Seismic Experiments And SAP2000 Analytical Study on the Aseismic Footing of Precision Machinery in Hi-tech Factories

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SUMMARY:
In high-tech industries, one of the major concerns of their seismic safety is whether their earthquake proof anchorages are capable to resist the seismic loading.

The purpose was to understand the mechanical acts during earthquakes; we designed a standard anchorage and went through the destruction-test to understand the anchorage destructive model. Also aim to analyze and estimate the supporting reactions of the machines subjected to the seismic loading by SAP2000.

Some significant findings are remarked as following: The Z-type earthquake proof anchorage resisted the horizontal force; the L-type earthquake proof anchorage provided more comprehensive resistance of seismic force. The one-joint link with multi-linearity in the nonlinear static analysis can simulate the earthquake proof anchorages with compression-resistant-only property.

This study identified the foot performance and built the qualitative and quantitative risk analysis model, it may be available to provide reference to CMI and industries.

Keywords: high-tech industries, Nonlinear Analysis, SAP2000

1. GENERAL INSTRUCTIONS

Taiwan is located in the circum-pacific seismic belt. Due to the activities between the Philippine Sea Plate and the Eurasian plate dislocated, the earthquakes frequently occur in Taiwan. Moreover, there is not only large population, but also many seismic belts in Taiwan; earthquakes cannot be predicted accurately. In fact, Taiwanese high-tech industries have little choice avoiding or keeping away from the seismic belts when it comes to the plant locations.

With high-tech panel display industries blooming and R&D technology constant innovation, the display size of substrate glass is increasing. The equipment size and process also tends to be larger and more complex. Relatively, that is a costly investment- a single equipment can even cost more than tens of millions US dollar.

From previous experiences of earthquakes, it was found, usually after small or/ and medium earthquakes, that nonstructural damage is more serious than building structure damage. To consider the cost and operation in business, the equipment in high-tech industries should be highly concerned. However, It lacks of references on preventing damage from earthquakes to the equipment of high-tech industries, and the risk still not be defined qualitatively and quantitatively.

1.1. Background and Motivation of the study

In high-tech industries, from the previous earthquake experiences, losses due to the seismic damages of the precision machinery have been found greater than that due to the building components. Because the machines are usually large and heavy, one of the major concerns of their seismic safety is whether their supporting feet are capable to resist the seismic loading.

At present, neither the industrial, nor the academia field, not even equipment suppliers, are able to provide a complete test data for further seismic retrofit. To enhance or improve the seismic measured and technology content, one should first understand the sabotage-mechanism of the machine during earthquake. At the moment, most equipment suppliers use the computer simulation system to analysis the equipment strength, then they try to find a method to prevent damages from earthquakes. As the simulation system is based on the imitated model on computer, it is not possible to be sure the enhancement of the equipment is 100% successful.

In addition to its sustainability of the seismic performance of the equipment, for process equipment could be operate after earthquake, the other major condition is the anchor method equipment itself and the anchor's actual installation environment. Unfortunately, the supplier could not attach more importance or assist proactively to help users to understand fully on real setup condition in the clean-room for each difference plant, and the information communication and exchange with users is not sufficient. Resulting: the industry could be purchased the equipment for production, but could not ensure that the equipment is able to operator properly after earthquakes.

1.2. Research Questions

When architects construct a building they only focus on the safety of building structure, while the structural engineers not understanding the original type and characteristics of the process equipment, furthermore, though the supplier are familiar with the original type and characteristics of the process equipment, they are not fully aware of the effects and regulations regarding earthquakes which causes the lack of the concepts and knowledge of seismic performance for equipment when equipment is designed.

Another serious issue to consider is the cost; suppliers are less initiative to assist users. It means the equipment damages from earthquakes, thereby affecting the output and production capacity, yet no one could put forward to prevent the equipment failure mechanism of earthquake, or further to provide effective seismic retrofit of seismic technology. Such a phenomenon is also encountered in the industry plight.

In Taiwan, for major and large size of equipment in TFT-LCD display, we will continue to find the regulations and define the order or methods to prevent nonstructural equipment and to avoid earthquake damage. We wish the result could help and solve some of the problems through these references for our plant and other plants.

1.3. Literature Review

Since the high density of population in Taiwan, among many seismic belts and the unpredictability of earthquakes, Taiwanese high-tech industries have little choice to avoid or keep away from the seismic belts when deciding a plant location. A compromised mean is to use thick foundation slabs to dissipate micro- vibration between the plant floors in building the clean-rooms. This type of foundation-slab construction has made as the clean-room formation, multilevel fabs, wafer type, or sandwich type, model. (figure 1) The need of the structure of multilevel type is not unique in the Taiwanese high-tech factories, we have found such needs in other countries around the world.

As we can see, due to the weakness of the structure of a stacked plant, it does not meet the Taiwanese building seismic code, robust columns and thin beams design, the principles in the design of laminated plant. It could caused serious damage in structure of multilevel fabs when an earthquake occurs. Industrial building designers usually accommodate preventing slight vibration in their designs, and ignore the issue regarding irregular earthquake damage threats.

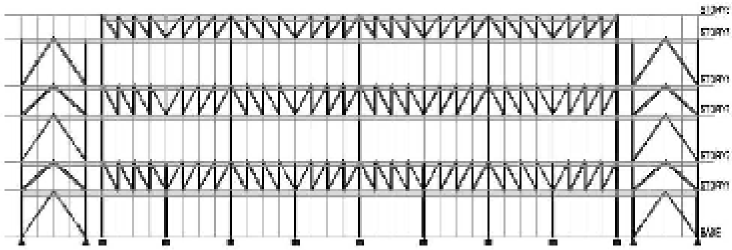


Figure 1. Front Elevation of Structural Blueprint for High-Tech Plant

From previous experiences, the character of the non-building-structure, process equipment, in Taiwanese high-tech industries, after experienced from small/ medium earthquakes, was found that non-structural damage is more serious than building structure damage. There are two types of the non-structural damage and loss: 1. The loss of purchasing cost on equipment leading low productivity. 2. The loss of the non-structural damage causing the enfeeblement of the building function leading the loss of opportunity cost.

The current situation is that all suppliers rarely conduct the seismic restraint for equipment or specifically address on the seismic restraint performance of their equipment. The major concern of the equipment design is focusing rather on product manufacturing and increasing its productivity than on considering earthquake proof design.

In addiction, even it is able to confirm the seismic capacity of equipment itself, but the on-site condition of installation varies accordingly to the equipment anchored in different plant; the situation of each fab is different that needs to take in consideration in equipment design in order to meet various needs of each fab. Moreover, the warranty conditions of equipment do not include the anchored method and earthquake proof device. Therefore, the problem is that there is no rule in the current regulations, and the suppliers refuse to assist with in proposing an anchor method that resulting the industry though can purchase equipment, but is unable to ensure that the operational capability of the equipment after the earthquake.

From all the reasons mentioned, the industry should actively cultivate mechanics with self-evaluating techniques so that they are able to assess the on-site situation for the equipment, then to confirm the equipment seismic capacity. To sum up, this study focuses on research and integration of anchored fixer of equipment in the clean-room. The anchored fixer is designed with reference to the equipment design charts; the design sheet is easier to apply.

2. Study Aim

There are various modes of equipment in the high-tech factories, so are the anchorages. Regarding the earthquake protection issue, the suppliers are often unable to provide the anchorage design or experiment on the rated strength. The purpose of this study was to understand the mechanical acts during earthquakes; we designed a standard anchorage and went through the destruction-test. By observation during experiment, the study was able to facilitate the follow-up simulation analysis, and to understand the anchorage destructive model. Also aim to analyze and estimate the supporting reactions of the machines subjected to the seismic loading by SAP2000.

3. METHODS

3.1. Experiment and analysis of shockproof fixed foot

This study, cooperated with the Metal Industries Research and Development Centre in Taiwan, used the tensile testing machine to simulate the model of earthquake force to understand the damage mode of earthquake proof anchorages. The types of earthquake proof anchorages tested were Z type and L type (figure 2 and 3). The study experimented and observed the results of their damage acts and mechanical data of the earthquake proof anchorages, Z type and L type, using universal testing machine tested in different directions.

The destruction experiment of earthquake proof on anchorages was in accordance with CNS 2111 G2013 standard. The instruments included the universal testing machine, the load sensor, and displacement sensor. Figure 4 shows the layout of the experiment.

The speed of universal testing machine parameter with force controls was 2 kg/s. Due the unpredictability and undetermination before an earthquake occurs; the experiment process undertook three axles, X, Y, and Z, and four different force directions in the experiment, as shown in Figure 5 and 6. Each experiment was conducted three experimental tests individually.

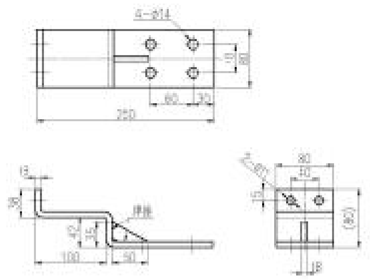


Figure2. Z-type of shockproof fixed foot

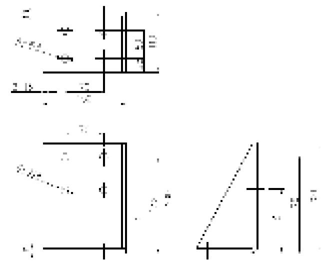


Figure3. L-type of shockproof fixed foot

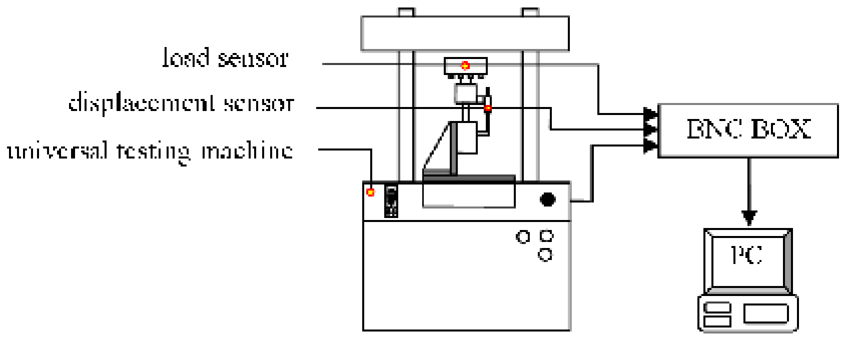


Figure 4. Layout of Experiment of Shockproof Fixed Feet

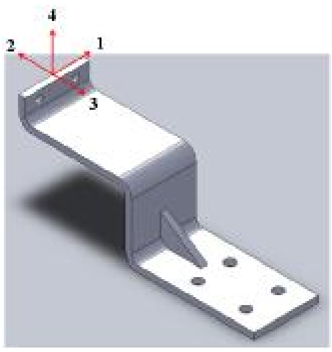


Figure 5. Define Z-type with Directions of the Experiment

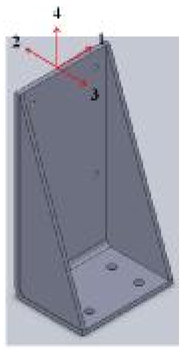


Figure 6. Define L-type with Directions of the Experiment

Figure 7 and Figure 8 were the experimental duration response map for the Z-type and L-type anchorage destruction. The method was to change the force direction of earthquake proof anchorage in the tests; three specimens were used in each group of tests. All the specimens, earthquake proof anchorages, were bolt installed to the transfer boards. The determination during the process in the test destruction was on any a component damage, cut or material yield of the earthquake proof anchorage.

The Z-type and L-type earthquake proof anchorage damage mode shown as Figure 9 and Figure 10.

Test results shown as linear regression, the overall limit strength of Z-type earthquake proof anchorage was 36.7KN, occurred at the Y (outward) direction; the deformation was 60.5mm, occurred at the X direction. The overall limit strength of Y-type earthquake proof anchorage was 89.9KN, occurred at the Y (outward) direction, the deformation was 65.2mm, occurred at the Y (outside) direction. The results revealed that the Z-type earthquake proof anchorage resisted the horizontal force; the L-type earthquake proof anchorage provided more comprehensive resistance of seismic force.

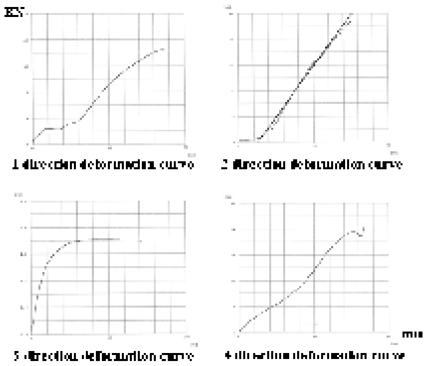


Figure 7. Z-type fixed feet experimental duration responses

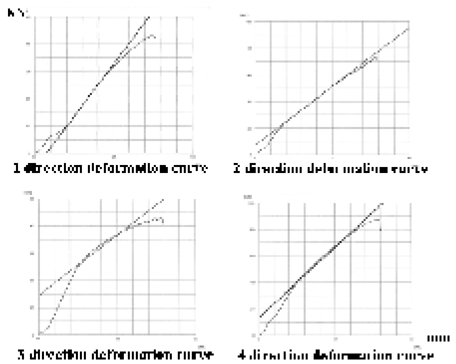
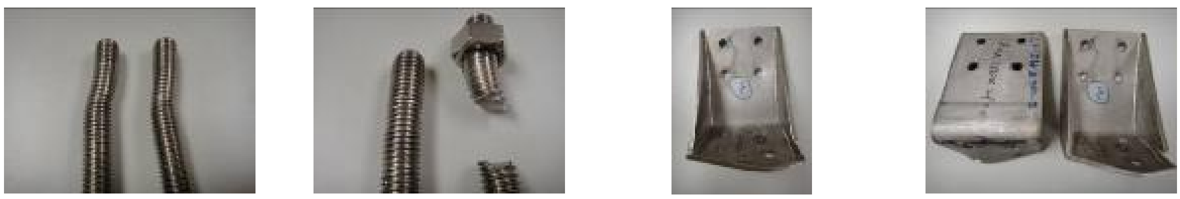


Figure 8. L-type fixed feet experimental duration responses

a. b. c.

Figure 9. Z-type shockproof fixed foot damage mode

a. screw fixed in the ground was cut、b. U-shaped screw was sheared damaged、c. overall of Z-type shockproof fixed foot was externally deformed.



a. b. c. d.

Figure 10. L-type shockproof fixed foot damage mode

a. Screw fixed in the framework, was deformed、b. screw fixed in the ground was cut、c. stiffened board was cleaved、d. overall of L-type shockproof fixed foot externally deformed.

3.2. Set up and Analysis of the SAP2000 model

The study selected the equipment, Precision Machine A, to be analyzed from the high-tech plant. Machine A is a high-priced Precision Machine and is one of the major industrial process equipment; therefore, the subject on seismic force, the safety issue of Machine A have been taken seriously. In order to enhance the seismic capacity, Machine A was installed earthquake proof to the anchorage. To recheck whether the effect of earthquake proof anchorage met the seismic requirements, we cooperated with National Cheng Kung University analyzing the process equipment, Machine A. (check your font and size of the word here) To understand the loading response of earthquake proof anchorage through earthquake, the program of the stiffness of earthquake proof-anchorage was written into SAP 2000 software system, The second study aim to analyze and estimate the supporting reactions of the machines subjected to the seismic loading by SAP2000, and whether the magnitude of the earthquakes is in conformance to the Taiwanese Building Code.

The strength of Z-type earthquake proof anchorage is to resist the horizontal force, and the Z-type one was already installed and anchored to the support foot of Machine A itself (figure 11).The L-type earthquake proof anchorage provided more comprehensive resistance of seismic force; it was mainly through the fixture to fix onto equipment structure, shown as Figure 12.

During the process of installation in clean-room, high-tech plants, the suppliers more focused on adjusting the support foot to calibrate and adjust the horizontal level and support of machine weight. They rarely provide related earthquake proof anchorage mode or specifications. In the current situation, to ensure the fundamental process of seismic engineering in the high-tech plant, after moving in, installing, and adjusting the horizontal level, the suppliers or users would install various earthquake proof anchorages. Therefore, there is no unified or standard specification for earthquake proof anchorage available.

Therefore, this study was implemented by ChiMei-Innolux (CMI) Corporation. The result, the Z-type earthquake proof anchorage resisted the horizontal force; the L-type earthquake proof anchorage provided more comprehensive resistance of seismic force, was thoroughly taken as a reference for the company’s earthquake proof anchorage specification and installation consideration for process equipment, and the two kind of earthquake proof anchorage were used to install on process equipment’s seismic support location. The subject of this study was a major process equipment, Machine A, form the CMI corporation. The quantity needed of Z- type and L-type earthquake proof anchorage installation on Machine A was to determined in the study; the number of the L-type earthquake proof anchorage needed was 6, while that of the Y-type earthquake proof anchorage 34.

Machine A was consisted by 7 chambers- a, b, c, d, e, f, g chambers, shown as Table 1. The total size was bigger than 10 x 11 x 3 m 3, the total weight of Machine A was > 9 x 105N. The component parts in Machine A were very complex, included automatic arm, chemical pipeline, wireless sensor and so on. The model experimented was established and simplified, then the main structure and the force transmission component parts were retained, shown as Figure 13. In the analysis, we presumed the machine mass concentrated at the center of gravity position, and when setting up SAP2000 model, the condition we set up for earthquake proof anchorage was a nonlinear spring.

Table 1. Machine A Detail Information

Machine A detail information			
Chamber name	Weight (N)	Height (m)	Mass location (m)
a unit	> 110000	>3.0	>1.0
b unit	>16000	>3.0	>1.0
c unit	>190000	>3.0	>1.0
d unit	>1000	>0.4	<0.4
e unit	>10000	>0.4	<0.4
f unit	>10000	>0.1	>0.1
g unit	>10000	>0.1	>0.1

Figure 11. Real Installed Condition of Z-type in Clean-room

Figure 12. Real Installed Condition of L-type in Clean-room

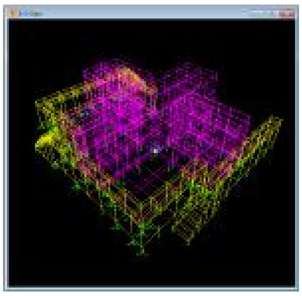


Figure 13. SAP 2000 model of Machine A

3.2.1. SAP 2000 Model Analysis

The subject of simulation analysis, Machine A, was located in the floor of 10- meter height. To consider the floor magnification factor, the team started to set up the SAP2000 model. Firstly, the ambient vibration measurements were performed to estimate the frequency nature of the precision machinery, and the results were then used to verify the model analysis of the machines in SAP2000. Secondly, the nonlinear property of the supporting feet is considered can only sustain the vertical compression but resist non-tensions, so the nonlinear static analysis cases were utilized to estimate their supporting reactions to seismic loadings. Three dimensional analyses, including two horizontal and one vertical direction, were performed.

The study analyzed the external force, the maximum resisting horizontal force; the L-type earthquake proof anchorage was >3 KN. The study showed that the horizontal force resisted by L-type earthquake proof anchorage in Machine A. Under different force conditions, the sample of maximum reaction force in each earthquake proof anchorage was shown in Table2.

Table 2. Sample of Maximum Reaction Force in each Shockproof Fixed Foot

Load Case	Rx(N)	Ry(N)	Rv(N)
	3D analysis	3D analysis	3D analysis
W+EQX(*0.36g*)+EQY(*0.36g*)+EQV(*0.24g*)	-25678.62	-30939.26	32065.88
W+EQX(*0.36g*)-EQY(*0.36g*)+EQV(*0.24g)*	-23017.26	11106.39	32019.49

4. Resulting and Discussion

According to the experiment by universal testing machine, and analysis of SAP 2000 model on the reaction force of Z-type and L-type earthquake proof anchorages in Machine A, the study result showed that the overall vision, earthquake proof anchorage on Machine A resisting the external force was steady. The result of experiments and analysis shown as below:

1. Experimental limitation: As the actual Machine A component parts are really complex, the model was established and simplified for this study. We could not determine whether Machine A component parts, between each chamber (a to g chambers), used bolts jointed completely, or false fixed to connect to machine. In addiction, it is still needed to verify the correctness of the simplified version of the SAP2000 model. The study will continue to follow-up by using the micro-vibration measurement to obtain the natural frequency of Machine A.
2. The one-joint link with multi-linearity in the nonlinear static analysis can simulate the supporting feet with compression-resistant-only property. Furthermore, it is found that the magnitude of the reactions relates to both the amount and the geometrical distribution of the supporting feet.
3. The earthquake proof anchorages with critical reactions are mostly located at the edge of the precision machinery. The result shown that Machine A resisted the external force by L-type

earthquake proof anchorage. Through the test of earthquake proof anchorage destruction experiment, the maximum strength of the L-type earthquake proof anchorage was greater than the reaction force. The reaction force was smaller the external force. The earthquake may produce maximum force and may concentrate on the six L-type earthquake proof anchorage pedestals. The Z-type could only resist the horizontal force. To ensure the earthquake proof anchorage effect, it is recommended to take particular attention to the symmetry of the L-type earthquake proof anchorage during the foot installation.

4. The prevention earthquake of equipment safety management team at CMI found the reaction force location of equipment's earthquake proof anchorage through the risk analysis techniques of the study. Further, the study examined the adequacy of earthquake proof anchorages strength.

Although this study only selected Machine A to do analysis, the data of the analysis could only be applied to similar equipment seismic evaluation, protection, and improvement. The data is limited to all types of equipment in the high-tech plant and could not be directly applied to.

However, the 2 kinds of earthquake proof anchorage's development specifications, research method, and risk analysis model, could not only be applied to each fundamental equipment process on the earthquake proof anchorages risk analysis, and that of assessment on the number of the earthquake proof anchorages; but also could be the quantitative assessment of earthquake proof anchorage's the procurement cost. This study identified the earthquake proof anchorage performance during fundamental equipment process and built the qualitative and quantitative risk analysis model, as an equipment earthquake proof specification in CMI and may be available to provide reference to industries

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