FINAL MASTER THESIS

INDUSTRIAL TECHNOLOGY ENGINEERING

ESTIMATION OF THE ACCELERATION RESPONSE OF A BUILDING UNDER EARTHQUAKE EXCITATION

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RESUME

This master thesis is included inside a project bigger. This project consist in predict the response of a building submitted an earthquake only measuring the first seconds of the earthquake.

In order to do that, this big project is divided into small projects with different objectives. First, it is necessary to predict all the earthquake using the first seconds of this earthquake. For do that, one member of the resilience lab of Taiwan has created a prediction model which using some data from the first seconds of an earthquake, estimate the rest of the earthquake.

After that, it has to calculate the response of the prototype through any earthquake. With this objective, it has been created a finite element model of the prototype and it has been applied forty earthquakes. For each earthquake, it has been done a modal analysis and it has been obtained the acceleration response of the prototype.

This acceleration has been used for calculate the transfer function which relates the acceleration that appears on each floor of the model with the acceleration applied on the base of the structure (the earthquake). In consequence, if a new earthquake happens, using the prediction model it is possible to calculate how big it will be the earthquake after only the first three seconds, and then, using the transfer function, it is possible to calculate the acceleration that will strike the complete structure. So, when a new earthquake appears, it is only needed the first three seconds to know the consequences of this earthquake in a building and, if it is necessary, it is possible to act in order to minimize the damages of the earthquake.

The last part of the thesis is based in testing the methodology experimentally. The prototype of the building has been tested in the shaking table and the results has been compared with the results obtained with the finite element model. The objective of this last part is to know if it is possible to predict, with the same precision, the acceleration of a building only using a finite element model of that building than installing some sensors to the building and predict the acceleration using the record of the past earthquakes.

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1 INTRODUCTION

1.1 OBJECTVES

The main objective of this project is to prove that is possible to predict the acceleration that will appear in a building because of an earthquake, measuring only the first three seconds of this earthquake.

In order to do that it has been created a finite element model of the prototype of a building and it has been applied forty earthquakes. This information has been used to calculate the transfer function and it has been done a statistic study of the results to validate the complete procedure (the combination of the prediction model with the transfer function).

In the last part, it has been tested the prototype and it have been done an statistic study in order to know if it is possible to predict the acceleration of a building which have sensors with the same precision that if we only use a finite element model.

1.2 SCOPE

This thesis is a base for a bigger project. The objective of this thesis consist in develop a new methodology which allows to make a good prediction of the acceleration that appears in a structure because of an earthquake using only the first three seconds of that earthquake. In order to make this thesis simpler it has been studied a prototype of a building and not a real building.

In order to apply this methodology to a future projects, it should be done an element finite model of the structure of a complete building and install some sensors in this building in order to measure the acceleration of each floor during an earthquake. It should be done the same studies that have been done in this thesis but using a real building and not a prototype.

Finally, in order to validate the results of the procedure, it should be done a statistic study of these.

2 THE PREDICTION MODEL

2.1 INTRODUCTION

Before explain how the prediction model works, it is important to know a basic information about the earthquakes.

When an earthquake appears, it is produced two types of waves. The first ones, named P-wave (primary wave), are compressional waves that travel faster than the others waves (heir speed is 1,7 bigger than the secondary waves) and, for this reason, this type of wave are the first ones to be detected on the seismic stations.

The other type, named the S-wave (secondary wave), are waves in which the displacement is transverse to the direction of propagation. Its speed is less than the speed of the P-waves and, for this reason, they appear on the ground a little after than the P-waves. S-wave are the responsible of generating the ground oscillation during an earthquake and those that produce the most of the damage.

The prediction model uses only the first three seconds to obtain some information from the earthquake (at this time only the P-waves have arrived to most of the station) and, with this data, it predicts all the earthquake.

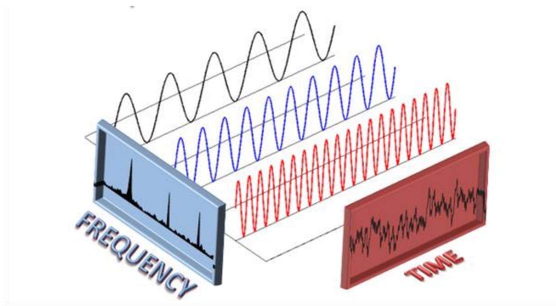
Before to explain the prediction model is important to know the mathematical tools that it use. In the next paragraph it has been explained the concept of this tools without entering in details and only explaining the most important things in order to be able to understand d the prediction model.

2.2 FOURIER TRANSFORMATION

The Fourier transformation convert a function of time into a function of frequency. The function obtained is a complex function, whose absolute value represents the amount of that frequency present in the original function, and whose complex argument is the phase offset of the basic sinusoid in that frequency.

Using an example for explain this, in the picture bellow you can observe that the time function is composed of three function which present a different frequency and period. In the time function all the values are mixed and is impossible to extract any information of the three original functions. The

Fourier transformation allow to pass from the time function to the frequency function showed in blue, which shows the frequencies which forms the time function.

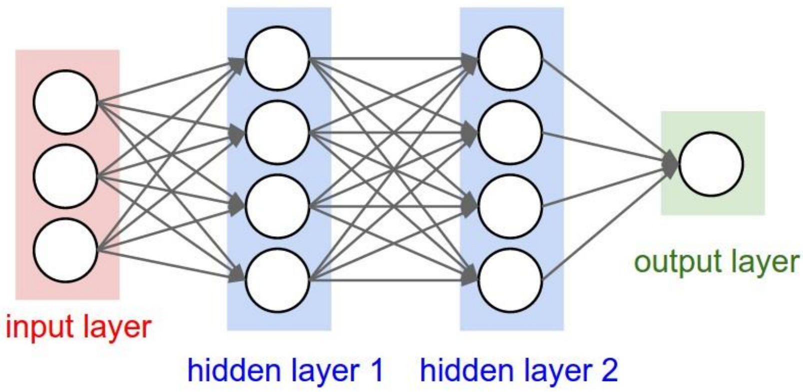


Picture 1. Fourier transformation [1]

2.3 ARTIFICIAL NEURAL NETWORK

An artificial neural network (ANN) is a computing neural network inspired by biological networks that constitute animal brains. Such system is based on learning task considering examples.

This system is based on a collection of connected units or nodes called artificial neurons. Each connection can transmit a signal from one neuron to another and the neuron that receives the signal can process it. The typical structure are shown in the following picture.



Picture 2. Estructure of an ANN [2]

In common ANN implementations, the signal at a connection between artificial neurons is a real number, and the output of each artificial neuron is calculated by a non-linear function of the sum of its inputs. Artificial neurons and connections typically have a weight which increases or decreases the strength of the signal at a connection.

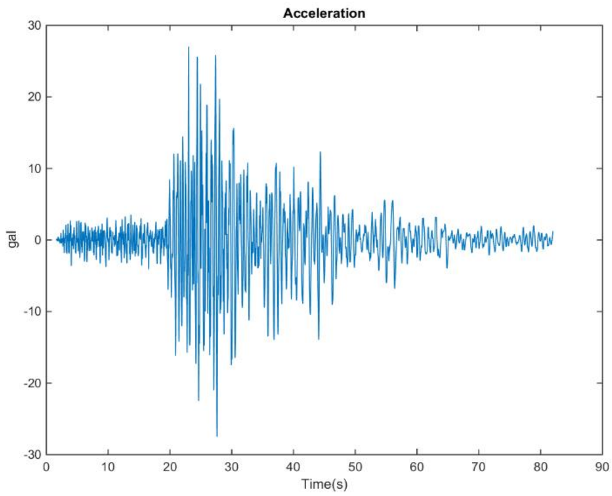
The learning process is based on testing the neural network with examples and adjust the weights of each neuron till the outputs are always true.

Typically, artificial neurons are organized in layers. Different layers may perform different kinds of transformations on their inputs.

2.4 HOW DOES IT WORKS

As it has been said in the introduction, the prediction model use some information from the first three seconds of an earthquake to predict the acceleration history of the entire earthquake.

The acceleration obtained from the seismic stations is a file which contains the acceleration value and the time in which value has been measured. The typical acceleration function is shown in the picture bellow where the vertical axis represents the value of the acceleration and the horizontal axis represents time.

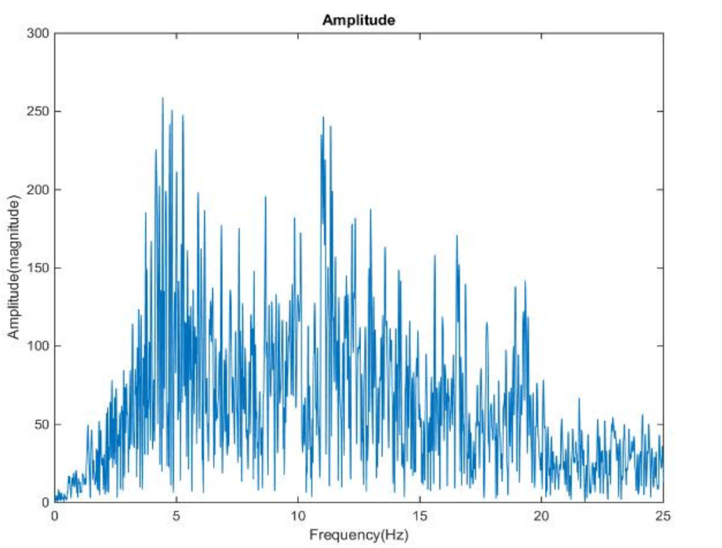


Picture 3. Time record for acceleration

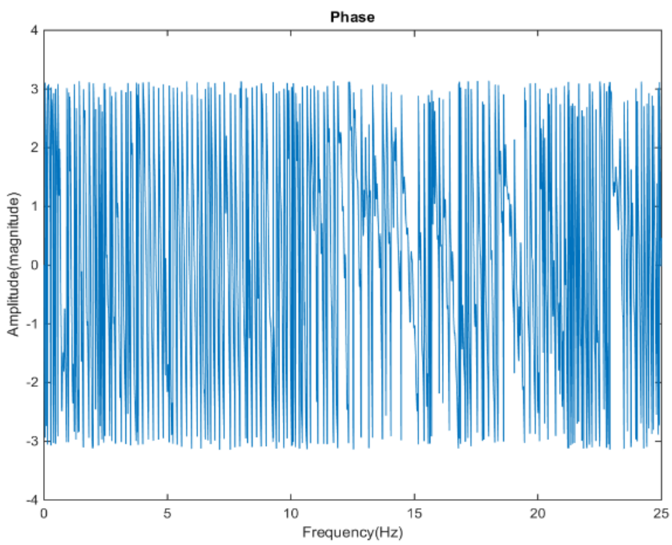
Due to this acceleration function depends on time, it is possible to integrate it and obtain one time function for velocity and one for displacement. With this three functions it has been calculated the variables: peak acceleration (**P_a**), peak velocity (**P_v**), peak displacement (**P_d**), the cumulative absolute velocity (**CAV**) and the integral of the squared velocity (**IV2**).

It is important to remark that the picture shows the acceleration record of the all earthquake but the mentioned variables have been calculated only with the first three seconds.

As it has been explained in the Fourier transformation explanation, it is possible to obtain a frequency function from a time function. Applying Fourier transformation to acceleration function it has been obtained a frequency function for acceleration. The following pictures shows this function, the vertical axis represents the module of acceleration (first picture) or the phase of acceleration (second picture) and the horizontal axis represents the frequency.



Picture 4. Fourier transformation for amplitude



Picture 5. Fourier transformation for phase

It is important to say that prediction model is divided in two parts. The first one is to obtain the Fourier spectrum of acceleration (amplitude) and the second part is to obtain the phase.

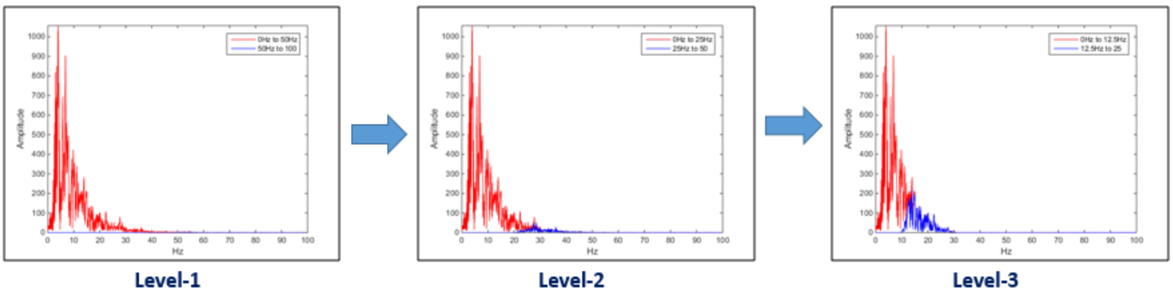
In the first one, it has been only used the acceleration data (obtained from the seismic stations) in the vertical direction. It has also been selected 25 frequencies and it has been transformed the acceleration into the frequency function (Fourier). The six variables obtained from the time function and the 25 points of frequency function have been introduced as input variables in an artificial neural network (ANN) programed with the software Matlab.

The output data obtained of the ANN are 25 acceleration values corresponding to the same 25 frequencies introduced but, in this case, this acceleration corresponds to 150 seconds (all the earthquake) and not only to the first three seconds.

The second part is to obtain the phase of the 25 points of accelerations obtained in the first part. In order to do that it has been used not only the vertical direction of accelerations but the two horizontal directions also. For each direction it has been calculated the same variables as in the first part so it has been calculated 18 variables from the time functions.

In this case, it has been selected only four frequencies for measuring the acceleration in the frequency function. All these data has been introduced in a second ANN also programed with Matlab.

This second neural network works different than the first one. This one takes the frequency function of acceleration and filters it. It starts applying a filter of 50 Hz and divide the acceleration in two parts (0-50 Hz and 50-100 HZ). Then it takes the low filtered data and does the same task. This process is shown in the following picture.



Picture 6. Process of filtration

Every process of filtration is named with a level number. At the end of the iteration it has been done ten filters (level -10).

For each group of acceleration points, it has been derived their phase respect the angular speed (calculated using the frequency) and it has been obtained the delay time.

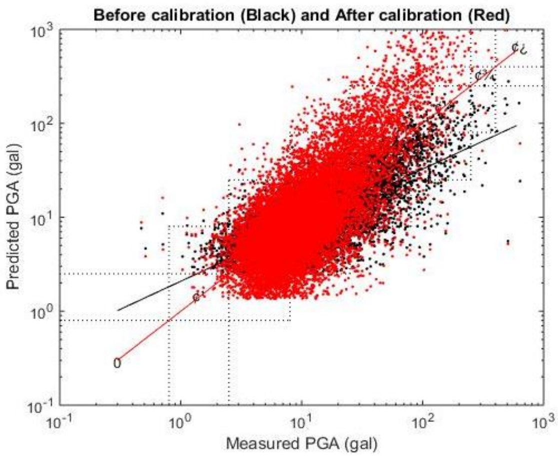
For each group it has been approximated the delay time with a Gaussian distribution and it has integrated this distribution. As a result, it has been obtained the mean and the deviation of the phase of each group of frequency.

Therefore with the first part of the method it has been calculated 25 acceleration points (amplitude) of the all earthquake for a 25 specific frequencies and with the second part it has been calculated the phase for these frequencies.

Finally, with the acceleration value and the phase of each point, it has been done an inverse Fourier transformation and it has been obtained the acceleration time function of the all earthquake.

2.5 ADJUST OF THE PREDICTION MODEL

After complete and test the prediction model it has been compared the predicted results with the real ones (following picture).



Picture 7. Adjust of the prediction model

It has been plotted the experimental results (red) with his regression line and it has been compared with the predicted results (black) and his regression line. As you can see there is significant difference with the two lines.

In order to solve this problem it has been introduced an adjustment to the prediction model which modifies the value of the predicted result (in black) and express it with the correct regression line (the red one)

3 THE STUDIED BUILDING

3.1 REAL BUILDING

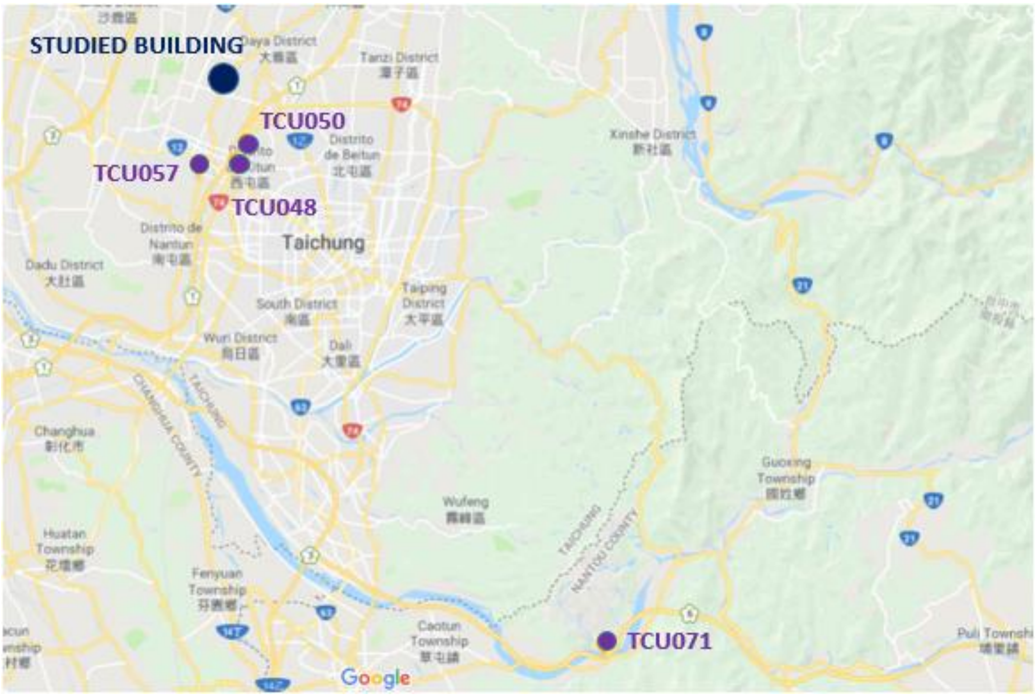
The target of the study is located in Central Taiwan Science park and it is a building used for the research and development of new technologies. In the following picture you can see the building studied.

Picture 8. Building studied

The reason why this building has been chosen is that it is located in active seismic zone near the seismic stations and it is property of the government of Taiwan. This reasons makes easier the access to all the information of the building and to all data of the earthquakes reported by the seismic stations.

In total it has been done forty analysis of earthquakes. The information has been taken of four different stations. Three of them, the stations TCU-048, TCU-050, TCU-057 are close to the studied building so they have the most exact data of the earthquakes that the building have to support. The other one, the station TCU-071, is more closed to the epicenter of the earthquakes so it has bigger data of earthquakes than the other stations.

In the next picture you can see the locations of the building studied and the four earthquake stations.



Picture 9. Location of the stations

The information of the forty earthquakes is shown in the following table:

STATION	EARTHQUAKE NUMBER	MAGNITUDE	PGA (cm/s^2)	DATE
TCU-048	6	6,5	10,074	05/06/1994
	19	7,3	175,567	20/09/1999
	25	6,6	35,608	20/09/1999
	28	6,7	168,983	20/09/1999
	43	4,4	3,949	20/09/1999
	54	6,8	149,274	22/09/1999
	57	6,2	72,491	22/09/1999
	58	5,04	20,778	22/09/1999
	69	5,08	58,925	28/09/1999
	83	6,7	138,547	10/06/2000
TCU-050	20	6,6	325,35	20/09/1999
	21	5,24	698,17	20/09/1999
	41	6,59	217,51	20/09/1999
	48	6,8	1489,86	22/09/1999
	50	6,2	810,5	22/09/1999
	52	6	177,08	22/09/1999
	62	5,08	1090,93	28/09/1999
	78	6,9	416,9	01/11/1999
	86	4,06	66,12	17/11/1999
	105	6,7	595,26	10/06/2000
	9	7,3	1113,17	20/09/1999
	16	6,7	934,71	20/09/1999

TCU-057	17	6,66	891,04	20/09/1999
	30	6,2	556,66	22/09/1999
	31	6	247,43	22/09/1999
	38	6,8	377,16	25/09/1999
	45	4,16	23,29	18/10/1999
	51	6,9	717,67	01/11/1999
	69	6,7	598,96	10/06/2000
	87	4,9	135,56	15/02/2004
TCU-071	17	7,3	638,966	20/09/1999
	19	5,71	132,632	20/09/1999
	20	5,24	84,975	20/09/1999
	21	5,13	66,676	20/09/1999
	23	6,66	363,307	20/09/1999
	24	5,22	40,878	20/09/1999
	36	4,79	5,529	20/09/1999
	95	4,06	4,333	17/11/1999
	120	4,32	30,789	20/05/2000
	136	3,26	10,096	17/02/2001

Table 1. Earthquake information

3.2 PROTOTYPE

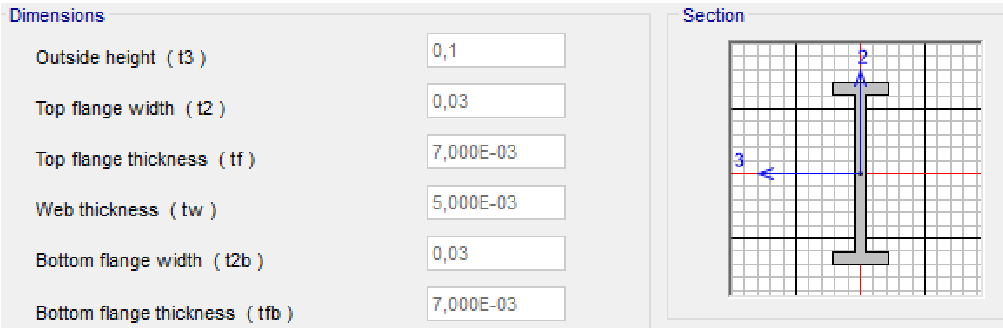
The prototype of the building is located in the Center for Earthquake Engineering. It is a structure with two towers, one of these with five floors and the other one with four floors. The two towers are connected on the first floor. The following picture shows the prototype.

Picture 10. Prototype

The structure has a maximum height of 8,5 m in the highest tower, a total width of 5,25 m and a thickness of 1,1 m. All the structure is made of steel which have an elastic module of 203900 N/mm^2 and a Poisson coefficient of 0,3. It is built with different types of elements which have different sections.

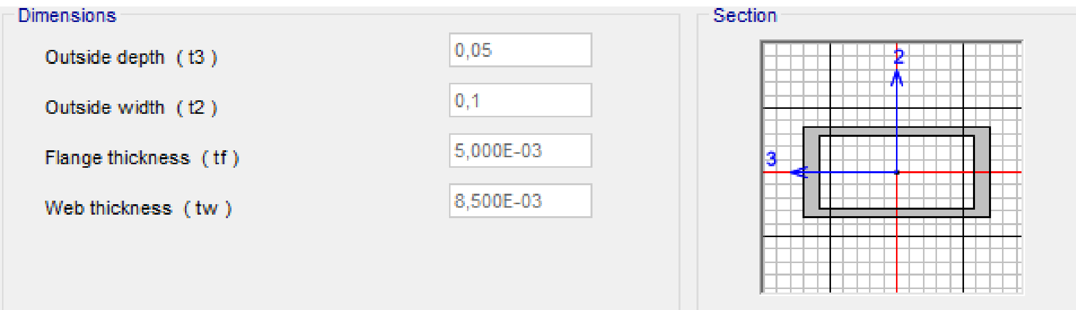
The different types of elements are:

- **Columns:** The columns of the structure are made of IPN sections. This sections are not commercial and they have been made welding some plates of different thinness.
  In the following picture is shown the dimensions of the IPN profiles. Each column has a height of 1,7 m.



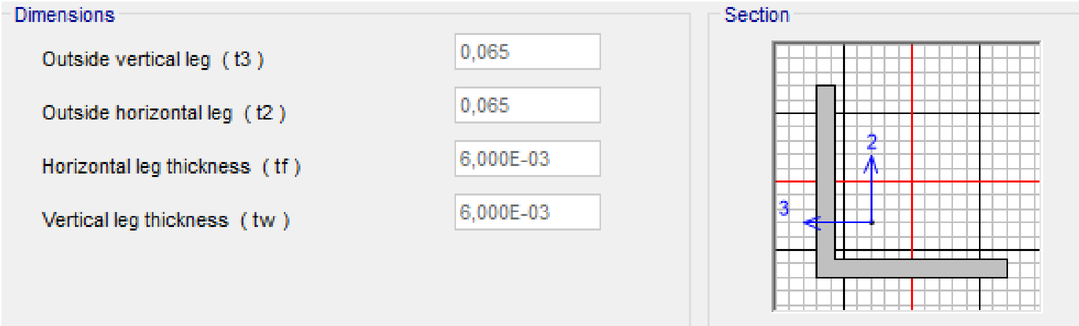
Picture 11. IPN section

- **Beams:** Each floor has a rectangular area of 1,1x1,5 m^2. It is composed by two element. In the external part, the floor are made of beams with rectangular section. In order to cover the hole in the interior it has been used a sheet of two centimeters of thickness. In the picture below is shown the tubular section of the beams.



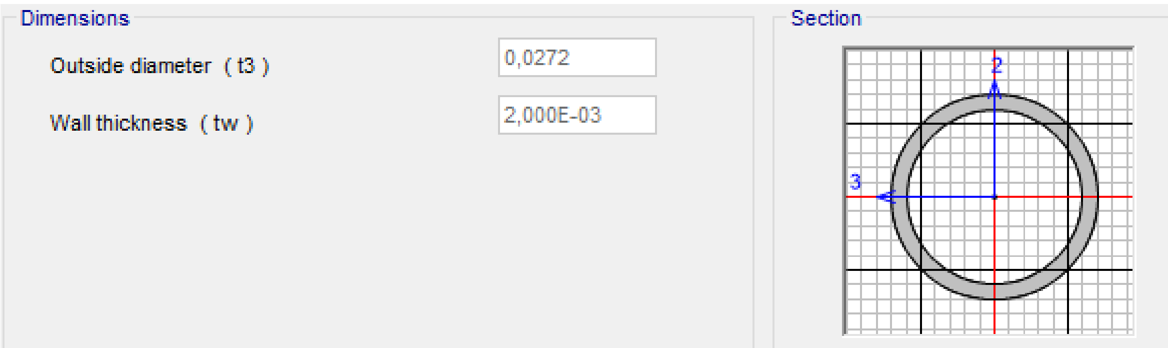
Picture 12. Beam section

- **Bracing type 1:** In order to increase the resistance of the prototype it has been introduced angular profiles. These elements are located in two of the diagonals of the sides of each floor. The dimensions of each angular profile are shown in the picture below.



Picture 13. Angular section

- **Bracing type 2:** The functions of these elements are the same as the angular profiles (increase the resistance) with the difference that these elements works at traction and the angular profiles works at compression. The dimensions are shown below.

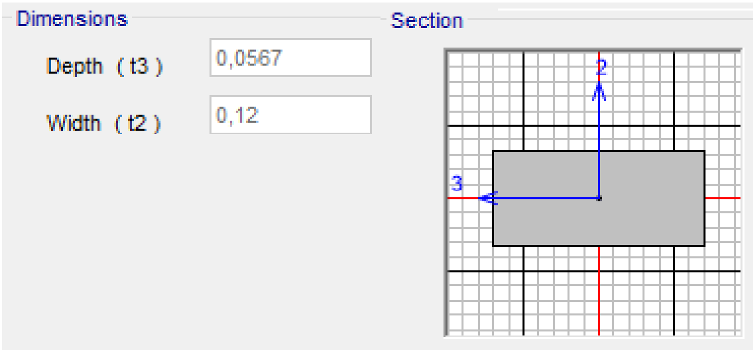


Picture 14. Bracing type 2 section

- **Joint elements:** In order to connect the tensors with the floor is necessary introduce an especial element with this purpose. In the prototype this element has a tringle form with variable thinness. So as to simulate this element, it has been used a rectangular element (simpler) and it has been imposed the same height and the same area of contact with the floor as the original element.

  In the following pictures is shown the original element and the dimensions of the simulated one.

Picture 15. Real joint section



Picture 16. Simulated joint section

- **Mass:** In order to simulate the weight of the elements which are inside the building, it has been introduced a mass of 500 kg on each floor.

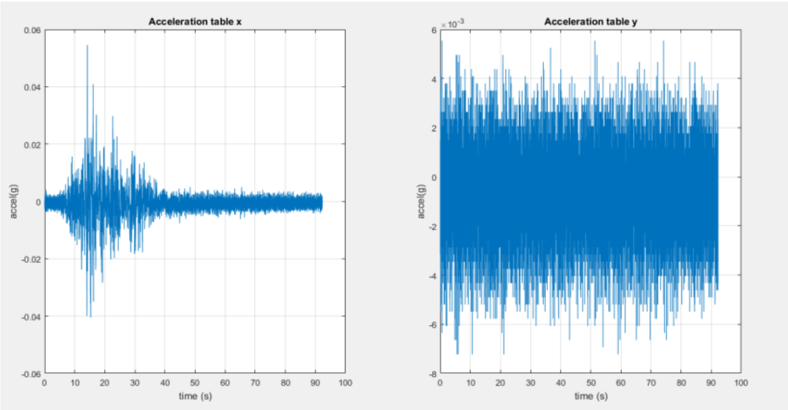
4 ANALYSIS

4.1 VALIDATION OF THE MODEL

Before apply the forty earthquakes to the model and use this information to calculate the transfer function it is very important to make sure that the model is correct.

In order to do that it has been done an experiment in the Center for Earthquake Engineering. The prototype has been tested in a shaking table and the acceleration of each floor has been measured during the experiment.

The input acceleration applied to the shaking table is shown in the picture below.

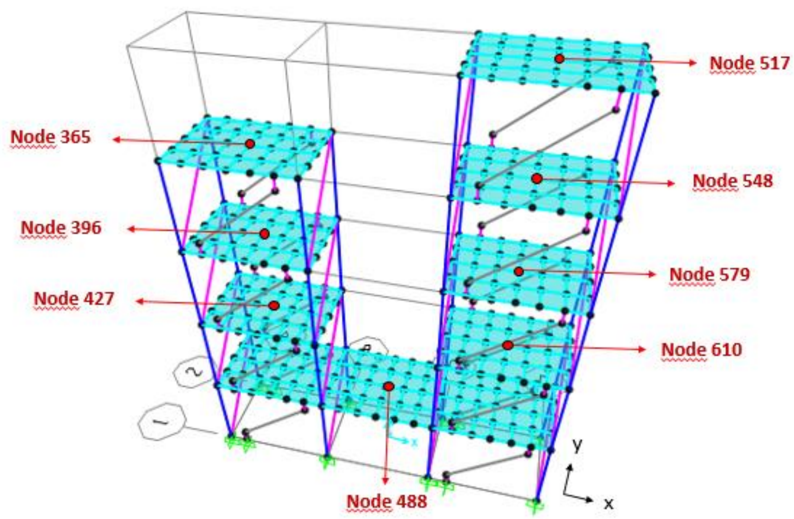


Picture 17. Acceleration table

The same acceleration it has been applied to the finite element model and the results has been compared.

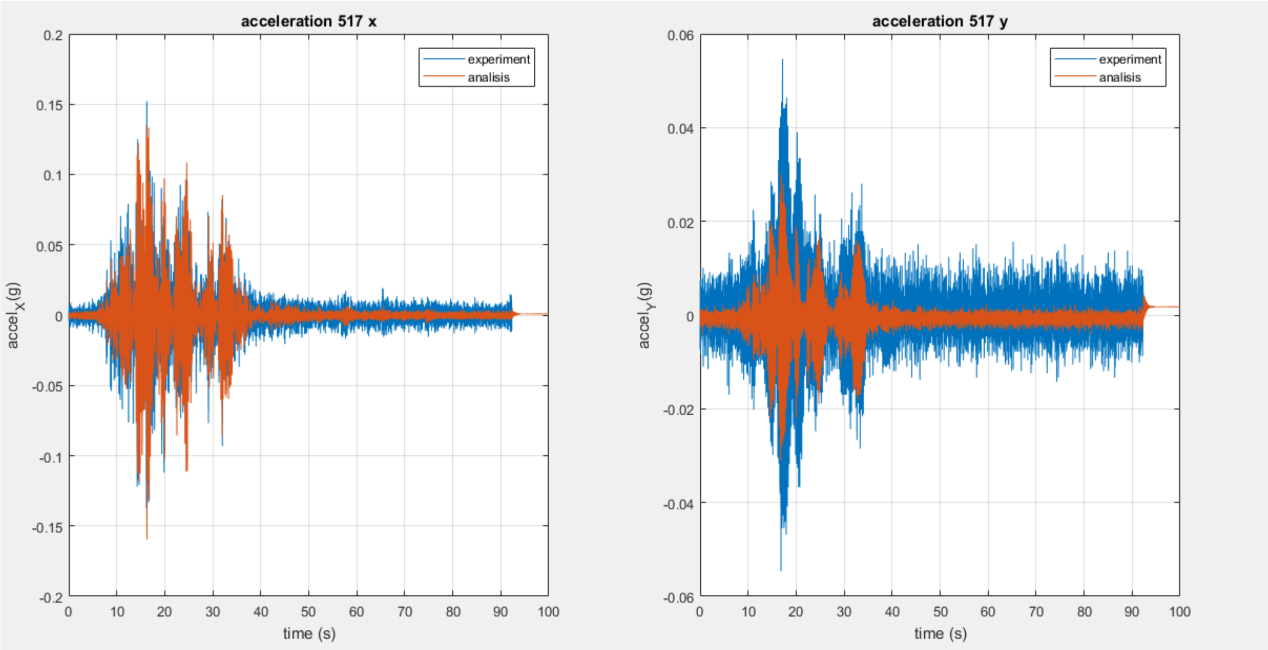
In order to measure the peak acceleration for each floor of the finite element model it has been selected the central node of each floor (because of the finite analysis, each floor has divided in small areas united with nodes) and it has been measured the acceleration of this central node.

In the following picture is shown the finite element model with the position and the identification number of the nodes selected. This information is very important because all results are referred to his corresponding node number.



Picture 18. Location of the studied nodes

The acceleration measured in the experiment and the accelerations results obtained from the SAP analysis is shown in the following pictures. It is important to mention that it is only shown the acceleration on the directions *x* and y of only one floor (the fifth floor with node number 517) but in the study the results of all the floors has been compared.



Picture 19. Experimental validation of the model

Due that the prediction model presents results very similar to the experiments results it can be considered that the element finite model is valid.

4.2 ANALYSIS RESSULTS

After complete and validate the finite element model, it has been applied forty earthquakes and it has been done a modal analysis for each earthquake.

In the following table is shown a resume of the results of the analysis. The complete table is located in the ANNEX: *1. ANALISIS RESULTS TABLE*.

The first column of the resume analysis table shows the node where the acceleration has been measured, the second column contain the earthquake. In this one, the first number is the station where the earthquake has been measured (it has been used the stations 48, 71, 50 and 57) and the last number is the identification number of the earthquake.

The last three columns shows the peak acceleration in the *x* direction (U_1), the peak acceleration in the *y* direction (U_2) and the maximum acceleration between the previous two.

JOINT	EARTHQUAKE	U_1 (cm/s^2)	U_2 (cm/s^2)	U_{max} (cm/s^2)
517	TH-48-06	34,182	19,221	34,182
517	TH-48-19	391,806	272,983	391,806
517	TH-48-25	68,156	100,404	100,404
365	TH-48-28	284,059	469,407	469,407
517	TH-48-43	12,802	10,821	12,802
365	TH-48-54	393,433	209,945	393,433
365	TH-48-57	121,258	146,617	146,617
365	TH-48-58	51,866	37,72	51,866
517	TH-48-69	201,983	134,181	201,983
365	TH-48-83	285,413	370,672	370,672
365	TH-50-105	12,427	28,170	28,170
517	TH-50-20	11,345	13,457	13,457
517	TH-50-21	40,790	13,825	40,790
517	TH-50-41	6,834	7,148	7,148
365	TH-50-48	0,010	0,026	0,026
517	TH-50-50	21,160	29,332	29,332
517	TH-50-52	7,541	4,560	7,541
365	TH-50-62	19,846	31,853	31,853
517	TH-50-78	15,718	12,754	15,718
517	TH-50-86	1,491	0,727	1,491
517	TH-57-09	25,110	29,007	29,007
365	TH-57-16	-1,405	33,904	33,904
517	TH-57-17	14,193	12,447	14,193
365	TH-57-30	6,215	12,974	12,974
517	TH-57-31	8,606	10,910	10,910
517	TH-57-38	10,343	9,494	10,343
365	TH-57-45	0,164	0,385	0,385
517	TH-57-51	11,525	24,212	24,212
365	TH-57-69	20,182	17,489	20,182
365	TH-57-87	1,504	1,957	1,957
365	TH-71-120	59,499	165,149	165,149
365	TH-71-136	14,806	40,29	40,29
517	TH-71-17	2400,28	3253,273	3253,273
365	TH-71-19	384,488	716,503	716,503
365	TH-71-20	987,884	2331,138	2331,138
517	TH-71-21	779,318	418,262	779,318
517	TH-71-23	1243,942	711,747	1243,942
517	TH-71-24	167,524	-98,55	167,524
517	TH-71-36	73,79	83,668	83,668
517	TH-71-95	14,044	7,812	14,044

Table 2. Resume ressults anàlisys table

It can be observed that, in all the cases, the maximum acceleration correspond to the nodes 517 and 365 which are the nodes located in the top of the towers (fifth floor and fourth floor).

5 THE TRANSFER FUNCTION

Before explaining how it has been calculated the transfer function, it has to be introduced two new mathematic concepts that will be used in the procedure for obtaining the transfer function. This concepts are the power spectral density and the cross power spectral density.

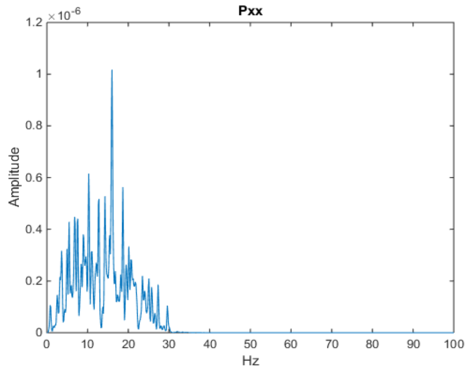
As it has been explained in the Fourier transformation explanation, a time function can be expressed as a frequency function. The power spectral density describes the distribution of power for the range of frequency that compose that function.

The concept of cross power spectral density is the same concept as the power spectral density but using cross correlation which is used for comparing two signals. Thus the cross power spectral density provide information of the power shared by the two functions for a range of frequencies and also give information about the phase shift between the two functions.

The transfer function relates the acceleration that appears on each floor of the structure with the acceleration applied on the base of the structure (the earthquake).

Using the finite element model it has been obtained the acceleration time function of each floor and for each case of earthquake. In order to calculate the transfer function the first steep is calculate the power spectral density of the base (using the time record of the earthquake).

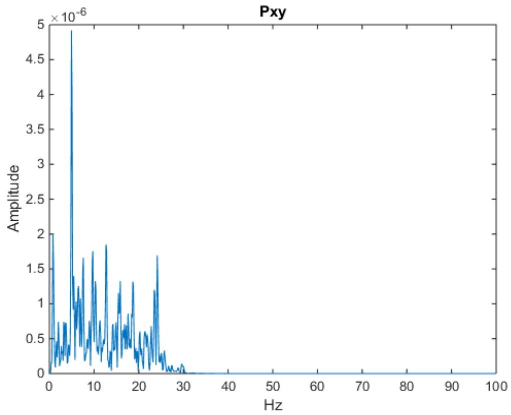
The function obtained for one case of earthquake is shown in the picture below.



Picture 20. Power spectral density

As it has been explained this graph shows the power of the earthquake for each frequency.

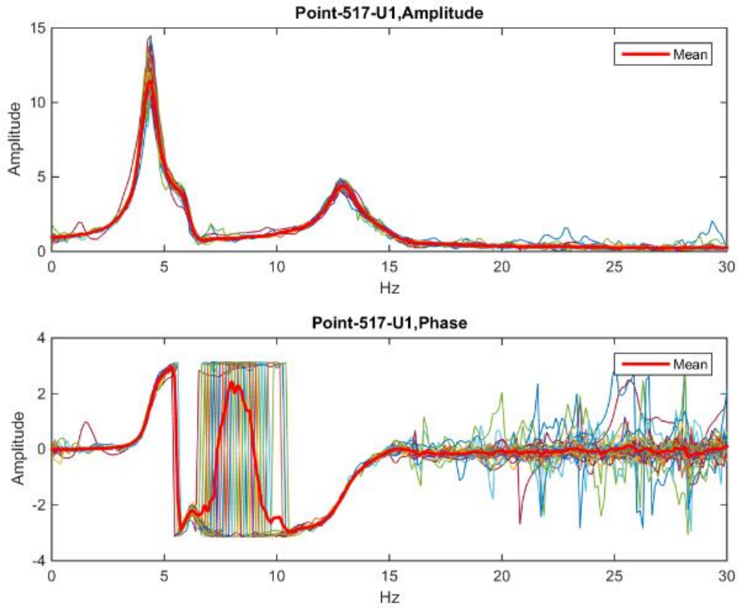
After that it has been calculated the cross power spectral density for the acceleration function obtained with analysis results and the time function data of the earthquake. This function is shown below.



Picture 21. Cross power spectral density

The transfer function is calculated doing the quotient between the cross power spectral density of the two function and the power spectral density of the earthquake. Due that the result is shown as a frequency function, it has been done the inverse Fourier transformation in order to obtain the time function.

Applying the same procedure with the other earthquakes, it has been calculated the transfer function and it has been represented in a graph. The resultant transfer function has been calculated as the mean of the forty transfer functions. In the picture below you can see the transfer function spectrum and the transfer function resultant for the fifth floor (node 517).



Picture 22. Transfer function for the fifth floor

The transfer function of each floor can be found in the ANNEX: *2.TRANSFER FUNCTION RESULTS*

6 STATISTIC ANALYSIS OF THE RESULTS

Once the transfer function of each floor has been calculated, it has been done three statistic studies in order to validate the results of the prediction model, the transfer function and the complete procedure (the prediction model and the transfer function unified).

The analysis has been done using the software Matlab. The horizontal axis of the graphs shows the measured results (the measured acceleration in the seismic station or the results of SAP depending on the graph) and the vertical axis show the results of the prediction model, the transfer function and the complete procedure for the respective graph. All the results are referred to the PGA (peak ground acceleration) which is equal to the maximum ground acceleration that occurred during the earthquake.

Every result is represented as a red point. If the predicted results and the measured results are equals, the point should be located in the diagonal of the graph (the ideal case).

The graph also shows squares. This ones are related with the measure of the intensity of the earthquake. Using the peak acceleration of an earthquake it is possible to calculated the intensity of that earthquake using a mathematic expression. This fact is very important because the consequences of an earthquakes and the actuation protocols are much related with this intensity so it is necessary that the intensity calculated using the predicted results is the same as the intensity of the measured results.

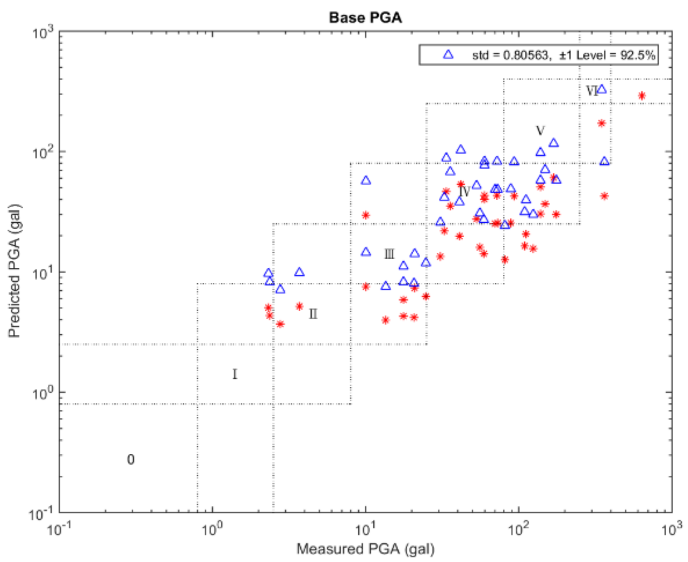
Referred to the graph squares, if the point represented is situated inside the square means that the predicted results presents the same intensity as the measured results. The size of the squares depends on the country where the study is realized. In this case, it has been used the dimensions that are imposed by the Taiwanese legislation.

The variable *ratio* represents the percentage of points that are inside the squares (the percentage of points that present the same intensity as the measured results).

In order to measure the precision of the results it has been calculated the distribution of the error (difference between the measured and predicted value) and it has been calculated the standard deviation of the error and the logarithm of the standard deviation of the error.

As it has been explained in the explanation of the prediction model, it is necessary to adjust the predicted results. Using the statistic study it has been compared the adjusted and unadjusted results in order to validate this adjust.

Starting with the study of the **prediction model** it has been compared the predicted results (the predicted ground acceleration) with the data of the real earthquake obtained from the seismic stations.



Picture 23. Prediction model results

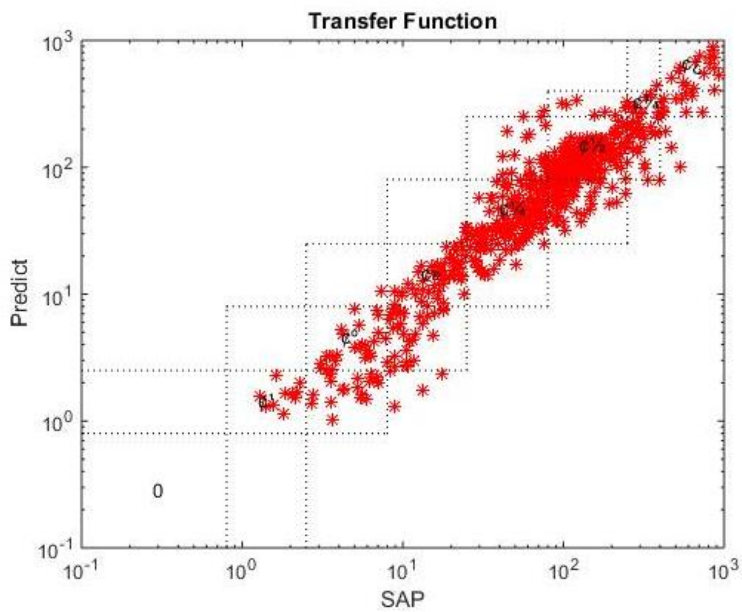
The picture shows the results of the prediction model without the adjustment (red) and the same points but adjusted (blue).

Using the variable *ratio* is compared this two results. The ratio of the unadjusted results is 87,5 % and the ratio of the adjusted results is 92,5%. So it is has been proved that the adjust result is necessary.

Respect the precision of the results, the standard deviation of the error and standard deviation of the logarithm of the error of the adjusted results are 65,588 Gal and 0,785 respectively.

The small error and the high ratio allows to confirm that the prediction model is able to estimate the acceleration of the ground with a high precision.

The next study has been done in order to validate the results of the **transfer function**. It has been compared the results obtained with SAP with the predicted results using the transfer function. It is important to mention that, in this case, it has been only compared the results of the transfer function and not the prediction model, which means that the predicted acceleration it has been obtained from the acceleration measured by the seismic stations (the prediction model has not been used).

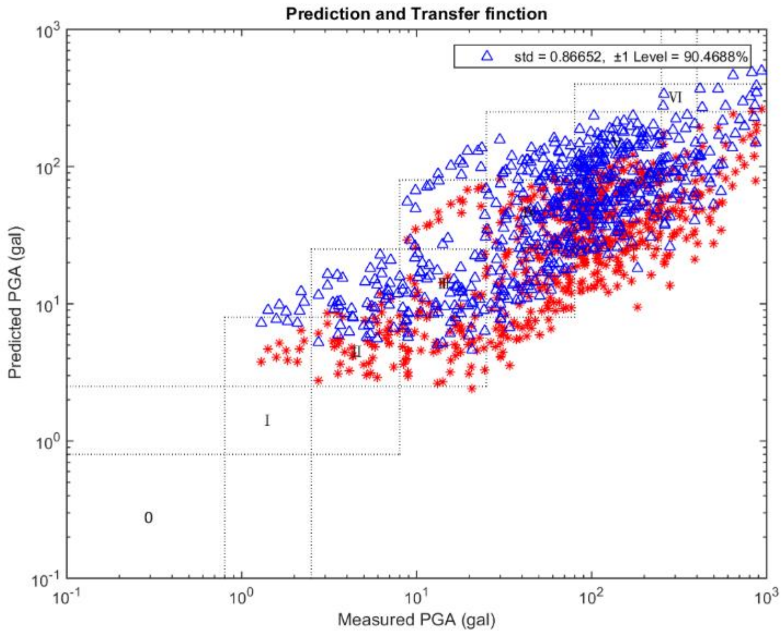


Picture 24. Predicted acceleration obtained with TF compared with SAP results

In this case, the ratio is 98,44 % and the standard deviation of the error and the standard deviation of the logarithm of the error is 105,16 Gal and 0,46 respectively.

The results shows that the transfer function allows to predict the acceleration of each floor with a high precision.

The last study is done in order to validate the **complete procedure**. In this case, it has been compared the results of SAP with the results obtained applying the transfer function to the acceleration obtained from the prediction model. The results are shown in the following picture.



Picture 25. Prediction and transfer function study results

The ratio of the adjusted results is 90,5 % and the standard deviation of the error and the standard deviation of the logarithm of the error is 248,37 Gal and 0,87 respectively.

Considering the small error and the high value of the variable ratio (upper than 90%) it is confirmed that the procedure using the prediction model and the transfer functions allows to estimate the acceleration that appears in a structure as a result of an earthquake using only the first three seconds of this earthquake with a high precision.

7 EXPERIMENTAL VALIDATION

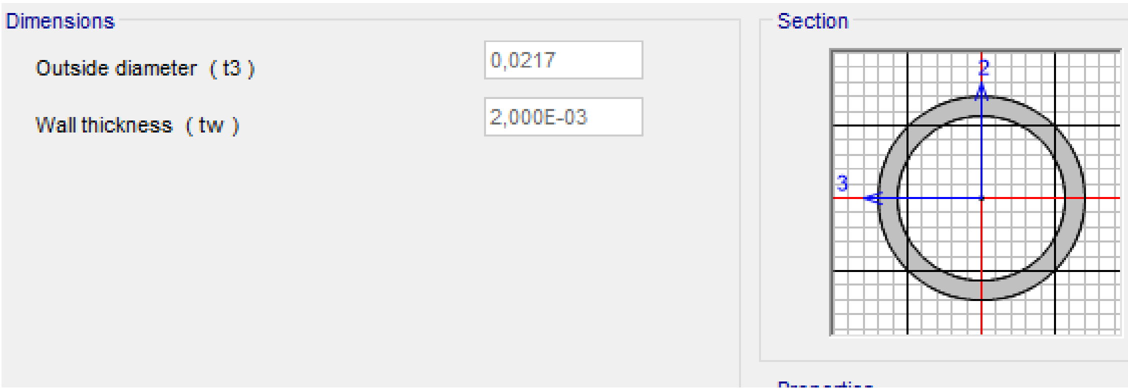
As it has been explained, the aim of this study is the application of the methodology studied in real buildings in order to prevent and minimize the damages produced by the earthquakes.

There are building which have sensors that have recorded the acceleration data during the past earthquakes but there are others that don't have these sensors. This part of the thesis is based on study if it is possible to predict the acceleration response of the building which don't have any sensor with the same precision as the buildings with sensors.

With this objective it has been used the prototype located in the center for the earthquake engineering of Taipei. In order to study different types of buildings (with different geometry) it has been introduced some modifications to the prototype.

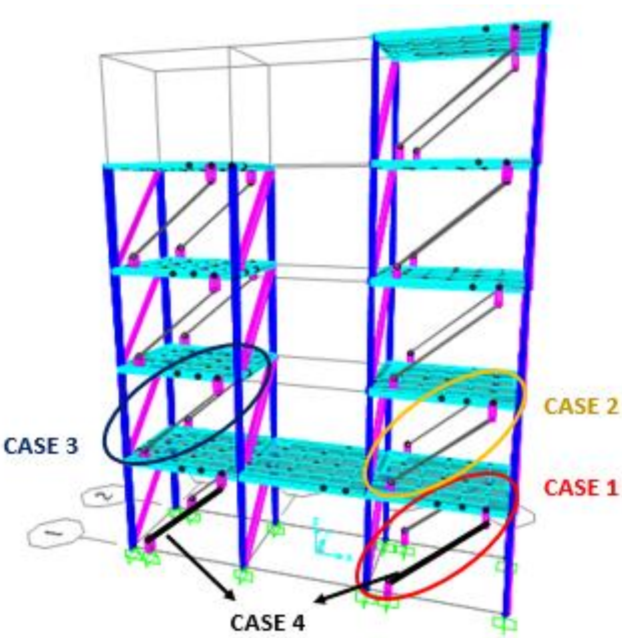
In total it has been studied four different cases with some modifications. This modifications consist in change the section of two of the bracings located in the prototype.

The new sections and its properties are shown in the image below.



Picture 26. Geometry of the new bracings

The picture below shows which bracings have been modified on each case. In the cases one, two and three it has been modified the two sensors of the same floor but in the case four it has been modified only one of the sensors of each tower.



Picture 27. Modifications for each case

For each case it has been applied six different earthquakes with a different peak ground acceleration (50, 200, 400, 600, 800 and 1000 gal).

The prototype has been tested in the shaking table and it has been measured the acceleration response. Using this data it has been calculated the transfer function and it has been used this to predict the acceleration of each floor. The prototype represents the building with sensors that make possible to measure the acceleration response.

At the same time, it has been created one finite element model for each case with the software SAP2000 and it has been done the analysis using the same earthquakes applied in the shaking table. This case represents the study of the buildings which don't have sensors so therefore is necessary to create an element finite model of the structure of the building.

As in the prototype case, the transfer function has been calculated and it has been used this to predict the acceleration of each floor.

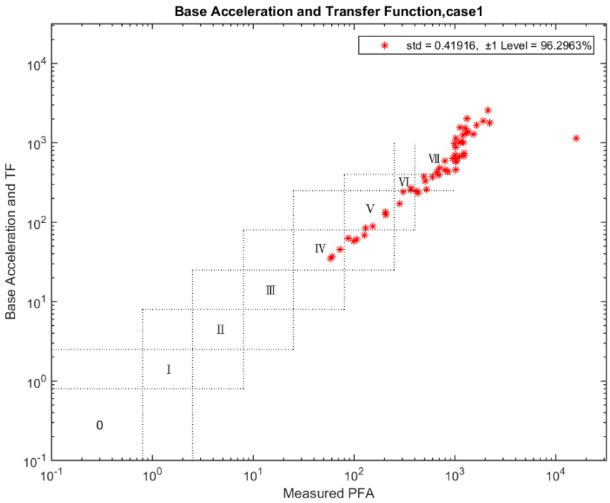
The conclusion has been obtained doing a statistic analysis of the results and comparing the two cases.

Due that it is possible that the structure is damaged with the higher peak acceleration earthquakes, the transfer function has been calculated using only the smallest case (earthquake with 50 gal of peak ground acceleration.

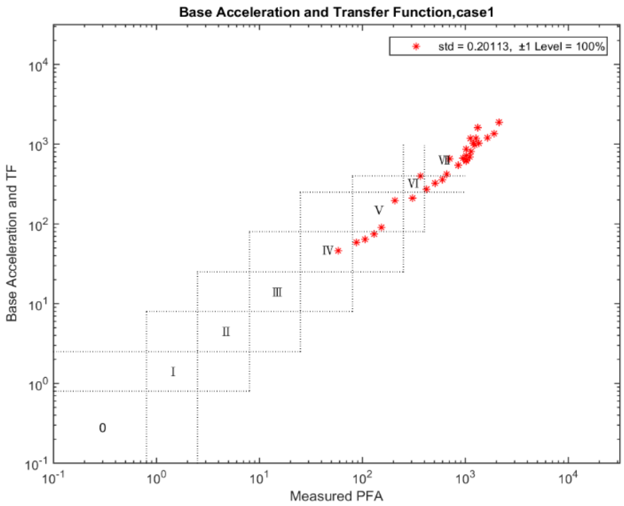
The transfer function for each case and each floor is shown in the ANNEX: *3. TRANSFER FUNCTION OF THE EXPERIMENTAL RESULTS* and *4. TRANSFER FUNCTION OF SAP RESULTS.*

In the statistic study it has been compared the predicted acceleration obtained with the transfer function of each floor with the acceleration of the prototype measured with the sensors. It is important to mention that, in this study, it has not been used the prediction model, so the ground acceleration used is the acceleration introduced to the shaking table and not the predicted one.

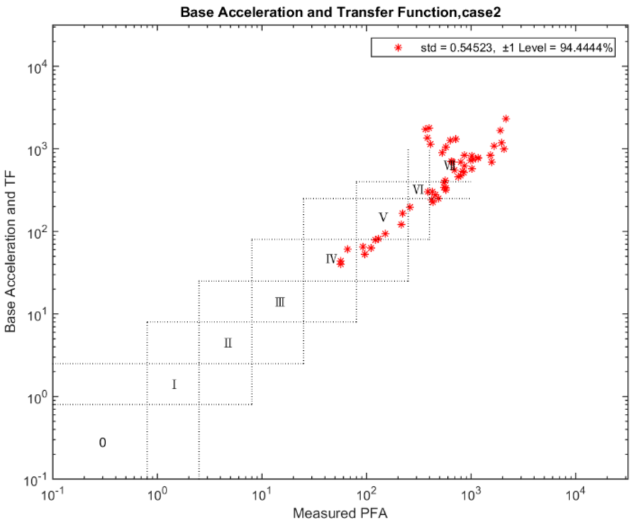
The following eight pictures show the result of the statistic studies of the experiments with prototype (left) and the statistic studies of finite element model (right) for each case. The results are referred to the PFA (peak floor acceleration) which is the maximum value of acceleration measured during the experiments or the analysis.



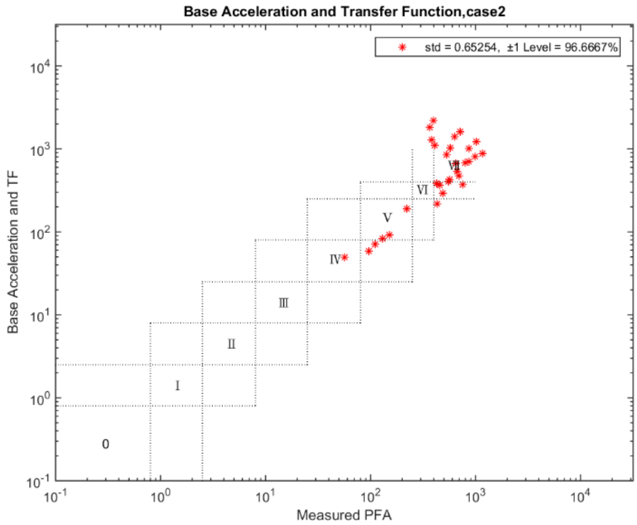
Picture 28. Experiment result of case 1



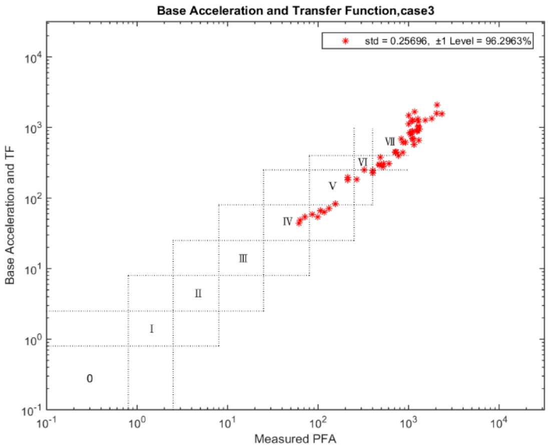
Picture 29. SAP result of case 1



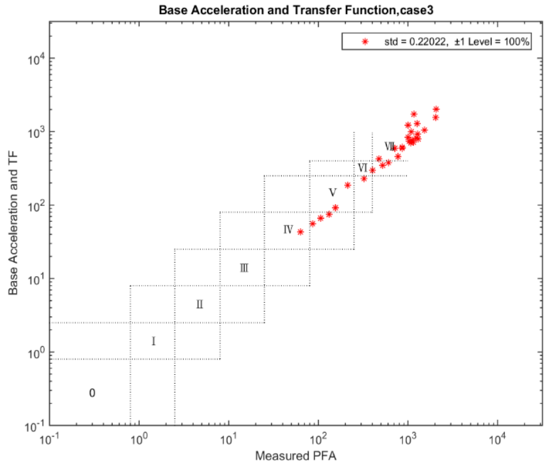
Picture 30. Experiment result of case 2



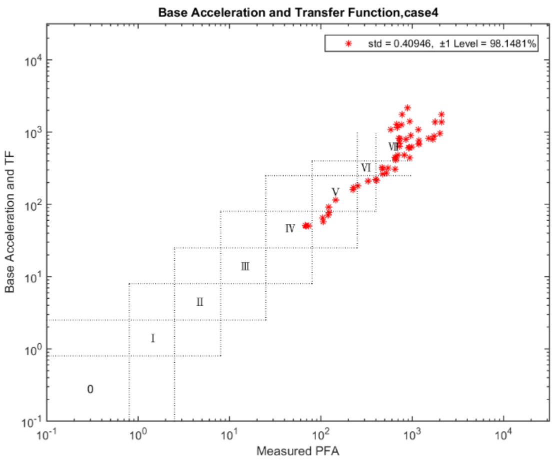
Picture 31. SAP result of case 2



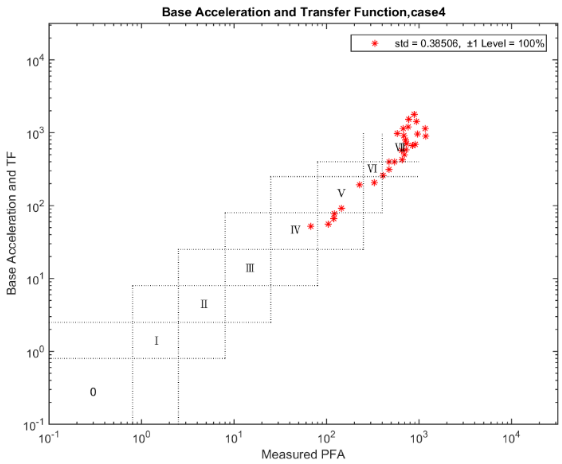
Picture 32. Experiment result of case 3



Picture 33. SAP result of case 3



Picture 34. Experiment result of case 4



Picture 35. SAP result of case 4

The variable ratio and the standard deviation of the logarithm of the error for each case is shown in the table below.

		EXPERIMENT	SAP
Case 1	Ratio (%)	96,3	100
	std. Error	0,42	0,2
Case 2	Ratio (%)	94,4	96,67
	std. Error	0,54	0,65
Case 3	Ratio (%)	96,3	100
	std. Error	0,25	0,22
Case 4	Ratio (%)	98,1	100
	std. Error	0,4	0,38

Table 3. Statistic study results

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The results of the statistic study of the experiments with the prototype and the finite element model has been compared. Due that the results of the experiments and the element finite model are very similar, it makes possible to confirm that it is not necessary to install sensors to a building in order to predict the acceleration that will appear through an earthquake. It is only necessary to create a finite element model of the building.

8 CONCLUSIONS

In this project it has been created a finite element model of the prototype of one building and it has been tested with forty earthquakes in order to obtain the acceleration of each floor.

With the help of one of the members of the department of construction of the NTUST it has been used this acceleration to calculate the transfer function each floor. The transfer function has been combined with the prediction model and it has been created a procedure which one is possible to predict the acceleration of a structure during an earthquake measuring the first three seconds of this earthquakes. After that it has been validated this procedure with a statistic study.

In the last part of the project it has been tested four variations of the prototype in the shaking table located in the National Center for Research on Earthquake Engineering and it has been done a statistic study of the results.

Finally, it has been created four new element finite models, it has been replicated the experiments done to the prototypes and it has been done a statistic study of the results.

The two statistic studies has been compared and it has been confirmed that it is possible to estimate, with the same precision, the acceleration of a building during an earthquake using a finite element model of this building than installing some sensors which had recorded the acceleration in the past earthquakes and use this information to predict the acceleration of the new earthquakes.

9 GRATEFULLNESS

I would like to thank to Chia-Wei Liang which, without his prediction model and the transfer function procedure, it wouldn't been possible to realize this thesis and to my professor Ting-Yu Hsu who has guide me since the beginning with his knowledge and experience.

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