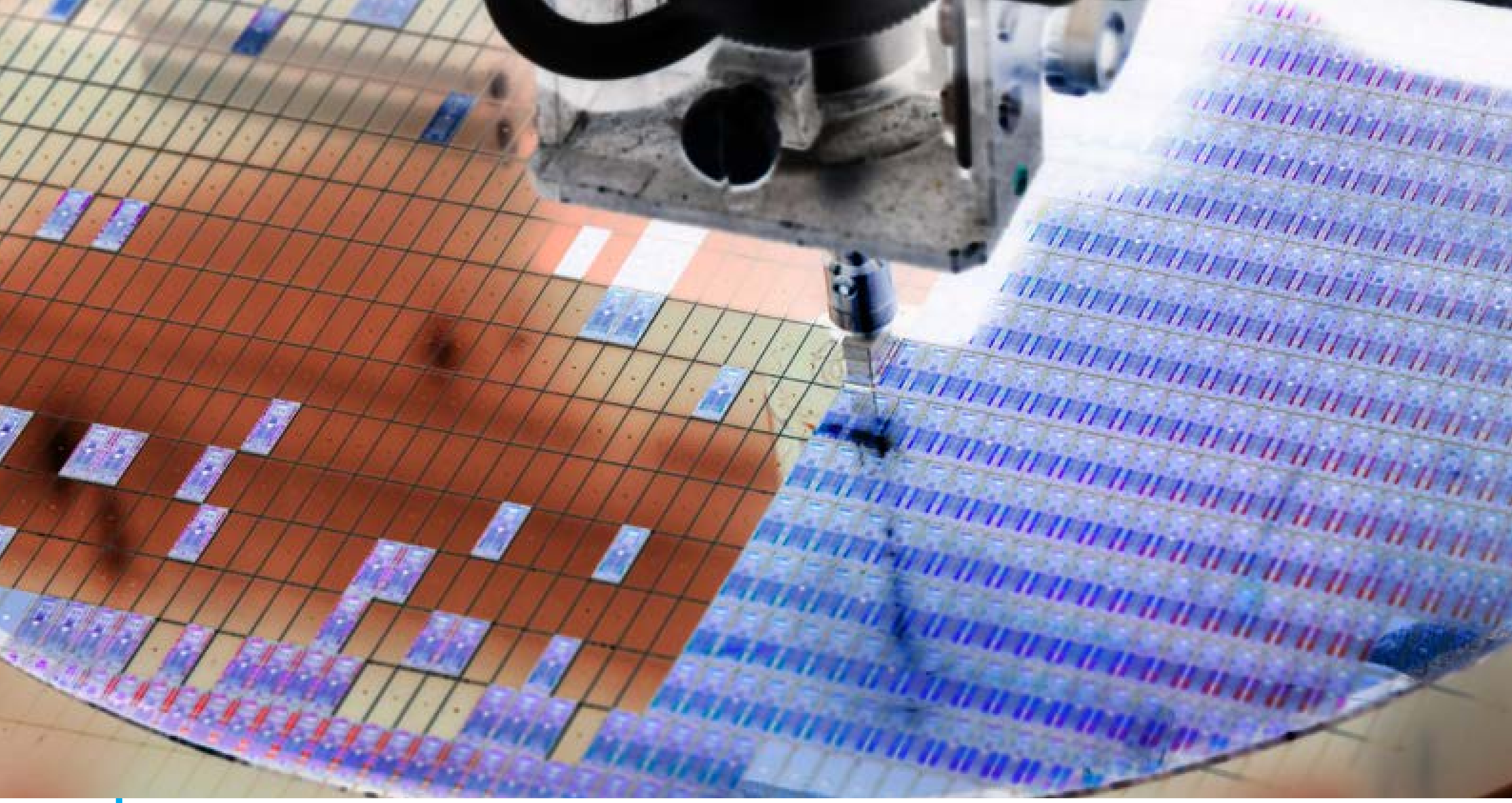

Taiwan 403 Earthquake: Protections for Semiconductor Industry from Seismic Damages

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At 07:58:11 local time on 3 April 2024, a magnitude (M_W) 7.2 earthquake struck 15.5 km (9.3 mi) south of Hualien City of Taiwan (hence the name “403 Quake”). The epicenter was located at N 23.77°, E 121.67°, and the intensity was reported as 6+ in Heping, 6- in Hualien City and Taroko, and 5- in Taipei and New Taipei city.

Given Taiwan’s vulnerability to earthquakes, robust emergency preparedness measures and response protocols were already in place. These responses were activated swiftly especially in the facilities of its valuable semiconductor industry.

Most of the semiconductor factories have reported a downtime during the earthquake. This affected major wafer factories, IC testing plants and TFT-LCD panel factories. Personnel were evacuated and some process tools in the cleanrooms of the fab buildings were shut down. These manufactories stated that all personnel were safe and gradually returned to their workstations.

Preliminary inspections have shown that these constructions are in normal condition. For safety, many companies have decided to suspend work at their operation sites within hours and resume after inspections. According to reports, some operations for advanced process were suspended during the earthquake. In addition, the extreme ultraviolet (EUV) lithography equipment crucial for these advanced nodes was halted at the site for a period of 8-15 hours.

From observations, most of the damages and losses are related to earthquake magnitude in the factory’s area, the capacity utilization rate when an earthquake occurs, and the anti-seismic design of the factory buildings. The two major questions are: whether anti-seismic measures for non-structure elements (NSEs) and production equipment are complete, and whether the original equipment and the factory’s hardware design have any anti-seismic characteristics.

In the beginning of the earthquake, semiconductor manufactories took precautionary measures and paused production on some of their factories immediately. Most companies reported minimal damage to critical equipment except some experienced damage to the internal quartz components of vertical diffusion furnaces (VDFs). It was reported that 70-80% of process equipment was back in operation within hours or a few days. Similarly, almost all semiconductor manufacturers reported minimal impact on their operations and stated that they did not expect the earthquake to have any impact on their supply after consulting their local suppliers.

Taiwanese semiconductor manufacturers have fortified their factories against seismic damage in the past decades. Many have employed automatic shutdown systems to minimize loss to their production equipment in an earthquake. Industry reports have shown that wafer fab buildings have quite high seismic resistance coefficients, capable of withstanding magnitude 7 earthquakes. However, typically occurring earthquakes of intensity 3 to 4 may trigger process equipment to activate defense mechanisms and automatic shutdowns. Further detailed inspections by the owners or equipment vendors are required to check for other damage. They need to determine whether normal operations can resume directly after facilities restart. Some issues like partially damage to wafers produced in cleanrooms and rupture of quartz tubes and pipelines will require at least 1 to 2 days for further checking and inspection.

Fortunately, major semiconductor factories located in northern, central, and southern Taiwan did not suffer severe operational disruptions from 403 Quake. They suffered simply from a loss in production capacity. A typical physical property loss of a single wafer fab could range from several million to tens of millions of US dollars. Among them, there are still a few insureds experienced no business interruptions and did not need to initiate claims because their actual physical damage loss amount is lower than their insurance deductible.

The earthquake

The 403 Quake is the second biggest earthquake ever recorded in Taiwan, following the 1999 Jiji earthquake ("921 Quake") which had a magnitude of 7.3 and struck at a depth of just 8 kilometers. The Wednesday temblor struck deeper, had a slightly lower magnitude and had a lower maximum intensity of 6+ on Taiwan's seismic intensity scale. It is estimated about 84 buildings were severely damaged with Hualien City being the most affected area.

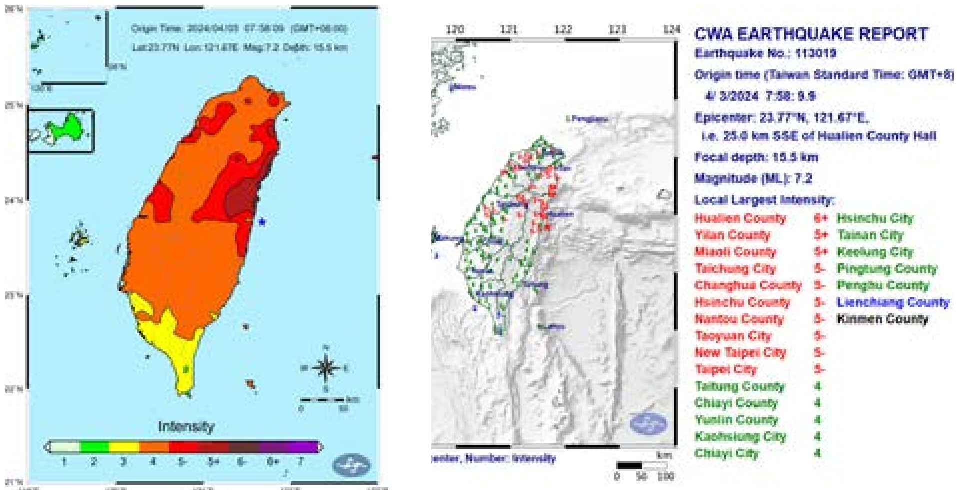

Photo courtesy of Central Weather Administration

At least 18 people were killed and over 1,100 were injured during the incident. Following the main shock, there was a substantial sequence of aftershocks, registering in excess of M6 within the first 24 hours of the main shock, which has caused more than 300,000 households to lose power, roads and buildings damage and transportation obstruction. Some buildings tilted at precarious angles in a mountainous, sparsely populated county of Hualien, near the epicenter. The 7.2 magnitude quake, which struck just offshore, has triggered massive landslides. Other three aftershocks in excess of M6 have been recorded over the next four days with magnitudes between 4 and 6.

The experts from local authorities said that the 403 Quake could activate faults in the Central Mountain Range, or the Ryukyu Trench which has no seismic sensors. This could trigger an even more powerful earthquake in the future, worst of all, without any warnings. Faults in the Central Mountain Range could also be activated.

Although damages and collapses of residential buildings can be seen in local and international media reports, the vast majority of structures withstood the ground motion with only minor damage. They provided adequate safety protection for the people inside.

According to an estimate from a large insurance company in Taiwan, the insurance claims caused by the 403 Quake in Taiwan are expected to exceed USD 2 billion, at least half of which may have come from the microelectronics industry.

Impact on the industry

Most of the microelectronics industry in Taiwan operate in the major “Science-Based Industrial Parks” in Hsinchu, Taichung, Tainan and Kaohsiung. These parks are located a few dozen to over 100 kilometers north, central and south of the earthquake epicenter. Almost all the wafer fabrication facilities are equipped with accelerometers that can trigger shutdown of hazardous gas and chemical dispensing systems. Based on data from these devices, the peak ground acceleration (PGA) in these parks was on the order of 0.07 g (60 cm/s^2) to within 0.1 g (98 cm/s^2). However, as the cleanrooms in those fab factories are situated at a different height than their earthquake-resistant structure, the seismic intensity detected ranged from PFA (peak floor acceleration) 100 to 390 gal on the different process floors. The shock has also caused damage to the wafers manufactured in each fab factory.

The areas with most of these wafer foundries and manufactories have experienced a level 4 intensity shake. Owing to the high construction standards of Taiwanese semiconductor factories, which feature world-class seismic mitigation measures capable of reducing seismic impacts by 1 to 2 levels, the facilities were largely able to resume operations after inspection shutdowns quickly. Even though there were instances of wafer breakages or damages due to emergency shutdowns or earthquake damages, the capacity utilization rates of mature process factories showed an average between 50-80%. This meant losses were quickly recovered after operations resumed and impacts on capacity were only minor.

According to observation reports on the substantial property damage to these factories, high proportions of the affected areas are concentrated in the WIP in process equipment and wafer breakages or damages from vertical diffusion furnaces (VDFs) in the cleanrooms. In response to the impact, most factories are currently confirming the details of equipment situations. While partial shutdowns of process equipment were reported, the owners have made efforts to resume operations within hours or days after the earthquake. This is expected to have a short-term impact on their operations, potentially necessitating acquisitions of new parts for process tools (e.g., quartz tubes for vertical diffusion furnaces, quartz made reticle tables for scanners) from their original vendors. Thus, there could be a slight increase in capital expenditure. Some facilities resumed operations after inspection with no significant damage reported and operations at each manufacturing site progressively returned to normal following evacuation or inspection. The industry believes that the impact on the operations of related companies should be limited.

As shown in the data from past major earthquakes, the industry suffered from losses not due to damage to the major facilities or process equipment (except for VDFs) but rather interruption of electrical utilities resulting from damage to the power grid. This subsequently created electrical outages and rationing lasted for almost two weeks.

Semiconductor facilities usually have a certain degree of emergency power generation capacity. However, it is intended for emergency purposes (e.g. running exhaust fans, lighting, life safety and fire protection systems) but not for actually production.

The epicenter of 403 Quake was near Hualien, not a business or commercial center but one for tourism, on the east coast of Taiwan. The earthquake's economic impact to the city would be very small. However, if it happened near Taipei or the west coast where semiconductor factories are dispersed, then the impact is bound to be greater. Therefore, the impact of 403 Quake on Taiwan's economy should be mild in short term, but this will largely depend on whether semiconductor factories find any damage, even minor ones, in their equipment that could lead to production delays.

Taiwan plays a critical role in chip and semiconductor manufacturing and is the heart of the global electronics industry. It houses around 92% of the world's most advanced chip production and 18% of global semiconductor manufacturing capacity*. There have been initial concerns about the possible impact on the global chip and semiconductor supply in the aftermath of this earthquake. Based on recent reports, analysts now predict a minimal long-term interruption to the supply chain.

The semiconductor industry has implemented comprehensive earthquake protection measures which minimize damages to sensitive technologies and immediate impact to the economy. However, this event still serves as a wake-up call for all business owners of the microelectronics industry. Diversification in their chip and semiconductor supply chains can help mitigate risks associated with future interruptions. One possible solution could involve investments in overseas chip manufacturing facilities.

This natural disaster attracted special attention from international markets. Moody, a major credit rating agency in the world, issued a comment about this earthquake on April 8 from the three perspectives - economy, insurance and supply chain. They believed that the economic impact was very small, but the supply chain must spread risks. The 403 Quake made the concentration risk that suppliers have been paying attention to more obvious. It also highlighted the importance of integrating climate data into supply chain risk analysis and management which can enhance the industry's resilience.

* "Taiwan—The Silicon Island" - U.S. International Trade Commission

Physical damages on the facilities

The distance from the epicenter to all science parks is far enough that much of the shock's acceleration was attenuated. As expected, there was very little structural damage for accelerations on the order of 0.07 g (60 cm/s^2) to within 0.1 g (98 cm/s^2) range. No damage to exterior wall systems in the steel frame structures of fab buildings was observed. Similarly, no major damage to the interior partition walls of the cleanrooms was reported or observed except minor cracks. Some minor cracking and spalling of the exterior tile on the reinforced concrete structures was observed around the buildings. This damage was generally caused by the cracking of concrete frames and concrete or masonry infill walls behind tile façades. It was found to be very minor on most buildings.

WIP Wafers and quartz tubes breakages inside the Vertical Diffusion Furnace

Based on the loss experience of 921 Quake, it is a well-known fact that sensitive equipment should be properly fixed on metal deck raised floors or perforated (waffle type) RC floors of the cleanrooms. Most of the anti-seismic measures employed in the industry are based on local regulations. To avoid process equipment displacement and damage or production interruption, these measures are planned according to seismic intensity design or expert model analysis which selected the most appropriate protection methods in withstanding the maximum earthquake intensity.

We have discovered a special loss case from a particular semiconductor factory where the clear spaces between expansion joints on metal deck raised floor in their cleanroom were blocked. This caused damage to their process equipment and has a big impact on its production.

Normally, gaps in these expansion joints are covered with metal steel plates to prevent objects from falling. Metal steel covers with insufficient thickness and width warped and affected the transportation of wafer carts on top of them. So, the factory has steel covers locked with screws to prevent warping. During this earthquake, the expansion joints with these metal steel plates (covers) could not slide on the top of metal deck raised floor smoothly. This created a squeezing effect to the raised floor which housed all process tools. The floor shook together with the surrounding RC floor. And the earthquake intensity of the metal deck raised floor instantly rose to nearly 390 gal resulting in wafer breakage and damages to a series of equipment (e.g., ion implanters and vertical diffusion furnaces). For comparison, the intensity recorded in nearby cleanrooms of this fab building was about the same, at below 140 gal only. The amount of damaged process equipment and wafers in these rooms was lower. Blockage of those expansion joints could be the reason contributing to the significantly higher floor acceleration (PFA) and the greater earthquake intensity on the raised floor in the cleanroom. This caused subsequent damage to parts of the equipment that were not fixed properly.

In one instance, ceramic supports for electrical bushings of an ion implanter fractured. This made the tool shut down. The coupling of the generator inside the equipment was broken due to misalignment of the generator's axis after excessive vibration. All the equipment had to be shut down for replacement of coupling parts in the damaged generator.

It is commonly known that vertical diffusion furnaces (VDFs) are most vulnerable to damage from earthquake among all process equipment. Facilities mostly experienced damage to the internal quartz components in their equipment during earthquakes. In some cases, over 60% of their VDFs had damage to the quartz tubes and quartz made internal parts.

VDFs come with tall setups of over 3 meters high in some cases. It was postulated that the internal shaking experienced during the earthquake was sufficient to crack the quartz tubes at their bottoms (which rested on baseplates) from stress and at tops due to impact. Thousands of WIP wafers were also thrown away from their VDFs and broke in the event.

Photolithography scanners were another category of equipment that have been reported to be very susceptible to shaking damage. These devices must be kept very stable, and their optical parts must be protected from vibration for the fine resolution of circuit geometry. To re-calibrate optics, many of these scanner systems needed to be shut down in the event. These scanners are critical in the whole production process. Any interruption would significantly halt the fab's production.

Seismic protection needs

In this earthquake, buildings of the science park areas experienced relatively low peak ground acceleration which was the primary reason for the little physical damage occurred amid movements of process equipment.

In past records, reports showed that there were movements of the equipment on upper floors where acceleration was amplified. Based on experience, it is estimated that the level of acceleration required to overcome friction between a piece of equipment and its supporting floor to be on the order of 0.20 g (196 gal).

During 403 Quake, the recorded PGA was around 0.07 g (60 cm/s^2) to 0.1 g (98 cm/s^2). The PFA of process area in the fab buildings' cleanroom floors was approximately under 0.15 g (147 gal). This local acceleration was apparently not great enough to overcome friction between the equipment and their supporting floors. In this case, even if the equipment's anti-seismic measures were not perfect, the earthquake did not cause major displacement or damage to them.

From a structural perspective, most facilities appeared to be well designed. The vast majority of the buildings in science parks were built after 1980 and could have incorporated modern lateral force-resisting systems. Constructions around these science parks were typically made with concrete frames or steel frames. Concrete frame buildings were generally older, low-rise offices and support utilities. These buildings were made of concrete columns and beams with concrete or unreinforced masonry exterior walls. Generally, their concrete shear walls or concrete moment frame action provided their lateral resistance. Many new, tall office structures were built with steel moment frame structures and lightweight, exterior window wall systems.

After 921 Quake, it has been observed that most of these factories' processing tools were well anchored. We understood that only a small fraction of process equipment has incorrect anti-seismic measures which should have been designed and installed according to local earthquake intensity requirements.

These cases of inadequate anchorage can be summarized in the below categories:

- lack of anchorage feet
- poor configuration of anchorage feet
- poor connection of anchorage feet to process units
- poor connection of anchorage feet to access floor system (metal deck raised floor/RC perforated floor)

A correct design of seismic anchorage for process equipment should guarantee:

- the equipment is designed to resist anticipated seismic loads and
- the equipment is anchored to structural elements of the building to prevent sliding, overturning, or collision.

To build a complete system for the seismic anchorage of production equipment, owners must consider the design and installation of an access floor system. They should delegate the task to their facilities' engineering department, or by a licensed consulting engineer.

Since most production equipment is mounted directly on top of an access floor system and anchored to a RC floor for horizontal loading, the design of this access floor must enable transport of its load to a waffle slab below. As mentioned before, the original design and installation of the access floor system should include a requirement for horizontal loading. This is an extremely critical issue, since the access floor system's failure during a seismic event may result in significant damage to all production equipment mounted on it regardless of individual tools' anchorage quality. It is recommended that this anchorage should be accurately designed by experienced structural technicians with respect to the equipment's anti-seismic requirements to ensure the best anti-seismic performance.

Piping and ductwork are another vulnerable system that require attention. In older facilities, these were generally supported on individual pipe hangers or small pipe racks with no seismic bracing. In the newer ones, their sub fab generally came with a continuous steel pipe support frame (made of structural steel or strut framing) that was hung below the concrete waffle slab and attached to the concrete columns inside the sub fab. This kind of framing system is usually designated to support piping and ductwork and to deliver seismic loads directly to the building's structural system. Most pipes are supported by this type of system. However, in cases where they used individual hangers or trapeze supports, little or no bracing was observed. Apart from the lack of seismic bracing, it was also observed that several facilities allowed poor pipe installation practices including hanging pipes on other pipes.

As a tradition, the installation contractor is responsible for designing and installing seismic bracing for pipes and ducts according to recognized standards. By necessity, these standards are general in nature and may not account for every situation or material. Microelectronics facilities use many different pipe and duct materials and in situations that are not covered by the local building regulations. During this process, it is necessary for business owners to engage a professional engineer who also should be responsible for designing and installing these systems.

In order to completely solve the problem of wafers and the quartz components damage inside VDFs, a seismic isolation platform with friction pendulum system (Fig. 1) was successfully developed to effectively protect the parts from damages by earthquake events. The charts on the right (Fig. 2) show the comparison of VDF acceleration responses, under the achieved PFA of 70 gal. The maximum displacement reads 10 cm, which is well within the allowed displacing capacity of 18 cm reserved for the VDF. Evidently, all the recorded acceleration responses are remarkably reduced when the VDF is controlled with the isolation platform. The illustration of the isolation platform is shown in the pictures below (Fig. 3).

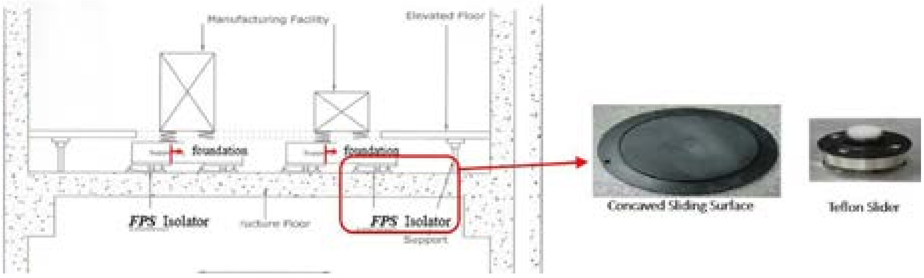

Fig. 1 Seismic Isolation Platform w/ Friction Pendulum System (FPS) (photo courtesy of NYCU)

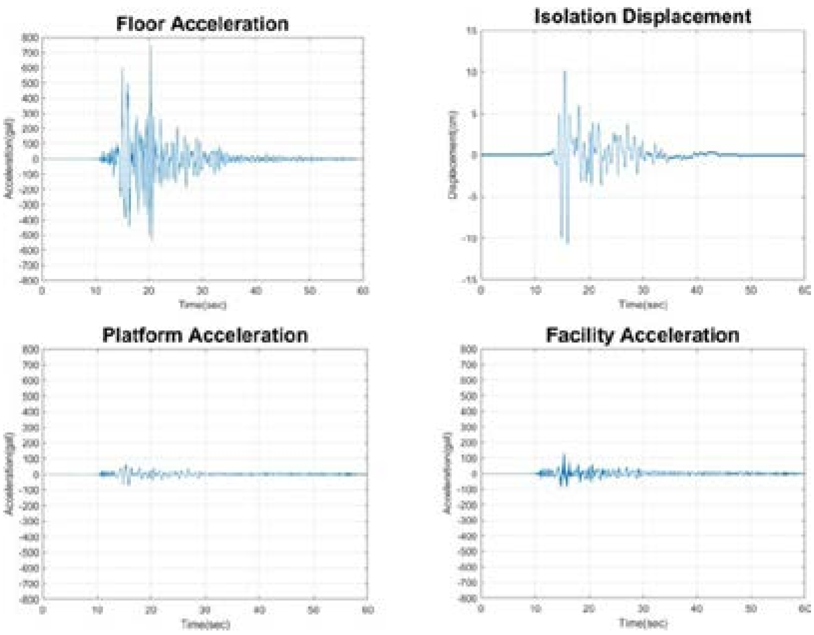

Fig. 2 Full-scale test result for Kobe Quake 700 gal. The vibration of the VDF is minimized when the friction pendulum system is implemented (photo courtesy of NYCU)

Fig. 3 Illustration of VDF on Isolation Platform w/ Friction Pendulum System (FPS) (photo courtesy of NYCU)

Literature related to earthquake-proof techniques for vibration-sensitive manufacturing tools are rarely available. From statistics, it is shown that loss was attributed mainly to the automated stocker systems (STK) where massive FOUPs (front opening unified pods) or cassettes containing fully processed wafers or glass panels collided or being shaken off, no matter if it is a semiconductor or TFT-LCD fab. Maintenance of the automated stocker system in the aftermath also extends the main lead time of the overall recovering process.

During the earthquake, the storage cassettes (FOUPs) slid and collided with stocker frames which caused damage to the wafers inside. Several FOUPs were even shaken off from the stockers and created wrecks which were difficult to remove. In view of this, seeking effective earthquake protection measures for the stockers has the highest priority among all to mitigating seismic risks.

With a passive control force via an energy dissipative mechanism, the stockers hung from the ceiling are expected to vibrate more quietly and both their displacement and acceleration responses could be significantly reduced. This control force exerted on the dampers is moderate as the length of perpendicular moment arm is quite long. So, a small force could generate considerable counteracting moment to counteract the overturning moment during an earthquake. The ideal damper size is relatively small compared to those used in building or bridge applications. Therefore, these dampers need to be custom-made.

TESTING ON DAMPERS

To make sure dampers meet the design requirements, a Lockton client has carried out a component test on the dampers used in our experiment and the stocker retrofit project for semiconductor businesses.

Lockton Taiwan's Risk Consulting team, with help from a professor of National Yang Ming Chiao Tung University (NYCU), conducted a series of shake table tests to verify feasibility of our proposed scheme applied to an industrial, full-scale stocker under realistic earthquake scenarios (Fig. 4).

This scheme has been proven successful in meeting the desired seismic performance. It met with the loss control goal of preventing wafer damage from sliding off the stockers or falling to the ground (Fig. 5).

Fig. 4 Stocker and frame implemented on the shake table (Photos courtesy of NYCU)

Fig. 5 Viscous fluid dampers provided on top of Stockers (Photos courtesy of Lockton client & NYCU)

Another type of earthquake protection is the wafer/reticle carts used in cleanrooms. This could be easily overlooked and misunderstood.

It is a common practice to lock the four wheels of a cart when it is in position. This can prevent the table from sliding in cleanrooms. However, it has been proven to be a wrong approach from the perspective of earthquake prevention after the 2016 Tainan earthquake (206 Quake). During that incident, a lot of locked wafer/reticle carts and hundreds of tall and narrow carts were tipped over, resulting in serious wafer/reticle losses.

In view of this, we have also conducted a series of full-scale tests on wafer/reticle carts (Fig. 6) to find ways to prevent them from tipping over during an earthquake. Our tests proved that the wheels of all the wafer/reticle carts should have their brakes off to prevent tipping over during earthquakes.

Fig. 6 Wafer/reticle cart implemented on the shake table (Photos courtesy of NYCU)

Referencing the test and experiment results, we applied measures to a major high-tech client in Taiwan. It was demonstrated and confirmed that the client has no wafer and reticle damage or loss due to cart tipping over in recent earthquakes (206, 403 Quakes, etc.).

The seismic performance of support equipment following earthquakes can be as important as the process tools when businesses attempt to resume their facilities' full operations. This is why seismic anchorage designs of their facilities should be applied with the same level of care and attention as all process tools and associated piping and ductwork.

A qualified civil or structural engineer should be employed to deal with seismic anchorage designs of all process and facility equipment. These designs should at least be compliant with local code requirements. When such local requirements were proven insufficient, it is recommended that correct anti-seismic measures for protecting high value process and/or facility equipment should be implemented. Business owners and insurance procurement managers can consider performance-based design (PBD) such as an earthquake risk modeling analysis to determine basic seismic design requirements suitable for factory buildings and non-structure elements (process and facility).

To stay safe, the equipment should be designed to fulfill the goal of seismic protection in controlling the risk of personnel injuries, adverse environmental impact, equipment and facility damage due to movement or overturning, and leakage of gases and chemicals (including liquid splashing) during a seismic event. This design should also control wafer breakage and equipment damage due to failure of fragile parts of process equipment (e.g. quartz-ware, ceramics).

We have learnt from earthquake losses in the past 25 years that older designs, even if they were compliant with current local earthquake regulations, seemed to be inadequate to protect the facilities. Anti-seismic protection for the equipment that is sensitive to earthquakes, such as stockers and ceiling systems in cleanrooms must be treated cautiously. Business owners and their engineers are advised to apply appropriate performance-based design based on local conditions to avoid serious damage.

Conclusions

The effects of the 403 Quake on the microelectronics industry were relatively minimal. The main impact is some capital assets being damaged due to damage to process equipment (e.g., VDFs) in contrast to 921 Quake where operations were disrupted due to large-scale utility power outages. As reported, the insurance claims caused by 403 Quake are expected to exceed USD 2 billion.

It is reported that the losses could have been far greater had the ground accelerations at the science parks been higher. One expectation is that much higher accelerations can be anticipated in future quakes caused by Hsincheng Fault's movement which is in closer proximity to the Hsinchu Science Park.

Should an event with PGAs of 0.35 - 0.39g occur, damages would likely be found in (but not limited to) the following areas:

- Possible lateral displacement of equipment in the sub-fabs and fabs on the order of several centimeters to a meter or more on the upper floors (often main fabs are located), if the equipment does not have appropriate anti-seismic measures.
- A longer lead time (6 to 18 months) caused by earthquake damage of quartz tubes and internal quartz related components of the vertical diffusion furnaces (VDFs) in cleanrooms.
- Overturning of equipment with higher height-to-base ratios which is anchored to the metal deck raised floor only, but not connected to the RC perforated floor.
- Damage to metal deck raised floors.
- Hazardous production materials (HPMs) are released from liquid spills in wet benches and possible hazardous gas leaks from facilities without seismic gas shutdowns.
- Severe damage to WIP and reticle storage systems (stockers) resulting in substantial loss of wafers.
- Wafer rework processes shall be implemented for scanners in the lithography process area.
- Loss of critical facilities support systems such as scrubbed exhaust, HVAC, DI Water, waste neutralization.
- Severe flood from damage to inadequately braced sprinkler and process water pipelines.
- Structural damage to older facilities and potentially new facilities.

Recently, Taiwan's semiconductor industry has been expanding to new science parks located in the southern part of the island like Tainan and Kaohsiung. It should be noted that those are also seismically active regions where a magnitude 7.0 Mw earthquake occurred before. Therefore, the design of these new facilities must incorporate the best practices mentioned in this report. For the past few years, several of the new and expanded fabs in those areas have been built using the latest seismic design considerations exceeding what has been used in the local requirements.

Revised several times since 1999, the current local code is a minimum requirement with a basic objective to ensure that the facilities will not collapse and threaten life safety in the event of an earthquake. It is not intended to ensure that the facilities can resume operation easily or even be salvageable after the impact. The decisions on implementing seismic designs, on levels above basic safety, need to be made based on risk-benefit. Because of the tremendous capital investment in these new fabs (which estimated to be US$3-4 billion or more for a 300 mm fab), business owners are deciding on performance-based designs for essential facilities with equivalent to 1-2 levels higher than the code minimum needed in high value semiconductor industry.

Although less severe than the 921 Quake, the 403 Quake has created business interruptions in many businesses not due to asset damage but to infrastructure disruptions as utility electrical power supply outage. At present, the public power supply is gradually stabilizing thanks to underground cables. However, the semiconductor industry must plan ahead for comprehensive anti-seismic improvement strategies, strong protection measures for all seismically sensitive process equipment, and corresponding earthquake emergency response plan.

These strategies should address issues that arise immediately after the earthquake as well as those during the business recovery phase in the days and weeks that follow. Facilities should have an in-house emergency response team (ERT) trained to respond to earthquakes and any emergencies that may result from earthquakes e.g., medical injuries, fires, process gas and chemical leakage, or even preliminary inspection on buildings to confirm safety for personnel's return to work in production areas after an earthquake. The emergency response plan involves two phases: initial damage assessment phase (i.e., evaluation of structural integrity and of the facility and production equipment) and the recovery phase (i.e., recalibration, requalification and recovery/restoration of the equipment and processes) until business is back to normal.

Through the experience of 921 Quake in 1999, 206 Quake in 2016 and 403 Quake in 2024, Taiwan's semiconductor industry has learnt valuable lessons and become more resilient and well-prepared for future earthquakes.

How Lockton Can Help

Lockton's Risk Consulting team in Taiwan has successfully assisted semiconductor industry by providing them with seismic protection solutions in the past major earthquakes. The team has implemented risk improvement programs for the major high-tech clients with the cooperation of a professional licensed third party (e.g. National Yang Ming Chiao Tung University) certified for seismic protection civil and structure engineering. With their knowledge background, the team has carried out performance-based design solutions and developed a number of anti-seismic engineering facilities, such as seismic isolation platform w/ friction pendulum system (FPS) used for vertical diffusion furnaces (12-inch wafer fab), and viscous fluid dampers installed in the wafer stockers, ceiling systems, and VDFs (8-inch wafer fab), etc. These improvements have also proven their effectiveness in several earthquakes already.

The other essential loss prevention measures have also been taken for processing equipment in cleanrooms. Lockton's Risk Consulting Services aimed at addressing risks posed by earthquakes, to help semiconductor clients to evaluate and reduce seismic exposure for the nonstructural elements in the cleanrooms include interior partitions, raised floor, ceiling system of the cleanrooms, process equipment, AMHS (automated material handling system), wafer/reticle stockers, wafer/reticle carts, pipelines of special gas, chemicals, utility water systems and automatic wet pipe sprinkler system, etc.

On the other hand, the team worked closely with licensed third party to implement an EQ modeling analysis program through catastrophe risk modeling software to fulfill the analysis work which focused on "earthquake resistant capacity" evaluation for clients' facilities and buildings. The modeling analysis is based on the client's insurance premise, and the analysis results can be used as a basis for subsequent earthquake improvements. This data often exceeds local regulatory requirements.

A careful analysis is needed for semiconductor manufactories to identify significant life safety risks from potential structural damage and significant property loss from potential NSEs damage, especially in the cleanrooms; to identify and achieve short-term, high-cost benefit mitigation measures; and to plan for longer-term overall mitigation. Based on the key issues identified with current practice surrounding the design and installation of NSEs, the end-user has the responsibility to ensure that the equipment anchorage is designed and implemented to withstand the forces expected in their location. By providing basic equipment information to a licensed and experienced seismic engineer, the design process of appropriate anchorages will become more effective.

Recommendations

Lockton recommends the following actions to improve the seismic performance within the semiconductor industry risk management environment and regulatory regime:

1. **Perform a seismic structural evaluation of existing buildings that contribute to the wafer fabrication function** by engaging a licensed structural engineer (or a team) experienced in seismic evaluation and design. The primary purpose of such an analysis is to quickly identify buildings that may be seriously damaged under the strongest earthquakes of expected intensity, as defined in the local seismic code. A secondary purpose is to gain an understanding of the probable performance of the structural and non-structural systems of each building.

2. **Evaluate the probable seismic performance of the NSEs and systems** by engaging a licensed structural engineer (or a team) experienced in seismic design. It should cover the systems installed in the fabrication buildings include truss, cleanroom and sub-fab levels, for example, cable trays, process pipelines used for chemicals and gases delivery, suspending ceiling and raised access floor in cleanrooms, AMHS (OHT/OHB), process equipment, wafer/reticle stockers, wafer/reticle storage carts or racks, internal partitions and automatic sprinkler systems in cleanrooms.

3. **Make seismic design criteria information widely and easily available** for non-structural elements across the design and construction team of the site. The semiconductor industry shall establish the nonstructural design criteria as defined in the local seismic code or the result of EQ modeling analysis. This will allow contractors, manufacturers, designers of non-structural elements and building officials to be appraised of the design requirements for non-structural elements.

4. **Update the existing emergency response plan and business continuity plan (BCP),** considering the results of the seismic evaluations, with particular focus on non-structural elements. An emergency plan that considers the care of the staff and the vendors of the facility, as well as the surrounding community, should be kept up to date and should include a realistic estimation of the seismic performance of the structural and nonstructural systems in each building, and on the site in general.

5. **An earthquake disaster recovery plan (DRP) shall be also developed in place,** and it will be able to identify and exploit the potential of earthquake restoration methods for damage minimization and restoration. It is recommended that semiconductor industry shall engage a professional disaster recovery third party to assist the initial emergency response and mitigation through the final reconstruction phase and assessing potential damage minimization by means of restoration and electing restoration methods.

6. **Ensure enough coverage for disaster damage and business interruption.** It is vital that businesses reinspect their existing policies to make sure there is a professional crisis response and catastrophe claims support in place. A dedicated team can let business owners resolve catastrophic insurance claims and funding for restoration faster and with fewer hassles, under the guidance of the experts in the response and claims teams.

The majority of the world's semiconductor and equipment productions are located on what is sometimes referred to as the "ring of fire" (e.g. Taiwan, Japan, California), where adjacent plates of the Earth's crust around the Pacific meet. Despite the efforts and expenses made on seismic preparedness, a great deal remains to be done. Business owners, risk management specialists and insurance providers need to continue to learn and improve as we prepare for future seismic events.

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