The Effects of Earthquake Ground Motions on Dif fer ent Build ing Construction 1. MotivationThe Chi Chi earthquake, Sept. 21, 1999, caused enor mous seismic damage to Taiwan. While re view ing this catastrophic event, it was found that there were some interesting topics that were worth while to study. First, was how the seis mic force , can in flu ence the amount of damage caused by an earthquake. Ac cord ing to media reports, it was shown that for earthquakes of the same magnitude, different depths of focus resulted in dif fer ent de grees of devastation. Secondly, as well as the geo graph i cal aspect, geometrically, is how the shape of a build ing can govern the amount of dam age it can sustain during an earthquake. As the me dia pointed out, buildings with par tic u lar char ac ter is tics tended to be damaged easier, such as build ings with height ened bottom space, build ings with slen der bot tom columns and isolated buildings with small ground floor areas. To un der stand these phenomena, it is desirable to study the factors that contributed to the ca tas tro phe of the chichiearthquake. 2. Objectives(1) To study the effects of the geometryof build ings to their abilities to re sist seismic activity. (2) To study the effects of the variations of seis mic fourcs on buildings. (3) To study the effects of the variations of seismic wave propagation direction on buildings. 3. Experimental Equipment(1) Simulation of Seismometer--A self-designed model constructed with 2000 lbs. hard paper sheets(weight: 2000 /500 sheets of standard size paper) and springs. Instruction-Following the theory of inertia as the seismic pickup designed, 4 sheets of octavo hard paper suspended with 24 springs in be- tween are assembled to mod el the seismometer .Below the seismometer is a standard-size hard pa per sheet with 8 rigid steel bars fixed on its four sides and corners, and the seismometer is at tached to those steel columns by springs.Thus, by adjusting the length and the stiffness of the springs between layers , we can use the model to simulate earthquakes given by different situ- ations. (2) Simulation of Buildings--Self-designed mod els constructed with 2000lbs. hard papersheets and springs. Instruction - Use the hard paper sheet as floor slab and the springs as columns to assemble the build ing model. By having dif fer ent sizes of sheets, lbs

as well as different num bers and lengths of springs, we can use the model to sim u late the various types of building construction.(3) Surveying Instrument--A self-designed survey ing instrument including a spherical mirror, a tripod, one sheet of hard paper, and a laser indicator.Instruction - This instrument is designed ac cord ing to the theory of op tics that the angle of in ci dence is equal to the an gle of reflection, and to the principle that the spherical mir ror is of different tangent plane at each point of the surface. First, a la ser il lu mi na tor is fastened on the top lay er of the building mod el to indicate its displacement. Then, a spherical mirror, act ing as an amplitude amplifier is sta bi lized on the hard paper sheet on a tripod. When vi brat ing the b\ uilding, let the laser light oscillatory point to the spherical mir ror surface, by which light can be am pli fied and reflected to a wall marked with Car te sian co-ordinate grids.Hence by read ing X and Y scales on the wall, we can get the seismic records. 4. Experiment Methods Methods to simulate the input earthquakes motion in dif fer ent situations are:(1) Elongate the springs that are attached to the seismometer by 5mm, 10mm, 15mm,and 20mm, respectively, to simulate earthquakes with different magnitudes.(2) Elongate the springs that are attached to the seismometer at angles of 90°, 180°, and 45°, respectively, to simulate the seismic waves propagating from different directions. Apply all the above mentioned experimental processes to the following dif fer ent con struc tion conditions, respectively, 5 times for each, record and average the displacements in both X and Y co or di nates case by case, and then do comparison of the results:(1) Building models all with a floor area of 200 cm (10cm20cm) but different stories as two, four and six stories, respectively.(2) Building models with different floor areas as 100cm and 200 cm, respectively. (3) Building models all with floor area of 200 cm but different planes as square, rectangle and L-shaped, respectively.(4) Building models given as an isolated square one with floor area of 100 cm, two square ones with floor area of 100 cm attached side by side, as well as an iso lat ed rectangular one with floor area of 200 cm.(5) Building models all with floor area of 100 cm given as an isolated one, two separate ones with the top layers connected together, as well as two separate ones with both the top and the bottom layers connected together.(6) Rectangular building models with floor area of 200 cm subjected to seismic waves propa- gating from different directions as 90°,180° and 45°, respectively.(7) Area 200 cm, rectangular building models with non-uniform distributed bottom columns of the bottom two stories to a normal one. (8) Area 200 cm, rectangular building models with less bottom columns to a normal one.(9) Area 200 cm, four-story rectangular building 2 2 2 2 2 2 2 2 2 2 2 2

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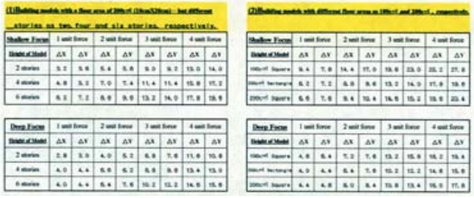
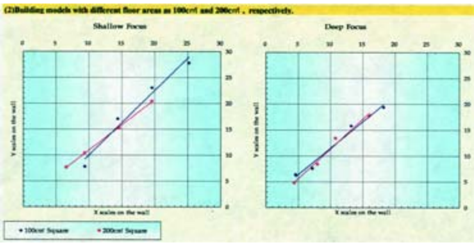
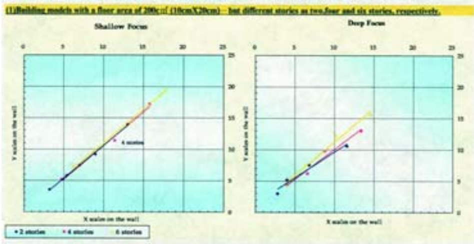
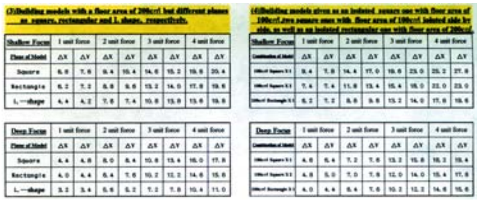
models with heightened bottom/top space to an ordinary one. *For the above experiments, the distance from the base of the seismometer to the wall screen is 75 cm; and the distance between the laser in di ca tor and the spher i cal

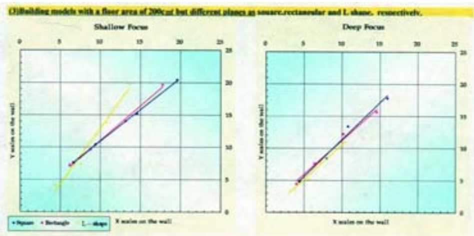


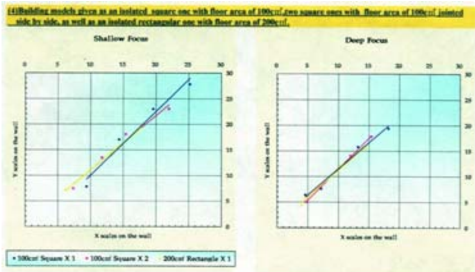
mir ror is 60cm while in static equilibrium.5.Results

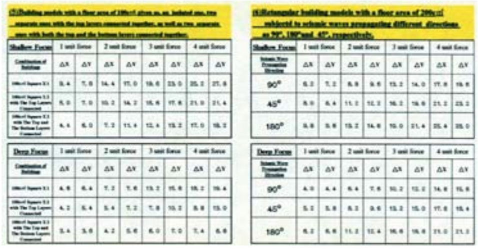


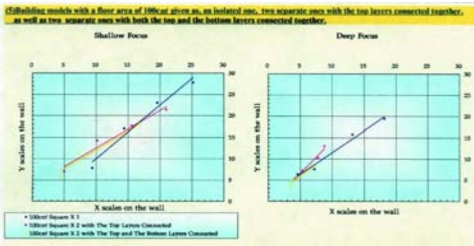


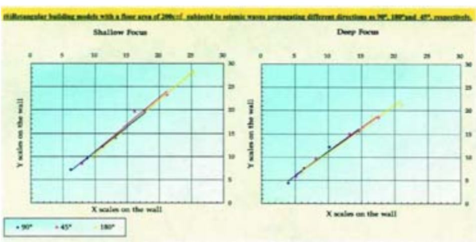


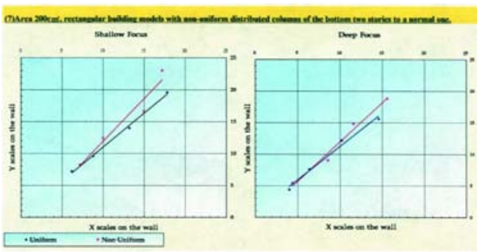


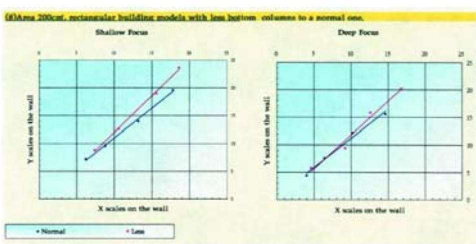


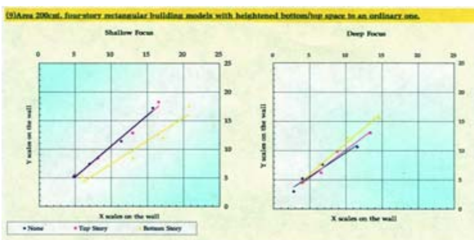


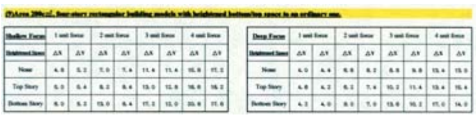












6. Discussion The previous section, listed the av er ag ing dis place ments in X and Y coordinates, respectively, for var i ous conditions. Moreover, in order to dis tinct ly iden ti fy their differences, the results were also dem on strat ed in line and bar charts. Nevertheless, there are still defects of outcome. First of all, not all fac tors were considered in the experiments. Also, as the instruments used in this ex per i ment are rudimentary, accuracy is limited. It is quite hard for us to grasp all the variations, we can hence con clu sions can be drawn about the ob ser va tions only.(1) For building models with the same floor area but different stories: 1. The higher the building, the larger the displac- ement. 2. The stronger the seismic force, the more sig- nificant the difference of dis place ment be tween models. (2) For building models with different floor areas (100 cm and 200 cm): The building with an area of 100 cm is square shaped. To filter the shape factor out, com par i sons 2 2 2

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2 2 to the square building with an area of 200 cm and the rect an gu lar one are both included. 1. The smaller the floor area, the larger the dis- placement. 2. The stronger the seismic force, the more sig- nificant the difference of dis place ment be tween models. (3) For building models with a floor area of 200 cm but different planes as square, rectangle and L- shape, respectively. 1. When subjected to earthquakes of the same magnitude, the square building has the larg est displacement, then the rect an gle building, and the last the L-shaped building. In this experiment, the seismic wave is propa- gated from 180°, that is, the wave is per pen dic u lar to the front side (the long side) of the building. Accordingly, we reason that the larger the front side, the larger the displacement. The front sides of the square and the rectangle are 14.1cm and 10 cm, respectively, the square can there for displace more significant. The L-shaped building displaces the least, we can reason that the results to the product of the lengths of X and Y as 270 cm (15 cm ｛?8 cm) is larg er than that of the square and that of the rect an gle as 200 cm, or the sum of X and Y as 33 cm (15 cm + 18 cm) is larger than that of the square as 28.2 cm (14.1 cm + 14.1 cm) and that of the rect an gle as 30 cm (10 cm + 20 cm). 2. The stronger the seismic force, the more sig- nificant the difference of dis place ment between models.(4) For building models given as, an iso lat ed square 2 2 2 building with a floor area of 100 cm, two square buildings with floor areas of 100 cm joined side by side, as well as an isolated rect angular building with a floor area of 200 cm : 1. When subjected to earthquakes of the same magnitude, the isolated 100 cm square building has the largest displacement, then the two 100 cm square joined buildings, and the third is the isolated 200 cm rectangular building. The experiment shows that when two joined 100 cm square buildings are subjected to re peat ed seis mic motions, the model may respond with small er displacement than an isolated square build ing since it has larg er momentum. Its displacement, however, is still larger than that of the iso lat ed 200 cm rect an gu lar building be cause of its rigidness.2. The stronger the seismic force, the more sig- nificant the difference of dis place ment between models.(5) For building models with the same floor area of 100 cm given as an isolated building, two separate buildings with the top layers con nect ed together, as well as two separate buildings with both the top and the bottom layers connected together. 1. When subjected to earthquakes of the same magnitude, the isolated building has the larg- est displacement, then the two separate build- ings with the top layers connected together followed by the two separate buildings with both the top and the bottom layers connected together. The experiment shows that when two sep a rate build ings with the top layers con nect ed to geth er are sub ject ed to repeated seismic motions, the model 2 2 2 2 2 2 2 2

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may respond with smaller dis place ment than an iso lat ed building because it has a lessend degree of movement, also, the extra weight of the top layer helps to en hance its stability. For the building with both the top and the bottom layers connected, its stability is increased, it thus has the least displacement. 2. The stronger the seismic force, the more sig- nificant the difference of dis place ment be tween models.(6) For rectangular building models with floor ar eas of 200 cm subjected to seis mic waves propa- gating from different di rec tions such as 90°, 180°, and 45°, respectively. 1. The 90°seismic wave results in the larg est displacement to the model, then the 45°one and last the 180°one. The experiment shows that the larger the side per pen dic u lar to the seismic wave, the larger the displacement.The sides perpendicular to the 90° and 180°seismic waves are 20 cm and 10 cm, respectively, the 90°wave can therefor results in larg er displacement. The 45°seismic wave results in dis place ment at the corner of the building. We reason the re sults to its middle momentum. 2. The stronger the seismic force, the more sig- nificant the difference of dis place ment be tween models.(7) For areas of 200 cm, rectangular building mod- els with non-uniform dis trib ut ed columns of the bottom two stories to a normal one: In order to increase the available middle space of the first and second stories for com mer cial 2 2 reasons, some buildings are designed to have the columns arranged on the sides. Thus the pur pose of this ex per i ment is to see how a building with non-uniform distributed columns responds dif fer ent ly from the building with uni form ly dis trib ut ed columns. 1. When subjected to earthquakes of the same magnitude, the building with non-uniformly distributed bottom columns has the larger dis- placement than the building with uniformly distributed bottom columns. 2. The stronger the seismic force, the more sig- nificant the difference of dis place ment be tween models.(8) For area of 200 cm, rectangular build ing mod- els with fewer bottom columns to a normal building: In order to increase the available middle space of the bottom story for commercial reasons, peo ple may remove the existing columns. Thus the pur pose of this ex per i ment is to see how a building with few er bottom columns responds differently from a normal building. 1. When subjected to earthquakes of the same magnitude, the building with fewer bot tom col- umns has a greater displacement than a nor mal building. 2. The stronger the seismic force, the more sig- nificant the difference of dis place ment be tween models.(9) For a area of 200 cm, four-story rectangular building models with height ened bottom/top space to an ordinary one: In order to make it looks aesthetically pleasing, 2 2

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some buildings are designed with height ened the bottom space, while other building are designed with height en space on the top floor. Thus the pur pose of this experiment is to see how a build ing with ex tra height at the bottom or top story re sponds dif fer ent ly from a building with or di nary bottom space. 1.When subjected to earthquakes of the same magnitude, the building with height ened bot tom space has the largest displacement. Although the building with heightened top space may not dis- place as significantly as the former building, still it dis plac es to a greater extent than the ordinary building. 2. The stronger the seismic force, the more sig- nificant the difference of dis place ment between models. 7. Conclusions 1. The results of the experiments showed that the buildings when subjected to earthquakes of dif- ferent fource, or earth quakes from different directions, or when built under different con- struction conditions, there are indeed sig nif i cant differences of response between models. Nevertheless, the ex per i men tal instruments are simple and not all variations are included. We can therefor conclusions from the observations only. 2. The stronger the seismic force, the more serious the possible seismic damage. 3. The higher the building, the more se ri ous the possible seismic damage. 4. The smaller the floor area, the more serious the possible seismic damage. 5. For building with the same floor area, the build- ing with a L-shape plane has the best seismic resistance. 6. The seismic resistance of continuous buildings is superior to that of isolated building. 7. The seismic resistance of buildings with the top layer connected is superior to that of an isolated building. 8. For seismic waves propagated from different directions, the larger the degree to the front side (i.e. the long side) of the building, the more se- rious the pos si ble seismic damage. 9.Buildings with non-uniform bottom col umns should be subjected to more possible se ri ous seismic damage.10.Buildings with fewer bottom columns should be subjected to more serious pos si ble seismic damage.11.Buildings with heightened space should be sub- jected to more serious possible seismic damage, es pe cial ly for building with heightened bottom space.