attributed to faulty design or construction.

Collapsed 12-story condominium in Tali.

Collapsed condominium complex in Touliu.

More than about 5 km from the fault line, it was repeatedly observed that the older buildings performed well, but many of the modern structures over six stories tall performed poorly. This can be attributed to faulty design and construction, and improper enforcement of seismic design provisions in the building code - even though the building code used in Taiwan is comparable to those used in Japan and in California.

In Taipei, despite the relatively low level of ground shaking, two 12-story buildings collapsed, falling on their sides. There is no obvious reason why those two buildings, in very different parts of Taipei, collapsed among the thousands of similar-appearing buildings that had minimal to no damage.

Industrial Facilities

Varying degrees of damage to industrial facilities were observed. Aggregate and concrete batch plants were damaged heavily throughout Taiwan. Silos and hoppers with heavy fill loads collapsed, causing severe damage to adjacent structures and equipment as they fell. Within about 40 km of the fault line, damage was observed at essentially every aggregate and concrete batch plant. The seismic design practice that is used for the design and construction of such facilities clearly requires a major revision.

Damage to rice wine aging buildings at the Puli winery.

In the city of Puli, a 30-year-old winery sustained heavy damage. Many of the buildings were constructed of reinforced concrete frames with masonry infill walls, and many collapsed. A brewery in the city of Nantou experienced losses from a fire resulting from spilled spirits ignited by sparks. Business interruption costs are projected to be very high.

At Taichung Port, about 70 km from the epicenter, many large flat-bottom steel storage tanks containing molasses were affected by the earthquake. Sloshing of the contents caused heavy damage to the roof and walls of the tanks, resulting in content spillage. A nearby food processing plant had several grain silos, which were filled with product by plant operators because of an impending typhoon predicted before the earthquake. When the earthquake hit, all of the full silos collapsed.

Typical collapse of aggregate and concrete batch plants, which is one of many in the epicentral area.

Collapsed grain silos located in Taichung.

Toppled control equipment in 345 kV Chungliao substation.

There are a few industrial park areas in the cities of Nantou and Taichung. Moderate damage occurred to reinforced concrete-frame buildings with concrete walls or brick infill walls. Equipment slid or overturned within many facilities, resulting in extended business interruption that could have been easily avoided by equipment anchoring. A steel-frame warehouse building was heavily damaged, leaning to one side, when its columns failed due to the impact of collapsing storage racks inside of the building.

Infrastructure

Lifelines

Electrical power supply throughout the country was partially restored within a few days. Long outages occurred due to a combination of extensive switchyard and substation damage, high-voltage transmission tower damage, and a trip off-line of two nuclear power plant units. Water and gas supplies in Taipei were also impacted by the power outage. Telephone service was continuously interrupted.

There are three hydroelectric power stations located within about 10 km of the epicenter. The stations performed well, with only minor damage to building structures. Landslides caused some damage to piping at one of the plants.

There are two nuclear power plants in the northern end of the island, Chinshan and Kuosheng. Neither of these plants had earthquake damage. They were tripped off-line due to failures in the transmission grid system when they could no longer meet the demands of the northern part of the island. The Maanshan plant at the southern tip of the island did not trip. However, due to both substation and transmission tower damage, electrical power produced by power plants in the southern part of the island could not be transmitted to the northern part.

There were no reports of damage to the two cogeneration power plants on the island located in Hsinchu and Mailiao (which is about 50 km west of the epicenter).

The 345 kV Chungliao substation is the most important facility within the national electrical power distribution system. It is the link for the surplus power generated in the south to be transmitted to the north. Only minor structural damage was noted in the main control building. Although the control panels in the control building were not damaged, some protected panels overturned due to anchorage failure. Equipment components out in the yard sustained heavy damage. This was due to the intense ground shaking as well as some local soil settlement and slumping. As many as 200 components, including ceramic insulator columns, bushings, and busses, will need to be replaced.

Ports

The amount of liquefaction in the port of Taichung was severe despite its distance from the fault. Up to 20m wide sink holes developed, apparently due to liquefaction of deep silty sand layers below the reclaimed land. Quay walls tilted slightly; with the land behind them settling up to 2m. The effort to rebuild the Taichung port facilities is estimated to take up to 2 years. Other major ports in Taiwan performed well.

Water Supply

The drinking water reservoir in Shihkang was lost due to failure of the dam. The left side of the dam dropped about 15m due to ground faulting. The tremendous force of the earthquake distorted the entire massive structure (all gates are inoperable) and caused one section to fail. The dam will likely not be repaired. Reportedly, a new dam will be constructed upstream.

The significant ground heaving in Shihkang diverted the flow in a drinking water channel completely away from its original path. Temporary channels were hurriedly dug to restore the water flow. Open culverts and buried water piping were broken at fault crossings. Within 4 days of the earthquake, much new piping had already been laid in newly dug trenches.

Road Network

Numerous road sections were heavily damaged by vertical ground offsets from the fault rupture and landslides. Repair work, removal of collapsed buildings, and emergency supply vehicles desperately trying to get to damaged areas resulted in extreme traffic jams.

On the outskirts of the city of Nantou, sections of the new (Nantao) elevated expressway were shored-up due to earthquake damage distress to the superstructure. There was severe cracking at the tops of the massive support piers, and the outboard traffic lane was sagging.

Implications to the Insurance Industry

Taiwan has several areas of high value concentrations, such as the Hsinchu Science Based Industrial Park, for which insurance coverage is quite high. Catastrophic insurance coverage (including earthquake) for such locations is typically heavily oriented towards high-tech equipment and contents (about 2/3 of coverage) and business interruption (BI, about 1/3 of coverage), with building structural coverage representing only a nominal amount.

The main contributor to BI claims will be the island-wide power outage, which prevented initiation of equipment calibration and restoration activities until reliable power was available. Given that the Taiwan economy is approximately $1 billion per day GDP, total economic losses due to interruption of power and other business operations may be as much as US $5 to 10 billion. However, given that much of this is probably not insured (except in the high tech industries), insured claims will probably be several billions (the current best estimate is US $2 billion), a significant portion of which will be BI.

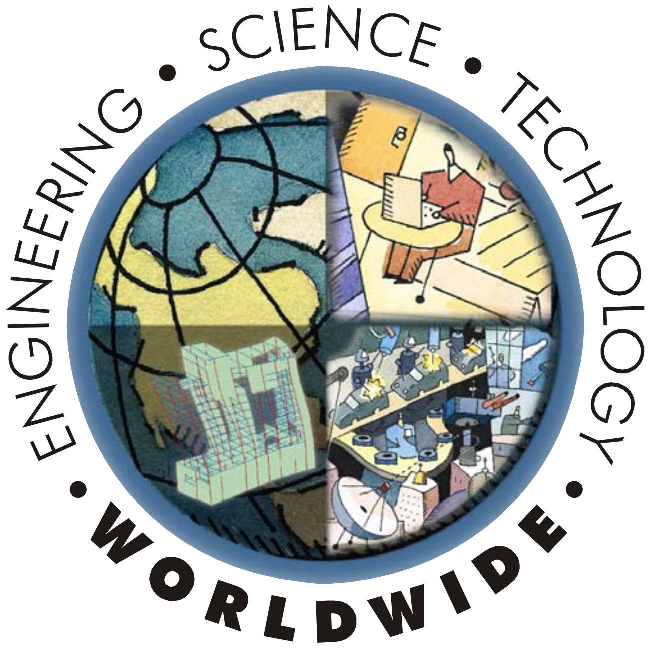
Conclusions

The Chichi, Taiwan earthquake provides lessons that unfortunately have been taught repeatedly by past devastating earthquakes:

- The significant business interruption to the crucial high-tech industry could have been minimized through adequate seismic strengthening of equipment and the proper implementation of emergency plans that would have more specifically addressed the loss of off-site power in detail.
- Loss of life and building collapse were avoidable. Today, it is horrifying that new buildings are being designed and constructed in an unsafe manner without regard to earthquakes and other natural disasters. This is especially true given the generally good design criteria provided in the Taiwan building code. The presence of a good building code does not guarantee good performance of buildings and their contents. It is critical to also have adequate design, construction quality, and especially independent review of design and inspection of construction.
- Owners do not understand the intent of the building code. Buildings properly designed to code requirements will sustain damage during major earthquakes. The intent of the code is to ensure that buildings remain safe and occupants can exit. If building owners want better buildings, then this will have to be specifically requested, and can be accomplished by more sophisticated, "performance-based designs."
- Severe industrial losses also were avoidable. None of the industrial losses that occurred in this earthquake were surprises. All of the losses could have been readily predicted. The lack of redundancy in the power grid was a problem identified well before the earthquake. Construction of a back-up line had begun years ago, but progress was reportedly on hold due to land acquisition problems.

  In this earthquake, there are no significant lessons with respect to structural behavior. Experienced structural engineers could have pinpointed and remedied most building and equipment configurations that led to earthquake damage.
- Limited earthquake insurance availability. There are reports that less than 1% of the residences in Taiwan are insured for earthquakes. Improvements in hazard mapping and use of sophisticated catastrophe management software will hopefully enable Taiwan to improve insurance availability through risk-based catastrophe policy pricing. Risk-based underwriting and pricing could also provide support for changes in land use planning, mitigation and building retrofit programs, and improvements in building construction practices.

Foundation failure of a transmission tower due to fault rupture in Mingchien.



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